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Reevaluation of Minimum Levels for Lake Tulane in Highlands County, Florida

March 1, 2024

Southwest Florida
Water Management District

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Table of Contents

Executive Summary

The Southwest Florida Water Management District (District) is directed by the Florida Legislature to establish minimum levels for lakes within its boundaries. Minimum levels are defined in Section 373.042(1) of the Florida Statutes as “the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area.” Once adopted into District rules, minimum levels can be used for water supply planning, water use permitting, and environmental resource regulation.

This report identifies minimum levels that were developed as part of a reevaluation of minimum levels currently adopted within the District’s Water Level and Rates of Flow rules (Chapter 40D-8, Florida Administrative Code) for Lake Tulane in Highlands County. The reevaluation was conducted to support an ongoing assessment of the implementation of the Southern Water Use Caution Area Recovery Strategy in a region of the District where recovery of minimum flows and minimum water levels has been necessary.

For the reevaluation, the physical setting of Lake Tulane and other relevant information, including regional physiography and hydrogeology, water level and bathymetric data for the basin, land-use and area water use information, and currently established minimum levels and their status were reviewed and summarized. The reevaluation also included development and use of a new water budget model for simulating lake water levels, and use of newly developed criteria and screening procedures, including the use of a Xeric Wetland Offset and other best available information, for development of proposed minimum levels that address all relevant environmental values identified in the Florida Water Resource Implementation Rule (specifically, Rule 62-40.473, Florida Administrative Code) for consideration when setting minimum levels.

Two minimum water levels were developed as a result of the reevaluation of currently established levels for the lake. A Minimum Lake Level of 111.7 ft above the National Geodetic Vertical Datum of 1929 (NGVD29) is proposed as a water surface elevation that must be equaled or exceeded 50% of the time, on a long-term basis. A High Minimum Lake Level of 115.2 ft NGVD29 is proposed as a water surface elevation that must be equaled or exceeded 10% of the time, on a long-term basis.

Assessment of long-term water levels in Lake Tulane indicates the proposed Minimum Lake Level and High Minimum Lake Level are both currently met, and adoption of modification of an existing recovery strategy would, therefore, not be required in association with adoption of the proposed minimum levels. Additionally, projected data indicate that the Minimum Lake Level and High Minimum Lake Level will continue to be met during the next two decades, so implementation of a preventative strategy is similarly not required. If the lake’s levels fall below, or are projected to fall below an applicable minimum level, the FDEP or District will expeditiously adopt or modify and implement a recovery or prevention strategy in accordance with Section 373.042(2), F.S. Additionally, the District will continue to implement a general, three-pronged approach that includes monitoring, annual status assessment of established minimum levels, and regional water supply planning, to ensure that the adopted minimum levels for the lake continue to be met. The

District will also continue to monitor levels in Lake Tulane and other lakes to further understanding of lake hydrology and ecology and to support as-necessary, future refinements to District minimum levels methods.

CHAPTER 1 – INTRODUCTION

The Southwest Florida Water Management District (District or SWFWMD) is directed by the Florida Legislature to establish minimum water levels for priority water bodies within its boundaries. Minimum levels are defined for surface waters in Section 373.042(1) of the Florida Statutes (F.S.) as "the level of surface water at which further withdrawals would be significantly harmful to the water resources or ecology of the area." Once established, i.e., adopted into the District's Water Levels and Rates of Flow rules (Chapter 40D-8, Florida Administrative Code or F.A.C.), minimum levels are used for water resource regulation and management.

Minimum water levels were last established in 2008 for Lake Tulane in Highlands County, replacing management levels that included minimum levels established for the lake in 1981. Reevaluation of the currently established minimum levels is scheduled for completion in 2023 to support the ongoing assessment of recovery needs in the Southern Water Use Caution Area, a region of the District where a recovery strategy is being implemented to help achieve minimum flows and minimum water levels that are currently not being met (see Rule 40D-80.074, F.A.C., and SWFWMD 2006, 2023b).

In support of the reevaluation, information on the physical setting and other relevant characteristics of Lake Tulane are summarized in this document. Regional physiography and hydrogeology are described, as are water level and bathymetric data for the basin, land-use and area water use information, and the currently established minimum levels for the lake. Application of an updated approach for modeling lake water levels and new and updated lake-level standards and screening criteria for minimum levels establishment, are also described.

Using this best available information, revised minimum water levels for Lake Tulane were developed in accordance with all relevant statutory and rule requirements pertaining to minimum levels establishment. In addition, a status assessment that indicated the recommended, revised minimum levels are currently met and are projected to be met during the next 20 years was completed. Based on these findings, removal of the minimum water levels established for Lake Tulane from the District's Water Levels and Rates of Flow rules and their replacement with the revised minimum levels described in this document is recommended.

1.1 Legal Directives

Section 373.042 of the F.S. requires the Florida Department of Environmental Protection (FDEP) or the state water management districts to establish minimum water levels, which are defined as "…the level of groundwater in the aquifer and the level of surface water at which further withdrawals would be significantly harmful to the water resources of the area". Minimum water levels are to be calculated using the "best information available" and when appropriate, "may be calculated to reflect seasonal variations."

When establishing minimum water levels, the "department and the governing board shall consider, and at their discretion may provide for, the protection of nonconsumptive uses in the establishment of minimum flows and minimum water levels." In addition, "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", must be considered when establishing minimum water levels, with the caveat that these considerations shall not allow significant harm caused by withdrawals (Section 373.0421, F.S.).

Minimum water levels are adopted into the District's Water Levels and Rates of Flow Rules (Chapter 40D-8, F.A.C.) and used for water supply 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.

Emphasizing the importance of minimum water levels (and minimum flows) for water resource protection and management, Section 373.0421(2), F.S., requires development of a recovery or prevention strategy for water bodies "If 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." Necessary recovery or prevention strategies are 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." Further supporting the adaptive management aspect of minimum levels establishment and implementation, Section 373.0421(3), F.S., requires the periodic reevaluation and, as necessary, revision of established minimum levels.

The District's Recovery and Prevention Strategies for Minimum Flows and Levels Rules (Chapter 40D-80, F.A.C.) describe the regulatory portions of the recovery or prevention strategies to achieve or protect, as applicable, minimum flows and levels established within the District.

The Florida Water Resource Implementation Rule (Chapter 62- 40.473, Florida Administrative Code; hereafter F.A.C.) provides additional guidance for the establishment of minimum flows and levels, requiring that "consideration shall be given to the protection of water resources, natural seasonal fluctuations in water flows, and environmental values associated with coastal, estuarine, aquatic and wetland 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." The Water Resource Implementation Rule also indicates that "minimum 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".

The Central Florida Water Initiative Area Uniform Process for Setting Minimum Flows and Minimum Water Levels and Water Reservations Rule 62-41.304, F.A.C., within the Regulation of the Consumptive Use of Water Rules of the DEP (Chapter 62-41, F.A.C.) identifies additional requirements for minimum flow and level prioritization, establishment, and status assessments for certain waterbodies. These water bodies include those within the Central Florida Water Initiative (CFWI) area, which as defined in Section 373.0465, F.S., includes all of Orange, Osceola, Polk and Seminole counties and southern Lake County. The CFWI is a collaborative water supply planning effort among the St. Johns River, South Florida and Southwest Florida water management districts, the FDEP, the Florida Department of Agriculture and Consumer

Services, regional utilities, business organizations, environmental groups, agricultural interests, and other stakeholders (CFWI 2020). Rule 62-41.304, F.A.C., requires the FDEP, St. Johns River Water Management District, Southwest Florida Water Management District, and the South Florida Water Management District to meet prior to the annual submission of each District's MFLs priority list to FDEP for approval to discuss CFWI-area waterbodies proposed for inclusion on the priority lists. The annual noticing and facilitation of a joint public workshop within the CFWI Area by the three districts for discussion of each district's proposed priority list applicable to the CFWI is also required. In addition, the sharing of information supporting any proposed MFL between the three water management districts and the FDEP is required prior to a district seeking independent scientific peer review of the proposed MFL or prior to publishing a Notice of Proposed Rule associated with the proposed MFL, whichever comes first.

Although Lake Tulane is not located within the CFWI area, it is near the Highlands County border with Polk County and withdrawals from within the CFWI, including those from within the Southwest Florida Water Management District and those from adjacent water management districts have the potential to affect the lake's water levels. Accordingly, these potential effects have been identified for the prioritized reevaluation of minimum levels established for Lake Tulane included on the District's Priority List and Schedule for the Establishment of Minimum Flows and Levels and Reservations, and coordination with the South Florida Water Management District and St. Johns River Water Management District for the reevaluation has been conducted as part of the minimum level reevaluation described in this report.

1.2 Minimum Levels: Background Information

To address relevant legislative mandates and rule requirements within its boundaries, the District has developed, and as appropriate, updated specific methodologies for establishing minimum levels for lakes, wetlands, and aquifers. Methods that have been used by the District for minimum level establishment for lakes and wetlands are described in Campbell et al. (2020), Cameron (2022), Cameron et al. (2022a, b, c), GPI & SWFWMD (2022), Leeper (2006), Leeper et al. (2001), and SWFWMD (1999a, b, 2022). Bedient et al. (1999), Dierberg & Wagner (2001), Emery et al. (2022a, b), and Wagner & Dierberg (2006) include peer-review findings for the methods. Minimum aquifer levels are not further discussed in this reevaluation document for Lake Tulane; information on their development and use can be found in documents available from the District's Minimum Flows and Levels Documents and Reports web page[2].

Once a minimum level is developed and approved by the Governing Board, rulemaking is initiated to adopt the level into District rules. Minimum levels, including Minimum Wetland Levels, High Minimum Lake Levels, Minimum Lake Level and Minimum Aquifer Levels established by the District are defined in Rule 40D-8.021(7), F.A.C., as "the Long-term level of surface water, water table, or potentiometric surface at which further withdrawals would be significantly harmful to the water resources of the area and which may provide for the protection of nonconsumptive uses."

For minimum level purposes, "'Long-term' means an evaluation period used to establish Minimum Flows and Minimum Water Levels, determine compliance with established Minimum Flows and

[2] Southwest Florida Water Management District Minimum Flows and Levels Documents and reports web page is available at https://www.swfwmd.state.fl.us/projects/mfl/documents-and-reports.

Minimum Water Levels, and assess withdrawal impacts on established Minimum Flows and Minimum Water 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 an average water level, the average will be based upon the historic expected range and frequency of levels. Relative to Minimum Flow and Level establishment and compliance, the best available information, selected through application of reasonable scientific judgement, that is sufficiently representative of Long-term conditions will be used" (Rule 40D-8.021(5), F.A.C.).

Two minimum levels, a Minimum Lake Level and a High Minimum Lake Level are established for lakes. The Minimum Lake Level is the elevation that a lake's water levels are required to equal or exceed fifty percent of the time (P50) on a long-term basis (Rule 40D-8.624(4), F.A.C.).
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 (P10) on a long-term basis (Rule 40D-8.624(3), F.A.C.).
Several terms relevant to and necessary for understanding the development and implementation of minimum levels by the District are defined in Rule 40D-8.021, F.A.C. These terms include "Current", which "means a recent Long-term period during which Structural Alterations and hydrologic stresses are stable" and "Historic", which "means a Long-term period when there are no measurable impacts due to withdrawals and Structural Alterations are similar to current conditions." For these definitions, "Structural Alteration" "means human alteration of an inlet or outlet of a lake or wetland that affects water levels." Also, for minimum level purposes, ""P50"" means the percentile ranking represented by the elevation of the water surface of a lake or wetland that is equaled or exceeded 50 percent of the time as determined from a Long-term stage frequency analysis", and "P10" and "P90" are similarly defined as percentile rankings associated with water levels equaled or exceeded ten and ninety percent of the time.

1.3 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 minimum flows and minimum water levels originated, and following subsequent modifications to this directive and adoption of relevant requirements in the Water Resource Implementation Rule and District rules, the District has actively pursued the adoption, i.e., establishment of minimum flows and levels for priority water bodies. The District implements established minimum flows and levels 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 Minimum Flows and Levels (MFLs) program addresses all relevant requirements expressed in the Florida Water Resources Act, the Water Resource Implementation Rule and within its own rules.

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.

The District's MFLs Program is implemented based on three fundamental assumptions. First, it is assumed that many water resource values and associated attributes 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 minimum flows and minimum water levels. 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.

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, minimum flows and levels may represent minimum acceptable rather than historic or potentially optimal hydrologic conditions.

Support for the assumptions inherent in the District's establishment of minimum flows and minimum water levels 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 minimum flows and minimum water levels 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).

1.4 Consideration of Changes and Structural Alterations and Environmental Values

As noted in Section 1.1, 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…" when establishing minimum flows and levels. Also, as required by statute, the District does not establish minimum flows or levels 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 minimum flows and levels, 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; and
- evaluate the status of water bodies with proposed or established minimum flows or levels (i.e., determine whether the current flow and/or water level are below, or are projected to fall below the applicable minimum flow or level).

As indicated in Section 1.2, the District has developed specific methodologies for establishing minimum flows or levels for lakes, wetlands, rivers, estuaries and aquifers, and subjected the methodologies to independent, scientific peer-review.

In 2022, the District finalized a multiyear effort to review and update criteria and methods used to support development of minimum levels for lakes. Details regarding the updated criteria and methods are summarized in Cameron and Ellison (2019), Cameron (2020), Cameron et al. (2022a, b, 2023), GPI and SWFWMD (2022), and SWFWMD (2022a). As a consequence of the review effort, lake categories and methods associated with minimum lake levels were removed from District rules in 2021 (SWFWMD 2021b). Lakes had previously been divided into three categories, with methods identified for each (SWFWMD 1999a, 1999b; Leeper et al., 2001, SWFWMD 2021b). These rule changes supported further methods refinements and are expected to enhance flexibility regarding future methods development and application to better address each lake's unique characteristics during the development of minimum levels.

Currently, the environmental criteria and associated methods used for minimum lake level development are classified as "standards" or "screenings" (SWFWMD 2022). A standard identifies a lake-specific water surface elevation which is considered with other standards for identification of a recommended Minimum Lake Level that is based on the most sensitive, appropriate standard, i.e., standard associated with the highest water surface elevation. A recommended High Minimum Lake Level is subsequently developed using the recommended Minimum Lake Level and lake-specific water level fluctuations. Screening criteria are then used to assess lake-specific sensitivity for a given environmental value associated with the recommended minimum levels. If the screening indicates potential sensitivity, additional analyses are completed, and as necessary, the standard-based, recommended minimum levels are revised.

The approach involves assigning the greatest initial weight to the highest-confidence criteria/methods, while allowing for use of additional criteria/methods on a site-specific basis, as needed, to ensure sufficient protection against significant harm for all relevant environmental values. Collectively, the District's updated criteria and methods for the establishment of minimum lake levels address all the environmental values identified in the Water Resource Implementation Rule for consideration in when developing minimum flows and levels (Table 1-1).

Table 1-1: Environmental values from the Water Resource Implementation Rule (62-40.473, F.A.C.), associated significant change standards and screening criteria considered when establishing minimum lake levels.

Environmental Value	Associated Significant Change Standards and Screening Criteria
Recreation in and on the water	Basin Connectivity, Aesthetics, Species Richness, Dock Use, Aquatic Habitat Zone, Wetland Offsets
Fish and wildlife habitats and the passage of fish	Wetland Offsets, Basin Connectivity, Species Richness, Aquatic Habitat Zone
Estuarine resources	NA
Transfer of detrital material	Wetland Offsets, Basin Connectivity, Aquatic Habitat Zone
Maintenance of freshwater storage and supply	All
Aesthetic and scenic attributes	Wetland Offsets, Dock Use, Aesthetics, Species Richness, Aquatic Habitat Zone
Filtration and absorption of nutrients and other pollutants	Wetland Offsets, Aquatic Habitat Zone
Sediment loads	NA
Water quality	Wetland Offsets, Aquatic Habitat Zone, Basin Connectivity
Navigation	Basin Connectivity, Aquatic Habitat Zone, Dock Use

NA = Not applicable for consideration for most priority lakes.

Many of the standards and screenings rely on estimates of historic lake water levels, i.e., water levels in the absence of withdrawal impacts but with current structural alterations in place. The modeling procedures used to develop Historic records were evaluated as part of the lake methods review and the resulting updated processes are described in Cameron and Ellison (2019), Cameron (2020), Cameron (2022), and Cameron et al. (2022a). Status assessment, a separate but necessary process for minimum levels development and implementation was also updated as part of the District's recent minimum level methods review and is described in Cameron et al. (2023).

Each minimum levels evaluation or reevaluation incorporates the best available information and involves professional scientific judgement. On a lake-specific basis, individual standards, screenings, or methods may be deemed inappropriate or in need of refinement, or additional assessments or adjustments may be found necessary to address factors such as flooding concerns.

1.5 Currently Established Minimum Levels for Lake Tulane

Minimum levels for Lake Tulane (Table 1-2) were established by the District in 2008 and are currently included in Table 8-2 within Rule 40D-8.624(6), F.A.C. The Minimum Lake Level of 116.6 ft above the National Geodetic Vertical Datum of 1929 (NGVD29) and the High Minimum Lake Level of 117.9 ft NGVD were developed using best available information at that time, which included historic water surface elevation exceedance percentiles identified for characterizing expected water levels in the absence of withdrawal impacts, given the existing structural conditions at the lake and, significant harm standards that were previously used for minimum lake level development, as described in SWFWMD (2007).

The levels established in 2008 replaced management levels that had been adopted for Lake Tulane in 1981, including those which had initially been established as minimum levels (see Gant 1996, SWFWMD 2007, SWFWMD 2023a). The 2008 levels also included a High Guidance Level of 118.7 ft NGVD29 and a Low Guidance Level of 116.2 ft NGVD29, which corresponded with the Historic P10 and Historic P90 elevations, respectively. These guidance levels were, however, removed from District rules in 2021.

Table 1-2. Currently established minimum levels for Lake Tulane.

Minimum Levels	Stage Elevation (ft NGVD29)	Stage Elevation (ft NAVD88)
High Minimum Lake Level	117.9	116.9
Minimum Lake Level	116.6	115.6

To be considered met or achieved, the established minimum levels for Lake Tulane must be equaled or exceeded fifty (Minimum Lake Level) and ten (High Minimum Lake Level) percent of the time, respectively, on a Long-term basis. A status assessment completed in 2007 to support development of the currently established minimum levels indicated they were not being met. Subsequent annual status assessments completed through 2023 indicated the minimum levels established for the lake have continued to not be met (Leeper 2023). Based on its location in Highlands County, the recovery strategy outlined in Rule 40D-80.074, F.A.C., for the Southern Use Water Caution Area would be applicable.

Because the District has recently completed a multi-year process of migrating all vertical elevation data from NGVD 29 to the North American Vertical Datum of 1988 (NAVD 88), tables in this report include elevation data values in both NGVD 29 and NAVD 88. Elevation data values shown on graphs and the topographic contours on the bathymetric map are presented using NGVD 29. In some circumstances within this document, elevation data that were collected or reported relative to mean sea level or relative to NGVD 29 are converted to elevations relative to NAVD 88. All datum conversions were derived using the Corpscon 6.0 software distributed by the United States Army Corps of Engineers or based on elevations provided by professional surveyors.

CHAPTER 2 – PHYSICAL SYSTEM

2.1 Location

Lake Tulane is located within the Southwest Florida Water Management District in the City of Avon Park within Highlands County, Florida (Sections 22 and 27, Township 33 South, Range 28 East; latitude 27.586015, longitude -81.503642) (Figures 2-1, 2-2 and 2-3). Residential development occurs along the northern, western and southern shores of the lake as well as in most of the surrounding region. A CSX railroad line runs along the eastern shore of the lake. A public boat ramp located on the western shore provides access to the lake.

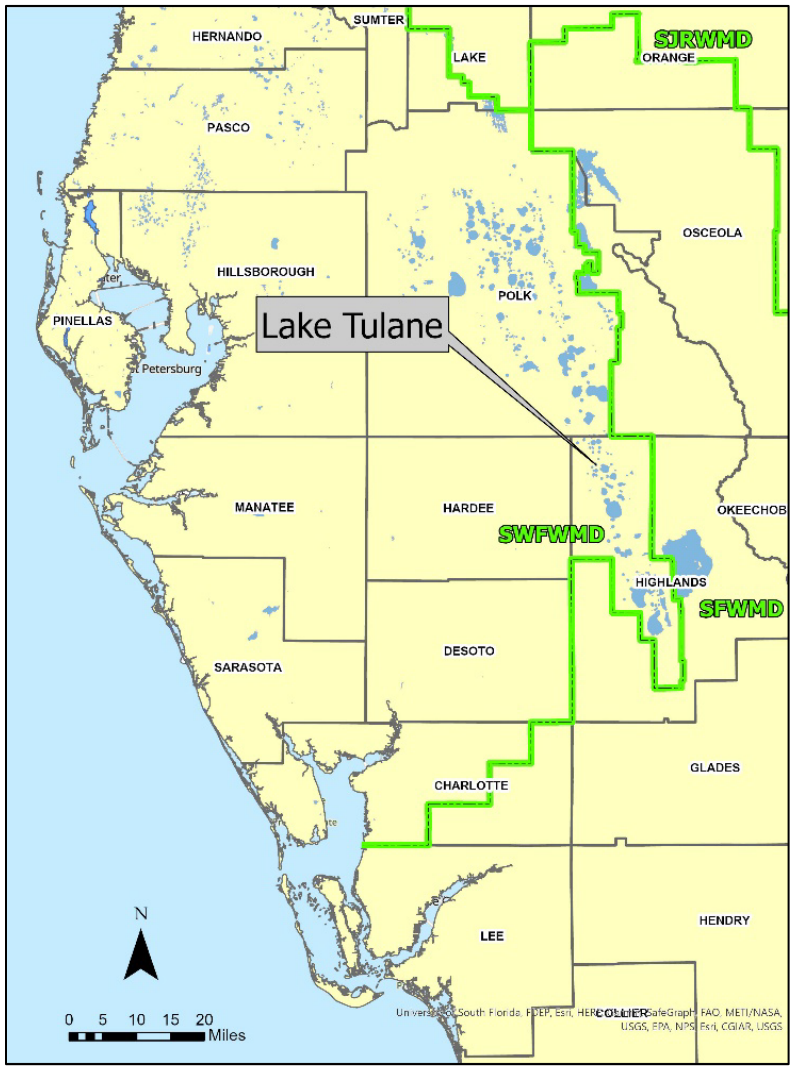

Figure 2-1. Location of Lake Tulane in Highlands County, within the Southwest Florida Water Management District (SWFWMD). Adjacent areas of the South Florida Water Management District (SFWMD) and St. Johns River Water Management District (SJRWMD) are also shown.

Figure 2-2. Local setting of Lake Tulane in the City of Avon Park, Florida.

Figure 2-3. Water level gage and public boat ramp locations at Lake Tulane.

2.2 Watershed and Structural Control

With a drainage area of approximately 380 acres (Dewberry, 2011), Lake Tulane lies within the Carter Creek drainage basin of the Kissimmee River watershed (USGS 2004a, b) (Figures 2-4 and 2-5). Rainfall that does not immediately infiltrate into the soils in the contributing watershed could potentially runoff into the lake. Overall runoff volumes to the lake are expected to be low due to the relatively small size of the drainage area, well-drained soils prevalent within the watershed (discussed in Section 2.5), and generally deep water-table in the area. However, the

high degree of residential development and rather steep topographic gradient (discussed in Section 2.4) within the watershed serves to increase local runoff to the lake.

Surface water inflows to the lake occur through numerous stormwater discharge pipes that convey runoff from the surrounding residential development. Based on review of one-foot contour interval maps and field survey data (Figures 2-3, 2-4 and 2-18), it was determined that Lake Tulane does not have an outlet conveyance system that is the principal control of surface water elevations within the lake. The lake is therefore considered a closed-basin system and there is no Control Point elevation (Figures 2-3, 2-4 and 2-18).

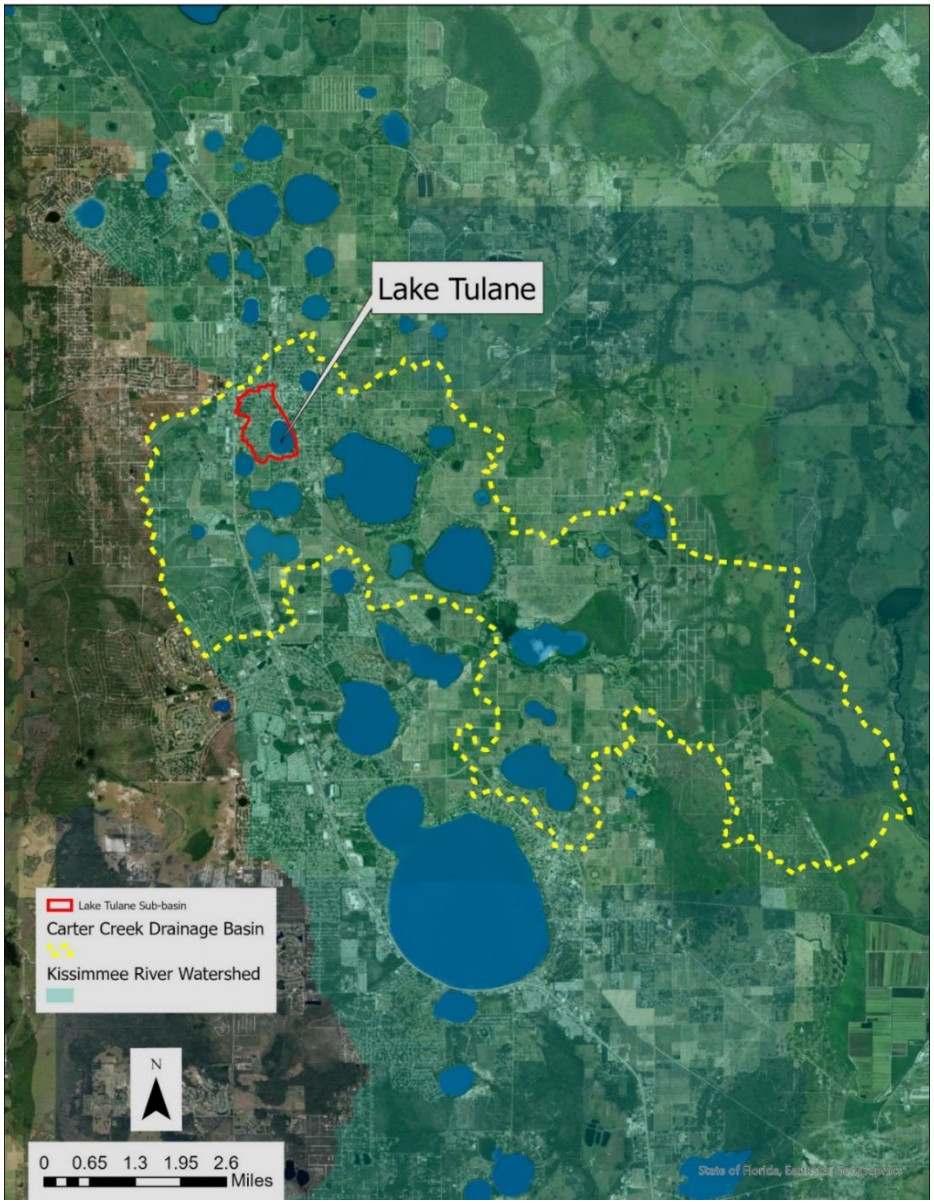

Figure 2-4. Lake Tulane subbasin of the Carter Creek Drainage Basin in the Kissimmee River Watershed (source: Dewberry 2012, USGS 2004a, 2004b). Note that only a portion of the Kissimmee River Watershed is shown.

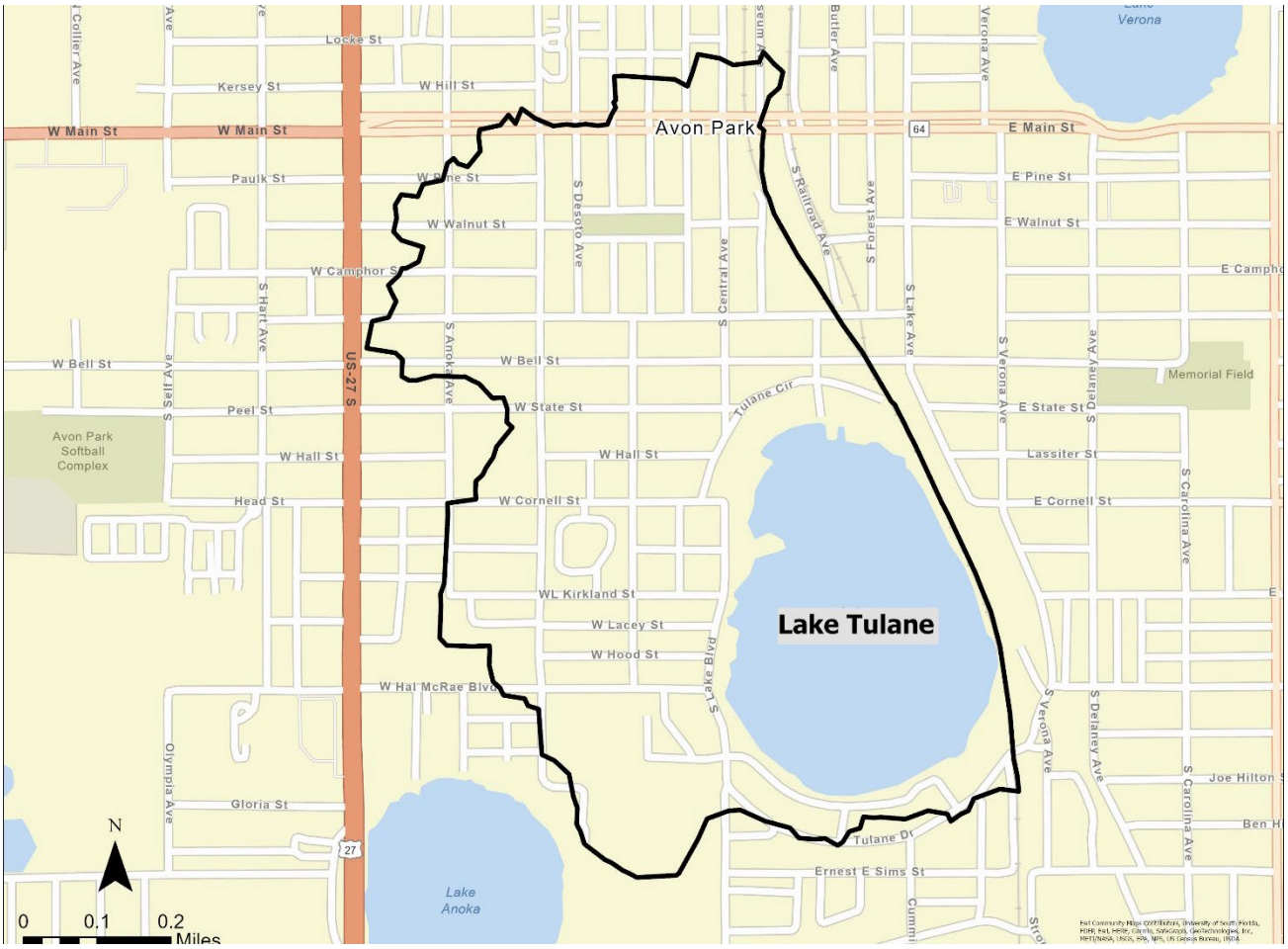

Figure 2-5. Lake Tulane sub-basin which contributes runoff to the lake.

2.3 Stage History

The 1953 United States Geological Survey 1:24,000 Avon Park, Fla. quadrangle map (photo revised 1972 and 1987) includes an elevation of 117 ft NGVD 29 (116.1 ft NAVD 88) for Lake Tulane. Surface water elevations for Lake Tulane (District Station No. 25507) expressed in ft relative to NGVD29 and NAVD88 are available from the District's Environmental Data Portal from June 11, 1981 to the present (Figure 2-6). The highest lake surface elevation based on period of record data collected through December 06, 2022, was 119.15 ft NGVD29 (118.28 ft NAVD88) and occurred on October 10, 2016. The record low, 106.84 ft NGVD29 (105.97 ft NAVD88), occurred on June 21, 2001. The data record for Lake Tulane is not continuous, i.e., there are some months during the period of record when lake surface elevations were not recorded.

Based on the period-of-record data from June 1981 through December 2022, the P10 (10th exceedance percentile), P50 (median), and P90 (90th exceedance percentile) stage elevations for Lake Tulane are 116.99, 113.04, and 109.90 ft NGVD29, respectively. These values yield a P10-P50 difference of 4.3.95 ft and P10-P90 difference of 7.09ft. This P10-P50 difference is almost

four times greater than for mesic-type lakes with a shallow water-table, such as lakes located in the Tampa Bay region (SWFWMD, 1999; Cameron et al., 2022).

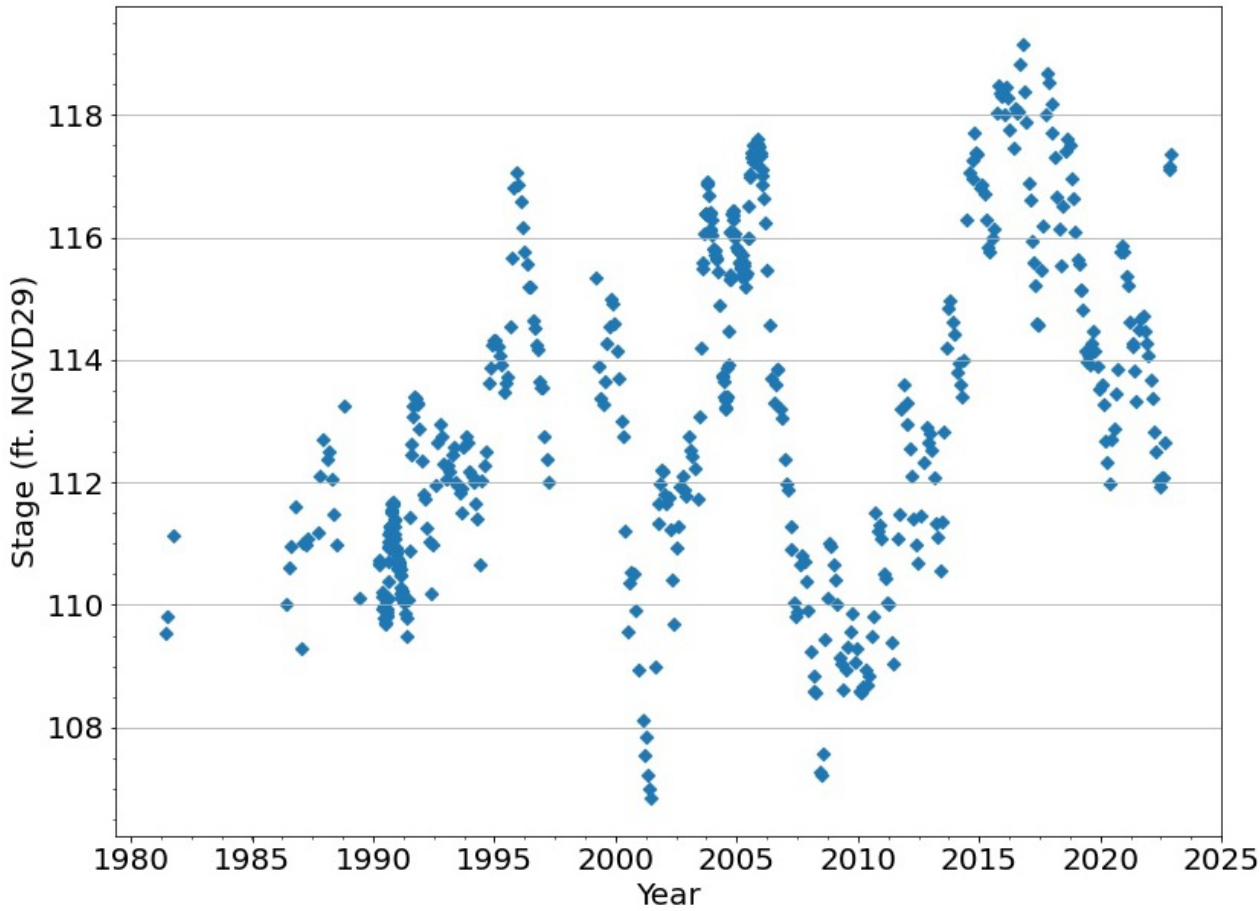

Figure 2-6. Lake Tulane water level (stage) observations (ft NGVD29) from June 11, 1981 through December 06, 2022.

2.4 Bathymetry

Relationships between water surface elevation (i.e., stage), inundated area, and volume can be used to evaluate expected fluctuations in water body size that may occur in response to climate, other natural factors, and anthropogenic impacts such as structural alterations or water withdrawals. Because long term reductions in stage and size can be detrimental to many of the environmental values identified for consideration when establishing minimum water levels, stage-area-volume data are useful for minimum level development and assessment. This information is also needed for development of lake water budget models used for estimating the lake-level response to rainfall, evaporation, runoff, outflow, leakance, and groundwater withdrawals.

Stage-area-volume relationships for Lake Tulane were previously developed by the District (SWFWMD 2007) to support minimum levels development. For reevaluation of the minimum

levels, elevations of the lake bottom and land surface elevations were used with ESRI® ArcGIS Pro software, the 3D Analyst ArcGIS Pro Extension, and Python to build a new model for estimating stage-area-volume relationships. The process involved merging the terrain morphology of the drainage basin in the vicinity of Lake Tulane with the basin morphology to develop a single continuous 3D digital elevation model (DEM).

Two elevation data sets were used to develop the terrain model. Light Detection and Ranging (LiDAR) data ADS40 sensor were merged with bathymetric data for the lake collected with both sonar and mechanical (manual) methods. The LiDAR data was obtained in February 2021 using a DJI Matrice 600 Unmanned Aerial Vehicle (UAV), coupled with a Snoopy V-Series VUX-1UAV LiDAR sensor along with an STIM300 Inertial Measurement Unit (IMU), and Flight control system of the A3 Flight Controller Pro D-RTK GNSS units, and provided to the District by Survtech, Inc. The bathymetric data (SurvTech, Inc. 2021) were collected in February 2021 using a Norbit iWBMS sonar system with an Applanix AP-20 Wavemaster Inertial Navigation system (INS). Sound velocity was collected using an AML BaseX2 sound velocity caster.

The combined elevation data sets were used to develop a DEM (Figure 2-7), that was then used to develop stage-area-volume data by 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 from a peak or flood-stage elevation downward to a base elevation associated with the deepest portion of the lake. The DEM was also used to develop topographic contours of the lake (Figure 2-8).

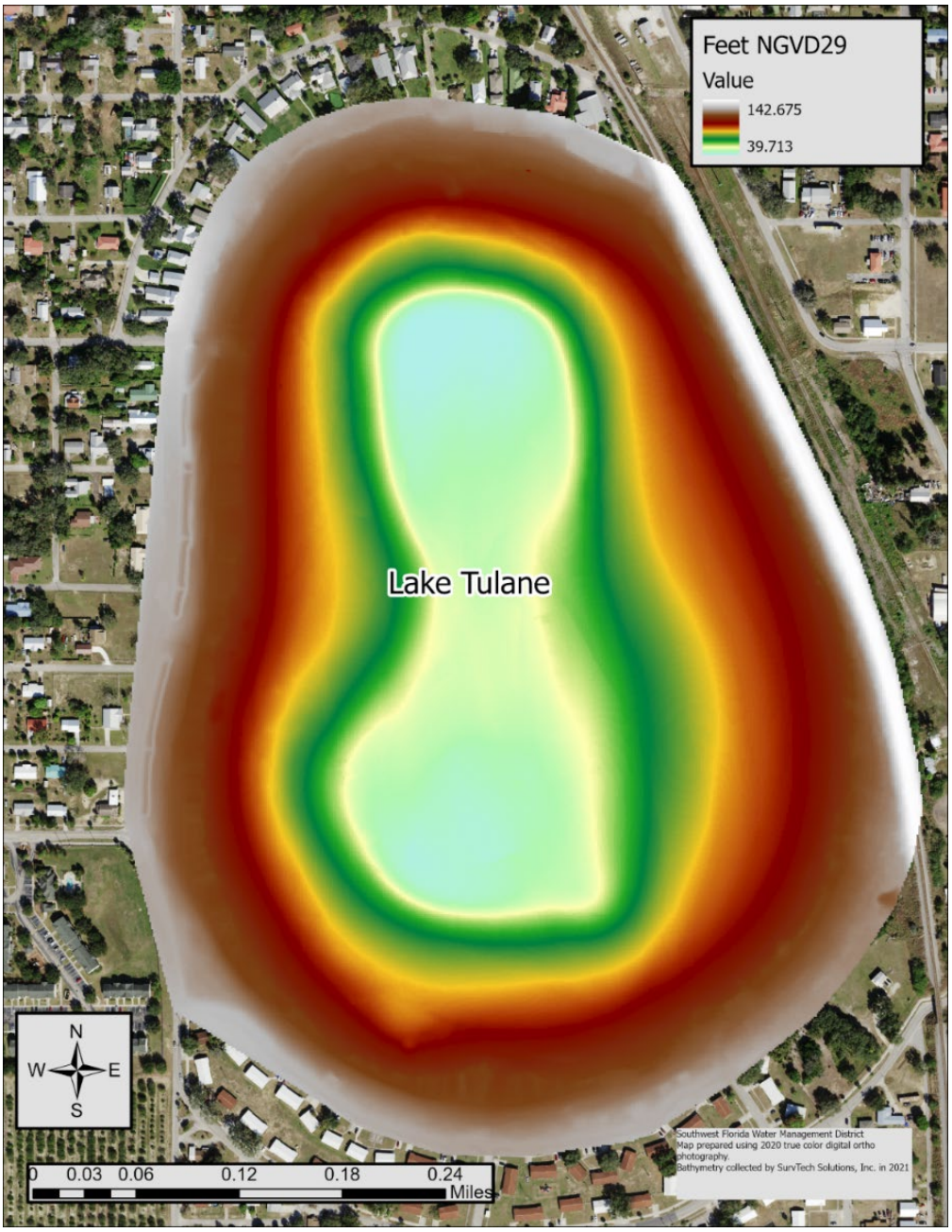

Figure 2-7. Digital Elevation Model (DEM) for Lake Tulane. Note this DEM was used to develop elevation contours depicted in Figure 2-8

Figure 2-8. Topographic and lake bottom elevations (NGVD 29) of Lake Tulane.

Lake Tulane is a sinkhole lake with a steeply sloped bottom that grades toward two deep areas, with the deepest portion of the lake bottom occurring at an elevation of 39.8 ft NGVD29 in the north-central portion of the basin (Figure 2-8). Based on the lake's relatively great depth, for a Florida lake, and its age, which is associated with its location in the Lake Wales Ridge area of peninsular Florida, cores from the lake have yielded information on environmental conditions spanning back 50,000-60,000 years from the present (e.g., Grimm et al., 1993, Huang et al. 2006).

At the period-of-record median (P50) stage of 113.0 ft NGVD29, Lake Tulane extends over 84 acres. From the period-of-record P90 (109.9 ft NGVD29) to P10 (117.0 ft NGVD29) stages, the lake area varies from 77 to 91 acres. Surface area, maximum depth, mean depth, and volume relationships with lake stage are shown in Figure 2-9, and a summary table for these data is provided in Appendix A.

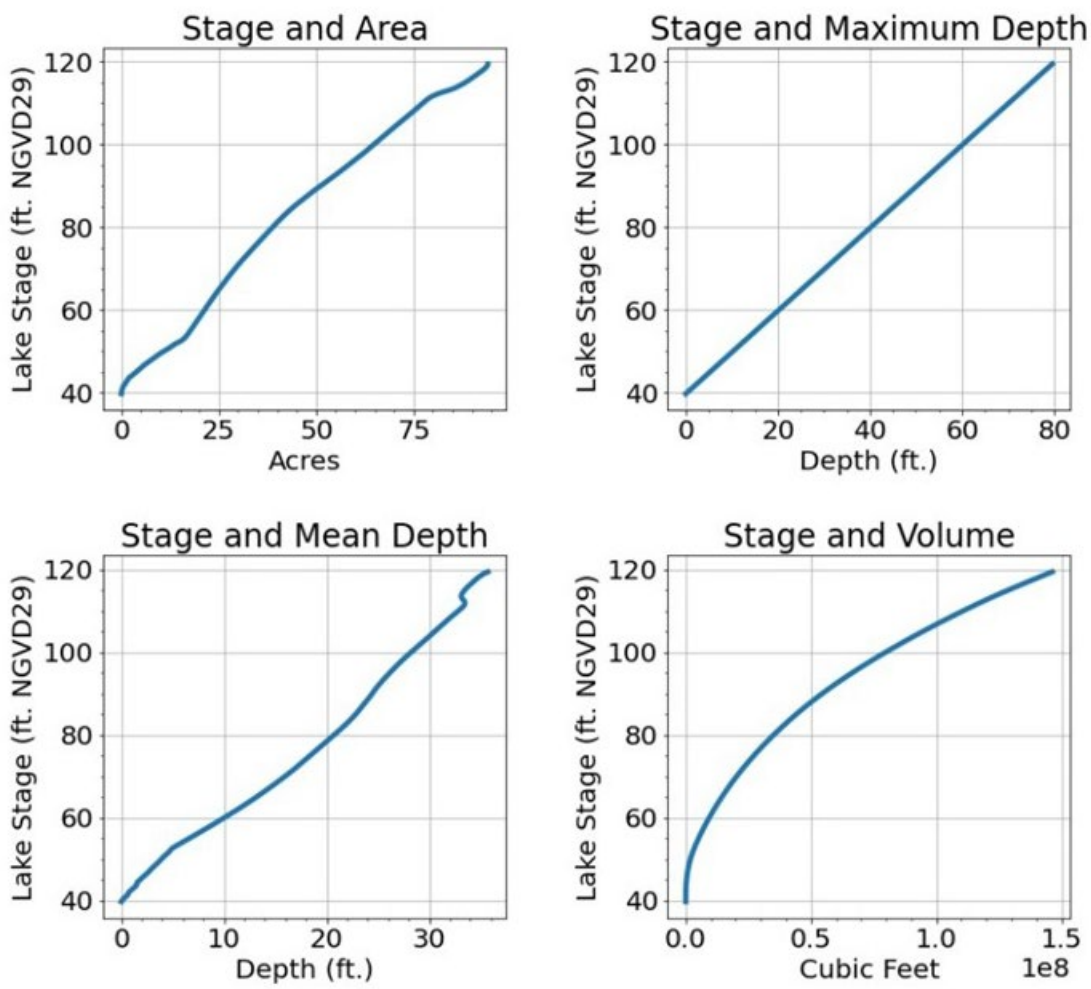

Figure 2-9. Surface area, maximum depth, mean depth, and volume versus lake stage for Lake Tulane.

2.5 Physiography and Soils

Lake Tulane lies within the Central Highlands of the Central or Mid-peninsular physiographic zone of Florida, an area of near parallel north-south ridges that are remnants of beach and sand-dune

systems associated with Miocene, Pliocene or Pleistocene shorelines (White, 1970; Arthur et al, 2008). Landforms in the region include xeric residual sand hills, beach ridges, and dune fields interspersed with numerous sinkhole lakes and basins formed from erosion of the underlying limestone bedrock.

White (1970) classified the area containing Lake Tulane as the Intraridge Valley, a region of numerous karst features that is surrounded by divided ridges that comprise the southern Lake Wales Ridge physiographic region (Figure 2-10). Brooks (1981) characterized the area surrounding Lake Tulane as the Eastern Complex of the Central Ridge unit of the Lake Wales Ridge subdivision of the Central Lake District physiographic district and described the unit as containing some residual high hills with considerable amounts of Upper Miocene coarse clastics underlying the ridge. As part of the Florida Department of Environmental Protection's Lake Bioassessment/ Regionalization Initiative, the area has been identified as the Southern Lake Wales Ridge lake region and also described as the Intraridge Valley, where there are mostly clear-water, acidic to alkaline lakes with low color and low nutrient concentrations (Griffith et al. 1997).

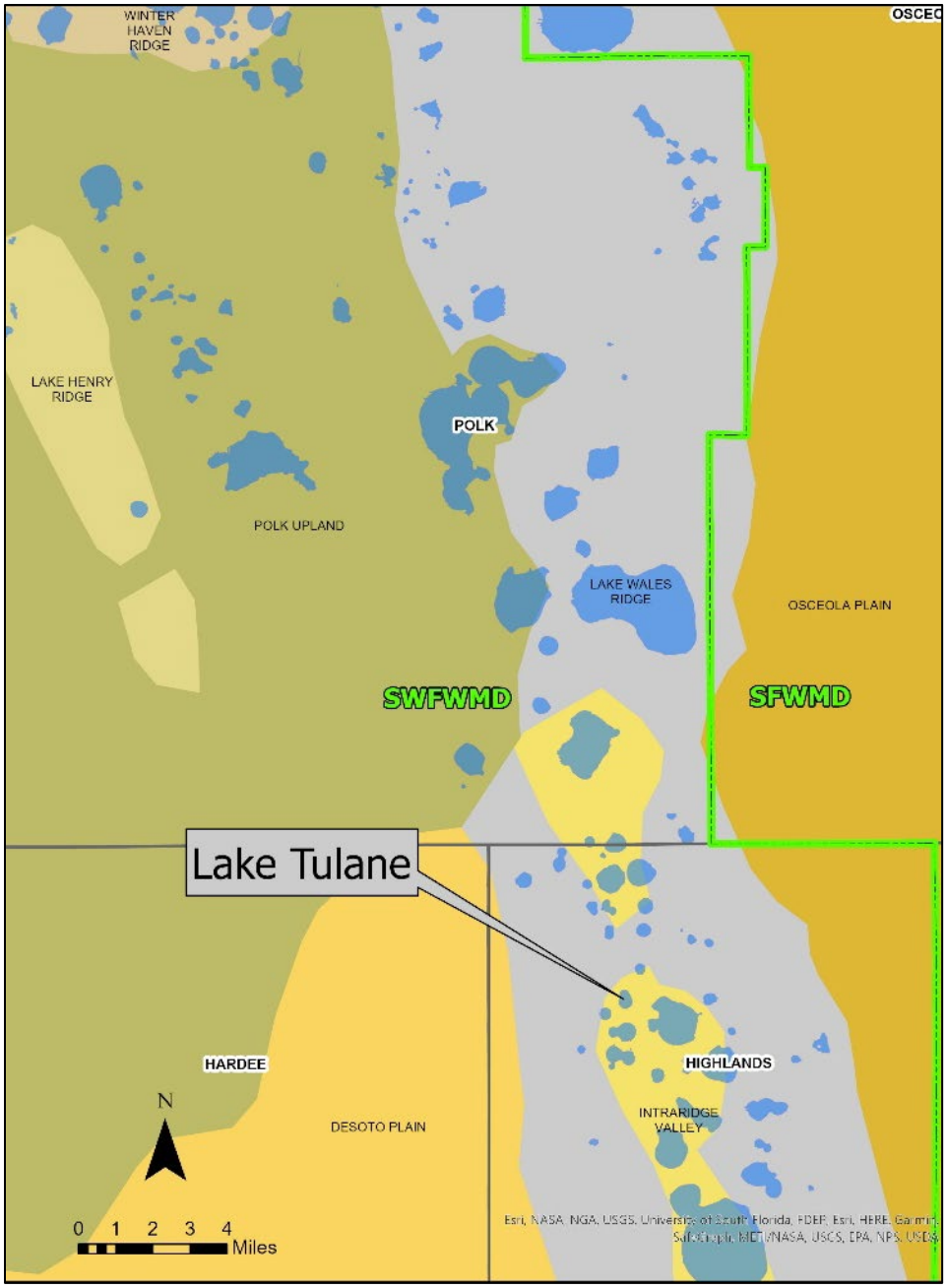

Figure 2-10. Physiographic regions in the vicinity of Lake Tulane.

The Lake Wales Ridge is the highest and longest of the central-Florida ridges, with maximum altitudes of 305 ft NGVD29 (Spechler and Kroening, 2007). Within a few miles of Lake Tulane, land surface elevations range from approximately 100 to 150 ft NGVD29 (Figure 2-11).

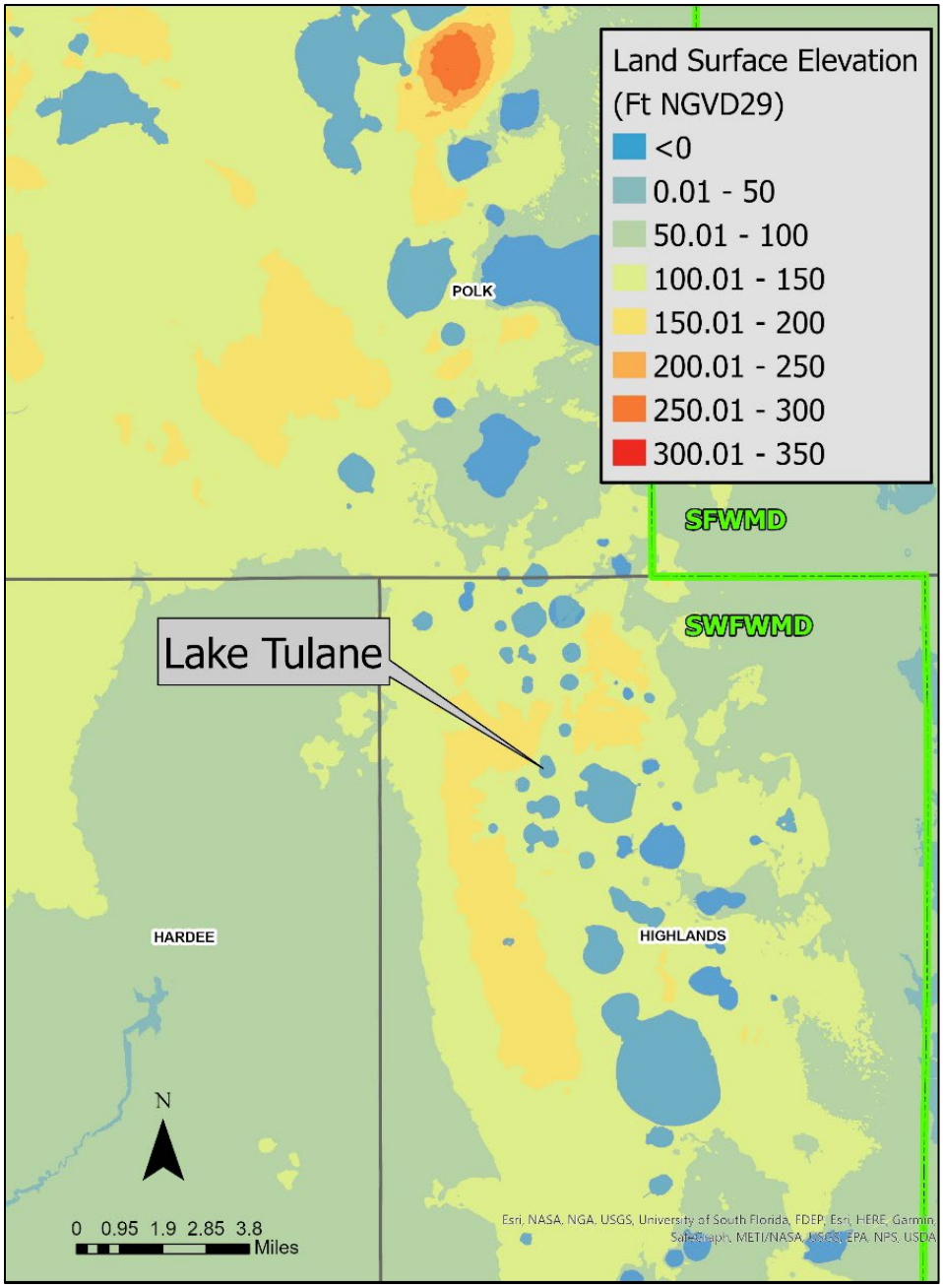

Figure 2-11. Land surface elevation near lake Tulane and surrounding area.

Weekley et al. (2008) provide an updated, ecologically-based map of the Lake Wales Ridge that was derived using topographic features, soils, vegetation, typical land use, previously developed maps of the ridge area, and field surveys. Based on this mapping effort, Lake Tulane lies in an area of xeric upland soil groups characterized as “yellow sands” vs. “white sands”, with the two classes supporting distinct vegetative communities. In support of District minimum level evaluations, GPI (2021a, 2021b) recently classified Lake Tulane as a xeric-associated system based on surrounding soils characteristics.

Soils in the vicinity of Lake Tulane are primarily Group “A” soils (Figure 2-12). The Group A, Astatula series predominate the soils in the immediate lake basin. The Astatula series “consists of very deep, excessively drained, very rapidly permeable soils on uplands of the South Central Florida Ridge (MLRA 154), Southern Florida Flatwoods (MLRA 155) and a few areas of the Eastern Gulf Coast Flatwoods (MLRA 152A) (USDA-NRCS 2023a). Other soils in areas near the lake area include those of the Group A Tavares series that “consists of very deep, moderately well drained soils that formed in sandy marine or eolian deposits” (USDA-NRCS 2023d), those of the Group A Paola series, which “consists of very deep, excessively drained soils that formed in sandy marine sediments” (USDA-NRCS 2023c), and to
those of the Group A/D Myakka series, which “consists of very deep, very poorly or poorly drained, moderately rapid or moderately permeable soils that occur primarily in mesic flatwoods of peninsular Florida” (USDA-NRCS 2023b).

Figure 2-12. Soils group and series (in parentheses) and unclassified areas (Water and Urban land) in the vicinity of Lake Tulane.

2.6 Land Use and Cover and Additional Wetlands Information

Uplands immediately adjacent to Lake Tulane are used primarily for residential development and transportation corridors (see Figures 2-3 and 2-8). Only a few homes are sited directly on the lake, primarily along the northern lakeshore. A fringe of undeveloped land or road easements

occur along approximately three-quarters of the lake shoreline. The City permits passive recreation and foot traffic in the land parcel they own at the south end of the lake.

Land use/cover information for the area surrounding Lake Tulane within the District (note that portions of Highlands County lie within the South Florida Water Management District) in 2020 and 1990 are provided in Table 2-1 and Figure 2-13. Agriculture is the primary form of land use throughout the county and includes citrus groves, dairies, pasture, sod, and vegetable farms (Spechler, 2010). Citrus production is the most widespread form of agriculture and is primarily concentrated along the Lake Wales Ridge. Agricultural lands comprised 33 percent of Highlands County land within the District in 2020, a slight decrease from 34 percent in 1990. This change can be attributed to citrus greening and urban development. Urban and built-up lands in the District portion of the county have expanded from approximately 22 percent in 1990 to 26 percent in 2020. Development has been primarily concentrated around the cities of Avon Park, Sebring, and Lake Placid.

Table 2-1. Land Use Land Cover in the SWFWMD portion of Highlands County in 1990 and 2020.

	1990 LULC (acres)	% of total acreage	2020 LULC (acres)	% of total acreage
Urban and Built-Up	49272.32	22.21	65393.20	26.10
Agriculture	76123.22	34.32	82621.11	32.97
Rangeland	20718.10	9.34	18064.27	7.21
Upland Forests	27386.71	12.35	21153.44	8.44
Water	19761.12	8.91	22472.34	8.97
Wetlands	26617.40	12.00	37946.12	15.14
Barren Land	490.03	0.22	378.39	0.15
Transportation, Communication and Utilities	1430.38	0.64	2557.89	1.02

The percentage of forest cover in the District portion of Highlands County has decreased from approximately 12 percent in 1990 to 8 percent in 2020, with forested lands primarily located in the northeastern and western areas of Highlands County. The percentage of rangeland also decreased between 1990 and 2020, from approximately 9 percent of the area in 1990 to 7 percent in 2020. These decreases have likely been associated with increased urban development.

The percentage of wetland acreage within the District portion of Highlands County has increased from approximately 12 percent in 1990 to 15 percent in 2020, However, due to the increase in urban development, this apparent increase in wetlands is likely a result of variation in the methods used for wetland classification more so than an actual increase in the extent of wetlands present within the county. This is evident in a local comparison of the land use and land cover for the Lake Tulane sub-basin (Figure 2-13). There were no wetlands mapped within the Lake Tulane sub-basin in 1990 but 15 acres of shoreline wetlands in 2020 were mapped. Historical photography for the Lake Tulane area from 1944 through 2020 (Figures 2-14 through 2-18) illustrates the persistence of wetland plant coverage in a relatively narrow, near-shore band within the relatively deep, steeply-sloped basin.

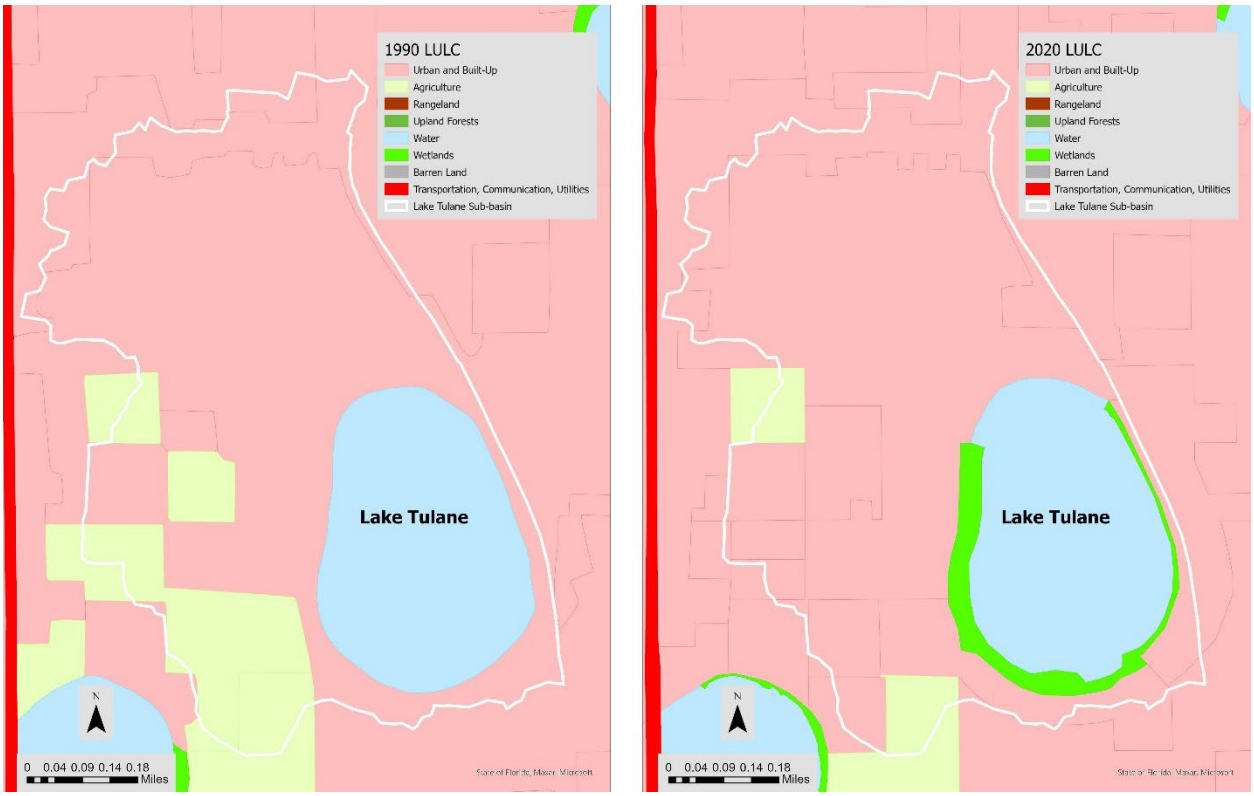

Figure 2-13. 1990 and 2020 Land Use Land Cover in vicinity of Lake Tulane.

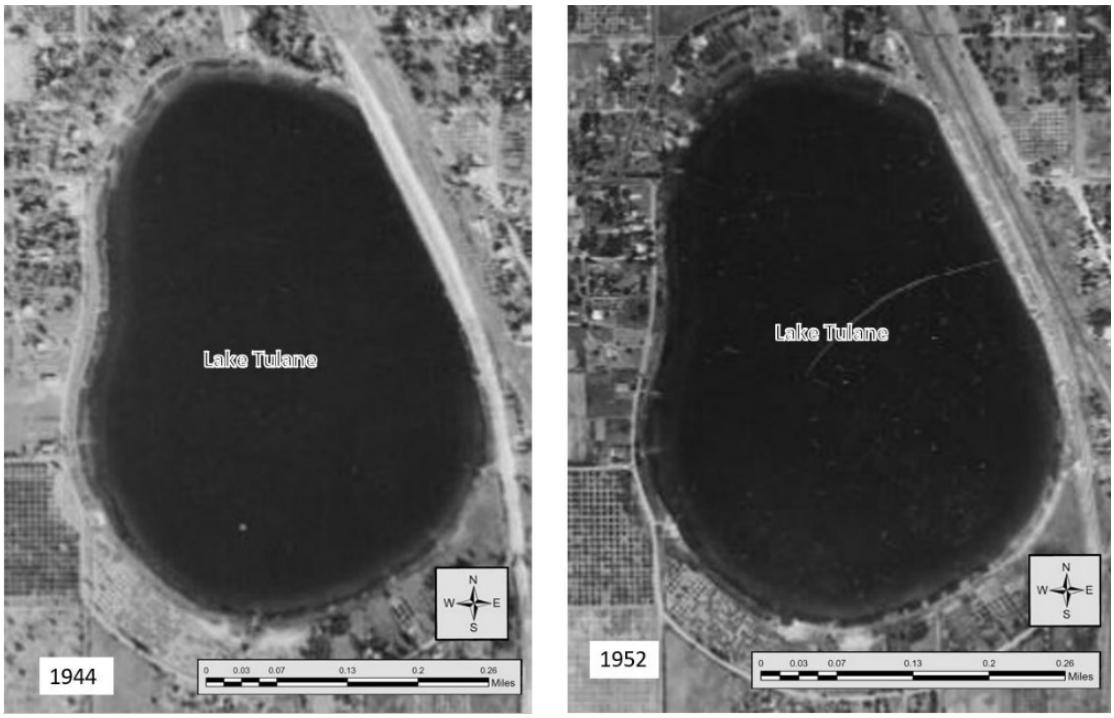

Figure 2-14. 1944 and 1952 Aerial photographs of Lake Tulane.

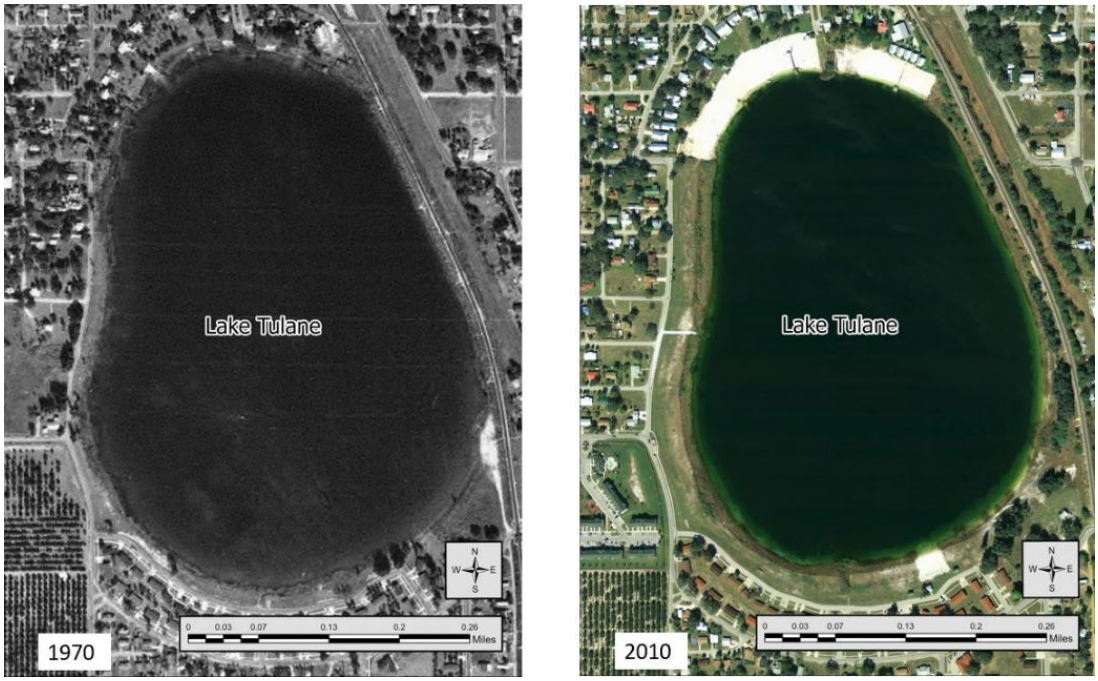

Figure 2-15. 1970 and 2010 Aerial photographs of Lake Tulane.

Figure 2-16. 2020 Aerial photograph of Lake Tulane.

A recent Lake Vegetation Index assessment (FDEP, unpublished data) based on methods described by Fore (2007) and FDEP (2011, 2017), indicates torpedo grass (*Panicum repens*) and southern umbrella sedge (*Fuirena scirpoidea*) are co-dominants in Lake Tulane. Other species common in the emergent marsh zone include maidencane (*Panicum hemitomon*), Mexican primrose willow (*Ludwigia octovalvis*), and dog fennel (*Eupatorium capillifolium*). Spatterdock (*Nuphar* sp.) and humped bladderwort (*Utricularia gibba*) occur in deeper areas.

The area available for aquatic plant growth was estimated for Lake Tulane based on a relationship of light attenuation as measured with Secchi depth (SD), and maximum depth of plant colonization (MDC). Using data from 1995 through 2022 for Lake Tulane obtained through the Florida LAKEWATCH monitoring program, the mean SD was 5.1 meters. Use of this Secchi depth with equation 2-1 below from Caffrey et al. (2007) yielded an MDC value of 19.2 ft.

```
(Equation 2-1)  log MDC (in meters) = 0.66 log (SD in meters) + 0.30
```

Based on a 19.2 ft MDC and stage-area information developed in support of the reevaluation of minimum levels for Lake Tulane (described in Section 2.4.2 of this document), the area available for aquatic plant colonization would range from 23.5 to 28.3 acres at water surface elevations from 100 to 119.4 ft NGVD29 in the Lake Tulane basin (Figure 2-19).

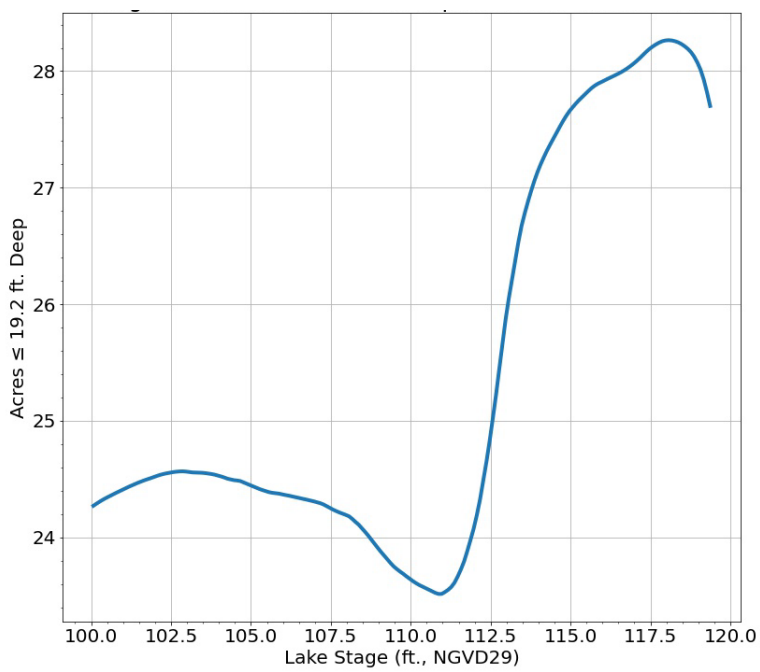

Figure 2-19: Lake stage and area available for aquatic plant colonization in Lake Tulane.

2.7 Climate and Rainfall

2.7.1 Air Temperature

Northern Highlands County, where Lake Tulane is located, lies within a humid subtropical zone that is influenced by its proximity to the Gulf of Mexico and Atlantic Ocean. Subtropical zones are characterized by hot, humid summers and mild to cool winters. The temperature of the Gulf and Atlantic Ocean water moderates the air temperatures on the Florida Peninsula. The average mean daily temperature is approximately 72ºF (21ºC). Mean summer temperatures are in the low 80s (ºF), and the mean winter temperatures are in the upper 50s (ºF).

2.7.2 Peninsular Florida Rainfall and AMO/ENSO Effects

In southwest Florida, wet season rainfall occurs during the summer rainy season, defined as the months of June through October, with remaining months considered “dry season” months. Coincident with the wet season is the tropical storm and hurricane season, which is generally defined as extending from June to November, although most activity occurs between August and the first half of October. This increased tropical activity leads to greater rainfall totals during the summer and early fall.

As shown by Enfield et al. (2001), Kelly (2004), and Kelly and Gore (2008), warmer North Atlantic Sea Surface Temperatures (SSTs) lead to increased summer rainfall on the Florida peninsula that results in higher river flows, lake stages, and spring flows. Conversely, cooler North Atlantic SSTs are associated with decreased summer rainfall and tropical cyclonic activity for the peninsula, and therefore lower river flow, lake stages, and spring flows.

North Atlantic SSTs have fluctuated between “warm” and “cool” phases at 20- to 50-year intervals, a long-term decadal cycle called the Atlantic Multidecadal Oscillation or AMO (Kerr, 2000; Enfield et al., 2001; Knudsen et al., 2011). Long-term periods of above-average or warm North Atlantic SSTs are referred to as “warm” or “positive” AMO phases, while long-term periods with below-average SSTs are “cool” or “negative” phases.

Although the actual deterministic mechanisms of the AMO remain poorly understood, warm phases are associated with a stronger thermohaline circulation in the Atlantic Ocean and cool phases with weaker thermohaline circulation. This thermohaline circulation is a global deep ocean current often described as a “conveyor belt” that transports warmer equatorial water in the south Atlantic Ocean northward to the North Atlantic region south of Greenland.

Research from proxy data such as tree rings and ice cores suggest that the AMO has existed for most of the Holocene, i.e., from 11,700 years ago to the present. Based on recorded SSTs from the beginning of the 20th century, the National Oceanic and Atmospheric Administration has identified cool phases for the periods from 1900 to 1925 and 1970 to 1995, and warm phases from around 1925 to 1969 and from 1995 to the present (Figure 2-20).

Records from most long-term rainfall stations in the District span these two warm and cool phases. However, most of the earliest continuous daily observations for rivers, lakes, and springs in Florida were initiated by the USGS during the early-1930s and therefore do not reflect conditions associated with the 1900 to 1925 cool phase.

Superimposed on the long-term fluctuations of the AMO is the shorter-term El Niño–Southern Oscillation (ENSO), a largely Pacific Ocean phenomenon that nevertheless has important implications for climate in Florida and throughout the United States. While the AMO largely affects wet season rainfall, ENSO largely impacts dry season precipitation during the winter-early spring. Specifically, El Niño events in Florida are associated with increased dry season rainfall and La Niña events with lower-than-average precipitation. During El Niño, easterly trade winds in the Pacific Ocean weaken, allowing warmer oceanic waters to migrate from the west to east which suppresses the upwelling of cool seawater along the western South American coast. In winter

and early spring, this situation allows the jet stream to migrate southward in the Pacific Ocean and across the southern United States and Florida, bringing with it wet winter and early spring weather. During La Niña, the easterlies strengthen, increasing upwelling along the western South American coast which causes the jet stream to be displaced northward. During "neutral months," an intermediate state exists. Typically, an El Niño or La Niña event will last several months, recurring every 2 to 7 years as the intensity varies. Thus, the AMO and ENSO differ in their duration, frequency, and the seasons for which they most impact precipitation.

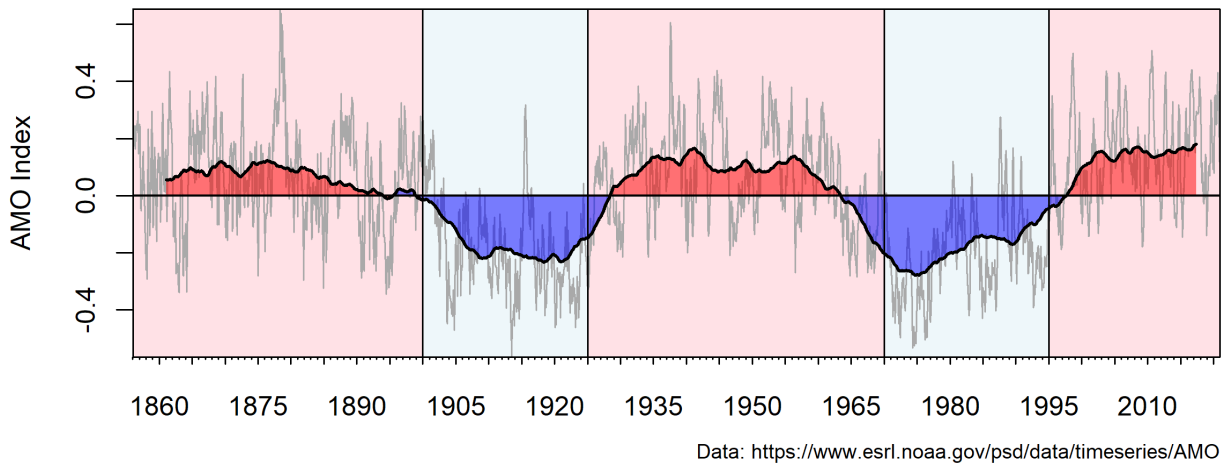

Figure 2-20. Atlantic Multidecadal Oscillation (AMO) index from 1856 to 2021, smoothed (121 months; black line) and unsmoothed (gray line), from the National Oceanic and Atmospheric Administration. Vertical lines indicate shifts between AMO phases (warm in red; cool in blue) defined after Enfield et al. (2001).

As noted by Enfield (2001), Basso and Schultz (2003), Kelly (2004), and Kelly and Gore (2008), greater mean annual rainfall totals for the period 1940 to 1969 and lower rainfall totals for the period 1970 to 1994 are explained partially by the increase and decrease, respectively, in tropical cyclone activity of the two periods. In addition to changes in tropical cyclone activity, other atmospheric pattern changes contribute to enhanced summer rainfall on the Florida peninsula during warm AMO phases. Basso and Schultz (2003) found that tropical cyclone activity accounted for about one-third of changes in wet season rainfall over the long-term period of an AMO cycle in their study of west-central Florida.

2.7.3 Highlands County Rainfall

Rainfall in Highlands County averaged 52.1 in/yr from 1915 through 2022 based on annual rainfall data available from the District's Hydrologic Data Section[3], but varies widely from season to season and year to year (Figure 2-21). About 60% of annual rainfall occurs in the summer rainy season months of June through September[3] when convective thunderstorms are common due to daytime heating and afternoon sea breezes. In addition, summer and fall rainfall can be enhanced by tropical cyclone activity from June through November.

Annual, ten-year moving average (Figure 2-21), and cumulative departure from the long term mean rainfall (Figure 2-22) are indicative of increasing trend in rainfall up until 1970 and a declining trend thereafter. This trend is consistent with long-term cycles associated with the Atlantic Multidecadal Oscillation (AMO) (Enfield et al., 2001; Kelly and Gore, 2008; Cameron et al., 2018), although rainfall in the more recent warm AMO phase which began in 1995 has not increased much from the preceding cool AMO phase. Cameron et al. (2018) attributed the lower rainfall during the most recent warm AMO phase to a decrease in dry season rainfall due to more frequent La Niña events. In addition, wet season rainfall, while generally greater than the preceding cool AMO phase (1970-1994), has been hindered by the smaller number of tropical systems making landfall in Florida during the most recent warm phase, relative to prior phases. While overall tropical cyclone activity in the Atlantic Basin has been above average during the most recent warm AMO cycle, landfalling storms in Florida have been below average.

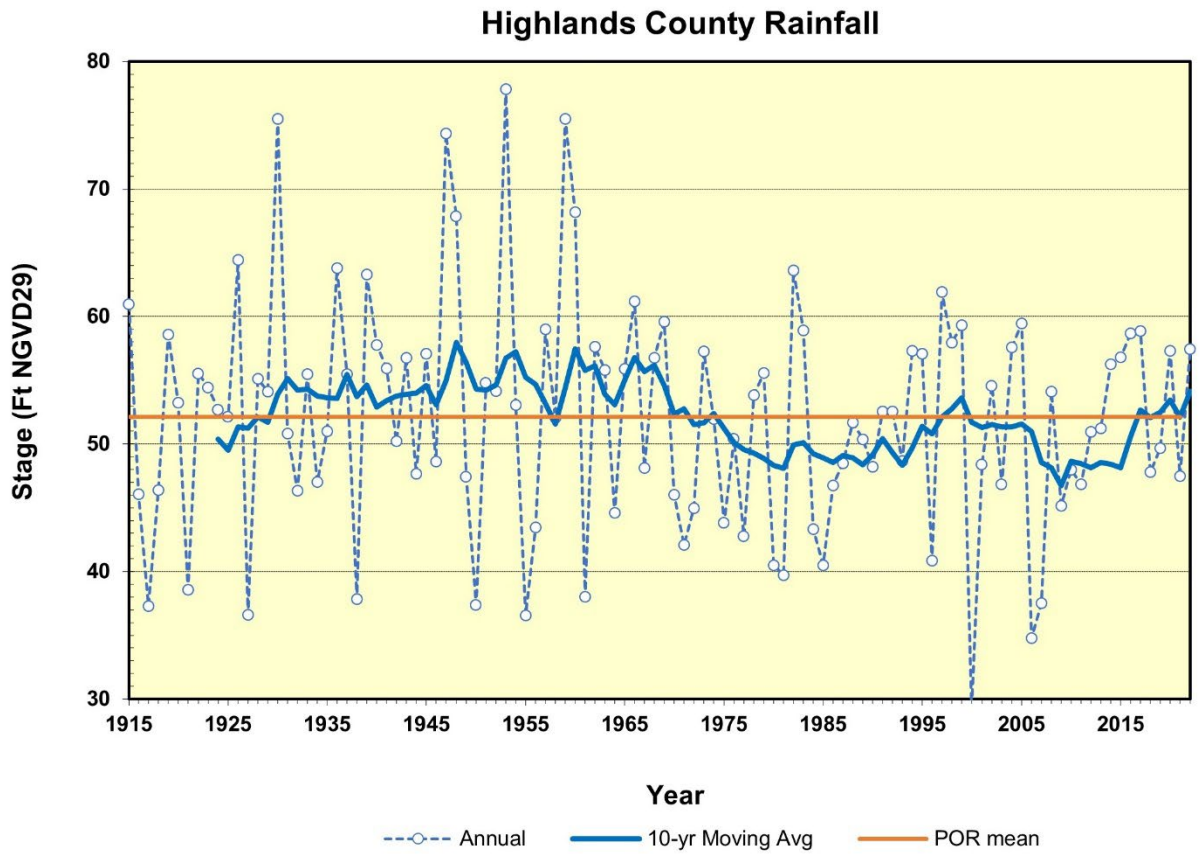

Figure 2-21. Annual, 10-year moving average, and period-of-record average rainfall for Highlands County from 1915 through 2022 (source: https://www.swfwmd.state.fl.us/resources/data-maps/rainfall-summary-data-region).

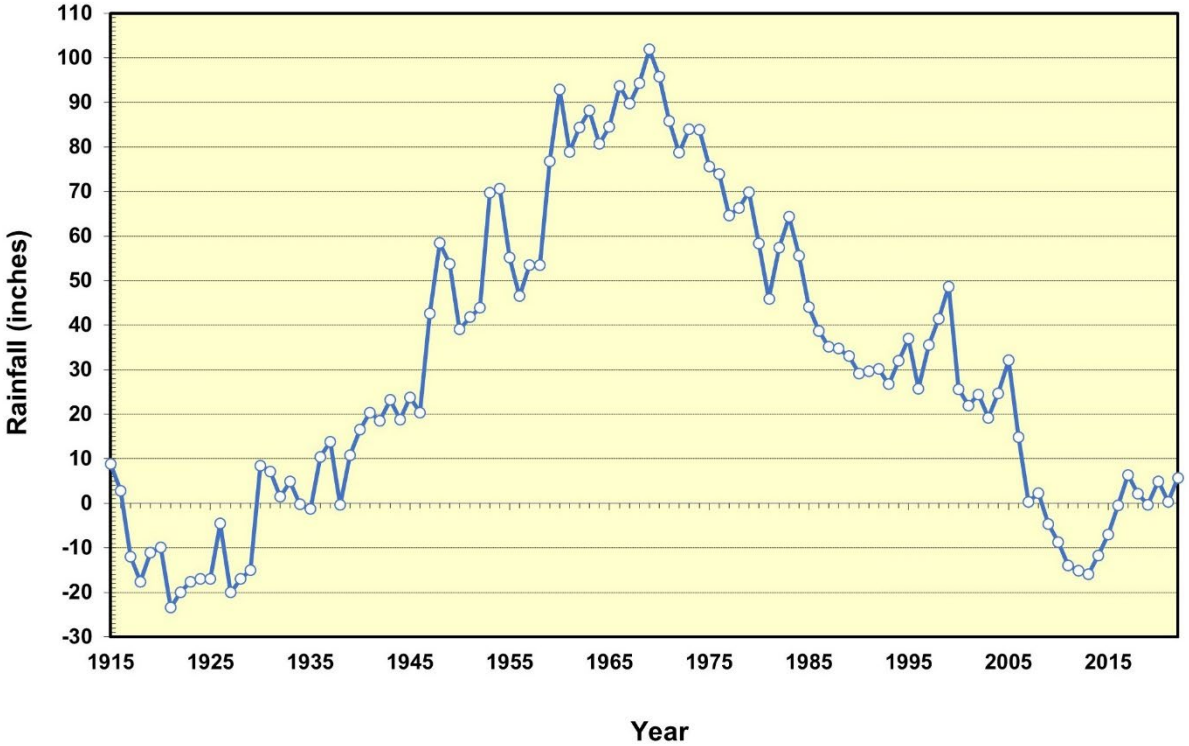

Figure 2-22. Cumulative departure in Highlands County rainfall from 1915 through 2022 expressed relative to the period-of-record average depicted as 0 inches (source: https://www.swfwmd.state.fl.us/resources/data-maps/rainfall-summary-data-region).

The 1970 through 2012 period was exceptionally dry along the Lake Wales Ridge, especially compared with the much wetter pre-1970 period (see Figure 2-21). Based on Highlands County rainfall data, rainfall in 27 out of 43 years, almost two-thirds of the 1970 through 2012 period was below average (Figure 2-23). The cumulative rainfall departure for the period was -119.1 inches. Only since 2013 has rainfall returned to more average or slightly above average conditions.

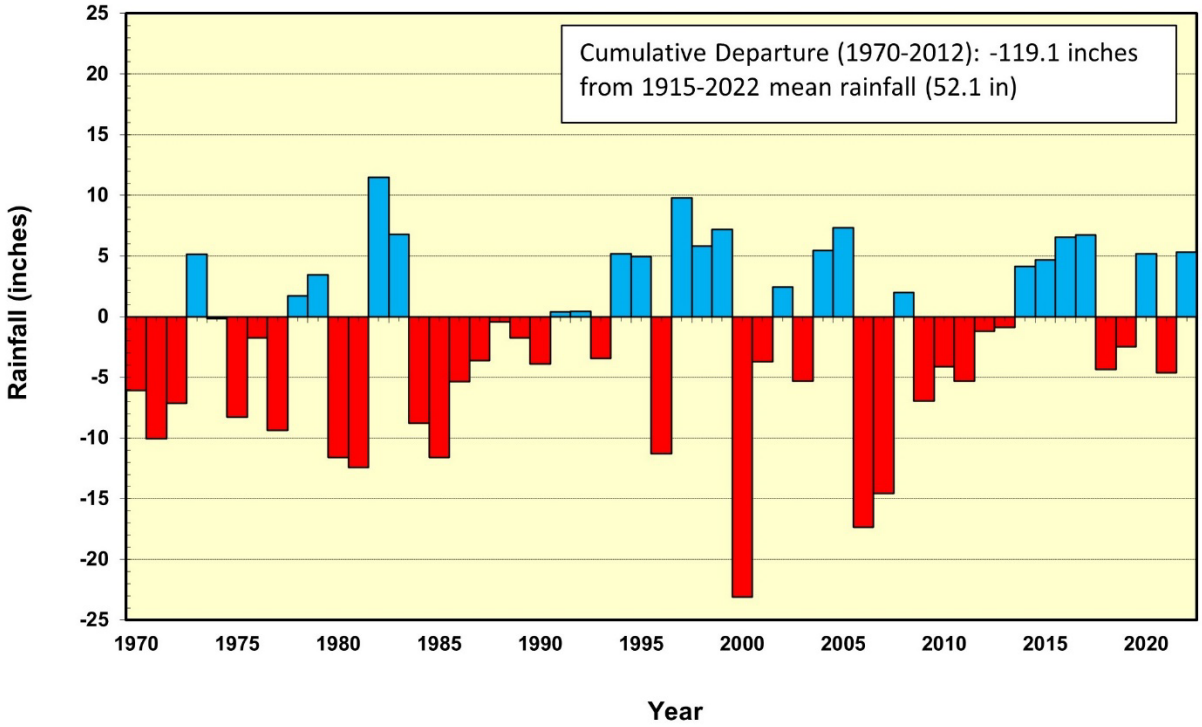

Figure 2-23. Annual rainfall departure for Highlands County from 1970 through 2022 (source: https://www.swfwmd.state.fl.us/resources/data-maps/rainfall-summary-data-region).

2.7.4 Rainfall in the Vicinity of Lake Tulane

Local rainfall in the vicinity of Lake Tulane for the period March 1999 through December 2022 was characterized using radar-estimated (NEXRAD) rainfall available for a grid (square 2 km cells) that includes and extends beyond the District boundaries. This rainfall was also used as input to the lake budget model (see Chapter 3).

Based on estimates from the dataset for pixel 88528, which encompasses Lake Tulane, annual rainfall for the period from March 1999 through December 2022 averaged 53.1 in/yr. Using these data, annual rainfall departure, as compared to the Highlands County long-term mean of 52.1 in/yr, is shown in Figure 2-26. The local rainfall data indicates higher rainfall for the 2000 through 2022 period, as compared to the county data, which yielded a 50.6 in/yr average for the 23-year record. The 53.1 in/yr average for the local rainfall estimates is only slightly above the county long-term County-based mean, and resulted in a cumulative departure of +23.6 in from that mean value for the 2000 through 2022 period.

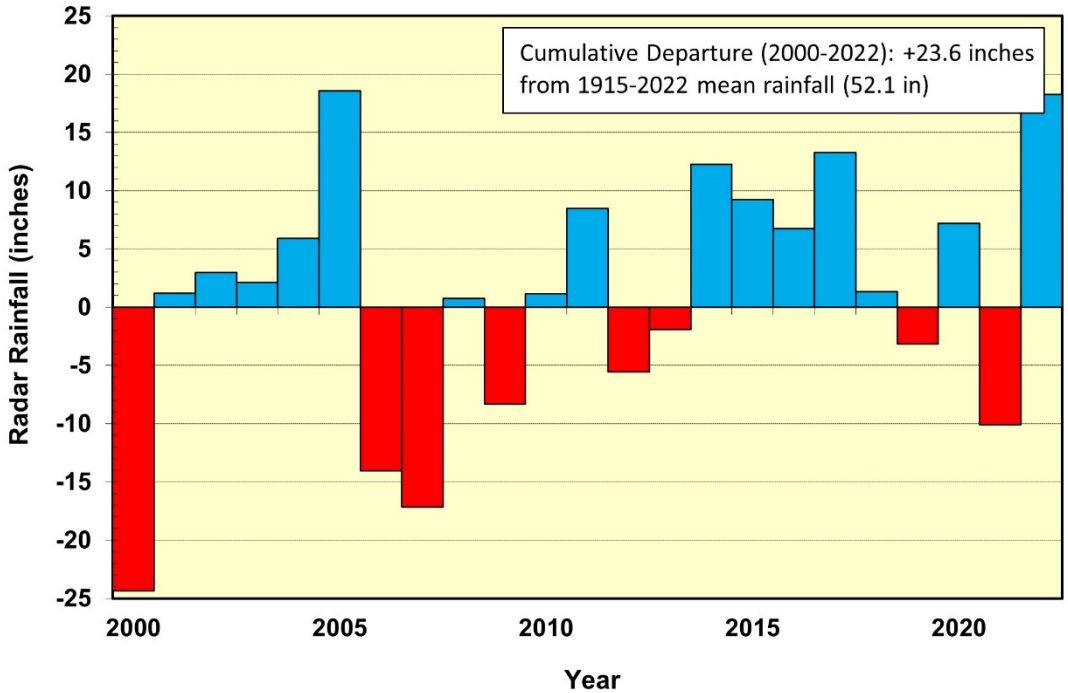

Figure 2-26. Annual rainfall departure at Lake Tulane from 2000 through 2022 (source: District radar rainfall data for pixel 88528).

2.8 Hydrogeologic Setting

Lake Tulane lies within the Intraridge Valley, a region of numerous karst features that is surrounded by divided ridges that comprise the southern Lake Wales Ridge physiographic region (White, 1970). The hydrogeologic framework over the Polk and Highlands County area of the Lake Wales Ridge includes a relatively thick unconfined surficial aquifer (SA), a variable thickness intermediate confining unit (ICU) and a thick carbonate Upper Floridan aquifer (UFA). The Lake Wales Ridge region is semi-confined and a source of high recharge to the UFA.

The SA thickness along the Lake Wales Ridge varies from 40 to 380 ft, with average thickness of nearly 200 ft. It is generally comprised of fine-to-medium grained quartz sands that grade into clayey sand just above the interface with the underlying ICU.

The ICU is a clay layer of varying thickness, ranging between 0 and 233 ft, indicating discontinuous confinement. Thin, isolated permeable zones of limestone, shell, gravel, or sand that form local aquifers may be imbedded in some portions of the ICU. These thin permeable zones have been identified as the upper Arcadia and lower Arcadia aquifers of the Hawthorn Aquifer System. Withdrawals from the aquifers imbedded in the ICU are primarily associated with household water use.

All of Highlands County is underlain by the UFA, which is composed of a thick sequence of carbonate rocks that include the upper half of the Avon Park Formation, the Ocala Limestone, and (where present) the Suwannee Limestone. The total thickness of the UFA ranges from about

1,150 to 1,500 ft in Highlands County (Clayton, 1998; DeWitt, 1998; Mallams and Lee, 2005; Arthur et al., 2008). Most of the groundwater withdrawal within Highlands County is from the UFA.

Lake Tulane and the other lakes in the Lake Wales Ridge area of Highlands County straddle a potentiometric high that forms a dividing line between the Southern West Central Florida Groundwater Basin to the west and the East-Central Florida Groundwater Basin to the east. The orientation and shape of the Lake Wales Ridge potentiometric high has changed little since predevelopment, i.e., prior to significant groundwater withdrawals, which began circa 1930. The potentiometric surface elevations for the UFA for May and September 2015 are shown in Figures 2-27 (Florida Geological Survey, 2016a and Florida Geological Survey, 2016b) as an example of the typical UFA potentiometric surface pattern.

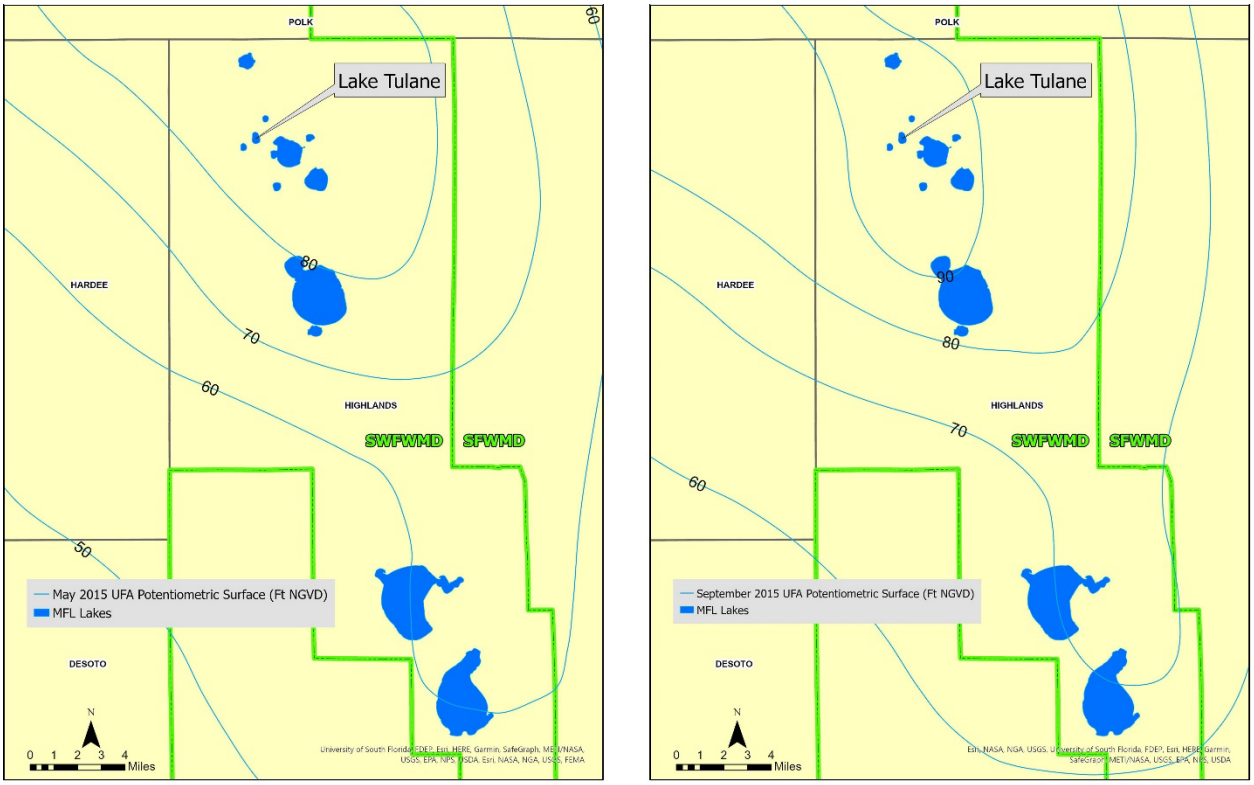

Figure 2-27. Upper Floridan aquifer potentiometric surface in May 2015 (left panel) and September 2015 (right panel) near lakes in Highlands County with established minimum levels.

2.9 Water Withdrawals

There are no surface water withdrawals from Lake Tulane currently permitted by the District, but numerous permitted ground water withdrawals occur in the lake vicinity. The District maintains a database of estimated and metered groundwater withdrawals for all permits by well. This database contains monthly and annual withdrawal data extending back to 1992 and is updated annually. The availability of these geospatially-distributed data typically lags by two years (e.g.,

2020 geospatial data became available in 2022). Estimated annual pumping for domestic self-supply (household) wells across the District is provided in another database.

Based on these databases, groundwater withdrawals within five miles of Lake Tulane (Figure 2-28) consist mainly of public supply, agricultural, and mining uses. Annual average groundwater withdrawals within the defined area averaged 19.4 mgd from 1992 through 2020, and have been relatively stable (varying from 16.5 to 22.1 mgd) since the mid-2000s (Figure 2-28).

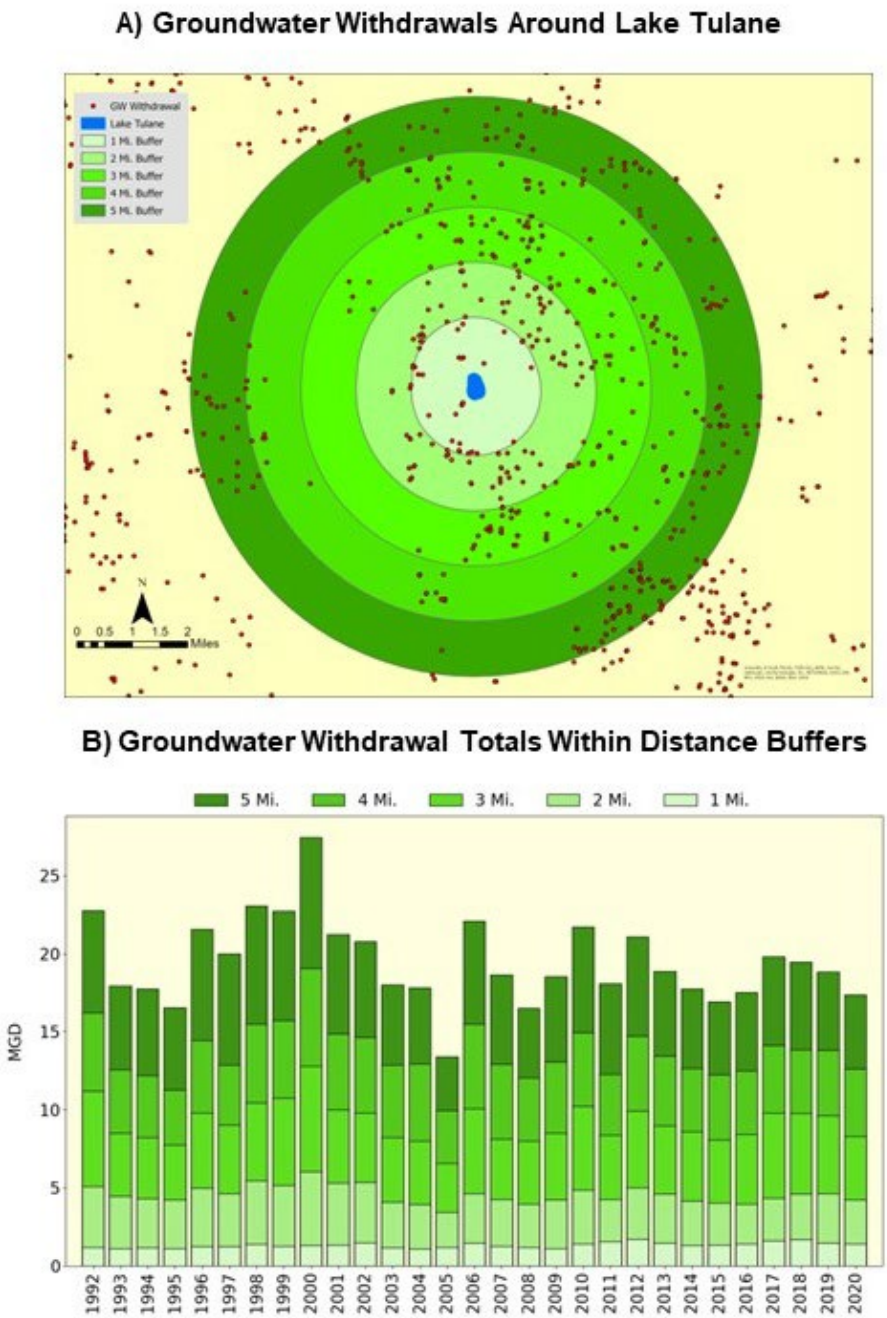

Figure 2-28. Groundwater withdrawal locations in the vicinity of Lake Tulane and annual average withdrawals from 1992 through 2020.

The spatial distribution of estimated and metered groundwater use from permitted wells in 2020 within the District in the vicinity of Lake Tulane is shown in Figures 2-29 and 2-30. Groundwater withdrawals in the area are generally dispersed, with no centralized major pumping center within Highlands County or near the lake. Total groundwater withdrawn within two miles of Lake Tulane in 2020 was 4.2 mgd, with approximately 0.3 mgd predominantly from the SA (likely with some minor IAS contributions) and 3.9 mgd from the UFA. Within five miles of Lake Tulane, total groundwater withdrawn in 2020 was 17.4 mgd with 1.72 mgd from the SA/IAS and 15.65 mgd from the UFA. Water use within five miles of Lake Tulane is associated with water use permits that authorize total withdrawals of up to 33.7 average mgd.

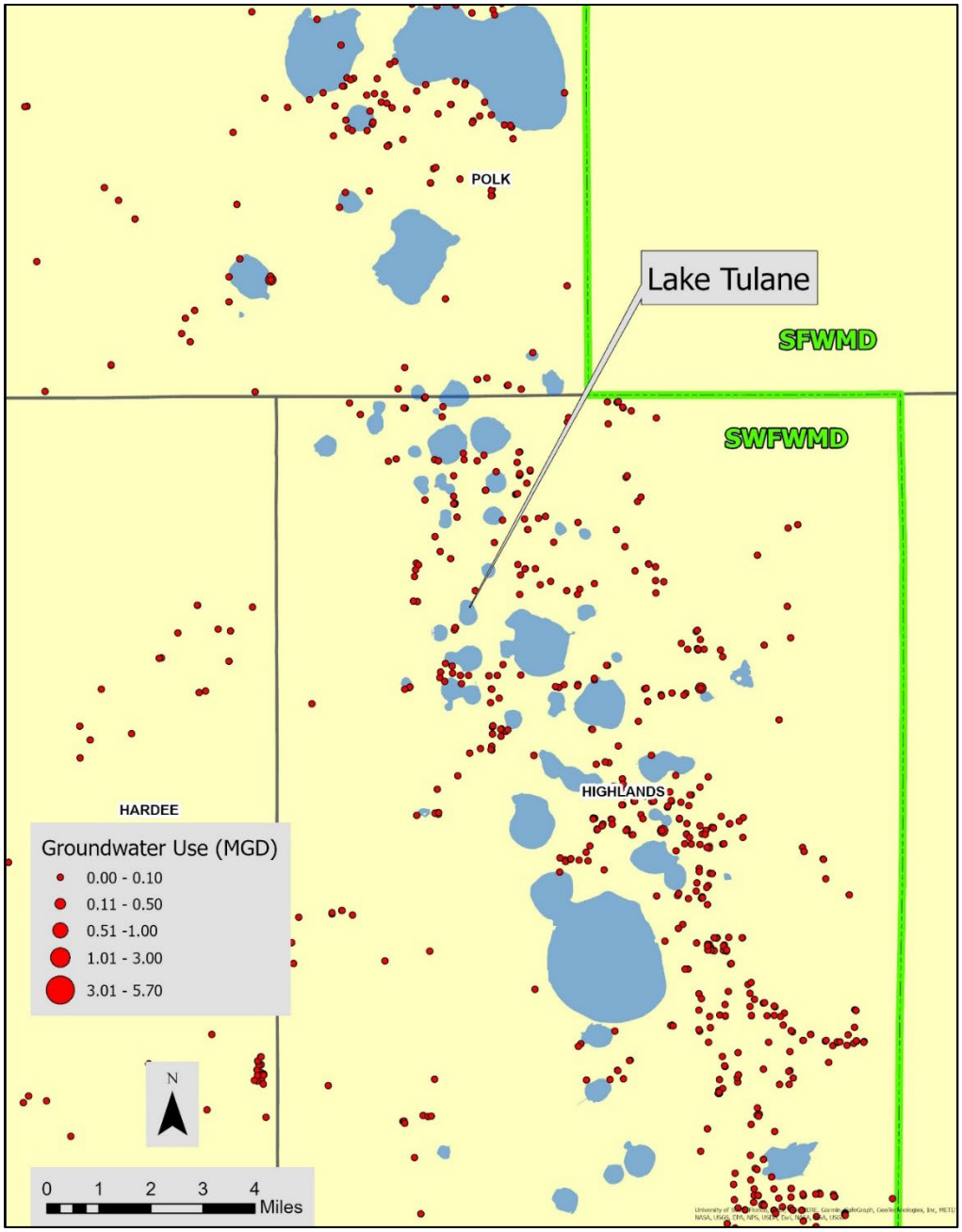

Figure 2-29. Spatial distribution of groundwater use associated with permitted withdrawals from the SA/IAS (well depths equal to or less than 200 ft) in the vicinity of Lake Tulane in 2020.

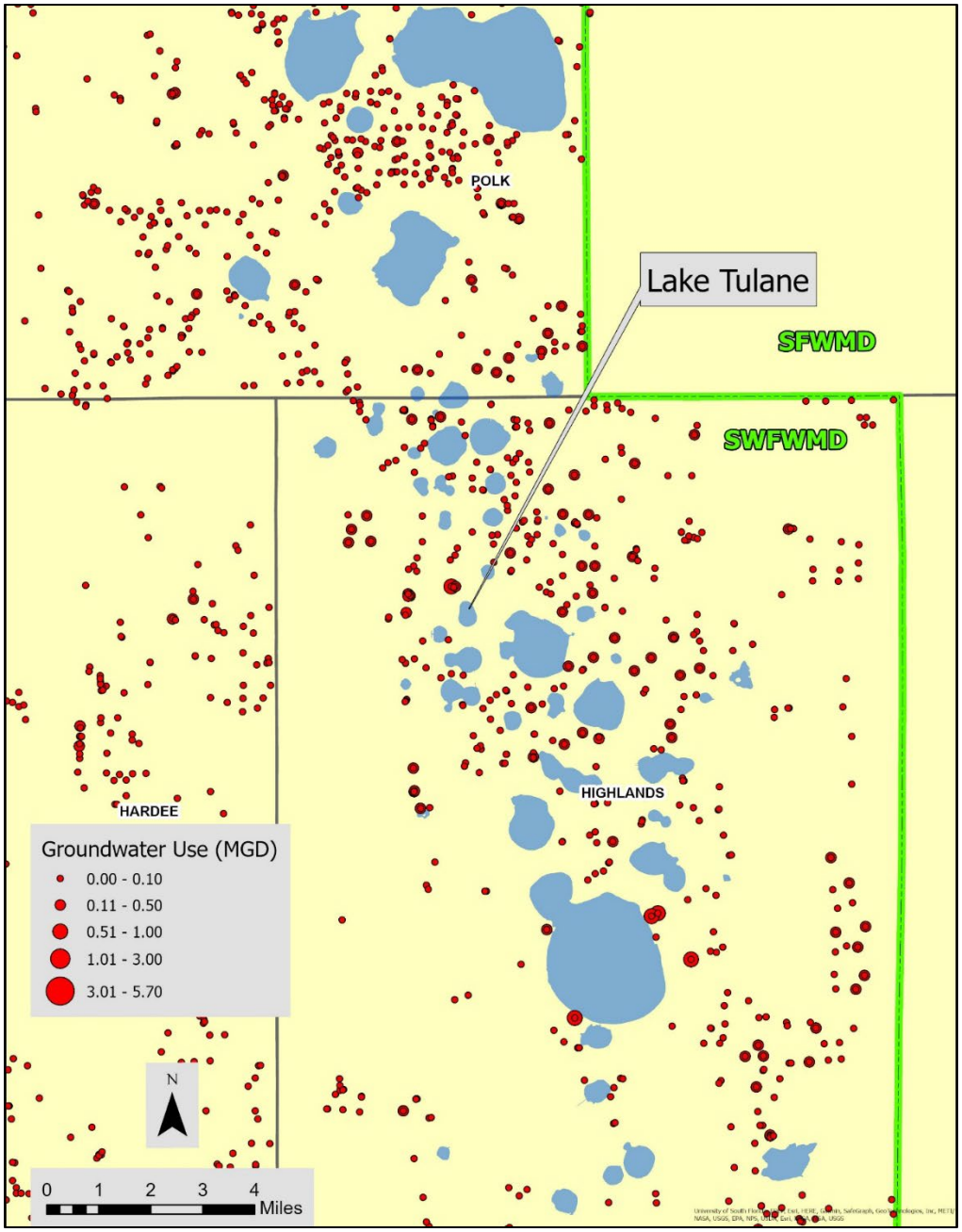

Figure 2-30. Spatial distribution of groundwater use associated with permitted withdrawals from the Upper Floridan aquifer (well depths greater than 200 ft) in the vicinity of Lake Tulane in 2020.

Spechler (2010) provides historical estimates of groundwater use in all of Highlands County, noting that groundwater withdrawals were approximately 37 mgd in 1965 and had risen to approximately 157 mgd by 2000. This increase was attributed primarily to increased use of water for agricultural purposes and secondarily to increased use for public supply. Spechler (2010) reported withdrawals decreased to approximately 107 mgd in 2005, attributing the reduction to above average rainfall.

Based on the District's estimated and metered water use data, plus domestic self-supply use estimates for the portion of Highlands County within the District, the annual average groundwater use of 64 mgd in the 1990s declined to 52.8 mgd for the period from 2010 through 2020 (Figure 2-31). The declines in groundwater use have occurred as a result of water conservation, higher rainfall, and increased use of reclaimed water. The District's 2020 estimated water use report (SWFWMD 2021) indicates that in 2020, agricultural groundwater use comprised 75 percent of the total groundwater withdrawn in the District portion of Highlands County (Figure 2-32). Twenty percent was withdrawn for public supply, and recreational use accounted for 5 percent of the total. Groundwater use for mining and industrial/commercial purposes were less than 0.2 percent of the total use.

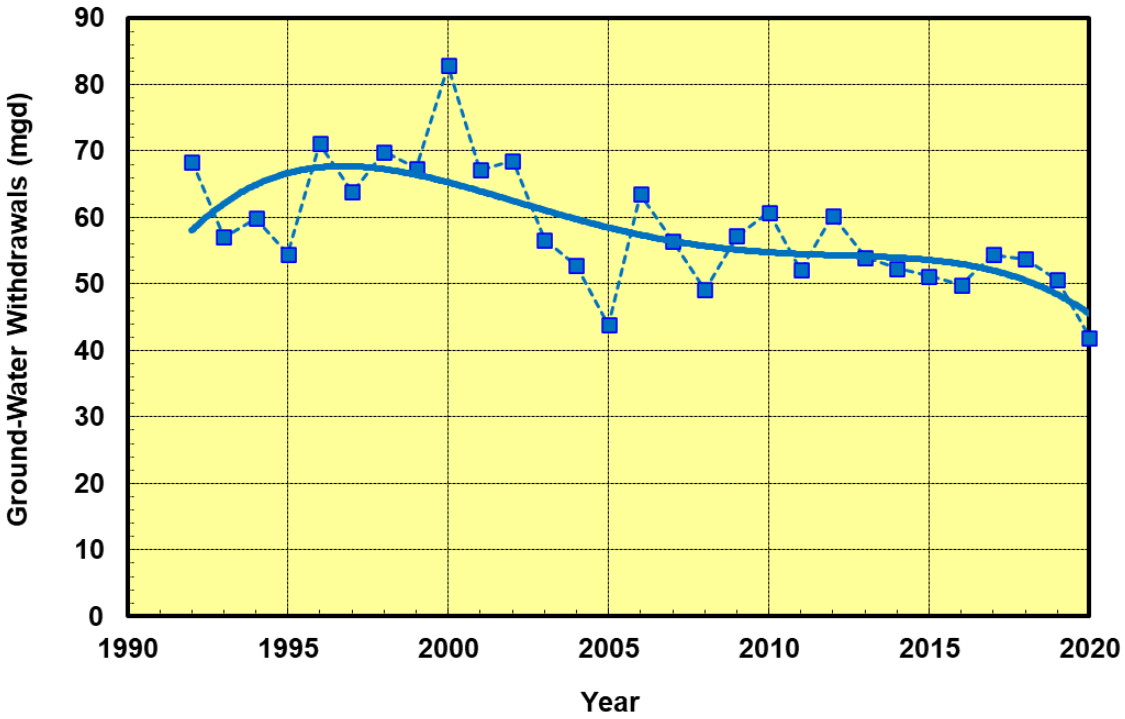

Figure 2-31. Groundwater withdrawals from 1992 through 2020 in the District portion of Highlands County with fourth-order polynomial trend line applied for smoothing (includes estimated and metered permitted use and domestic self-supply estimates).

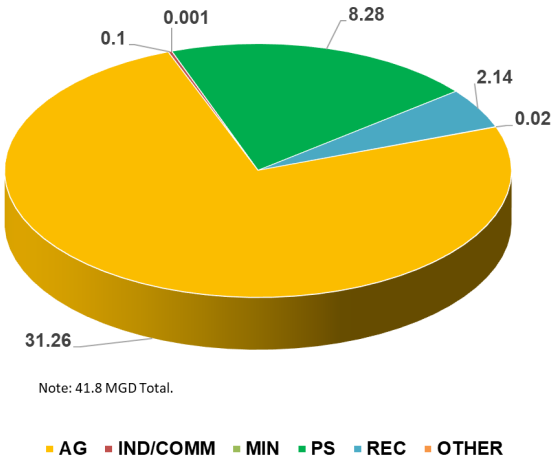

Figure 2-32. Groundwater withdrawn (mgd) in 2020 within the District portion of Highlands County by major water use type (AG = agriculture, IND/COMM = industrial/commercial, MIN = mining, PS = public supply, REC=recreational use) (source: SWFWMD, 2021a).

Declines in groundwater use within the District portion of Highlands County mirror trends in groundwater withdrawals in the Southern Water Use Caution Area (SWUCA). Groundwater withdrawals in the SWUCA increased substantially through the 1960s and 1970s, remained relatively high through the 1980s and 1990s, and have subsequently decreased (Figure 2-33). In the 1990s, SWUCA-wide withdrawals averaged 644 mgd, and for the ten-year period from 2010 to 2020 decreased to an average 514 mgd (Figure 2-34). This trend in groundwater use occurred, in part, as a result of establishment and implementation of SWUCA I rules in the early 2000s that address conservation measures, alternative water supply development, and water use permitting requirements (SWFWMD 2023a, b).

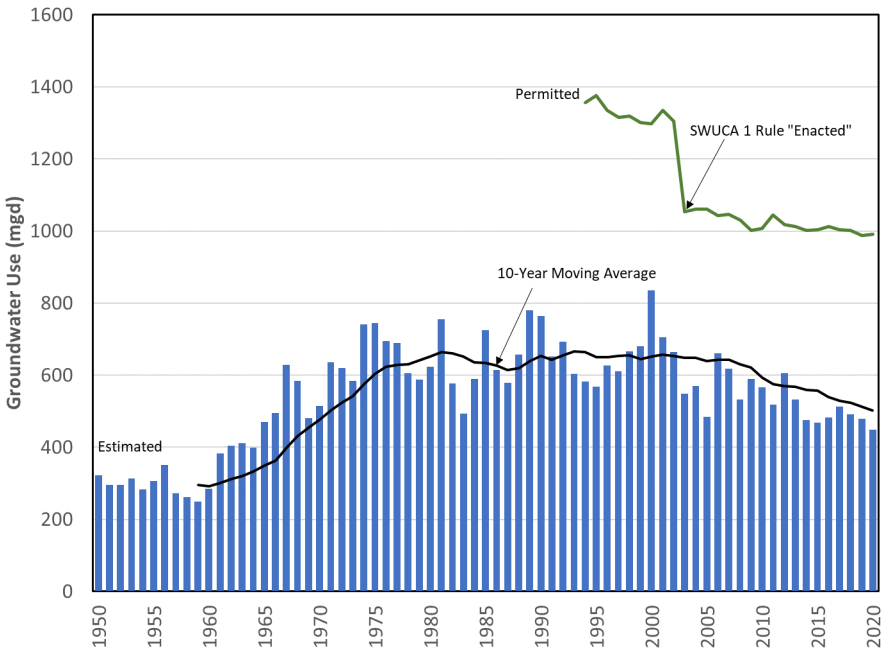

Figure 2-33. Groundwater withdrawals in the Southern Water Use Caution Area from 1950 through 2020 and permitted withdrawals for the area (image reproduced from SWFMWD, 2023).

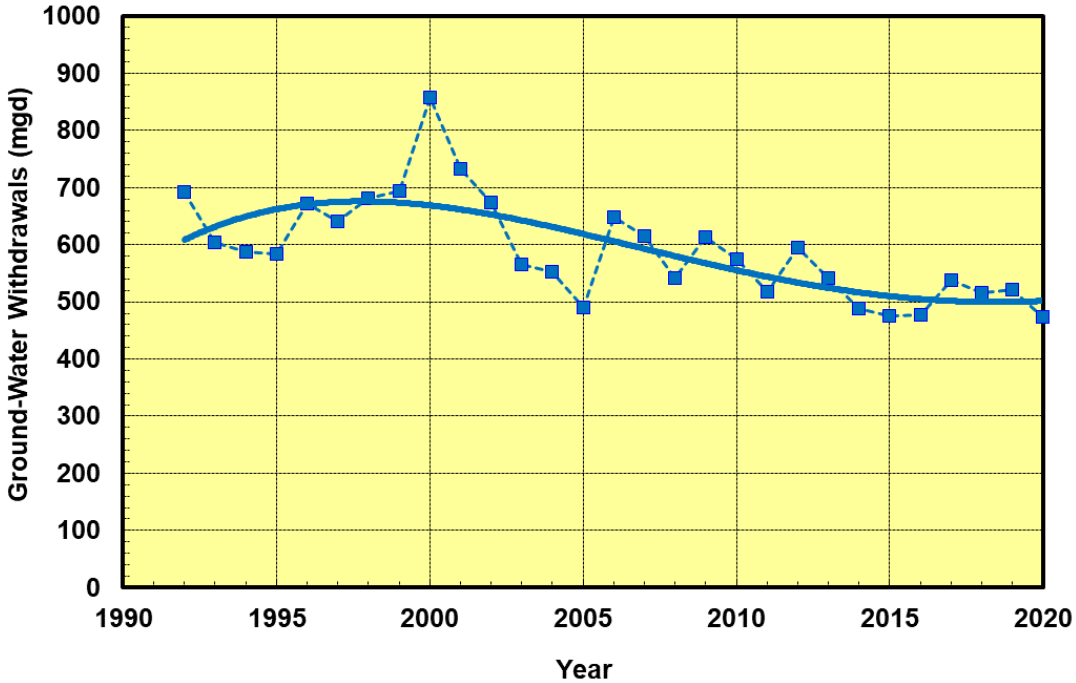

Figure 2-34. Groundwater withdrawals from 1992 through 2020 in the Southern Water Use Caution Area with fourth-order polynomial trend line applied for smoothing (includes estimated and metered permitted use and domestic self-supply estimates).

CHAPTER 3 – WATER BUDGET MODEL FOR LAKE TULANE

3.1 Water Budget Models

Water budgets (also called water balances) are widely used to represent hydrologic fluxes for lakes and other waterbodies (e.g., Healey et al., 2007). Using this approach, change in lake stage or volume can be calculated as the difference between its summed inflows and summed outflows over a specified time-period. Calibrated water budget models can be used to develop predictive scenarios, such as to estimate lake levels if groundwater levels increase. These models can also be used to characterize lake levels expected for historic conditions, i.e., in the absence of withdrawal impacts, given current structural alterations.

Examples of studies using water budgets for specific Florida lakes include Fellows & Brezonik (1980), Deevey (1988), Sacks et al. (1992), Belanger & Kirkner (1994), Grubbs (1995), Lee & Swancar (1997), Motz (1998), Sacks et al. (1998), Swancar et al. (2000), Motz et al. (2001), Watson (2001), Metz & Sacks (2002), Swancar (2015), and McBride et al. (2017). Schiffer (1996) provides a generalized overview of the hydrology and water budgets of central Florida lakes, and Healy et al. (2007) explore the use of water budgets for water resource management, including an example from Florida. Water budgets have been used by the District for the development of minimum levels for numerous lakes.

The water budget model implemented by the District for minimum lake level development is a calibrated spreadsheet model that tracks lake water inputs and outputs on a daily timestep to calculate an estimated lake water level (Cameron et al., 2022b). The model developed specifically for Lake Tulane includes precipitation, evaporation, surficial aquifer fluxes, Upper Floridan aquifer fluxes, overland flow, and directly connected impervious area (DCIA) runoff. Since Lake Tulane is a closed basin lake, surface outflow was not included in the model.

3.2 General Model Structure

3.2.1 Overview

As described in Cameron et al. (2022a) a water budget model for a lake such as Lake Tulane can be simplified as Equations 3-1 and 3-2, where LAKE is the lake stage, $\triangle S$ is the change in storage, RAIN is rainfall directly onto the lake, EVAP is evaporation directly from the lake, NET_UFA is the net exchange between the lake and Upper Floridan aquifer (positive or negative), NET_SA is the net exchange between the lake and surficial aquifer (positive or negative), OVERLAND is overland flow into the lake from its watershed, and DCIA is runoff from impervious surfaces directly connected to the lake. For closed basin lakes such as Lake Tulane, a term for channel outflow can be omitted. Also, once calculated, the change in storage is added to the prior day's lake stage to calculate an estimated lake stage for the current day.

(Equation 3-1) $LAKE_n = LAKE_{n-1} + \triangle S_n$

(Equation 3-2) $\triangle S_n = RAIN_n - EVAP_n + NET\_UFA_n + NET\_SAS_n + DCIA_n + OVERLAND_n$

3.2.2 LAKE

For the first day of the model simulation, $LAKE_n$ is initialized using an observed lake water level elevation. Starting with the second day of the simulation, $LAKE_n$ is calculated using Equations 1 and 2.

3.2.3 RAIN

$RAIN_n$ is used to calculate rainfall falling directly onto the lake and is also used in runoff calculations ($DCIA_n$ and $OVERLAND_n$).

Daily data rainfall are required for the entire model period. These data are compiled using the best available data, which may vary throughout the model period. Typically, radar rainfall (NEXRAD) or record from the nearest rain gage with quality data are used. Radar rainfall estimates are derived via calibration of Doppler weather radar images to rainfall gauge measurements and are provided on a grid with cell sizes of 2 by 2 km. Weather radar imagery is developed by the National Weather Service, and calibration is performed by a consultant via a cooperative program involving multiple water management districts.

3.2.4 EVAP

Swancar (2015) found that seasonal evaporation rates are generally similar for lakes in central Florida that have similar depths. Using an energy budget method, Swancar evaluated data from Lake Starr in Polk County and Lake Calm in Hillsborough County and found that, despite 60 miles of (mostly east-west) distance between the lakes, their evaporation rates were nearly identical.

Lake Tulane is approximately 25 miles southwest of Lake Starr, with both lakes located along the Lake Wales Ridge. Evaporation data for Lake Starr, which are available from August 1996 to July 2011 via Swancar et al. (2000) and Swancar (2015), were, therefore, used for the Lake Tulane model. For any period in the model that falls within August 1996 to July 2011, the period for which Lake Starr evaporation data are available, Lake Starr monthly total evaporation data were disaggregated into daily total evaporation time series (assuming a uniform distribution) and used in the model. For months that occur before August 1996 or after July 2011, period-of-record means for the month of the year from the Lake Starr evaporation data were used (i.e., a repeating time series), disaggregated into daily values.

3.2.5 NET_UFA

Fluxes between the lake and Upper Floridan aquifer (NET_UFA_n, ft) can be estimated using a Darcian approach that multiplies the vertical head difference between the Upper Floridan (UFA_n, ft) and (modeled) lake ($LAKE_n$, ft) water level elevations by a leakance coefficient (L_UFA, ft/d/ft) as shown in Equation 3-3.

$$\text{(Equation 3-3)}\quad NET\_UFA_n = L\_UFA*(UFA_n - LAKE_n)$$

Water has the potential to move downward from the lake into the UFA when its stage is higher than the UFA groundwater level, and vice versa, with the degree of flux controlled by the leakance.

Leakance represents the ease with which water can move vertically between the lake and UFA, with higher values increasing the hydraulic connection between the lake and UFA, i.e., increasing the "leakiness."

Physically, leakance is equal to the average vertical hydraulic conductivity of the confining unit separating the lake and aquifer, divided by the thickness of the confining unit. Since this is not precisely known at lakes, L_UFA is a calibration parameter, i.e., it can be changed in the lake budget model to better match simulated lake stage with observed values.

Given Florida's karst hydrogeology, the leakance coefficient and associated fluxes can vary widely (e.g., Fellows & Brezonik, 1980; Deevey, 1988; Belanger & Kirkner, 1994; Grubbs, 1995; Katz et al., 1995; Lee & Swancar, 1997; Motz, 1998, Sacks et al., 1998; Swancar et al., 2000; Motz et al., 2001; Watson, 2001; Lee, 2002; Metz & Sacks, 2002; Sacks, 2002; Swancar, 2015; McBride et al., 2017). In west-central Florida, the L_UFA typically varies between 10^{-2} ft/d/ft (very leaky) to 10^{-6} ft/d/ft (tightly confined), with inferred lake leakiness values informed by long-term vertical head differences between the lake and UFA. For these inferences, larger head differences suggest tighter conditions, and smaller head differences suggest more leaky conditions. For most isolated lakes in Florida, flux varies between less than 1 in/yr to as high as 50 in/yr.

Upper Floridan aquifer water levels are obtained for the model from the nearest representative Upper Floridan well with quality data. Daily data are required for the entire model period; typically monthly data must be interpolated into daily data for use in the model. Depending on typical UFA water levels at the well versus the lake, UFA water level values may be adjusted to better reflect potentiometric conditions at the lake. The adjustment value, if any is needed, can be determined through: review of UFA well data from multiple sites in the area, if available; review of empirical or modeled potentiometric surface maps, which can be used to compare UFA water levels in the area of the lake versus the well; and other relevant information.

3.2.6 NET_SA

Fluxes between the lake and surficial aquifer (NET_SA_n, ft) can be estimated using the difference between the surficial aquifer (SA_n, ft) and (modeled) lake ($LAKE_n$, ft) water level elevations multiplied by a leakance coefficient (L_SA, ft/d/ft), as shown in Equation 3-4.

(Equation 3-4) $NET\_SA_n = L\_SA*(SA_n - LAKE_n)$

The leakance coefficient, L_SA, is a calibrated constant with consideration given to soils and sediments in and around the lake, the hydraulic conductivity of the SA around the lake, and hydraulic gradient between the lake and SA. The L_SA term represents the ease with which water can move between the lake and SA, with higher values increasing volume of flux. Therefore, this parameter controls the amount of SA seepage into the lake.

Conceptually, L_SA should be larger than L_UFA, since the ICU that exists between the lake and the deeper UFA always provides some hydraulic resistance to lake-UFA interaction, whereas no distinct hydrogeologic unit separates the lake and SA, with just thin and discontinuous lakebed sediments potentially between the two. Relatively few studies on lakebed sediment thickness and hydraulic conductivity exist for Florida lakes, but reported thickness values typically range

between 0 to 13 ft, while estimates of hydraulic conductivity are typically on the order of 10^{-2} ft/d, although both parameters vary within and between lakes (Sacks et al., 1992; Katz et al., 1995; Lee & Swancar, 1997; Swancar et al. 2000; Lee, 2002; Metz & Sacks, 2002; Kenney et al., 2016; Summerfield et al., 2018). Heath (1983) reports hydraulic conductivity for silts, a typical lakebed sediment, as between 10^{-3} to 10^{1} ft/d.

Water moves into the lake when the SA water level is higher than the lake stage, and vice versa, moderated by L_SA. A lake's relationship with the SA can vary between gaining, losing, and flow-through conditions (e.g., Schiffer, 1996; Metz and Sacks, 2002; Virdi et al., 2013). Although one of these conditions may occur more commonly than the others at a given lake, a single lake can experience each of these three conditions over time, in response to changes in climate and withdrawals. Using isotopic data for 81 lakes in west-central Florida, Sacks (2002) found large variability in groundwater inflow rates, ranging from 0 to >100 in/yr (representing approximately 0 to 80% of inflows), with a median of approximately 30 in/yr (representing approximately 40% of inflows). Other studies on individual lakes in Florida also vary widely in estimated groundwater inflows, typically reporting between 10 to 50 in/yr (e.g., Fellows & Brezonik, 1980; Lee & Swancar, 1997; Swancar, 2000; Motz et al., 2001; Watson et al., 2001; Virdi et al., 2013).

Within the Lake Wales Ridge, lakes frequently display flow-through groundwater conditions (e.g., Sacks et al., 1998; Virdi et al., 2013). For this reason, the water budget model conceptualizes the lake as a flow-through system, where SA water levels are above the lake stage on one half of the lake and lower than the lake stage on the other half of the lake. This conceptualization is consistent with topography and ECFTX-modeled SA water levels around the lake within its watershed. Although an average value could be used for SA_n to calculate NET_SA_n, the model tracks SA inflow and outflow components separately, which allows for better characterization and assessment of the flow-through lake water balance. These calculations are performed as shown in Equations 3-5 through 3-7, where SA_In_n and SA_Out_n are the groundwater flux (ft) into and out of the lake, respectively, and SA_{in_n} and SA_{out_n} represent the SA water levels (ft) on the inflow and outflow sides of the lake, respectively. Although different values of L_SA could be assigned to the two lake halves, the model uses the same value for each under the assumption that lakebed and surrounding SA characteristics do not differ substantially between the two halves.

(Equation 3-5) $NET\_SA_n = SA\_In_n - SA\_Out_n$

(Equation 3-6) $SA\_In_n = L\_SA*(SA_{in\_n} - LAKE_n)$

(Equation 3-7) $SA\_Out_n = L\_SA*(SA_{out\_n} - LAKE_n)$

For water budget modeling purposes, SA water levels are obtained from the nearest representative SA well with quality data. Daily data are required for the entire model period. To develop these data, monthly data must often be interpolated into daily data. Depending on the typical SA water level at the well versus the lake, SA water level values may be adjusted to better reflect conditions at the lake. In many areas of the District, the SA locally varies with topography. The adjustment value, if needed, can be determined through review of: topographic differences between the lake and well; SA well data from multiple sites in the area, if available; and empirical or modeled water level surface maps, which can be used to compare SA water levels in the area of the lake versus the well. Adjustments may also be needed if either the well or lake is located near a center of heavy withdrawals that would cause localized effects or in or near an area of abrupt land surface elevation differences, such as the Lake Wales Ridge area.

3.2.7 DCIA

Rainfall falling onto impervious areas directly connected to the lake, such as roads and drainage systems, has no opportunity to infiltrate and therefore flows directly to the lake within a short amount of time. This inflow to the lake is called "directly connected impervious area" (DCIA) inflow. DCIA inflow to the lake ($DCIA_n$, ft) can be calculated by multiplying rainfall ($RAIN_n$, ft) by the relevant proportion (P_DCIA, dimensionless) of the lake watershed area (AREA_WS, ft^2) divided by the current lake area ($AREA\_LAKE_n$, ft^2), as shown in Equation 3-8. As part of this calculation, an initial abstraction of 0.1 inch is removed from daily rainfall, which represents rainfall captured in irregularities in impervious surfaces (Harper & Baker, 2007).

(Equation 3-8) $DCIA_n = MAX(0, (RAIN_n-0.1/12)*P\_DCIA*AREA\_WS/AREA\_LAKE_n)$

P_DCIA is a calibrated constant that represents the proportion of the lake's watershed, inclusive of the lake, that is directly connected to the lake via impervious surfaces. The lake area, $AREA\_LAKE_n$, varies by day according to the lake stage and is determined using the lake's stage-area curve. The stage-area curve is created by District staff using a Python script and process that combines and interpolates LiDAR data and professionally surveyed bathymetric and topographic data (see Section 2.4.2 for development of stage-area-volume information for Lake Tulane). The current day's lake area is estimated using the stage-area curve given the previous day's lake stage.

3.2.8 OVERLAND

Overland flow is calculated via the SCS curve number methodology (NRCS, 1986), an empirically-derived approach that is widely used in stormwater studies. Curve numbers are dimensionless empirical parameters that can vary between 0 (low runoff) and 100 (highest runoff). Sandy soils, deep water table conditions, and low development are associated with lower curve numbers. Clayey soils, shallow water table conditions, and higher development are associated with greater curve numbers.

Additionally, higher antecedent moisture conditions (AMC) result in more saturated soils and therefore higher runoff, necessitating higher curve numbers. The SCS methodology incorporates three antecedent moisture conditions: AMCI (dry), AMCII (average), and AMCIII (wet). The average condition curve number, CN_{II}, is the basis for the others. To convert CN_{II} into CN_I, and CN_{III}, the model implements the mathematical relationships recommended in Harper & Baker (2007):

(Equation 3-9) $CN_I = (4.2*CN_{II})/(10-0.058*CN_{II})$
(Equation 3-10) $CN_{III} = (23*CN_{II})/(10+0.13*CN_{II})$

The water budget model is initialized with the AMCII curve number, CN_{II}. CN_{II} is a calibrated parameter, with consideration given to soils and land uses in the lake watershed, exclusive of the lake. CN_{II} is used for the first five days of the model, after which the model begins assessing antecedent moisture conditions and Equations 3-9 and 3-10 to determine CN_n. Antecedent moisture conditions are defined using the approach recommended in Harper & Baker (2007),

which uses different criteria for the dormant season (October to February) and the growing season (March to September), as shown in Table 3-1. Using this approach, less rainfall is required to generate runoff during the dormant season, when vegetative evapotranspiration in the watershed is reduced.

Table 3-1. Recommended seasonal rainfall depths for three antecedent moisture conditions (AMC), from Harper & Baker (2007). Values represent total antecedent 5-day rainfall (in).

AMC	Dormant Season (Oct-Feb)	Growing Season (Mar-Sep)
I	<0.5	<1.4
II	0.5-1.1	1.4-2.1
III	>1.1	>2.1

The daily curve number CN_n is used with $RAIN_n$ in Equation 3-11 to calculate the depth of "excess" rainfall (rainfall available for overland flow), $EXCESS\_RAIN_n$ (in) for the watershed (NCRS, 1986).

(Equation 3-11)

$$EXCESS\_RAIN_n = [12*RAIN_n - 0.2*(1000/CN_n - 10)]^2 / [RAIN_n - 0.8*(1000/CN_n - 10)]$$

Since the size of the watershed also determines how much overland flow the lake receives, $EXCESS\_RAIN_n$ (in) must be converted to feet and then multiplied by the watershed area ($AREA\_WS$, ft^2), exclusive of the lake and the portion of the watershed that has already been addressed by $DCIA_n$. To convert the resulting volume (ft^3) into linear units (ft), the product is divided by the lake area, $AREA\_LAKE_n$ (ft^2). The lake is excluded from overland flow calculations because the lake itself does not generate runoff, and the $RAIN_n$ term captures rainfall that falls directly on the lake. The final value, $OVERLAND_n$ (ft), represents the increase in lake stage due to overland flow, as shown in Equation 3-12.

(Equation 3-12)

$$OVERLAND_n = EXCESS\_RAIN_n/12*[AREA\_WS*(1-P\_DCIA) - AREA\_LAKE_n]/AREA\_LAKE_n$$

Many studies for central Florida lakes assume negligible contribution by overland flow (e.g., Lee & Swancar, 1997; Metz, 2002; Swancar, 2000; Sacks, 2002). Swancar (2015) found that overland flow contributed to stage increases at Lake Calm in Hillsborough County (Northern Tampa Bay area) but not at Lake Starr in Polk County (southern District), which was attributed to poorly-drained soils occurring around the former and well-drained soils at the latter. Motz et al. (2001) and Watson et al. (2001) used the SCS curve number method in developing water budgets for north-central Florida lakes in well-drained settings, respectively Lakes Magnolia and Lowry (Sand Hill), both studies setting CN_I (dry) at 19, CN_{II} (average) at 36, and CN_{III} (wet) at 56. Motz et al. (2001) estimated annual runoff at 27.2 in/yr, while Watson et al. (2001) found near-zero runoff.

3.3 Lake Tulane Water Budget Model

3.3.1 Time Period

Selecting the appropriate time-period to use for the model requires balancing the availability of required data, the timing of any significant changes to land use in the watershed and structural conditions at the lake, and the need to capture a period that is long enough to reasonably characterize lake hydrology. Very short model periods reduce the ability to adequately characterize lake hydrology and assess model performance. Very long model periods increase the likelihood of including land use or structural changes that would require different model parameterizations relative to current conditions; i.e., those associated with current structural alterations, as discussed previously in Sections 1.2 and 1.4, and encountering issues with the availability of representative high-quality data for the lake.

Based on review of data availability, model calibration for the Lake Tulane water budget was performed for the March 1999 through December 2020 time-period. This time-period was selected based on a gap in lake stage data immediately preceding this period (see Figure 2-16), and to allow sufficient data for model verification. Model verification was performed for the periods of January 2021 to December 2021.

Review of long-term monthly Highlands County rainfall data obtained from the District's Data Collection Bureau indicates average annualized rainfall from January 1915 to December 2021 of 52.1 in/yr, versus 52.8 in/yr for the water budget model time-period of March 1999 to December 2020. A Kolmogorov-Smirnov test did not find a statistically significant difference between the monthly rainfall total distributions for the two time-periods ($p = 0.80$). This suggests the water budget model time-period is reasonably representative of long-term conditions for the lake.

3.3.2 Input Data

For the Lake Tulane water budget model, data were obtained from the District's Environmental Data Portal (EDP) as described below and indicated in Figures 3-1 and 3-2 and Table 3-2.

- Lake stage data were obtained for the Lake Tulane staff gauge (District Station No. 25507). These data are available from 1981 to present, with various gaps. Data collection frequency has varied through the period of record but has generally been sampled monthly.
- SA water levels were obtained from the Ridge WRAP H-2 Surf, (District Station No. 25524), located approximately 1.7 miles northwest of Lake Tulane, and Lake Lotela water level (District Station No. 25521), approximately 0.5 miles southeast of Lake Tulane. Ridge WRAP H-2 Surf was used for SA inflows and Lake Lotela water levels were used for SA outflows. Data collection for the well began in 1991, with various gaps and frequency. Data collection at the Lake Lotela gage began in 1989, and water level recording has generally occurred monthly. For dates lacking water level values, bilinear interpolation was performed to produce a daily time series for use in the model.
- UFA water levels were obtained from the 43XX U Fldn Aq Monitor well (District Station No. 25532), located approximately 1.7 miles northeast of Lake Tulane. Data for the well are available since 1982, coalescing collection efforts by the USGS and the District, with various gaps and frequency. Well water levels have been recorded daily since 1992. For dates when daily data were not available, bilinear interpolation was performed to produce a daily time series for use in the model.

- Rainfall data was obtained from the average of NEXRAD pixels 88527 and 88528, which intersect the lake's watershed. Daily rainfall totals are available without gaps from 1995 to the present.

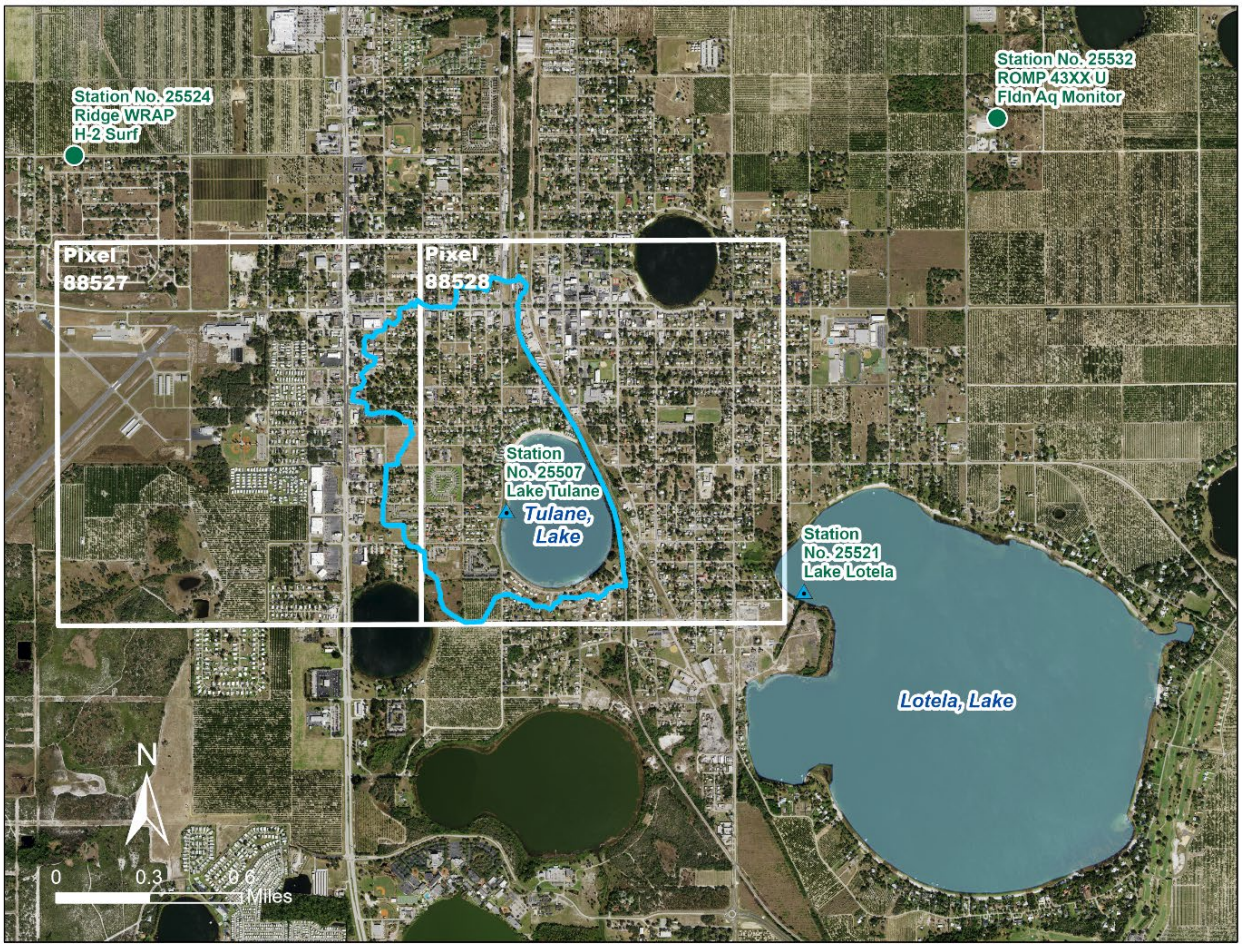

Figure 3-1. Locations of Lake Tulane and its staff gage, Lake Lotela and its staff gauge, Ridge WRAP H-2 Surf well, ROMP 43XX U Fldn Aq Monitoring well, and radar rainfall pixels 88527 and 88528 used to obtain input time series data for development of the Lake Tulane water budget model.

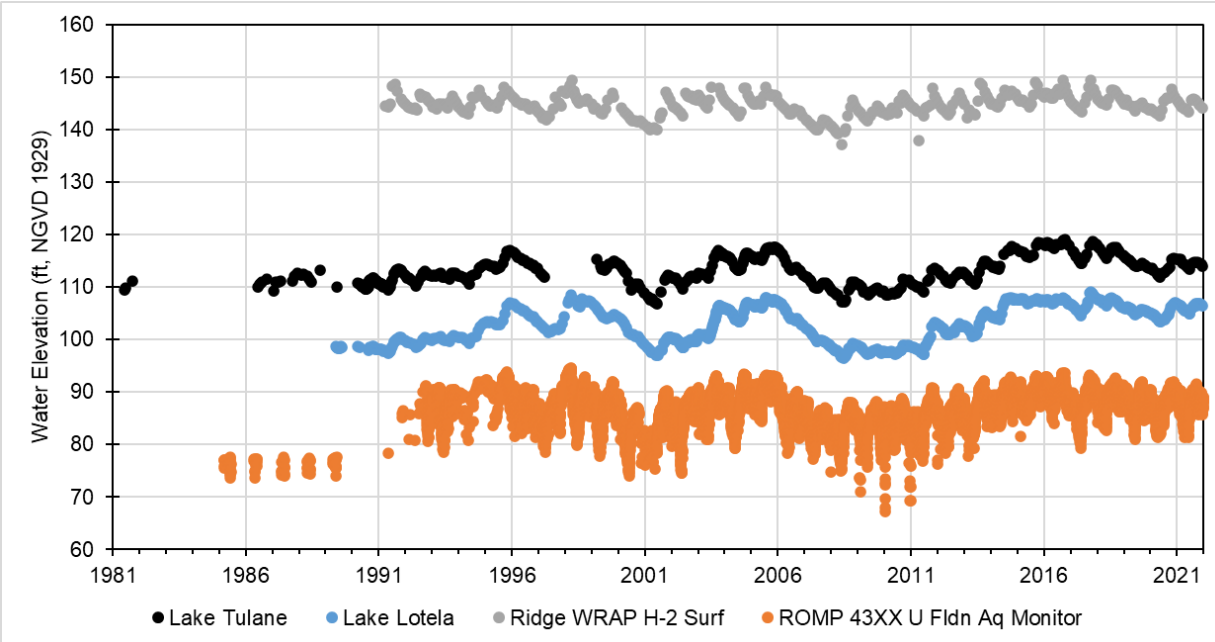

Figure 3-2. Observed water level data available for the Lake Tulane water budget model. Note that, for use in the model, surficial aquifer water levels associated with the Ridge WRAP H-2 Surf site were adjusted to better reflect conditions at the lake, as described in the text.

Table 3-2. Time series data input sources for the Lake Tulane water budget model.

Input Type	Station/Pixel ID(s)	Station Name(s)
Lake Water Level	25507	Lake Tulane
SA In Water Level	25524	Ridge WRAP H-2 Surf
SA Out Water Level	25521	Lake Lotela
UFA Water Level	25532	ROMP 43XX U Fldn Aq Monitor
Rainfall	88527, 88528	NEXRAD (Radar Rainfall)

3.3.3 Model Calibration

3.3.3.1 Calibration Approach

During calibration of the water budget model, which is performed manually, the modeler seeks to minimize residuals between pairwise model and observation data by modifying calibration parameters, while constraining parameters and outputs to reasonable values based on an understanding of the physical system. At its simplest, the reasonableness of model outputs can be assessed through comparing observed to simulated lake water levels. However, all model calibration is non-unique, meaning that there are numerous combinations of parameter values that can produce acceptable calibrations, i.e., match of simulated and observed lake stages, and the parameterization that results in the best calibration based on statistical performance metrics

may not always best represent the physical system. Unrealistic parameterizations and fluxes should never be accepted, even if they result in ostensible improvements in calibration criteria relative to a more realistic parameterization.

Therefore, the key in the modeling effort is assessing the reasonableness of any calibrated parameter against independent data and limiting parameter changes to physically realistic values or ranges of values for the hydrogeologic system. This practice provides more certainty to model predictions, as the parameterization that results in the best calibration may not always best represent the physical system. Calibrated models can potentially produce acceptable modeled water levels but contain unrealistic parameterizations given the physical system, which can negatively influence predictive scenarios. The modeler considers the magnitude of specific terms and their relative contribution to the overall water balance and how this compares to expected fluxes at the lake, as informed by previous work and other relevant information. Ultimately, professional judgement is applied in selecting which model parameterization best balances acceptable calibration with accurate representation of the physical system.

3.3.3.2 Runoff and Channel Fluxes

- The lake's watershed area, `AREA_WS`, was determined to be 380 acres using a delineation available from a regional floodplain study (Dewberry, 2012) and validated as reasonable by review of digital elevation data and stage-area-volume information developed from that data (see Figures 2-4, 2-5, 2-17, 3-1 and Appendix B).
- The curve number, CN_{II}, was calibrated to a value of 50. This value was guided by site visits, review of soils and land use geospatial data (Figures 2-11, 2-12 and 2-13), and assessment of curve numbers developed in BCI (2004) for the region and sub-basins of the Lake Tulane watershed. This curve number is consistent with the thick, well-drained, sandy soils in a deep water-table setting that characterize the Lake Wales Ridge (Basso, 2019) and is close to the estimate of 39 from both BCI (2004) and an updated area-weighted analysis of soil and land use geospatial data.
- The portion of the watershed which is directly connected impervious area, `P_DCIA`, was calibrated to a value of 0.32. This value was guided by site visits, Sacks' (2002) classification of the lake as receiving high runoff, BCI's (2004) estimate for `P_DCIA` of approximately 0.32, and National Land Cover Database (NLCD) imperviousness data for 2019 suggesting that secondary and tertiary roads comprise approximately 0.42 of the lake watershed (Dewitz, 2021). Although `P_DCIA` was somewhat higher than anticipated, this parameter typically includes considerable uncertainty that may be associated with spatial resolution issues and general lack of information about watershed conditions. In conjunction with the relatively simple water budget modelling approach we employ, which assumes that all portions of the watershed contribute equally to DCIA fluxes irrespective of distance to the lake, the `P_DCIA` value used for calibration may not fully reflect actual local runoff patterns. However, the final calibrated value produced significant fluxes to Lake Tulane, consistent with our conceptual understanding of the lake's physical system.
- The lake was determined to be closed basin (i.e., no surface outflow) based on site visits, review of digital elevation data, and information available in floodplain studies (BCI, 2004; Dewberry, 2012). Although surface outflow can occur when water levels exceed 140 ft NGVD29, this far exceeds the observed maximum lake water level and even the modeled 500-year, 24-hour flood elevation of approximately 120 ft NGVD29 (Dewberry, 2012).

Therefore, no channel outflow occurs in the model, nor does the lake have channel inflow from another waterbody.

3.3.3.3 Groundwater Fluxes

- The SA leakance coefficient, `L_SA`, was calibrated to a value of 3.0×10^{-3} ft/d/ft. This value was guided by the literature on Florida lakebed sediment thicknesses and hydraulic conductivities described in Section 3.2.6. This value corresponds to approximately 1 to 5 feet of lakebed sediments with hydraulic conductivities between 3.0×10^{-3} to 1.5×10^{-2} ft/d, which is consistent with the literature.
- SA inflows were modeled by using water levels of Ridge WRAP H-2 Surf and applying a constant adjustment of -20.0 ft, i.e., a 20- ft downward shift, for inflows. SA outflows were modeled by using water levels of Lake Lotela and a constant adjustment of -3.0 ft for outflows. These shifts were guided by expected flow-through conditions at the lake based on literature described in Sections 3.2.6, ECFTX-modeled SA water levels and water-table depths near the lake, and topographic differences between the well and around the lake (Figures 2-11 and 3-2). Additionally, the long-term SA influx was assessed to ensure consistency with isotope-derived groundwater flux estimates for Lake Tulane of >100 in/yr provided by Sacks (2002).
- Based on the proximity of the ROMP 43XX U Fldn Aq well to the lake, along with review of potentiometric surface maps for various years showing that the well and lake consistently fall within the same contour (Figures 2-37), it was determined that no adjustment was necessary for the well to be representative of UFA water levels under the lake.
- The UFA leakance coefficient, `L_UFA`, was calibrated to a value of 2.0×10^{-4} ft/d/ft. This value, which falls within the range for semi-confined conditions, is consistent with observed lake-UFA and SA-UFA head differences, the lake's hydrogeologic province, and stratigraphic information in the vicinity of the lake (Basso, 2019). Additionally, the long-term UFA flux was assessed to ensure consistency with the typical values for central Florida lakes described above in Section 3.2.5.

3.3.3.4 Model Performance

Errors occur due to the model's inability to completely represent the physical system, as well as due to errors and uncertainties associated with inputs and parameters used in the models. Winter (1981) provides a summary of uncertainties and errors associated with lake water budgets, while Moriasi et al. (2007; 2015) provide widely accepted performance criteria for hydrologic modelling efforts.

Based on review of performance criteria for the District's regional groundwater models, guidelines from Moriasi et al. (2007; 2015), and professional judgement considering the intended application of the water budget models, staff developed the following general guidelines for quantifying acceptable lake water budget model performance (Table 3-3) (Cameron et al., 2022).

The final calibrated Lake Tulane water budget model was deemed acceptable for the purposes of characterizing long-term water level percentiles in support of minimum levels development for Lake Tulane. The parameterization (Table 3-4) produced reasonable fluxes (Table 3-5), met all

performance metrics (Table 3-6), and model-predicted water levels visually (qualitatively) match the pattern and magnitude of observed water levels (Figure 3-3).

Table 3-3. Lake water budget model performance metrics and goals.

Metric	Unit	Goal
P10 Residual	feet	± 0.3
P50 Residual	feet	± 0.1
P90 Residual	feet	± 0.5
Mean Error	feet	± 0.3
Mean Absolute Error	feet	0.75
Root Mean Square Error	feet	1.0
Maximum Residual	feet	2.0
Minimum Residual	feet	-2.0
R^2	-	0.8
Nash-Sutcliffe Efficiency	-	0.7

Table 3-4. Parameters for the calibrated Lake Verona water budget model.

Parameter	Value
SA Leakance Coefficient, `L_SA` (ft/d/ft)*	0.003
SA Inflow Water Level Adjustment (ft)*	-20.0
SA Outflow Water Level Adjustment (ft)*	-3.0
UFA Leakance Coefficient, `UFA_L` (ft/d/ft)*	0.0002
UFA Water Level Adjustment (ft)*	0
Curve Number, CN_{II}*	50
DCIA Proportion of Watershed, `P_DCIA`*	0.32
Watershed Area (including lake), `WS_AREA` (ft^2)	16,552,800
Outflow Efficiency Coefficient†	Not applicable
Control Point (Outflow) Elevation (ft)†	140

* Calibrated parameter.
† Lake Tulane is a closed basin lake.

Table 3-5. Long-term water balance for the calibrated Lake Tulane water budget model, which includes data from March 1999 to December 2020.

Flux	In (in/yr and percentage of total flux)	Out (in/yr and percentage of total flux)	Net (in/yr)
Atmosphere			-5.9
Rainfall	52.6 (20.8%)	-	
Evaporation	-	58.5 (23.1%)	
Groundwater			
Surficial Aquifer	151.0 (59.8%)	171.0 (67.7%)	-20.0
Upper Floridan Aquifer	0 (0%)	23.3 (9.2%)	-23.3

Surface Water			49.1
Overland Flow	1.6 (0.6%)	-	
DCIA	47.5 (18.8%)	-	
Channel	-	0 (0%)	
Total	252.7 (100%)	252.7 (100%)	0

Table 3-6. Performance assessment of the calibrated Lake Tulane water budget model, based on comparing pairwise modeled versus observed lake stage data from March 1999 to December 2020. Negative values indicate model underprediction.

Metric	Unit	Value
P10 Residual	feet	-0.2
P50 Residual	feet	0.0
P90 Residual	feet	0.1
Mean Error	feet	0.30
Mean Absolute Error	feet	0.51
Root Mean Square Error	feet	0.66
Maximum Residual	feet	1.45
Minimum Residual	feet	-1.70
R^2	-	0.96
Nash-Sutcliffe Efficiency	-	0.95

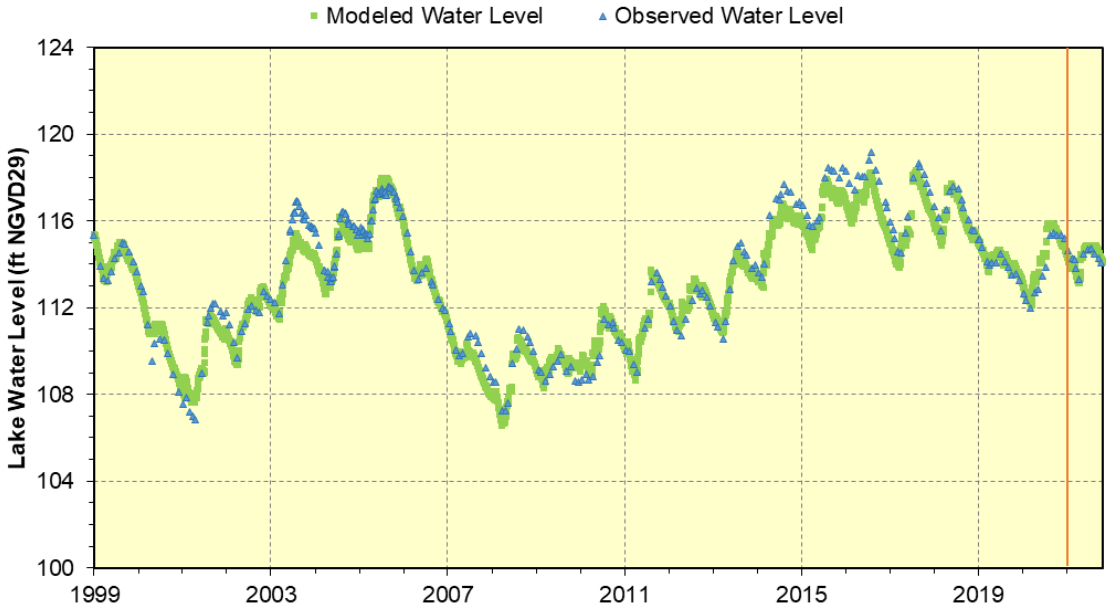

Figure 3-3. Observed and pairwise modeled lake water levels for the calibrated Lake Tulane water budget model. Verification periods shown to the right of red vertical bar.

Verification testing was performed to assess the calibrated model's ability to predict water levels using a time-period for which it was not calibrated, which helps to exclude overfitting as a reason for acceptable model calibration. The verification test used data from 1/1/2021 to 12/31/2021, a relatively wetter period. For the verification tests, all quantitative metrics and qualitative visual matches were achieved (Table 3-7 and Figure 3-3), further supporting use of the model for development of minimum levels for Lake Tulane.

Table 3-7. Performance assessment of the verification test for the Lake Tulane water budget model, based on comparing pairwise modeled versus observed lake stage data from 1/1/2021 to 12/31/2022. Negative values indicate model underprediction.

Metric	Unit	Value
P10 Residual	feet	0.0
P50 Residual	feet	0.1
P90 Residual	feet	0.0
Mean Error	feet	0.10
Mean Absolute Error	feet	0.14
Root Mean Square Error	feet	0.19
Maximum Residual	feet	0.35
Minimum Residual	feet	-0.11
R^2	-	0.92
Nash-Sutcliffe Efficiency	-	0.88

CHAPTER 4 – DEVELOPMENT OF HISTORIC LAKE STAGE PERCENTILES

The development of minimum lake levels requires an estimation of lake stage in the absence of withdrawals, given existing structural alterations. These historic water level records serve as a baseline hydrologic condition for use with the significant harm standards and minimum level screening criteria described in Chapter 5. The determination of historic lake levels is a three-step process:

1. First, the drawdown that has occurred in both SA and UFA water levels is estimated. Drawdown is the change in aquifer water levels relative to predevelopment conditions that has occurred due to pumping. Drawdown can be estimated from regional models by comparison of water levels simulated for “pumps-on” and “pumps-off” scenarios or through evaluation of reduced pumping scenarios, as well as through analysis of actual pumping rates and observed water level data.

2. A historic water budget model scenario is then simulated using the estimated drawdown information to increase SA and UFA water level inputs in a calibrated lake water budget model. With the adjusted groundwater level time series inputs, the lake water budget model calculates historic lake stage values.

3. The historic lake stage is then extended by using a correlation between long term rainfall and historic lake stage values.

Implementation of these steps for development of a historic water level record for Lake Tulane are described in this chapter.

4.1 Surficial and Upper Floridan Aquifer Water Level Change Due to Withdrawals

The ECFTX was used to predict long-term drawdown in the SA and UFA at Lake Tulane. The ECFTX is an 11-layer regional groundwater flow model, which was constructed and calibrated for the years 2003-2014 by the Hydrologic Assessment Team (HAT) for the Central Florida Water Initiative (CFWI) in 2020. The model extends from the Gulf of Mexico on the west to the Atlantic Ocean on the east and from southern Marion County in the north to the Highlands-Glades county line in the south, covering an approximate 24,000 square mile area (Figure 4-1). Version 1.0 of the model (CFWI-HAT 2020), which was peer-reviewed in 2020 (Andersen et al., 2020) simulates three-dimensional groundwater flow in the SA, IAS/ICU, UFA, LFA, and associated middle confining units.

The ECFTX version 1.0 model (CFWI-HAT 2020) was originally developed to support water supply planning decisions and was later updated to make the model a more suitable tool for regulatory decisions and to improve performance in areas where critical water bodies with established MFLs are located. A groundwater modeling team from the three water management districts participating in the CFWI, the SJRWMD, SWFWMD and SFWMD, reviewed portions of the model where the original calibration could be improved and identified an area within the CFWI portion of the domain to focus recalibration efforts. The focus area primarily included the Wekiva River springs groundwater contributing basin and Seminole County in SJRWMD and SFWMD.

The recalibration effort was conducted only in the focus area with the goals of improving the model's ability to better match observed water levels and spring flows. Performance of the recalibrated ECFTX version 2.0 model was considerably improved within the focus area and aquifer parameters were adjusted within a range consistent with the known hydrogeology in the region (CFWI-HAT 2022). Accordingly, the model-wide calibration performance was also improved as a result of the changes in the focus area.

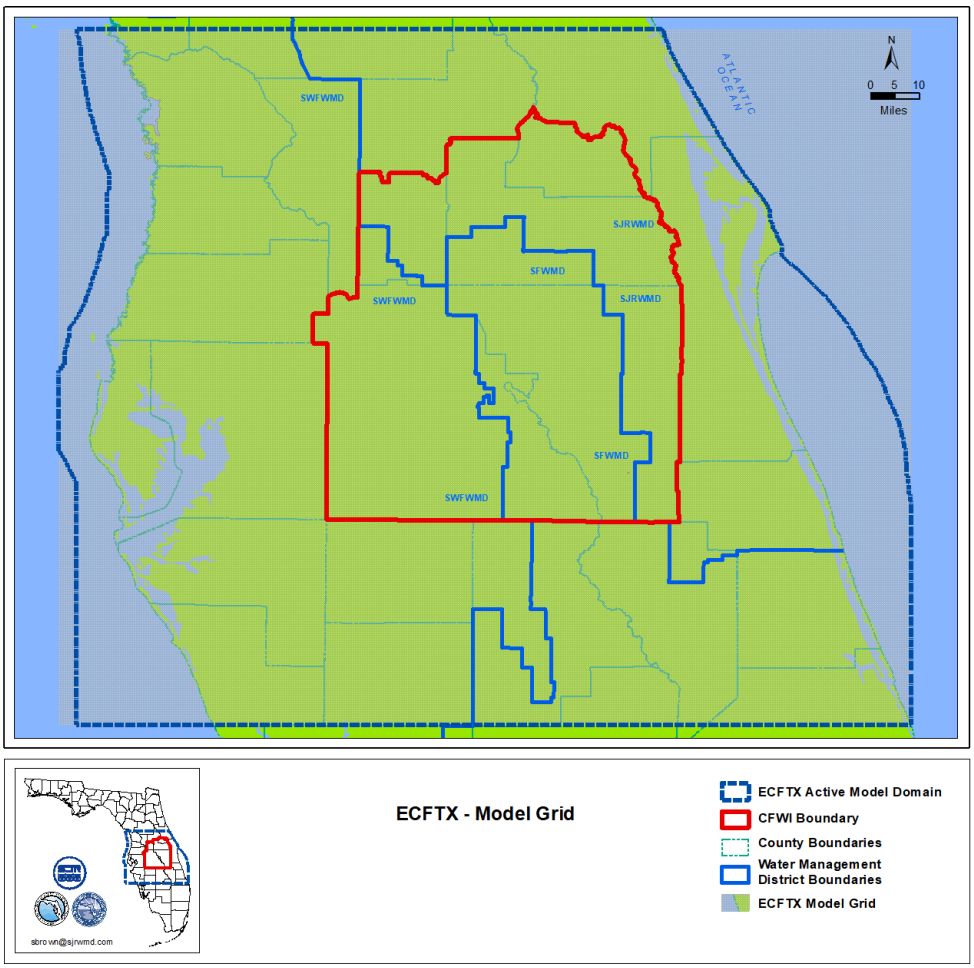

Figure 4-1. The ECFTX model domain in central Florida.

4.1.1 Long-term Average Drawdown

Versions 1.0 and 2.0 of the ECFTX model were both used to determine UFA and SA drawdown at Lake Tulane. An initial scenario that involved reducing existing groundwater withdrawals by 50 percent (and their associated return water from the recharge package) across the model domain from 2003 through 2014 was evaluated using ECFTX, version 1.0. Simulated heads from the scenario run were compared with calibrated-model predictions for the same period to determine aquifer water level changes associated with the 50 percent reduction in withdrawals. These differences were then doubled to estimate drawdown associated with a 100 percent reduction in

withdrawals, which would approximate a “pumps-off” condition. A 5-year average head change, i.e., withdrawal-associated drawdown, for the simulated 2010 through 2014 period was then calculated to estimate long-term average drawdown in the UFA and SA. This procedure had previously been used by the CFWI-HAT Team in 2020 to estimate current withdrawal impact to water bodies with established minimum flows and levels as part of the CFWI regional water supply planning process.

A second scenario simulation was run with version 2.0 of the ECFTX model under steady-state conditions using average recharge and 5-year average groundwater withdrawals from 2014 through 2018. A third simulation with version 2.0 of the model, involved reducing pumping to zero and accordingly adjusting recharge. The head change between these two simulations made with the ECFTX version 2.0 model, was used to estimate the 5-year average drawdown from more current withdrawals than had previously been simulated.

At Lake Tulane, the ECFTX model results predict average drawdown of 0.9 ft and 5.7 ft, respectively, for the SA and UFA for the 2010 through 2014 withdrawal conditions, while model results for more recent 2014 through 2018 withdrawal condition simulation predict average drawdown of 0.8 ft and 5.1 ft for the SA and UFA, respectively (Table 4-1). Modeled drawdown in ECFTX model grids in the vicinity of Lake Tulane are shown in Figures 4-2 and 4-3.

Table 4-1. Average drawdown for Lake Tulane from ECFTX model results.

Time Period	SA (ft)	UFA (ft)
2010-2014	0.9	5.7
2014-2018	0.8	5.1

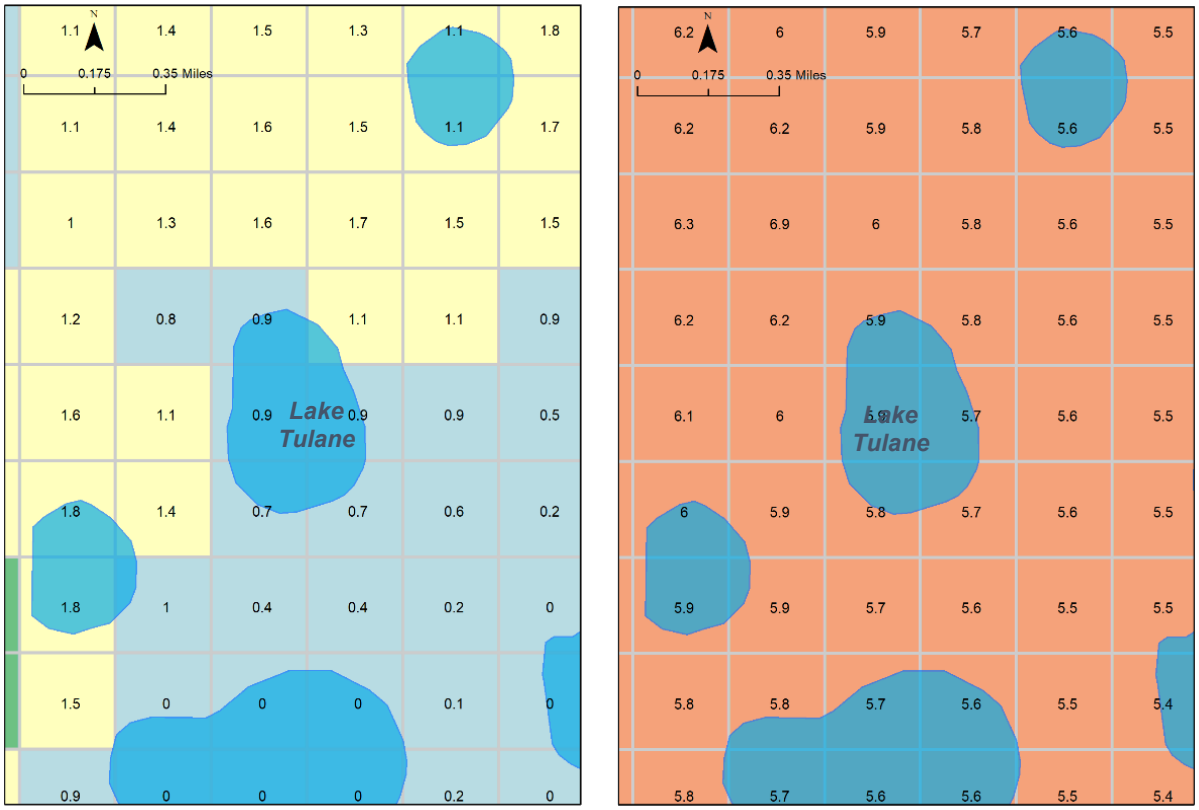

Figure 4-2. Predicted average surficial aquifer (left panel) and Upper Floridan aquifer (right panel) drawdown in feet from 2010 through 2014 withdrawal conditions simulated with the ECFTX model near Lake Tulane; grid size is 1,250 x 1,250 ft.

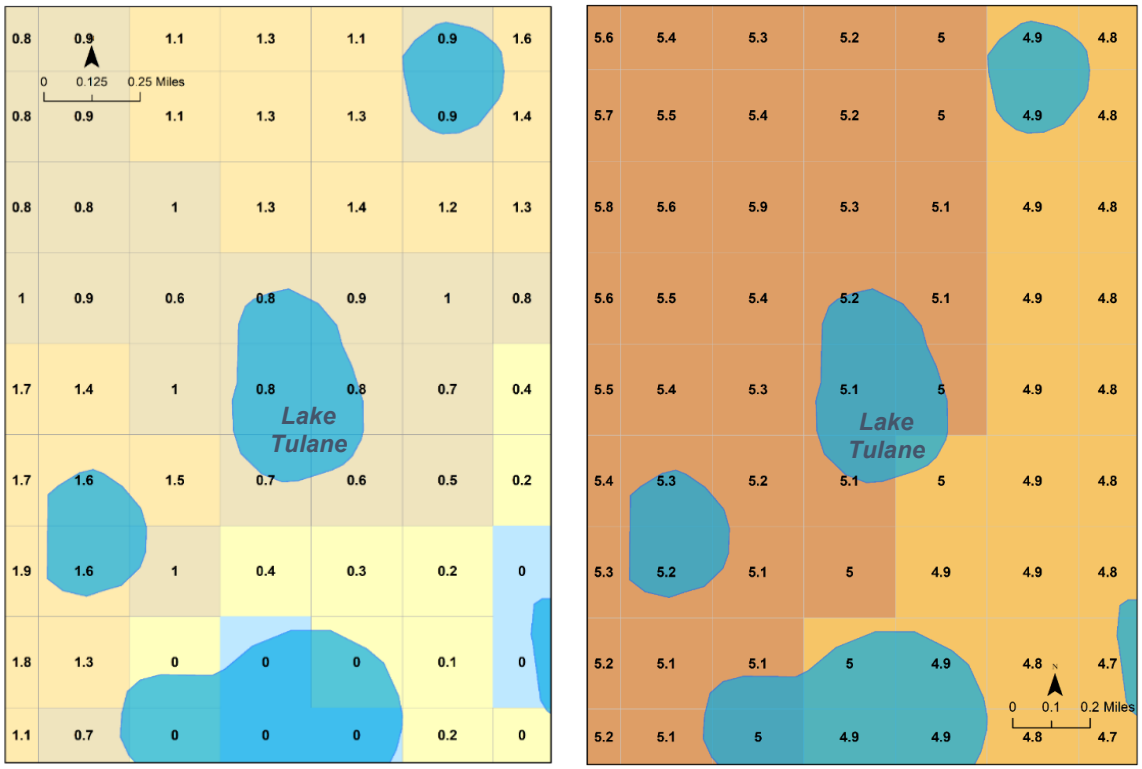

Figure 4-3. Predicted average surficial aquifer (left panel) and Upper Floridan aquifer (right panel) drawdown in feet from 2014 through 2018 withdrawal conditions simulated with the ECFTX model near Lake Tulane; grid size is 1,250 x 1,250 ft.

Regional model simulation results for the UFA from the ECFTX runs were verified against measured data. The average 5.1 and 5.7 ft changes in the UFA at Lake Tulane estimated with the ECFTX model for the 2014-2018 and 2010-2014 periods, respectively, are consistent with the observed 5-6 ft water level decrease observed at the Coley Deep well from the late-1940s to recent conditions. Comparison of UFA potentiometric maps between predevelopment and either 2015 or 2017 (May and September average) suggest a smaller water level change of a few feet; however, the USGS predevelopment map has a larger degree of uncertainty compared to long-term measurements from observation wells.

Relative to UFA drawdown, SA drawdown is typically more difficult to characterize due to high local variability. A lake-specific estimate of SA drawdown is, however, necessary or desirable for characterizing fluxes between the lake and the SA in the lake's water budget model, as described in Section 3.2.5. Therefore, an estimate of SA drawdown was developed for Lake Tulane based on work conducted by Hancock and Basso (1999) for the Northern Tampa Bay area, which indicates that given the elevation of the UFA water level in ft (`L_UFA`), the ratio of SA to UFA drawdown (`DRAWDOWN_SA/DRAWDOWN_UFA`, ft/ft or dimensionless) can be calculated using Equation 4-1. The resultant ratio can then be multiplied by the UFA drawdown to estimate SA drawdown. The ratio is an approximation developed using results from a regional groundwater

flow model, and SA drawdown estimates derived using this ratio were compared with other estimates described above.

(Equation 4-1) $DRAWDOWN\_SA/DRAWDOWN\_UFA = L\_UFA/(8.3*10^{-4} + 0.98*L\_UFA)$

An estimate for L_UFA for Lake Tulane is available from the calibrated lake water budget, as described in the previous chapter, and 5.1 and 5.7 ft estimates for UFA drawdown at the lake derived from ECFTX simulations are available as described above. Given the lake's calibrated L_UFA value of 0.000225 ft/d/ft and the estimated UFA drawdown ranging from values, Equation 4-1 predicts average SA drawdown of between 1.1 to 1.2 ft, values that are comparable to, but 0.3 to 0.4 ft greater than the ECFTX-predicted SA drawdowns for the 2014 through 2018 and 2010 through 2014 periods.

Although presented values represent long-term average drawdowns affecting the lake, withdrawals and therefore drawdowns vary through time. Generally, near most lakes, the lowest groundwater withdrawals tend to occur during times of high rainfall (e.g., due to reduced need to irrigate), which is also when lake water levels are naturally higher. Conversely, the highest groundwater withdrawals occur during times of low rainfall, which is also when lake water levels are naturally lower. Due to this pattern, a constant long-term average drawdown value tends to underpredict impacts at lower water levels and overpredict impacts at higher water levels.

However, the latter bias can be somewhat mitigated at lakes with structures, due to the lake's decreased ability to rise above a certain water level, irrespective of how much, within realistic limits, groundwater levels are increased. In addition to its conceptual support, this bias has been quantitatively demonstrated for several District lakes by comparing the differences in impacts estimated to lake water levels when applying a time-varying (monthly) drawdown correction versus the corresponding average long-term drawdown correction to groundwater levels in water budget models (Cameron, 2018; Cameron & Ellison, 2019; Cameron, 2022). The magnitude of the bias increases with increasing drawdowns and lake leakances and is more pronounced at the extremes of the stage-frequency curve. Due to the potential bias associated with usage of a long-term average drawdown, time-varying drawdown time series for the UFA and SA were also developed.

4.1.2 Monthly Drawdown

Monthly drawdown values for the UFA and SA were developed using data from ECFTX version 1.0 model for cells intersecting Lake Tulane for the 2004 through 2014 time period. At the time of writing, monthly data for reduced pumping scenarios using version 2.0 of the ECFTX model were not available. Drawdown was calculated by comparing reduced pumping and actual pumping scenario results, using the same procedure described in the previous section. The monthly aquifer levels predicted with the linear models were ultimately converted to daily values for use in the water budget model.

Numerical groundwater model results typically represent the most accurate source available for monthly drawdown estimates, but these results are limited to the available model period, which may not capture the entire period of interest for minimum level analyses. However, updating regional groundwater models involves significant time and effort. As a practical way to leverage

available information to extend drawdown records beyond time periods or scenarios currently available from groundwater models, linear relationships between drawdowns and pumping in the UFA have been identified or assumed in some previous District minimum lake level investigations, with use of the approach validated based on site-specific assessments (e.g., Campbell & Patterson, 2020; Campbell & Sealy, 2020; Venning & Cameron, 2020; Hurst et al., 2019; Sutherland et al., 2021; Campbell et al., 2021). The approach recommended by the CFWI-HAT for calculating drawdown using the ECFTX model described in the previous section also assumes a linear response of UFA drawdown to pumping changes.

Therefore, to extend the availability of monthly drawdown estimates beyond the 2004 through 2014 period available from ECFTX version 1.0 simulations to the entire 2001 through 2020 water budget model period for Lake Tulane, a linear relationship was developed between modelled monthly UFA drawdown in ECFTX model cells that underly the lake and average monthly pumping within specified buffer distances from the lake. Monthly pumping data used for the regressions were obtained from the District's estimated and metered groundwater withdrawals database described in Section 2.6.8 of this report. For simplicity, domestic self-supply (DSS] withdrawals were not included in the water use estimates due to their relatively small contributions to overall withdrawals, and because excellent fit was obtained for pumping-drawdown models fit despite exclusion of DSS withdrawals.

Modeled monthly drawdown in the UFA derived with the ECFTX model and average monthly pumping with buffer distances ranging from 0.5 miles to 8 miles were assessed (Figure 4-3). Buffer distances of 2 miles and greater showed a strong linear correlation between pumping and drawdown ($R^2 \geq 0.86$). The regression associated with the 6-mile buffer, representative of the relatively stable and high coefficient of determination values derived for regressions based on the 5-mile and greater buffer distances is shown in Equation 4-2, where `DRAWDOWN_UFA` is monthly drawdown in the UFA (ft) and `6_MI_PUMP` is total average estimated/metered monthly groundwater withdrawals (MGD) within a 6-mile buffer of the lake.

```
(Equation 4-2) DRAWDOWN_UFA = 0.181*6_MI_PUMP + 1.540
```

The NSE of the regression is 0.96, the standard error 0.36 ft, 75% of residuals fell within 0.24 ft, the residuals were not significantly different from normal based on a Shapiro-Wilks test, and the residuals did not demonstrate apparent heteroscedasticity. However, the intercept suggests a small amount of drawdown occurring even under no zero pumping (i.e. "pumps off") conditions within the 6-mile buffer, which is unrealistic. The intercept could reflect drawdown related to pumping beyond the buffer zone. The intercept also reflects the limitations of a simple linear model, as a non-zero intercept would almost certainly be expected even with the inclusion of a zero-zero point in the regression dataset. Since zero pumping does not occur within the 6-mile buffer during any time period of interest, and the intercept represents a small value of equivalent SA drawdown and associated impact to the lake (<0.2 ft), the impact of the non-zero intercept was considered de minimis for the proposed application.

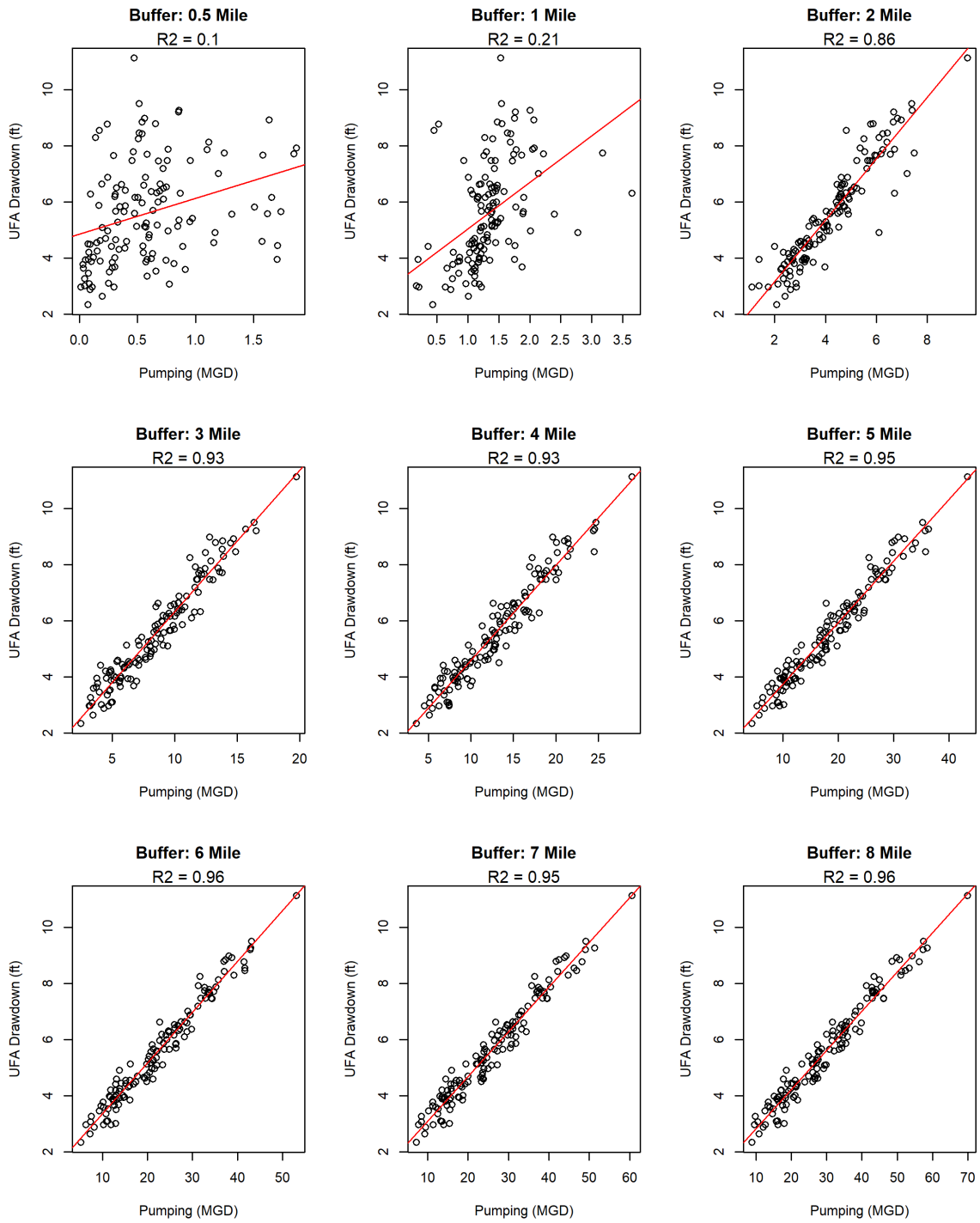

Figure 4-3. Relationship between monthly pumping in million gallons per day (MGD) within various buffer distances of Lake Tulane and monthly drawdown in the Upper Florida aquifer (UFA) in ECFTX, version 1.0 model cells that underly Lake Tulane for a 2010 through 2014 withdrawal conditions simulation. Red lines in the plots represent linear regressions of the presented points, with coefficients of determination (R^2) values listed for each regression line.

Drawdown-pumping relationships can change in response to differing recharge (e.g., rainfall) conditions. To assess how the pumping-drawdown relationship for the representative 6-mile buffer area varies by season, individual regressions were developed for each month of the year. The resulting month-specific slopes were similar to the slope for all data combined, irrespective of month, with notable exceptions for some wet season months, in particular July through September (Figure 4-4). The difference between the all-months regression and the November regression is explained by the single low pumping point which skewed the regression (Figure 4-4). These wet season months were, however, typified by low pumping which resulted in limited ability to adequately characterize the pumping-drawdown relationship for higher pumping conditions. Interestingly, the wet-season months tended to show less drawdown given per unit pumping compared to the all-months regression, which is consistent with the conceptual expectation of reduced drawdown in unconfined and semi-confined settings during times of higher recharge. Differences in slopes between the all-months and month-specific regressions could also likely be attributed to the influence of fewer data points for the month-specific regressions, as opposed to an actual, substantial difference.

Based on these uncertainties, the “all-months” regression for pumping within a 6-mile buffer of Lake Tulane (Equation 4-2) was selected to relate pumping and drawdown in the UFA, as it provided satisfactory performance and was developed using a relatively large data set representative of a wide range of pumping conditions. Potential influences of differing recharge on SA drawdown were not evaluated separately and were assumed to follow those affecting the UFA, and were estimated on a monthly basis using the UFA/SA drawdown relationship described in Equation 4-1.

Specifically, Equation 4-2 was used with 2001 through 2020 6-mile estimated/metered monthly pumping data to estimate monthly UFA drawdown for the 2001-2020 period used in the Lake Tulane water budget model (Figure 4-5, top panel). Equation 4-1 was used with inputs of the monthly UFA drawdown estimates from the ECFTX model and the calibrated `L_UFA` value of 0.000225 ft/d/ft for Lake Tulane to estimate monthly SA drawdown for the 2001 through 2020 period (Figure 4-5, bottom panel). The regression-predicted drawdown values for the periods from 2001 through 2003 and 2015 through 2020 were then combined with ECFTX-derived monthly drawdown values available for the 2004 through 2014 simulations to create monthly time-series of UFA and SA drawdown for the 2001-2020 for use in the Lake Tulane water budget model to simulate historic water levels, as described in Section 4.2.

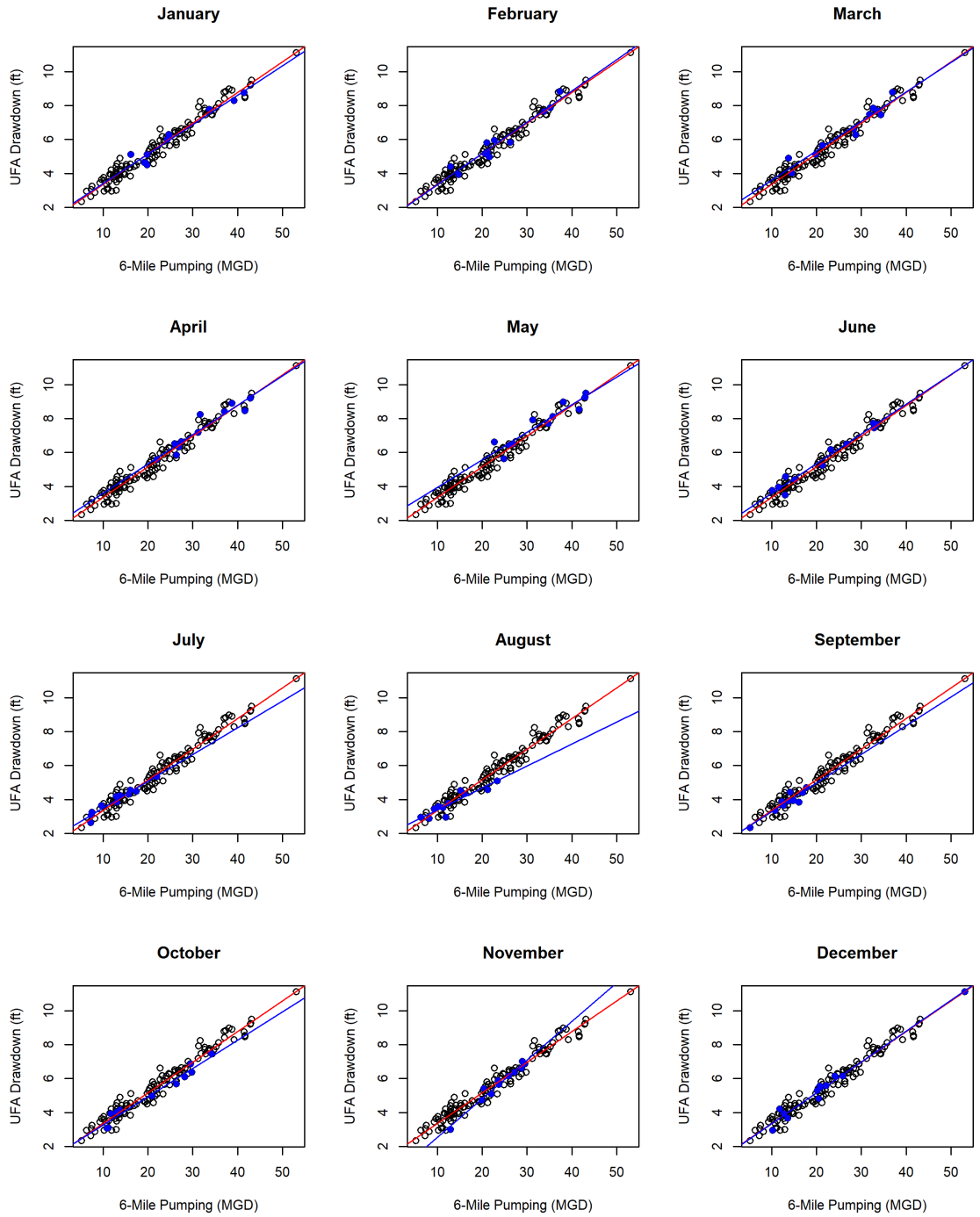

Figure 4-4. Relationship between pumping within various buffer distances of Lake Tulane by month in million gallons per day (MGD) and monthly drawdown in the Upper Floridan aquifer (UFA) in ECFTX, version 1.0 model cells that underly Lake Tulane for a 2010 through 2014 withdrawal conditions simulation. Red line in each plot is the linear regression of all data points (open black symbols), irrespective of month. The blue line in each plot is the regression using only the data points (blue points) for the month indicated in the plot title.

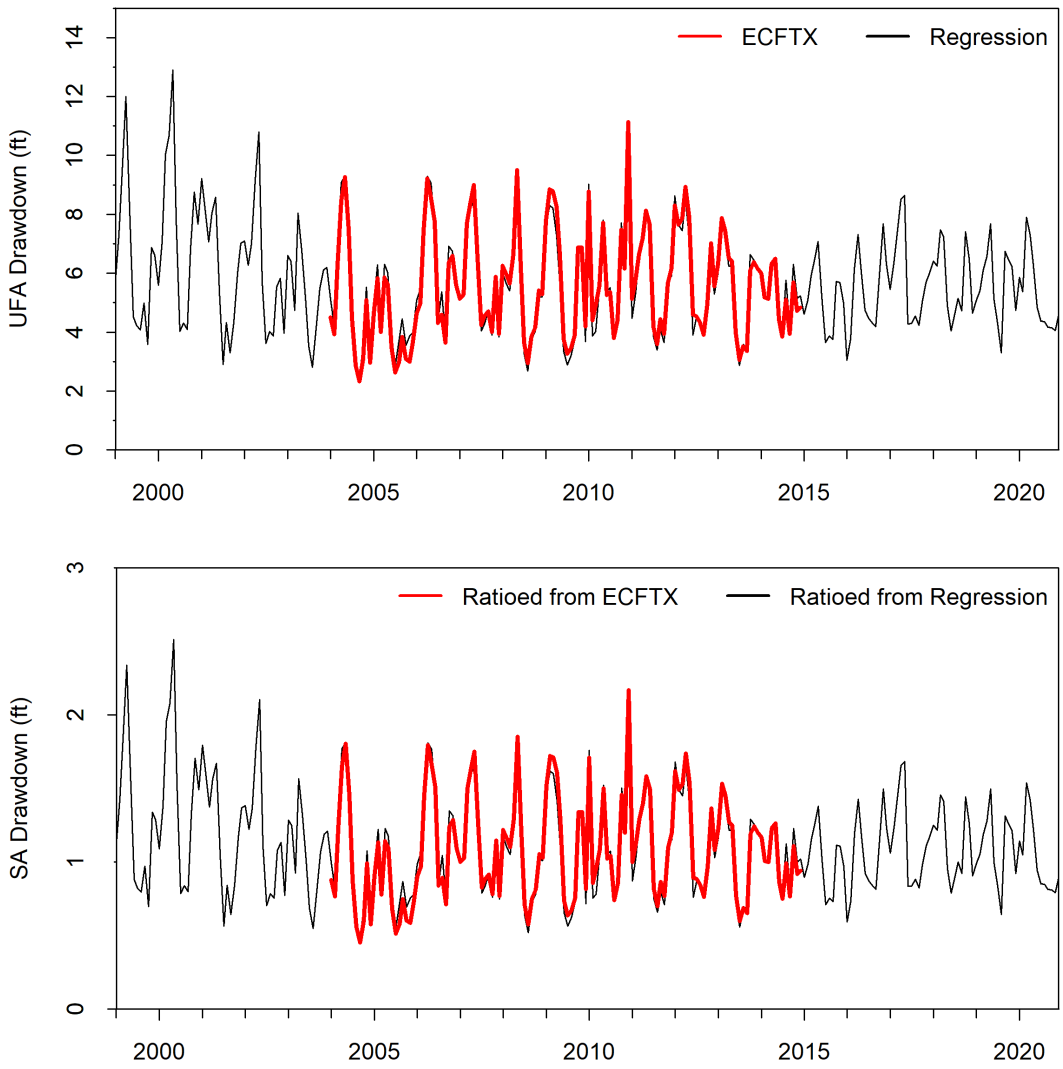

Figure 4-5. Monthly Upper Florida aquifer (UFA; top panel) and surficial aquifer (SA; bottom panel) drawdowns for Lake Tulane from ECFTX version 1.0 (red line) and a pumping-drawdown regression using pumping within a 6-mile buffer of the lake (black line). SA drawdowns were ratioed from UFA drawdowns based on lake-specific leakance, as described in the text.

4.2 Historic Lake Tulane Scenario and Historic Stage Records

4.2.1 Historic Water Budget Model Development

The calibrated Lake Tulane water budget model, described in Chapter 3, represents current structural conditions at the lake and can simulate lake levels for the period from March 2001 through December 2020. However, groundwater level inputs from this period used for model calibration include empirical water level data that integrate impacts of withdrawals occurring at

the time of data collection, and these impacts must be removed for representation of the Historic condition. Therefore, a Historic water budget model scenario for Lake Tulane that uses the calibrated water budget model, with SA and UFA groundwater level time series inputs adjusted upwards to offset drawdown in each aquifer was needed. This Historic scenario provided a means to estimate water levels expected in the absence of withdrawals, given existing structural alterations or structural alterations similar to those that currently exist.

The UFA and SA drawdown estimates for Lake Tulane described in Section 4.1 of this report include long-term average estimates and monthly estimates. The monthly drawdowns provide a more accurate estimate of actual drawdowns occurring under the lake and less biased estimates of stage exceedance percentiles associated with water level higher than the Historic P50, relative to use of a constant long-term average drawdown. Usage of the monthly drawdowns is also supported by the acceptable calibration of the ECFTX in the vicinity of Lake Tulane, the strength of the pumping-drawdown relationship for the UFA developed for the lake, and agreement between the 5.4 ft average (of the 5.8 ft and 5.1 ft) monthly UFA drawdown with average long-term drawdown that was verified using independent empirical data.

To produce the Historic scenario for use in the water budget model, SA and UFA water levels were increased using the average monthly drawdown estimates described in Section 4.1.2, which were disaggregated into daily time series, assuming a uniform distribution (e.g., all days within January 2019 repeat the average January 2019 value, all days within February 2019 repeat the average February 2019 value, and so on). In response to the increase in groundwater level inputs, the model recalculates water levels, predicting their behavior in the absence of groundwater withdrawals.

4.2.2 Historic Water Budget Model Results

Results of the Historic scenario along with those for the calibrated model and observed lake stage record for the period from March 2001 through December 2020, are provided in Figure 4-5 and Table 4-1. In the absence of withdrawals, the P10, P50, and P90 for Lake Tulane would increase 0.6, 0.4, and 1.0 ft respectively, relative to comparable percentiles predicted for the model calibration condition. Differences between the Historic and observed P50 were equivalent to those between the Historic and calibrated conditions, while the Historic P10 and P90 was predicted to be 0.4 and 1.1 ft higher than the observed P10 and P90 respectively.

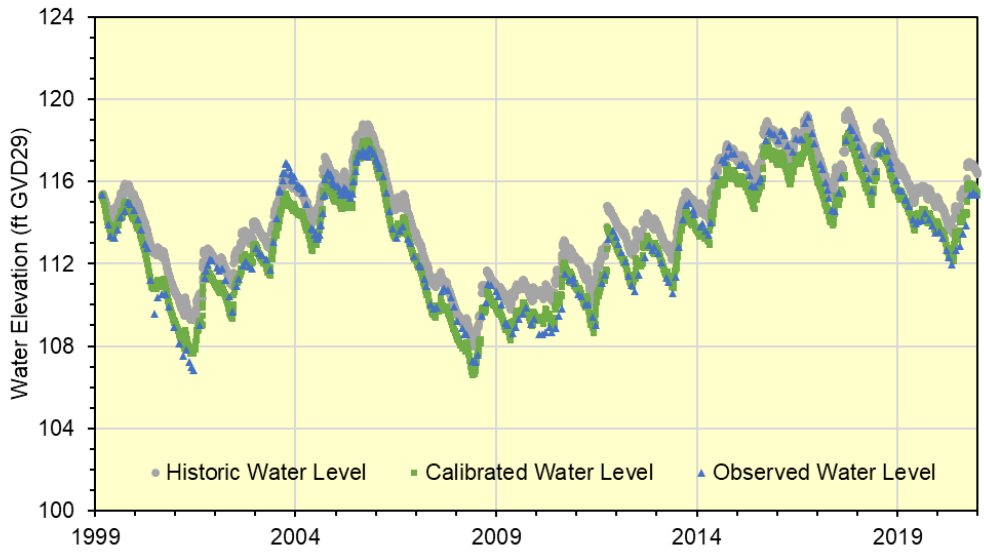

Figure 4-5. Lake Tulane observed, calibrated, and Historic scenario water levels from March 1999 to December 2020. Calibrated and Historic scenario results were obtained using the Lake Tulane water budget model.

Table 4-1. Water level elevations associated with the P10, P50 and P90 from March 1999 to December 2020 from observed lake stages and calibrated and Historic conditions simulated with the Lake Tulane water budget model.

Percentile	Observed (ft NGVD29)	Calibrated (ft NGVD29)	Historic (ft NGVD29)
P10	117.4	117.2	117.8
P50	114.2	114.2	114.6
P90	109.5	109.6	110.6

4.2.2 Historic Water Budget Model Limitations

The difference between calibrated and Historic lake water levels depends on the magnitude of the leakance coefficients and drawdown estimates, with higher values for either producing greater increases in Historic lake water levels, all else being equal. For lakes with structures, structure efficiency will dampen the difference for water levels above structure elevations. As previously described, during calibration, the modeler selects parameters based on an assessment of the physical system and related data and achieving a reasonable match to observed water levels, while drawdown adjustments are determined using regional groundwater model data and validated using empirical data. Although the leakance coefficients and drawdown adjustments used for the Historic scenario represent the best available data, they are associated with some uncertainty. Previously, detailed sensitivity testing of all inputs and parameters conducted for representative calibrated lake water budget models found that generally, leakance coefficients and groundwater level adjustments are sensitive parameters (Qi et al., 2022).

4.3 Long-term Historic Percentiles

A locally estimated scatterplot smoothing (LOESS) was performed using the results of the Historic water budget model and long-term rainfall to derive a long-term (60 year) Historic water level record for Lake Tulane. This long-term Historic record served as a basis for identifying Historic lake stage percentiles that are an essential component of minimum lake levels development. LOESS, the most widely used smoothing algorithm, was used for this application since it produces "a resistant centerline that is fit to the data whose level and slope varies locally in response to the data themselves" (Helsel et al., 2020).

For the water-level data set extension, Historic lake stages were correlated with Long-term rainfall. The Historic lake stages were derived by 1) calculating the lake stage difference between the Historic lake stage predicted with the water budget model and the lake stage predicted with the calibrated water budget model, and 2) adding the difference to the observed lake stage. The Long-term rainfall data set was developed by adding additional, representative rainfall records to the March 1999 – December 2021 rainfall records used in the water budget model. Records from the Avon Park 2 W NWS rain gage (SID 25508) with a gap filled with the DeSoto City 8 SW NWS rain gage (SID 25554) were used to extend the data back to 1963. The Avon Park gage is approximately 1.5 miles west of Lake Tulane, and the DeSoto City rain gage is approximately 15 miles south of Lake Tulane. In addition, NEXRAD data were used to extend the rainfall time series to December 2022.

The rainfall data were correlated to the Historic lake stage 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. For this application, weighted sums varying from 6 months to 10 years were separately used, the results compared, and the correlation with the lowest residual standard error (RSE) chosen as the best model. For Lake Tulane, the 4-year weighted model had the lowest RSE of 1.16.

Historic water budget model results (i.e., water levels) from January 2003 to December 2020 were correlated with the weighted rainfall values using the LOESS procedure (Figure 4-6). This period was selected based on a reduction in regional groundwater withdrawals that began around 2003 (see Section 2.9 Water Withdrawals). Daily lake water surface elevations from January 1963 to December 2022 (60 years) were then derived using the resulting stage-rainfall relationship (the LOESS model). The lake's predicted behavior in the absence of withdrawals, i.e., the predicted Historic water level record, is presented in Figure 4-7. Historic percentiles (P10, P50 and P90) for the Lake Tulane Historic water level record are included in Table 4-2.

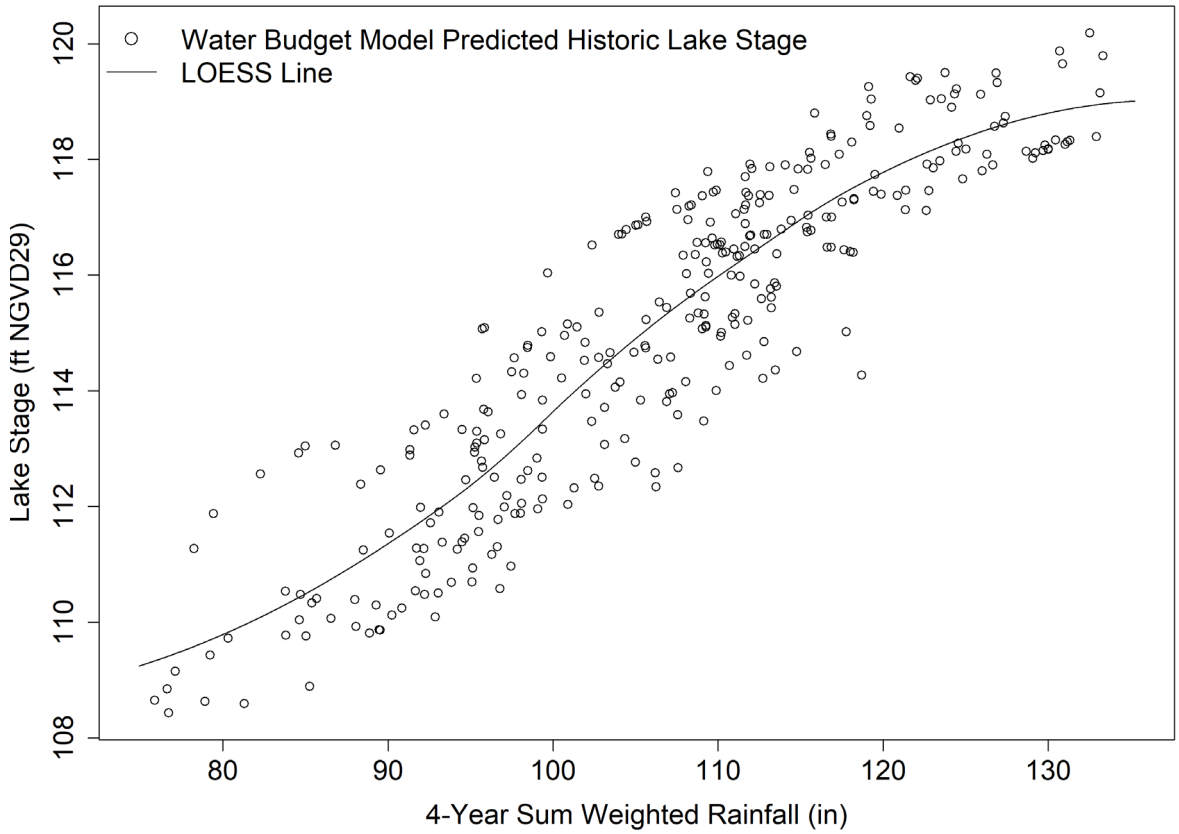

Figure 4-6. Lake Tulane water levels from Historic water budget model correlated with 4-year weighted sum rainfall using Loess method.

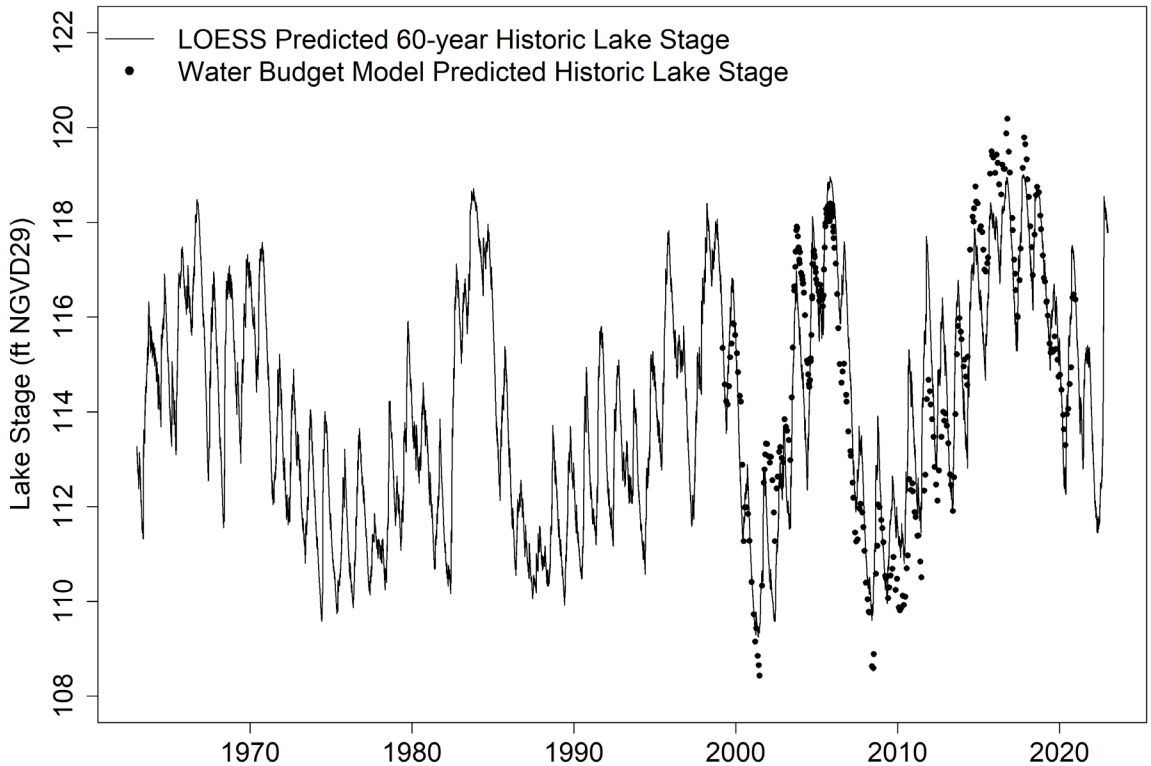

Figure 4-7. LOESS predicted 60-year Historic Lake Tulane water levels from January 1963 to December 2022 and Water Budget Model predicted Historic Lake Tulane water levels from March 1999 to December 2020.

Table 4-2. Lake Tulane P10, P50 and P90 water level elevations predicted from March 1999 to December 2020 with the Historic water budget model and from January 1963 to December 2022 using the Historic LOESS method.

Percentile	Historic Water Budget Model (ft NGVD29)	Historic Loess Model (ft NGVD29)
P10	117.8	117.4
P50	114.6	113.9
P90	110.6	110.9

4.4 Summary

Best available information was used to develop a Historic scenario for Lake Tulane using a calibrated water budget model. Collectively, given calibration, verification, and sensitivity testing results (see Section 3.3.3), an estimate of approximately ±0.5 ft for error/uncertainty is reasonable for the Historic P10, P50 and P90 produced by the Historic scenario using the calibrated Lake Tulane water budget model. Lake minimum levels most heavily rely on the estimate of the Historic P50, which is the highest confidence percentile derived for the Historic scenario. The modeled Historic P50 is still associated with some uncertainty but appears reasonable and represents the

best estimate available. The Historic scenario results were considered acceptable for supporting minimum levels development for Lake Tulane.

CHAPTER 5 – ENVIRONMENTAL CRITERIA METHODS, RESULTS AND DISCUSSION

Revised minimum levels were developed for Lake Tulane using lake-specific significant change standards and environmental screening methods (SWFWMD 2022a). The standards were used to identify a provisional Minimum Lake Level. The screening methods were used to evaluate the provisional Minimum Lake Level and determine whether any modification of the provisional level was necessary based on consideration of all relevant environmental values associated with the lake. Based on results from this screening, no need for modification of the provisional Minimum Lake Level was identified, and the difference between the Historic P10 and P50 elevations for the lake was used to identify a proposed High Minimum Lake Level.

5.1 Historic Lake Stage Percentiles

As described in Chapter 4, Historic lake stage exceedance percentiles for Lake Tulane were developed for the period from March 1999 through December 2022 using a water budget model and extending the record to January 1963 through December 2022 using a LOESS method as described in Section 4.3 (Table 5-1). The simulated historic water level time-series used for percentile development is shown in Figure 4-7. The historic percentiles included a Historic P10, P50 and P90, which characterize water levels expected to be equaled or exceeded ten, fifty and ninety percent of the time on a long-term basis, in the absence of withdrawal impacts and given existing structural alterations.

Table 5-1. Historic lake stage percentiles for Lake Tulane based on a LOESS predicted lake water levels for the period from January 1963 through December 2022.

Percentile	Elevation (ft NGVD29)	Elevation (ft NAVD88)
P10	117.4	116.5
P50	113.9	113.0
P90	110.9	110.0

5.2 Normal Pool Elevation and Other Hydrologic Indicators of Sustained Inundation

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

As was the case for Normal Pool determination for Lake Tulane, other useful hydrologic indicators of sustained inundation were similarly not identified for the lake.

5.3 Structural Alterations and Other Information for Consideration

Additional information to consider in establishing minimum levels are the Control Point elevation and elevations associated with the lowest building floor/slab elevation and other relevant features such as low roads, within the lake basin.

As discussed in Sections 1.1, 1.2 and 1.4, 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. Because Lake Tulane does not have an outlet conveyance system and is considered a closed basin lake, a control point elevation was not identified for the lake (see Sections 2.2).

A low floor slab elevation, based on survey reports (Survtech, 2021), was established at 122.9 ft NGVD29 for the Lake Tulane basin.

5.4 Significant Change Standards

Two significant change standards, the Xeric Wetland Offset and the Species Richness Standard were established for Lake Tulane based on historic lake stage percentiles and stage-area-volume relationships for the lake. The Xeric Wetland Offset was used for Lake Tulane based on its characterization as a xeric lake (GPI 2021a; see also Sections 2.3, 2.5 and 5.4.1).

5.4.1 Xeric Wetland Offset

The Xeric Wetland Offset is developed to protect lake fringing wetlands in xeric settings that are not dominated by cypress. Xeric waterbodies are geographically isolated lakes and wetlands in landscapes dominated by xeric soils and are typically associated with deep water-table conditions and sand pine scrub or longleaf pine–turkey oak hills ecosystems (GPI 2016; GPI 2021b; Nowicki 2019; Nowicki et al. 2021, 2022). Xeric soils contrast with mesic and hydric soils by having low moisture content, typically with a hydric rating below 3.5% (CFWI-EMT 2013; GPI 2016, 2021b). Water levels at xeric waterbodies frequently display high range and low symmetry (Epting et al. 2008; GPI 2016; Schmutz 2019). Additionally, xeric waterbodies are usually internally drained, such that maximum elevations are not typically controlled by surface outflows (GPI 2016, Basso 2019).

The Xeric Wetland Offset was developed using hydrologic data and stress-status determinations for xeric wetland sites in the Lake Wales Ridge and northern Tampa Bay areas (GPI & SWFWMD 2022). The standard is applied as an offset from the Historic P50 elevation and is based on the finding that significant harm is likely to occur at a xeric wetland when the P50 is lowered by more than 2.2 feet relative to Historic conditions.

The Xeric Wetland Offset for Lake Tulane was, therefore, established at 111.7 ft NGVD29, an elevation 2.2 ft. below the Historic P50 elevation of 113.9 ft NGVD29.

5.4.2 Species Richness Standard

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 (SWFWMD 2001, Emery et al. 2009).

For Lake Tulane, the Species Richness Standard was established at 106.7 ft NGVD29, based on a 15% reduction in lake surface area from that at the Historic P50 elevation (Figure 5-1).

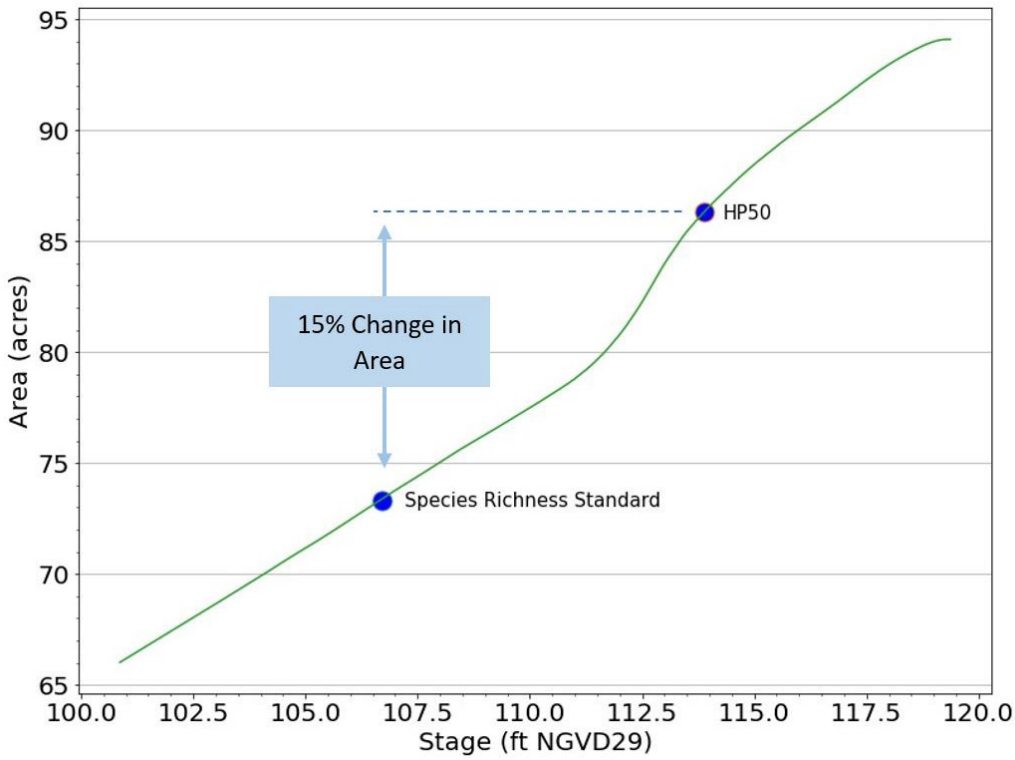

Figure 5-1: Species Richness Standard for Lake Tulane compared to the Historic P50 (HP50) elevation.

5.5 Provisional Minimum Lake Level and MFL Condition Time Series

For Lake Tulane, The Xeric Wetland Offset elevation of 111.7 ft NGVD29 was higher, i.e., more sensitive to stage reductions, than Species Richness standard of 106.7 ft NGVD29. The Xeric Wetland Offset was therefore used to identify a provisional Minimum Lake Level for the lake, which was used to develop an “MFL Condition” water level timeseries for use in the screening methods described in the following section.

The MFL Condition water level records were developed using the Lake Tulane water budget model and a LOESS rainfall regression, similar to the development of the historic water level timeseries. Model simulations involving incremental reductions in UFA and SA inputs from those associated with the historic condition were iteratively conducted to identify a timeseries associated with the least change in aquifer inputs that would yield a P50 elevation of 111.7 ft NGVD29, the elevation associated with a provisional Minimum Lake Level based on the Xeric Wetland Offset.

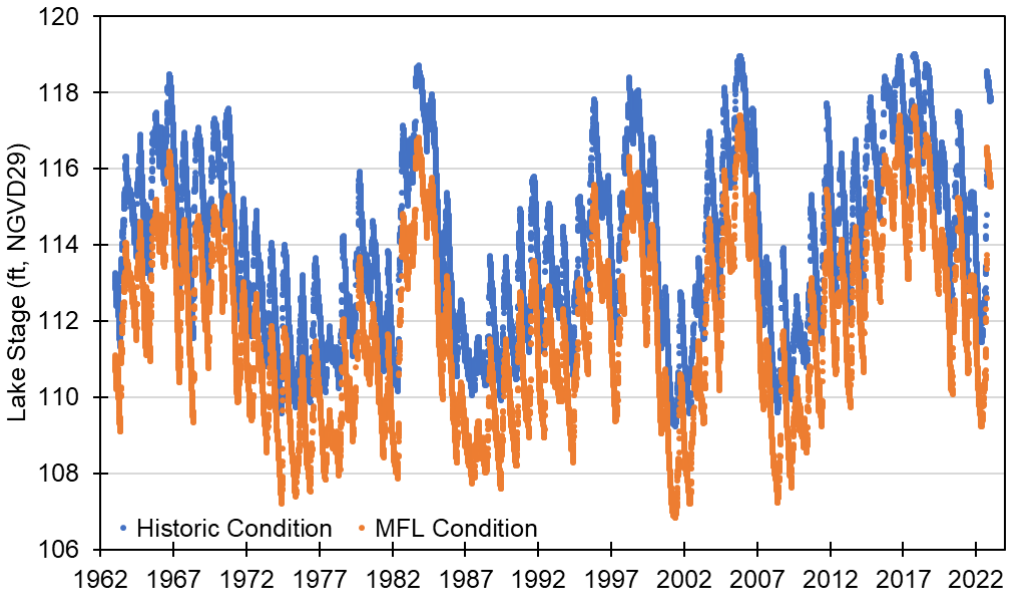

Figure 5-2. Historic and MFL Condition water levels simulated with the Lake Tulane water budget model from January 1963 to December 2022.

5.6 Screening of Provisional Minimum Lake Level

Additional information associated with four screening processes was evaluated and considered for development of minimum levels for Lake Tulane. This information, associated with aquatic habitat zones, basin connectivity, dock-use, and aesthetics, was evaluated to ensure all relevant environmental values associated with Lake Tulane would be protected with implementation of the provisional Minimum Lake Level, and to identify any potentially needed additional analyses prior to identification of proposed minimum levels.

5.6.1 Aquatic Habitat Zone Screening

Aquatic habitat zone screening is used to ensure protection of fish and wildlife habitats, other natural system values, and human-use values. The screening is based on evaluation of potential changes in the areal extent of aquatic habitat zones associated with changes in water levels. Each habitat zone is defined by a specific water depth or range of depths, so the extent of each habitat and its change with water level change are easily assessed using bathymetric data and water level time-series data. The screening focuses on identifying habitat zone changes of 15% or greater, a threshold commonly used in minimum flow and minimum water level determinations

within the District[3] and elsewhere in Florida (e.g., Sutherland et al., 2021; HSW Engineering, Inc. 2016).

Habitat zones assessed in the screening process include those associated with shallow, nearshore (littoral zone) and deep-water (limnetic zone) areas or zones. The littoral zone, typically defined as the area from the lake's edge to the deepest portion of the lake where rooted plant species can grow, provides critical foraging habitats for wading birds, fish, and other wildlife. Aquatic macrophytes, periphyton and aquatic invertebrates, which are typically abundant in the littoral zone, also contribute greatly to lake biodiversity, food webs, and nutrient cycling. Deep-water areas similarly provide critical habitat for myriad species and ecosystem goods and services and are conducive to a variety of recreational activities.

High quality habitat for most recreational sport fish that occur in Florida lakes typically requires a littoral zone populated by aquatic macrophytes and a limnetic zone with deeper, open water. For example, Hoyer and Canfield (1996) report abundance of young-of-the-year Largemouth Bass (*Micropterus salmoides*) in Florida lakes smaller than 300 hectares was directly related to the percentage of lake volume containing aquatic macrophytes, although no significant relationships between aquatic macrophyte abundance and subadult or adult largemouth bass abundances were identified. Aquatic macrophyte zones also support myriad non-aquatic species associated with the lake, including piscivorous birds such as osprey. Sport fish species observed during site visits to Lake Tulane in support of minimum levels development include Largemouth Bass, Bluegill (*Lepomis macrochirus*), and Redear Sunfish (*Lepomis microlophus*). Forage fish include Mosquito fish (*Gambusia* spp.) and Killifish (*Fundulus* spp.).

Most lakes in Florida are relatively small and shallow and have a higher proportion of shoreline length to lake surface area. The littoral zone therefore accounts for a relatively high proportion of available habitats and productivity. Even when aquatic macrophyte coverage is low and may therefore contribute minimally to total system productivity, littoral habitats often provide preferred spawning habitat for certain fish species. Water level fluctuations and siltation rates can inhibit spawning or egg incubation in lake littoral zones (Winfield, 2004), and the structure associated with aquatic macrophytes can affect siltation (Madesen et al., 2001).

Altering a lake's natural water level fluctuation can impact littoral zone structure and functions. Water control structures and water level stabilization for the purpose of flood control can alter aquatic macrophyte communities, as well as impact the physiochemical environment (Bunch et al., 2010). When phytoplankton and color levels increase, negatively impacting water clarity, a littoral zone may be reduced in size due to the limitation of light available for aquatic macrophytes.

Productivity by phytoplankton in deeper, open water areas represents a larger proportion of total lake productivity in larger and deeper lakes, increasing with lake size and depth. The algae, cyanobacteria and other microbes that compose the phytoplankton support a diverse community of zooplankton, zooplanktivorous fish, and their predators. Deep-water habitat can also be

[3] See minimum flow reports available from the Southwest Florida Water Management District's Minimum Flows and Levels Documents and Reports page at https://www.swfwmd.state.fl.us/projects/mfl/documents-and-reports

important in shallow lakes, contributing to system productivity and biodiversity (e.g., Havens et al. 1996).

Additionally, deep-water habitat can provide thermal refuge for some species when the lake water column is deep enough to thermally stratify. Low water conditions in lakes due to drought or excess water use can reduce habitat area and increase competition or vulnerability to predation for certain species (Magoulick & Kobza, 2003). Areas of deep water can serve as refuge during periods of low water. In lakes impacted by drought conditions, nutrient concentrations, warm temperatures, and associated low dissolved oxygen levels can lead to fish mortality (Lennox et al., 2019). Most aquatic organisms rely on the refuge of deep-water areas in lakes during low water conditions, although adaptations for coping with this and other types of abiotic disturbances are also common (Rosenberger & Chapman, 2000).

Deep-water habitat is essential or supports numerous recreational uses, including safe water-skiing depths of 5-6 feet or greater, boating, navigation, and swimming. Other recreational activities, such as bird watching, benefit from conservation of deep-water areas used by diving birds. Deep water is also important for maintaining lake water quality (Bachmann et al., 2000). The outdoor recreation activities in Florida identified by the FDEP (Seidel et al., 2017) that are applicable to lakes can all be protected by maintaining a lake's natural balance of shallow, littoral habitat and open, deep water habitat.

The habitat zones and associated depth ranges used in the District's screening process for provisional Minimum Lake Levels were developed by the St. Johns River Water Management District as part of their minimum levels program. As described in Sutherland et al. (2021), the habitat zones and corresponding water depth ranges are:

- small wading bird forage (0-0.5 ft),
- sandhill crane nesting habitat (0.5-1.0 ft),
- large wading bird forage (0-1.0 ft),
- game fish spawning habitat (1.0-4.0 ft),
- emergent marsh (0-6.0 ft), and
- Open-Water (i.e., deep-water) habitat (>5.0 ft).

Bathymetric data used in the screening include stage-area-volume relationships for the lake basin that are developed using a digital elevation model (DEM) and data analysis tools to calculate the area and volume between the modeled lake basin and a reference plane at 0.1 foot intervals between a specified starting and ending elevation. The resulting output from this stage/area analysis is then used to identify stage-specific areas for the water depths associated with the identified lake habitat zones. Habitat areas are quantified at 0.1 ft elevation intervals using stage-area-volume information and used with a water level time series to develop a habitat area time series. An average habitat area is then calculated for each time series.

The screening involves determining percentage differences in the average habitat areas associated with a simulated historic water level time series and a simulated MFL Condition time series. For cases when all assessed habitat differences between the historic scenario and the MFL Condition are ≤15%, the proposed minimum lake level is considered protective of the habitat zones. For other situations, additional conditions are simulated to identify a time series of water

level records that yields a time series of habitats that yields average values that are 15% smaller than the average habitat areas associated with the historic condition. These additional condition simulations include incremental increases in withdrawal quantities or effects (e.g., increased drawdown in underlying aquifers) from the historic condition to identify the time series that yields water levels sufficient to not result in more than a 15% difference in habitat areas relative to the areas associated with the historic condition.

Under the historic condition the small wading bird habitat at Lake Tulane generally increased with water levels up to an elevation of 113.0 ft NGVD29 where it peaked at 1.72 acres and then generally declined at higher elevations, although a slight increase in acreage occurred at water surface elevations from 116.8 ft to 117.6 ft (Figure 5-3). The mean small wading bird habitat area under historic conditions was 0.97 acres (Table 5-2). Small wading bird habitat for the MFL Condition scenario exhibited a similar pattern, peaking at 1.72 acres when the lake was staged at 113.0 feet NGVD29 and then declining in area at higher elevation (Figure 5-3). Under the MFL Condition, small wading bird habitat extended over 0.92 acres, which was, on average, a 6% decrease from the historic condition (Table 5-2).

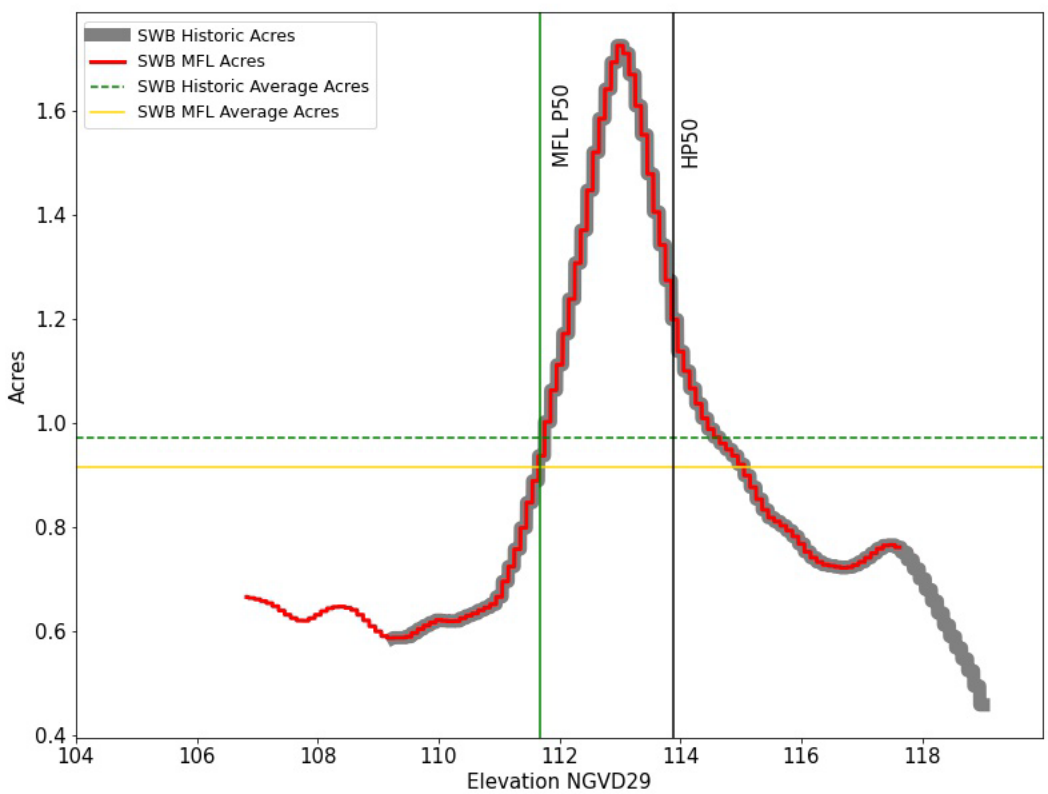

Figure 5-3. Stage/area relationship for small wading bird (SWB) habitat simulated for historic and MFL conditions at Lake Tulane.

Table 5-2. Modeled historic and MFL condition habitat area, and percentage change between the historic and MFL condition for Lake Tulane.

Habitat	Historic Average Habitat Area (acres)	MFL Condition Average Habitat Area (acres)	% of Historic Average Under MFL Condition
Small Wading Bird	0.97	0.92	94
Large Wading Bird	1.93	1.82	95
Sandhill Crane	0.95	0.91	95
Game Fish	5.43	4.82	89
Emergent Marsh	10.5	9.26	88
Deep Water Habitat	76.6	73.5	96

Large wading bird habitat under the historic condition exhibited the same general pattern as the small wading bird habitat. Habitat increased with increasing water levels up to a peak area at 113.2 feet NGVD29 (Figure 5-4). The minimum area for large wading bird habitat for the historic condition scenario was 1.05 acres, the maximum area was 3.25 acres, and the average was 1.93 acres. The response for the MFL Condition was similar, with large wading bird habitat ranging from 1.19 to 3.25 acres and averaging 1.82 acres. On average, large wading bird habitat differed by about 5% between the two simulated conditions (see Table 5-2).

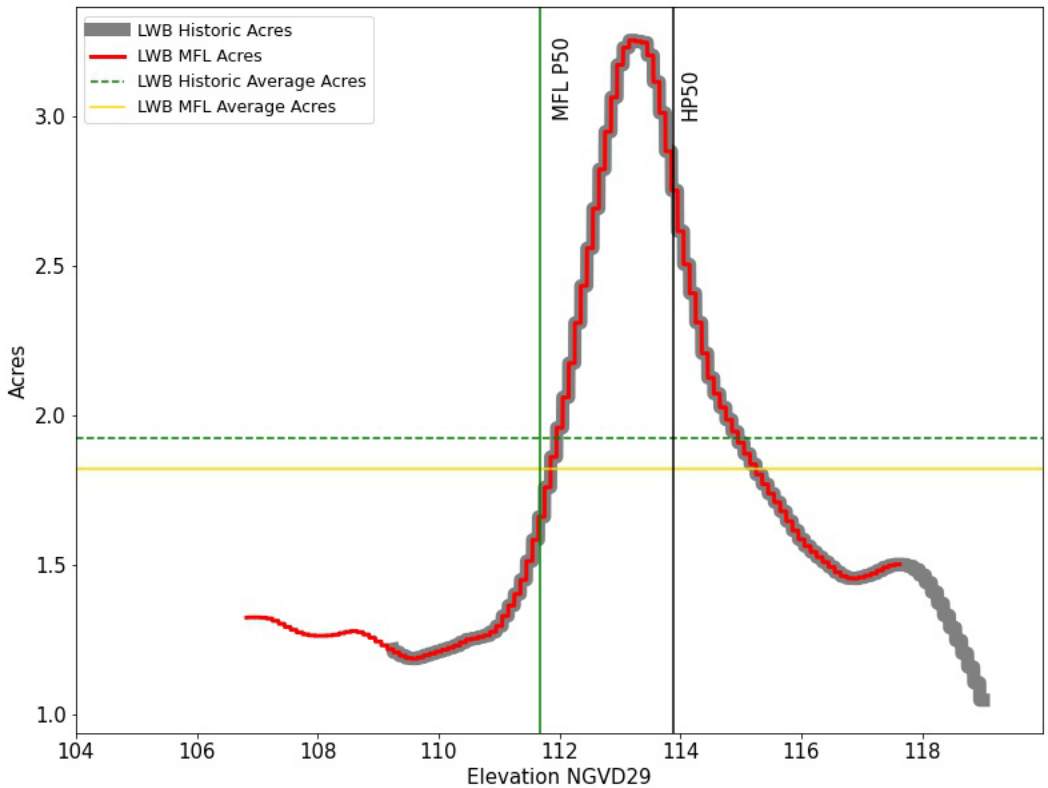

Figure 5-4 Stage/area relationship for large wading bird (LWB) habitat simulated for historic and MFL conditions at Tulane.

Sandhill crane nesting habitat also closely matched the trend of the small wading bird and large wading bird habitat, with increasing habitat under the historic condition to an elevation of 113.5 ft NGVD29, peaking at an area of 1.72 acres (Figure 78). The average area for sandhill crane nesting habitat for the historic condition was 0.95 acres (see Table 5-2). The area for sandhill crane nesting habitat under the MFL Condition generally increased with increasing water levels, with a peak of 1.72 acres at 113.5 feet NGVD29 (Figure 5-5). The minimum area for sandhill crane nesting habitat under MFL Condition was 0.59 acres, and the average was 0.91 acres. Sandhill crane nesting habitat area therefore had a 5% decrease on average between the historic and MFL Condition (see Table 5-2).

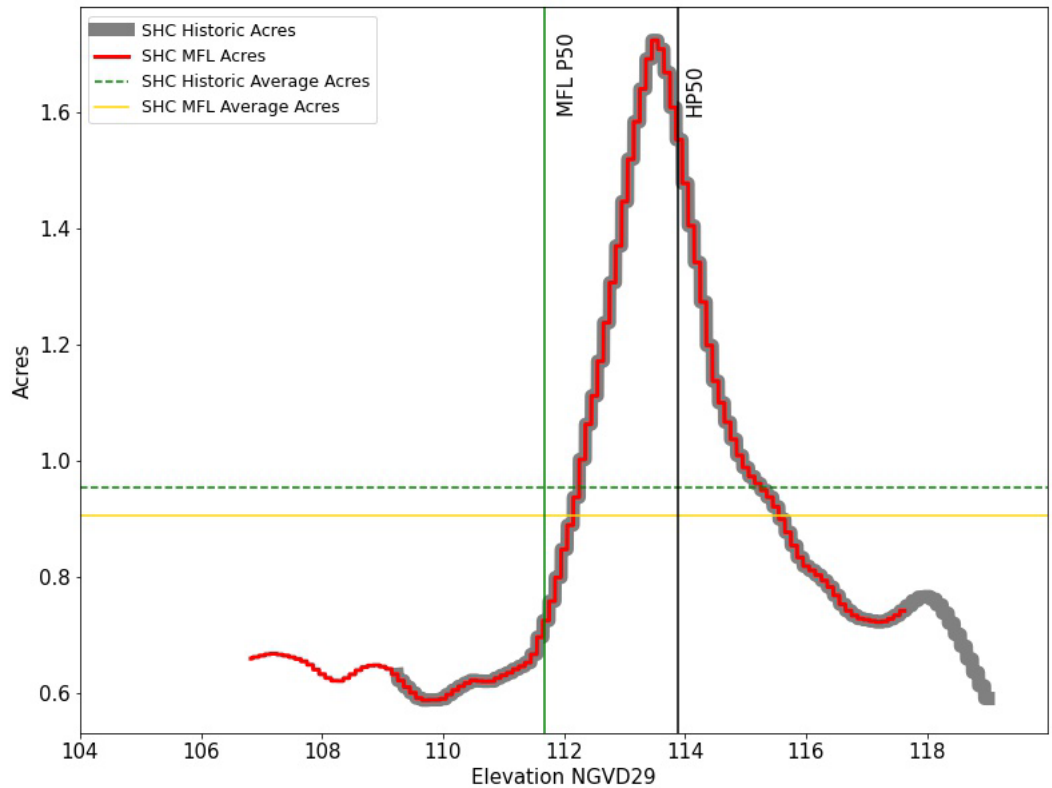

Figure 5-5. Stage/area relationship for sandhill crane (SHC) nesting habitat simulated for historic and MFL conditions at Lake Tulane.

Gamefish spawning habitat area for the historic condition increased with increasing water levels up to a peak in area of 7.89 acres at 115.5 feet NGVD29 and decreased to 3.71 acres at a water level elevation of 111.3 feet, averaging 5.43 acres (Figure 5-6). Habitat area for gamefish spawning for the MFL Condition exhibited the same general pattern as the historic condition results, with a maximum area of 7.89 acres occurring at a water level of 115.5 feet NGVD29, a minimum area of 3.71 acres at a water level of 111.3 feet NGVD29 (Figure 5-6), and an average area of 4.82 acres. Based on the average area result, gamefish spawning habitat simulated for the MFL Condition was 11% less than that associated with the historic condition (see Table 5-2).

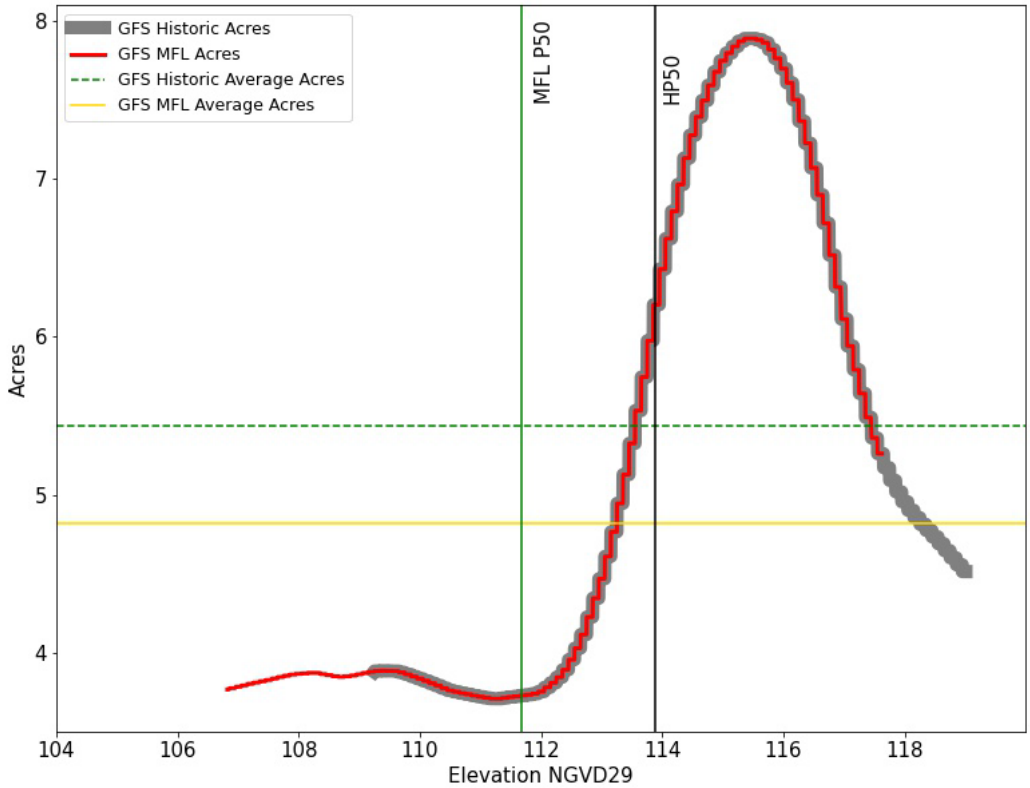

Figure 5-6. Stage/area relationship for gamefish spawning (GFS) habitat simulated for historic and MFL condition at Lake Tulane.

Emergent marsh habitat area under the historic condition increased with increasing water levels up to a maximum of 12.7 acres at an elevation of 117.0 feet NGVD29, decreased at higher water surface elevations, and averaged 10.5 acres (Figure 5-7). The MFL Condition for emergent marsh habitat exhibited a similar pattern, increasing in area with increasing water level, up to a maximum of 12.7 acres at 117.0 feet NGVD29 (Figure 5-7). The average area for emergent marsh habitat under the MFL Condition was 9.26 acres, which was 12% less than the average habitat area associated with the historic condition (see Table 5-2).

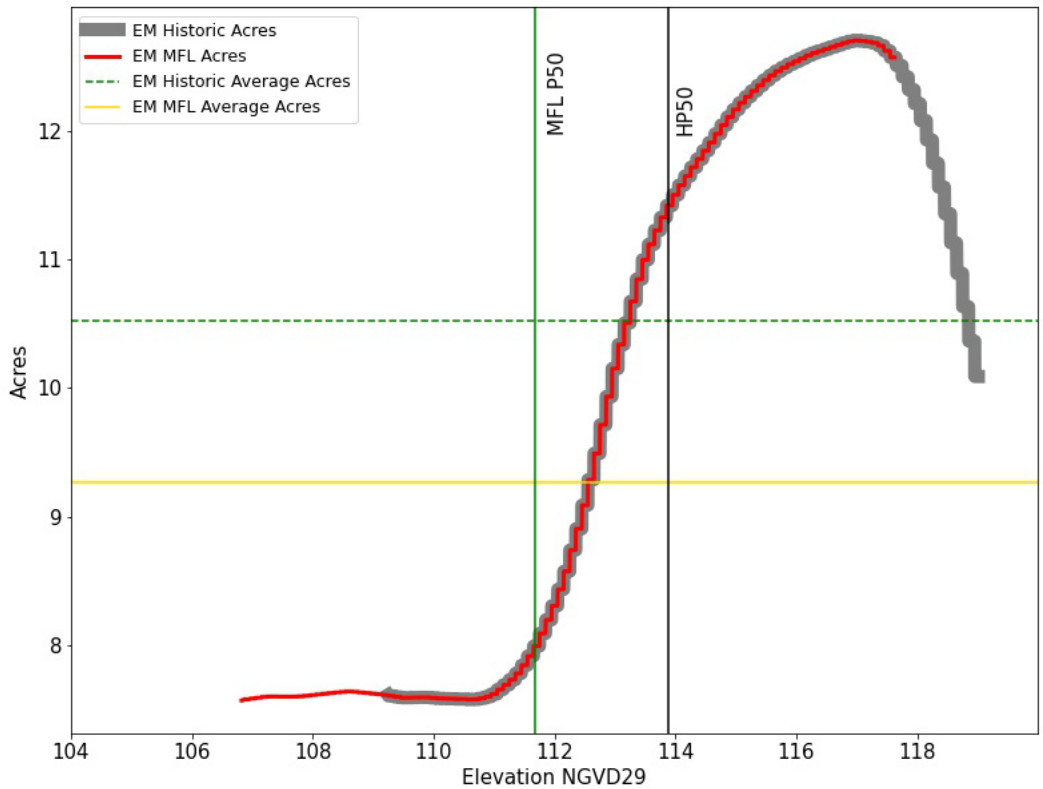

Figure 5-7. Stage/area relationship for emergent marsh (EM) habitat simulated for historic and MFL conditions at Lake Tulane.

The deep-water habitat in Lake Tulane under historic condition and MFL Condition exhibited a near-linear increase in area with increasing water levels, with non-linear variation at the higher end of the hydrologic regime (Figure 5-8). The deep-water habitat area for the historic condition ranged from 70.1 to 86.5 acres and averaged 76.6 acres (Table 5-2). Under the MFL Condition deep water habitat ranged from 67.1 to 82.5 acres (Figure 5-8), and averaged 73.5 acres, a 4% decrease from the historic condition (see Table 5-2).

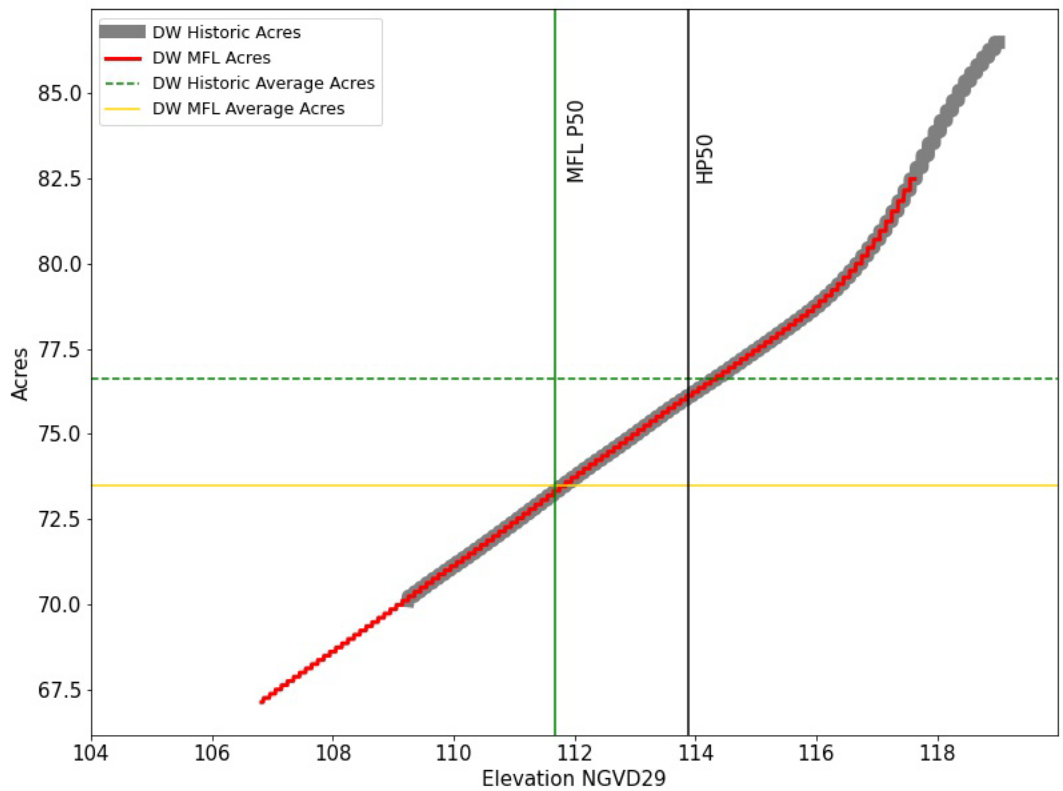

Figure 5-8. Stage/area relationship for deep water (DW) habitat simulated for historic and MFL conditions at Lake Tulane.

None of the assessed habitat zone areas for the MFL Condition differed by more than 12% from their respective areas associated with the historic condition. All differences were, therefore, less than the presumptive 15% change threshold associated with identification of the need for further analysis. The provisional Minimum Lake Level for Lake Tulane was therefore considered protective of the environmental values associated with the aquatic habitat screening criteria, as listed in Table 1-1.

5.6.2 Basin Connectivity Screening

Basin Connectivity Screening is applied to lakes with sub-basins and in some cases at lakes connected to other lakes or waterbodies for the purpose of protecting surface water connections between lake basins or among sub-basins within lake basins. These surface water connections allow for movement of aquatic biota, such as fish, and support recreational uses. Basin connectivity is evaluated by determining high-spot elevations for all areas of connectivity between relevant lake sub-basins and between the lake and other waterbodies. A high-spot elevation is

the lowest elevation at which surface water connection between any two given sub-basins or two waterbodies occurs. A critical fish passage elevation is then determined by adding 0.6 feet to the critical high-spot elevation and this elevation is evaluated to determine if it is inundated at minimum 80% of the time.

Lake Tulane can be characterized as having two sub-basins. A high spot elevation of approximately 52.2 ft NGVD29 occurs in the central portion of the lake between the northern and southern sub-basins (see Figure 2-6). Based on this elevation, a critical fish passage elevation of 52.8 ft NGVD29 was identified. Observed water levels, including the record low of 106.84 ft NGVD29 (see Figure 2-16) and historic and MFL Condition water levels simulated with the Lake Tulane water budget model (see Figure 5-2) indicated this elevation would be exceeded 100% of the time. The provisional Minimum Lake Level was therefore considered sufficiently protective of basin connectivity at the lake.

5.6.3 Dock Use Screening

Dock Use Screening is conducted for lakes with functional, fixed-platform docks. Floating docks which may move up and down in response to water level variation are typically not considered in the screening process, nor are dilapidated docks or those that can be moved up or down the lakeshore in response to changing water levels. The screening process involves determining the mean elevation of sediments at the ends of existing docks, which is referred to as the mean dock sediment elevation (MDSE), and characterizing dock use by relating the MDSE to water-depth percentiles for various scenarios including observed (i.e., measured) period of record (POR) water levels, historic water levels, and water levels associated with achieving proposed minimum lake levels, i.e., an MFL condition scenario. Typically, P10, P50 and P90 water-level percentiles are used for comparison with the MDSE.

Because only two docks currently exist on Lake Tulane (Figure 5-9) a MDSE was not calculated. Dock-use was instead characterized for each dock based on the sediment elevation measured at the end of each respective dock and comparison of these elevations with water-level percentiles.

Figure 5-9. Dock locations on Lake Tulane.

Period of record water level data collected through December 6, 2022 (see Figure 2-16) indicated dock “one” had at least 8.6, 4.6 and 1.5 feet of water at the end of dock ten, fifty and ninety percent of time (Table 5-3). Historic water levels derived with the Lake Tulane water budget model (Figure 5-2) also indicated there would be approximately 9.0 feet of water at the P10 water level, approximately 5.5 feet of water at the P50 water level, and approximately 2.5 feet of water at the P90 water level.

The water level record derived with the water budget model for the MFL Condition indicated water depths at dock one would be 2.3, 2.2 and 2.2 ft less than the depths that occurred 10, 50 and 90 percent of the time under the historic condition (Table 5-3).

Based on the POR data, there was 10.7, 6.7 and 3.6 feet of water at the end of dock “two” at the P10, P50 and P90 water levels, respectively (Table 5-3). The simulated historic condition indicated water depths of approximately 11.1, 7.6, and 4.6 feet of water would be expected at the end of dock at the P10, P50 and P90 water levels. For the simulated MFL Condition, water level record water depths at dock two would be 2.3, 2.2 and 2.2 ft less than the depths that occurred 10, 50 and 90 percent of the time under the historic condition.

Table 5-3. Water depths at the end of two docks on Lake Tulane for Period of record (POR) and Historic and MFL Condition water level records simulated with a water budget model.

Stage Percentiles	Water Depths at End of Dock (ft)		
Dock One	**POR**	**Historic**	**MFL Condition**
P10	8.6	9.0	6.7
P50	4.6	5.5	3.3
P90	1.5	2.5	0.3
Dock Two			
P10	10.7	11.1	8.8
P50	6.7	7.6	5.4
P90	3.6	4.6	2.4

Dock platform height was also measured to characterize the distance between dock platforms and the surface of the water for the assessed scenarios. The POR water level data indicated that dock one would have 7.10 feet between the dock platform and the water at the P10 water level, 11.10 feet from dock to water for the P50 water level, and 14.20 feet from dock to water for the P90 water level (Table 19). Dock one would have approximately 6.70 feet from dock to water at the P10 water level for the historic water level record, approximately 10.20 feet at the P50 water level, and would have approximately 13.20 feet from dock to water at the P90 water level. The MFL condition for Lake Tulane indicates that at the P10 water level, there would be approximately 9.00 feet from dock to water level, approximately 12.40 feet from dock platform to water for the P50 water level, and approximately 15.73 feet from dock to water at the P90 water level.
Dock two POR water level record indicates 8.89 feet from dock to water surface at the P10 water level, 12.89 feet from dock to water surface at the P50 water level, and 15.99 feet from dock to water at the P90 water level (Table 5-4). The historic condition indicates that dock two would have approximately 8.49 feet between the dock platform and water at the P10 water level, approximately 11.99 feet at the P50 water level, and approximately 14.99 feet at the P90 water level. The MFL condition indicates that there is approximately 10.79 feet from dock platform to water at the P10 water level, approximately 14.19 feet from dock to water at the P50 water level, and approximately 17.19 feet from dock to water at the P90 water level.

Table 5-4. Distance from dock platform to water surface for two docks on Lake Tulane for POR, Historic, and MFL water level records.

Distance from dock platform to water (ft.)			
Dock One	**POR**	**Historic**	**MFL**
P10	7.10	6.70	9.00
P50	11.10	10.20	12.40
P90	14.20	13.20	15.73
Dock Two			
P10	8.89	8.49	10.79
P50	12.89	11.99	14.19
P90	15.99	14.99	17.19

Based on the characterization of water depths at the end of the two existing docks on Lake Tulane for the simulated MFL Conditions, as well as consideration of expected distances between the dock platforms and the lake surface, implementation of the provisional Minimum Lake Level is not expected to adversely affect dock-use and associated environmental values.

5.6.4 Aesthetics Screening

Aesthetics screening is completed to address and protect aesthetic values associated with lake basin inundation. The screening is used to help prevent unacceptable changes to lake aesthetic attributes that may be associated with the lowering of lake water levels by withdrawals. The screening is based on a lake-user survey that indicates those in Florida prefer water level conditions between the P80 and P10. The screening presumes that aesthetic values are protected if the Minimum Lake Level equals or exceeds the Historic P80.

The provisional Minimum Lake Level of 111.7 ft NGVD29 for Lake Tulane is equal to the Historic P80 of 111.7 ft NGVD29 developed using the lake water budget model. Since the provisional Minimum Lake Level is not lower than the HP80 elevation, the minimum level was deemed sufficiently protective of aesthetic and scenic attributes.

CHAPTER 6 – PROPOSED MINIMUM LEVELS AND CONSIDERATION OF ENVIRONMENTAL VALUES

6.1 Proposed 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. The Minimum Lake Level is developed using a process that considers applying professional experience and judgement, and the standards and screenings described in Chapter 5. For Lake Tulane a MLL of 111.7 ft NGVD29 was identified at the elevation developed for the Xeric Wetland Offset.

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. 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 a Reference Lake Water Regime statistic. Based on the availability of Historic percentiles, the proposed HMLL for Lake Tulane was set at 115.2 ft NGVD29 by adding the Historic P50 to Historic P10 difference to the proposed MLL.

The current vertical datum used by many federal, state, and local agencies for the contiguous United States is NAVD88. The proposed minimum levels for Lake Tulane were therefore converted from elevations relative to NGVD29 to those relative to NAVD88 (Table 6-1). The datum shift was calculated based on third-order leveling ties from vertical survey control stations with known elevations above NAVD88. The NGVD29 datum conversion to NAVD88 is -0.87 ft. for the District water-level gaging station no. 25507 at Lake Tulane.

Table 6-1. Proposed Minimum Levels for Lake Tulane.

Minimum Levels	Elevation (ft NGVD29)	Elevation (ft NAVD88)
High Minimum Lake Level	115.2	114.3
Minimum Lake Level	111.7	110.8

Proposed minimum levels for Lake Tulane are plotted in Figure 6-1 along with the observed water level record for the lake. The approximate locations of the lake margin when water levels equal the proposed minimum levels are shown in Figure 6-2.

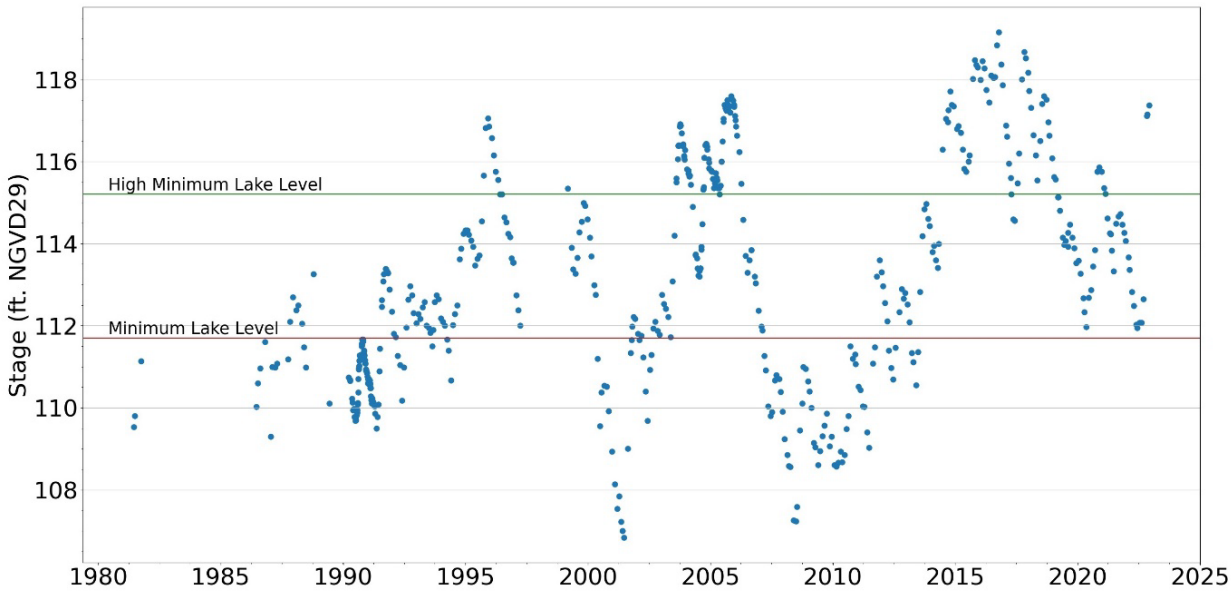

Figure 6-1. Proposed Minimum Lake Level and High Minimum Lake Level for Lake Tulane and water level records for the lake (District Station No. 25507) from 1981 through 2022.

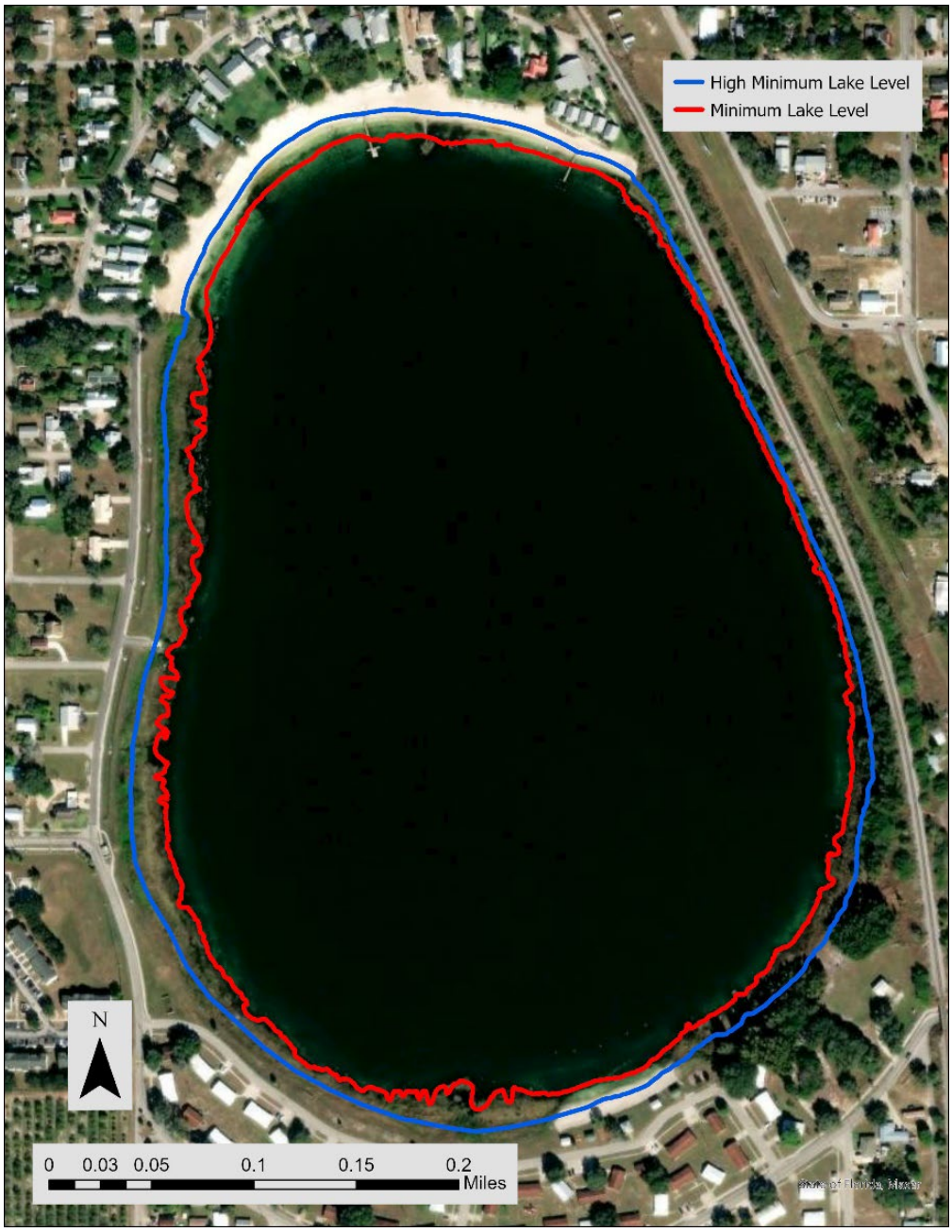

Figure 6-2. Proposed Minimum Lake Level and High Minimum Lake Level for Lake Tulane overlayed on a 2020 aerial photograph.

6.2 Consideration of Environmental Values

The minimum levels for Lake Tulane are protective of all 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 described in Chapter 5, the District evaluated and considered significant change standards and other available information for the lake that could potentially exhibit sensitivity to long-term changes in lake water levels.

The Xeric Wetland Offset was used to develop the proposed minimum levels for Lake Tulane. This standard is associated with protection of several environmental values identified in Rule 62-40.473, F.A.C., including: fish and wildlife habitats and the passage of fish, transfer of detrital material, aesthetic and scenic attributes, filtration and absorption of nutrients and other pollutants, and water quality (summarized in Table 1-1).
Screening methods associated with dock-use, basin connectivity, aesthetics and various aquatic habitat zones were also used to support development of the proposed minimum levels. Collectively, these assessments addressed environmental values associated with recreation in and on the water, fish and wildlife habitats and the passage of fish, transfer of detrital material, aesthetic and scenic attributes, filtration and absorption of nutrients and other pollutants, water quality, and navigation (see Table 1-1).

In addition, the environmental value of maintenance of freshwater storage and supply is also expected to be protected by the proposed 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. Additionally, the cumulative impact analysis that occurs for new water use permits or increased allocations for existing permits must demonstrate that existing legal users and established minimum flows or levels are protected, further linking minimum flows and levels with the protection of freshwater storage and supply. Also, reasonable assurance that construction activities addressed in environmental resource permits will not adversely impact the maintenance of surface or groundwater levels or surface water flows associated with established minimum flows and levels is required.

Two environmental values identified in the Water Resource Implementation Rule were not considered relevant to development of the minimum levels proposed for Lake Tulane. Estuarine resources were not considered relevant because Lake Tulane is a closed-basin lake that 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.

6.3 Comparison of Proposed and Currently Adopted Minimum Levels

The proposed minimum levels identified in this report differ from those currently adopted for Lake Tulane (Table 6-2). The proposed High Minimum Lake Level is 2.7 ft lower than the currently adopted High Minimum Lake Level, and the proposed Minimum Lake Level is 4.9 ft lower than the adopted Minimum Lake Level. These differences are associated with application of a differing modeling approach for characterizing Historic water level fluctuations within the lake, as well as use of additional hydrologic information that has become available since the previous evaluation. The use of updated lake-level methods which differ from those used previously also contributed to differences between the proposed and currently adopted minimum levels. In particular, use of the Xeric Wetland Offset, a recently developed wetland-based criterion that is more appropriate for Lake Tulane than the previously used wetland-based criterion, contributed to differences between the proposed and currently adopted levels.

Table 6-2. Proposed and existing minimum levels for Lake Tulane.

Minimum Levels	Proposed Elevations (ft NGVD29)	Currently Adopted Elevations (ft NGVD29)
High Minimum Lake Level	115.2	117.9
Minimum Lake Level	111.7	116.6

Chapter 7 - MINIMUM LEVELS STATUS ASSESSMENT AND MINIMUM LEVELS RECOMMENDATION

7.1 Status Assessment

To assess the current status and the projected 2040 status of the proposed minimum levels for Lake Tulane, P10 and P50 water elevations were calculated by extending recent measured stage data to long-term (1963 to 2022) lake stage using a method similar to the method described in Section 4.3.

The current status used stage data measured at the lake (Station No. 20557) from 2003 through 2022 (SWFWMD, 2022b). The timeframe was selected based on data availability and regional groundwater use trend (Figures 2-28, 2-31, 2-33, and 2-34). This recent measured stage data was then extended to long-term lake stage based on long-term rainfall, using the LOESS method. The current P10 is 1.2 ft higher than the proposed High Minimum Lake Level and the current P50 is 1.1 ft higher than the proposed Minimum Lake Level (Table 7-1). These results indicate the proposed minimum levels for Lake Tulane are currently being met and development and adoption of a recovery strategy for the lake would not be required in association with adoption of the proposed levels into District rules.

Based on results from ECFTX regional groundwater model (CFWI-HAT, 2020) scenario simulations, UFA drawdown at Lake Tulane is estimated to increase by 0.3 feet between recent representative (2014) and 2040 withdrawal conditions. This equates to approximately a 6% increase in drawdown relative to the water budget model period (see Figure 4-2), and this information was used for a projected 2040 status assessment for the proposed minimum levels for Lake Tulane.

For this 2040 condition assessment, the monthly drawdown time series used in the Lake Tulane water budget model was increased by 6% to adjust groundwater levels projected for 2040 conditions. Lake water levels predicted for the 2040 condition with the water budget model were then extended to long-term lake stage values based on long-term rainfall, using the LOESS method. The P10 and P50 water surface elevations were then calculated from the resulting long-term lake stages for the projected 2040 condition. The P10 simulated for the 2040 conditions scenario was 1.1 ft higher than the proposed High Minimum Lake Level and the P50 for the scenario results was 0.9 ft higher than the proposed Minimum Lake Level (Table 7-1). These results indicate the proposed minimum levels are projected to be met during the coming approximately 20-year planning horizon, and indicate that development and adoption of a specific prevention strategy for Lake Tulane would not be necessary or required in association with adoption of the proposed levels.

As the lake is meeting its minimum levels, no recovery strategy is required at this time. However, the lake lies within the region of the District covered by an existing recovery strategy for the Southern Water Use Caution Area (Rule 40D-80.074, F.A.C.).

Table 7-1. Proposed minimum levels and current and projected P10 and 50 water levels used to assess the status of the proposed minimum levels for Lake Tulane.

Percentile	Minimum Levels (ft NGVD29)*	Current Water Levels (ft NGVD29)	Projected 2040 Water Levels (ft NGVD29)
P10	115.2	116.4	116.3
P50	111.7	112.8	112.6

* The High Minimum Lake Level is the P10 and Minimum Lake Levels is the P50 that must, respectively, be equaled or exceeded on a long-term basis.

7.2 Minimum Levels Recommendation

Based on results of the reevaluation described in this document, removal of the minimum lake levels established for Lake Tulane from the District's Water Levels and Rates of Flow rules (Chapter 40D-8, F.A.C.) and their replacement with a Minimum Lake Level of 111.7 ft NGVD29 and High Minimum Lake Level of 115.2 ft NGVD29 within the rule is recommended.

A status assessment of the recommended minimum levels indicates the levels are being met and are projected to be met during the next 20 years, so there is no need for development and implementation of a water-body specific recovery or prevention strategy. The District will continue to implement its general, three-pronged approach that includes monitoring, annual status assessment of established minimum levels,, 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 Lake Tulane, other lakes and surface water bodies, and relevant groundwater systems to further our understanding of lakes and as necessary, to refine our minimum level methods.

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Appendix A: Lake Tulane Water Depth and Stage-Area-Volume Relationships

Relationships between water surface elevation, i.e., stage, inundated area, and volume can be used to evaluate expected fluctuations in water body size that may occur in response to climate, other natural factors, and anthropogenic impacts such as structural alterations or water withdrawals. Because long term reductions in stage and size can be detrimental to many of the environmental values identified in the Water Resource Implementation Rule for consideration when establishing minimum water levels, stage-area-volume data are useful for minimum level development and assessment.

In support of a reevaluation of the minimum levels for Lake Tulane, a digital elevation model (DEM) of the lake basin and surrounding watershed was developed in 2023. Elevations of the lake bottom and land surface elevations were used to build the model with ESRI® ArcGIS Pro software, the 3D Analyst ArcGIS Pro Extension, and Python. The process involved merging the terrain morphology of the drainage basin in the vicinity of Lake Tulane with the basin morphology to develop a single continuous 3D digital elevation model (DEM). The 3D DEM was subsequently used to iteratively calculate the inundated surface area of Lake Tulane and the associated water volume at different elevations, from the peak or flood stage elevation for the water body, downward to a base elevation associated with the deepest (i.e., lowest) area of the basin.

Two elevation data sets were used to develop the terrain model. Light Detection and Ranging (LiDAR) data ADS40 sensor were merged with bathymetric data for the lake collected with both sonar and mechanical (manual) methods. The LiDAR data was obtained in February 2021 using a DJI Matrice 600 Unmanned Aerial Vehicle (UAV), coupled with a Snoopy V-Series VUX-1UAV LiDAR sensor along with an STIM300 Inertial Measurement Unit (IMU), and Flight control system of the A3 Flight Controller Pro D-RTK GNSS units, and provided to the District by SurvTech, Inc. The bathymetric data were collected in February 2021 using a Norbit iWBMS sonar system with an Applanix AP-20 Wavemaster Inertial Navigation system (INS). Sound velocity was collected using an AML BaseX2 sound velocity caster.

The combined elevation data sets were used to develop a DEM (Figure A-1) that was then used to develop stage-area-volume data by 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 from a peak or flood-stage elevation downward to a base elevation associated with the deepest portion of the lake. The DEM was also used to develop topographic contours of the lake (Figure A-2).

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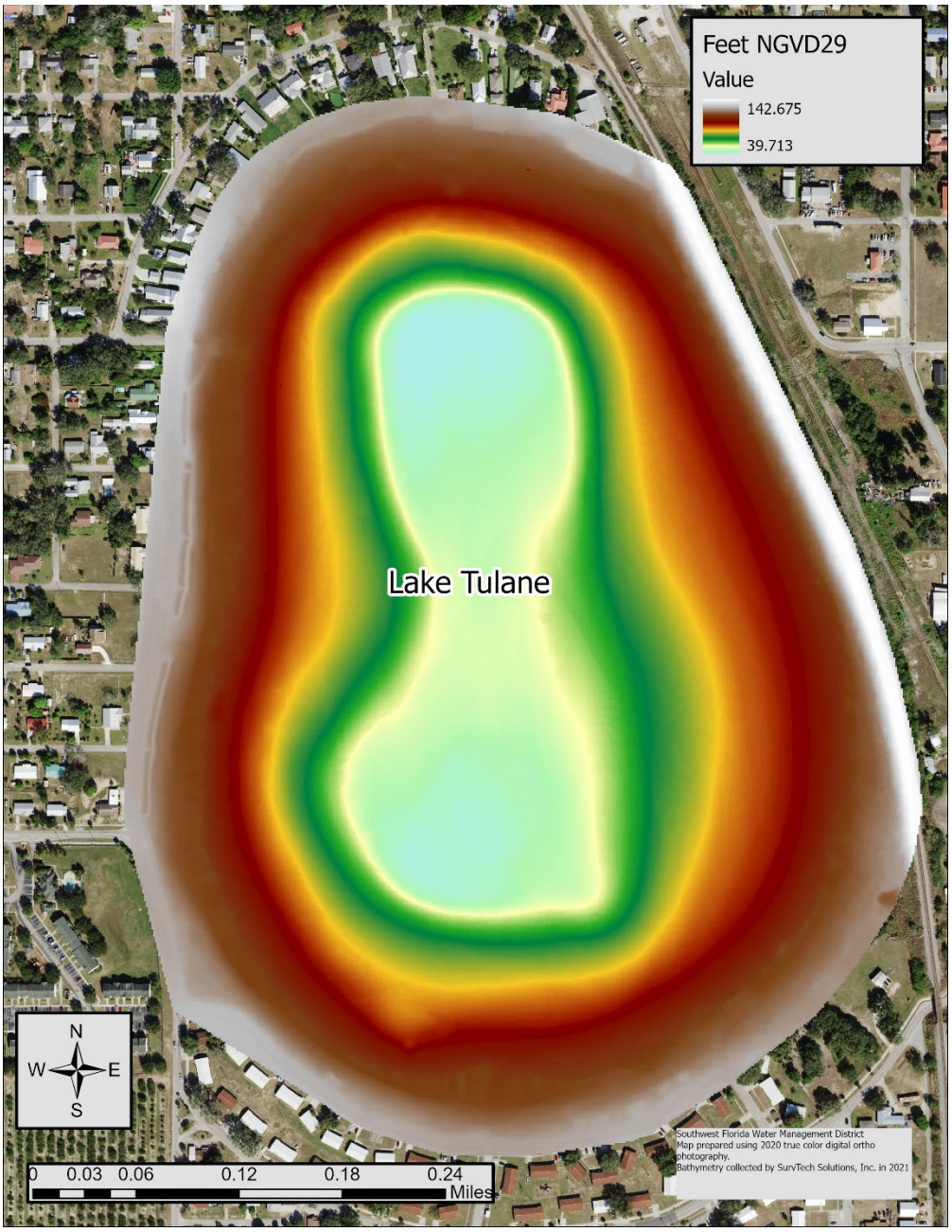

Figure A-1. Digital Elevation Model (DEM) for Lake Tulane.

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Table A-1. Stage-area-volume and water depth information for Lake Tulane. Highlighted rows in the table correspond with the maximum observed water level (119.2 ft), Historic* P10 (117.4 ft), Historic P50 (113.9 ft) and Historic P90 (110.9 ft) elevations (all NGVD29).

Elevation (ft NGVD29)	Elevation (ft NAVD88)	Maximum Depth (feet)	Mean Depth (feet)	Acres	Acres <=4 ft Deep	Acres <=6 ft Deep	Acres >5 ft Deep	Volume (cubic feet)
119.4	118.5	79.6	35.70	94.09	5.03	9.01	87.29	146329803.0
119.3	118.4	79.5	35.60	94.09	5.18	9.30	87.10	145919571.2
119.2	118.3	79.4	35.51	94.07	5.33	9.58	86.90	145509347.6
119.1	118.2	79.3	35.42	94.03	5.46	9.84	86.70	145099355.0
119.0	118.1	79.2	35.35	93.97	5.56	10.09	86.50	144689632.0
118.9	118.0	79.1	35.28	93.90	5.67	10.37	86.28	144280300.3
118.8	117.9	79	35.21	93.81	5.76	10.63	86.06	143871312.3
118.7	117.8	78.9	35.14	93.72	5.85	10.89	85.83	143462691.4
118.6	117.7	78.8	35.08	93.61	5.94	11.13	85.60	143054598.8
118.5	117.6	78.7	35.02	93.51	6.03	11.36	85.36	142647030.3
118.4	117.5	78.6	34.96	93.40	6.11	11.56	85.08	142239858.0
118.3	117.4	78.5	34.90	93.29	6.19	11.75	84.79	141833216.6
118.2	117.3	78.4	34.85	93.17	6.27	11.93	84.49	141427126.6
118.1	117.2	78.3	34.79	93.05	6.35	12.08	84.20	141021587.7
118.0	117.1	78.2	34.74	92.92	6.42	12.21	83.88	140616526.0
117.9	117.0	78.1	34.69	92.79	6.51	12.32	83.53	140212158.3
117.8	116.9	78	34.64	92.65	6.59	12.42	83.18	139808394.9
117.7	116.8	77.9	34.59	92.51	6.67	12.51	82.82	139405126.3
117.6	116.7	77.8	34.55	92.37	6.76	12.57	82.49	139002482.8
117.5	116.6	77.7	34.50	92.22	6.86	12.62	82.15	138600449.8
117.4	116.5	77.6	34.46	92.07	6.98	12.66	81.84	138199033.3
117.3	116.4	77.5	34.42	91.91	7.13	12.69	81.54	137798253.8
117.2	116.3	77.4	34.38	91.76	7.26	12.69	81.24	137398188.3
117.1	116.2	77.3	34.33	91.60	7.41	12.70	80.97	136998840.9
117.0	116.1	77.2	34.29	91.45	7.57	12.70	80.71	136600116.0
116.9	116.0	77.1	34.25	91.30	7.77	12.70	80.47	136202166.7
116.8	115.9	77	34.20	91.15	7.97	12.68	80.23	135804814.3
116.7	115.8	76.9	34.16	91.01	8.18	12.67	80.00	135408052.9
116.6	115.7	76.8	34.11	90.86	8.38	12.65	79.79	135011990.4
116.5	115.6	76.7	34.07	90.72	8.56	12.64	79.60	134616453.4
116.4	115.5	76.6	34.02	90.57	8.74	12.62	79.40	134221538.8
116.3	115.4	76.5	33.97	90.43	8.89	12.61	79.23	133827344.3
116.2	115.3	76.4	33.93	90.28	9.05	12.59	79.06	133433804.4
116.1	115.2	76.3	33.88	90.14	9.17	12.56	78.90	133040935.5
116.0	115.1	76.2	33.84	89.99	9.28	12.54	78.75	132648678.1

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Elevation (ft NGVD29)	Elevation (ft NAVD88)	Maximum Depth (feet)	Mean Depth (feet)	Acres	Acres <=4 ft Deep	Acres <=6 ft Deep	Acres >5 ft Deep	Volume (cubic feet)
115.9	115.0	76.1	33.79	89.85	9.38	12.52	78.60	132257130.0
115.8	114.9	76	33.75	89.70	9.47	12.49	78.47	131866104.9
115.7	114.8	75.9	33.71	89.54	9.54	12.47	78.34	131475711.0
115.6	114.7	75.8	33.67	89.38	9.59	12.43	78.21	131085938.7
115.5	114.6	75.7	33.63	89.22	9.63	12.40	78.08	130696944.1
115.4	114.5	75.6	33.59	89.06	9.66	12.35	77.95	130308624.0
115.3	114.4	75.5	33.55	88.90	9.67	12.31	77.82	129921031.0
115.2	114.3	75.4	33.51	88.74	9.68	12.27	77.70	129534179.6
115.1	114.2	75.3	33.47	88.57	9.67	12.22	77.57	129148013.2
115.0	114.1	75.2	33.44	88.40	9.66	12.17	77.45	128762614.0
114.9	114.0	75.1	33.40	88.23	9.62	12.11	77.33	128377872.3
114.8	113.9	75	33.37	88.05	9.58	12.05	77.20	127993953.5
114.7	113.8	74.9	33.34	87.86	9.52	11.98	77.08	127610848.9
114.6	113.7	74.8	33.31	87.67	9.47	11.91	76.95	127228583.3
114.5	113.6	74.7	33.29	87.48	9.40	11.85	76.83	126847127.1
114.4	113.5	74.6	33.26	87.29	9.34	11.78	76.71	126466482.8
114.3	113.4	74.5	33.23	87.10	9.28	11.72	76.59	126086622.1
114.2	113.3	74.4	33.21	86.90	9.20	11.65	76.47	125707612.7
114.1	113.2	74.3	33.18	86.70	9.13	11.58	76.36	125329503.2
114.0	113.1	74.2	33.16	86.50	9.05	11.50	76.24	124952309.7
113.9	113.0	74.1	33.15	86.28	8.96	11.42	76.12	124576023.6
113.8	112.9	74	33.13	86.06	8.86	11.33	76.00	124200686.9
113.7	112.8	73.9	33.12	85.83	8.76	11.23	75.89	123826246.8
113.6	112.7	73.8	33.11	85.60	8.65	11.12	75.76	123452837.9
113.5	112.6	73.7	33.10	85.36	8.53	11.00	75.64	123080463.2
113.4	112.5	73.6	33.11	85.08	8.37	10.85	75.51	122709255.7
113.3	112.4	73.5	33.12	84.79	8.20	10.67	75.38	122339226.6
113.2	112.3	73.4	33.14	84.49	8.02	10.51	75.25	121970392.0
113.1	112.2	73.3	33.16	84.20	7.84	10.34	75.12	121602917.3
113.0	112.1	73.2	33.18	83.88	7.64	10.15	74.99	121236784.2
112.9	112.0	73.1	33.22	83.53	7.41	9.93	74.86	120872026.5
112.8	111.9	73	33.26	83.18	7.18	9.71	74.73	120508876.1
112.7	111.8	72.9	33.30	82.82	6.94	9.49	74.61	120147256.3
112.6	111.7	72.8	33.34	82.49	6.72	9.29	74.48	119787136.6
112.5	111.6	72.7	33.37	82.15	6.52	9.09	74.36	119428412.7
112.4	111.5	72.6	33.40	81.84	6.33	8.91	74.24	119071118.6
112.3	111.4	72.5	33.42	81.54	6.16	8.74	74.11	118715303.4
112.2	111.3	72.4	33.45	81.24	5.99	8.57	73.99	118360664.3
112.1	111.2	72.3	33.46	80.97	5.84	8.43	73.86	118007383.4

DRAFT

Elevation (ft NGVD29)	Elevation (ft NAVD88)	Maximum Depth (feet)	Mean Depth (feet)	Acres	Acres <=4 ft Deep	Acres <=6 ft Deep	Acres >5 ft Deep	Volume (cubic feet)
112.0	111.1	72.2	33.47	80.71	5.72	8.31	73.73	117655190.4
111.9	111.0	72.1	33.47	80.47	5.60	8.20	73.60	117304196.2
111.8	110.9	72	33.46	80.23	5.50	8.09	73.46	116954142.8
111.7	110.8	71.9	33.46	80.00	5.39	7.99	73.33	116605129.3
111.6	110.7	71.8	33.45	79.79	5.31	7.92	73.20	116256984.5
111.5	110.6	71.7	33.43	79.60	5.24	7.84	73.07	115909850.3
111.4	110.5	71.6	33.41	79.40	5.17	7.78	72.93	115563480.5
111.3	110.4	71.5	33.39	79.23	5.11	7.73	72.80	115218012.0
111.2	110.3	71.4	33.35	79.06	5.08	7.69	72.66	114873334.7
111.1	110.2	71.3	33.32	78.90	5.05	7.66	72.53	114529230.2
111.0	110.1	71.2	33.29	78.75	5.02	7.62	72.40	114185874.8
110.9	110.0	71.1	33.25	78.60	5.01	7.60	72.27	113843243.9
110.8	109.9	71	33.21	78.47	5.00	7.59	72.14	113501181.9
110.7	109.8	70.9	33.16	78.34	5.01	7.58	72.01	113159728.6
110.6	109.7	70.8	33.12	78.21	5.01	7.58	71.88	112818831.6
110.5	109.6	70.7	33.07	78.08	5.02	7.58	71.75	112478422.7
110.4	109.5	70.6	33.02	77.95	5.02	7.58	71.62	112138660.2
110.3	109.4	70.5	32.98	77.82	5.03	7.58	71.50	111799444.4
110.2	109.3	70.4	32.93	77.70	5.03	7.58	71.37	111460732.7
110.1	109.2	70.3	32.89	77.57	5.04	7.59	71.25	111122622.0
110.0	109.1	70.2	32.84	77.45	5.05	7.59	71.13	110784967.0
109.9	109.0	70.1	32.79	77.33	5.06	7.59	71.01	110447849.1
109.8	108.9	70	32.74	77.20	5.06	7.59	70.88	110111351.9
109.7	108.8	69.9	32.70	77.08	5.07	7.59	70.76	109775335.5
109.6	108.7	69.8	32.65	76.95	5.07	7.59	70.63	109439854.6
109.5	108.6	69.7	32.60	76.83	5.08	7.59	70.50	109104952.2
109.4	108.5	69.6	32.55	76.71	5.09	7.60	70.37	108770645.2
109.3	108.4	69.5	32.50	76.59	5.10	7.61	70.24	108436803.8
109.2	108.3	69.4	32.45	76.47	5.10	7.61	70.11	108103443.1
109.1	108.2	69.3	32.40	76.36	5.11	7.62	69.99	107770597.0
109.0	108.1	69.2	32.35	76.24	5.11	7.62	69.86	107438318.5
108.9	108.0	69.1	32.30	76.12	5.12	7.63	69.73	107106478.6
108.8	107.9	69	32.25	76.00	5.12	7.63	69.61	106775282.0
108.7	107.8	68.9	32.20	75.89	5.13	7.64	69.48	106444496.5
108.6	107.7	68.8	32.15	75.76	5.13	7.64	69.36	106114213.1
108.5	107.6	68.7	32.11	75.64	5.14	7.64	69.24	105784484.0
108.4	107.5	68.6	32.06	75.51	5.14	7.63	69.11	105455263.1
108.3	107.4	68.5	32.02	75.38	5.14	7.63	68.99	105126623.8
108.2	107.3	68.4	31.97	75.25	5.14	7.62	68.86	104798543.2

DRAFT

Elevation (ft NGVD29)	Elevation (ft NAVD88)	Maximum Depth (feet)	Mean Depth (feet)	Acres	Acres <=4 ft Deep	Acres <=6 ft Deep	Acres >5 ft Deep	Volume (cubic feet)
108.1	107.2	68.3	31.93	75.12	5.14	7.62	68.74	104471046.0
108.0	107.1	68.2	31.88	74.99	5.13	7.61	68.62	104144127.2
107.9	107.0	68.1	31.84	74.86	5.13	7.61	68.49	103817804.0
107.8	106.9	68	31.79	74.73	5.13	7.60	68.37	103491989.5
107.7	106.8	67.9	31.74	74.61	5.12	7.60	68.25	103166719.3
107.6	106.7	67.8	31.70	74.48	5.12	7.60	68.12	102841971.4
107.5	106.6	67.7	31.65	74.36	5.12	7.60	68.00	102517701.3
107.4	106.5	67.6	31.60	74.24	5.13	7.60	67.88	102194059.4
107.3	106.4	67.5	31.55	74.11	5.13	7.60	67.75	101871030.5
107.2	106.3	67.4	31.51	73.99	5.13	7.60	67.63	101548499.4
107.1	106.2	67.3	31.46	73.86	5.12	7.59	67.51	101226532.4
107.0	106.1	67.2	31.42	73.73	5.11	7.59	67.38	100905117.5
106.9	106.0	67.1	31.38	73.60	5.10	7.58	67.26	100584266.3
106.8	105.9	67	31.33	73.46	5.09	7.57	67.13	100263950.9
106.7	105.8	66.9	31.29	73.33	5.08	7.56	67.01	99944181.7
106.6	105.7	66.8	31.24	73.20	5.07	7.55	66.88	99625060.0
106.5	105.6	66.7	31.20	73.07	5.06	7.54	66.76	99306529.2
106.4	105.5	66.6	31.16	72.93	5.05	7.53	66.64	98988552.5
106.3	105.4	66.5	31.12	72.80	5.04	7.52	66.51	98671170.7
106.2	105.3	66.4	31.07	72.66	5.03	7.51	66.39	98354311.8
106.1	105.2	66.3	31.03	72.53	5.03	7.50	66.27	98038026.2
106.0	105.1	66.2	30.99	72.40	5.02	7.50	66.14	97722335.3
105.9	105.0	66.1	30.94	72.27	5.01	7.49	66.02	97407317.1
105.8	104.9	66	30.90	72.14	5.01	7.48	65.89	97092807.3
105.7	104.8	65.9	30.85	72.01	5.00	7.48	65.77	96778844.6
105.6	104.7	65.8	30.81	71.88	4.99	7.47	65.65	96465458.1
105.5	104.6	65.7	30.76	71.75	4.99	7.47	65.52	96152631.0
105.4	104.5	65.6	30.72	71.62	4.99	7.47	65.40	95840296.1
105.3	104.4	65.5	30.67	71.50	4.98	7.47	65.28	95528630.4
105.2	104.3	65.4	30.63	71.37	4.98	7.47	65.15	95217387.7
105.1	104.2	65.3	30.58	71.25	4.98	7.48	65.03	94906760.3
105.0	104.1	65.2	30.53	71.13	4.99	7.48	64.90	94596634.0
104.9	104.0	65.1	30.48	71.01	4.99	7.49	64.78	94287107.0
104.8	103.9	65	30.44	70.88	4.99	7.49	64.66	93978053.2
104.7	103.8	64.9	30.39	70.76	4.99	7.50	64.53	93669594.2
104.6	103.7	64.8	30.34	70.63	4.98	7.50	64.41	93361676.9
104.5	103.6	64.7	30.30	70.50	4.98	7.50	64.28	93054318.6
104.4	103.5	64.6	30.26	70.37	4.97	7.50	64.15	92747493.5
104.3	103.4	64.5	30.21	70.24	4.96	7.50	64.03	92441262.2

DRAFT

Elevation (ft NGVD29)	Elevation (ft NAVD88)	Maximum Depth (feet)	Mean Depth (feet)	Acres	Acres <=4 ft Deep	Acres <=6 ft Deep	Acres >5 ft Deep	Volume (cubic feet)
104.2	103.3	64.4	30.17	70.11	4.96	7.50	63.90	92135506.8
104.1	103.2	64.3	30.12	69.99	4.96	7.51	63.77	91830378.6
104.0	103.1	64.2	30.08	69.86	4.96	7.51	63.65	91525731.4
103.9	103.0	64.1	30.03	69.73	4.95	7.52	63.52	91221726.8
103.8	102.9	64	29.98	69.61	4.95	7.52	63.39	90918278.3
103.7	102.8	63.9	29.94	69.48	4.95	7.53	63.26	90615345.7
103.6	102.7	63.8	29.89	69.36	4.95	7.54	63.13	90312979.6
103.5	102.6	63.7	29.85	69.24	4.96	7.55	63.00	90011159.1
103.4	102.5	63.6	29.80	69.11	4.96	7.56	62.87	89709828.1
103.3	102.4	63.5	29.75	68.99	4.96	7.57	62.74	89409015.2
103.2	102.3	63.4	29.71	68.86	4.96	7.58	62.61	89108626.7
103.1	102.2	63.3	29.66	68.74	4.96	7.59	62.48	88808934.6
103.0	102.1	63.2	29.61	68.62	4.97	7.60	62.35	88509856.8
102.9	102.0	63.1	29.57	68.49	4.98	7.61	62.22	88211238.1
102.8	101.9	63	29.52	68.37	4.98	7.62	62.08	87913262.8
102.7	101.8	62.9	29.47	68.25	4.99	7.64	61.95	87615788.9
102.6	101.7	62.8	29.42	68.12	4.99	7.65	61.82	87318683.0
102.5	101.6	62.7	29.38	68.00	5.00	7.66	61.69	87022182.8
102.4	101.5	62.6	29.33	67.88	5.00	7.68	61.55	86726203.9
102.3	101.4	62.5	29.28	67.75	5.01	7.70	61.42	86430741.0
102.2	101.3	62.4	29.24	67.63	5.02	7.71	61.28	86135945.7
102.1	101.2	62.3	29.19	67.51	5.02	7.73	61.15	85841612.0
102.0	101.1	62.2	29.15	67.38	5.03	7.74	61.02	85547917.8
101.9	101.0	62.1	29.10	67.26	5.04	7.76	60.88	85254731.8
101.8	100.9	62	29.05	67.13	5.05	7.77	60.75	84962009.2
101.7	100.8	61.9	29.01	67.01	5.06	7.78	60.61	84669823.5
101.6	100.7	61.8	28.96	66.88	5.07	7.80	60.48	84378180.7
101.5	100.6	61.7	28.91	66.76	5.08	7.81	60.34	84087088.7
101.4	100.5	61.6	28.87	66.64	5.08	7.82	60.20	83796533.2
101.3	100.4	61.5	28.82	66.51	5.10	7.83	60.06	83506544.5
101.2	100.3	61.4	28.78	66.39	5.11	7.84	59.92	83217145.2
101.1	100.2	61.3	28.73	66.27	5.12	7.85	59.78	82928242.8
101.0	100.1	61.2	28.68	66.14	5.13	7.86	59.64	82639830.9
100.9	100.0	61.1	28.64	66.02	5.14	7.87	59.50	82351974.0
100.8	99.9	61	28.59	65.89	5.15	7.89	59.36	82064622.8
100.7	99.8	60.9	28.54	65.77	5.16	7.90	59.22	81777874.0
100.6	99.7	60.8	28.50	65.65	5.17	7.91	59.09	81491673.6
100.5	99.6	60.7	28.45	65.52	5.19	7.92	58.95	81205993.9
100.4	99.5	60.6	28.40	65.40	5.20	7.94	58.82	80920873.5

DRAFT

Elevation (ft NGVD29)	Elevation (ft NAVD88)	Maximum Depth (feet)	Mean Depth (feet)	Acres	Acres <=4 ft Deep	Acres <=6 ft Deep	Acres >5 ft Deep	Volume (cubic feet)
100.3	99.4	60.5	28.36	65.28	5.22	7.95	58.68	80636258.2
100.2	99.3	60.4	28.31	65.15	5.23	7.96	58.55	80352177.1
100.1	99.2	60.3	28.27	65.03	5.25	7.98	58.41	80068575.6
100.0	99.1	60.2	28.22	64.90	5.27	7.99	58.28	79785609.6
99.9	99.0	60.1	28.17	64.78	5.28	8.01	58.14	79503162.2
99.8	98.9	60	28.13	64.66	5.30	8.02	58.01	79221285.5
99.7	98.8	59.9	28.08	64.53	5.31	8.04	57.87	78939949.5
99.6	98.7	59.8	28.04	64.41	5.32	8.06	57.74	78659133.1
99.5	98.6	59.7	27.99	64.28	5.33	8.07	57.60	78378782.0
99.4	98.5	59.6	27.95	64.15	5.34	8.08	57.47	78099017.1
99.3	98.4	59.5	27.90	64.03	5.34	8.10	57.33	77819859.4
99.2	98.3	59.4	27.86	63.90	5.35	8.11	57.19	77541273.2
99.1	98.2	59.3	27.81	63.77	5.36	8.12	57.05	77263228.5
99.0	98.1	59.2	27.77	63.65	5.37	8.13	56.91	76985719.5
98.9	98.0	59.1	27.72	63.52	5.37	8.14	56.77	76708744.3
98.8	97.9	59	27.68	63.39	5.38	8.15	56.63	76432332.1
98.7	97.8	58.9	27.64	63.26	5.39	8.17	56.49	76156456.4
98.6	97.7	58.8	27.59	63.13	5.39	8.18	56.35	75881208.0
98.5	97.6	58.7	27.55	63.00	5.40	8.20	56.21	75606507.0
98.4	97.5	58.6	27.51	62.87	5.41	8.21	56.07	75332331.3
98.3	97.4	58.5	27.46	62.74	5.42	8.23	55.93	75058755.0
98.2	97.3	58.4	27.42	62.61	5.42	8.24	55.79	74785750.5
98.1	97.2	58.3	27.38	62.48	5.43	8.25	55.65	74513334.2
98.0	97.1	58.2	27.34	62.35	5.44	8.26	55.51	74241422.2
97.9	97.0	58.1	27.29	62.22	5.44	8.27	55.37	73970075.4
97.8	96.9	58	27.25	62.08	5.45	8.28	55.23	73699312.5
97.7	96.8	57.9	27.21	61.95	5.46	8.29	55.09	73429146.6
97.6	96.7	57.8	27.17	61.82	5.47	8.30	54.95	73159657.9
97.5	96.6	57.7	27.13	61.69	5.48	8.31	54.80	72890706.7
97.4	96.5	57.6	27.09	61.55	5.48	8.33	54.66	72622288.5
97.3	96.4	57.5	27.04	61.42	5.49	8.34	54.52	72354457.4
97.2	96.3	57.4	27.00	61.28	5.49	8.35	54.38	72087121.2
97.1	96.2	57.3	26.96	61.15	5.50	8.37	54.23	71820413.2
97.0	96.1	57.2	26.92	61.02	5.50	8.38	54.09	71554394.4
96.9	96.0	57.1	26.88	60.88	5.51	8.40	53.95	71288932.4
96.8	95.9	57	26.84	60.75	5.51	8.42	53.81	71024108.7
96.7	95.8	56.9	26.80	60.61	5.52	8.44	53.66	70759780.2
96.6	95.7	56.8	26.76	60.48	5.53	8.45	53.52	70496025.1
96.5	95.6	56.7	26.72	60.34	5.54	8.47	53.37	70232821.3

DRAFT

Elevation (ft NGVD29)	Elevation (ft NAVD88)	Maximum Depth (feet)	Mean Depth (feet)	Acres	Acres <=4 ft Deep	Acres <=6 ft Deep	Acres >5 ft Deep	Volume (cubic feet)
96.4	95.5	56.6	26.68	60.20	5.54	8.48	53.23	69970306.7
96.3	95.4	56.5	26.65	60.06	5.54	8.50	53.08	69708420.9
96.2	95.3	56.4	26.61	59.92	5.54	8.52	52.93	69447139.2
96.1	95.2	56.3	26.57	59.78	5.54	8.53	52.78	69186412.1
96.0	95.1	56.2	26.53	59.64	5.55	8.54	52.63	68926286.5
95.9	95.0	56.1	26.49	59.50	5.55	8.56	52.48	68666821.5
95.8	94.9	56	26.46	59.36	5.55	8.56	52.33	68407960.8
95.7	94.8	55.9	26.42	59.22	5.56	8.56	52.18	68149723.1
95.6	94.7	55.8	26.38	59.09	5.57	8.57	52.02	67892081.0
95.5	94.6	55.7	26.34	58.95	5.58	8.57	51.87	67634925.1
95.4	94.5	55.6	26.30	58.82	5.59	8.57	51.72	67378403.1
95.3	94.4	55.5	26.26	58.68	5.61	8.58	51.56	67122415.0
95.2	94.3	55.4	26.22	58.55	5.62	8.58	51.40	66867156.4
95.1	94.2	55.3	26.18	58.41	5.63	8.58	51.25	66612457.4
95.0	94.1	55.2	26.14	58.28	5.65	8.59	51.09	66358344.7
94.9	94.0	55.1	26.10	58.14	5.66	8.59	50.94	66104731.7
94.8	93.9	55	26.06	58.01	5.68	8.59	50.80	65851716.9
94.7	93.8	54.9	26.02	57.87	5.70	8.59	50.66	65599274.9
94.6	93.7	54.8	25.98	57.74	5.71	8.59	50.52	65347509.2
94.5	93.6	54.7	25.94	57.60	5.73	8.60	50.38	65096352.9
94.4	93.5	54.6	25.91	57.47	5.75	8.60	50.25	64845712.9
94.3	93.4	54.5	25.87	57.33	5.77	8.60	50.11	64595693.7
94.2	93.3	54.4	25.83	57.19	5.79	8.60	49.97	64346288.2
94.1	93.2	54.3	25.79	57.05	5.80	8.61	49.83	64097527.9
94.0	93.1	54.2	25.75	56.91	5.82	8.61	49.69	63849295.4
93.9	93.0	54.1	25.72	56.77	5.83	8.61	49.56	63601666.6
93.8	92.9	54	25.68	56.63	5.83	8.60	49.42	63354615.0
93.7	92.8	53.9	25.65	56.49	5.83	8.60	49.28	63108234.5
93.6	92.7	53.8	25.61	56.35	5.83	8.59	49.14	62862521.5
93.5	92.6	53.7	25.57	56.21	5.82	8.58	49.00	62617341.7
93.4	92.5	53.6	25.54	56.07	5.82	8.58	48.87	62372807.3
93.3	92.4	53.5	25.50	55.93	5.82	8.58	48.73	62128888.2
93.2	92.3	53.4	25.46	55.79	5.82	8.57	48.58	61885584.5
93.1	92.2	53.3	25.43	55.65	5.82	8.57	48.45	61642814.6
93.0	92.1	53.2	25.39	55.51	5.82	8.57	48.31	61400672.1
92.9	92.0	53.1	25.36	55.37	5.82	8.56	48.17	61159135.2
92.8	91.9	53	25.32	55.23	5.81	8.55	48.03	60918259.1
92.7	91.8	52.9	25.29	55.09	5.81	8.55	47.90	60677951.9
92.6	91.7	52.8	25.25	54.95	5.80	8.54	47.76	60438377.1

DRAFT

Elevation (ft NGVD29)	Elevation (ft NAVD88)	Maximum Depth (feet)	Mean Depth (feet)	Acres	Acres <=4 ft Deep	Acres <=6 ft Deep	Acres >5 ft Deep	Volume (cubic feet)
92.5	91.6	52.7	25.22	54.80	5.80	8.53	47.63	60199329.4
92.4	91.5	52.6	25.18	54.66	5.79	8.51	47.49	59960860.2
92.3	91.4	52.5	25.15	54.52	5.79	8.51	47.36	59723102.8
92.2	91.3	52.4	25.11	54.38	5.79	8.50	47.22	59485931.5
92.1	91.2	52.3	25.08	54.23	5.79	8.50	47.08	59249413.3
92.0	91.1	52.2	25.05	54.09	5.79	8.49	46.95	59013419.1
91.9	91.0	52.1	25.01	53.95	5.78	8.48	46.81	58778162.1
91.8	90.9	52	24.98	53.81	5.77	8.48	46.68	58543434.8
91.7	90.8	51.9	24.94	53.66	5.77	8.47	46.55	58309404.8
91.6	90.7	51.8	24.91	53.52	5.76	8.45	46.41	58075998.2
91.5	90.6	51.7	24.88	53.37	5.75	8.43	46.28	57843211.3
91.4	90.5	51.6	24.85	53.23	5.73	8.42	46.14	57611017.0
91.3	90.4	51.5	24.82	53.08	5.72	8.40	46.01	57379461.3
91.2	90.3	51.4	24.79	52.93	5.71	8.37	45.87	57148534.9
91.1	90.2	51.3	24.76	52.78	5.70	8.35	45.74	56918305.4
91.0	90.1	51.2	24.73	52.63	5.69	8.33	45.60	56688783.7
90.9	90.0	51.1	24.70	52.48	5.67	8.30	45.47	56459847.2
90.8	89.9	51	24.67	52.33	5.65	8.28	45.33	56231585.2
90.7	89.8	50.9	24.64	52.18	5.63	8.25	45.20	56003977.6
90.6	89.7	50.8	24.61	52.02	5.61	8.22	45.07	55777025.7
90.5	89.6	50.7	24.59	51.87	5.59	8.19	44.94	55550674.4
90.4	89.5	50.6	24.56	51.72	5.57	8.15	44.81	55325069.8
90.3	89.4	50.5	24.53	51.56	5.55	8.11	44.68	55100118.9
90.2	89.3	50.4	24.51	51.40	5.53	8.07	44.56	54875879.0
90.1	89.2	50.3	24.48	51.25	5.51	8.04	44.43	54652397.9
90.0	89.1	50.2	24.46	51.09	5.49	8.00	44.30	54429447.1
89.9	89.0	50.1	24.43	50.94	5.48	7.96	44.18	54207201.6
89.8	88.9	50	24.40	50.80	5.47	7.94	44.05	53985613.7
89.7	88.8	49.9	24.36	50.66	5.46	7.91	43.93	53764592.1
89.6	88.7	49.8	24.33	50.52	5.46	7.89	43.81	53544183.1
89.5	88.6	49.7	24.30	50.38	5.45	7.86	43.68	53324388.0
89.4	88.5	49.6	24.26	50.25	5.44	7.84	43.57	53105287.9
89.3	88.4	49.5	24.23	50.11	5.42	7.82	43.45	52886764.9
89.2	88.3	49.4	24.20	49.97	5.41	7.79	43.33	52668831.3
89.1	88.2	49.3	24.16	49.83	5.40	7.76	43.21	52451452.4
89.0	88.1	49.2	24.13	49.69	5.39	7.74	43.09	52234625.2
88.9	88.0	49.1	24.10	49.56	5.38	7.71	42.98	52018371.7
88.8	87.9	49	24.06	49.42	5.37	7.68	42.86	51802850.6
88.7	87.8	48.9	24.03	49.28	5.35	7.66	42.75	51587922.0

DRAFT

Elevation (ft NGVD29)	Elevation (ft NAVD88)	Maximum Depth (feet)	Mean Depth (feet)	Acres	Acres <=4 ft Deep	Acres <=6 ft Deep	Acres >5 ft Deep	Volume (cubic feet)
88.6	87.7	48.8	24.00	49.14	5.34	7.63	42.63	51373588.9
88.5	87.6	48.7	23.97	49.00	5.32	7.60	42.52	51159836.7
88.4	87.5	48.6	23.93	48.87	5.30	7.57	42.41	50946652.5
88.3	87.4	48.5	23.90	48.73	5.28	7.54	42.29	50734152.9
88.2	87.3	48.4	23.87	48.58	5.26	7.51	42.18	50522148.3
88.1	87.2	48.3	23.84	48.45	5.23	7.47	42.07	50310795.3
88.0	87.1	48.2	23.81	48.31	5.21	7.44	41.96	50100006.4
87.9	87.0	48.1	23.78	48.17	5.19	7.41	41.85	49889941.9
87.8	86.9	48	23.74	48.03	5.17	7.38	41.74	49680489.7
87.7	86.8	47.9	23.71	47.90	5.15	7.35	41.63	49471613.1
87.6	86.7	47.8	23.68	47.76	5.13	7.31	41.52	49263220.6
87.5	86.6	47.7	23.65	47.63	5.11	7.28	41.41	49055439.4
87.4	86.5	47.6	23.61	47.49	5.09	7.25	41.30	48848230.0
87.3	86.4	47.5	23.58	47.36	5.06	7.22	41.19	48641678.6
87.2	86.3	47.4	23.55	47.22	5.04	7.18	41.08	48435699.4
87.1	86.2	47.3	23.52	47.08	5.01	7.15	40.97	48230347.6
87.0	86.1	47.2	23.48	46.95	4.99	7.12	40.86	48025623.3
86.9	86.0	47.1	23.45	46.81	4.97	7.09	40.76	47821375.2
86.8	85.9	47	23.42	46.68	4.94	7.05	40.65	47617689.8
86.7	85.8	46.9	23.39	46.55	4.92	7.02	40.55	47414640.2
86.6	85.7	46.8	23.35	46.41	4.90	6.99	40.45	47212240.4
86.5	85.6	46.7	23.32	46.28	4.87	6.96	40.34	47010384.5
86.4	85.5	46.6	23.29	46.14	4.85	6.93	40.24	46809091.6
86.3	85.4	46.5	23.26	46.01	4.82	6.89	40.14	46608377.2
86.2	85.3	46.4	23.22	45.87	4.80	6.86	40.03	46408237.1
86.1	85.2	46.3	23.19	45.74	4.77	6.82	39.93	46208699.8
86.0	85.1	46.2	23.16	45.60	4.74	6.79	39.83	46009767.4
85.9	85.0	46.1	23.13	45.47	4.71	6.75	39.73	45811434.9
85.8	84.9	46	23.10	45.33	4.68	6.72	39.62	45613667.3
85.7	84.8	45.9	23.07	45.20	4.65	6.69	39.52	45416539.7
85.6	84.7	45.8	23.04	45.07	4.62	6.66	39.42	45219900.8
85.5	84.6	45.7	23.00	44.94	4.60	6.63	39.32	45023892.5
85.4	84.5	45.6	22.97	44.81	4.57	6.60	39.22	44828424.5
85.3	84.4	45.5	22.93	44.68	4.55	6.57	39.12	44633492.9
85.2	84.3	45.4	22.90	44.56	4.52	6.55	39.01	44439101.1
85.1	84.2	45.3	22.86	44.43	4.50	6.52	38.91	44245324.0
85.0	84.1	45.2	22.83	44.30	4.47	6.49	38.81	44052054.9
84.9	84.0	45.1	22.79	44.18	4.45	6.46	38.71	43859355.9
84.8	83.9	45	22.76	44.05	4.43	6.44	38.61	43667198.8

DRAFT

Elevation (ft NGVD29)	Elevation (ft NAVD88)	Maximum Depth (feet)	Mean Depth (feet)	Acres	Acres <=4 ft Deep	Acres <=6 ft Deep	Acres >5 ft Deep	Volume (cubic feet)
84.7	83.8	44.9	22.72	43.93	4.40	6.41	38.51	43475561.0
84.6	83.7	44.8	22.68	43.81	4.38	6.38	38.41	43284424.2
84.5	83.6	44.7	22.65	43.68	4.37	6.36	38.31	43093859.5
84.4	83.5	44.6	22.61	43.57	4.35	6.34	38.21	42903852.1
84.3	83.4	44.5	22.57	43.45	4.33	6.31	38.11	42714368.2
84.2	83.3	44.4	22.53	43.33	4.31	6.29	38.01	42525373.7
84.1	83.2	44.3	22.49	43.21	4.30	6.27	37.91	42336863.3
84.0	83.1	44.2	22.45	43.09	4.28	6.25	37.81	42148881.4
83.9	83.0	44.1	22.41	42.98	4.27	6.24	37.71	41961433.2
83.8	82.9	44	22.37	42.86	4.25	6.22	37.62	41774437.1
83.7	82.8	43.9	22.33	42.75	4.24	6.20	37.52	41588006.6
83.6	82.7	43.8	22.29	42.63	4.22	6.18	37.42	41402022.4
83.5	82.6	43.7	22.25	42.52	4.21	6.17	37.32	41216592.9
83.4	82.5	43.6	22.21	42.41	4.19	6.15	37.23	41031584.1
83.3	82.4	43.5	22.17	42.29	4.18	6.14	37.13	40847133.1
83.2	82.3	43.4	22.13	42.18	4.17	6.12	37.03	40663176.5
83.1	82.2	43.3	22.09	42.07	4.16	6.11	36.94	40479644.9
83.0	82.1	43.2	22.05	41.96	4.15	6.10	36.84	40296582.4
82.9	82.0	43.1	22.01	41.85	4.13	6.09	36.74	40114080.5
82.8	81.9	43	21.96	41.74	4.12	6.08	36.64	39932070.1
82.7	81.8	42.9	21.92	41.63	4.11	6.06	36.55	39750499.6
82.6	81.7	42.8	21.88	41.52	4.09	6.05	36.45	39569474.5
82.5	81.6	42.7	21.84	41.41	4.08	6.04	36.35	39388823.7
82.4	81.5	42.6	21.80	41.30	4.07	6.03	36.25	39208643.5
82.3	81.4	42.5	21.75	41.19	4.05	6.03	36.15	39029010.1
82.2	81.3	42.4	21.71	41.08	4.04	6.02	36.06	38849886.7
82.1	81.2	42.3	21.67	40.97	4.03	6.01	35.96	38671230.4
82.0	81.1	42.2	21.62	40.86	4.02	6.00	35.86	38492925.7
81.9	81.0	42.1	21.58	40.76	4.02	6.00	35.76	38315116.9
81.8	80.9	42	21.54	40.65	4.01	5.99	35.66	38137783.0
81.7	80.8	41.9	21.49	40.55	4.00	5.99	35.56	37960933.3
81.6	80.7	41.8	21.45	40.45	4.00	5.98	35.46	37784534.3
81.5	80.6	41.7	21.40	40.34	3.99	5.98	35.36	37608603.8
81.4	80.5	41.6	21.36	40.24	3.99	5.97	35.26	37433104.6
81.3	80.4	41.5	21.31	40.14	3.98	5.97	35.16	37258074.8
81.2	80.3	41.4	21.26	40.03	3.98	5.96	35.06	37083461.5
81.1	80.2	41.3	21.22	39.93	3.97	5.96	34.96	36909240.6
81.0	80.1	41.2	21.17	39.83	3.97	5.96	34.86	36735545.3
80.9	80.0	41.1	21.13	39.73	3.97	5.95	34.76	36562244.1

DRAFT

Elevation (ft NGVD29)	Elevation (ft NAVD88)	Maximum Depth (feet)	Mean Depth (feet)	Acres	Acres <=4 ft Deep	Acres <=6 ft Deep	Acres >5 ft Deep	Volume (cubic feet)
80.8	79.9	41	21.08	39.62	3.96	5.95	34.66	36389423.2
80.7	79.8	40.9	21.04	39.52	3.96	5.94	34.56	36217044.0
80.6	79.7	40.8	20.99	39.42	3.96	5.94	34.46	36045104.5
80.5	79.6	40.7	20.95	39.32	3.96	5.93	34.37	35873653.8
80.4	79.5	40.6	20.90	39.22	3.96	5.93	34.27	35702649.4
80.3	79.4	40.5	20.85	39.12	3.96	5.93	34.17	35531994.3
80.2	79.3	40.4	20.81	39.01	3.95	5.92	34.07	35361814.5
80.1	79.2	40.3	20.76	38.91	3.95	5.92	33.97	35192045.4
80.0	79.1	40.2	20.72	38.81	3.95	5.92	33.87	35022730.7
79.9	79.0	40.1	20.67	38.71	3.95	5.91	33.78	34853921.4
79.8	78.9	40	20.62	38.61	3.95	5.91	33.68	34685520.0
79.7	78.8	39.9	20.58	38.51	3.95	5.91	33.58	34517530.3
79.6	78.7	39.8	20.53	38.41	3.95	5.90	33.48	34350000.3
79.5	78.6	39.7	20.48	38.31	3.95	5.90	33.39	34182929.3
79.4	78.5	39.6	20.44	38.21	3.94	5.90	33.29	34016300.6
79.3	78.4	39.5	20.39	38.11	3.94	5.90	33.19	33850044.4
79.2	78.3	39.4	20.34	38.01	3.94	5.90	33.09	33684230.3
79.1	78.2	39.3	20.30	37.91	3.94	5.90	32.99	33518906.8
79.0	78.1	39.2	20.25	37.81	3.94	5.90	32.90	33353933.8
78.9	78.0	39.1	20.20	37.71	3.94	5.90	32.80	33189381.3
78.8	77.9	39	20.16	37.62	3.94	5.89	32.70	33025327.5
78.7	77.8	38.9	20.11	37.52	3.94	5.89	32.60	32861732.0
78.6	77.7	38.8	20.06	37.42	3.94	5.89	32.51	32698572.7
78.5	77.6	38.7	20.01	37.32	3.94	5.89	32.41	32535758.1
78.4	77.5	38.6	19.96	37.23	3.94	5.89	32.31	32373383.8
78.3	77.4	38.5	19.91	37.13	3.94	5.89	32.21	32211434.6
78.2	77.3	38.4	19.87	37.03	3.94	5.88	32.11	32049891.7
78.1	77.2	38.3	19.82	36.94	3.94	5.88	32.01	31888752.8
78.0	77.1	38.2	19.77	36.84	3.94	5.87	31.92	31728062.7
77.9	77.0	38.1	19.72	36.74	3.94	5.87	31.82	31567813.3
77.8	76.9	38	19.68	36.64	3.94	5.86	31.72	31408010.9
77.7	76.8	37.9	19.63	36.55	3.94	5.86	31.62	31248579.1
77.6	76.7	37.8	19.58	36.45	3.94	5.85	31.53	31089604.0
77.5	76.6	37.7	19.53	36.35	3.94	5.85	31.43	30931063.3
77.4	76.5	37.6	19.49	36.25	3.94	5.84	31.34	30772948.9
77.3	76.4	37.5	19.44	36.15	3.94	5.83	31.25	30615296.6
77.2	76.3	37.4	19.39	36.06	3.94	5.82	31.15	30457990.4
77.1	76.2	37.3	19.35	35.96	3.94	5.81	31.06	30301092.3
77.0	76.1	37.2	19.30	35.86	3.94	5.80	30.96	30144624.6

DRAFT

Elevation (ft NGVD29)	Elevation (ft NAVD88)	Maximum Depth (feet)	Mean Depth (feet)	Acres	Acres <=4 ft Deep	Acres <=6 ft Deep	Acres >5 ft Deep	Volume (cubic feet)
76.9	76.0	37.1	19.25	35.76	3.94	5.79	30.87	29988673.8
76.8	75.9	37	19.21	35.66	3.94	5.78	30.78	29833164.5
76.7	75.8	36.9	19.16	35.56	3.94	5.77	30.69	29678094.7
76.6	75.7	36.8	19.11	35.46	3.93	5.76	30.60	29523464.2
76.5	75.6	36.7	19.07	35.36	3.93	5.75	30.51	29369191.7
76.4	75.5	36.6	19.02	35.26	3.92	5.73	30.41	29215350.8
76.3	75.4	36.5	18.98	35.16	3.91	5.72	30.32	29061905.5
76.2	75.3	36.4	18.93	35.06	3.91	5.71	30.23	28908914.7
76.1	75.2	36.3	18.88	34.96	3.90	5.70	30.14	28756412.8
76.0	75.1	36.2	18.84	34.86	3.90	5.68	30.06	28604403.7
75.9	75.0	36.1	18.79	34.76	3.89	5.67	29.97	28452836.4
75.8	74.9	36	18.74	34.66	3.88	5.66	29.88	28301660.7
75.7	74.8	35.9	18.70	34.56	3.88	5.64	29.79	28150875.6
75.6	74.7	35.8	18.65	34.46	3.87	5.63	29.70	28000472.5
75.5	74.6	35.7	18.60	34.37	3.86	5.62	29.61	27850528.5
75.4	74.5	35.6	18.56	34.27	3.85	5.61	29.53	27701037.3
75.3	74.4	35.5	18.51	34.17	3.84	5.60	29.44	27551957.1
75.2	74.3	35.4	18.46	34.07	3.84	5.59	29.35	27403375.4
75.1	74.2	35.3	18.42	33.97	3.83	5.57	29.26	27255237.7
75.0	74.1	35.2	18.37	33.87	3.82	5.56	29.18	27107513.6
74.9	74.0	35.1	18.32	33.78	3.81	5.55	29.09	26960176.7
74.8	73.9	35	18.28	33.68	3.80	5.53	29.00	26813174.0
74.7	73.8	34.9	18.23	33.58	3.79	5.52	28.92	26666669.8
74.6	73.7	34.8	18.18	33.48	3.78	5.51	28.83	26520589.1
74.5	73.6	34.7	18.14	33.39	3.77	5.49	28.74	26374944.5
74.4	73.5	34.6	18.09	33.29	3.76	5.48	28.66	26229775.1
74.3	73.4	34.5	18.04	33.19	3.75	5.46	28.57	26085037.9
74.2	73.3	34.4	18.00	33.09	3.74	5.45	28.48	25940671.8
74.1	73.2	34.3	17.95	32.99	3.73	5.43	28.40	25796711.5
74.0	73.1	34.2	17.90	32.90	3.72	5.42	28.31	25653163.9
73.9	73.0	34.1	17.86	32.80	3.71	5.40	28.23	25510056.8
73.8	72.9	34	17.81	32.70	3.70	5.38	28.14	25367379.5
73.7	72.8	33.9	17.76	32.60	3.69	5.37	28.06	25225191.5
73.6	72.7	33.8	17.71	32.51	3.67	5.35	27.98	25083422.5
73.5	72.6	33.7	17.67	32.41	3.66	5.34	27.89	24942042.2
73.4	72.5	33.6	17.62	32.31	3.65	5.32	27.81	24801047.8
73.3	72.4	33.5	17.58	32.21	3.64	5.30	27.73	24660508.7
73.2	72.3	33.4	17.53	32.11	3.63	5.28	27.64	24520440.0
73.1	72.2	33.3	17.48	32.01	3.62	5.27	27.56	24380757.8

DRAFT

Elevation (ft NGVD29)	Elevation (ft NAVD88)	Maximum Depth (feet)	Mean Depth (feet)	Acres	Acres <=4 ft Deep	Acres <=6 ft Deep	Acres >5 ft Deep	Volume (cubic feet)
73.0	72.1	33.2	17.44	31.92	3.60	5.25	27.48	24241531.2
72.9	72.0	33.1	17.39	31.82	3.59	5.23	27.40	24102714.6
72.8	71.9	33	17.34	31.72	3.58	5.22	27.32	23964336.7
72.7	71.8	32.9	17.30	31.62	3.56	5.20	27.24	23826352.9
72.6	71.7	32.8	17.25	31.53	3.55	5.19	27.15	23688769.8
72.5	71.6	32.7	17.20	31.43	3.54	5.17	27.07	23551609.9
72.4	71.5	32.6	17.15	31.34	3.53	5.16	26.99	23414899.1
72.3	71.4	32.5	17.10	31.25	3.52	5.15	26.91	23278621.0
72.2	71.3	32.4	17.05	31.15	3.51	5.13	26.83	23142766.4
72.1	71.2	32.3	17.01	31.06	3.50	5.12	26.75	23007268.1
72.0	71.1	32.2	16.96	30.96	3.48	5.10	26.67	22872157.0
71.9	71.0	32.1	16.91	30.87	3.47	5.09	26.59	22737415.9
71.8	70.9	32	16.86	30.78	3.46	5.08	26.50	22603124.4
71.7	70.8	31.9	16.81	30.69	3.45	5.07	26.42	22469197.5
71.6	70.7	31.8	16.76	30.60	3.44	5.06	26.34	22335779.1
71.5	70.6	31.7	16.71	30.51	3.43	5.04	26.26	22202769.3
71.4	70.5	31.6	16.66	30.41	3.42	5.03	26.18	22070078.7
71.3	70.4	31.5	16.61	30.32	3.41	5.02	26.10	21937791.5
71.2	70.3	31.4	16.56	30.23	3.41	5.01	26.02	21805878.4
71.1	70.2	31.3	16.51	30.14	3.40	5.00	25.94	21674329.8
71.0	70.1	31.2	16.46	30.06	3.39	4.99	25.86	21543130.2
70.9	70.0	31.1	16.40	29.97	3.38	4.98	25.78	21412448.9
70.8	69.9	31	16.35	29.88	3.37	4.97	25.70	21282120.1
70.7	69.8	30.9	16.30	29.79	3.37	4.96	25.62	21152189.5
70.6	69.7	30.8	16.25	29.70	3.36	4.95	25.54	21022666.1
70.5	69.6	30.7	16.20	29.61	3.35	4.94	25.46	20893489.3
70.4	69.5	30.6	16.14	29.53	3.35	4.93	25.38	20764658.9
70.3	69.4	30.5	16.09	29.44	3.34	4.92	25.30	20636162.9
70.2	69.3	30.4	16.04	29.35	3.33	4.91	25.22	20508147.0
70.1	69.2	30.3	15.99	29.26	3.32	4.90	25.14	20380511.6
70.0	69.1	30.2	15.94	29.18	3.32	4.89	25.07	20253194.0
69.9	69.0	30.1	15.88	29.09	3.31	4.88	24.99	20126289.5
69.8	68.9	30	15.83	29.00	3.30	4.87	24.91	19999755.7
69.7	68.8	29.9	15.78	28.92	3.30	4.86	24.83	19873597.3
69.6	68.7	29.8	15.72	28.83	3.29	4.85	24.75	19747863.6
69.5	68.6	29.7	15.67	28.74	3.28	4.84	24.67	19622462.7
69.4	68.5	29.6	15.62	28.66	3.27	4.83	24.60	19497409.0
69.3	68.4	29.5	15.57	28.57	3.27	4.82	24.52	19372772.1
69.2	68.3	29.4	15.51	28.48	3.26	4.81	24.44	19248460.1

DRAFT

Elevation (ft NGVD29)	Elevation (ft NAVD88)	Maximum Depth (feet)	Mean Depth (feet)	Acres	Acres <=4 ft Deep	Acres <=6 ft Deep	Acres >5 ft Deep	Volume (cubic feet)
69.1	68.2	29.3	15.46	28.40	3.25	4.80	24.37	19124579.0
69.0	68.1	29.2	15.41	28.31	3.25	4.79	24.29	19001088.6
68.9	68.0	29.1	15.35	28.23	3.24	4.78	24.21	18878051.6
68.8	67.9	29	15.30	28.14	3.24	4.77	24.14	18755233.1
68.7	67.8	28.9	15.24	28.06	3.23	4.76	24.06	18632770.9
68.6	67.7	28.8	15.19	27.98	3.23	4.75	23.98	18510679.1
68.5	67.6	28.7	15.13	27.89	3.22	4.74	23.91	18389007.6
68.4	67.5	28.6	15.08	27.81	3.21	4.73	23.83	18267694.6
68.3	67.4	28.5	15.02	27.73	3.21	4.72	23.75	18146749.0
68.2	67.3	28.4	14.97	27.64	3.20	4.70	23.68	18026129.0
68.1	67.2	28.3	14.91	27.56	3.20	4.69	23.60	17905906.6
68.0	67.1	28.2	14.86	27.48	3.19	4.68	23.53	17786083.0
67.9	67.0	28.1	14.80	27.40	3.19	4.67	23.45	17666595.1
67.8	66.9	28	14.75	27.32	3.18	4.66	23.38	17547395.1
67.7	66.8	27.9	14.69	27.24	3.17	4.65	23.30	17428494.8
67.6	66.7	27.8	14.63	27.15	3.17	4.64	23.23	17310014.3
67.5	66.6	27.7	14.58	27.07	3.16	4.63	23.16	17191909.6
67.4	66.5	27.6	14.52	26.99	3.16	4.62	23.08	17074235.4
67.3	66.4	27.5	14.47	26.91	3.16	4.61	23.01	16956863.6
67.2	66.3	27.4	14.41	26.83	3.15	4.60	22.94	16839768.3
67.1	66.2	27.3	14.35	26.75	3.15	4.59	22.87	16723078.9
67.0	66.1	27.2	14.30	26.67	3.14	4.58	22.80	16606718.3
66.9	66.0	27.1	14.24	26.59	3.13	4.57	22.73	16490754.4
66.8	65.9	27	14.18	26.50	3.13	4.56	22.66	16375153.5
66.7	65.8	26.9	14.13	26.42	3.12	4.56	22.59	16259847.0
66.6	65.7	26.8	14.07	26.34	3.11	4.55	22.52	16144822.9
66.5	65.6	26.7	14.01	26.26	3.11	4.54	22.45	16030290.4
66.4	65.5	26.6	13.96	26.18	3.10	4.54	22.38	15916083.6
66.3	65.4	26.5	13.90	26.10	3.09	4.53	22.30	15802252.3
66.2	65.3	26.4	13.84	26.02	3.08	4.52	22.23	15688762.8
66.1	65.2	26.3	13.78	25.94	3.07	4.52	22.16	15575606.1
66.0	65.1	26.2	13.73	25.86	3.06	4.51	22.09	15462777.1
65.9	65.0	26.1	13.67	25.78	3.05	4.50	22.01	15350245.1
65.8	64.9	26	13.61	25.70	3.04	4.50	21.94	15238073.1
65.7	64.8	25.9	13.55	25.62	3.03	4.49	21.87	15126320.8
65.6	64.7	25.8	13.50	25.54	3.02	4.48	21.79	15014938.4
65.5	64.6	25.7	13.44	25.46	3.01	4.48	21.72	14903796.1
65.4	64.5	25.6	13.38	25.38	3.01	4.47	21.64	14793091.7
65.3	64.4	25.5	13.32	25.30	3.00	4.46	21.57	14682652.3

DRAFT

Elevation (ft NGVD29)	Elevation (ft NAVD88)	Maximum Depth (feet)	Mean Depth (feet)	Acres	Acres <=4 ft Deep	Acres <=6 ft Deep	Acres >5 ft Deep	Volume (cubic feet)
65.2	64.3	25.4	13.26	25.22	2.99	4.46	21.50	14572651.1
65.1	64.2	25.3	13.20	25.14	2.98	4.45	21.42	14462980.1
65.0	64.1	25.2	13.15	25.07	2.98	4.45	21.35	14353616.9
64.9	64.0	25.1	13.09	24.99	2.97	4.44	21.28	14244596.4
64.8	63.9	25	13.03	24.91	2.97	4.43	21.20	14135856.6
64.7	63.8	24.9	12.97	24.83	2.96	4.43	21.13	14027504.8
64.6	63.7	24.8	12.91	24.75	2.96	4.43	21.06	13919523.3
64.5	63.6	24.7	12.85	24.67	2.95	4.42	20.98	13811869.7
64.4	63.5	24.6	12.79	24.60	2.95	4.42	20.91	13704598.9
64.3	63.4	24.5	12.73	24.52	2.95	4.42	20.84	13597660.5
64.2	63.3	24.4	12.67	24.44	2.95	4.41	20.77	13491045.8
64.1	63.2	24.3	12.61	24.37	2.94	4.41	20.69	13384726.8
64.0	63.1	24.2	12.55	24.29	2.94	4.41	20.62	13278720.2
63.9	63.0	24.1	12.49	24.21	2.94	4.41	20.55	13173069.0
63.8	62.9	24	12.43	24.14	2.93	4.41	20.47	13067731.3
63.7	62.8	23.9	12.37	24.06	2.93	4.40	20.40	12962797.4
63.6	62.7	23.8	12.31	23.98	2.93	4.40	20.33	12858093.2
63.5	62.6	23.7	12.25	23.91	2.92	4.40	20.25	12753792.5
63.4	62.5	23.6	12.19	23.83	2.92	4.40	20.18	12649812.4
63.3	62.4	23.5	12.12	23.75	2.92	4.39	20.10	12546173.3
63.2	62.3	23.4	12.06	23.68	2.91	4.39	20.03	12442894.3
63.1	62.2	23.3	12.00	23.60	2.91	4.38	19.95	12339937.9
63.0	62.1	23.2	11.94	23.53	2.91	4.38	19.88	12237250.9
62.9	62.0	23.1	11.88	23.45	2.91	4.38	19.81	12134915.9
62.8	61.9	23	11.82	23.38	2.90	4.37	19.73	12032948.5
62.7	61.8	22.9	11.75	23.30	2.90	4.37	19.66	11931229.7
62.6	61.7	22.8	11.69	23.23	2.90	4.37	19.58	11829829.1
62.5	61.6	22.7	11.63	23.16	2.91	4.36	19.51	11728807.9
62.4	61.5	22.6	11.56	23.08	2.91	4.37	19.43	11628164.6
62.3	61.4	22.5	11.50	23.01	2.91	4.37	19.36	11527818.7
62.2	61.3	22.4	11.44	22.94	2.91	4.37	19.29	11427677.3
62.1	61.2	22.3	11.37	22.87	2.92	4.37	19.22	11327872.2
62.0	61.1	22.2	11.31	22.80	2.92	4.38	19.15	11228386.5
61.9	61.0	22.1	11.24	22.73	2.92	4.38	19.08	11129237.0
61.8	60.9	22	11.18	22.66	2.93	4.38	19.01	11030415.8
61.7	60.8	21.9	11.11	22.59	2.93	4.38	18.93	10931854.1
61.6	60.7	21.8	11.04	22.52	2.93	4.39	18.86	10833600.1
61.5	60.6	21.7	10.98	22.45	2.94	4.39	18.79	10735695.6
61.4	60.5	21.6	10.91	22.38	2.94	4.39	18.72	10638093.3

DRAFT

Elevation (ft NGVD29)	Elevation (ft NAVD88)	Maximum Depth (feet)	Mean Depth (feet)	Acres	Acres <=4 ft Deep	Acres <=6 ft Deep	Acres >5 ft Deep	Volume (cubic feet)
61.3	60.4	21.5	10.85	22.30	2.94	4.40	18.64	10540737.2
61.2	60.3	21.4	10.78	22.23	2.94	4.40	18.57	10443713.1
61.1	60.2	21.3	10.72	22.16	2.94	4.40	18.50	10347034.1
61.0	60.1	21.2	10.65	22.09	2.94	4.40	18.42	10250672.6
60.9	60.0	21.1	10.59	22.01	2.94	4.40	18.35	10154638.2
60.8	59.9	21	10.52	21.94	2.94	4.40	18.28	10058856.4
60.7	59.8	20.9	10.46	21.87	2.93	4.40	18.20	9963466.4
60.6	59.7	20.8	10.40	21.79	2.93	4.40	18.13	9868332.3
60.5	59.6	20.7	10.33	21.72	2.93	4.40	18.05	9773641.0
60.4	59.5	20.6	10.27	21.64	2.93	4.41	17.98	9679200.3
60.3	59.4	20.5	10.20	21.57	2.93	4.41	17.91	9585050.3
60.2	59.3	20.4	10.14	21.50	2.93	4.41	17.83	9491201.4
60.1	59.2	20.3	10.07	21.42	2.93	4.42	17.76	9397653.7
60.0	59.1	20.2	10.00	21.35	2.93	4.43	17.69	9304511.9
59.9	59.0	20.1	9.94	21.28	2.93	4.44	17.61	9211649.6
59.8	58.9	20	9.87	21.20	2.93	4.45	17.54	9119148.8
59.7	58.8	19.9	9.81	21.13	2.93	4.46	17.47	9026967.9
59.6	58.7	19.8	9.74	21.06	2.93	4.48	17.39	8935087.6
59.5	58.6	19.7	9.67	20.98	2.93	4.50	17.32	8843491.8
59.4	58.5	19.6	9.61	20.91	2.93	4.53	17.24	8752295.7
59.3	58.4	19.5	9.54	20.84	2.93	4.57	17.16	8661309.0
59.2	58.3	19.4	9.47	20.77	2.93	4.60	17.08	8570674.6
59.1	58.2	19.3	9.41	20.69	2.93	4.65	17.00	8480354.4
59.0	58.1	19.2	9.34	20.62	2.93	4.69	16.92	8390314.8
58.9	58.0	19.1	9.27	20.55	2.93	4.74	16.84	8300645.7
58.8	57.9	19	9.21	20.47	2.93	4.79	16.76	8211338.7
58.7	57.8	18.9	9.14	20.40	2.93	4.85	16.67	8122307.5
58.6	57.7	18.8	9.07	20.33	2.93	4.93	16.58	8033650.6
58.5	57.6	18.7	9.01	20.25	2.93	5.03	16.48	7945255.5
58.4	57.5	18.6	8.94	20.18	2.94	5.16	16.38	7857247.5
58.3	57.4	18.5	8.87	20.10	2.94	5.29	16.27	7769498.7
58.2	57.3	18.4	8.81	20.03	2.94	5.43	16.16	7682072.1
58.1	57.2	18.3	8.74	19.95	2.95	5.58	16.05	7594963.2
58.0	57.1	18.2	8.67	19.88	2.96	5.70	15.93	7508184.3
57.9	57.0	18.1	8.60	19.81	2.96	5.83	15.81	7421736.5
57.8	56.9	18	8.53	19.73	2.98	5.96	15.68	7335621.4
57.7	56.8	17.9	8.47	19.66	2.99	6.05	15.55	7249857.3
57.6	56.7	17.8	8.40	19.58	3.01	6.14	15.40	7164335.3
57.5	56.6	17.7	8.33	19.51	3.03	6.23	15.22	7079214.3

DRAFT

Elevation (ft NGVD29)	Elevation (ft NAVD88)	Maximum Depth (feet)	Mean Depth (feet)	Acres	Acres <=4 ft Deep	Acres <=6 ft Deep	Acres >5 ft Deep	Volume (cubic feet)
57.4	56.5	17.6	8.26	19.43	3.06	6.31	15.01	6994430.9
57.3	56.4	17.5	8.19	19.36	3.09	6.38	14.81	6909963.6
57.2	56.3	17.4	8.12	19.29	3.13	6.46	14.60	6825739.8
57.1	56.2	17.3	8.05	19.22	3.17	6.55	14.38	6741829.7
57.0	56.1	17.2	7.98	19.15	3.22	6.63	14.18	6658215.5
56.9	56.0	17.1	7.91	19.08	3.27	6.70	13.97	6574892.9
56.8	55.9	17	7.84	19.01	3.32	6.78	13.77	6491946.3
56.7	55.8	16.9	7.77	18.93	3.39	6.88	13.61	6409347.3
56.6	55.7	16.8	7.70	18.86	3.46	7.00	13.45	6327041.2
56.5	55.6	16.7	7.63	18.79	3.57	7.11	13.28	6245042.0
56.4	55.5	16.6	7.56	18.72	3.70	7.21	13.13	6163396.4
56.3	55.4	16.5	7.49	18.64	3.83	7.32	12.98	6082041.0
56.2	55.3	16.4	7.42	18.57	3.97	7.43	12.83	6000977.7
56.1	55.2	16.3	7.35	18.50	4.12	7.55	12.67	5920219.7
56.0	55.1	16.2	7.28	18.42	4.25	7.66	12.52	5839784.7
55.9	55.0	16.1	7.21	18.35	4.38	7.78	12.37	5759689.9
55.8	54.9	16	7.13	18.28	4.50	7.86	12.22	5679908.2
55.7	54.8	15.9	7.06	18.20	4.59	7.95	12.05	5600458.5
55.6	54.7	15.8	6.99	18.13	4.68	8.03	11.87	5521296.0
55.5	54.6	15.7	6.92	18.05	4.78	8.11	11.69	5442530.1
55.4	54.5	15.6	6.85	17.98	4.85	8.20	11.51	5363991.5
55.3	54.4	15.5	6.78	17.91	4.93	8.26	11.33	5285790.2
55.2	54.3	15.4	6.70	17.83	5.01	8.33	11.14	5207983.5
55.1	54.2	15.3	6.63	17.76	5.09	8.41	10.95	5130438.3
55.0	54.1	15.2	6.56	17.69	5.17	8.49	10.76	5053245.0
54.9	54.0	15.1	6.49	17.61	5.24	8.56	10.57	4976310.5
54.8	53.9	15	6.41	17.54	5.32	8.63	10.42	4899789.2
54.7	53.8	14.9	6.34	17.47	5.42	8.70	10.26	4823551.3
54.6	53.7	14.8	6.27	17.39	5.52	8.77	10.10	4747623.0
54.5	53.6	14.7	6.19	17.32	5.63	8.85	9.94	4672134.4
54.4	53.5	14.6	6.12	17.24	5.73	8.92	9.78	4596888.3
54.3	53.4	14.5	6.05	17.16	5.83	8.99	9.64	4522025.6
54.2	53.3	14.4	5.98	17.08	5.94	9.05	9.50	4447477.5
54.1	53.2	14.3	5.90	17.00	6.05	9.12	9.35	4373241.6
54.0	53.1	14.2	5.83	16.92	6.16	9.19	9.20	4299343.2
53.9	53.0	14.1	5.76	16.84	6.27	9.25	9.05	4225831.9
53.8	52.9	14	5.69	16.76	6.34	9.30	8.91	4152656.0
53.7	52.8	13.9	5.62	16.67	6.41	9.37	8.76	4079848.2
53.6	52.7	13.8	5.55	16.58	6.48	9.44	8.62	4007435.7

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Elevation (ft NGVD29)	Elevation (ft NAVD88)	Maximum Depth (feet)	Mean Depth (feet)	Acres	Acres <=4 ft Deep	Acres <=6 ft Deep	Acres >5 ft Deep	Volume (cubic feet)
53.5	52.6	13.7	5.48	16.48	6.54	9.49	8.46	3935413.6
53.4	52.5	13.6	5.42	16.38	6.59	9.53	8.32	3863783.5
53.3	52.4	13.5	5.35	16.27	6.63	9.57	8.17	3792682.2
53.2	52.3	13.4	5.29	16.16	6.66	9.60	8.04	3722000.6
53.1	52.2	13.3	5.22	16.05	6.70	9.65	7.88	3651861.9
53.0	52.1	13.2	5.16	15.93	6.73	9.70	7.73	3582272.6
52.9	52.0	13.1	5.10	15.81	6.76	9.73	7.59	3513151.6
52.8	51.9	13	5.04	15.68	6.78	9.75	7.46	3444551.5
52.7	51.8	12.9	4.99	15.55	6.78	9.74	7.30	3376571.5
52.6	51.7	12.8	4.93	15.40	6.78	9.71	7.14	3309155.4
52.5	51.6	12.7	4.89	15.22	6.75	9.64	6.99	3242487.2
52.4	51.5	12.6	4.86	15.01	6.69	9.55	6.85	3176734.3
52.3	51.4	12.5	4.82	14.81	6.64	9.47	6.70	3111827.9
52.2	51.3	12.4	4.79	14.60	6.56	9.37	6.56	3047794.9
52.1	51.2	12.3	4.77	14.38	6.49	9.27	6.40	2984690.8
52.0	51.1	12.2	4.73	14.18	6.45	9.19	6.22	2922525.0
51.9	51.0	12.1	4.70	13.97	6.38	9.11	6.07	2861208.9
51.8	50.9	12	4.67	13.77	6.32	9.03	5.93	2800867.7
51.7	50.8	11.9	4.62	13.61	6.31	8.99	5.81	2741253.3
51.6	50.7	11.8	4.58	13.45	6.31	8.94	5.69	2682326.8
51.5	50.6	11.7	4.54	13.28	6.29	8.90	5.58	2624139.1
51.4	50.5	11.6	4.49	13.13	6.28	8.88	5.46	2566659.9
51.3	50.4	11.5	4.44	12.98	6.28	8.86	5.34	2509756.5
51.2	50.3	11.4	4.39	12.83	6.27	8.83	5.23	2453546.9
51.1	50.2	11.3	4.34	12.67	6.27	8.79	5.11	2398021.0
51.0	50.1	11.2	4.30	12.52	6.29	8.75	4.99	2343177.7
50.9	50.0	11.1	4.25	12.37	6.30	8.72	4.86	2289006.1
50.8	49.9	11	4.20	12.22	6.29	8.69	4.74	2235434.5
50.7	49.8	10.9	4.16	12.05	6.24	8.64	4.62	2182574.6
50.6	49.7	10.8	4.12	11.87	6.18	8.59	4.51	2130435.0
50.5	49.6	10.7	4.08	11.69	6.11	8.54	4.38	2079126.7
50.4	49.5	10.6	4.05	11.51	6.04	8.49	4.25	2028660.8
50.3	49.4	10.5	4.01	11.33	5.98	8.45	4.12	1978972.5
50.2	49.3	10.4	3.98	11.14	5.92	8.43	4.00	1930088.9
50.1	49.2	10.3	3.94	10.95	5.84	8.40	3.88	1882013.7
50.0	49.1	10.2	3.91	10.76	5.77	8.35	3.77	1834759.4
49.9	49.0	10.1	3.88	10.57	5.71	8.30	3.65	1788297.2
49.8	48.9	10	3.84	10.42	5.68	8.30	3.53	1742620.7
49.7	48.8	9.9	3.80	10.26	5.63	8.24	3.41	1697578.0

DRAFT

Elevation (ft NGVD29)	Elevation (ft NAVD88)	Maximum Depth (feet)	Mean Depth (feet)	Acres	Acres <=4 ft Deep	Acres <=6 ft Deep	Acres >5 ft Deep	Volume (cubic feet)
49.6	48.7	9.8	3.76	10.10	5.59	8.17	3.27	1653272.0
49.5	48.6	9.7	3.72	9.94	5.56	8.09	3.15	1609637.2
49.4	48.5	9.6	3.68	9.78	5.53	8.01	3.02	1566686.0
49.3	48.4	9.5	3.63	9.64	5.52	7.94	2.87	1524418.8
49.2	48.3	9.4	3.58	9.50	5.50	7.88	2.72	1482674.3
49.1	48.2	9.3	3.54	9.35	5.47	7.81	2.55	1441581.1
49.0	48.1	9.2	3.50	9.20	5.43	7.73	2.41	1401279.4
48.9	48.0	9.1	3.45	9.05	5.40	7.64	2.27	1361542.6
48.8	47.9	9	3.41	8.91	5.38	7.55	2.11	1322403.6
48.7	47.8	8.9	3.36	8.76	5.36	7.47	2.02	1283954.5
48.6	47.7	8.8	3.32	8.62	5.35	7.39	1.93	1246113.1
48.5	47.6	8.7	3.28	8.46	5.31	7.29	1.85	1208955.0
48.4	47.5	8.6	3.24	8.32	5.30	7.21	1.78	1172424.8
48.3	47.4	8.5	3.19	8.17	5.30	7.13	1.70	1136491.5
48.2	47.3	8.4	3.15	8.04	5.32	7.06	1.62	1101172.6
48.1	47.2	8.3	3.11	7.88	5.33	6.99	1.54	1066511.8
48.0	47.1	8.2	3.07	7.73	5.32	6.92	1.47	1032495.4
47.9	47.0	8.1	3.02	7.59	5.32	6.86	1.41	999098.2
47.8	46.9	8	2.98	7.46	5.34	6.81	1.36	966336.4
47.7	46.8	7.9	2.94	7.30	5.29	6.74	1.29	934140.9
47.6	46.7	7.8	2.90	7.14	5.21	6.64	1.23	902731.3
47.5	46.6	7.7	2.86	6.99	5.14	6.55	1.17	871948.5
47.4	46.5	7.6	2.82	6.85	5.07	6.45	1.11	841768.4
47.3	46.4	7.5	2.78	6.70	5.00	6.34	1.05	812282.9
47.2	46.3	7.4	2.74	6.56	4.94	6.23	0.98	783414.1
47.1	46.2	7.3	2.71	6.40	4.86	6.11	0.89	755184.7
47.0	46.1	7.2	2.68	6.22	4.76	5.96	0.82	727716.9
46.9	46.0	7.1	2.65	6.07	4.66	5.84	0.73	701000.7
46.8	45.9	7	2.61	5.93	4.58	5.73	0.65	674859.6
46.7	45.8	6.9	2.57	5.81	4.51	5.63	0.57	649316.5
46.6	45.7	6.8	2.52	5.69	4.46	5.55	0.50	624312.3
46.5	45.6	6.7	2.47	5.58	4.41	5.47	0.44	599816.9
46.4	45.5	6.6	2.42	5.46	4.35	5.39	0.40	575728.4
46.3	45.4	6.5	2.37	5.34	4.30	5.29	0.36	552188.9
46.2	45.3	6.4	2.32	5.23	4.25	5.19	0.32	529151.0
46.1	45.2	6.3	2.28	5.11	4.22	5.09	0.29	506636.0
46.0	45.1	6.2	2.23	4.99	4.17	4.98	0.26	484660.4
45.9	45.0	6.1	2.19	4.86	4.13	4.86	0.23	463203.4
45.8	44.9	6	2.14	4.74	4.10	4.74	0.20	442305.9

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Elevation (ft NGVD29)	Elevation (ft NAVD88)	Maximum Depth (feet)	Mean Depth (feet)	Acres	Acres <=4 ft Deep	Acres <=6 ft Deep	Acres >5 ft Deep	Volume (cubic feet)
45.7	44.8	5.9	2.09	4.62	4.06	4.62	0.18	421932.4
45.6	44.7	5.8	2.05	4.51	4.01	4.51	0.14	402044.1
45.5	44.6	5.7	2.00	4.38	3.94	4.38	0.11	382667.5
45.4	44.5	5.6	1.97	4.25	3.85	4.25	0.07	363886.7
45.3	44.4	5.5	1.93	4.12	3.76	4.12	0.05	345646.4
45.2	44.3	5.4	1.88	4.00	3.68	4.00	0.04	327970.1
45.1	44.2	5.3	1.84	3.88	3.59	3.88	0.02	310828.1
45.0	44.1	5.2	1.79	3.77	3.51	3.77	0.01	294140.9
44.9	44.0	5.1	1.75	3.65	3.42	3.65	0.00	277982.2
44.8	43.9	5	1.71	3.53	3.33	3.53	0.00	262378.5
44.7	43.8	4.9	1.67	3.41	3.23	3.41	0.00	247231.7
44.6	43.7	4.8	1.63	3.27	3.13	3.27	0.00	232703.0
44.5	43.6	4.7	1.59	3.15	3.04	3.15	0.00	218727.0
44.4	43.5	4.6	1.56	3.02	2.94	3.02	0.00	205283.4
44.3	43.4	4.5	1.54	2.87	2.83	2.87	0.00	192474.1
44.2	43.3	4.4	1.52	2.72	2.68	2.72	0.00	180327.5
44.1	43.2	4.3	1.52	2.55	2.53	2.55	0.00	168889.2
44.0	43.1	4.2	1.51	2.41	2.40	2.41	0.00	158087.1
43.9	43.0	4.1	1.50	2.27	2.27	2.27	0.00	147903.0
43.8	42.9	4	1.50	2.11	2.11	2.11	0.00	138371.0
43.7	42.8	3.9	1.47	2.02	2.02	2.02	0.00	129409.0
43.6	42.7	3.8	1.44	1.93	1.93	1.93	0.00	120845.0
43.5	42.6	3.7	1.39	1.85	1.85	1.85	0.00	112642.1
43.4	42.5	3.6	1.35	1.78	1.78	1.78	0.00	104727.3
43.3	42.4	3.5	1.31	1.70	1.70	1.70	0.00	97137.4
43.2	42.3	3.4	1.28	1.62	1.62	1.62	0.00	89927.7
43.1	42.2	3.3	1.24	1.54	1.54	1.54	0.00	83044.7
43.0	42.1	3.2	1.20	1.47	1.47	1.47	0.00	76503.5
42.9	42.0	3.1	1.14	1.41	1.41	1.41	0.00	70235.9
42.8	41.9	3	1.09	1.36	1.36	1.36	0.00	64195.9
42.7	41.8	2.9	1.04	1.29	1.29	1.29	0.00	58438.5
42.6	41.7	2.8	0.99	1.23	1.23	1.23	0.00	52938.7
42.5	41.6	2.7	0.94	1.17	1.17	1.17	0.00	47706.5
42.4	41.5	2.6	0.88	1.11	1.11	1.11	0.00	42739.9
42.3	41.4	2.5	0.83	1.05	1.05	1.05	0.00	38028.9
42.2	41.3	2.4	0.79	0.98	0.98	0.98	0.00	33608.5
42.1	41.2	2.3	0.76	0.89	0.89	0.89	0.00	29546.8
42.0	41.1	2.2	0.73	0.82	0.82	0.82	0.00	25847.0
41.9	41.0	2.1	0.70	0.73	0.73	0.73	0.00	22484.1

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Elevation (ft NGVD29)	Elevation (ft NAVD88)	Maximum Depth (feet)	Mean Depth (feet)	Acres	Acres <=4 ft Deep	Acres <=6 ft Deep	Acres >5 ft Deep	Volume (cubic feet)
41.8	40.9	2	0.69	0.65	0.65	0.65	0.00	19494.3
41.7	40.8	1.9	0.69	0.57	0.57	0.57	0.00	16885.1
41.6	40.7	1.8	0.67	0.50	0.50	0.50	0.00	14558.6
41.5	40.6	1.7	0.65	0.44	0.44	0.44	0.00	12537.1
41.4	40.5	1.6	0.62	0.40	0.40	0.40	0.00	10724.4
41.3	40.4	1.5	0.58	0.36	0.36	0.36	0.00	9082.2
41.2	40.3	1.4	0.54	0.32	0.32	0.32	0.00	7600.4
41.1	40.2	1.3	0.49	0.29	0.29	0.29	0.00	6262.2
41.0	40.1	1.2	0.44	0.26	0.26	0.26	0.00	5072.3
40.9	40.0	1.1	0.40	0.23	0.23	0.23	0.00	4015.8
40.8	39.9	1	0.35	0.20	0.20	0.20	0.00	3064.5
40.7	39.8	0.9	0.29	0.18	0.18	0.18	0.00	2237.7
40.6	39.7	0.8	0.25	0.14	0.14	0.14	0.00	1539.9
40.5	39.6	0.7	0.22	0.11	0.11	0.11	0.00	1008.6
40.4	39.5	0.6	0.19	0.07	0.07	0.07	0.00	623.3
40.3	39.4	0.5	0.18	0.05	0.05	0.05	0.00	378.6
40.2	39.3	0.4	0.12	0.04	0.04	0.04	0.00	194.5
40.1	39.2	0.3	0.07	0.02	0.02	0.02	0.00	69.1
40.0	39.1	0.2	0.05	0.01	0.01	0.01	0.00	17.2
39.9	39.0	0.1	0.04	0.00	0.00	0.00	0.00	2.3
39.8	38.9	0	0.02	0.00	0.00	0.00	0.00	0.1

* Historic percentiles are the water surface elevations expected to be equaled or exceeded ten (Historic P10), fifty (Historic P50), and ninety (Historic P90) percent of the time on a long-term basis in the absence of withdrawal impacts, given existing structural alterations that can affect water levels within the basin.

Figure A-2. Five-foot elevation contours of the Lake Tulane basin.

Surface area, maximum depth, mean depth, and volume versus water surface elevation (stage) for Lake Tulane in ft above the National Geodetic Vertical Datum of 1929 (NGVD29) are plotted in Figure A-3. Areas associated with shallow, < 4 ft and <6 ft depths and deep water (> 5 ft depth) are shown in Figure B-4.

Lake Tulane is a deep basin with a steep slope that grades to two deep subbasins (Figures A-1 and A-2). The lowest portion of the basin occurs at an elevation of 39.8 feet above NGVD29.

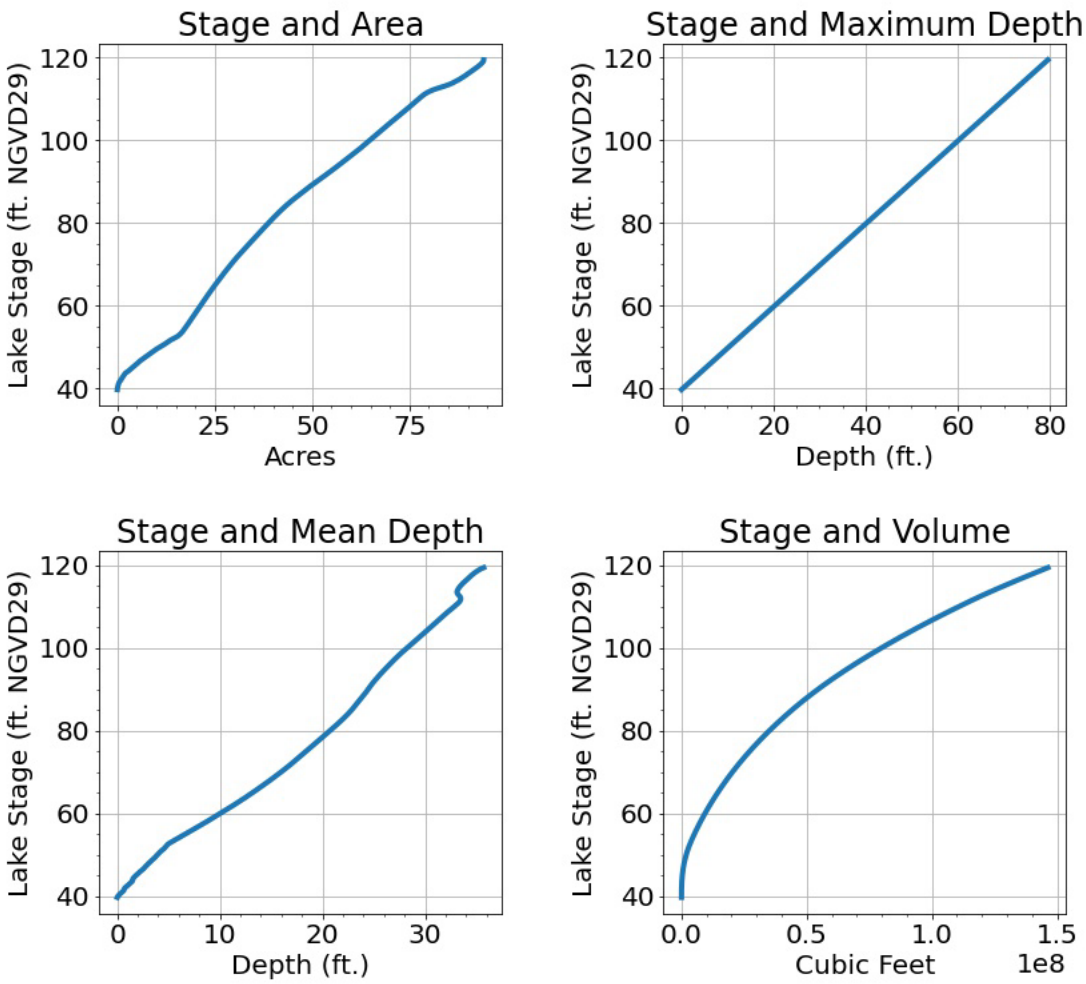

Figure A-3. Maximum depth, mean depth, surface area and volume versus stage for Lake Tulane.

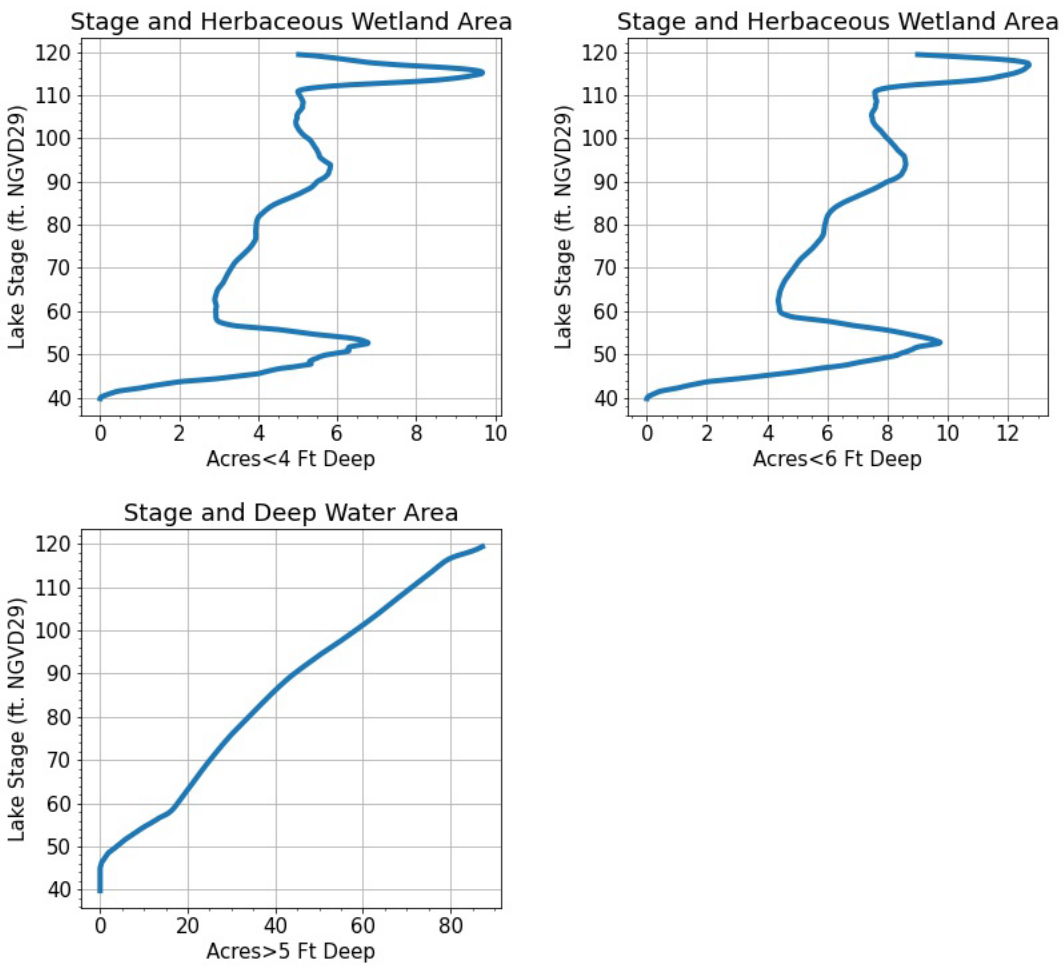

Figure A-4. Surface area with water depth less than 4 and 6 feet deep, associated with potential herbaceous wetland vegetation, and deep-water area where depth is greater than 5 feet versus stage for Lake Tulane.

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Appendix B: Lake Vegetation Index for Lake Tulane

The Lake Vegetation Index (LVI) was developed in 2005 by the Florida Department of Environmental Protection (FDEP). The LVI is a multifaceted metric designed for assessing the degree of similarity between a lake's plant community and one that would typically occur in a minimally disturbed environment. This assessment relies on a rapid field evaluation of aquatic and wetland plants, which serve as indicators of the cumulative impacts of human disturbances over time.

These disturbances encompass physical factors like the introduction of non-native species or alterations to the lakeshore, as well as chemical factors such as excessive nutrient input, particulate matter, or herbicides originating from surrounding land activities. The LVI comprises four key metrics:

1. Percentage of native taxa.

2. Percentage of invasive exotic taxa categorized as Category 1 by the Florida Exotic Pest Plant Council (FLEPPC).

3. Coefficient of conservatism (C of C) associated with the dominant or co-dominant taxa.

4. Percentage of sensitive taxa (those with a C of C value ≥ 7).

The coefficient of conservatism, expressed on a scale from 0 to 10, signifies the ecological niche breadth of a taxon, as determined by expert botanists. Taxa with low C of C scores typically include exotic species and widespread weedy native taxa, while those with high C of C scores exhibit a strong fidelity to specific ecological communities and heightened sensitivity to disturbances.

Lakes are assigned an LVI score within the range of 0 to 100. The FDEP has determined that a well-balanced floral community in a lake is achieved when the average LVI score from at least two temporally separate assessments, conducted at representative locations and times, equals or exceeds 43.

On July 15, 2020, an LVI evaluation was conducted for Lake Tulane, resulting in LVI rating of 48. An additional LVI assessment was conducted on July 25, 2022, and resulted in a rating of 41. The average of the two assessments is a rating of 45, indicating a well-balanced floral community.

Table B-1. Lake Tulane LVI macrophyte data from July 15, 2020, and July 25, 2022, provided by FDEP. “P” = taxa presence, “C” = co-dominant taxa, “D” = dominate taxon

Sample Date	Station Description	Latitude	Longitude	Taxon Name	Rep 1	Rep 2	Rep 3	Rep 4
7/15/2020	Lake Tulane	27.58598	-81.50351	Centella asiatica		P		
7/15/2020	Lake Tulane	27.58598	-81.50351	Cephalanthus occidentalis				
7/15/2020	Lake Tulane	27.58598	-81.50351	Chara	P	P	P	P
7/15/2020	Lake Tulane	27.58598	-81.50351	Cyperus lecontei	P	P		
7/15/2020	Lake Tulane	27.58598	-81.50351	Cyperus odoratus	P	P		P
7/15/2020	Lake Tulane	27.58598	-81.50351	Cyperus polystachyos		P		P
7/15/2020	Lake Tulane	27.58598	-81.50351	Cyperus virens				P
7/15/2020	Lake Tulane	27.58598	-81.50351	Eleocharis baldwinii				P
7/15/2020	Lake Tulane	27.58598	-81.50351	Eleocharis equisetoides	P	P	P	
7/15/2020	Lake Tulane	27.58598	-81.50351	Eleocharis vivipara				P
7/15/2020	Lake Tulane	27.58598	-81.50351	Eupatorium capillifolium	P	P	P	P
7/15/2020	Lake Tulane	27.58598	-81.50351	Fuirena scirpoidea	P	C	C	C
7/15/2020	Lake Tulane	27.58598	-81.50351	Hydrocotyle			P	P
7/15/2020	Lake Tulane	27.58598	-81.50351	Leersia hexandra				P
7/15/2020	Lake Tulane	27.58598	-81.50351	Ludwigia arcuata				P
7/15/2020	Lake Tulane	27.58598	-81.50351	Ludwigia leptocarpa	P	P	P	P
7/15/2020	Lake Tulane	27.58598	-81.50351	Ludwigia peruviana		P		P
7/15/2020	Lake Tulane	27.58598	-81.50351	Melaleuca quinquenervia		P		
7/15/2020	Lake Tulane	27.58598	-81.50351	Mimosa pigra				P

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Sample Date	Station Description	Latitude	Longitude	Taxon Name	Rep 1	Rep 2	Rep 3	Rep 4
7/15/2020	Lake Tulane	27.58598	-81.50351	Nuphar	P		P	P
7/15/2020	Lake Tulane	27.58598	-81.50351	Panicum hemitomon	P	P	P	P
7/15/2020	Lake Tulane	27.58598	-81.50351	Panicum repens	P	C	C	C
7/15/2020	Lake Tulane	27.58598	-81.50351	Pluchea		P		
7/15/2020	Lake Tulane	27.58598	-81.50351	Salix caroliniana	P	P		
7/15/2020	Lake Tulane	27.58598	-81.50351	Schinus terebinthifolius	P			
7/15/2020	Lake Tulane	27.58598	-81.50351	Typha	P	P		
7/15/2020	Lake Tulane	27.58598	-81.50351	Xyris		P		
7/25/2022	Lake Tulane	27.58598	-81.50351	Alternanthera philoxeroides	P			
7/25/2022	Lake Tulane	27.58598	-81.50351	Bidens alba				P
7/25/2022	Lake Tulane	27.58598	-81.50351	Casuarina equisetifolia	P	P		
7/25/2022	Lake Tulane	27.58598	-81.50351	Centella asiatica		P		
7/25/2022	Lake Tulane	27.58598	-81.50351	Cephalanthus occidentalis			P	
7/25/2022	Lake Tulane	27.58598	-81.50351	Coreopsis floridana	P			
7/25/2022	Lake Tulane	27.58598	-81.50351	Crinum americanum	P	P		
7/25/2022	Lake Tulane	27.58598	-81.50351	Cyperus odoratus	P	P		P
7/25/2022	Lake Tulane	27.58598	-81.50351	Cyperus polystachyos		P		P
7/25/2022	Lake Tulane	27.58598	-81.50351	Eleocharis baldwinii	P			P
7/25/2022	Lake Tulane	27.58598	-81.50351	Eleocharis equisetoides		P	P	
7/25/2022	Lake Tulane	27.58598	-81.50351	Eupatorium capillifolium	P	P	P	P
7/25/2022	Lake Tulane	27.58598	-81.50351	Fabaceae	P			P
7/25/2022	Lake Tulane	27.58598	-81.50351	Fuirena scirpoidea	P	C	C	P

DRAFT

Sample Date	Station Description	Latitude	Longitude	Taxon Name	Rep 1	Rep 2	Rep 3	Rep 4
7/25/2022	Lake Tulane	27.58598	-81.50351	Hydrocotyle	P	P		P
7/25/2022	Lake Tulane	27.58598	-81.50351	Ludwigia octovalvis	P	P	P	P
7/25/2022	Lake Tulane	27.58598	-81.50351	Ludwigia peruviana	P	P	P	P
7/25/2022	Lake Tulane	27.58598	-81.50351	Nuphar	P		P	P
7/25/2022	Lake Tulane	27.58598	-81.50351	Panicum hemitomon	C	P	P	P
7/25/2022	Lake Tulane	27.58598	-81.50351	Panicum repens	C	C	C	D
7/25/2022	Lake Tulane	27.58598	-81.50351	Pluchea	P	P	P	
7/25/2022	Lake Tulane	27.58598	-81.50351	Rhynchospora nitens			P	
7/25/2022	Lake Tulane	27.58598	-81.50351	Salix caroliniana	P			
7/25/2022	Lake Tulane	27.58598	-81.50351	Sphagneticola trilobata				P
7/25/2022	Lake Tulane	27.58598	-81.50351	Typha	P		P	
7/25/2022	Lake Tulane	27.58598	-81.50351	Urena lobata		P	P	
7/25/2022	Lake Tulane	27.58598	-81.50351	Utricularia gibba	P	P	P	P
7/25/2022	Lake Tulane	27.58598	-81.50351	Vitis		P		
7/25/2022	Lake Tulane	27.58598	-81.50351	Xyris	P			