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

July 18, 2025

Southwest Florida Water Management District

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Environmental Flows and Levels Section
Natural Systems and Restoration Bureau
Southwest Florida Water Management District
2379 Broad Street Brooksville, Florida 34604-6899

Authors:

Brady Evans, Ph.D.
TJ Venning, PWS
Jill Qi, Ph.D., P.G
Jason Patterson, P.G.

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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 Angelo 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 Angelo 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 96.2 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 99.9 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 Angelo indicates the proposed Minimum Lake Level and High Minimum Lake Level are both currently met, and adoption or 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 prevention strategy is similarly not required. If the lake’s levels fall below, or are projected to fall below an applicable minimum level, the 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 Angelo 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 2007 for Lake Angelo 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 2025 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 Angelo 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 Angelo 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, an update of the minimum water levels established for Lake Angelo in Rule 40D-8.624, F.A.C., 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 Angelo 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 Angelo 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 Angelo; 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[1].

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

[1] 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 refinement 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 Angelo

Minimum levels for Lake Angelo (Table 1-2) were established by the District in 2007 and are currently included in Table 8-2 within Rule 40D-8.624(6), F.A.C. The Minimum Lake Level of 100.0 ft above the National Geodetic Vertical Datum of 1929 (NGVD29) and the High Minimum Lake Level of 101.3 ft NGVD29 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 2007 replaced management levels that had been adopted for Lake Angelo in 1981, including those which had initially been established as minimum levels (see Gant 1996, SWFWMD 2007, SWFWMD 2023a). The 2007 levels also included a High Guidance Level of 102.1 ft NGVD29 and a Low Guidance Level of 99.6 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 Angelo.

Minimum Levels	Stage Elevation (ft NGVD29)	Stage Elevation (ft NAVD88)
High Minimum Lake Level	101.3	100.1
Minimum Lake Level	100.0	98.8

To be considered met or achieved, the established minimum levels for Lake Angelo 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 2024 indicated the minimum levels established for the lake have continued to not be met (Leeper 2024). 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 Angelo is a 49-acre lake within the Southwest Florida Water Management District near the City of Avon Park within Highlands County, Florida (latitude 27.586313, longitude -81.466458) (Figure 2-1). Residential development primarily lines the northern and western shores of Lake Angelo, while citrus groves and patches of improved pasture dominate the landscape in the surrounding region of the lake. There is no public access to the lake.

Figure 2-1. Location of Lake Angelo in Highlands County, Florida.

2.2 Watershed and Structural Control

With a drainage area of approximately 351 acres, Lake Angelo lies within the Carter Creek drainage basin of the Kissimmee River watershed (USGS 2004a, b) (Figure 2-2). Rainfall that does not immediately infiltrate into the soils in the contributing watershed could potentially run off 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, residential development on the northwest shore and a moderately steep topographic gradient (discussed in Section 2.4) within the watershed serves to increase local runoff to the lake. Based on review of one-foot contour interval maps and field survey data, Lake Angelo does not have an outlet conveyance system. The lake is therefore considered a closed basin system and there is no Control Point elevation.

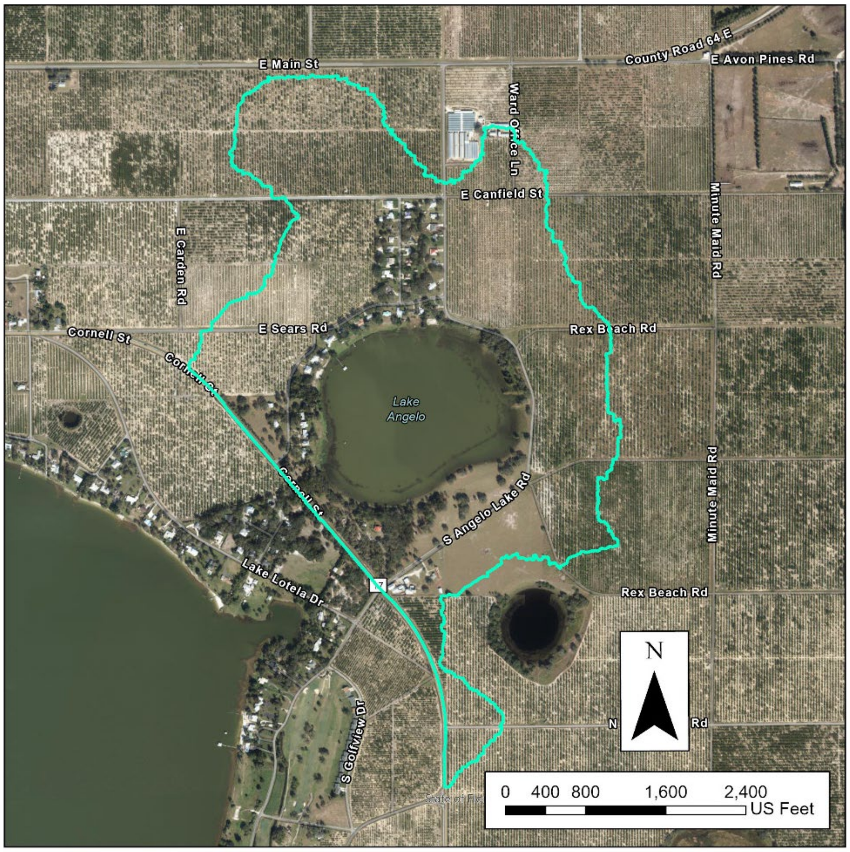

Figure 2-2. Lake Angelo watershed.

2.3 Stage History

The 1952 United States Geological Survey 1:24,000 Lake Arbuckle SW, Fla. quadrangle map (photo revised 1972, minor revision 1993) indicates an elevation of 92 feet above NGVD 29 (90.8 feet above NAVD 88) for Lake Angelo. Surface water elevations for Lake Angelo (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 2-3). The highest lake surface elevation based on period-of-record data collected through December 09, 2024, was 102.72 ft NGVD29 (101.77 ft NAVD88) and occurred on October 24, 2017. The record low, 90.31 ft NGVD29 (89.36 ft NAVD88), occurred on June 30, 2008. The data record for Lake Angelo 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 2024, the P10 (10^{th} exceedance percentile), P50 (median), and P90 (90^{th} exceedance percentile) stage elevations for Lake Angelo are 100.82, 97.05, and 93.36 ft NGVD29 (99.87, 96.10, and 92.41 ft NAVD88), respectively. These values yield a P10-P50 difference of 3.77 ft and P10-P90 difference of 7.46 ft. 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).

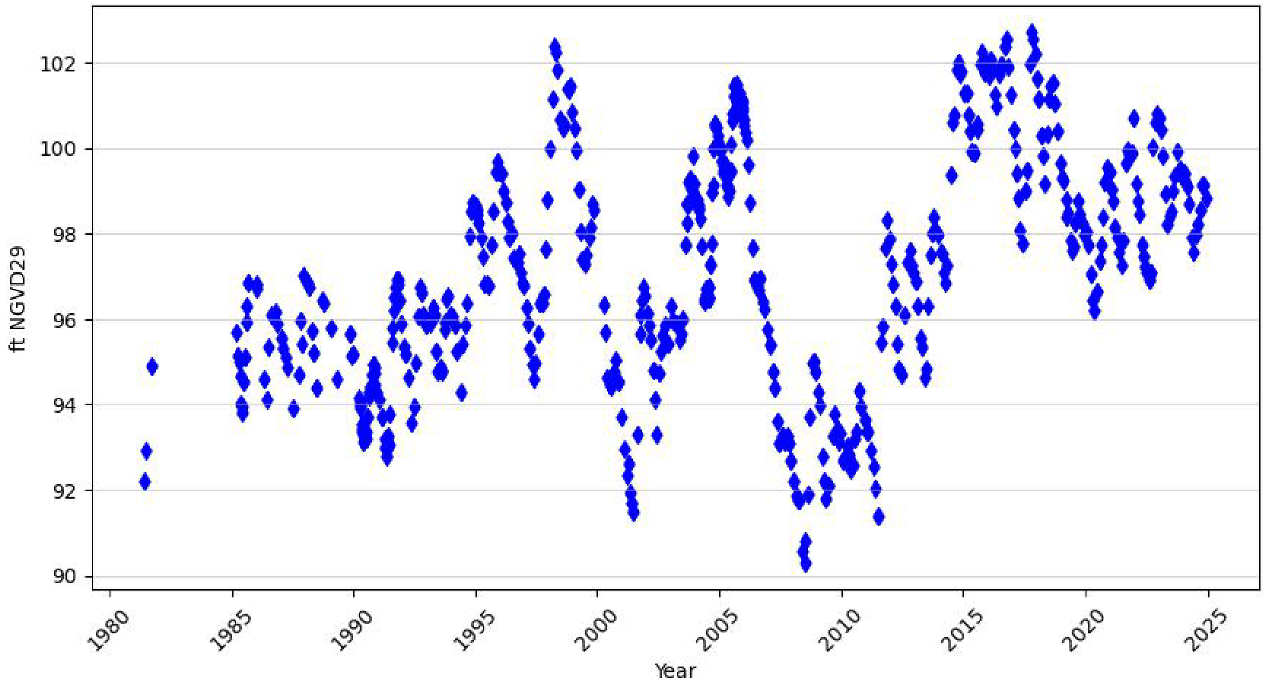

Figure 2-3. Lake Angelo water level (stage) observations (ft NGVD29) from June 11, 1981 through December 09, 2024.

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, inundated area, and total volume 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 Angelo 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 Angelo with the basin morphology to develop a single continuous 3D digital elevation model (DEM).

Two elevation data sets were used to develop the DEM. Light Detection and Ranging (LiDAR) data Snoopy A Series Velodyne 32-HDL sensor were merged with bathymetric data for the lake collected with both sonar and mechanical (manual) methods. The data collection process is outlined in SurvTech, Inc. 2021.

The combined elevation data sets were used to develop a DEM, 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 2-4).

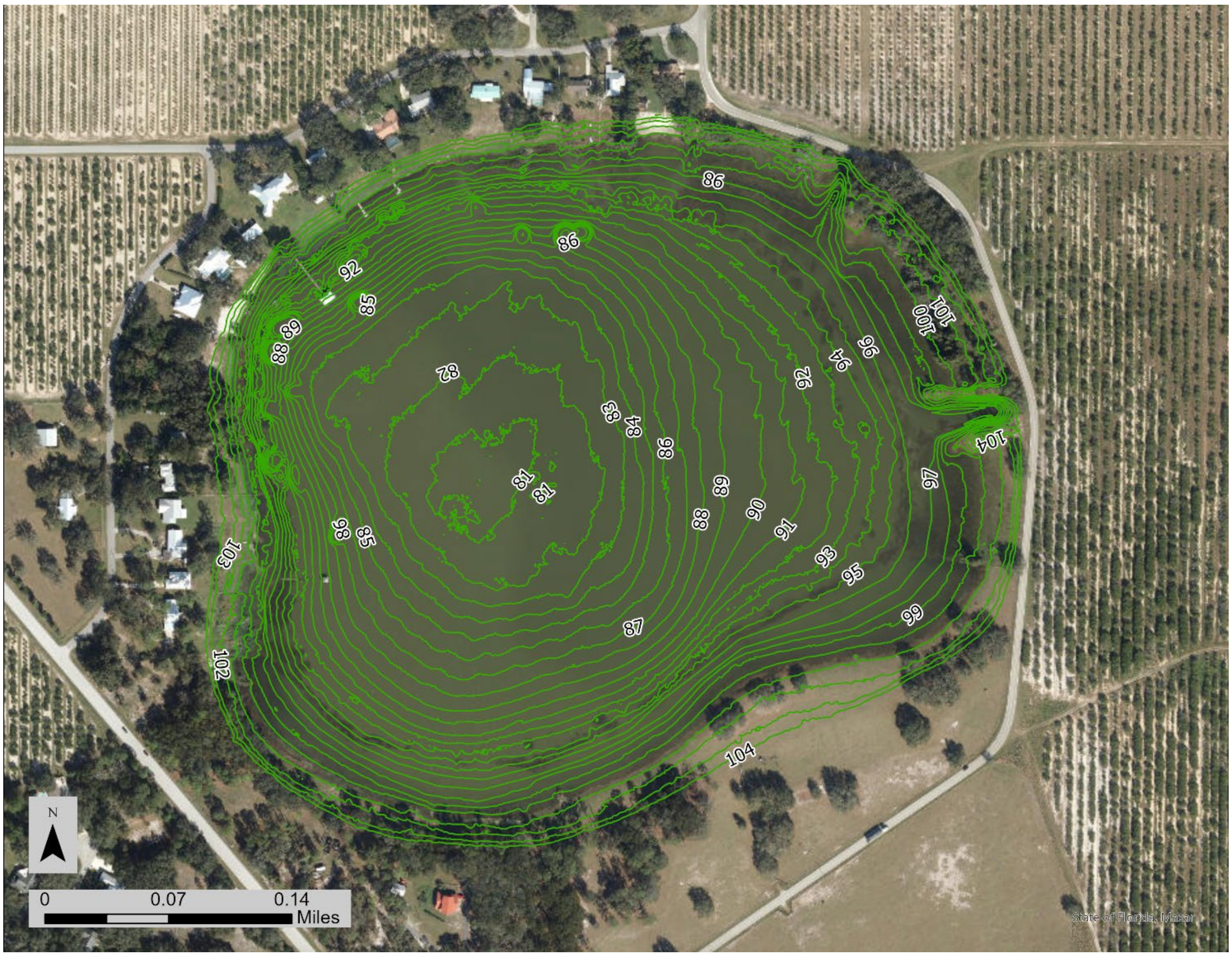

Figure 2-4. Topographic and lake bottom elevations (ft NGVD 29) of Lake Angelo.

Lake Angelo is a sinkhole lake with a bottom that grades toward a deep area near the center of the lake, with the deepest portion of the lake bottom occurring at an elevation of 80.2 ft NGVD29 in the central portion of the basin (Figure 2-4).

At the period-of-record median (P50) stage of 97.05 ft NGVD29, Lake Angelo extends over 52 acres. From the period-of-record P90 (93.36 ft NGVD29) to P10 (100.82 ft NGVD29) stages, the lake area varies from 41 to 65 acres. Surface area, maximum depth, mean depth, and volume relationships with lake stage are shown in Figure 2-5.

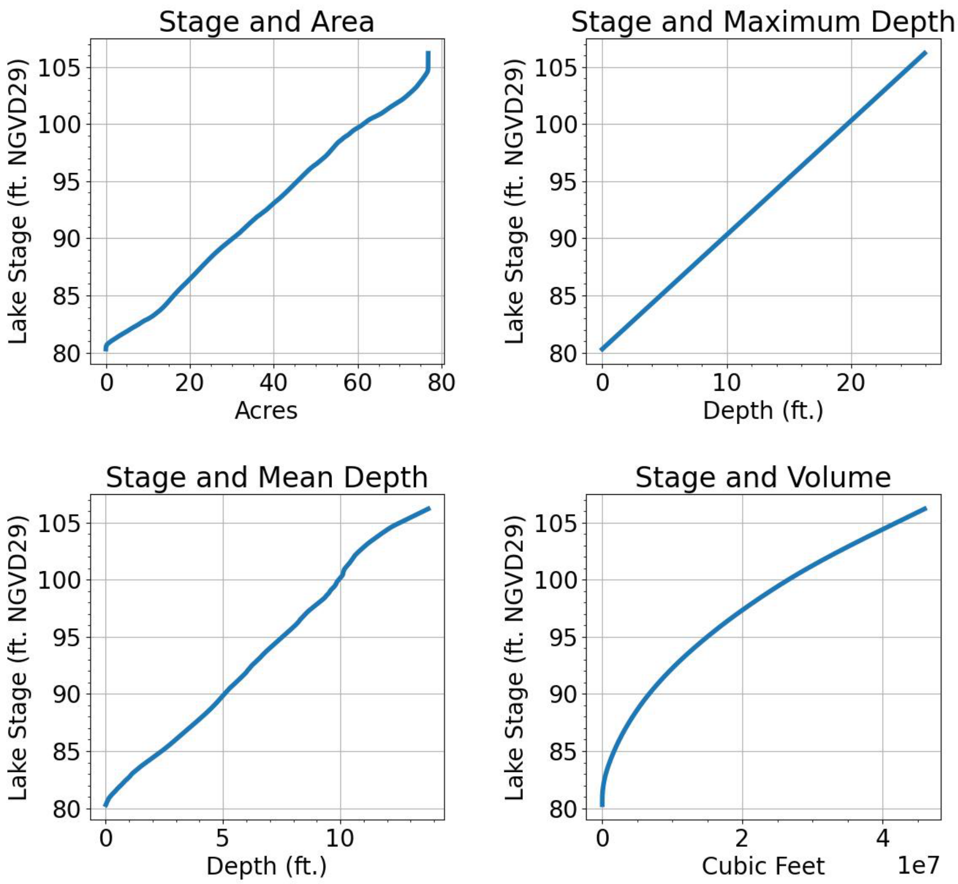

Figure 2-5. Surface area, maximum depth, mean depth, and volume versus lake stage for Lake Angelo.

2.5 Physiography and Soils

Lake Angelo lies within the Central Highlands of the Mid-peninsular physiographic zone of Florida, an area of 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 sinkhole lakes and basins formed from erosion of the underlying limestone bedrock. White (1970) classified the area containing Lake Angelo as the Intraridge Valley, a region of karst features that is surrounded by ridges that comprise the southern Lake Wales Ridge physiographic region (Figure 2-6). The Lake Wales Ridge is the highest and longest of the central-Florida ridges, with maximum elevations up to 305 ft NGVD29 (Spechler and Kroening, 2007). Within a few miles of Lake Angelo, land surface elevations range from approximately 100 to 150 ft NGVD29 (Figure 2-6).

Lake Angelo lies in an area of xeric upland soil groups characterized as “yellow sands” and “white sands”, with the two classes supporting distinct vegetative communities (Weekley et al., 2008). In support of District minimum level evaluations, GPI (2021a, 2021b) recently classified Lake Angelo as a xeric-associated system based on surrounding soils characteristics. Soils around Lake Angelo are primarily Group A Astatula series soils that consist of very deep, excessively drained, and 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).

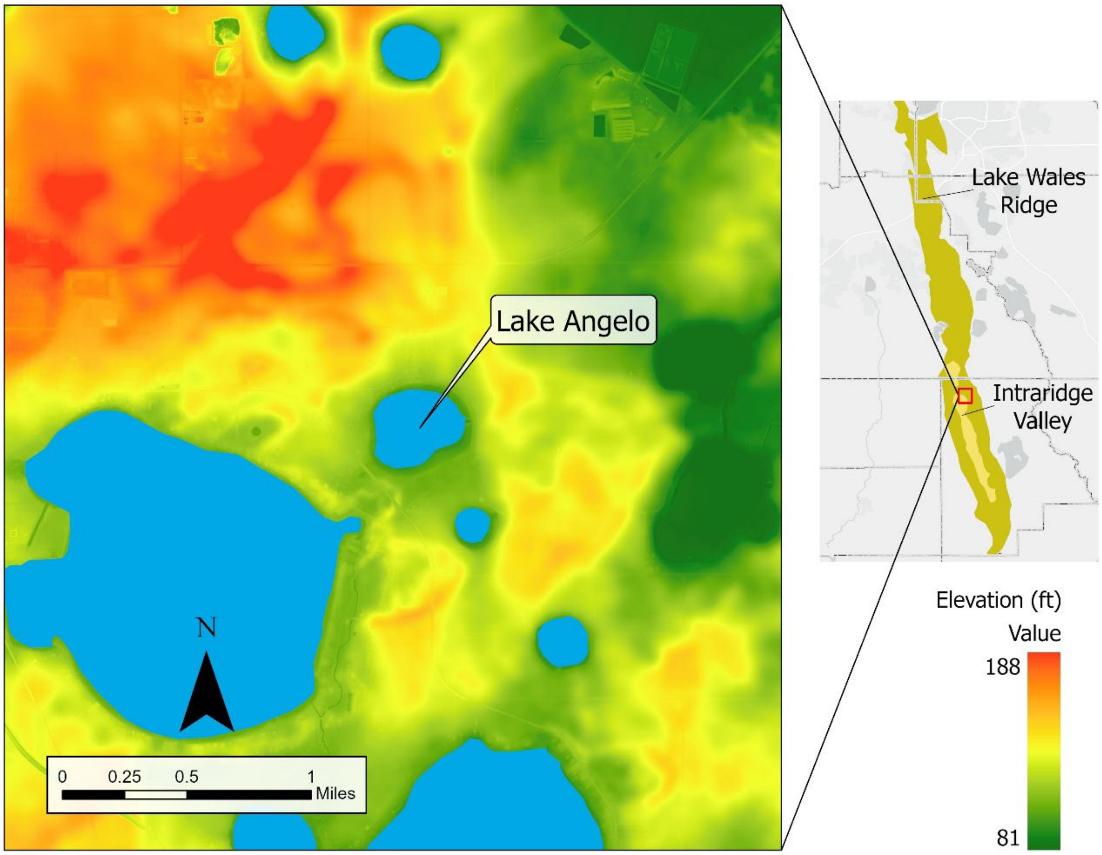

Figure 2-6. Land surface elevation (ft NGVD 29) near Lake Angelo within the Intraridge valley in Highlands County.

2.6 Land Use and Cover and Additional Wetlands Information

Uplands immediately adjacent to Lake Angelo are used primarily for residential development and agriculture (see Figures 2-7 and 2-8). Only a few homes are sited directly on the lake, primarily along the northern lakeshore. Cropland and pastureland occur along approximately three-quarters of the lake shoreline.

Land use/land cover (LULC) information for the area within the Lake Angelo watershed in 2020 and 1990 are provided in Table 2-1 and Figure 2-7. Agriculture is the primary form of land use and includes citrus groves, dairies, pasture, sod, and vegetable farms (Spechler, 2010), with citrus groves being the most common. Agricultural lands comprised 65 percent of the watershed in 2020, a moderate decrease from 71 percent in 1990. Additionally, Urban and built-up lands in the watershed increased from approximately 14 percent in 1990 to 19 percent in 2020. Several parcels of land around Lake Angelo were re-classified from Agriculture to Urban, from Forest to Urban, from Wetlands to Water, and from Urban to Water, but historical imagery around Lake Angelo (Figure 2-8) shows little change in land cover between 1994 and 2023. These observations suggest that land use data is classified differently in present day compared to the 1990s.

Table 2-1. Land Use Land Cover in the Lake Angelo watershed in 1990 and 2020.

	1990 LULC (acres)	% of total acreage	2020 LULC (acres)	% of total acreage
Urban and Built-Up	47	13.5	68	19.3
Agriculture	250	71.4	228	65.0
Upland Forests	10	2.8	0	0
Water	36	10.1	53	15.1
Wetlands	7	2.1	2	0.6

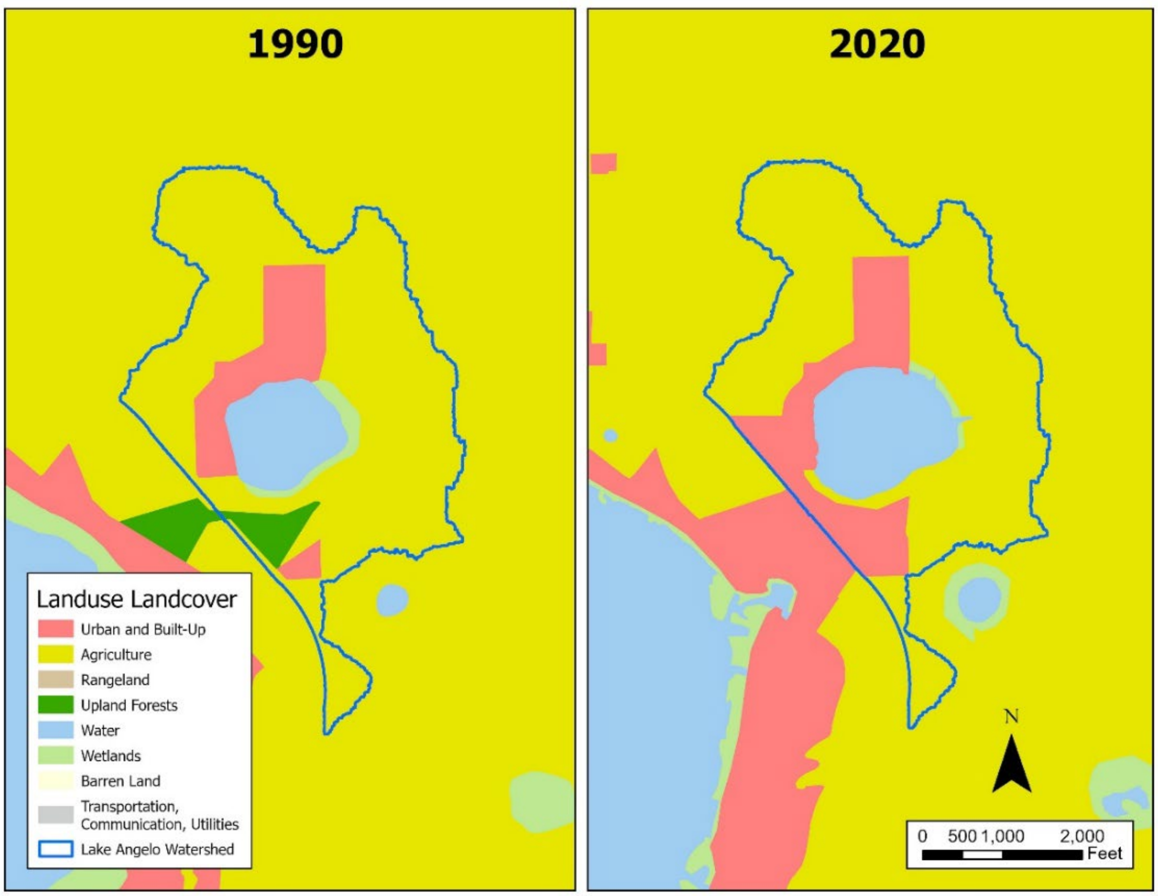

Figure 2-7. 1990 and 2020 Land Use Land Cover in vicinity of Lake Angelo.

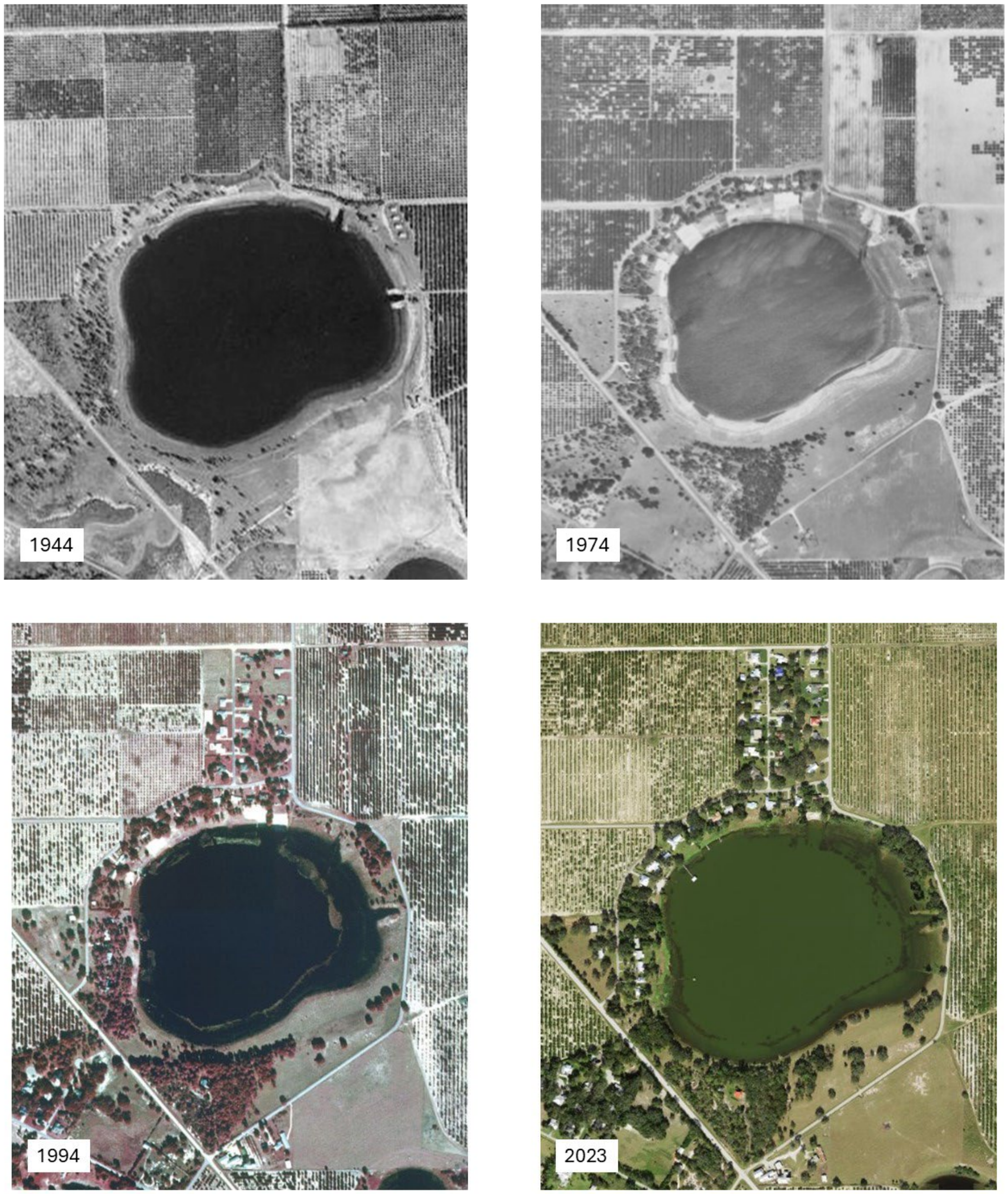

Figure 2-8. 1944, 1974, 1994 (infrared), and 2023 Aerial photographs of Lake Angelo.

Field surveys conducted at Lake Angelo since June 2023 indicate that knotted spikerush (*Eleocharis interstincta*) is the dominant emergent vegetation species, typically occurring at water depths between 3.8 and 6.0 feet. Additional commonly observed emergent species include cattails (*Typha* spp.) and maidencane (*Hymenachne hemitomon*).

The area available for aquatic plant growth was estimated for Lake Angelo based on a relationship of light attenuation as measured with Secchi depth (*SD*) and maximum depth of plant colonization (*MDC*). Using data from 2005 and 2022 for Lake Angelo obtained through the Florida LAKEWATCH monitoring program, the mean *SD* was 2.2 meters. Use of this Secchi depth with equation 2-1 below (where *MDC* and *SD* are in meters) from Caffrey et al. (2007) yielded an *MDC* value of 10.9 ft.

(Equation 2-1) $\log MDC = 0.66 \log SD + 0.3$

Based on a 10.9 ft *MDC* and stage-area information developed in support of the reevaluation of minimum levels for Lake Angelo (described in Section 2.4.2 of this document), the area available for aquatic plant colonization would range from 0 to 36.7 acres at water surface elevations from 80.3 to 106.2 ft NGVD29 in the Lake Angelo basin (Figure 2-9).

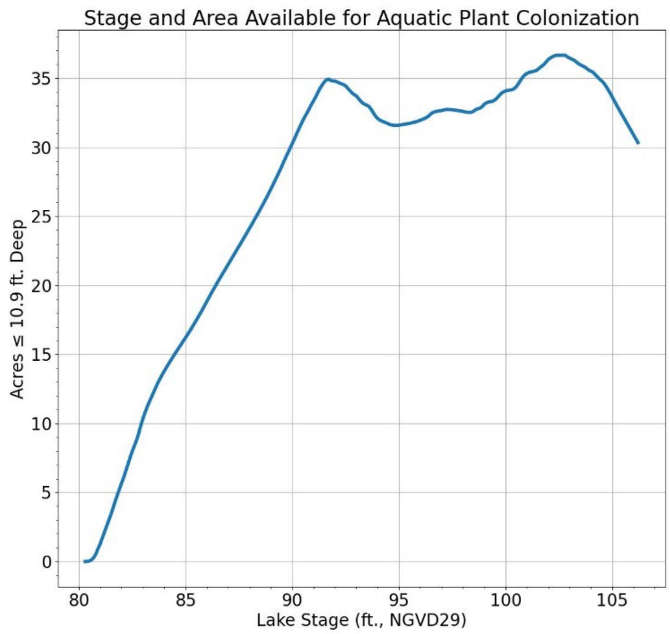

Figure 2-9: Lake stage and area available for aquatic plant colonization in Lake Angelo.

2.7 Climate and Rainfall

2.7.1 Climate

Highlands County lies within a humid subtropical zone that is influenced by the Gulf of America and Atlantic Ocean. The area experiences hot, humid summers with mean temperatures in the low 80s (ºF) and mild to cool winters with mean temperatures in the upper 50s (ºF). The annual mean daily temperature is approximately 72ºF (21ºC). Wet season rainfall occurs during the summer from June through October, with remaining months considered “dry season” months. Tropical storms and hurricanes mostly occur between August and the first half of October, which can lead to greater rainfall totals during the late summer and early fall.

Long-term rainfall in Florida is affected by an oscillation of North Atlantic sea surface temperatures known as Atlantic Multidecadal Oscillation (AMO) (Enfield 2001, Kelly 2004, Kelly and Gore 2008). AMO consists of a cool phase that leads to lower average rainfall and a warm phase that leads to higher average rainfall in Florida. In turn, water bodies within the District experience long-term periods of relatively high flows and levels that switch to periods of relatively low flows and levels. Because a full AMO cycle lasts 60-80 years (Enfield 2001), evaluations of water bodies in the District consider a time period of at least 60 years to best represent all climactic conditions.

2.7.2 Rainfall near Lake Angelo

Local rainfall in the vicinity of Lake Angelo for the period January 1996 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 dataset was also used as an input to the lake's water budget model (see Chapter 3).

Based on estimates from the dataset for Pixel ID No. 88530, which encompasses Lake Angelo, average annual rainfall for the period from January 1996 through December 2022 equaled 52.0 in/yr. This average is slightly below the long-term average (1915-2022) rainfall recorded in Highlands County of 52.1 in/yr derived from the District's annual hydrologic data. Using the NEXRAD data over Lake Angelo, annual rainfall departure from the Highlands County long term mean is shown in Figure 2-10. For the 1996 through 2022 period, the localized NEXRAD rainfall estimates resulted in a cumulative departure of -1.8 in from the long term mean of 52.1 in/yr. This estimated departure indicates rainfall conditions for 1996-2022 were nearly equal to long term rainfall conditions.

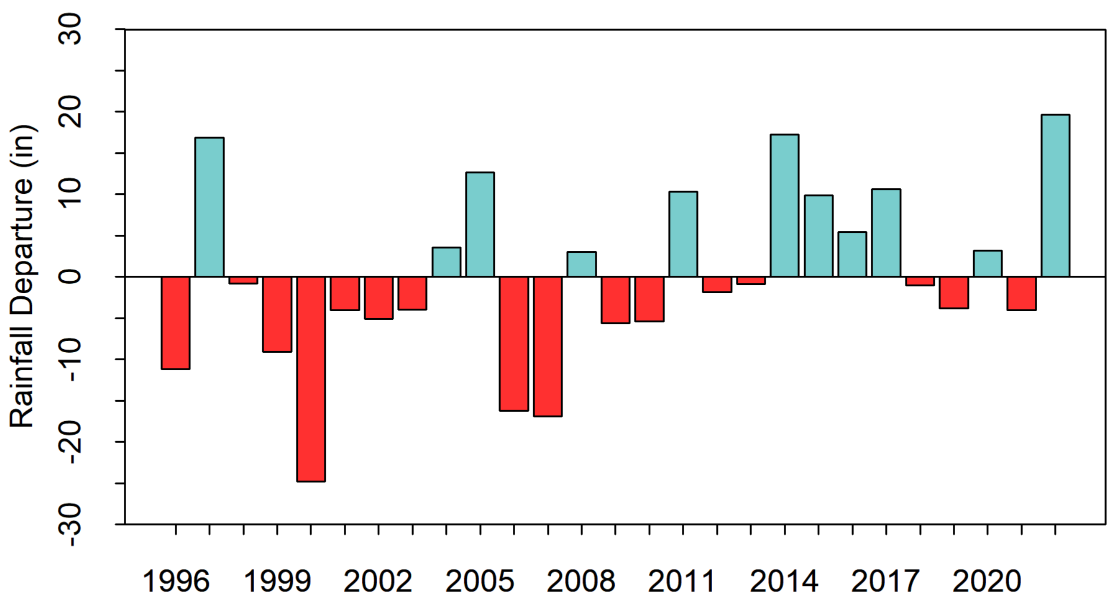

Figure 2-10. Annual rainfall departure at Lake Angelo from 1996 through 2022.

2.8 Hydrogeologic Setting

The hydrogeologic framework of the Lake Wales Ridge area includes a relatively thick unconfined surficial aquifer (SA), a variable thickness Hawthorn confining unit (HCU) and a thick carbonate upper Floridan aquifer (UFA). Lake Wales Ridge can provide high rates of recharge to the UFA depending primarily on the thickness and hydraulic conductivity of the overlying SA and HCU. Estimates of UFA recharge in the region range from 1 inch per year up to 20 inches per year

(Yobbi, 1986), typically with higher rates of recharge in the northern portion of Lake Wales Ridge (Aucott, 1988).

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 HCU.

The HCU 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 HCU. Withdrawals from the aquifers embedded in the HCU 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 groundwater withdrawals within Highlands County come from the UFA. Lake Angelo and the other lakes in the Lake Wales Ridge area of Highlands County provide recharge to the UFA through their subsidence features (Sacks et al., 1998). These lakes overlie a potentiometric high that separates two regional groundwater basins. 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 around 1930 (Figure 2-11).

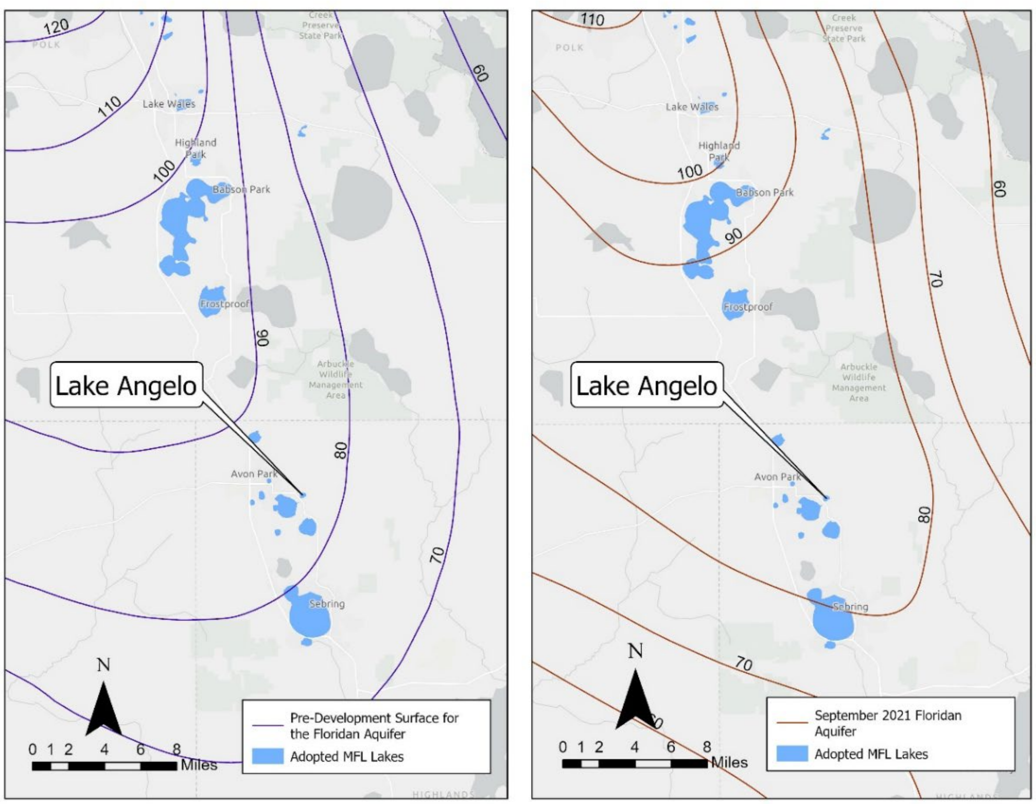

Figure 2-11. Pre-development upper Floridan aquifer (UFA) potentiometric surface (left panel) and September 2021 UFA (right panel) near lakes in Lake Wales Ridge.

2.9 Water Withdrawals

Ground water withdrawal permits near Lake Angelo result in 15-20 million gallons per day (mgd) of withdrawals within five miles of the lake (Figures 2-12 and 2-13). This estimate comes from the District's database containing geospatially distributed monthly groundwater and surface water withdrawal data and estimates for all permits extending back to 1992. The database is updated each year typically two-to-three years after the withdrawals occur (e.g., 2021 geospatial data became available in 2023). Estimated annual pumping for domestic self-supply (household) wells across the District is provided in another database that is updated concurrently with the permitted water use database. Lastly, there are no permitted surface water withdrawals from Lake Angelo.

Nearly all groundwater withdrawals within five miles of Lake Angelo are used for public supply, agriculture, and recreation (Figure 2-12). Within this area, 18.4 mgd were withdrawn in an average year in the period 1992-2021, and total withdrawals have been relatively stable (varying from 13.3 to 21.4 mgd) since the mid-2000s (Figure 2-13). Year-to-year variation is driven by agriculture while the remaining uses have accounted for an approximately constant 4.1 mgd over the 30-year period. In 2021, agricultural groundwater use comprised 76 percent of the total groundwater withdrawn within 5 miles of Lake Angelo. Public supply accounted for 17 percent of the total, while 7 percent was withdrawn for recreational use. Groundwater use for mining and industrial/commercial purposes was less than 1 percent of the total use.

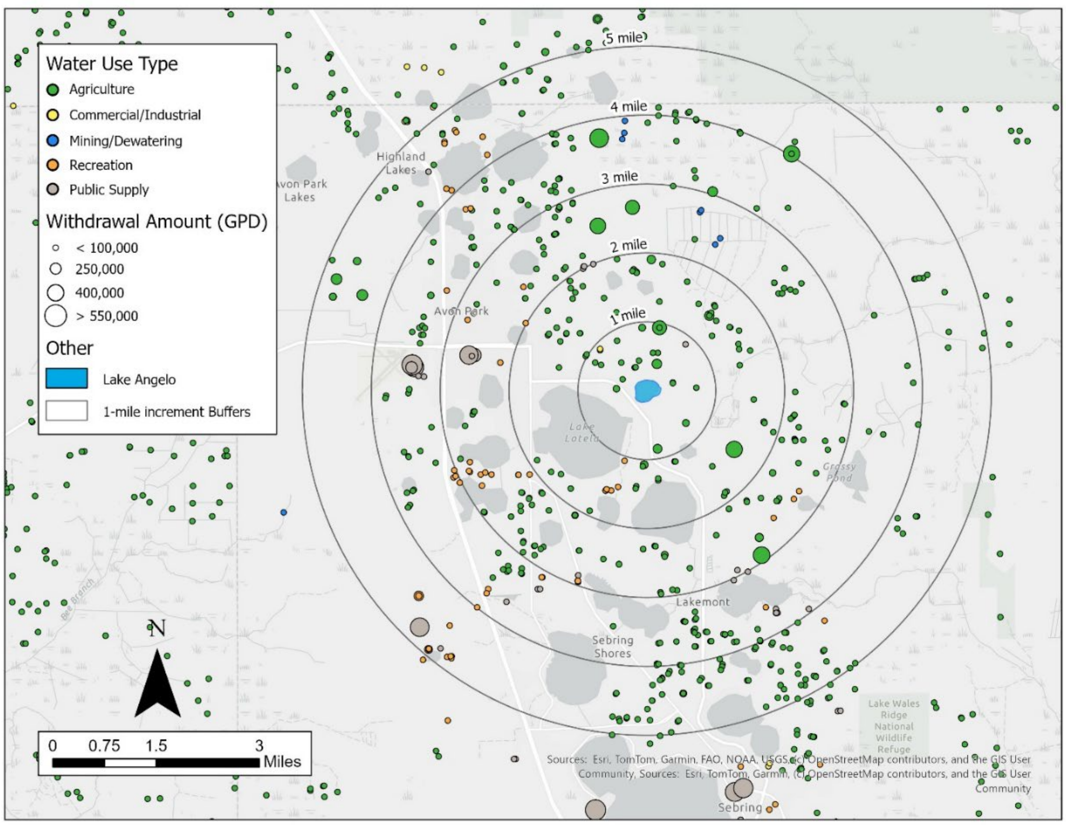

Figure 2-12. Permitted groundwater withdrawals in gallons per day (GPD) around Lake Angelo.

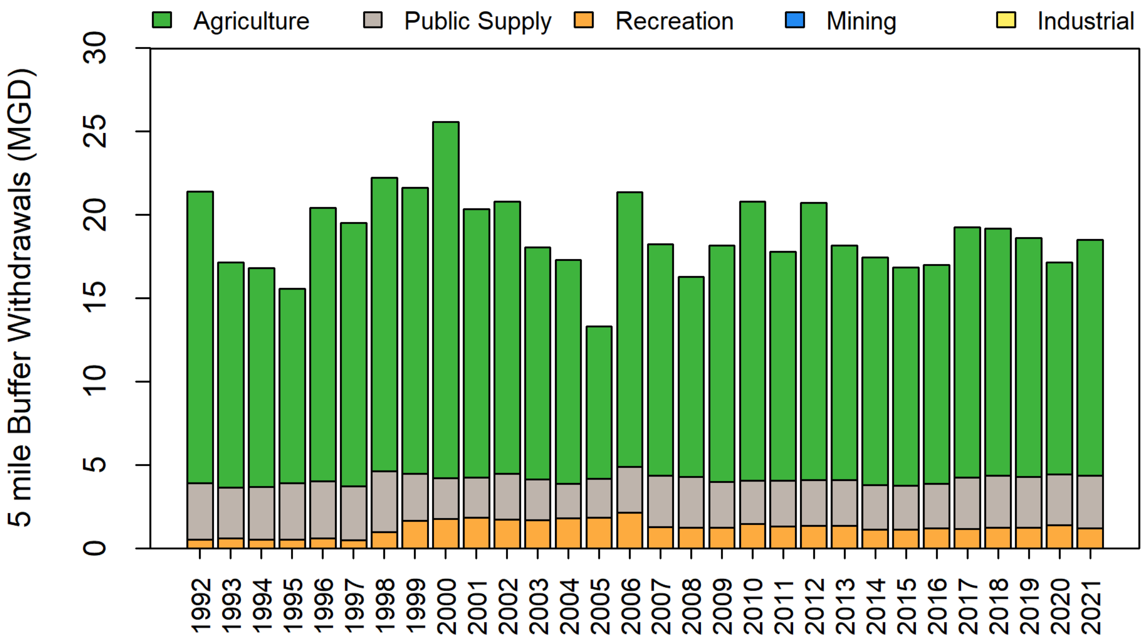

Figure 2-13. Annual average withdrawals within five miles of Lake Angelo.

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.

Annual average groundwater use within 5 miles of Lake Angelo has declined from 20.0 mgd for the period of 1992-2001 to 18.3 mgd for the period of 2012-2021 (Figure 2-13). The declines in groundwater use have occurred due to water conservation, higher rainfall, land use change, and increased use of reclaimed water. This long-term decreasing trend in water use near Lake Angelo is congruent with the implementation of Southern Water Use Caution Area (SWUCA) I rules in the early 2000s (Figure 2-14) that address conservation measures, alternative water supply development, and water use permitting requirements (SWFWMD 2023a, b). As part of the SWUCA Recovery Strategy, the District continues to work with users to develop alternative water supplies to meet water demands while reducing groundwater withdrawals when possible.

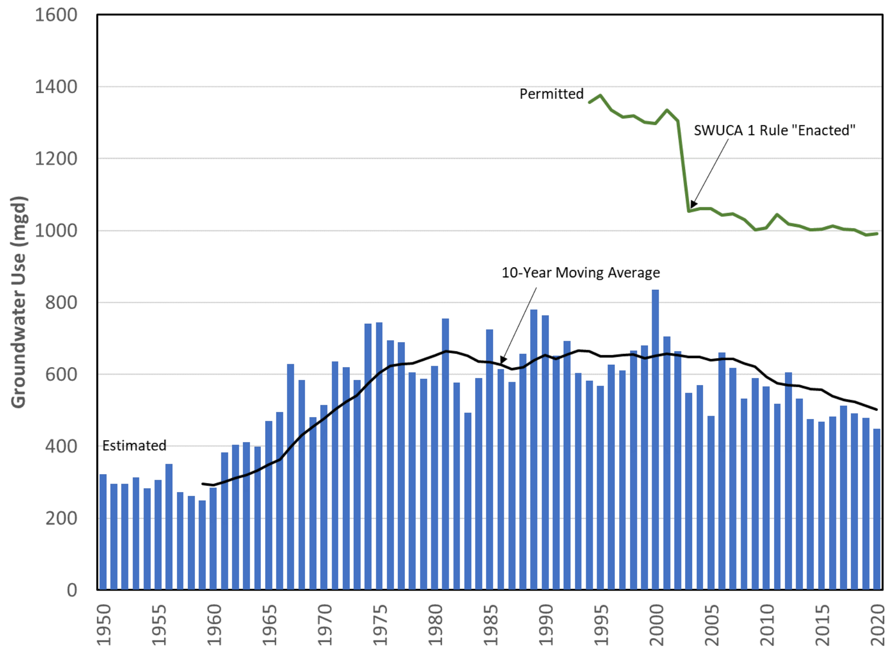

Figure 2-14. Groundwater withdrawals in the Southern Water Use Caution Area from 1950 through 2020 and permitted withdrawals for the area (image reproduced from SWFMWD, 2023).

CHAPTER 3 – WATER BUDGET MODEL FOR LAKE ANGELO

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). The change in lake stage or volume in a water budget is estimated as the difference between 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 estimate expected lake levels under historic conditions, i.e., in the absence of withdrawal impacts, given current structural alterations.

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 estimate lake water levels. The model developed specifically for Lake Angelo includes precipitation, evaporation, surficial aquifer fluxes, upper Floridan aquifer fluxes, overland flow, and directly connected impervious area (DCIA) runoff. Since Lake Angelo is a closed basin lake, surface outflow was not included in the model.

3.2 General Model Structure

The technical approach for lake water budget models at the District is summarized by Equations 3-1 and 3-2, where LS is the lake stage, $\triangle S$ is the change in storage, R is rainfall directly onto the lake, E is evaporation directly from the lake, UFA_{net} is the net exchange between the lake and upper Floridan aquifer, SA_{net} is the net exchange between the lake and surficial aquifer, O is overland flow into the lake from its watershed, and $DCIA$ is runoff from impervious surfaces directly connected to the lake. Change in storage is added to the prior day's lake stage (LS_{n-1}) to estimate lake stage for the current day (LS_n).

(Equation 3-1) $LS_n = LS_{n-1} + \Delta S_n$
(Equation 3-2) $\Delta S_n = R_n - E_n + UFA_{net,n} + SA_{net,n} + O_n + DCIA_n$

Both R and E in Equation 3-2 were estimated using only the input data, where rainfall data was collected daily. Monthly evaporation data was available from two studies at Lake Starr (i.e., Swancar et al., 2000, and Swancar, 2015) for the period of August 1996 through July 2011. Swancar (2015) showed that evaporation rates in central Florida lakes can be nearly identical to each other even when the lakes are 60 miles apart, and Lake Angelo is 26 miles south of Lake Starr. Thus, evaporation data from Lake Starr was considered appropriate for the Lake Angelo water budget from August 1996 through July 2011, and monthly normal evaporation rates from this dataset were used for all other months in the water budget model.

Lake Angelo was determined to have flow-through groundwater conditions based on local topography and SA water levels ($SA_{in,lev}$ and $SA_{out,lev}$) that were modeled using the ECFTX regional groundwater model (see Chapter 4 for details on this model). Thus, SA inflow and outflow were estimated separately as $SA_{in,n}$ and $SA_{out,n}$ using different data sources for each, with $SA_{net,n}$ being the difference between the two variables (Equations 3-3 through 3-5). The leakance coefficient between the lake and the SA (L_{SA}) is a calibrated parameter used in this estimation of SA flux.

(Equation 3-3) $SA_{net,n} = SA_{in,n} - SA_{out,n}$
(Equation 3-4) $SA_{in,n} = L_{SA}(SA_{in,lev} - LS_n)$
(Equation 3-5) $SA_{out,n} = L_{SA}(SA_{out,lev} - LS_n)$

Fluxes between Lake Angelo and the UFA were estimated similarly to SA flux using a calibrated leakance coefficient, L_{UFA}, shown in Equation 3-6 below, where UFA_{lev} is the water level in the UFA.

(Equation 3-6) $UFA_{net,n} = L_{UFA}(UFA_{lev,n} - LS_n)$

Both runoff variables, *DCIA* and *O*, were estimated using the SCS curve number methodology (NRCS, 1986). The percentage of the Lake Angelo basin that contributes DCIA runoff (*pDCIA*) and the curve number (*CN*) are calibrated parameters used in the estimation of *DCIA* and *O*. Harper and Baker (2007) outlined a procedure for estimating runoff in Florida based on seasonal rainfall patterns and vegetation conditions. Using this procedure (outlined in Chapter 4 of Harper and Baker, 2007) *DCIA* was estimated assuming an initial abstraction of 0.1 inches, and *O* was estimated using antecedent soil moisture conditions that vary between the growing (Mar-Sept) and dormant seasons (Oct-Feb). Both *DCIA* and *O* were estimated daily in the Lake Angelo water budget model and multiplied by the ratio of the watershed's land surface area (A_{WL}) to the area of Lake Angelo (A_L, which was estimated daily with the stage-area-volume relationship described in Chapter 2).

3.3 Lake Angelo Water Budget Model

3.3.1 Calibration Period

The calibration period for the Lake Angelo water budget model was January 1996 through December 2021. This period was selected based on available pumping data and well data for the surficial aquifer. Additionally, there was no structural alteration to the hydrology of the lake during this period. The average annual rainfall, using District rainfall data, from January 1915 to December 2021 was 52.1 in/yr, versus 51.3 in/yr for the water budget model time-period of January 1996 to December 2021. Thus, the water budget model calibration period represents slightly drier than normal conditions at the lake.

3.3.2 Input Data

The water budget model input data were obtained from the District's Environmental Data Portal (EDP) as indicated in Table 3-1 with locations shown in Figure 3-1. All water level data used in the model is shown in Figure 3-2. Lake stage data were obtained from the Lake Angelo staff gage (District Station No. 25501), with records from 1981 to present. Data collection frequency has varied through the period-of-record but has generally been sampled monthly.

SA water levels were obtained from the ROMP 43XX Surf Aq Monitor (District Station No. 25529), located approximately 1.5 miles northwest of Lake Angelo, and Lake Letta water level (District Station No. 23798), approximately 1.1 miles south of Lake Angelo. ROMP 43XX Surf Aq was used for SA inflows and Lake Letta water levels were used for SA outflows. Data collection for the well began in 1995, with various gaps and frequency. Data collection at the Lake Letta gage began in 1983, and water level recording has generally occurred monthly since 1991. For dates lacking water level values, linear interpolation was performed to produce a daily time series for use in the model.

UFA water levels were obtained from the ROMP 43XX U Fldn Aq Monitor well (District Station No. 25532), located approximately 1.5 miles northwest of Lake Angelo. 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, linear interpolation was performed to produce a daily time series for use in the model.

Rainfall data was obtained from an area-weighted average of NEXRAD pixels 88529, 88530, and 88056, which intersect the lake’s watershed. Daily rainfall totals are available without gaps from 1995 to the present.

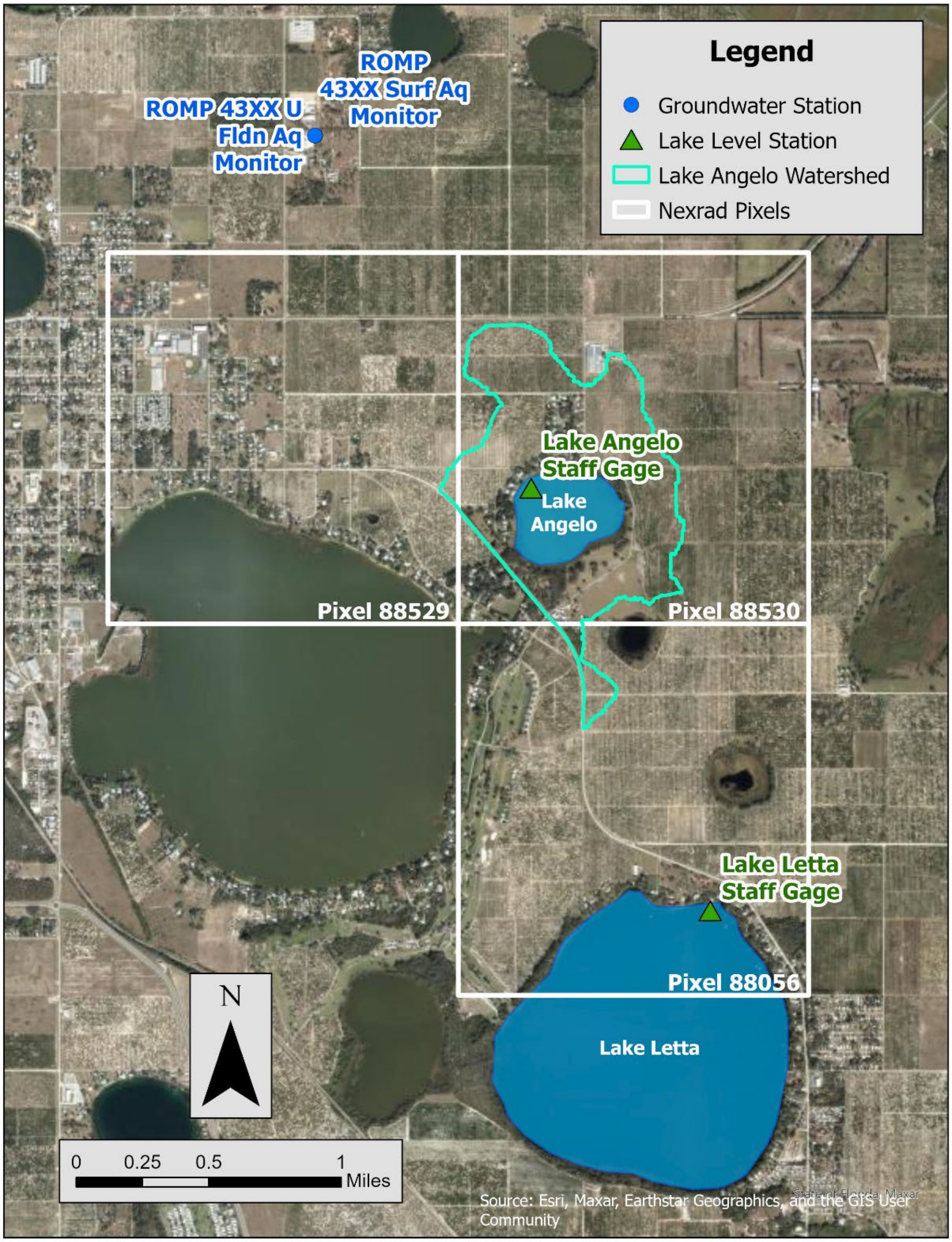

Figure 3-1. Locations of Lake Angelo and the data collection sites used for input data in the Lake Angelo water budget model.

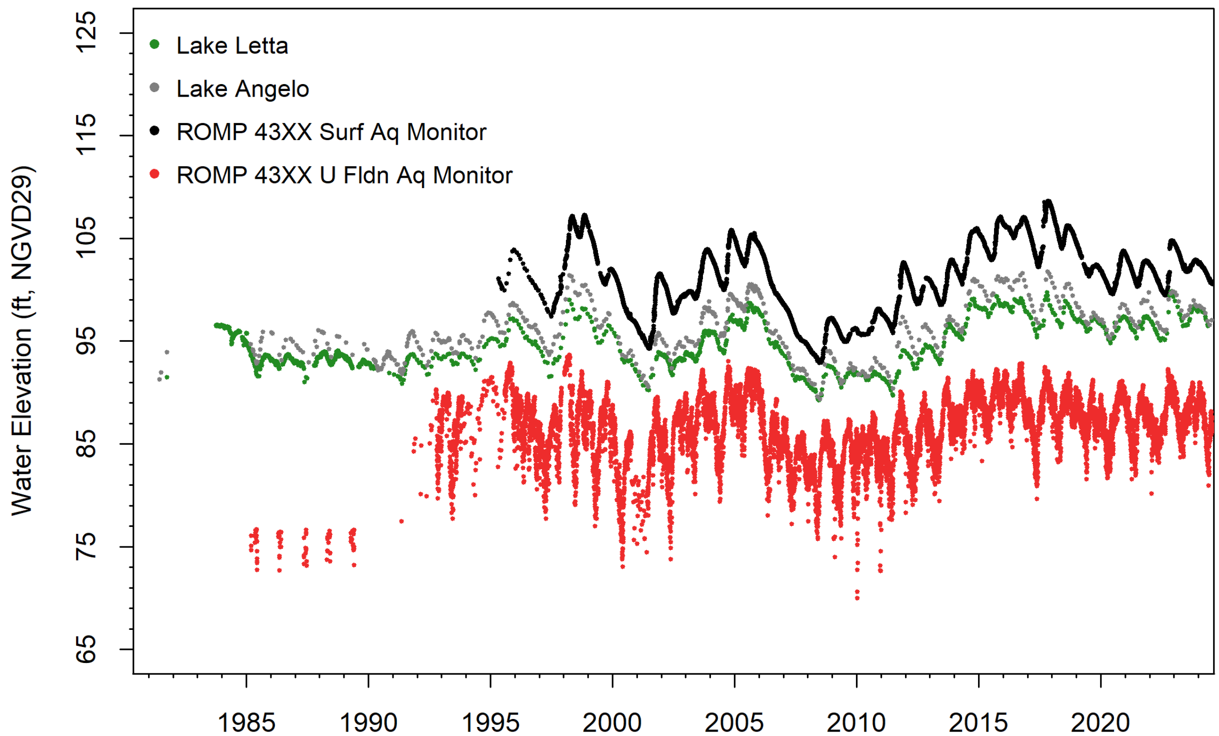

Figure 3-2. Observed water level data from the sites shown in Figure 3-1.

Table 3-1. Time series data input sources for the Lake Angelo water budget model.

Input Type	Station/Pixel ID(s)	Station Name(s)
Lake Water Level	25501	Lake Angelo
SA In Water Level	25529	ROMP 43XX Surf Aq Monitor
SA Out Water Level	23798	Lake Letta
UFA Water Level	25532	ROMP 43XX U Fldn Aq Monitor
Rainfall	88529, 88530, 88056	NEXRAD (Radar Rainfall)

3.3.3 Model Calibration

3.3.3.1 Calibration Approach

The objective of water budget model calibration is to minimize residuals between pairwise model and observation data by modifying calibration parameters. During calibration, model parameters and outputs must remain within an expected or realistic range of values given the physical setting of the lake. Model calibration is non-unique and there may be many combinations of parameter values that produce acceptable calibrations. However, the best match of simulated and observed lake stages may not best represent the physical system. Unrealistic parameterizations and fluxes should not be accepted even if they result in ostensible improvements in model performance relative to a more realistic parameterization.

The realism of modeling efforts is best assessed by verifying calibrated parameters and model output (i.e., the water balance) against independent data. This practice provides more certainty to model predictions as more realistic parameterizations better represent the physical system under a variety of conditions. Ultimately, professional judgement is used to select 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, A_W, was determined to be 351 acres using a subbasin delineation available from a regional floodplain study (Ardaman and Associates, 2013). This delineation is consistent with digital elevation data and stage-area-volume information developed from survey data (see Figures 2-4, 2-5).

The curve number, *CN*, was calibrated to a value of 58. This value was guided by site visits, review of soils and land use geospatial data (Figure 2-7). This curve number is relatively high for the thick, well-drained, sandy soils in a deep water-table setting that characterize the Lake Wales Ridge (Basso, 2019), but it is close to an area-weighted estimate of soil and land use geospatial data and reflects the steep topography within the basin (Figure 2-6). Steep topography has been shown to increase *CN* in various watersheds (Ajmal et al., 2020).

The portion of the watershed which is directly connected impervious area, *pDCIA*, was calibrated to a value of 0.0. This value was guided by site visits and National Land Cover Database (NLCD) data for 2021 (Dewitz, 2021). The NLCD data suggests approximately 7% of the watershed is impervious, but these impervious surfaces are not directly connected to the lake.

Information available in floodplain studies (Ardaman and Associates, 2013) led to Lake Angelo being classified as a closed basin. Although surface outflow can occur when water levels exceed 109 ft NGVD29, this exceeds the observed maximum lake water level and the modeled 100-year, 24-hour flood elevation of approximately 102 ft NGVD29 (Ardaman and Associates, 2013). Therefore, no channel outflow occurs in the model, nor does the lake have channel inflow from another waterbody.

3.3.3.3 Groundwater Fluxes

SA inflows were modeled by using water levels of both ROMP 43XX Surf Aq Monitor and applying a constant adjustment of -3.9 ft, i.e., a 3.9 ft decrease, for inflows. SA outflows were modeled by using water levels of Lake Letta and a constant adjustment of 1.0 ft for outflows. These shifts were guided by expected flow-through conditions at the lake (Lee, 2002; Sacks, 2002), ECFTX-modeled SA water levels and water-table depths near the lake, and topographic differences between the well and the area around the lake (Figures 2-6 and 3-2). Additionally, the SA leakage coefficient, L_{SA}, was calibrated to a value of 9.0×10^{-3} ft/d/ft. Calibration of both L_{SA} and SA level adjustments considered the long-term SA influx, which remained consistent with isotope-derived groundwater flux estimates for Lake Angelo of 34-55 in/yr provided by Sacks (2002).

Both the ROMP 43XX U Fldn Aq well and Lake Angelo are near the 80-ft contour of the UFA potentiometric surface (Figures 2-11). Because both the well and the lake have similar proximity to this contour line, only a minimal adjustment (if any at all) may be necessary for the well to be representative of UFA water levels under the lake. This led to a well level adjustment of -1.0 ft.

The UFA leakance coefficient, `L_UFA`, was calibrated to a value of 3.6x10^{-4} ft/d/ft. This value 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 (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).

3.3.3.4 Model Performance

Errors occur due to the model's inability to completely represent the physical system and due to uncertainties associated with inputs and parameters used in the models. Winter (1981) provides a summary of uncertainties and errors associated with lake water budgets. Because the MFL rules described in Chapter 1 are stated in terms of percentiles, the water budget model performance is graded on percentile error, while using model fit statistics (e.g., mean error, maximum/minimum error, R^2) as guidance. Ideally, residuals in the P10, P50, and P90 will be less than a tenth of a foot, though water budget errors may prevent this objective. The P50 residual is regarded as most important as the MLL is defined by the 50th percentile. Once the P50 residual is less than ±0.1 ft the P10 residual becomes the next objective, followed by the P90 residual. Both the P10 and P90 residuals may be greater than ±0.1 ft to avoid affecting the P50 residual while maintaining the objective of minimizing these residuals.

The final calibrated Lake Angelo water budget model is acceptable for the purposes of characterizing long-term water level percentiles in support of minimum levels development for Lake Angelo. The parameterization (Table 3-2) produced fluxes within expected values (Table 3-3) and met the percentile performance objectives described above (Table 3-4). Model-predicted water levels match the pattern and magnitude of observed water levels (Figure 3-3).

Table 3-2. Parameters for the calibrated Lake Angelo water budget model.

Parameter	Value
SA Leakance Coefficient, `L_SA` (ft/d/ft)*	0.009
SA Inflow Water Level Adjustment (ft)*	-3.9
SA Outflow Water Level Adjustment (ft)*	1.0
UFA Leakance Coefficient, `UFA_L` (ft/d/ft)*	0.00036
UFA Water Level Adjustment (ft)*	-1.0
Curve Number, CN_{II}*	58
DCIA Proportion of Watershed, `P_DCIA`*	0
Watershed Area (including lake), `WS_AREA` (ft^2)	15,273,800
Outflow Efficiency Coefficient†	Not applicable
Control Point (Outflow) Elevation (ft)†	109

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

Table 3-3. Average annual water balance for the calibrated Lake Angelo water budget model.

Flux	In (in/yr and percentage of total flux)	Out (in/yr and percentage of total flux)	Net (in/yr)
Atmosphere			-6.9
Rainfall	51.3 (56%)	-	
Evaporation	-	58.1 (63%)	
Groundwater			
Surficial Aquifer	31.1 (34%)	15.0 (16%)	-16.1
Upper Floridan Aquifer	0 (0%)	18.7 (20%)	-18.7
Surface Water			9.1
Overland Flow	9.1 (10%)	-	
DCIA	0 (0%)	-	
Channel	-	0 (0%)	
Total	91.4 (100%)	91.8 (100%)	-0.4

Table 3-4. Exceedance percentile residuals for the calibrated Lake Angelo water budget model. Negative values indicate model underprediction.

Metric	Unit	Value
P10 Residual	feet	0.0
P50 Residual	feet	0.0
P90 Residual	feet	0.0

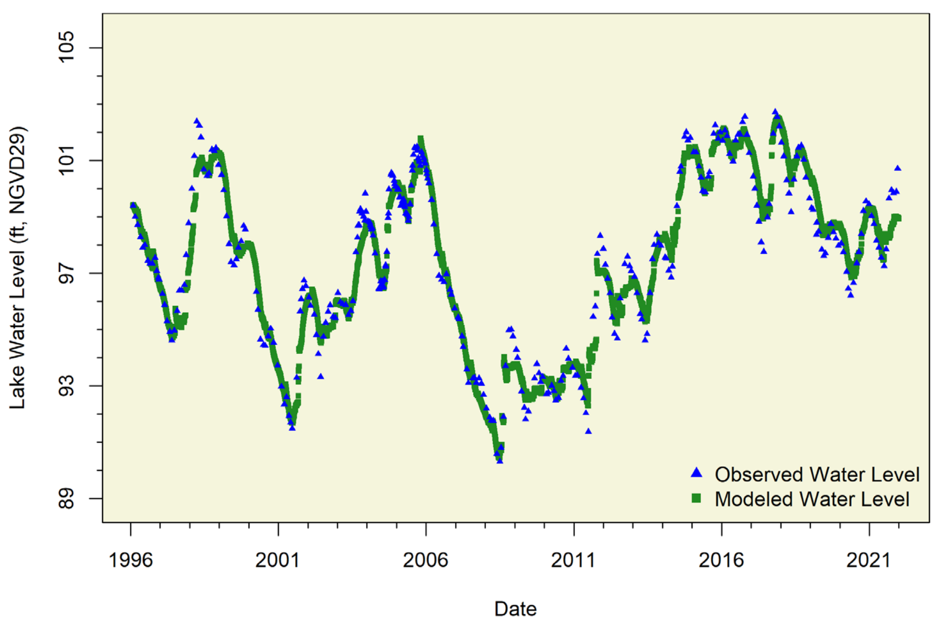

Figure 3-3. Observed and pairwise modeled lake water levels for the calibrated Lake Angelo water budget model.

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 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 Angelo are described in this chapter.

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

The East Central Florida Transient Expanded (ECFTX) model was used to predict long-term drawdown in the SA and UFA at Lake Angelo. 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 America 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, intermediate aquifer system (IAS), UFA, LFA, and associated intermediate and middle confining units. The ECFTX version 2.0 model (CFWI-HAT 2022) was developed to improve the original model calibration, support water supply planning decisions, regulatory decisions, and help determine withdrawal impacts in areas where critical water bodies with established MFLs are located.

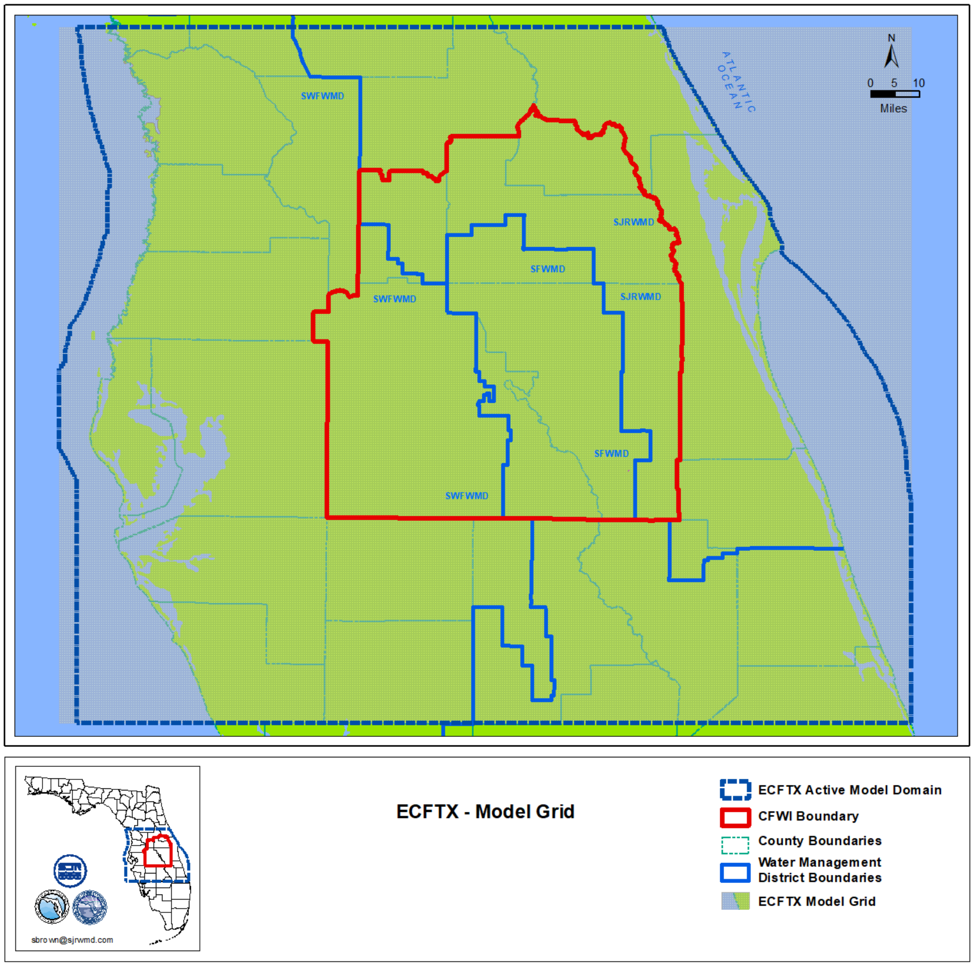

Figure 4-1. The ECFTX model domain in central Florida.

4.1.1 Monthly Drawdown

Monthly drawdown values for the UFA and SA were developed using data from ECFTX version 1.0 model for cells intersecting Lake Angelo for the 2004 through 2014 time period. Drawdown was calculated by comparing reduced pumping and actual pumping scenario results. The reduced pumping scenario used a 50 percent reduction in groundwater withdrawals (including associated return water from the recharge package) across the model domain from 2003 through 2014. The difference between simulated heads in the UFA from this scenario and those from the calibrated model represent aquifer water level changes associated with a 50 percent reduction in withdrawals. This change in water level was then doubled to estimate UFA drawdown associated with a 100 percent reduction in withdrawals, which would approximate a “pumps-off” condition. This procedure had previously been used by the CFWI-HAT Team in 2020 and in 2025 to estimate current withdrawal impact to water bodies with established minimum flows and levels as part of the CFWI regional water supply planning process.

Drawdown in the SA is difficult to characterize due to high local variability. However, a lake-specific estimate of SA drawdown is necessary for characterizing fluxes between the lake and the SA in the Historic version of the lake’s water budget model. Thus, an estimate of SA drawdown was developed for Lake Angelo based on work conducted by Hancock and Basso (1999) for the northern Tampa Bay area, which indicates that given the leakance coefficient of the UFA in ft/d/ft (L_{UFA}), the ratio of SA to UFA drawdown (DD_{SA}/DD_{UFA}, ft/ft) can be calculated using Equation 4-1. This 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 in the northern Tampa Bay area.

(Equation 4-1) $$\frac{DD_{SA}}{DD_{UFA}} = \frac{L_{UFA}}{8.3\times10^{-4}+0.98\times L_{UFA}}$$

Results from the ECFTX model are the most accurate source available for monthly drawdown estimates near Lake Angelo, but these results capture less than half the period used for water budget model calibration. In previous District minimum lake level investigations (e.g., Campbell & Patterson, 2020; Campbell & Sealy, 2020; Venning & Cameron, 2020; Hurst et al., 2019; Sutherland et al., 2021; Campbell et al., 2021), linear relationships between drawdowns and pumping in the UFA have been identified to extend drawdown records beyond time periods or scenarios currently available from groundwater models. The approach recommended by the CFWI-HAT for calculating drawdown using the ECFTX model also assumes a linear response of UFA drawdown to pumping changes. Thus, to extend available monthly drawdown estimates from the 2004-2014 period to the 1996-2021 water budget model period for Lake Angelo, a linear relationship was developed between modeled monthly UFA drawdown in ECFTX model cells that underlie the lake and average monthly pumping within a 5-mile radius of the lake (Figure 4-2). Monthly pumping data used for the regressions were obtained from the District's estimated and metered groundwater withdrawals database described in Section 2.9 of this report. Domestic self-supply (DSS) withdrawals were not included in the water use estimates due to their relatively small contributions to overall withdrawals.

The 5-mile radial distance gives a localized regional representation of the pumping-drawdown relationship in the UFA. Pumping limited to shorter radial distances may not include larger withdrawal permits that could have a strong influence on the drawdown at the lake, and the inclusion of pumping within longer radial distances may include withdrawals in areas of different hydrogeology from the area around the lake. The use of withdrawal data within both a 4-mile and a 6-mile radius was tested in the Historic water budget model (see Section 4.2) and produced Historic P50 lake stages identical to that developed from the 5-mile radius.

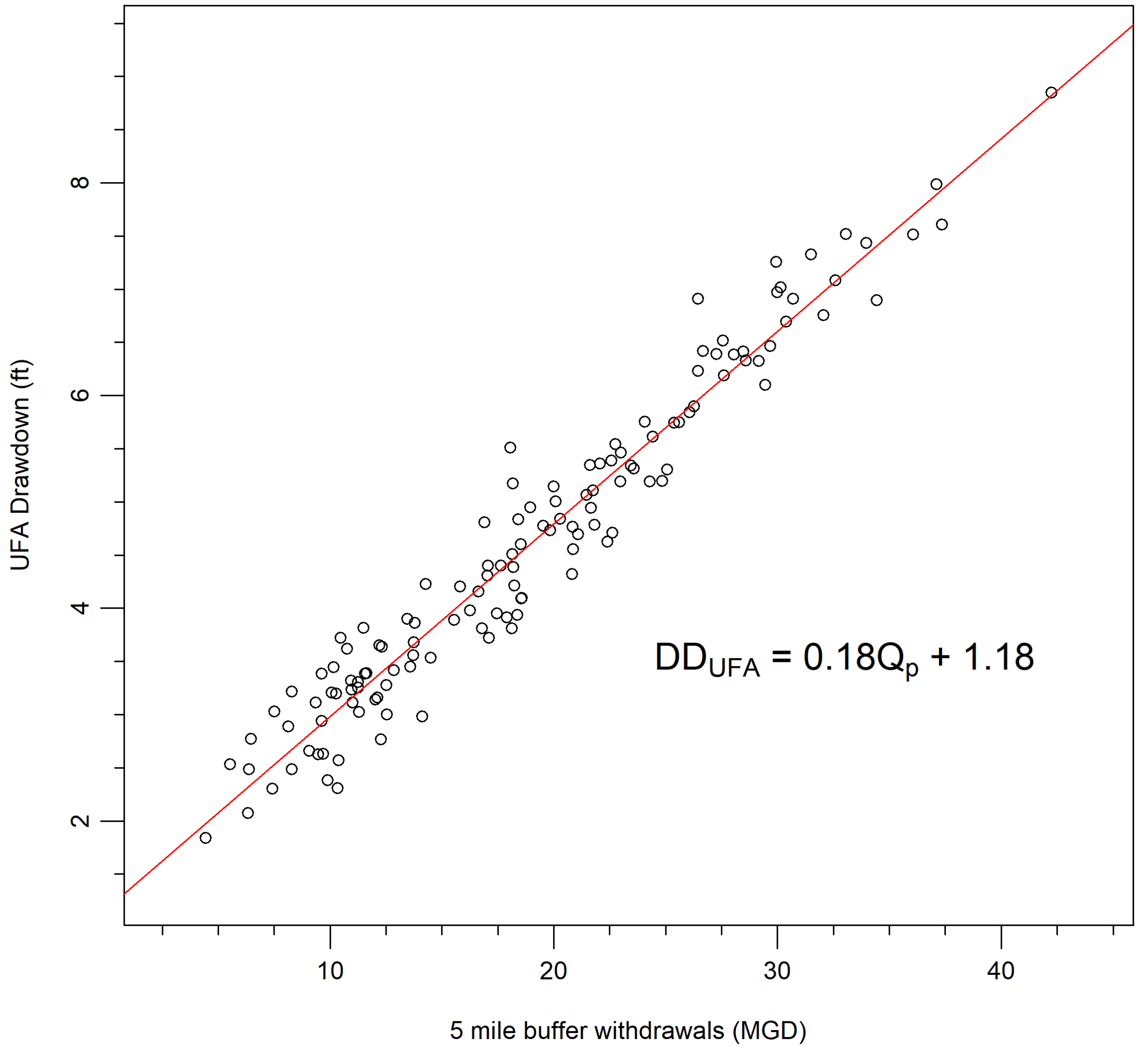

Figure 4-2. Linear regression between monthly drawdown in the UFA (DD_{UFA}) and monthly pumping (Q_p) in million gallons per day (MGD) within 5 miles of Lake Angelo.

The 5-mile pumping regression was used with 1996-2021 5-mile estimated/metered monthly pumping data to estimate monthly UFA drawdown for the 1996-2021 period used in the Lake Angelo water budget model (Figure 4-3, top panel). Equation 4-1 was used with inputs of the monthly UFA drawdown estimates from the ECFTX model and the calibrated value of 3.6×10^{-4} ft/d/ft for Lake Angelo to estimate monthly SA drawdown for the 1996-2021 period (Figure 4-3, bottom panel). The regression-predicted drawdown values for the periods from 1996-2003 and 2015-2021 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 1995-2021 for use in the Lake Angelo water budget model to simulate Historic water levels, as described in Section 4.2.

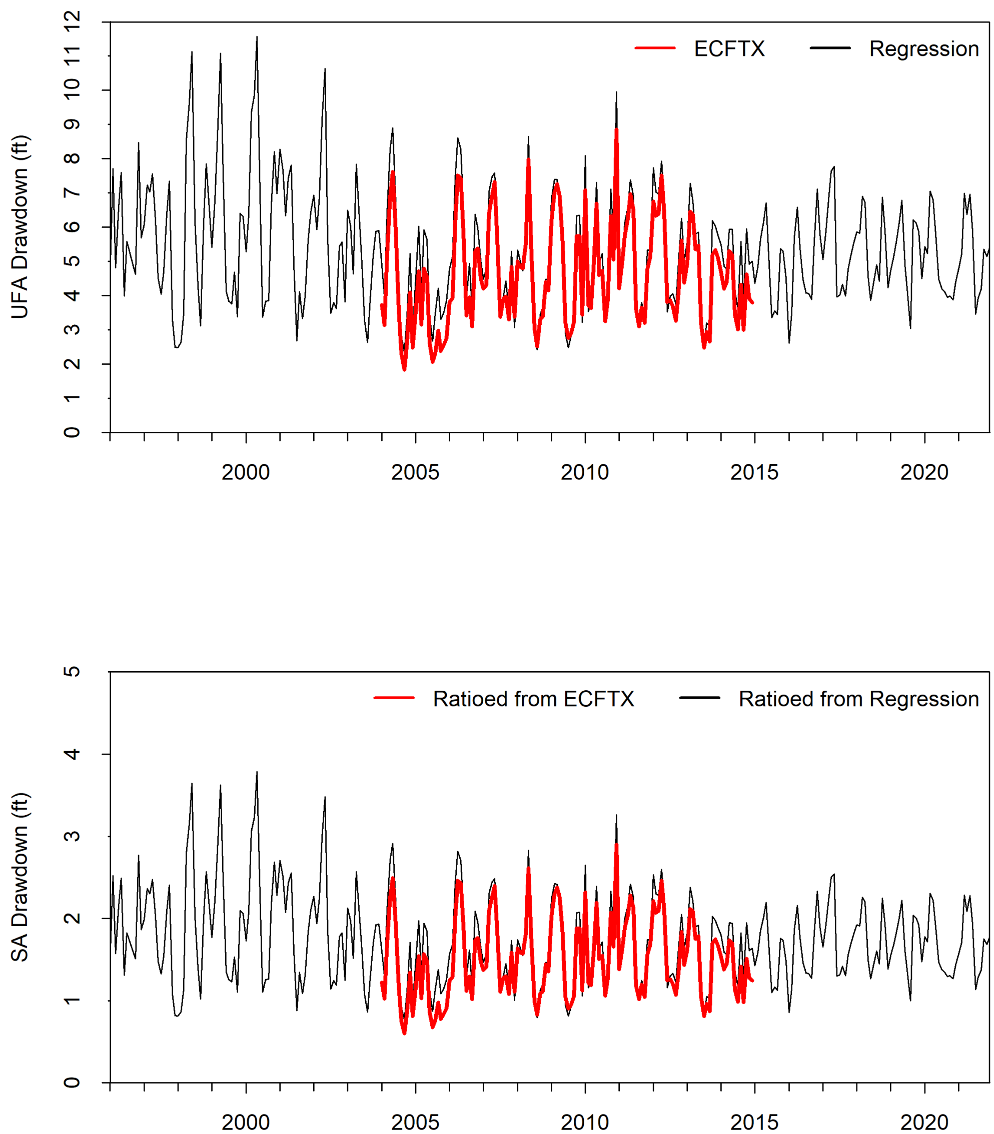

Figure 4-3. Monthly UFA (top panel) and SA (bottom panel) drawdowns for Lake Angelo (red line) and a pumping-drawdown regression using pumping within 5-miles of the lake (black line).

4.2 Historic Lake Angelo Scenario and Historic Stage Records

4.2.1 Historic Water Budget Model Development

The calibrated Lake Angelo water budget model, described in Chapter 3, represents current conditions at the lake and can simulate lake levels for the period from January 1996 through December 2021. Groundwater level inputs used for model calibration include water level data that were impacted by withdrawals at the time of data collection. These impacts must be removed to represent the Historic condition. Thus, SA and UFA groundwater level time series inputs were adjusted upwards in the calibrated water budget model to offset drawdown in each aquifer. This

Historic scenario provided a means to estimate water levels expected in the absence of withdrawals, given existing or similar structural alterations.

The UFA and SA monthly drawdown estimates for Lake Angelo (described in Section 4.1) minimize bias in the stage exceedance percentiles associated with water level higher than the Historic P50, as a constant long-term average drawdown would overpredict drawdown during periods of higher-than-average water levels. The use of monthly drawdowns is also supported by the acceptable calibration of the ECFTX near Lake Angelo and the strength of the pumping-drawdown relationship for the UFA developed for the lake.

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 4.1.1, 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). Then, the water budget is recalculated using the calibrated parameters (Table 3-2), and lake water levels are predicted 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 January1996 through December 2021, are provided in Figure 4-4 and Table 4-1. In the absence of withdrawals, the P10, P50, and P90 for Lake Angelo would increase 1.5, 1.6, and 0.6 ft respectively, relative to comparable percentiles predicted for the model calibration condition. The Historic P10, P50, and P90 were predicted to be 1.5, 1.6, and 0.6 ft higher than the observed P10, P50, and P90 respectively.

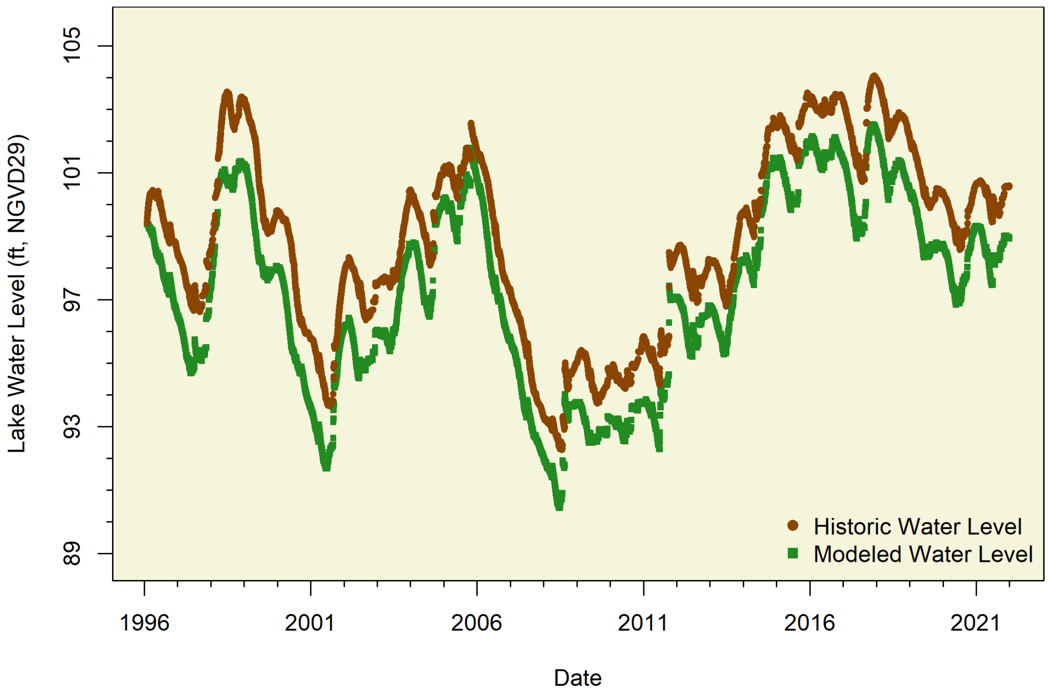

Figure 4-4. Lake Angelo water levels from calibrated and Historic water budget model scenarios.

Table 4-1. Comparison of exceedance percentiles for observed water levels and water levels from water budget model scenarios.

Percentile	Observed (ft NGVD29)	Calibrated (ft NGVD29)	Historic (ft NGVD29)
P10	101.3	101.3	102.8
P50	98.0	98.0	99.6
P90	93.3	93.3	93.9

4.2.3 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 increasing estimated Historic lake water levels. Also, for lakes with structures, structure efficiency dampens inflow/outflow for water levels above structure elevation. Uncertainty in calibrated leakance coefficients and groundwater level adjustments in the water budget model limit the accuracy of the estimated Historic lake water levels because the modeled lake stage percentiles are sensitive to changes in these parameters (Qi et al., 2022). Additionally, removing the effects of pumping (i.e., drawdown, which is limited by the accuracy of ECFTX) from the water budget model changes the hydraulic gradients used for the SA and UFA around the lake, and the availability of predevelopment hydraulic gradients in these units is low, which limits the accuracy of groundwater fluxes in the Historic water budget model. However, the drawdown estimates and calibrated water budget model parameters represent the best information available near Lake Angelo.

4.3 Long-term Historic Percentiles

The results of the Historic water budget model and long-term rainfall were used in a line of organic correlation (LOC) to derive a long-term (60 year) Historic water level record for Lake Angelo. This long-term Historic record served as a basis for identifying Historic lake stage percentiles as part of minimum lake levels development. The LOC is a linear fitting procedure that minimizes errors in both the x and y directions and defines the best-fit straight line as the line that minimizes the sum of the areas of right triangles formed by horizontal and vertical lines extending from observations to the fitted line (Helsel et al., 2020). LOC is preferable for this application since it produces a result that best retains the variance of the original data.

For the water-level data set extension, Historic lake stages were correlated with Long-term rainfall. The Long-term rainfall data set was developed starting with the ROMP 43XX Avon Park rain gage (SID 25189) for the January 1996 – December 2021 calibration period 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 rainfall records back to 1963. The Avon Park gage is approximately 3.7 miles west of Lake Angelo, and the DeSoto City rain gage is approximately 15 miles south of Lake Angelo. 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 highest Nash-Sutcliffe Efficiency (NSE) chosen as the best model. For Lake Angelo, the 6-year weighted model had the highest NSE of 0.81.

Historic water budget model results (i.e., water levels) from January 1996 to December 2021 were correlated with the weighted rainfall values using the LOC procedure (Figure 4-6). Daily lake water surface elevations from January 1963 to December 2022 (60 years) were then derived using the resulting stage-rainfall relationship (the LOC 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 Angelo Historic water level record are included in Table 4-2.

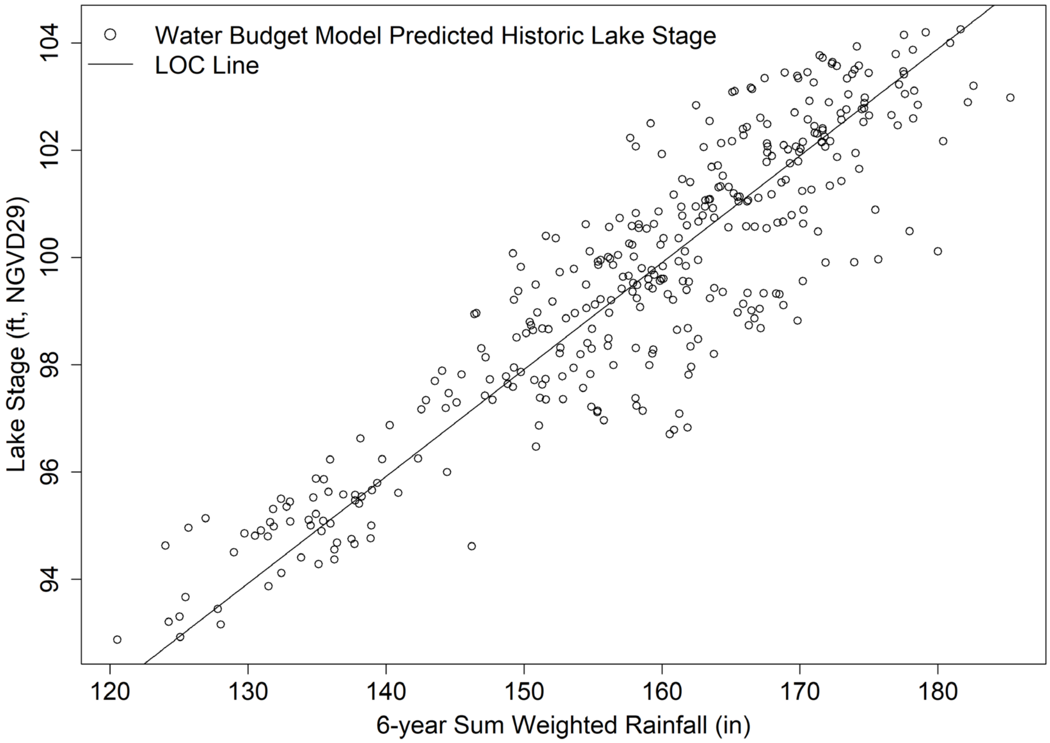

Figure 4-5. Lake Angelo water levels from Historic water budget model correlated with 6-year weighted sum rainfall using LOC method.

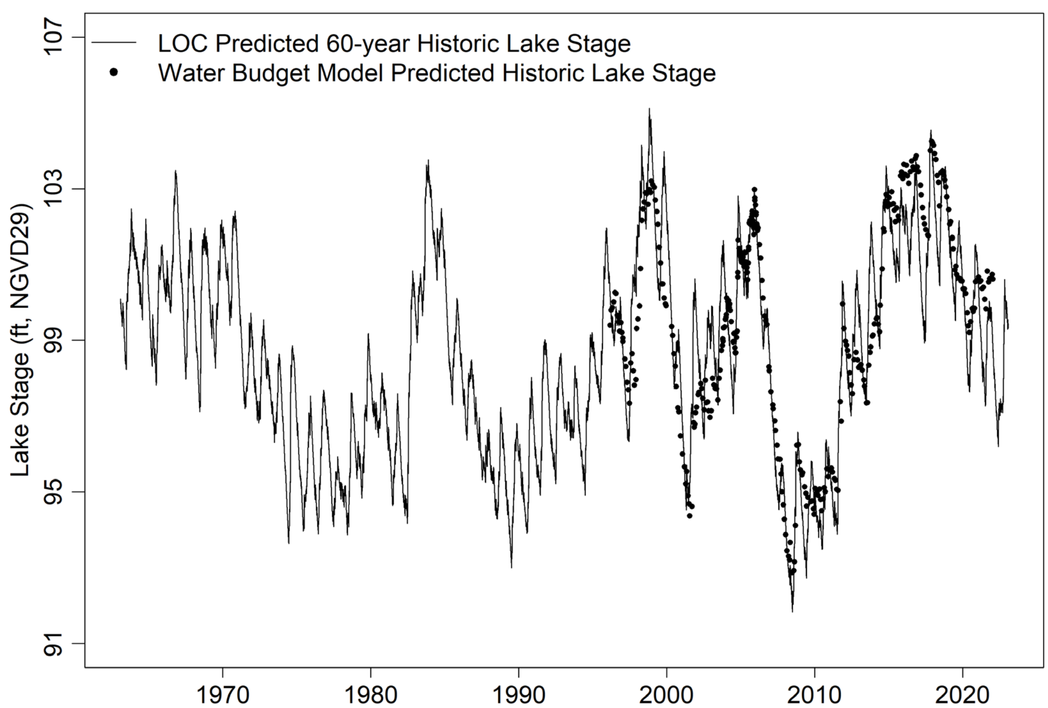

Figure 4-6. LOC predicted 60-year Historic Lake Angelo water levels from January 1963 to December 2022 and Water Budget Model predicted Historic Lake Angelo water levels from January 1996 to December 2021.

Table 4-2. Lake Angelo 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 LOC method.

Percentile	Historic Water Budget Model (ft NGVD29)	Historic LOC Model (ft NGVD29)
P10	102.8	101.9
P50	99.6	98.1
P90	93.9	94.4

4.4 Summary

Best available information was used to develop a Historic scenario for Lake Angelo using a calibrated 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 associated with some uncertainty but represents the best estimate available. The Historic scenario results were considered acceptable for supporting minimum levels development for Lake Angelo.

CHAPTER 5 – ENVIRONMENTAL CRITERIA METHODS, RESULTS AND DISCUSSION

Revised minimum levels were developed for Lake Angelo 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, the modification of the provisional level was warranted based on an assessment of deep-water habitat sensitivity, with the revised level ensuring that the proposed MFL condition results in no more than a 15% reduction in the average area of this habitat relative to average area of this habitat under the Historic condition. The difference between the Historic P10 and P50 elevations (Table 4-2) for the lake was used to identify a proposed High Minimum Lake Level.

5.1 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 Angelo 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 Angelo, other useful hydrologic indicators of sustained inundation were similarly not identified for the lake.

5.2 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 Angelo 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 Section 2.2).

A low floor slab elevation, based on survey reports (Survtech 2021), was established at 107.67 ft NGVD29 for the Lake Angelo basin.

5.3 Significant Change Standards

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

5.3.1 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 Angelo was, therefore, established at 95.9 ft NGVD29, an elevation 2.2 ft. below the Historic P50 elevation of 98.1 ft NGVD29.

5.3.2 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 Angelo, the Species Richness Standard was established at 95.3 ft NGVD29, based on a 15% reduction in lake surface area from that at the Historic P50 elevation (Figure 5-1).

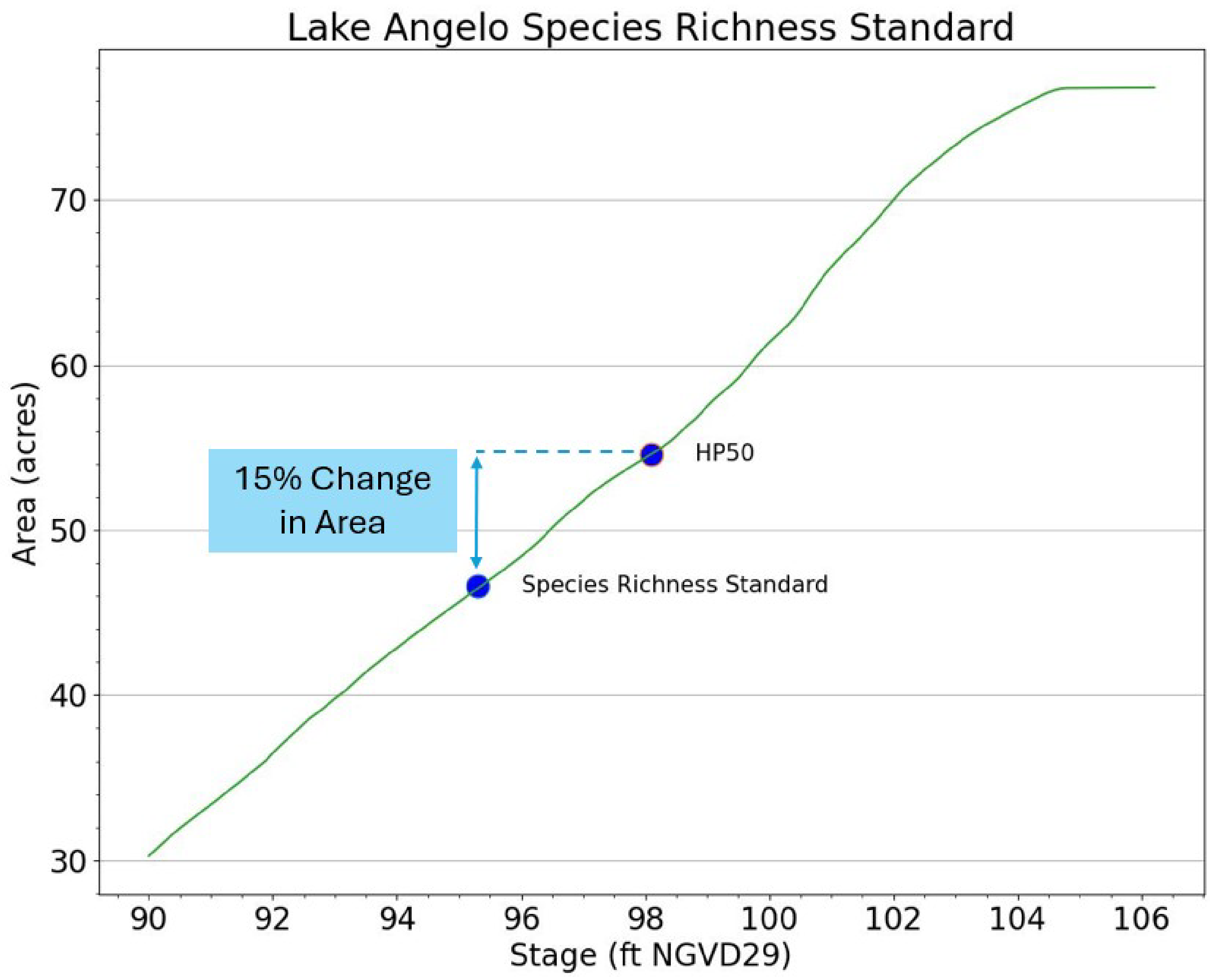

Figure 5-1: Species Richness Standard for Lake Angelo compared to the Historic P50 (HP50) elevation.

5.4 Provisional Minimum Lake Level and MFL Condition Time Series

For Lake Angelo, the Xeric Wetland Offset elevation of 95.9 ft NGVD29 was higher, i.e., more sensitive to stage reductions, than Species Richness standard of 95.3 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 Angelo water budget model and a LOC 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 95.9 ft NGVD29, the elevation associated with a provisional Minimum Lake Level based on the Xeric Wetland Offset.

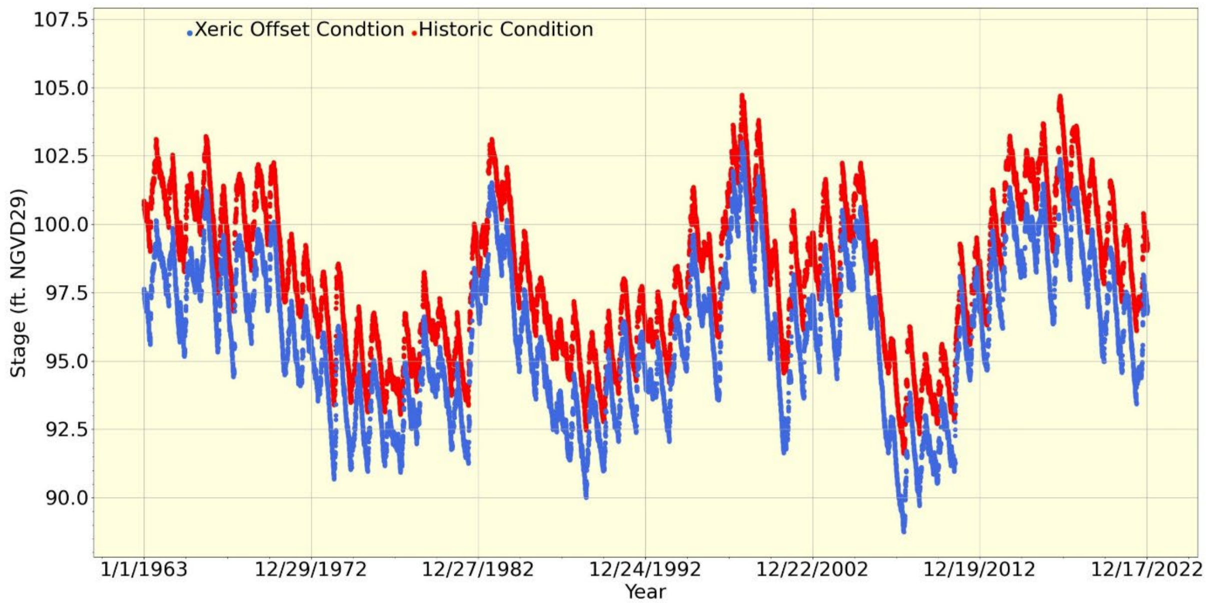

Figure 5-2. Historic and MFL Condition water levels simulated with the Lake Angelo water budget model from January 1963 to December 2022.

5.5 Screening of Provisional Minimum Lake Level

Additional information associated with four screening processes was evaluated and considered for development of minimum levels for Lake Angelo. This information, associated with aquatic habitat zones, basin connectivity, dock-use, and aesthetics, was evaluated to ensure all relevant environmental values associated with Lake Angelo would be protected with implementation of the provisional Minimum Lake Level, and to identify the need for additional analyses prior to identification of proposed minimum levels. A summary of the methods associated with these screenings can be found in SWFWMD 2022a.

5.5.1 Aquatic Habitat Zone Screening

Aquatic habitat zone screening ensures that fish and wildlife habitats, natural system functions, and human-use values are protected when assessing minimum lake levels. The method evaluates potential changes in the areal extent of key aquatic habitats under simulated water level conditions, using bathymetric data and water level time-series analysis.

The District applies a 15% change threshold, a standard commonly used in Florida minimum flows and levels assessments (Sutherland et al. 2021; HSW Engineering, Inc. 2016), to identify whether proposed minimum levels sufficiently protect critical habitat areas. Habitat zones evaluated include littoral and deep-water areas, each defined by specific depth ranges linked to ecological and recreational functions.

The aquatic habitat zone screening for Lake Angelo evaluates potential impacts of proposed minimum lake levels on six key habitat zones: small wading bird forage (0–0.5 ft), sandhill crane nesting (0.5–1.0 ft), large wading bird forage (0–1.0 ft), game fish spawning (1.0–4.0 ft), emergent marsh (0–6.0 ft), and deep-water habitat (>5.0 ft). Using stage-area-volume relationships derived from bathymetric data, average habitat areas under historic and simulated MFL conditions were compared.

Stage-area-volume relationships, derived from digital elevation models, are used to calculate average habitat areas across historic and minimum flow condition time series. If the average habitat area under the proposed minimum level condition is within 15% of the historic condition, the level is considered protective. When this threshold is exceeded, additional modeling is performed to identify protective conditions.

Initial screening results using the xeric wetland offset for a proposed MFL condition showed that all habitat zones except deep-water habitat remained within the District's 15% change threshold, a criterion used to ensure ecological protection. The percent change related to this initial screening is listed in Table 5-1. To address the deep-water exceedance, the water budget model was iteratively adjusted by modifying drawdown assumptions, producing a revised MFL scenario that reduced deep-water habitat impacts below the 15% threshold.

Table 5-1. Modeled historic and xeric offset MFL condition habitat area, and percentage change between the historic and xeric offset MFL condition for Lake Angelo.

Habitat	Historic Average Habitat Area (acres)	MFL Condition Average Habitat Area (acres)	% of Historic Average Under MFL Condition
Small Wading Bird	1.67	1.57	93.9
Large Wading Bird	3.34	3.12	93.4
Sandhill Crane	1.67	1.55	92.9
Game Fish	9.45	9.14	96.7
Emergent Marsh	18.9	18.3	96.7
Deep Water Habitat	40.0	33.3	83.4

A newly proposed MFL condition was generated resulting in a P50 and proposed minimum lake level of 96.2 ft NGVD29. The results of the aquatic habitat screening using this proposed MFL condition time series is included in Table 5-2 and Figure 5-3.

The small wading bird habitat (SWB) under historic conditions exhibited a steady variability in area with increasing water levels, with a more pronounced increase in area at elevations above the historic P50 and then a sharp decline at water levels above 102.1 ft NGVD29. Habitat area for the historic condition ranged from 0.66 to 2.58 acres and averaged 1.67 acres. Under the proposed MFL condition, small wading bird habitat ranged from 0.36 to 2.31 acres and averaged 1.58 acres, representing a 5.5 percent decrease compared to historic conditions.

The large wading bird (LWB) habitat displayed a similar pattern to the SWB habitat with variable area up to around the historic P50, then an increase in area till a water level of approximately 102.2 ft NGVD29. Under historic conditions, area ranged from 2.68 to 4.62 acres and averaged 3.34 acres. Under the proposed MFL condition, LWB habitat ranged from 1.59 to 4.35 acres, with an average area of 3.14 acres, representing a 5.9 percent decrease relative to historic conditions.

The sandhill crane nesting (SHC) habitat similarly demonstrated an increase in area with rising water levels just above the historic P50, with a sharp decrease in area beyond water levels of approximately 102.0 ft NGVD29. Historic SHC habitat area ranged from 0.64 to 2.36 acres and averaged 1.67 acres. Under the proposed MFL condition, habitat area ranged from 0.34 to 2.07 acres with an average of 1.56 acres, corresponding to a 6.3 percent decrease from the historic condition.

The game fish spawning (GFS) habitat under historic conditions exhibited variability above and below the long-term average area and then an increase in area occurring at approximately 99.5 ft NGVD29 with a sharp decline then occurring at a water level elevation of approximately 103.5 ft NGVD29. Historic GFS habitat area ranged from 8.19 to 9.62 acres and averaged 9.45 acres. Under proposed MFL conditions, GFS habitat ranged from 7.68 to 9.35 acres, with an average area of 9.16 acres, reflecting a 3.2 percent decrease compared to historic conditions.

The emergent marsh (EM) habitat exhibited a very similar pattern to the GFS habitat with a sharp increase in area occurring at water levels above approximately 98.6 ft NGVD29 with a drastic drop in area then occurring at water levels above approximately 102.3 ft NGVD29. Historic EM habitat area ranged from 16.92 to 20.64 acres and averaged 18.88 acres. Under a proposed MFL condition, habitat area ranged from 16.39 to 19.88 acres, with an average of 18.30 acres, a 3.1 percent decrease from historic conditions.

The deep water (DW) habitat demonstrated the largest reduction among the habitats evaluated. DW habitat area exhibited a near-linear increase across the hydrologic gradient under historic and MFL conditions. Historic DW habitat area ranged from 34.93 to 47.81 acres and averaged 39.95 acres. Under proposed MFL conditions, DW habitat ranged from 28.91 to 39.47 acres, with an average area of 34.09 acres, corresponding to a 14.7 percent decrease relative to historic conditions.

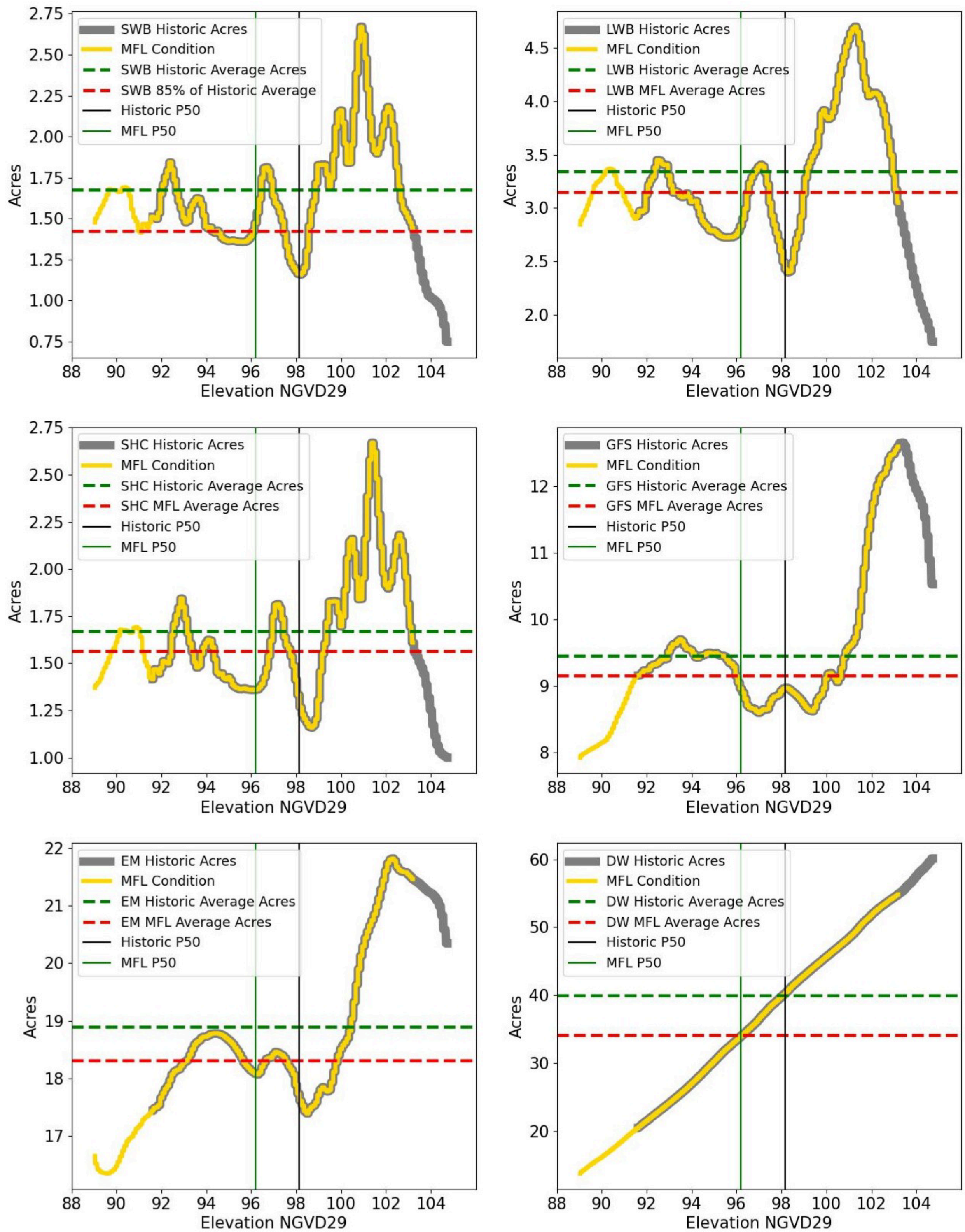

Figure 5-3. Stage/area relationship for assessed habitats simulated for historic and MFL conditions at Lake Angelo.

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

Habitat	Historic Average Habitat Area (acres)	MFL Condition Average Habitat Area (acres)	% of Historic Average Under MFL Condition
Small Wading Bird	1.67	1.58	94.5
Large Wading Bird	3.34	3.14	94.1
Sandhill Crane	1.67	1.56	93.7
Game Fish	9.45	9.16	96.8
Emergent Marsh	18.9	18.3	96.9
Deep Water Habitat	40.0	34.1	85.3

5.5.2 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 high-spot elevation and this elevation is evaluated to determine if it is inundated at minimum 80% of the time.

Lake Angelo can be characterized as not having sub-basins and is not connected to other waterbodies. The basin connectivity screening was determined to be not applicable for Lake Angelo.

5.5.3 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 Angelo (Figure 5-4) 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 5-4. Dock locations on Lake Angelo.

Period-of-record water level data collected through December 9, 2024 (see Figure 2-3) indicated dock “one” had at least 9.8, 6.1 and 2.5 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 Angelo water budget model (Figure 5-2) also indicated there would be approximately 10.9 feet of water at the P10 water level, approximately 7.1 feet of water at the P50 water level, and approximately 3.5 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 2.1, 1.8 and 2.0 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 6.0, 2.2 and 0.0 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 7.0, 3.3, and 0.0 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 2.0, 1.9 and 0.0 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 Angelo 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	9.8	10.9	8.8
P50	6.1	7.1	5.3
P90	2.5	3.5	1.5
Dock Two			
P10	6.0	7.0	5.0
P50	2.2	3.3	1.4
P90	0.0	0.0	0.0

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 10.2 feet between the dock platform and the water at the P10 water level, 14.0 feet from dock to water for the P50 water level, and 17.6 feet from dock to water for the P90 water level (Table 5-4). Dock one would have approximately 9.2 feet from dock to water at the P10 water level for the historic water level record, approximately 12.9 feet at the P50 water level, and would have approximately 16.6 feet from dock to water at the P90 water level. The MFL condition for Lake Angelo indicates that at the P10 water level, there would be approximately 11.2 feet from dock to water level, approximately 14.8 feet from dock platform to water for the P50 water level, and approximately 20.1 feet from dock to water at the P90 water level.

Dock two POR water level record indicates 3.8 feet from dock to water surface at the P10 water level, 7.6 feet from dock to water surface at the P50 water level, and 11.2 feet from dock to sediment at the P90 water level (Table 5-4). The historic condition indicates that dock two would have approximately 2.8 feet between the dock platform and water at the P10 water level, approximately 6.5 feet at the P50 water level, and approximately 10.2 feet to sediment at the P90 water level. The MFL condition indicates that there is approximately 4.8 feet from dock platform to water at the P10 water level, approximately 8.4 feet from dock to water at the P50 water level, and approximately 12.2 feet from dock to sediment at the P90 water level.

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

Distance from dock platform to water (ft.)			
Dock One	**POR**	**Historic**	**MFL**
P10	10.2	9.2	11.2
P50	14.0	12.9	14.8
P90	17.6	16.6	20.1
Dock Two			
P10	3.8	2.8	4.8
P50	7.6	6.5	8.4
P90	11.2	10.2	12.2

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

5.5.4 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 proposed Minimum Lake Level of 96.2 ft NGVD29 for Lake Angelo is greater than the Historic P80 of 95.4 ft NGVD29 developed using the lake water budget model. Since the proposed 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 Angelo a MLL of 96.2 ft NGVD29 was identified at the elevation developed to prevent greater than 15% change in average area to deep water habitat.

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 Angelo was set at 99.9 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 Angelo 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 -0.95 ft. for the District water-level gaging station no. 25501 at Lake Angelo.

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

Minimum Levels	**Elevation (ft NGVD29)**	**Elevation (ft NAVD88)**
High Minimum Lake Level	99.9	99.0
Minimum Lake Level	96.2	95.3

Proposed minimum levels for Lake Angelo 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.

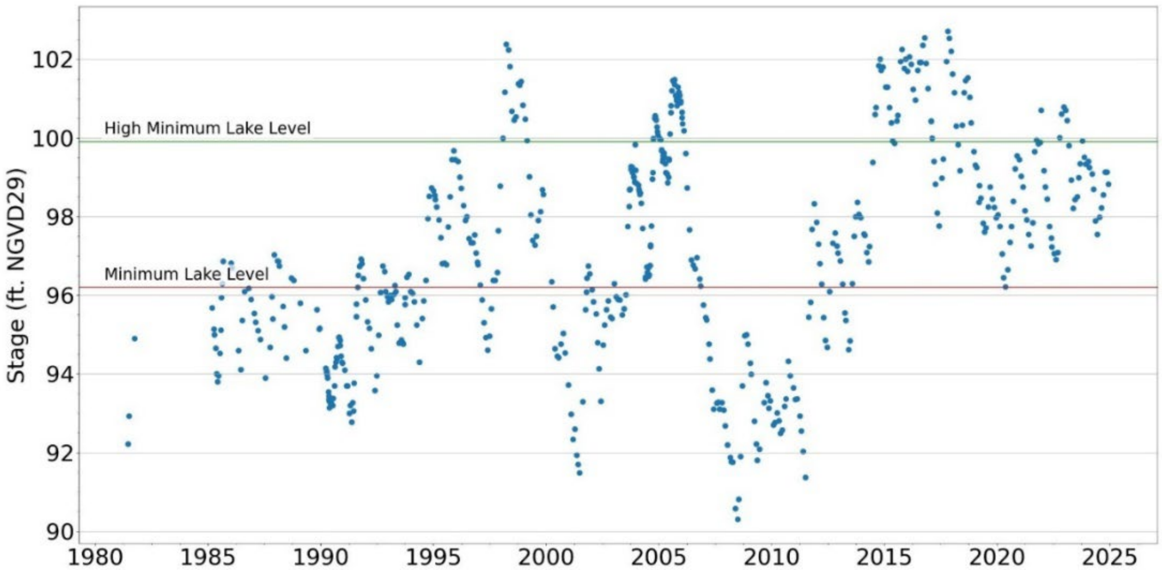

Figure 6-1. Proposed Minimum Lake Level and High Minimum Lake Level for Lake Angelo and water level records for the lake (District Station No. 25501) from 1981 through 2024.

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

6.2 Consideration of Environmental Values

The minimum levels for Lake Angelo 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 proposed minimum level for Lake Angelo was developed based on the aquatic habitat screening process, with a specific focus on ensuring protection of the deep-water habitat zone. This process was designed to prevent reductions exceeding 15% in the average area of deep-water habitat relative to historic conditions. The adopted approach aligns with the protection of multiple 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).

In relatively shallow, polymictic lakes of central Florida, deep water zones, despite their limited extent, play a disproportionately important role in maintaining ecological function and resilience. Unlike deeper stratified systems, polymictic lakes mix frequently, yet they still exhibit temperature and oxygen gradients that influence habitat availability and biological diversity. Research has shown that even in shallow systems, water depth influences alpha and beta diversity of aquatic communities, with deeper zones supporting distinct assemblages of fish and invertebrates due to thermal refugia, predator-prey interactions, and vegetation structure (Langer et al., 2017). Water level fluctuations can significantly influence the structure of littoral zones and the composition of benthic communities along depth gradients. When deeper areas are lost or compressed, the result can be a decline in habitat heterogeneity, leading to more uniform biological communities and diminished ecological complexity—ultimately impacting trophic interactions and ecosystem function (Evtimova & Donohue, 2016).

Several studies also point to the buffering capacity of deeper waters against environmental stressors. In small lakes, deeper waters often remain thermally stable over time, showing little to no long-term warming despite rising surface temperatures. This relative stability allows deep zones to function as thermal refugia, offering protection for aquatic species during periods of elevated surface heat (Winslow et al., 2015). Similarly, global assessments indicate that deeper waters are changing less consistently than surface waters, providing relative thermal stability that is vital under intensifying climate pressures (Jane et al., 2021). Deep zones may also mitigate deoxygenation impacts, which are increasingly prevalent due to warming and eutrophication (Foley et al., 2023). Given these findings, protecting deep water habitat—even in many relatively shallow polymictic lakes in Florida—supports critical biodiversity, ecosystem services, and resilience to climate variability.

While many peer-reviewed methods emphasize wetland sensitivity, lake-specific analysis shows that the deeper areas of Lake Angelo are more vulnerable to water level reductions. These deeper zones serve important ecological roles, such as providing critical refuge for fish during thermal extremes and buffering against hypoxic conditions. In shallow systems, small declines in water level can significantly compress or eliminate these habitats, triggering trophic shifts and accelerating ecological degradation. Therefore, setting the minimum level based on the preservation of deep-water habitat offers strong protection for the lake's biological integrity and overall function. Consultation with the Florida Fish and Wildlife Conservation Commission (FWC) was conducted to support the selection of habitat criteria used in establishing the minimum level. Additional documentation, including an official letter of support from FWC, is provided in Appendix A.

Additional screening methods, including evaluations of dock-use, basin connectivity, aesthetics, and other aquatic habitat zones, further support development of the proposed minimum level, collectively addressing environmental values associated with recreation, navigation, and ecosystem function (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 Angelo. Estuarine resources were not considered relevant because Lake Angelo 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 Angelo (Table 6-2). The proposed High Minimum Lake Level is 1.4 ft lower than the currently adopted High Minimum Lake Level, and the proposed Minimum Lake Level is 3.8 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, the use of lake-specific habitat screening, including evaluation of deep-water habitat to ensure no greater than 15% reduction in average area relative to historic conditions, contributed to differences between the proposed and currently adopted minimum levels.

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

Minimum Levels	Proposed Elevations (ft NGVD29)	Currently Adopted Elevations (ft NGVD29)
High Minimum Lake Level	99.9	101.3
Minimum Lake Level	96.2	100.0

Chapter 7 - MINIMUM LEVELS STATUS ASSESSMENT AND MINIMUM LEVELS RECOMMENDATION

7.1 Status Assessment

To assess the current status and the projected 2045 status of the proposed minimum levels for Lake Angelo, 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 (SID 25501) from 2003 through 2022 (SWFWMD, 2022b). The timeframe was selected based on data availability and regional groundwater use trend (Figures 2-13). This recent measured stage data was then extended to long-term lake stage based on long-term rainfall, using the LOC method. The current P10 is 1.0 ft higher than the proposed High Minimum Lake Level and the current P50 is 1.0 ft higher than the proposed Minimum Lake Level (Table 7-1). These results indicate the proposed minimum levels for Lake Angelo 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, 2022) scenario simulations, UFA drawdown at Lake Angelo is estimated to decrease by 4.8 feet between recent representative (2014) and 2045 withdrawal conditions. This equates to an aquifer recovery of 0.6 ft relative to the water budget model period (see Figure 4-2), and this information was used for a projected 2045 status assessment for the proposed minimum levels for Lake Angelo.

Projected water levels from the 2045 withdrawals condition scenario of ECFTX were used in the Lake Angelo water budget model to assess the 2045 status. Lake water levels predicted for the 2045 condition with the water budget model were then extended to long-term lake stage values based on long-term rainfall, using the LOC method. The P10 and P50 water surface elevations were then calculated from the resulting long-term lake stages for the projected 2045 condition. The P10 simulated for the 2045 conditions scenario was 0.7 ft higher than the proposed High Minimum Lake Level and the P50 for the scenario results was 0.8 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 Angelo 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 Angelo.

Percentile	Minimum Levels (ft NGVD29)*	Current Water Levels (ft NGVD29)	Projected 2045 Water Levels (ft NGVD29)
P10	99.9	100.9	100.6
P50	96.2	97.2	97.0

* 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 Angelo 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 96.2 ft NGVD29 and High Minimum Lake Level of 99.9 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 Angelo, 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: Lakes Angelo and Denton FWC Technical Assistance

FWC Letter

Florida Fish and Wildlife Conservation Commission

620 South Meridian Street
Tallahassee, Florida
32399-1600
Voice: 850-488-4676

Hearing/speech-impaired:
800-955-8771 (T)
800 955-8770 (V)

MyFWC.com

May 14, 2025

TJ Venning
Southwest Florida Water Management District
2379 Broad Street
Brooksville, FL 34604
TJ.Venning@swfwmd.state.fl.us

RE: Lakes Denton and Angelo Minimum Flows and Levels Technical Assistance Request, Southwest Florida Water Management District, Highlands County

Dear Mr. Venning:

Florida Fish and Wildlife Conservation Commission (FWC) staff received a request for technical assistance for the above-referenced project. The following comments and recommendations are provided as technical assistance to assist with future project planning and in accordance with FWC's authorities under Chapter 379, Florida Statutes.

Project Description

The Southwest Florida Water Management District (SWFWMD) is in the reevaluation process of the minimum lake levels (MLL) for Lakes Denton and Angelo in Highlands County. Lake Denton is a 66-acre spring filled, closed system lake. The lake is deep and clear with little vegetation or littoral zones. The public can access the lake via a boat ramp on the northeast shore. Lake Angelo is a 56-acre clear-water, closed system lake with no public access. The reevaluation for these lakes includes analyses of fish and wildlife habitat that may be affected by the MLL. The SWFWMD is evaluating the lakes utilizing a metric called the xeric offset standard. This standard will indicate if significant harm is likely to occur when the PE50 elevation (the water level equaled or exceeded 50% of the time) is lowered more than 2.2 feet (ft) below the Historic PE50 elevation (the water level equaled or exceeded 50% of the time associated with current structural alterations but in the total absence of withdrawals).

Comments and Recommendations

On January 23, 2025, FWC and SWFWMD staff met to discuss the application of the xeric offset standard in the analysis of the MLL for Lakes Denton and Angelo. Also discussed was the application of habitat screenings which are used to further evaluate aquatic habitat zones supported by fish and wildlife (and recreation) by using a presumptive standard of no more than a 15% change in average area, relative to historic conditions. The habitat screenings (and water depth ranges associated with each) applied to Lakes Denton and Angelo included:

- Small wading bird foraging habitat (0-0.5 ft),
- Sandhill crane nesting habitat (0.5-1.0 ft),
- Large wading bird foraging habitat (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).

FWC staff agrees that evaluating the potential changes in lake habitat zones associated with water level changes is a reasonable approach for protecting ecosystem function, and that the presumptive standard of no more than a 15% change in area relative to historic conditions within each zone should therefore be protective of fish and wildlife. The emergent marsh and open water zones broadly encompass the littoral and limnetic portions of the lakes, which functionally represents the entire lake area and volume, as well as the fish and wildlife that depend on those habitats. Habitat zones that support critical life history needs from Florida's iconic and economically important fish and wildlife were also considered to provide a more thorough understanding of potential impacts to those habitats with water level changes.

At Lake Angelo, the xeric offset standard resulted in a MLL of 95.9 ft (NGVD29), and the most limiting habitat zone screening was deep water habitat at a MLL of 96.2 ft (NGVD29), below which the acreage in deep water habitat is expected to be reduced by greater than 15%. At 96.2 ft, 85% of the average historic deepwater habitat is protected, in addition to 93-97% of the average historic habitat acreage from all other habitat zones. FWC staff support the proposed MLL at Lake Angelo of 96.2 ft as it is expected to be protective of ecosystem function and habitats that support fish and wildlife.

Lake Angelo				
Habitat zones	Historic Average Habitat Area (acres)	MLL Average Habitat Area (acres)	% of Historic Average Under MLL Condition	Reduction from historic average (acres)
Small Wading Bird	1.67	1.58	94	0.09
Large Wading Bird	3.34	3.14	94	0.21
Sandhill Crane nesting	1.67	1.56	93	0.11
Game Fish spawning	9.45	9.16	97	0.30
Emergent Marsh	18.88	18.30	97	0.60
Deep Water Habitat	39.95	34.09	85	6.15

At Lake Denton, the xeric offset standard resulted in a MLL of 108.7 ft (NGVD29), and the habitat zone screenings detected limitations for small/large wading bird foraging habitat and sandhill crane nesting habitat. These habitats required a MLL of more than 110 ft NGVD to avoid habitat reductions of greater than 15% within these zones. While the FWC supports the SWFWMD's policy of using the most limiting water resources values to recommend a MLL, in this instance, a MLL of approximately 110 ft NGVD protects negligibly more habitat than a MLL that is about one foot lower due to the lake's topography and limited amount of shallow water habitat. Lake Denton is an unproductive (chlorophyll <2 microgram/liter), deep (maximum depth = 51 ft.) lake with a steep gradient bathymetry. As such, the lake is composed of narrow bands of shallow water habitat, after which the depth drops off rapidly into the profundal zone of the lake. Due to the lake's trophic state and bathymetry, the quality of wading bird foraging habitat and sandhill crane nesting habitat is naturally low relative to other nearby lakes with productive and gentle gradient bathymetry (i.e., Lakes Istokpoga and Kissimmee) that offer vast acreages of shallow water habitat. FWC staff agrees that exceeding the presumptive standard of greater than 15% habitat loss in this instance (approximately 28% reduction in wading bird foraging habitat and 25% reduction in sandhill crane nesting habitat) will not cause significant harm to fish and wildlife given that the reduction from the historic average area to the MLL condition of 108.8 ft (NGVD29) will only amount to a reduction of approximately 1/3 to 3/4 acres in these zones.

DRAFT

Lake Denton				
Habitat zones	Historic Average Habitat Area (acres)	MLL Average Habitat Area (acres)	% of Historic Average Under MLL Condition	Reduction from historic average (acres)
Small Wading Bird	1.48	1.06	72	0.42
Large Wading Bird	2.8	2.05	73	0.75
Sandhill Crane nesting	1.32	0.99	75	0.33
Game Fish spawning	6.24	5.42	87	0.82
Emergent Marsh	12.63	10.76	85	1.87
Deep Water Habitat	57.49	53.92	94	3.57

FWC staff appreciates the opportunity to coordinate early on this project and looks forward to working with SWFWMD staff throughout the final approval process. For specific technical questions regarding the content of this letter, please contact Eric Nagid at (352) 273-3651 or by email at Eric.Nagid@MyFWC.com. All other inquiries may be sent to ConservationPlanningServices@MyFWC.com.

Sincerely,

Josh Cucinella
Land Use Planning Program Administrator
Office of Conservation Planning Services

jc/ms
Denton and Angelo MFL_61807_05142025