Revised Minimum and Guidance Levels for Lake Wailes (Wales) in Polk County, Florida

November 15, 2015

Southwest Florida
Water Management District

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Cover Page: 1941 and 2014 aerial photographs of Lake Wales from District archives.

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Executive Summary

This report describes the development of Minimum and Guidance Levels for Lake Wailes (also known as Lake Wales) in Polk County, Florida based on reevaluation of levels in Southwest Florida Water Management District rules. Minimum Levels are the levels at which further water withdrawals would be significantly harmful to the water resources of the area (Section 373.042(1)(b), F.S.). Minimum Levels are used to support water resource planning and permitting activities and Guidance Levels are used as advisory guidelines for construction of lakeshore development, water dependent structures, and operation of water management structures.

Section 373.0421(3), F.S., requires the periodic reevaluation and, as needed, the revision of established minimum flows and levels. Lake Wailes was selected for reevaluation based on development of modeling tools for simulating lake level fluctuations that were not available when levels previously adopted for the lake were developed. The previously adopted lake levels were also reevaluated to support ongoing assessments of minimum flows and levels in the Southern Water Use Caution Area (SWUCA), a region of the District where recovery strategies are being implemented to support recovery to minimum flow and level thresholds.

Revised Minimum and Guidance Levels for Lake Wailes were developed using current District methods for establishing Minimum Levels for Category 3 Lakes, which are lakes that are not contiguous with at least 0.5 acres of cypress-dominated wetlands. The Minimum Levels were developed with consideration of and 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.). The levels are expressed as elevations in feet above the National Geodetic Vertical Datum of 1929 (NGVD29) that must be equaled or exceeded specified percentages of time on a long-term basis. Table ES-1 identifies the revised elevations and includes generic descriptions for the levels in District rules (Rule 40D-8.624, F.A.C). Differences between the revised and previously adopted levels are primarily associated with application of a new modeling approach for characterization of historic water level fluctuations within the lake, i.e., water level fluctuations that would be expected in the absence of water withdrawal impacts while maintaining current structural alterations.

Based on these results, the revised Minimum and Guidance Levels replaced the previously adopted Guidance and Minimum Levels for Lake Wailes. The revised levels were approved by the District Governing Board on December 15, 2017, and became effective in 40D-8.624 on February 13, 2017.

Based on available measured and modeled water level records, Lake Wailes' Long-term P50 is currently 1.5 feet below the Minimum Lake Level, and the Long-term P10 is 0.2 feet above the High Minimum Lake Level. The Minimum Lake Level for Lake Wailes is, therefore, not currently being met. The adopted SWUCA Recovery Strategy (Rule 40D-80.074, F.A.C) is applicable for recovery of Minimum Levels for the lake.

Table ES-1., Minimum and Guidance Levels for Lake Wailes and level descriptions.

Minimum and Guidance Levels	Elevation (feet above NGVD29[a])	Level Descriptions
High Guidance Level	110.6	Advisory guideline for construction of lake shore development, water dependent structures, and operation of water management structures. The High Guidance Level is the elevation that a lake's water levels are expected to equal or exceed ten percent of the time on a long-term basis.
High Minimum Lake Level	107.7	Elevation that a lake's water levels are required to equal or exceed ten percent of the time on a long-term basis.
Minimum Lake Level	104.8	Elevation that the lake's water levels are required to equal or exceed fifty percent of the time on a long-term basis.
Low Guidance Level	101.8	Advisory guideline for water dependent structures, information for lakeshore residents and operation of water management structures. The Low Guidance Level is the elevation that a lake's water levels are expected to equal or exceed ninety percent of the time on a long-term basis.

[a] National Geodetic Vertical Datum of 1929

Acknowledgements

The authors would like to thank several of our Southwest Florida Water Management District colleagues for their contributions to the work summarized in this report. We thank Douglas Leeper for review of a previous version of this project report and field-data collection. We also thank our former District colleagues, Adam Munson and Dave Arnold for their assistance with field-data collection for the project.

Introduction

Reevaluation of Minimum and Guidance Levels

This report describes the development of Minimum and Guidance Levels for Lake Wailes in Polk County, Florida. The levels were developed based on the reevaluation of Minimum and Guidance Levels approved by the Southwest Florida Water Management District (SWFWMD or District) Governing Board for the lake, (see SWFWMD 2008) and adopted into District rules with an effective date of January 1, 2007. The levels presented in this report represent needed revisions. Lake Wailes was selected for reevaluation based on development of modeling tools for simulating lake level fluctuations that were not available when the levels were first developed. The lake levels were also reevaluated to support ongoing assessments of minimum flows and levels in the Southern Water Use Caution Area (SWUCA), a region of the District where recovery strategies are being implemented to support recovery to minimum flow and level thresholds.

The levels were developed using peer-reviewed District methods for establishing Minimum Levels and Guidance Levels for lakes and were developed with consideration of and 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, Florida Administrative Code, or F.A.C.). These levels were adopted by the District Governing Board, and replaced the levels previously adopted for Lake Wailes that are included in the District's Water Levels and Rates of Flow Rules (Chapter 40D-8, F.A.C.).

Minimum Flows and Levels Program Overview

Legal Directives

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

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

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

The Florida Water Resource Implementation Rule, specifically Rule 62-40.473, F.A.C., provides additional guidance for the MFLs establishment, requiring that "…consideration shall be given to natural seasonal fluctuations in water flows or levels, non-consumptive uses, and environmental values associated with coastal, estuarine, riverine, spring, aquatic and wetlands ecology, including: a) Recreation in and on the water; b) Fish and wildlife habitats and the passage of fish; c) estuarine resources; d) Transfer of detrital material; e) Maintenance of freshwater storage and supply; f) Aesthetic and scenic attributes; g) Filtration and absorption of nutrients and other pollutants; h) Sediment loads; i) Water quality; and j) Navigation."

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

Development of Minimum Lake Levels

Programmatic Description and Major Assumptions

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

A substantial portion of the District's organizational resources has been dedicated to its MFLs Program, which logistically addresses six major tasks: 1) development and reassessment of methods for establishing MFLs; 2) adoption of MFLs for priority water bodies (including the prioritization of water bodies and facilitation of public and independent scientific review of proposed MFLs and methods used for their development); 3) monitoring 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 report for Lake Wailes; additional information on all tasks associated with the District's MFL Program is summarized by Hancock *et al.* (2010).

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

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

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

Consideration of Changes and Structural Alterations and Environmental Values

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

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

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

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

Information regarding the development of adopted methods for establishing minimum and guidance lake levels is included in SWFWMD (1999a, b) and Leeper *et al.* (2001). Additional information relevant to developing lake levels is presented by Schultz et al. (2005), Carr and Rochow (2004), Caffrey *et al.* (2006, 2007), Carr *et al.* (2006), Hoyer *et al*. (2006), Leeper (2006), Hancock (2006, 2007) and Emery *et al.* (2009). Independent scientific peer-review findings regarding lake level methods are summarized by Bedient *et al.* (1999), Dierberg and Wagner (2001) and Wagner and Dierberg (2006).

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

Categorical significant change standards and other available information are developed to identify criteria that are sensitive to long-term changes in hydrology and can be used for establishing minimum levels. For all lake categories, the most sensitive, appropriate criterion or criteria is/are used to develop recommend minimum levels. For Category 1 or 2 Lakes, a significant change standard, referred to as the Cypress Standard, is developed. For Category 3 Lakes, six significant change standards, including a Basin Connectivity Standard, a Recreation/Ski Standard, an Aesthetics Standard, a Species Richness Standard, a Lake Mixing Standard and a Dock-Use Standard are typically developed. Other available information, including potential changes in the coverage of herbaceous wetland and submersed aquatic plants is also considered when establishing minimum levels for Category 3 Lakes. The standards and other available information are associated with the environmental values identified for consideration in Rule 62-40.473, F.A.C., when establishing minimum flows or levels (Table 1). Descriptions of the specific standards and other information evaluated to support development of proposed minimum levels for Lake Wailes are provided in subsequent sections of this report.

Two Minimum Levels and two Guidance Levels are typically established for lakes. The levels, which are expressed as elevations in feet above the National Geodetic Vertical Datum of 1929 (NGVD29), may include the following (refer to Rule 40D-8.624, F.A.C.).

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

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

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

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

The District is in the process of converting from use of the NGVD29 datum to use of the North American Vertical Datum of 1988 (NAVD88). While the NGVD29 datum is used for most elevation values included within this report, in some circumstances notations are made for elevation data that was collected or reported relative to mean sea level or relative to NAVD88 and converted to elevations relative to NGVD29. All datum conversions were derived using the Corpscon 6.0 software distributed by the United States Army Corps of Engineers.

Table 1. Environmental values identified in the state Water Resource Implementation Rule for consideration when establishing MFLs, and associated significant change standards and other information used by the District for consideration of the environmental values.

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

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

Data and Analyses Supporting Development of Minimum and Guidance Levels

Lake Setting and Description

Lake Wailes also known as Lake Wailes, is located on the western edge of Lake Wailes Ridge in Polk County, Florida (Section 1, Township 30S, Range 27E; Section 6, Township 30S, Range 28E) in the Kissimmee River Basin of the Southwest Florida Water Management District (Figure 1). Based on the U.S. Geological Survey Hydrologic Unit Classification System, the lake occurs within the Tiger Creek sub-basin of the Kissimmee River watershed, however, for watershed management modeling purposes, the lake is considered part of the Peace Creek watershed with a drainage area of about 2.4 square miles (ADA Engineering 2012, Atkins 2013). Brooks (1981) classified Lake Wailes as the Iron Mountains subdivision of the Lake Wailes Ridge in the Central Lake Physiographic District. This subdivision is characterized by residual sand hills underlain by sand, gravel, and clayey sand. According to the Florida Department of Environmental Protection's Lake Bioassessment/Regionalization Initiative, the area has been identified as the Northern Lake Wailes Ridge lake region; an area of alkaline, low to moderate nutrient, clear water lakes (Griffith *et al.* 1997).

The lake is included in the Heartland Planning Region of the District and is also located in the Southern Water Use Caution Area (SWUCA). The SWUCA encompasses approximately 5,100 square miles in all or part of 8 counties within the southern portion of the District. The SWUCA was established in 1992 to address withdrawal-related saltwater intrusion in coastal areas south of Tampa Bay, reduced flows in the Peace River and lowered lake levels in Polk and Highlands counties. In 2006, the District established several MFLs within the region and adopted a SWUCA recovery strategy (Rule 40D-80.074, F.A.C. and SWFWMD 2006) to address these water resource issues.

Lake Wailes is also located within the Central Florida Water Initiative (CFWI) Planning Area. The CFWI Planning Area consists of all of Orange, Osceola, Seminole and Polk counties and southern Lake County and is based predominately on public utility service areas in the region of central Florida where the boundaries of the District, the South Florida Water Management District (SFWMD) and the St. Johns River Water Management District (SJRWMD) converge. The CWFI Planning Area was developed to assess existing and projected water needs and water sources required to meet water demands within the planning area, while sustaining area water resources and related natural systems (SFWMD, SWFWMD and SJRWMD 2014). Uplands surrounding Lake Wailes and Crystal Lake, North Lake Wailes and Lake Bonnie, which are respectively located west, northwest and northeast of Lake Wailes, are primarily residential and citrus production. Lands to the east of Lake Bonnie have been extensively altered as a result of sand mining operations. Live oak (*Quercus virginiana*), saw palmetto, (*Serenoa repens*), cordgrass (*Spartina bakeri*), prickly-pear cactus (c.f. *Opuntia humifusa*) and pine (*Pinus sp.)* are among the native vegetation that are distributed in the upland area.

A line of large live oak trees and longleaf pine located along the north and south shoreline of Lake Wailes have previously been identified as historic high-water indicators (Figure 2) (SWFWMD 2008). There are no major, natural surface water systems draining into the basin, although several storm water systems discharge runoff directly into the lake. Historically, Lake Wailes was connected to Crystal Lake to the west (Water & Earth Sciences, Inc. and Ayres Associates 1991), and was known to discharge to the northeast prior to 1961. Lake Crystal and North Lake Wailes are currently connected by a shallow ditch and underground stormwater conveyance systems to Lake Wailes (SWFWMD 2007).

The “Gazetteer of Florida Lakes” (Florida Board of Conservation 1969, Shafer *et al.* 1986) lists the lake area at 326 acres. The U.S. Geological Survey 1952 (photo revised 1987) 1:24,000 Lake Wailes Quadrangle topographic map indicates a water level elevation of 112 ft., NGVD29. This elevation corresponds to a lake surface area of 329 acres, based on a topographic map of the basin generated in support of minimum levels development (Figure 3). Figure 4 shows land surface elevations around the lake with a transect A-A that shows detailed elevations from an area south of Crystal Lake, through North Lake Wailes, Lake Wailes and Lake Bonnie to a sand mine located east of Lake Wailes. Land surface elevations typically vary from 250 ft. (NGVD29) along the surrounding parts of the ridge to the valleys where elevations gradually decrease to around 98 ft. NGVD29, except in Lake Wailes where the elevation of the lake bottom averages 86 ft. NGVD29.

Information pertaining to climate, hydrogeology and land use is provided in detail in Appendix A.

There are no surface water withdrawals from the lake currently permitted by the District. However, there are numerous permitted groundwater withdrawals in the surrounding landscape (Figure 5). Monthly average water withdrawals from 2008-2012 within 1, 2 and three mile radius were 1.1 million gallons per day (mgd), 6.7 mgd and 12.4 mgd respectively. Public water supply and agriculture are the two largest water-use categories in the region. The highest withdrawals occur during the dry season in May, when water demands for irrigation increase, while the lowest withdrawals occur during the wet season, from July through September.

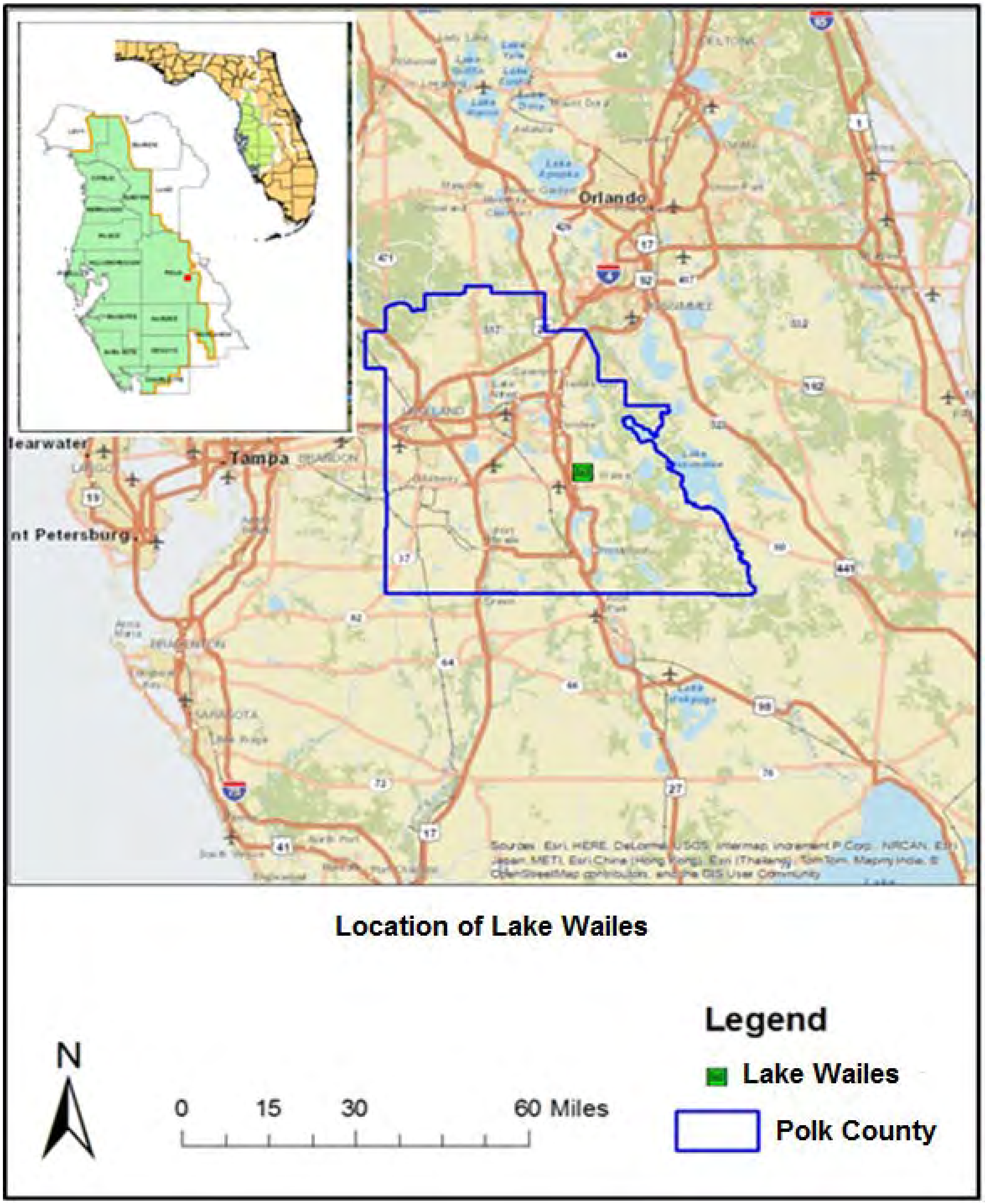

Figure 1. Location of Lake Wailes in Polk County, Florida.

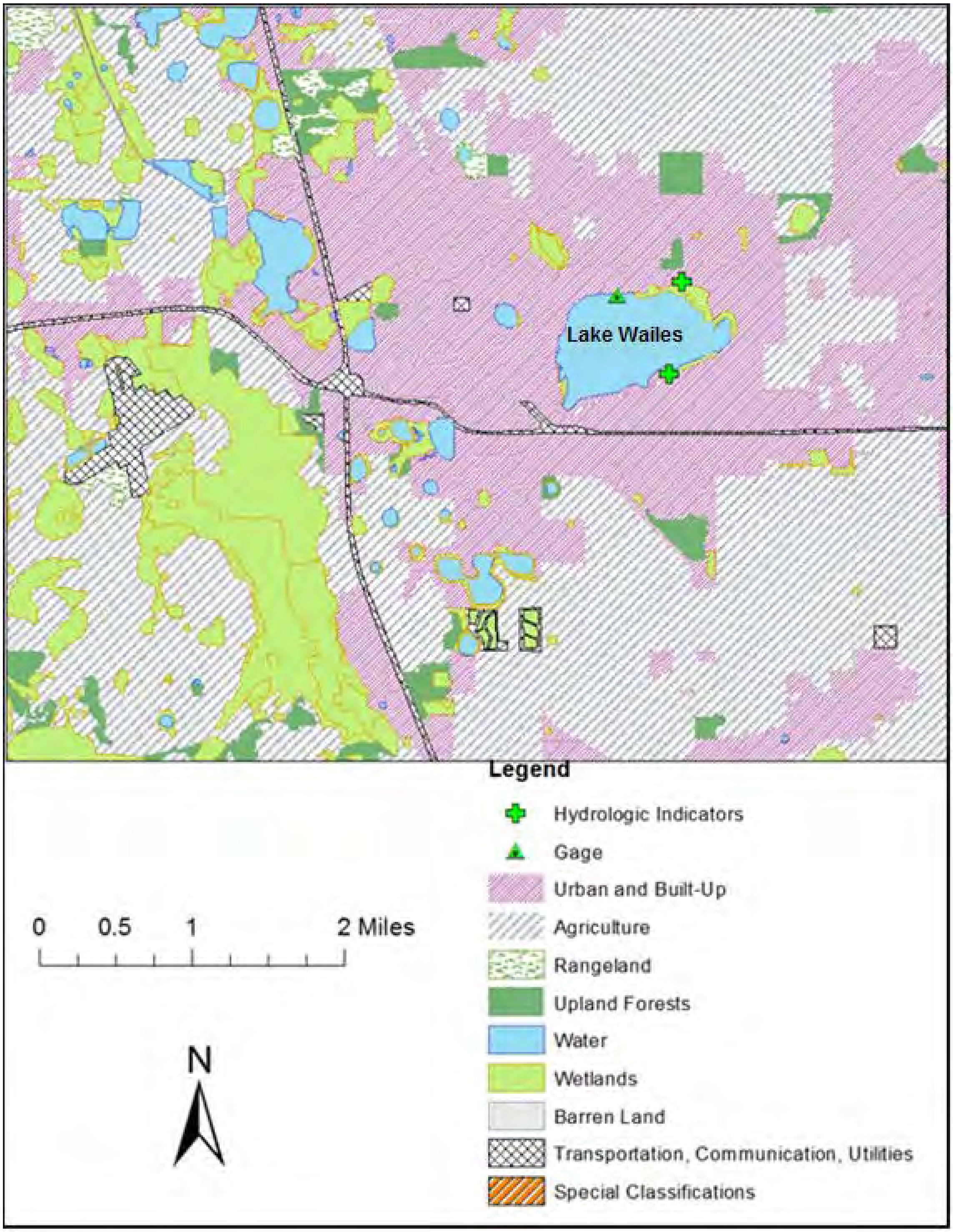

Figure 2. Land uses, location of the District lake gage and sites where hydrologic indicators of high water levels were measured in the Lake Wailes, Polk County, Florida.

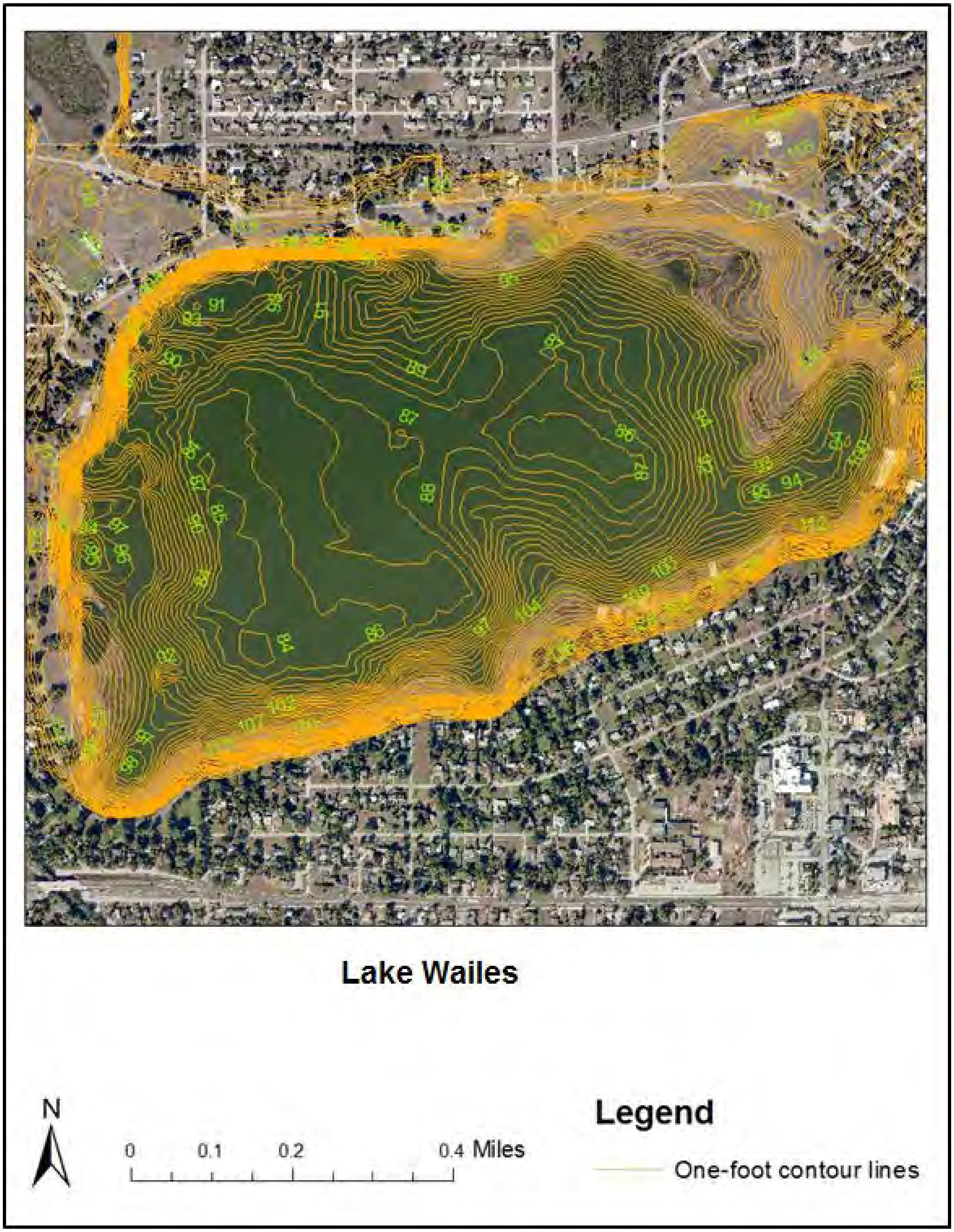

Figure 3. One-foot elevation contours near Lake Wailes. Values shown are in feet relative to the NGVD29.

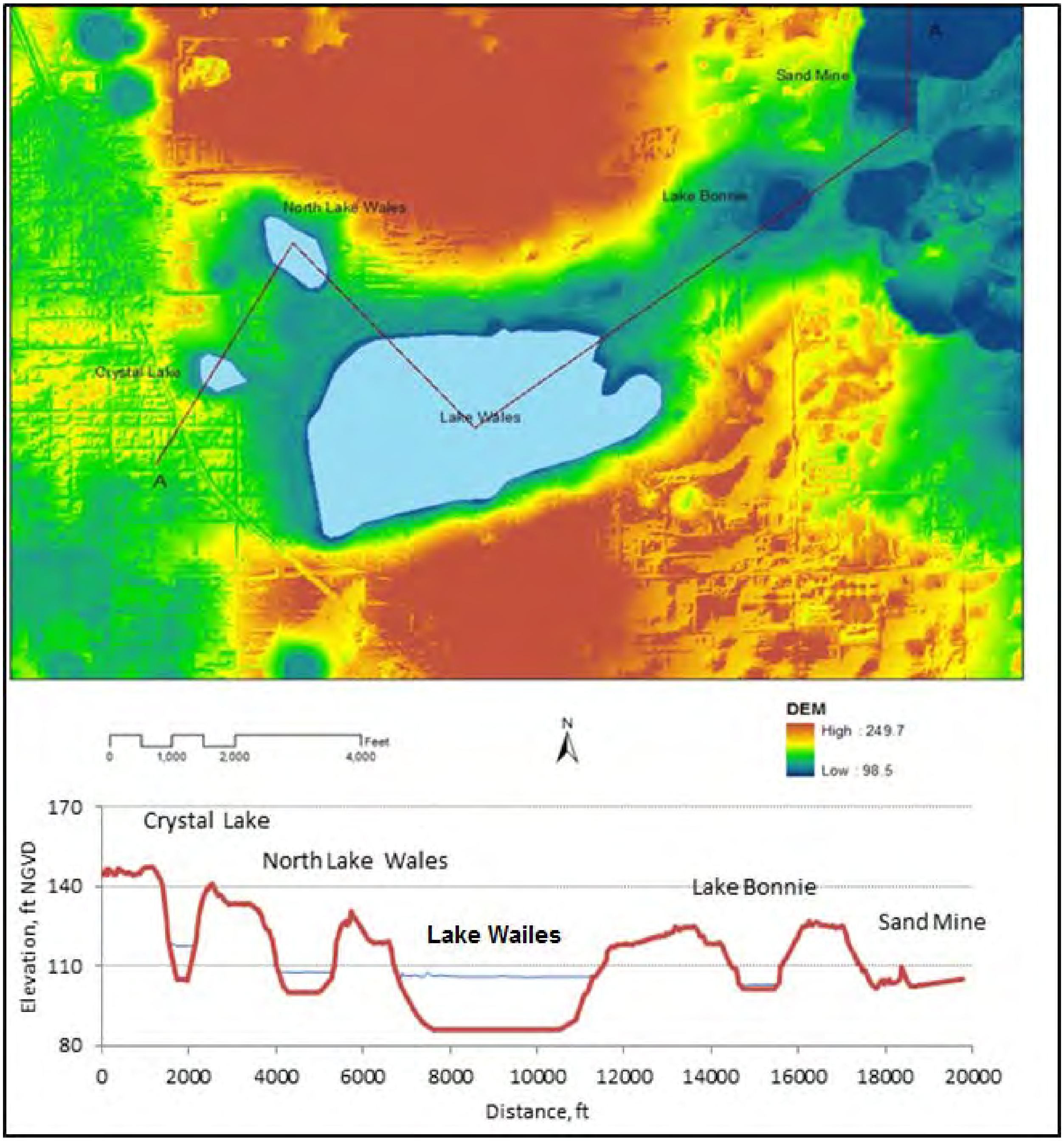

Figure 4. Digital Elevation Model (DEM) of the Lake Wailes area and elevation profile for transect A-A in feet relative to NGVD29.

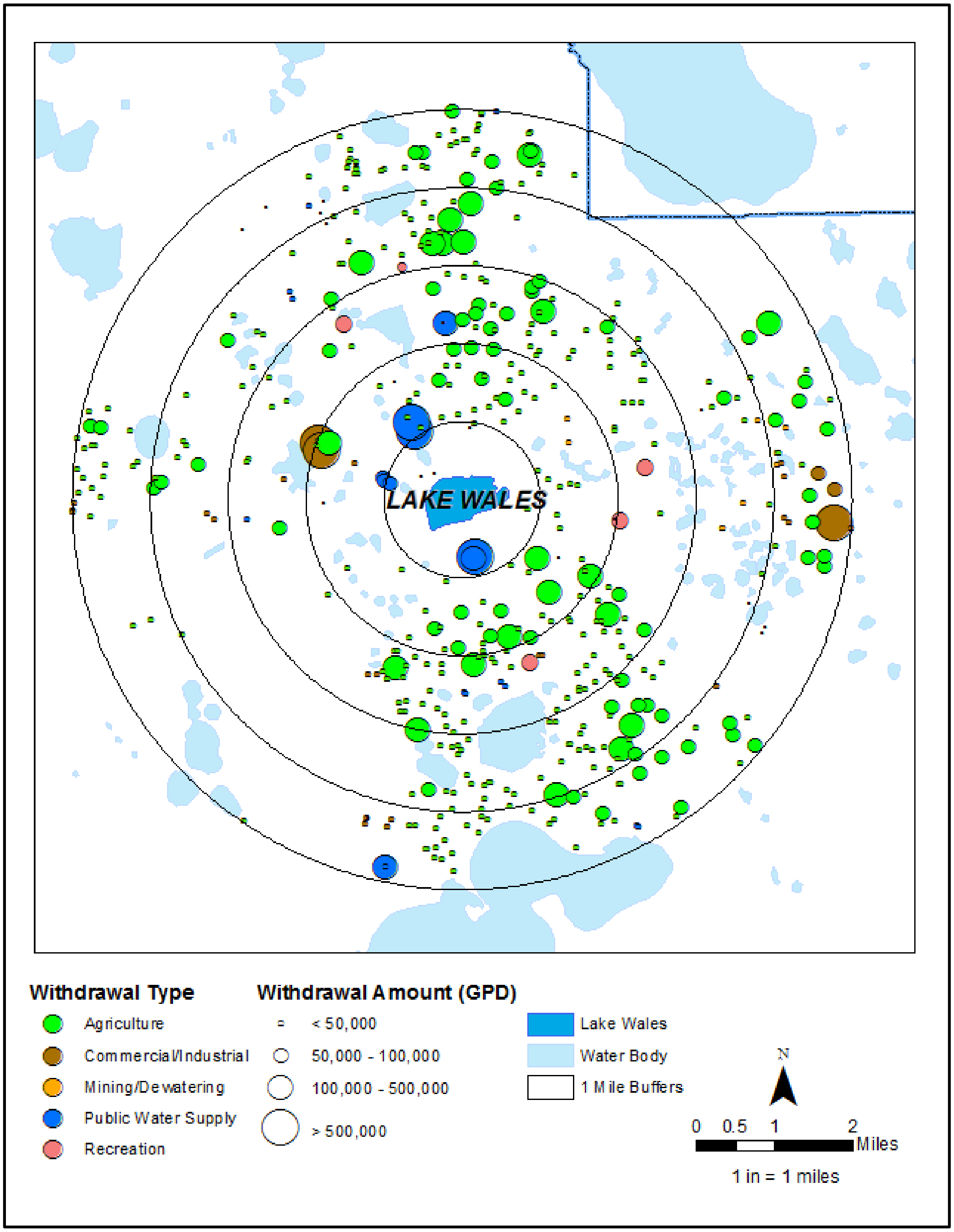

Figure 5. Permitted groundwater withdrawals by type and quantity within one to five miles of the centroid of Lake Wailes for the period from 2008 through 2012.

Previously Adopted Guidance Levels

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

Minimum and Guidance Levels were first developed for Lake Wailes in 2006 (SWFWMD 2008) using the methodology for Category 3 Lakes described in Leeper *et al.* (2001). These levels were approved by the District Governing Board in March 2006 and became effective on January 1, 2007 (listed in Table 1 along with area values for each water level). These Minimum and Guidance Levels replaced Guidance Levels that had previously been adopted for the lake in 1991 (see SWFWMD 2008). In 2007, one of the Guidance Levels adopted in 2006, a Ten-Year Flood Guidance Level of 53.0 ft. NGVD29, was removed from Chapter 40D-8, F.A.C., when the District Governing Board determined that flood-stage elevations should not be included in the District's Water Levels and Rates of Flow rules.

Table 2. Previously adopted Minimum and Guidance Levels for Lake Wailes as listed in Table 8-2 of Rule 40D-8.624(12), F.A.C.

Minimum and Guidance Levels	Elevation in Feet NGVD 29	Total Lake Area acres
Ten Year Flood Guidance Level*	114.1	348
High Guidance Level	ND	ND
High Minimum Level	107.7	311
Minimum Level	106.6	304
Low Guidance Level	ND	ND

ND - not determined

Annually since 1991, a list of stressed lakes has been developed to support the District's consumptive water use permitting program as referenced in the District's Water Use Permit (WUP) Handbook (Part B) dated May 19, 2014. This handbook defines a stressed condition for a lake" as "chronic fluctuation below the normal range of lake level fluctuations."

For lakes with Guidance Levels adopted prior to August 7, 2000, chronic fluctuation below a Guidance Level referred to as the Low Level is considered a stressed condition. For lakes without adopted levels, stressed conditions shall be determined on a case-by-case basis through site investigation by District staff during the permit evaluation process. A stressed condition is based on continuous monthly data for the most recent five-year period, with the latest readings being within the past 12 months, and two-thirds of the values are at or below the adopted minimum low management level. Using this method and the Guidance Levels adopted in 1991 that preceded the Minimum and Guidance Levels adopted in 2006, Lake Wailes was classified as stressed from 1993 through 1997 and from 2002 through 2005 (Kolasa, 2013). Following establishment of the currently adopted Minimum Levels for Lake Wailes, the lake was no longer included in the annual stressed lakes assessment. Instead, the status of lake water levels relative to the adopted Minimum Levels was determined and on an annual basis. The result of a current status assessment is presented later in this report.

Summary Data Used for Minimum and Guidance Levels Development

Minimum and Guidance Levels for Lake Wailes were developed using the methodology for Category 3 Lakes described in Rule 40D-8.624, F.A.C. Levels and additional information are listed in Table 3, along with lake surface areas for each level or feature/standard elevation. Detailed descriptions of the development and use of these data are provided in the subsequent sections of this report.

Table 3. Minimum and Guidance Levels, lake stage exceedance percentiles, normal pool, control point, various basin feature, and significant change standards and associated surface areas for Lake Wailes.

Levels	Elevation in ft. NGVD 29	Lake Area (acres)
Lake Stage Exceedance Percentiles		
Historic P10	110.6	324.1
Historic P50	105.6	297.9
Historic P90	101.8	267.1
Normal Pool, Control Point and Basin Features		
Normal Pool	NA	NA
Control Point	NA	NA
Lowest Utility Pole/box	109.7	321.0
Lowest Lift Station	112.7	333.0
Low Floor Slab	120.3	NA
Low end of Paved Public Boat Ramp	97.9	234.0
Significant Change Standards		
Species Richness Standard	100.1	253.7
Wetland Offset Elevation	104.8	291.8
Aesthetics Standard	101.8	267.1
Dock-Use Standard	NA	NA
Basin Connectivity Standard	93.8	187.5
Recreation/Ski Standard	98.8	242.4
Lake Mixing Standard	89.1	121.7
Minimum and Guidance Levels		
High Guidance Level	110.6	324.1

High Minimum Lake Level	107.7	312.4
Minimum Lake Level	104.8	291.8
Low Guidance Level	101.8	267.1

NA - not appropriate.

Bathymetry

Relationships between lake stage, inundated area and volume can be used to evaluate expected fluctuations in lake size that may occur in response to climate, other natural factors, and anthropogenic impacts such as structural alterations or water withdrawals. Long=term reductions in lake stage and size can be detrimental to many of the environmental values identified in the Water Resource Implementation Rule for consideration when establishing minimum flows and levels. Stage-area-volume relationships are therefore useful for developing significant change standards and other information identified in District rules for consideration when developing minimum lake levels.

Stage-area-volume relationships were determined for Lake Wailes by building terrain model of the lake basin and surrounding watershed. Lake bottom elevations and land surface elevations were used to build the model through series analyses using LP360 for ArcGIS, ESRI's ArcMap™ version 10.1 software, the 3D Analyst ArcMap Extension, Python and Xtools Pro. Light Detection and Ranging Data (LiDAR) data and bathymetric data were merged using ArcMap geoprocessing tools and converted to a raster of grid elevations known as digital elevation model (DEM) using the 3D Analyst tool. The DEM is converted to a TIN (Triangulated Irregular Network).

Topographic contours of the lake basin (refer to Figure 3) were developed from the TIN. Lake stage-area-volume estimates were also derived from the TIN using a Python script file to iteratively run the Surface Volume tool in the Functional Surface toolset of the ArcMap 3D Analyst Extension at one-tenth of a foot elevation change increments (selected stage-area-volume results are presented in Figure 6).

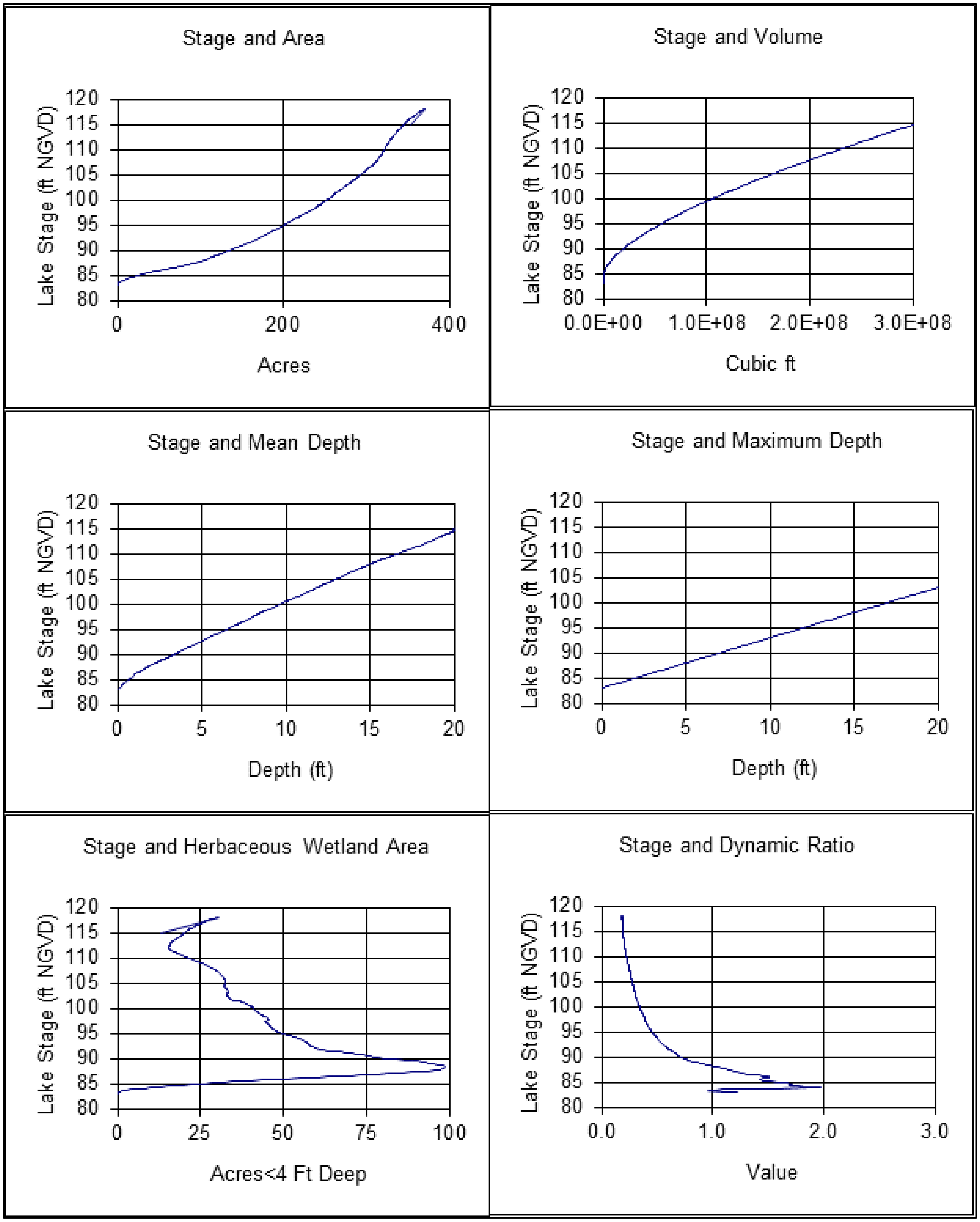

Figure 6. Lake surface area, volume, mean depth, maximum depth, potential herbaceous wetland area and dynamic ratio (basin slope) versus lake stage for Lake Wailes.

Lake Stage Data and Exceedance Percentiles

Daily surface water elevation data for Lake Wailes (District Site ID Number 25351) were obtained from the District Water Management Information System. Records are available from December 1951, May 1963, June 1964, and from September 1965 through the present date (Figure 7; see Figure 2 for the location of the District water level gage). The record is not continuous, i.e., there are some days during the period of record when lake surface elevations were not recorded.

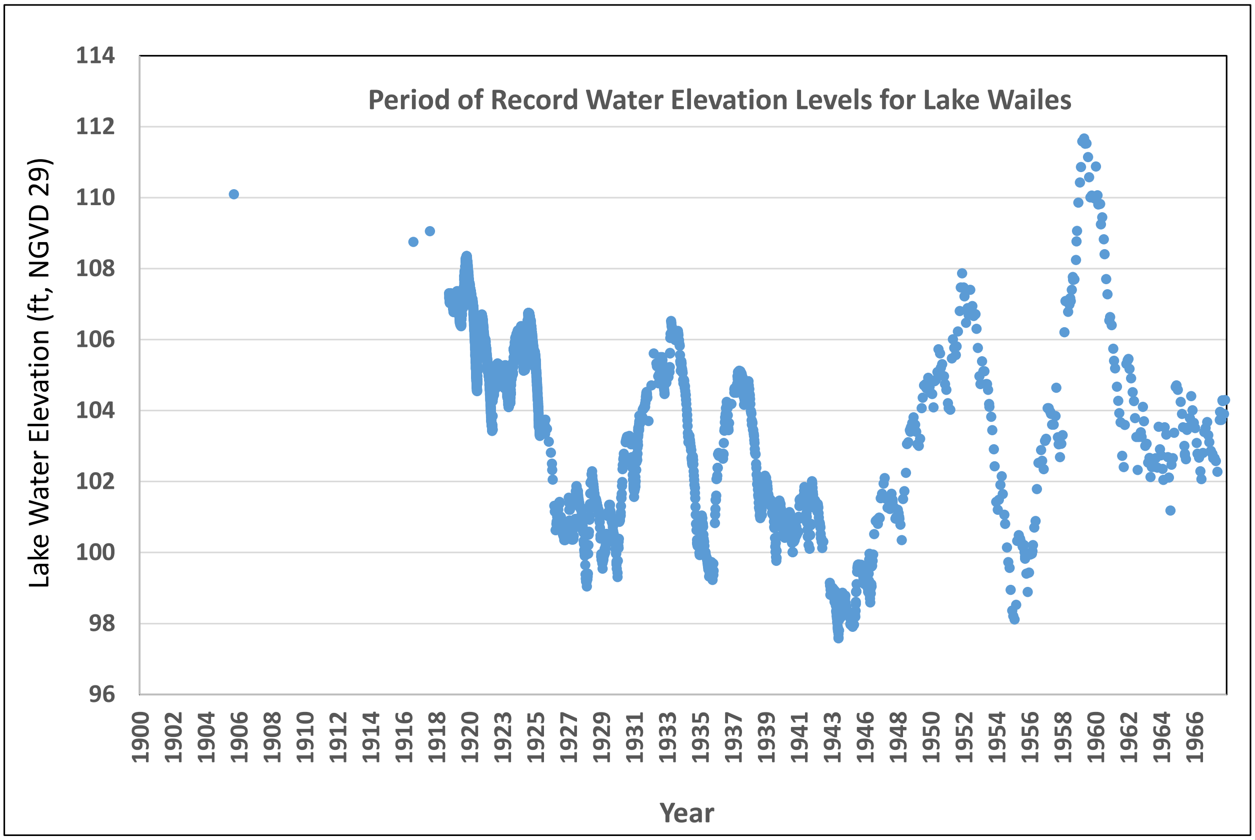

Figure 7. Lake Wailes stage data; December 1951 through December 2014.

Relatively high water levels, i.e., above 107 ft. NGVD29, occurred on 362 days out of the 3,570-day record from December 1951 through December 2014. The record-high water level of 111.7 ft. NGVD29 occurred in December 21, 2005. Low water levels, i.e., below 100.5 ft. NGVD29 occurred on 351 days, mostly between 1989 and 2002. The record-low water level was 97.6 ft. and occurred in May 22, 1990. Elevation contour lines associated with the record-high and low water levels are shown on a 2011 aerial photograph in Figure 8.

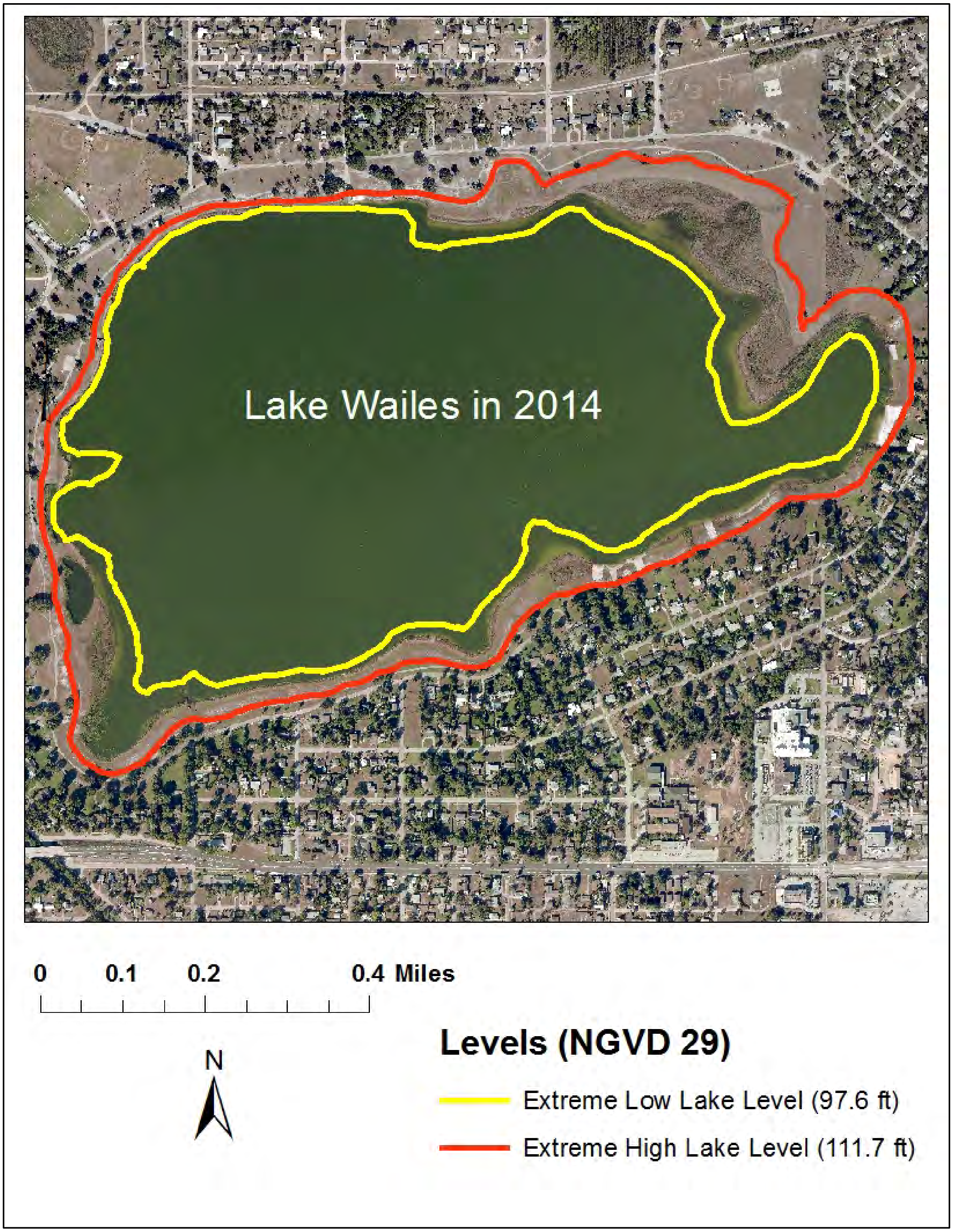

Figure 8. Aerial photograph of Lake Wailes with period of record high and low water level elevation contours.

Classification of Lake Stage Data and Development of Exceedance Percentiles

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

A long-term Historic lake stage record is a critical step to establish Minimum and Guidance Levels. No measured Historic data are available for Lake Wailes because effects from groundwater withdrawals from the surrounding area predate the lake stage record. A water budget model was therefore developed to simulate Historic water levels for the lake for the period from 1988 through 2014 (Appendix A). A line of organic correlation (LOC) model, with a coefficient of determination (r^2) of 0.75 was then used to predict lake stage for a long-term, Historic time period from 1946 through 2014 (Figure 9). The lake stage data obtained from the water budget model are included on the same chart to illustrate the model fit.

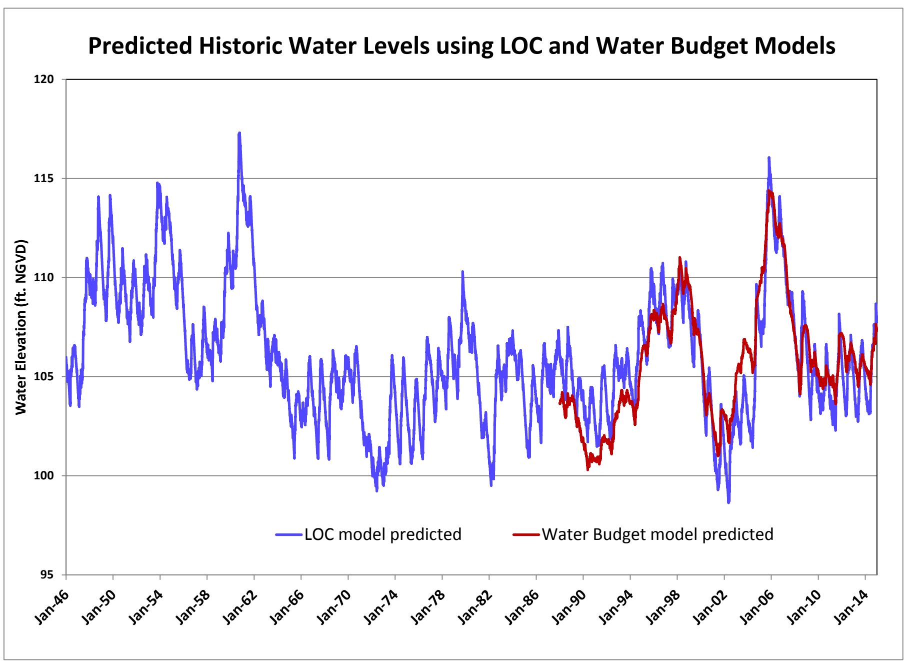

Figure 9. LOC-modeled water levels from January 1946 through December 2014 and water levels predicted with a water budget model from January 1988 through December 2014.

A Long-term, Historic water level record (Figure 10) was developed by replacing LOC-modeled water levels with water levels predicted with the water budget model, for dates they were available. The modeled hybrid Historic lake stage record was then used to calculate Historic P10, P50, and P90 lake stage percentile elevations (Figure 10, Table 3). The Historic P10 elevation, the elevation the lake water surface equaled or exceeded ten percent of the time during the Historic period, was 110.6 ft. NGVD29. The Historic P50 elevation, the elevation the lake water surface equaled or exceeded fifty percent of the time during the Historic period, was 105.6 ft. NGVD29. The Historic P90 elevation, the elevation the lake water surface equaled or exceeded 90 percent of the time during the Historic period, was 101.8 ft. NGVD29.

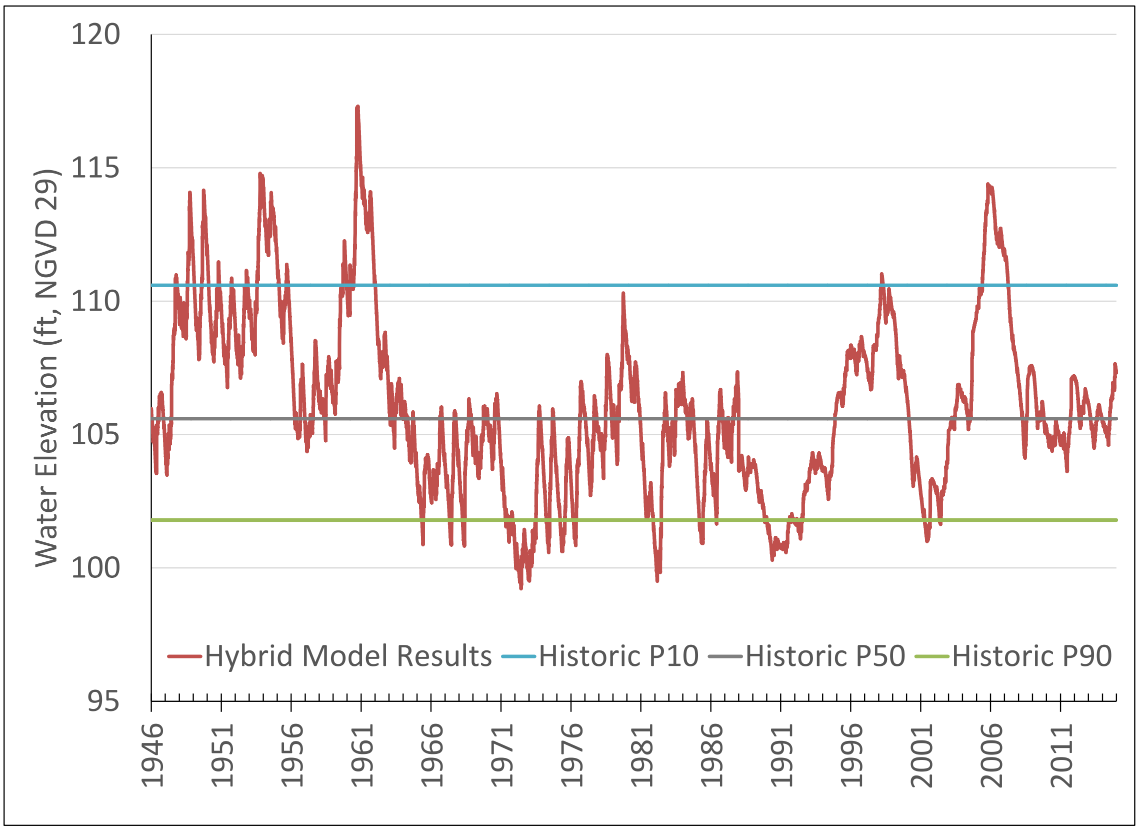

Figure 10. Long-term Historic lake level record and Historic P10, P50 and P90 lake stage percentiles for Lake Wailes based on a hybrid (LOC-modeled and water budget modeled) record.

Normal Pool Elevation, Control Point Elevation and Structural Alteration Status

The **Normal Pool** elevation, a reference elevation used for development of minimum lake and wetland levels, is established based on the elevation of hydrologic indicators of sustained inundation. Previously, a Normal Pool elevation for Lake Wailes was established based on the elevation of the waterward extent of longleaf pine (*Pinus palustris*) and live oak along the shore of the lake (SWFWMD 2008). However, these biological indicators have not shown to be reliable indicators of the sustained inundation (P10) and for that reason a Normal Pool elevation was not established for this MFLs reevaluation. Spot elevations for the lowest floor slab, the lowest spot on the paved walking trail surrounding the lake, the elevation of the lowest utility pole/box adjacent to the paved walking trail, and the lowest lift station were determined using available one-foot contour interval aerial maps, and field survey data (Table 3).

The **Control Point** elevation is the elevation of the highest stable point along the outlet profile of a surface water conveyance system (*e.g.,* weir, conservation structure, ditch, culvert, or pipe) that is the principal control of water level fluctuations in the lake. Lake Wailes is classified as a closed basin lake, so a control point elevation was not established for this reevaluation or the original assessment.

Structural Alteration Status is determined to support development of Minimum and Guidance Levels and modeling of Historic lake stage records. In addition to identification of outlet conveyance system modifications, comparison of the Control Point elevation with the Normal Pool is typically used to determine if a lake has been structurally altered. If the Control Point elevation is below the Normal Pool, the lake is classified as a structurally altered system. If the Control Point elevation is above the Normal Pool or the lake has no outlet, then the lake is not considered to be structurally altered. Because Lake Wailes does not have a Control Point, it is not considered to be structurally altered.

Lake Classification

Lakes are classified as Category 1, 2 or 3 for the purpose of Minimum Levels development. Systems with fringing cypress wetlands greater than 0.5 acres in size where water levels regularly rise to an elevation expected to fully maintain the integrity of the wetlands (*i.e*., the Historic P50 is equal to or higher than 1.8 ft. below the Normal Pool elevation) are classified as Category 1 Lakes. Category 2 lakes are also lakes with fringing cypress wetlands greater than 0.5 acres in size, but where structural alterations have prevented the Historic P50 from equaling or rising above an elevation that is equal to an elevation 1.8 ft. below Normal Pool elevation. Despite the structural alterations, the lake-fringing cypress swamp(s) remain viable and perform functions beneficial to the lake. Lakes without fringing cypress wetlands or with less than 0.5 acres of fringing cypress wetlands are classified as Category 3 Lakes. Because Lake Wailes does not have fringing cypress wetlands, it is classified as a Category 3 lake.

Significant Change Standards and Other Information for Consideration

Lake-specific significant change standards and other available information are considered for establishing Minimum Levels. The standards are used to identify thresholds for preventing significant harm to environmental values associated with lakes (refer to Table 1) in accordance with guidance provided in the Florida Water Resources Implementation Rule (Chapter 62-40.473, F.A.C.). Other information taken into consideration includes potential changes in the coverage of herbaceous wetland vegetation and aquatic plants.

Six significant change standards for Category 3 lakes, including a Dock-Use Standard, a Basin Connectivity Standard, an Aesthetics Standard, a Recreation/Ski Standard, a Species Richness Standard, and a Lake Mixing Standard are developed to identify desired median lake stages that if achieved, are intended to preserve various environmental values as described in Table 1. In addition, a Wetland Offset Elevation is also developed.

The **Aesthetics Standard** is developed to protect aesthetic values associated with the inundation of lake basins. The standard is intended to protect aesthetic values associated with the median lake stage from becoming degraded below the values associated with the lake when it is staged at the Low Guidance Level. The Aesthetic Standard is established at the Low Guidance Level, which for Lake Wailes is **101.8 ft.** NGVD29. Because the Low Guidance Level was established at the Historic P90 elevation, water levels equaled or exceeded the Aesthetics Standard 90 percent of the time during the Historic period.

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 Florida lakes, the standard is established at the lowest elevation associated with less than a 15 percent reduction in lake surface area relative to the lake area at the Historic P50 elevation. For Lake Wailes, the Species Richness Standard was established at **100.1 ft.** NGVD29. The species Richness Standard was equaled or exceeded more than 99 percent of the time, based on the Historic water level record.

The **Recreation/Ski Standard** is developed to identify the lowest elevation within the lake basin that will contain an area suitable for safe water skiing. The standard is based on the lowest elevation (the Ski Elevation) within the basin that can contain a five-foot deep ski corridor delineated as a circular area with a radius of 418 ft., or as used in this case, a rectangular ski area 200 ft. in width and 2,000 ft. in length, and use of Historic lake stage data. The Recreation/Ski Standard for Lake Wailes was established at **98.8 ft.** NGVD29, by adding five feet and the difference between the Historic P50 and Historic P90 (in feet) to the Ski Elevation (**86.0 ft.**). The Recreation/Ski Standard was equaled or exceeded more than 100 percent of the time, based on the Historic water level record.

The **Dock-Use** Standard is developed to provide for sufficient water depth at the end of existing docks to permit mooring of boats and prevent adverse impacts to bottom-dwelling plants and animals caused by boat operation. The standard is based on the elevation of lake sediments at the end of existing docks, a clearance water depth value for boat mooring, and use of Historic lake stage data. A Dock-Use Standard for Lake Wailes was not established because only one dock is available with in the basin and the dock is not used for boat mooring**.**

The **Basin Connectivity Standard** is developed to protect surface water connections between lake basins or among sub-basins within lake basins to allow for movement of aquatic biota, such as fish, and support recreational lake-use. The standard is based on the elevation of lake sediments at a critical high-spot between lake sub-basins, clearance water depths for movement of aquatic biota or powerboats and other watercraft, and use of Historic lake stage data or region-specific Reference Lake Water Regime statistics, which are differences between selected lake stage exceedance percentiles for a set of reference lakes. For Lake Wailes, the **Basin Connectivity Standard** was established at **93.8 ft.** NGVD29, based on the use of powerboats in the lake, a critical high spot elevation of **88.0 ft.** NGVD29 and Historic lake data. The Basin Connectivity Standard was equaled or exceeded 100 percent of the time, based on the Historic water level record.

The **Lake Mixing Standard** is developed to prevent significant changes in patterns of wind-driven mixing of the lake water column and sediment re-suspension. The standard is established at the highest elevation at or below the Historic P50 elevation where the dynamic ratio (see Bachmann *et al.* 2000) shifts from a value of <0.8 to a value >0.8, or from a value >0.8 to a value of <0.8. The Lake Mixing Standard for Lake Wailes was established at **89.1 ft.** NGVD29 (Figure 10). Review of the stage-area information (Figure 10) indicates that the lake size would be 121.7 acre at elevation corresponding to the Lake Mixing Standard. The Lake Mixing Standard was equaled or exceeded 100 percent of the time, based on the Historic water level record.

When developing Minimum Levels, information pertaining to **Herbaceous Wetlands** in the lake basin is also considered to determine the elevation at which the change in lake stage would result in substantial change in potential wetland area within the lake basin (*i.e*., basin area with a water depth less than or equal to four feet). Review of changes in potential herbaceous wetland area or area available for aquatic plant colonization in relation to change in lake stage did not indicate that of use of any of the significant change standards, with the exception of the Lake Mixing Standard, would be inappropriate for establishment of the Minimum Lake Level (Figure 6).

Changes in lake stage associated with changes in lake area available for colonization by rooted submersed or floating-leaved macrophytes are also typically evaluated when developing Minimum Levels. However, due to a lack of water transparency data needed for the assessment, this information was not evaluated for Lake Wailes.

Hancock (2006) determined that up to a 0.8 ft. decrease (or Wetland Offset) in the Historic P50 elevation would not likely be associated with significant changes in the herbaceous wetlands occurring within lake basins. A wetland offset elevation of **104.8 ft.** NGVD29 was therefore established for Lake Wailes by subtracting 0.8 feet from the Historic P50 elevation (**105.6 ft.** NGVD29). The Wetland Offset elevation was equaled or exceeded 63.3 percent of the time, based on the Historic water level record. The standard elevation therefore corresponds the Historic P63.

Guidance and Minimum Levels

The **High Guidance Level** is provided as an advisory guideline for construction of lake-shore development, water dependent structures, and operation of water management structures. The High Guidance Level is the expected Historic P10 of the lake and is established using Historic lake stage data if it is available, or is estimated using the Current P10 (which is the water surface elevation equaled or exceeded ten percent of the time for a Current period, which is a period when measurable, stable impacts due to water withdrawals, and impacts due to structural alterations were stable), the Control Point, and the Normal Pool elevation. The High Guidance Level for Lake Wailes was established at **110.6 ft.** NGVD29 based on the Historic P10 elevation derived from the modeled Historic water level record.

The **Low Guidance Level** is provided as an advisory guideline for water dependent structures, information for lake shore residents, and operation of water management structures. The Low Guidance Level is the elevation that a lake's water levels are expected to equal or exceed ninety percent of the time (P90) on a long-term basis. The level is established using Historic or Current lake stage data, and in some cases, Reference Lake Water Regime Statistics. The Low Guidance Level for Lake Wailes was established at **101.8 ft.**, the Historic P90 elevation derived from the modeled historic water level record (Figure 11, Table 3).

Minimum Lake Levels are developed using specific lake-category significant change standards and other available information or unique factors, including: substantial changes in the coverage of herbaceous wetland vegetation and aquatic macrophytes; elevations associated with residential dwellings, roads or other structures; frequent submergence of dock platforms; faunal surveys; aerial photographs; typical uses of lakes (*e.g.,* recreation, aesthetics, navigation, and irrigation); surrounding land-uses; socio-economic effects; and public health, safety and welfare matters. Minimum Levels development is also contingent upon lake classification*, i.e.,* whether a lake is classified as a Category 1, 2 or 3.

The **Minimum Lake Level (MLL)** is the elevation that a lake's water levels are required to equal or exceed 50 percent of the time on a long-term basis. For Category 3 Lakes, the MLL is typically established corresponding to the most conservative significant change standard, i.e., the standard with the highest elevation, except where that elevation is above the Historic P50 elevation, in which case the MLL is established at the Historic P50 elevation. Since all appropriate significant change standards were below the Historic P50 elevation, the MLL for Lake Wailes was established at **104.8 ft.** NGVD29, the elevation corresponding to the Wetland Offset. The MLL is 4.9 ft. below the lowest utility pole/box adjacent to the lake and 15.8 ft. below the elevation of the lowest residential floor slab within the lake basin. If the lake surface were at the Minimum Lake Level, the low end of the paved public boat ramp at the lake would be 6.9 ft. under water.

The **High Minimum Lake Level (HMLL)** is the elevation that a lake's water levels are required to equal or exceed ten percent of the time on a long-term basis. For Category 3 lakes, the HMLL is developed using the MLL, Historic data or Reference Lake Water Regime statistics. If Historic Data are available, the HMLL is established at an elevation corresponding to the MLL plus the difference between the Historic P10 and Historic P50.

Based on the availability of Historic data for Lake Wailes, a HMLL for Lake Wailes could be established at 109.8 ft. NGVD29 (Figures 9 and 10), by adding the difference between the Historic P50 and Historic P10 (5.0 ft) to the proposed MLL. However, portions of a paved walking trial that encircles much of the lake would be inundated if the lake water level exceeded 110 ft. NGVD29, as would several electric utility poles used to light the trail. Therefore, to mitigate this flooding potential, the HMLL was established at **107.7 ft.** NGVD29, an elevation 2 ft. below the lowest utility pole/box adjacent to the trail. This approach is consistent with the previous establishment of the HMLL for the lake (SWFWMD 2008). The HMLL is 5.0 ft. below the lift station and approximately 12.6 ft. below the lowest residential floor slab (Low Floor Slab) elevation within the lake basin.

Many federal, state, and local agencies, such as the U.S. Army Corps of Engineers, the Federal Emergency Management Agency, U. S. Geological Survey, and Florida’s water management districts are in the process of upgrading from the NGVD29 vertical datum to the NAVD88 datum for recording water level, ground and other elevations. For comparative purposes, the Minimum and Guidance Levels for Lake Wailes are presented relative to both vertical datums in Table 7. Elevations expressed relative to NGVD29 were converted to elevations relative to NAVD88 using a conversion factor of 0.951 ft. derived with Corpscon 6.0 software distributed by the U.S. Army Corps of Engineers.

Minimum and Guidance levels for Lake Wailes are shown in Figure 11 along with the Period of Record water levels. The approximate locations of the lake margin when water levels equal the Minimum Levels are shown superimposed on aerial photographs from several years in Figures 12 through 15. Figure 12 includes an aerial photograph from 2014 which shows the lake water level approximately 2.8 feet lower than the MLL. Figure 13 includes a 1968 aerial photograph that shows the lake when it was staged approximately 1.2 ft. higher than the MLL. Figure 14 includes a 1958 aerial photograph that shows the lake when the water level was 3.2 ft. above the MLL but 0.7 ft. below the HMLL. Figure 15 includes a 1941 aerial photograph from a date when the lake water level was 7.2 ft. above the MLL and 4.3 ft. above the HMLL.

Table 7. Minimum and Guidance Levels for Lake Wailes relative to NGVD29 and NAVD88.

Minimum and Guidance Levels	Elevation (Ft. NGVD29)	Elevation (Ft. NAVD88)
High Guidance Level	110.6	109.6
High Minimum Lake Level	107.7	106.7
Minimum Lake Level	104.8	103.8
Low Guidance Level	101.8	100.8

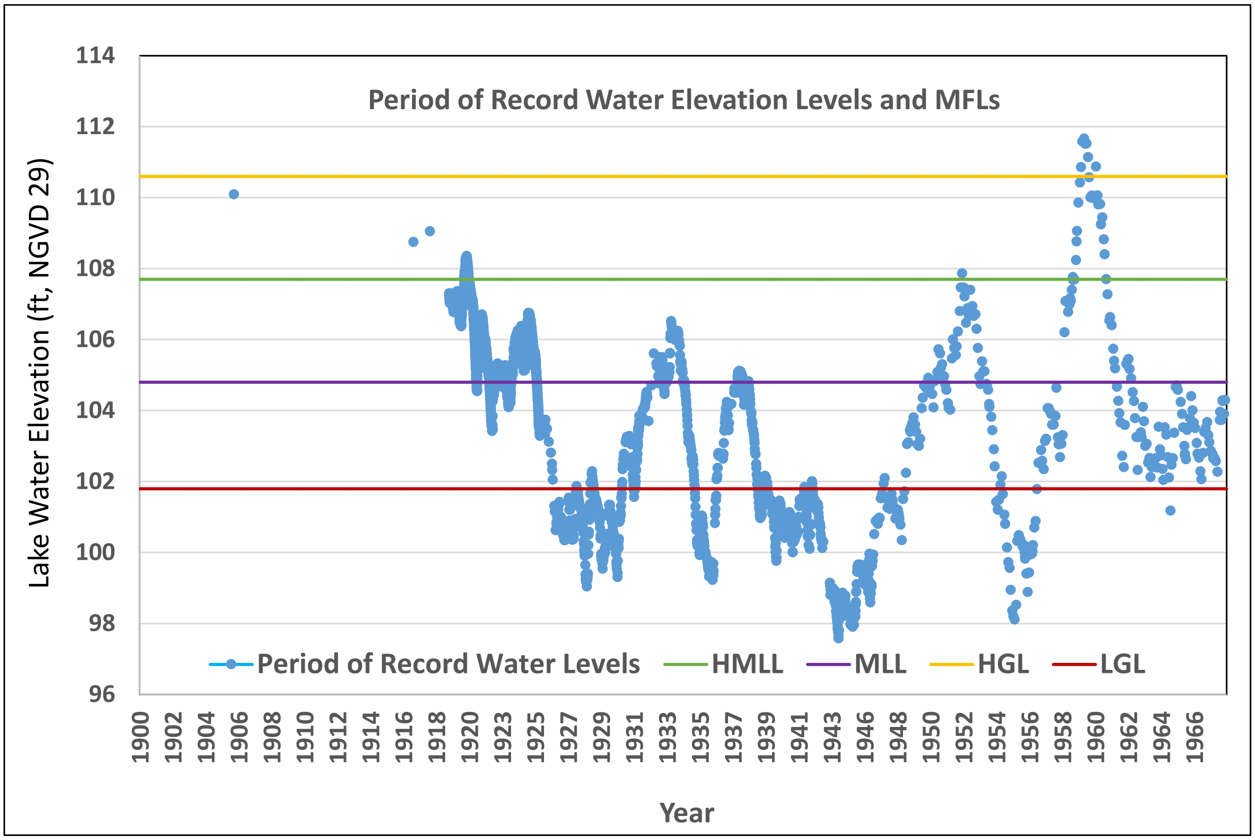

Figure 11. Period of Record water levels and Minimum and Guidance Levels for Lake Wailes. Levels include the High Guidance Level (HGL), High Minimum Lake Level (HMLL), Minimum Lake Level (MLL), and the Low Guidance Level (LGL).

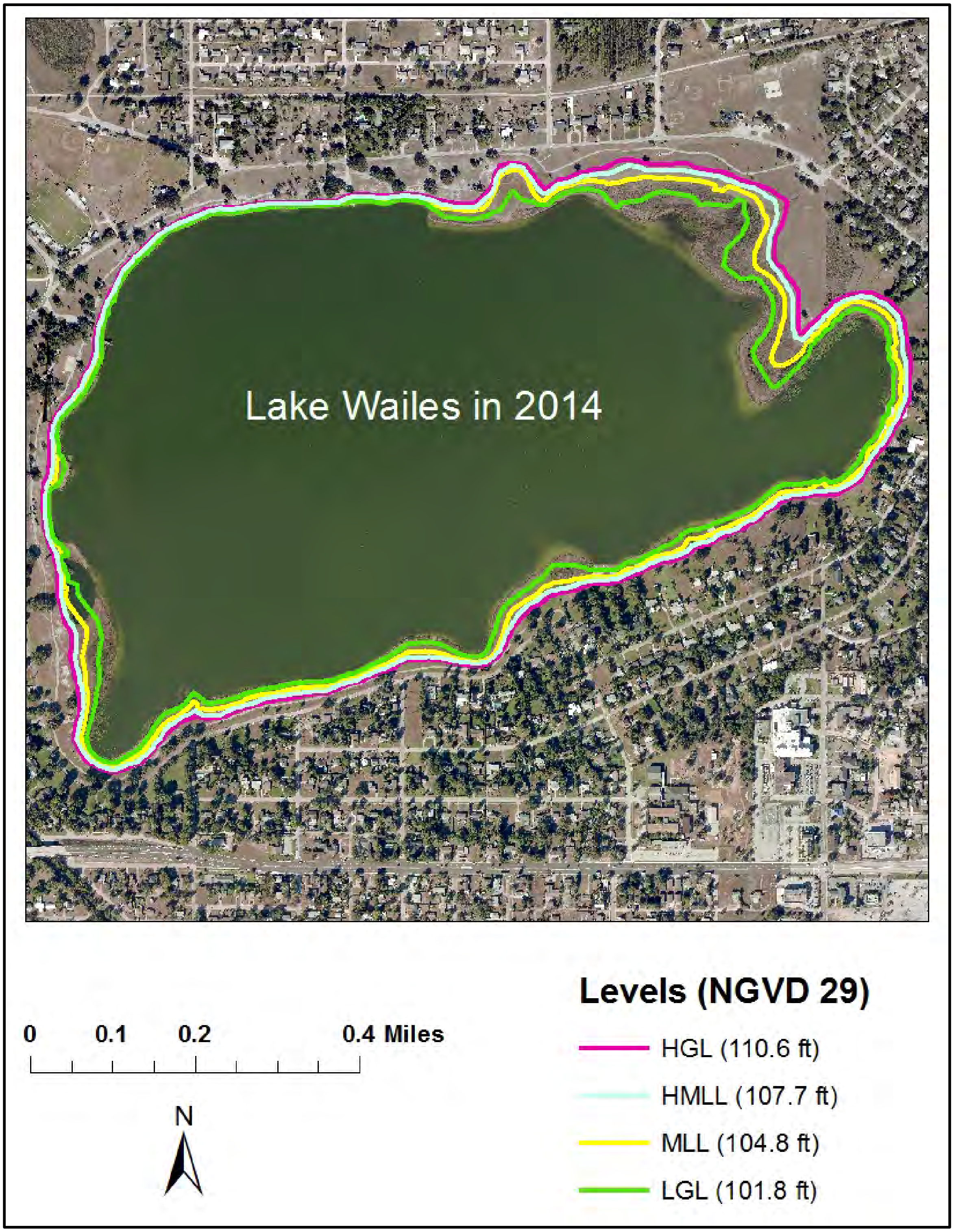

Figure 12. Approximate location of the Minimum Lake Level (MLL), High Minimum Lake Level (HMLL), High Guidance Level (HGL) and Low Guidance Level (LGL) for Lake Wailes relative to conditions in February 2014. Lake water level elevation was approximately 102.0 ft. NGVD29 when the imagery was taken.

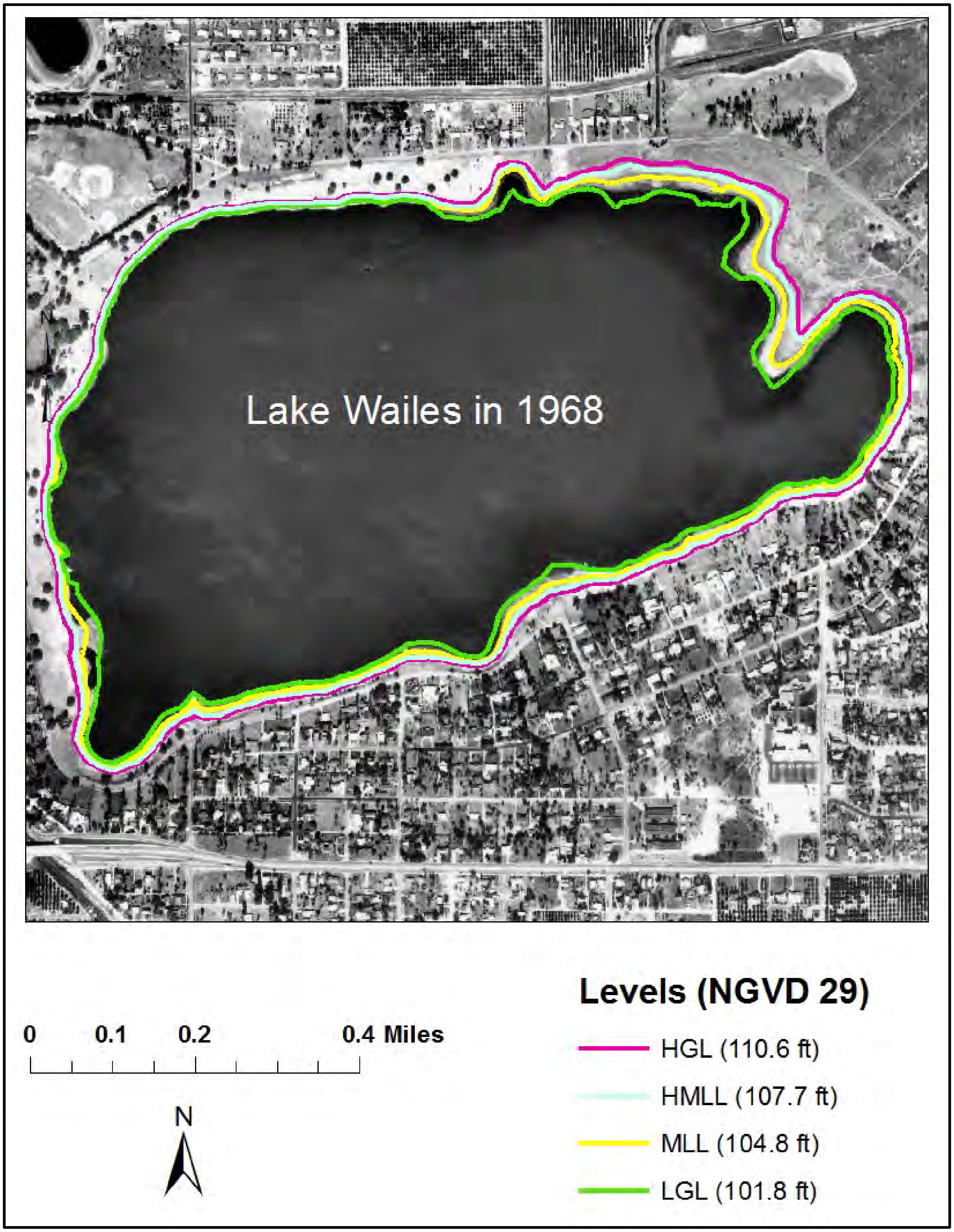

Figure 13. Approximate location of the Minimum Lake Level (MLL), High Minimum Lake Level (HMLL), High Guidance Level (HGL) and Low Guidance Level (LGL) for Lake Wailes relative to conditions in February 1968. Lake water level elevation was approximately 106.0 ft. NGVD29 when the imagery was taken.

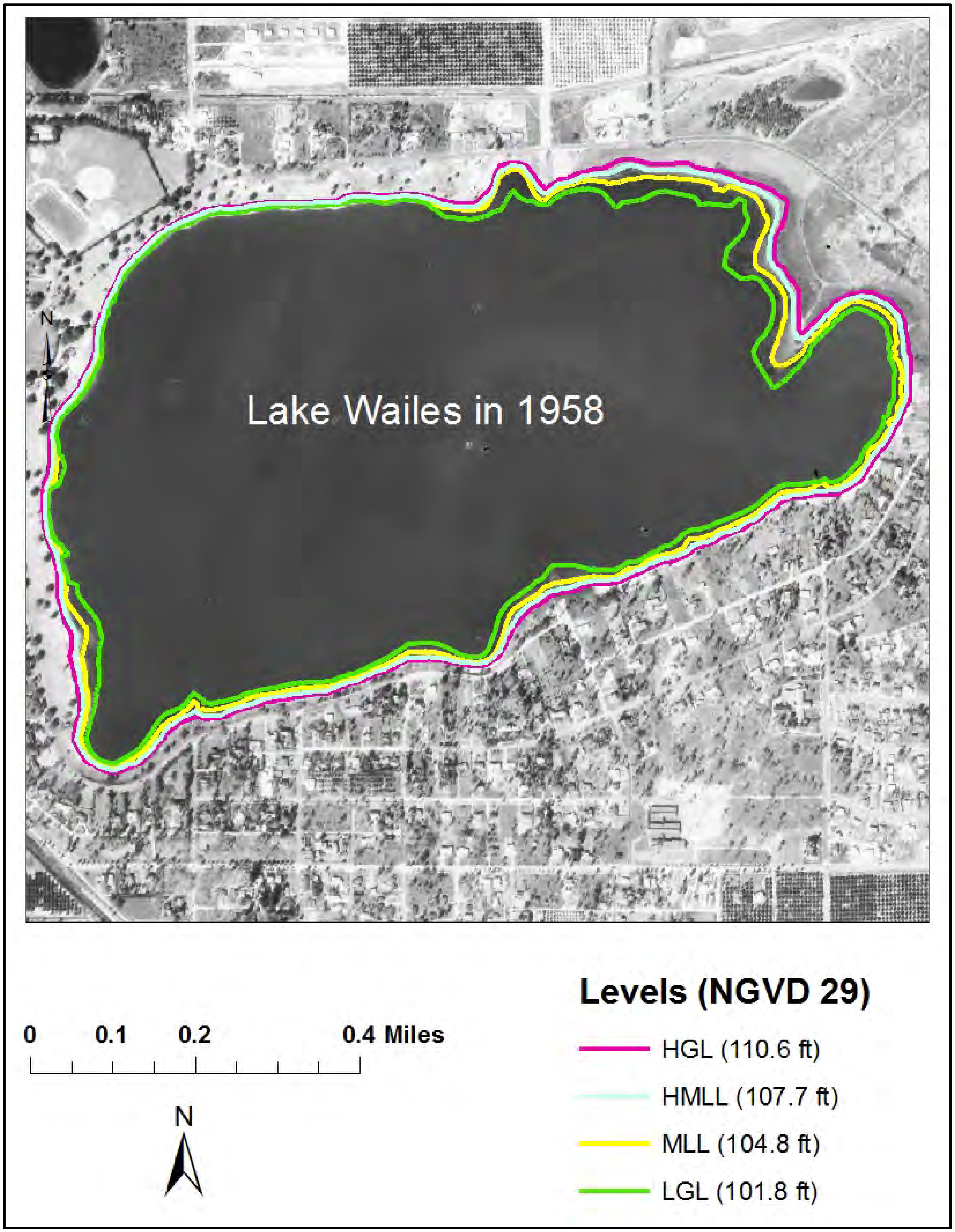

Figure 14. Approximate location of the Minimum Lake Level (MLL), High Minimum Lake Level (HMLL), High Guidance Level (HGL) and Low Guidance Level (LGL) for Lake Wailes relative to conditions in January 1958. Lake water level elevation was approximately 108.0 ft. NGVD29 when the imagery was taken.

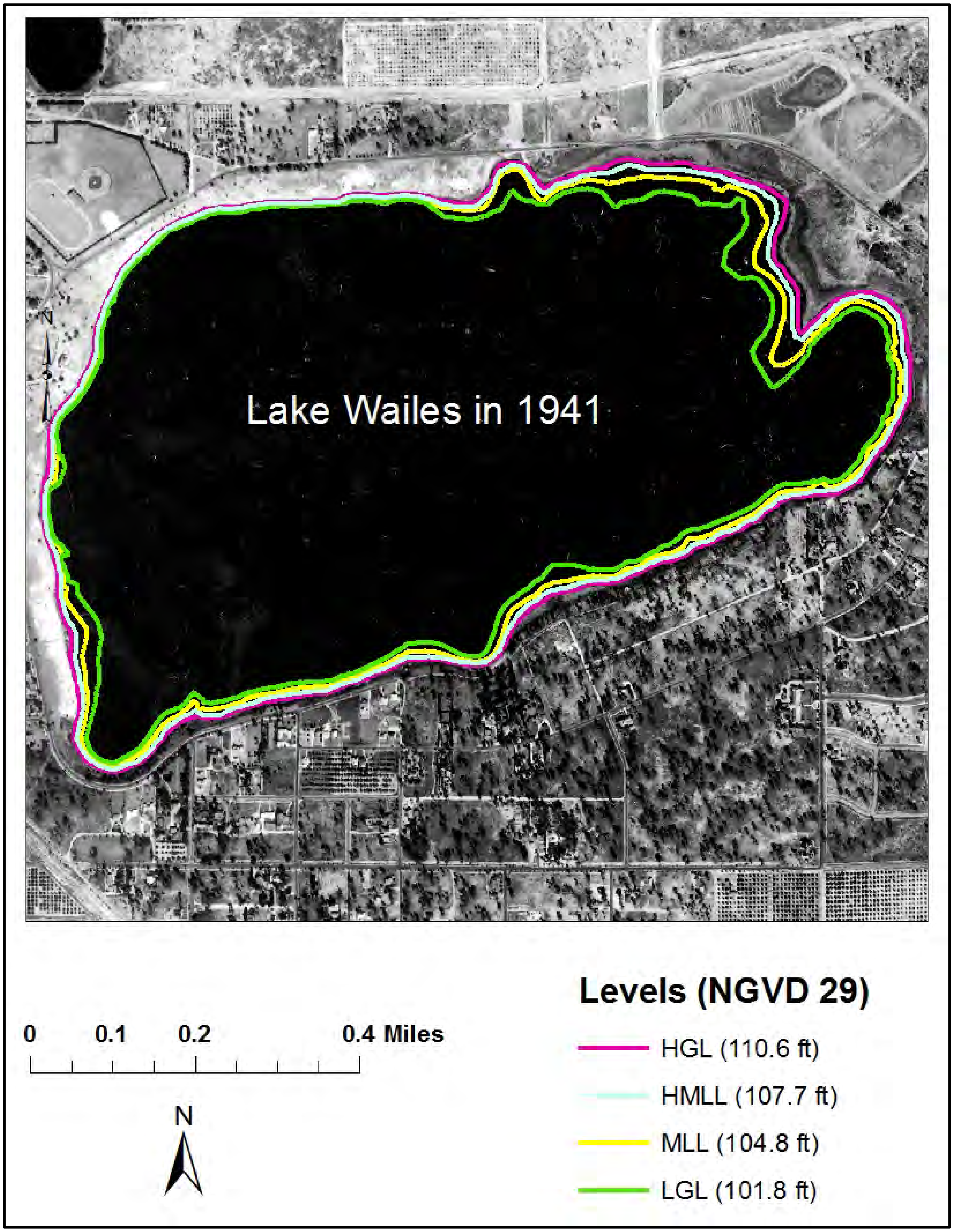

Figure 15. Approximate location of the Minimum Lake Level (MLL), High Minimum Lake Level (HMLL), High Guidance Level (HGL) and Low Guidance Level (LGL) for Lake Wailes relative to conditions in March 1941. Lake water level elevation was approximately 112.0 ft. NGVD29 when the imagery was taken.

Consideration of Environmental Values

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

The Wetland Offset was used to develop Minimum Levels for Lake Wailes based on its classification as a Category 3 Lake. This criterion is associated with protection of several environmental values identified in Rule 62-40.473, F.A.C., including: fish and wildlife habitats and the passage of fish: transfer of detrital material: aesthetic and scenic attributes; filtration and absorption of nutrients and other pollutants; and water quality (refer to Table 1). These and most of the other environmental values listed in Table 1 are associated with the other standards evaluated for development of levels for Lake Wailes, and given that those standards occur at lower elevations than the Wetland Offset elevation, the Minimum Levels are considered protective of the values associated with those standards. The environmental value, recreation in and on the water, is associated with the Species Richness, Basin Connectivity and Aesthetics standards developed for the lake, and each of these standards are associated with elevations lower than the Minimum Lake Level and the High Minimum Lake Level. Similarly, the environmental value, navigation, may be associated with Basin Connectivity Standard, which is, again, lower than the Minimum Lake Level and the High Minimum Lake Level. In addition, the environmental value, maintenance of freshwater storage and supply is also expected to be protected by the Minimum Levels based on inclusion of conditions in water use permits that stipulate that permitted withdrawals will not lead to violation of adopted minimum flows and levels.

Two environmental values identified in Rule 62-40.473, F.A.C., was not considered relevant to development of Minimum Levels for Lake Wailes. Estuarine resources were not considered relevant because the lake is not directly connected to estuarine resources and water level fluctuations in the lake are not expected to exert any effect on the ecological structure and functions of any estuaries. Sediment loads were similarly not considered relevant for minimum levels development for the lake, because the transport of sediments as bed load or suspended load is a phenomenon associated with flowing water systems.

Comparison to Previously Adopted Levels

Due to the lack of enough information on historic water levels and water withdrawal impacts, the High Guidance Level and the Low Guidance Level were not previously established when Minimum Levels were adopted for Lake Wailes in 2006. With the application of a new modeling approach, however, Historic water level fluctuations that would be expected in the absence of water withdrawal impacts given existing structural conditions were estimated (see Figure 9). Based on this information it was determined that the High Guidance Level and the Low Guidance Level are appropriate.

The High Minimum Lake Level for Lake Wailes is the same as the previously adopted High Minimum Lake Level. The Minimum Lake Level is, however, 1.8 ft. lower than the previously adopted Minimum Lake Level. This difference is associated with application of a new modeling approach for characterization of Historic water level fluctuations within the lake.

Assessment of the Lake Wailes Minimum Level Condition

Lake status was assessed (Appendix B) using actual lake stage data for Lake Wailes from 1988 through 2014, which was determined to represent the "Current" period when hydrologic stresses (including groundwater withdrawals) and structural alterations are reasonably stable. To create a data set that can reasonably be considered to be "Long-term", a line of organic correlation (LOC) analysis was performed on the lake level data from the Current period. "Long-term" is defined as a period that has been subjected to the full range of rainfall variability that can be expected in the future. The result of the analysis produces a 69-year long-term water level record (1946-2014) representing "Current" conditions, which can be compared to the Minimum Levels. Results from this assessment indicate that Lake Wailes' Long-term P10 is 0.2 ft. above the High Minimum Lake Level and the Long-term P50 is 1.5 ft. below the Minimum Lake Level. Based on the information presented in Appendix B, it is concluded that Lake Wailes' water levels are currently below the Minimum Lake Level, and above the High Minimum Lake Level for the lake.

The lake lies within the region of the District covered by an existing recovery strategy, the Southern Water Use Caution Area recovery strategy (Rule 40D-80.074, F.A.C., SWFWMD 2006). The District plans to continue regularly monitoring of water levels in Lake Wailes and will also routinely evaluate the status of the lake's water levels with respect to adopted Minimum Levels for the lake that are included in Chapter 40D-8, F.A.C.

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APPENDIX A

Draft Technical Memorandum

December 8, 2015

TO: Yonas Ghile, Ph.D. Senior Environmental Scientist, Natural Systems and Restoration Bureau

THROUGH: Jerry L. Mallams, P.G., Manager, Water Resources Bureau

FROM: Tamera McBride, P.G., Senior Hydrogeologist, Water Resources Bureau
Mark D. Barcelo, P.E. Chief Professional Engineer, Water Resources Bureau

Subject: Lake Wales Water Budget Model, Rainfall Regression Model, and Historic Percentile Estimations

A. Introduction

Water budget and rainfall regression models were developed to assist the Southwest Florida Water Management District (District) in the reassessment of minimum levels for Lake Wales (according to the USGS Geographic Information Names System at *geonames.usgs.gov*) (also locally known as Lake Wailes) in east-central Polk County, within the City of Lake Wales. Lake Wales currently has adopted minimum levels that are scheduled to be re-assessed in FY 2015. This document will discuss the development of the Lake Wales models and use of the models for development of Historic lake stage exceedance percentiles.

B. Background and Setting

Lake Wales is located in east-central Polk County, just northeast of the intersection of Alternate US Highway 27/State Road 17 and State Road 60 in the City of Lake Wales. (Figure 1). The lake is within the Peace Creek watershed, as identified by ADA Engineering (2012) and Atkins (2013) for watershed management program modeling. The lake has also been identified by the USGS as being part of the Tiger Creek sub-basin of the Kissimmee River watershed. There are no major natural surface water systems draining into the basin. Drainage into the lake is a combination of overland flow, flow through drainage swales and conveyance systems, as well as percolation from the surficial aquifer. It is classified as a closed basin lake (O'Reilly et al., 2014). There are currently no permitted surface water withdrawals from the lake; however, there are numerous permitted groundwater withdrawals in the vicinity.

Physiography

Lake Wales is situated between the eastern and western boundaries of a north-south oriented ridge (the Lake Wales Ridge) that is approximately 100 miles long and ranges from four to ten miles wide (Figure 1). The area surrounding the lake is categorized as the Iron Mountains in the Central Lake Physiographic District (Brooks, 1981). It is a sub-region of the Lake Wales Ridge and contains very high sand hills underlain by sand, gravel, and clayey sand that are deeply weathered. The Lake Wales Ridge area is predominantly well-drained and has internal drainage caused by numerous karst features; hence, it is an uplands recharge area for the Upper Floridan aquifer in Central Polk and Highlands counties. Dissolution of the underlying limestone creates the relief seen in the Lake Wales Ridge. The Lake Wales Ridge Complex is a remnant of a broader upland that has been eroded and lowered by sea level fluctuations, fluvial erosion, and aeolian redistribution of sediments (Green et al., 2012). The lake straddles the center of a north-south trending ridge that slopes downward to the east and west. Elevations within the immediate watershed range from the lake edge at about 105 feet to nearly 240 feet NAVD 88 on the south side of the lake.

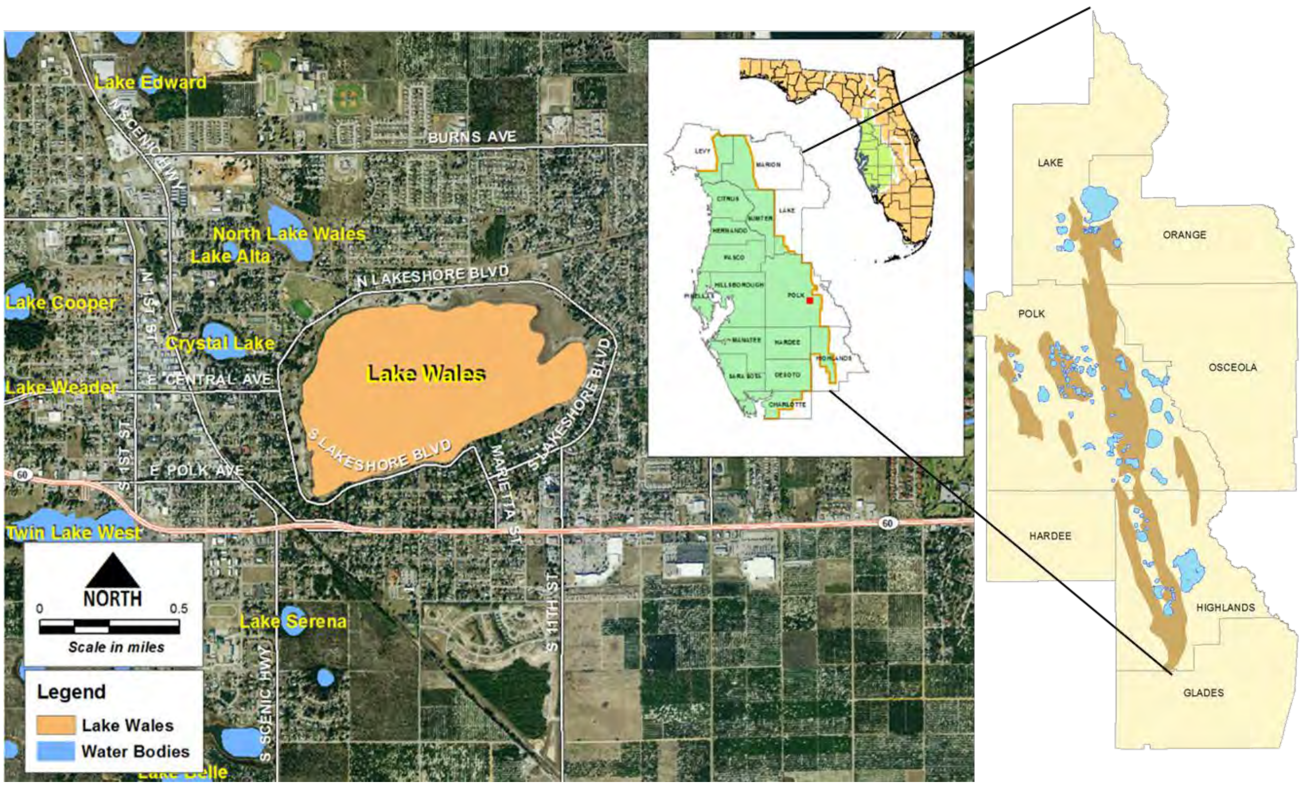

Figure 1. Location of Lake Wales and the Lake Wales Ridge in Polk County, Florida.

Hydrogeology

The hydrogeology of the area includes a sand surficial aquifer; a clay confining unit perforated by karst features (sinkholes); and the thick carbonate Upper Floridan aquifer (Spechler and Kroening, 2007). Sinkholes are numerous along the Lake Wales Ridge and range in size from small depressions to large lakes. Lake Wales is a sinkhole lake (Henderson, 1986). Sinkholes provide more direct avenues for water from the surficial aquifer to recharge the underlying Upper Floridan aquifer. Lateral movement of water through the surficial aquifer can be affected by individual lake basins because of the rolling topography, but there is also a sub-regional component to flows. The surficial aquifer is recharged by area rainfall; however, much of the rain that falls drains into lakes or is lost to evapotranspiration. Other sources of recharge that are applied to land include wastewater, reclaimed water, septic effluent, and irrigation of agricultural land or landscape areas (Spechler and Kroening, 2007). In elevated areas, such as the Lake Wales Ridge, the water table generally is a subdued reflection of land-surface topography (Yobbi, 1996). The Hawthorn aquifer system that consists mostly of interbedded clay, silt, phosphate, and sand is present at Lake Wales and serves as a confining unit except where breached by sinkholes.

Hydrogeology and stratigraphy near Lake Wales at the ROMP 57X wellsite are described in Henderson (1986). This site is approximately one-quarter mile south of Lake Wales at Hillcrest Elementary School. The surficial aquifer at this site consists of undifferentiated, unconsolidated quartz sand and clayey quartz sand deposits present from land surface datum (LSD) to 192 feet below LSD (5 feet above NGVD 29). The stratigraphy at the ROMP 57X wellsite is typical of the area, as the surficial aquifer generally thickens moving from west to east across Polk County, especially along the southern part of the Lake Wales Ridge where the thickness can exceed 200 feet (Spechler and Kroening, 2007). The surficial aquifer generally exhibited moderate to high porosity and permeability at the ROMP 57X wellsite. The water table at ROMP 57X was found to be 101 feet below LSD and typically responds fairly quickly to precipitation and groundwater withdrawals. Some area surficial aquifer wells declined to record or near-record lows in 2000 and 2001, when annual rainfall averaged about 21 and 27 inches below normal at the Mountain Lake and Avon Park rainfall stations, respectively (Spechler and Kroening, 2007).

Spechler and Kroening (2007) report that the intermediate confining unit (more recently referred to as the Hawthorn aquifer system) is present throughout much of northern and eastern Polk County and is locally absent or thin in the extreme northwestern part of Polk County. The Hawthorn aquifer system was present at ROMP 57X from 192 feet below LSD (5 feet above NGVD 29) to 257.8 feet below LSD (60.8 feet below NGVD 29). It is primarily composed of clayey/sandy limestones and sandy clays grading to clayey dolomites. The unit exhibited low to moderate porosity values with low permeability values. Preliminary comparisons of water levels for the surficial and Floridan aquifer system indicated that the Hawthorn aquifer system exhibits characteristics of a semi-leaky confiner (Henderson, 1986).

Below the Hawthorn aquifer system lies the limestone of the Upper Floridan aquifer that ranges from approximately 300 feet thick in eastern Polk County to more than 1,200 feet thick in the southwestern part of the county (Spechler and Kroening, 2007). The Floridan aquifer system, the principal source of water for this area, extended from 257.8 feet below LSD (60.8 feet below NGVD 29) to 344.5 feet below LSD (147.5 feet below NGVD 29) at the ROMP 57X wellsite. The Floridan aquifer system here consisted mainly of calcarenitic limestone with some dolomite lenses. Porosity and permeability were moderate to high. Henderson (1986) states a comparison of water levels between Lake Wales and the Floridan aquifer system suggests that they are hydrologically connected through a “conduit” possibly created by a sinkhole that caused the lake to form in the geologic past.

Data

Regular water level data collection at Lake Wales (SID 25351) began in September 1965, when the United States Geological Survey (USGS) started measuring water levels daily with a recorder (Figure 2), although a few manual data points exist prior to the daily record starting in 1951. Data collection frequency was daily through September 1971 when manual recording started. After September 1971, the frequency ranged from two times per week to monthly until the early 1990s, when data collection became monthly.

The nearest Floridan aquifer system monitor well with a significant period of water level data is the ROMP 57X Upper Floridan aquifer monitor well (SID 25354), with regular daily data collection beginning in November 1987 (Figures 3 and 4). Data gaps in the were infilled with estimated data generated using a linear regression of ROMP 57X Upper Floridan aquifer monitor well data with CL-1 Upper Floridan aquifer monitor well (SID 23873) data. The CL-1 Upper Floridan aquifer monitor well is located approximately 4.5 miles from Lake Wales (Figure 3).

The ROMP 57X suficial aquifer monitor well (SID 25355) is located approximately one-quarter mile south of Lake Wales (Figures 3 and 4), near the ROMP 57X Upper Floridan aquifer monitor well. The data for the surficial well start in November 1987 and are generally daily, with the exception of a few data gaps and a period from November 1994 through October 2003 when data collection was monthly. Missing data were linearly infilled since the gaps were relatively short.

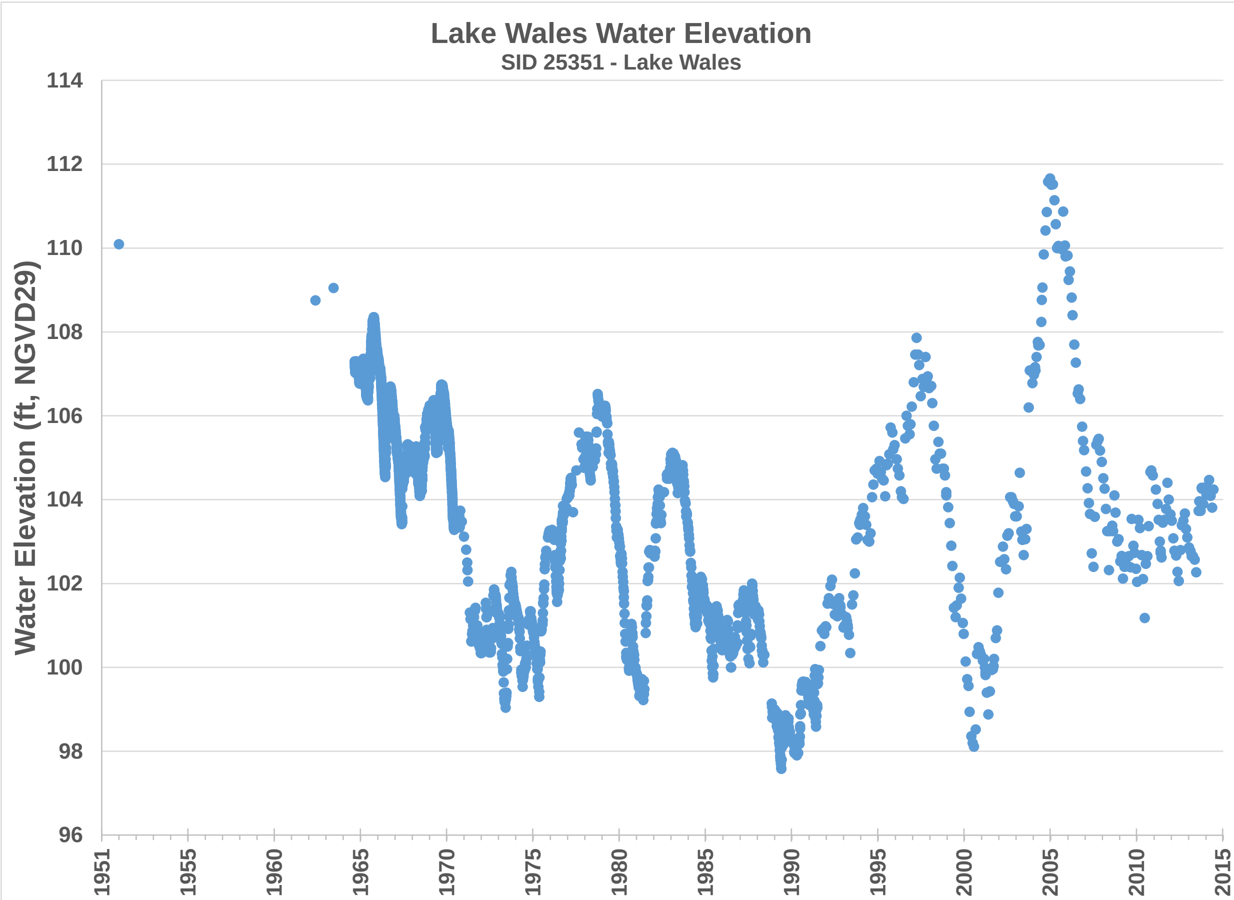

Figure 2. Lake Wales water levels.

In addition to the ROMP 57X surficial aquifer monitor well, surface water levels in North Lake Wales (SID 25353) and the gradient between Lake Wales and the South Mine Pond gage (Water Use Permit Number 5173, District ID 22) at a sand mine east of Lake Wales were used to simulate effects of the surficial aquifer in the water budget model (Figures 3 and 4). The North Lake Wales data begin in 1981 with a few water levels collected with irregular frequency. Collection with regular frequency began in October 1990; however, water levels were noted as being below the staff gage until September 1994. There were, for some periods, multi-month gaps in the North Lake Wales data. These gaps were infilled with estimated data generated using a linear regression of North Lake Wales water level data with ROMP 57X surficial aquifer monitor well data. The North Lake Wales gage is located approximately one-half mile northwest of Lake Wales.

The South Mine Pond gage is located just under a mile northeast of Lake Wales (Figure 3). Historical data for this gage and Lake Wales were used to estimate a hydraulic gradient from the mine to Lake Wales.

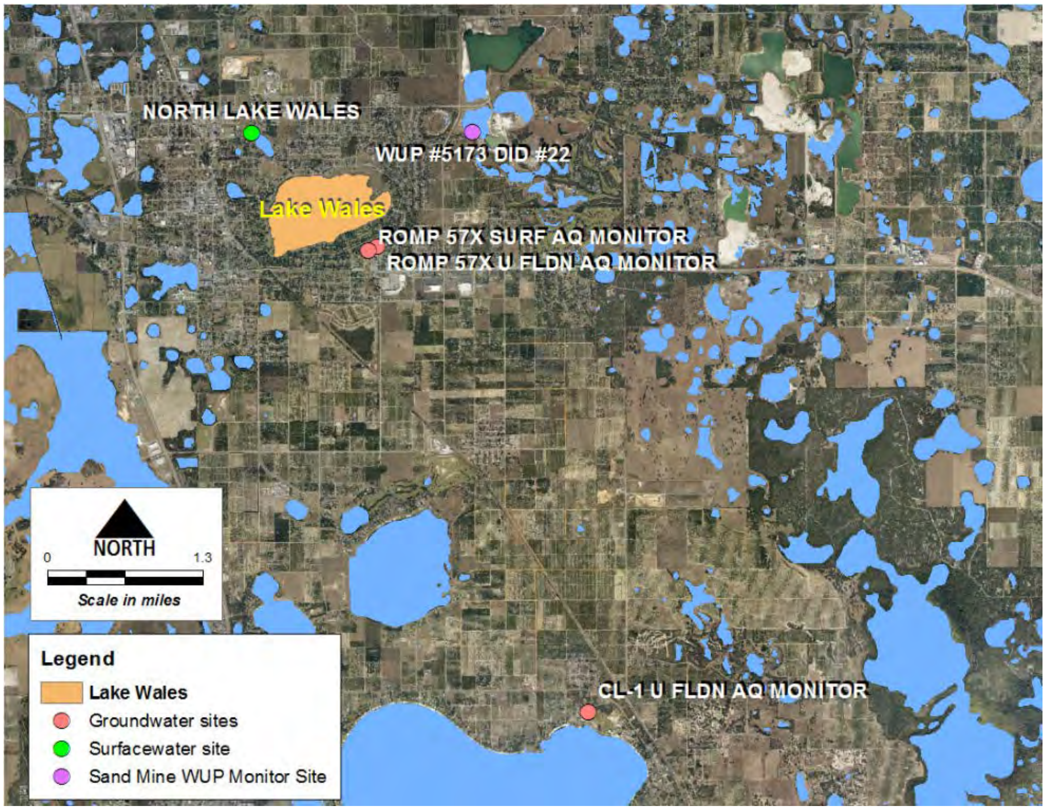

Figure 3. Location of monitoring wells near Lake Wales.

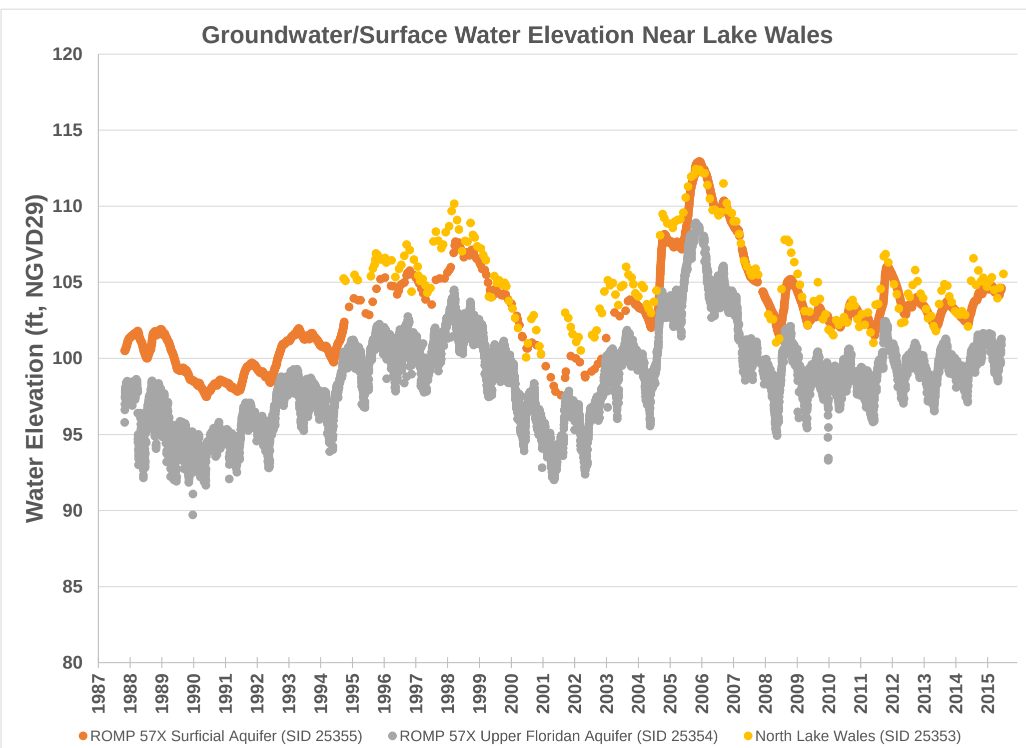

Figure 4. Water levels in monitoring wells near Lake Wales.

Land and Water Use

Land and water use in the area of Lake Wales has changed over the years. Figure 5 shows the land use around Lake Wales in 1941 and Figure 6 shows 2011 land use/land cover with 2014 aerial imagery. Much of the land use in 1941 consisted of citrus groves, undeveloped land, and some residential development on the south and west sides of the lake. In general, irrigation of citrus groves became more prevalent in the 1960s when it was determined that it could greatly improve crop yield. Also, water use by the phosphate industry, centered in an area approximately 30 miles to the west/southwest of Lake Wales, began to increase significantly throughout the late 1960s and 1970s. Today, land use and water use have changed (Figures 5 through 7, and Table 1). Land use has become more urban, replacing much of the citrus. Additionally, sand mining east of Lake Bonnie (which is east of Lake Wales) started between 1952 and 1958 (based on a review of aerial photography) and has continued to expand over time. The estimated total groundwater use average from 2008 to 2012 within one mile of the lake is approximately 1.1 million gallons per day (mgd), of which approximately 95 percent is for public supply. Within 5 miles of the lake, the estimated total groundwater use average from 2008 to 2012 is approximately 21 mgd, of which 57 percent is agricultural use, 13 percent is commercial/industrial use, 14 percent is public supply use, 17 percent is recreation use, and less than 1 percent is mining/dewatering use. (Note that numbers do not sum to 100 percent due to rounding.)

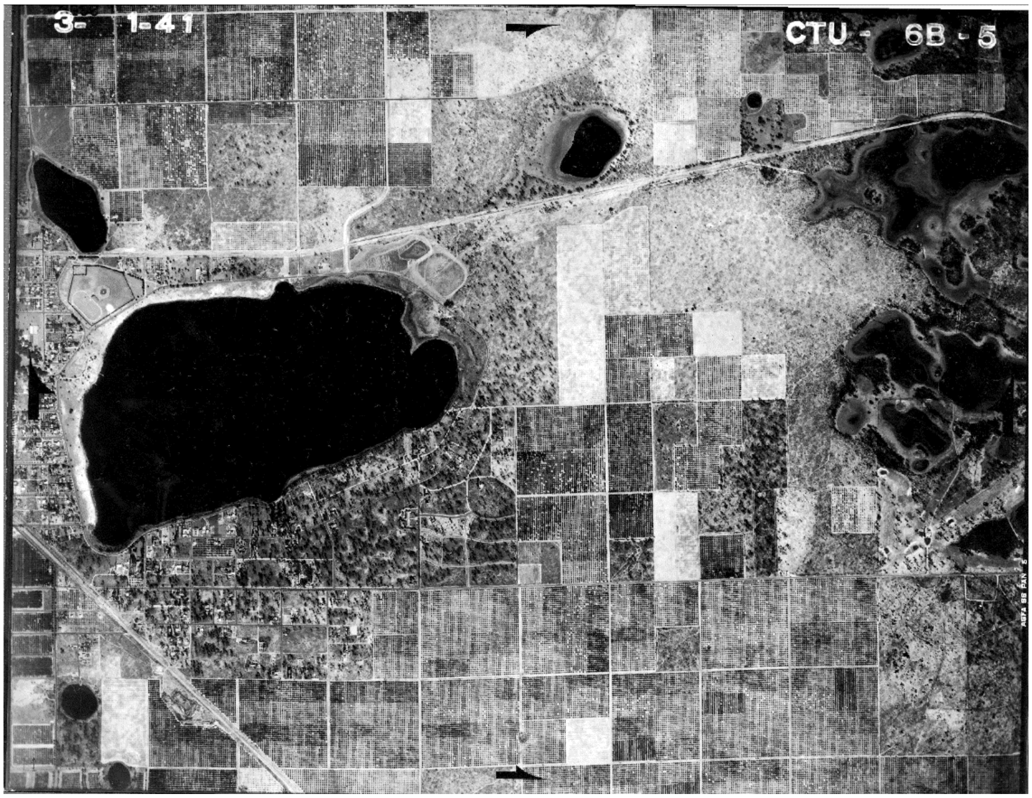

Figure 5. Land use around Lake Wales in 1941.

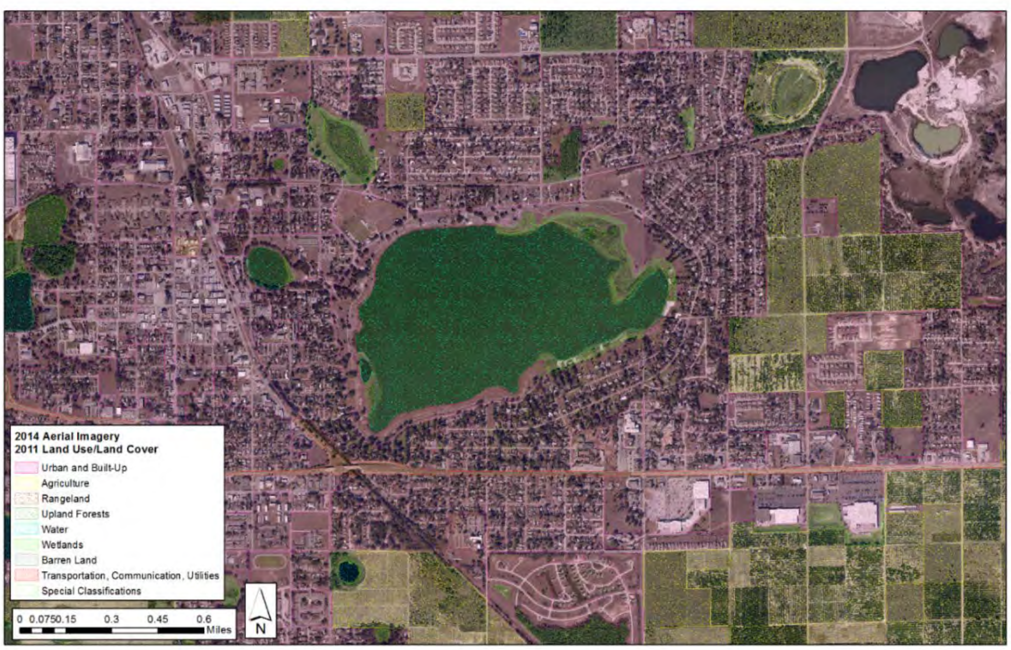

Figure 6. Land use/land cover in 2011 shown on 2014 aerial imagery.

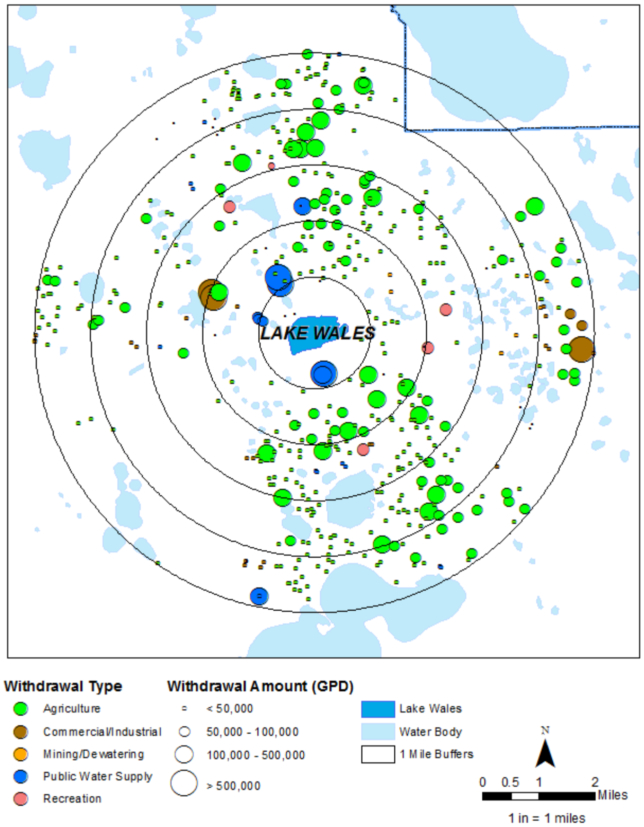

Figure 7. Lake Wales and average groundwater and surface water withdrawal amounts over the period 2008-2012

Table 1. Water Use in the Lake Wales area (2008-2012 average).

Water Use Within 1 Mile of Lake Wales (GPD)			
Use Type	**SW**	**GW**	**Total**
Agriculture		50,366	50,366
Commercial/Industrial			-
Mining/Dewatering			-
Public Supply		1,077,174	1,077,174
Recreation		8,335	8,335
Total	-	1,135,875	1,135,875
Water Use Within 5 Miles of Lake Wales (GPD)			
Use Type	**SW**	**GW**	**Total**
Agriculture	46,207	11,869,797	11,916,004
Commercial/Industrial	15,865	2,625,795	2,641,660
Mining/Dewatering	6,355	1,349	7,704
Public Supply		2,950,941	2,950,941
Recreation	11,111	3,519,943	3,531,053
Total	79,538	20,967,824	21,047,362

Figure 8 presents total estimated and measured groundwater withdrawals in Polk County since the 1930s (updated from Southwest Florida Water Management District, 2006). Significant groundwater withdrawals began in the area throughout the 1940s and 1950s, and peaked in the late 1960s and early 1970s. Groundwater withdrawals in Polk County have been relatively stable since the early to mid-1990s, although this period includes both extreme dry (2000) and wet (2004/2005) conditions. Since 1994, estimated groundwater withdrawals in Polk County averaged about 218 mgd and ranged from 172 mgd in 2011 to 274 mgd in 2000.

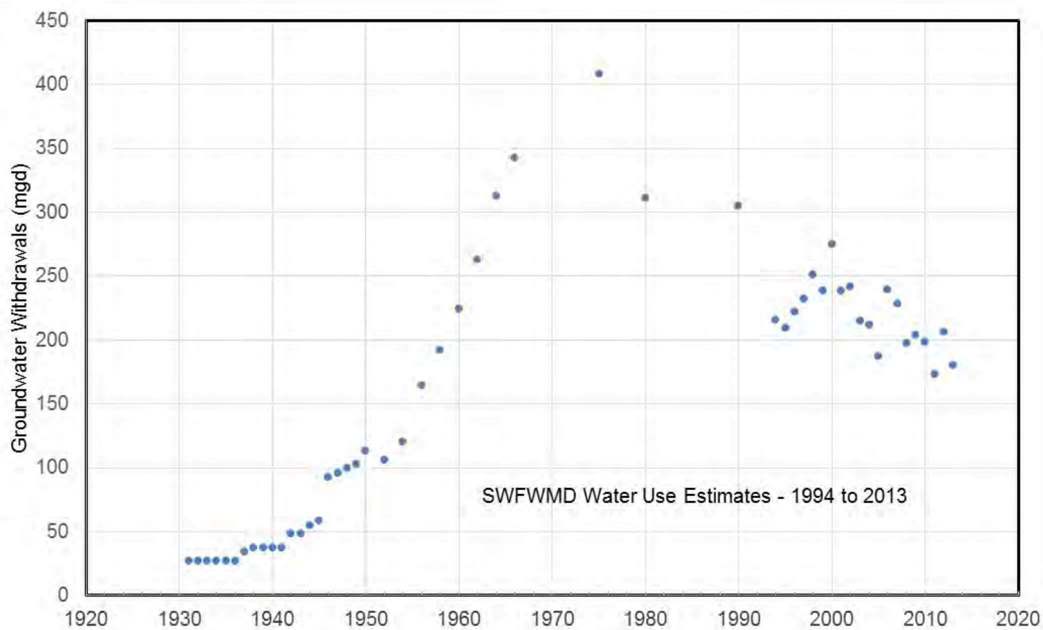

Figure 8. Total groundwater withdrawals in Polk County.

Figure 9 summarizes groundwater withdrawals in the SWFWMD portion of Polk County since 1994 by major water use type. Over this period, withdrawals for agriculture and mining/dewatering have steadily declined. Public supply withdrawals, however, increased until 2006 but since that time have returned to withdrawal levels experienced during earlier portions of the period. Factors that have been cited for declines in agricultural use include uncertainties associated with citrus greening and canker and increased urbanization, which is evidenced by reductions in citrus acreage that have occurred in the county. With respect to public supply, the economic recession that began in 2006 has been cited as a potential influence in the recent reductions that have occurred. Because permitted groundwater withdrawal quantities have remained fairly constant (with the exception of how agriculture has been permitted in the Southern Water Use Caution Area (SWUCA) since 2003), the permanancy of these declines is uncertain. 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.

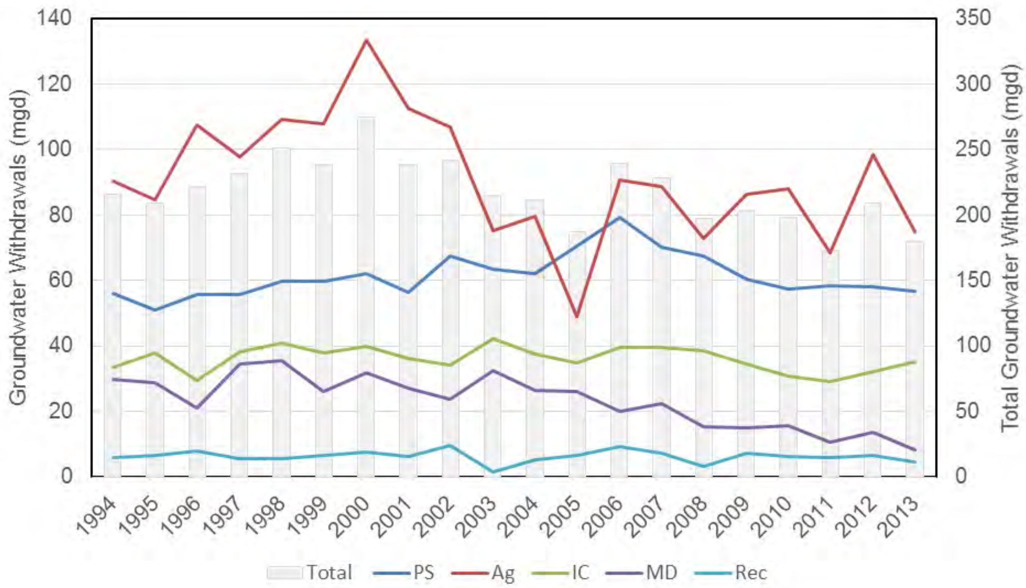

Figure 9. Estimated groundwater use in Polk County by use type (1994-2013)

The long-term response of groundwater levels to changes in the different hydrologic factors were assessed through use of cumulative mass plots where cumulative groundwater levels were plotted versus cumulative Polk County rainfall totals (county-wide averages from several stations published by the District). A straight-line relationship between these plotted values is an indication that the relationship between them is unchanged for the period evaluated. If a long-term change in groundwater withdrawals were to occur, a deviation from the straight line would be expected. Figure 10 is a cumulative mass plot of water levels in the ROMP 57 Upper Floridan aquifer monitor well (SID 25343) versus county rainfall. The plot shows a small break in the early 1990s, and then a stable period since. Because consistent data collection doesn't begin at this well until the late 1980s, very little data prior to the break can be presented. Figure 11 presents a similar cumulative mass plot using data from the Coley Deep (SID 25339) Upper Floridan aquifer monitor well, located several miles south and east of ROMP 57. This well has significantly more data, but a similar break can be seen in the early 1990s (along with other breaks prior to the early 1990s). Both Figures 10 and 11, along with the withdrawal data seen in Figures 8 and 9, show evidence of the general change in water withdrawals in Polk County starting in the early 1990s.

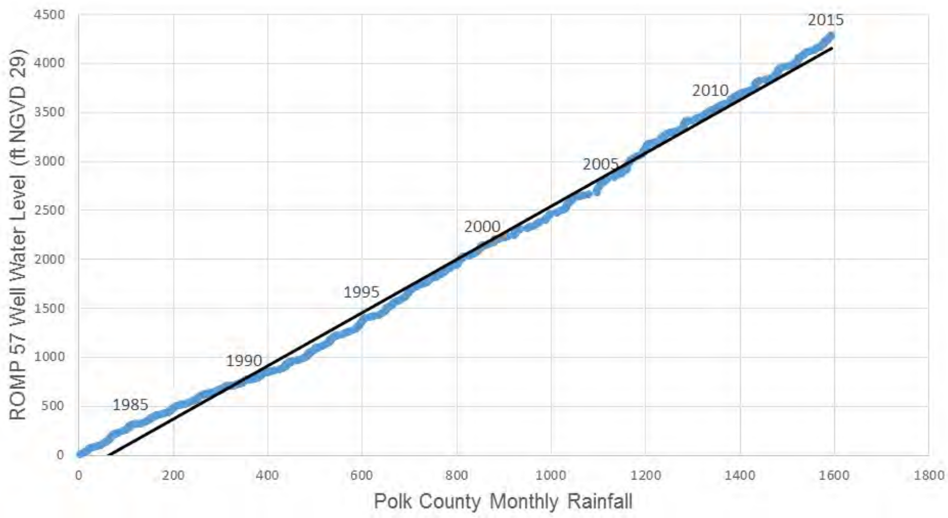

Figure 10. Cumulative double mass curve of ROMP 57 Upper Floridan aquifer monitoring well and Polk County-wide rainfall (1983 to 2014).

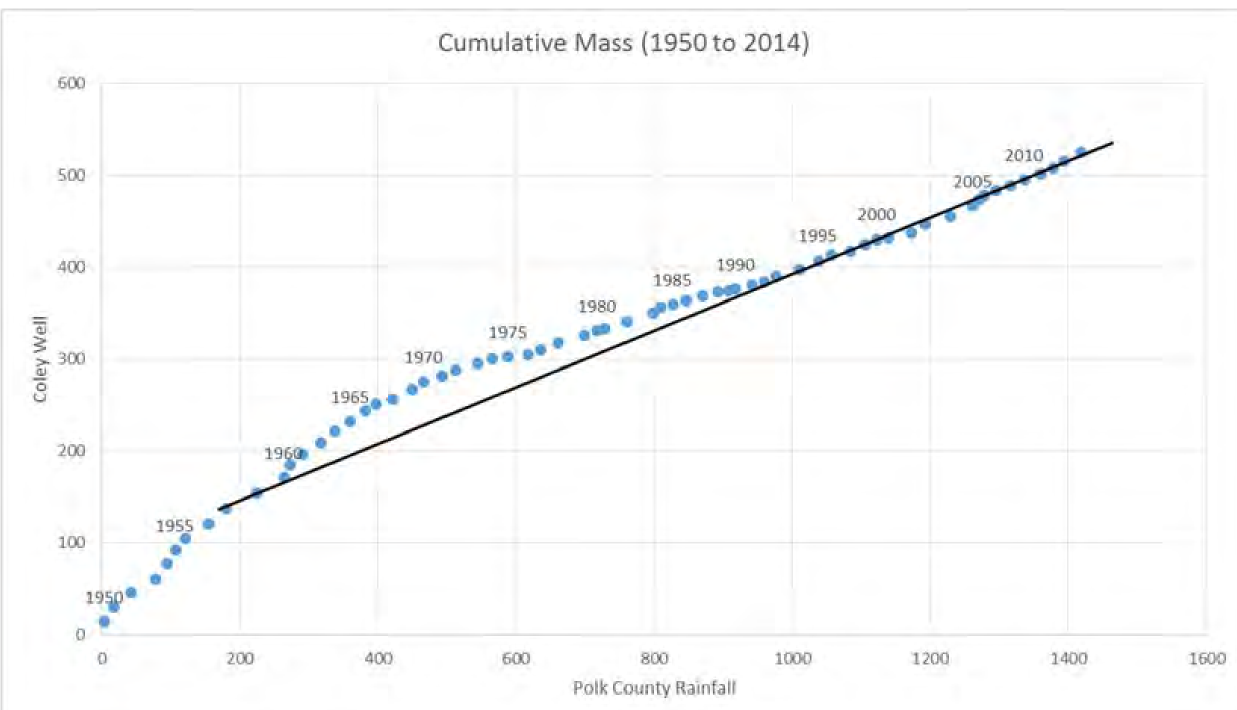

Figure 11. Cumulative double mass curve of the Coley Deep Upper Floridan aquifer monitoring well and Polk County-wide rainfall (1950 to 2014).

C. Purpose of Models

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

In the case of Lake Wales, withdrawals throughout the area have potentially affected water levels in the lake since about the early 1960s. No data from Lake Wales exist prior to the initiation of groundwater withdrawals. Therefore, the development of a water budget model coupled with a rainfall regression model of the lake was considered essential for estimating long-term Historic percentiles, accounting for changes in the lake's drainage system, and simulating effects of changing groundwater withdrawal rates.

D. Water Budget Model Overview

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

The hydrologic processes in the water budget model include:

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

The water budget model uses a daily time step, and tracks inputs, outputs, and lake volume to calculate a daily estimate of lake levels. The water budget model for Lake Wales was calibrated for the period from 1988 to 2014. This period provides the best balance of using available data for all components of the water budget and the desire to develop a long-term water level record.

E. Water Budget Model Components

Lake Stage/Volume

Lake stage-area and stage-volume estimates were determined by building a terrain model of the lake and surrounding watersheds. Lake bottom elevations and land surface elevations were used to build the model with LP360 (by QCoherent) for ArcGIS, ESRI's ArcMap 10.1, the 3D Analyst ArcMap Extension, Python, and XTools Pro. The overall process involves merging the terrain morphology of the lake drainage basin with the underlying lake basin morphology to develop one continuous three-dimensional (3D) digital elevation model. The 3D digital elevation model was then used to calculate area of the lake and the associated volume of the lake at different elevations, starting at the extent of the lake at its flood stage and working downward to the lowest elevation within the basin.

Precipitation

After a review of several rain gages in the area, a composite dataset consisting of rainfall data from various gages and NEXRAD (Next Generation Weather Radar) were used (Figure 12). Distance from the lake, data availability and reasonableness, and model calibration were considered when creating the composite dataset. The data used from January 1, 1988 through December 31, 2000 were an average of Mountain Lake NWS (SID 25147), Blue Lake North Polk (SID 25160), and ROMP 58 JH Wilson Elementary (SID 25146) rain gages. The ROMP 58 JH Wilson Elementary and Mountain Lake NWS gages are approximately 1.4 and 2.6 miles northwest of Lake Wales, respectively. The Blue Lake North Polk gage is located 2.8 miles south-southwest of Lake Wales.

Data for Mountain Lake NWS are available for the earliest date necessary to complete the LOC model (January 1935) through present. Data from Blue Lake North Polk are available from August 1967 to December 2003. Data from ROMP 58 JH Wilson Elementary are available from June 2000 to present. As is common in hydrologic data records, the gages had some periods of missing values in the time series data. Short gaps where data were not available for any of the three gages were infilled with data from the next closest gage to Lake Wales.

For the period January 1, 2001 through December 31, 2014, an average of data for four NEXRAD pixels coinciding with the lake were used. NEXRAD is a network of 160 high-resolution Doppler weather radars controlled by the NWS, Air Force Weather Agency, and Federal Aviation Administration. The NEXRAD data were used for the model starting in 2001, because it resulted in a better calibration of the water budget model than using the average or individual results of the gages used for the earlier model period. Furthermore, data collection at the Blue Lake North Polk gage ended in December 2003 and was not available for averaging for the entire simulation period. NEXRAD data are expected to be available in the future, so they can be used for future status assessments.

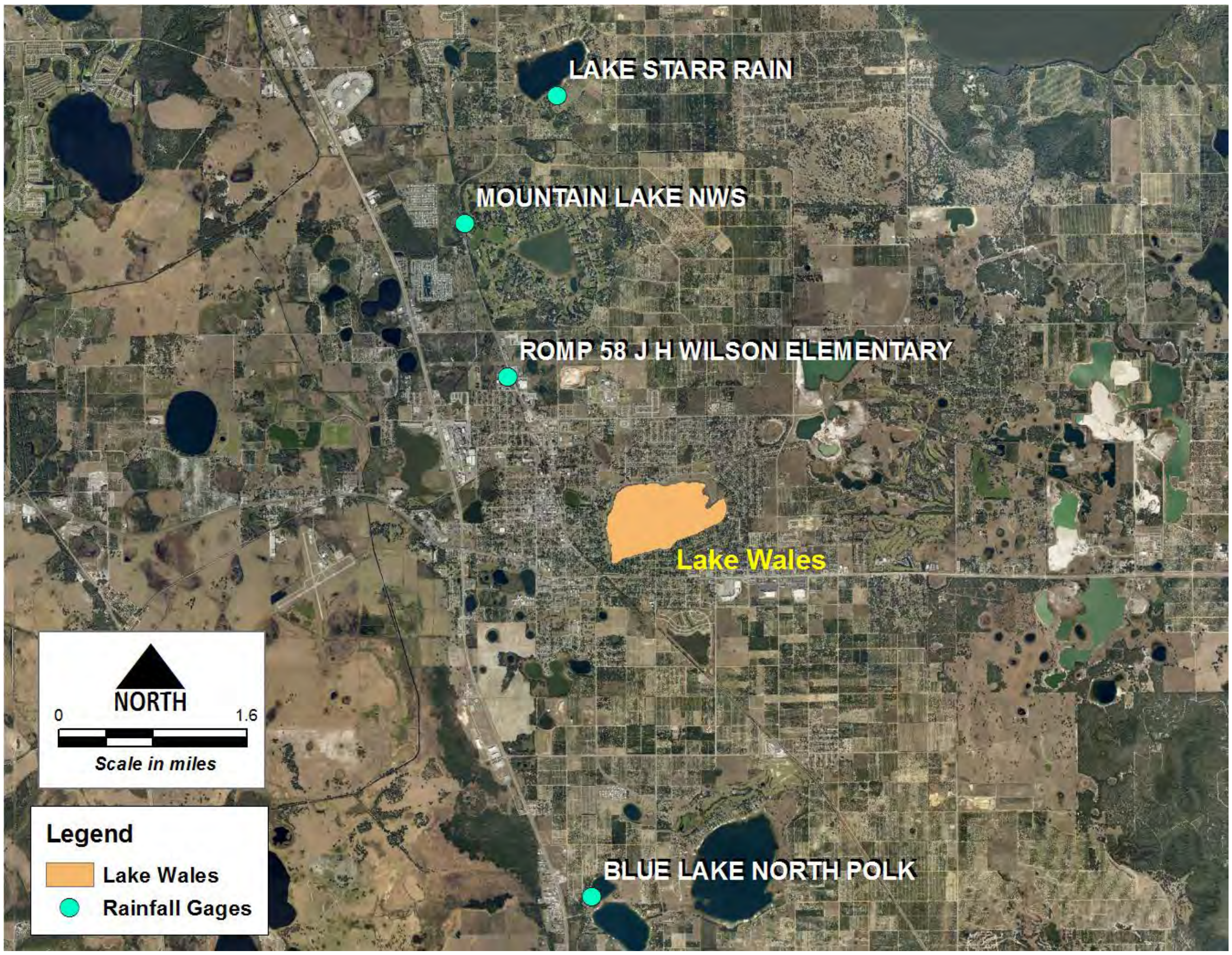

Figure 12. Rain gages assessed in the Lake Wales water budget model.

Lake Evaporation

Lake evaporation was estimated through use of monthly energy budget evaporation data collected by the U.S. Geological Survey (USGS) at Lake Starr in Polk County (Swancar et al., 2000) (Figure 13). Lake Starr is located approximately 3.5 miles to the northwest of Lake Wales. The data were collected from August of 1996 through July of 2011. Monthly Lake Starr evaporation data were used in the water budget model when available, and monthly averages for the period of record were used for those months when Lake Starr evaporation data were not available.

Jacobs (2007) produced daily potential evapotranspiration (PET) estimates on a 2-square kilometer grid for the entire state of Florida. The estimates began in 1995, and are updated annually. These estimates, available from the USGS, were calculated through use of solar radiation data measured by a Geostationary Operational Environmental Satellite (GOES). Because PET is equal to lake evaporation over open water areas, using the values derived from the grid nodes over the modeled lake was considered. A decision was made to instead use the Lake Starr evaporation data since the GOES data nodes typically include both upland and lake estimates, with no clear way of subdividing the two. It was thought that using the daily PET estimates based on the GOES data would increase model error more than using the Lake Starr data directly.

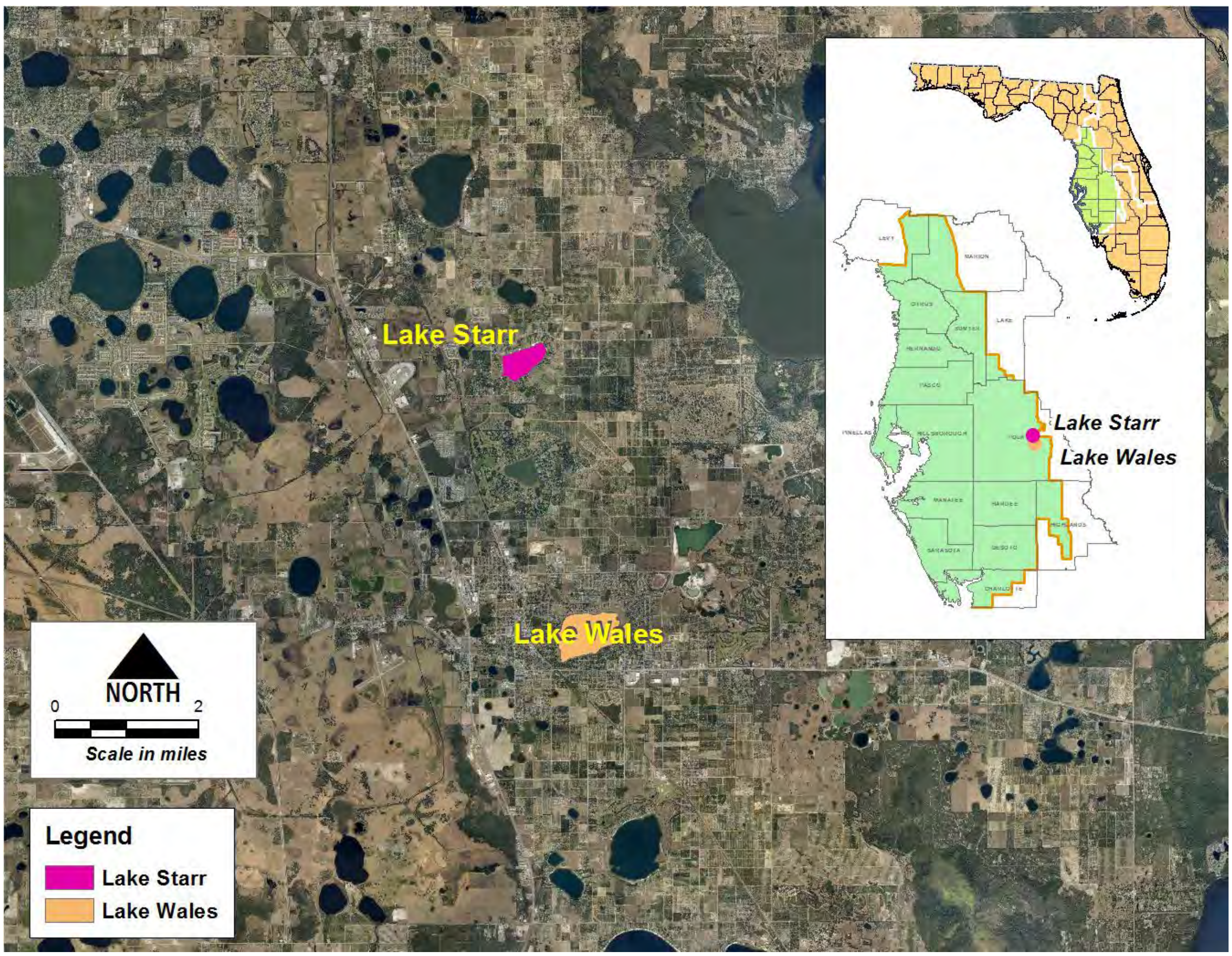

Figure 13. Location of Lake Wales and Lake Starr.

Drainage Well

A former drainage well (now capped) is located near the middle part of the lake about 250 feet south of the southern shore. A District Survey dated July 25, 1991 shows the top elevation of the 18-inch drainage well at 122.48 feet NGVD29. District files indicate the drainage well is 790 feet deep with about 155 feet of casing (Dave DeWitt, Personal Communication, 2015). The well construction date could not be found in District files; therefore, the age of the well and date the well was capped is not known. In addition, it is unknown if the lake ever overflowed into the drainage well; however, the highest measured period of record level for Lake Wales was 111.66 feet above NGVD 29 on December 21, 2005.

Overland Flow

The water budget model was set up to estimate overland flow via a modified version of the U.S. Department of Agriculture, Soil Conservation Service (SCS) Curve Number method (SCS, 1972), and via directly connected impervious area calculations. The free water area of the lake was subtracted from the total watershed area at each time step to estimate the watershed area contributing to surface runoff. The directly connected impervious area (DCIA) is subtracted from the watershed area for the SCS calculation, and then added to the lake water budget separately. Additionally, the curve number (CN) chosen for the watershed of the lake only represents the portion of the watershed not accounted for with DCIA.

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

The lake is oriented perpendicular to the Lake Wales Ridge and land surface elevations east and west of the lake do not increase as steeply as land surface to the north and south of the lake. For example, within a quarter mile of the northern and southern boundaries of the lake, land surface elevations can increase by 100 feet or more. The rate of rise to the east and west is generally much more gradual.

Several slightly varying estimates of watershed boundaries have been performed in the past for different modeling efforts in the area. One of the most recent set of estimates was developed as part of an effort to model Peace Creek for the Watershed Management Program (ADA Engineering 2012 and Atkins 2013). These watershed area values were adopted for the Lake Wales model (Table 2) after an independent check confirming that they are reasonable for modeling purposes (Figure 14). Lake Wales has no significant inflow from other lakes, so the entire watershed is as shown in Figure 14, which consists of 698.8 acres (including the lake area of 299.8 acres).

The DCIA and SCS CNs used for the direct overland flow portion of the watershed are listed in Table 2. The soils in the immediate lake watershed are mostly "A" soils, with some smaller areas of "B," "C," and "D" soils, typically near the lake edge. Land use in the watershed is mostly urban/built up, with some areas of tree crops. A curve number (model calibration parameter) of 55 was used in the model and was considered reasonable given the local soil types, land use types and hydrologic conditions. The DCIA parameter was used in addition to the curve number parameter to account for connected impervious areas that provide direct runoff to the lake through storm water systems. While there are no significant natural surface water inflows to the lake, there are several directly connected drains for street and residential storm water, with no observed retention ponds. It was estimated that 17 percent of the watershed (model calibration parameter) is directly connected impervious area, which was considered reasonable given current land use types.

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

Input Variable	Value
Overland Flow Watershed Size (acres)	698.8
SCS CN for watershed	55
Percent Directly Connected Area	17 percent
FL Monitor Well Used	ROMP 57X Upper Floridan
Surf. Aq. Monitor Well(s) Used to Simulate Surf. Aq. Leakance from South (varied with time)	ROMP 57X surficial
Staff Gage Used to Simulate Surf. Aq. Leakance from North/West (varied with time)	North Lake Wales
Staff Gage Used to Simulate Surf. Aq. Leakance from East (estimated constant with time)	South Mine Pond (WUP No. 5173 DID 22)
FL Aq. Leakance Coefficient (ft/day/ft)	0.0008
Surf. Aq. Conductance - North/West (ft/day/ft)	0.0067
Surf. Aq. Conductance - South (ft/day/ft)	0.0017
Surf. Aq. Specified Gradient to the East (ft/ft)	-0.0007
Outflow K	N/A
Outflow Invert (ft NGVD 29)	N/A
Inflow K	N/A
Inflow Invert (ft NGVD 29)	N/A

Figure 14. The Lake Wales watershed.

Inflow and Discharge via Channels from Outside Watersheds

Lake Wales is a closed basin lake with no significant inflows or outflows. LiDAR-derived contours show that Lake Wales would only connect to North Lake Wales when the lakes stages exceed approximately 120 feet above NGVD 29, and would connect to Lake Crystal when the lakes stages exceed approximately 121.5 to 122 feet above NGVD 29 (Keith Kolasa, personal communication, 2015). LIDAR (Light Detection and Ranging) is a remote sensing method that measures variable distances to create three-dimensional information about the shape of the Earth's surface. Period of record water level data do not have values that exceed the overflow level for either of these lakes (Figure 15). It should be noted, however, that the overflow elevation is estimated and overflow events may not be captured in the data due to measurement frequency. In general, it is reasonable to assume that overflow from Lakes Crystal and North Lake Wales into Lake Wales rarely occurs.

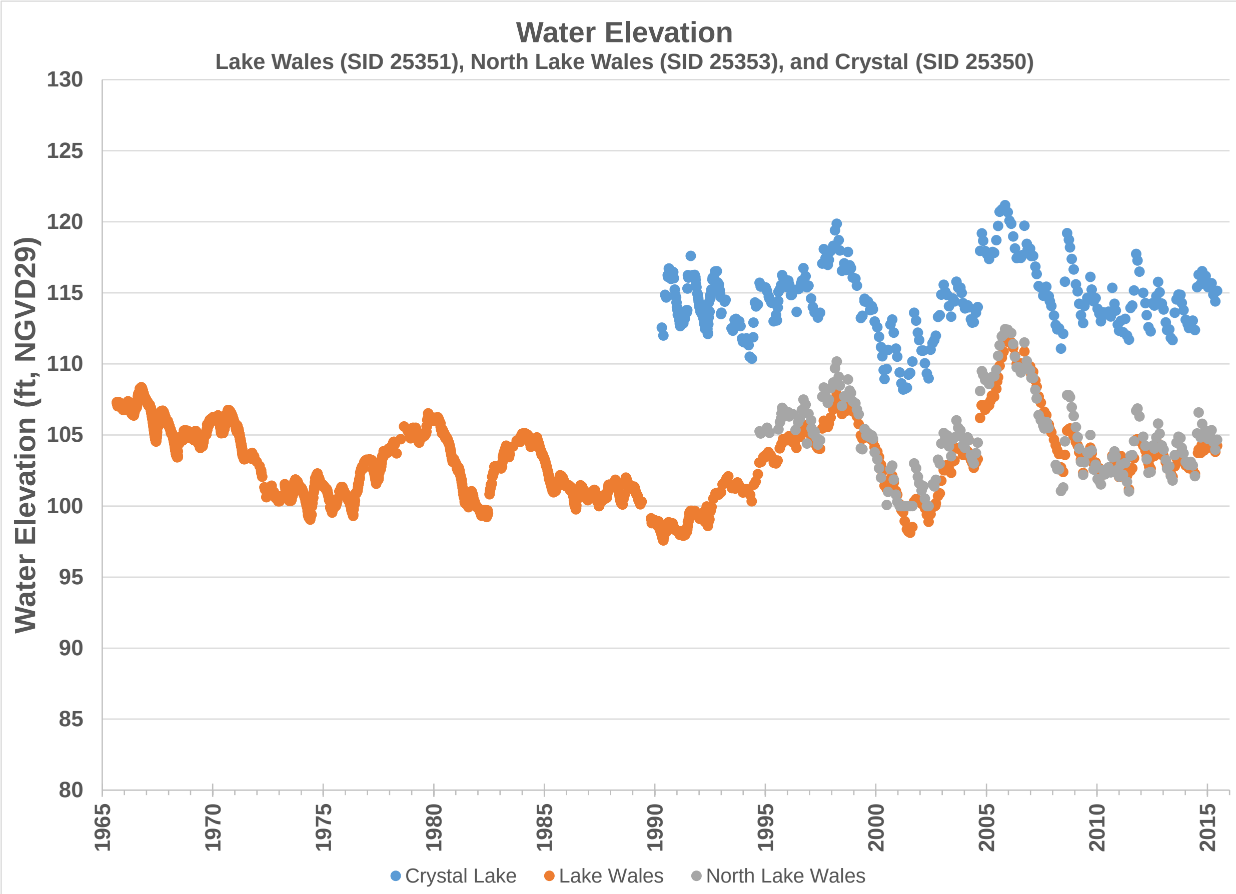

Figure 15. Water Elevation of lakes Crystal, Wales, and North Lake Wales.

Flow from and into the surficial aquifer and Upper Floridan aquifer

Water exchange between Lake Wales and the underlying aquifers is estimated using a vertical leakance coefficient and the head difference between the lake and the aquifer levels. For each day of the simulation period, the volumes of water exchanged between the lake and surficial aquifer and the lake and Upper Floridan aquifer were calculated independently. The surficial aquifer conductance terms and Upper Floridan aquifer leakance coefficient were then determined through calibration.

Data from three different areas around the lake were used to simulate surficial aquifer leakage for each model time step. Water level data from ROMP 57X surficial aquifer well and North Lake Wales were used to simulate Lake Wales' interaction with the surficial aquifer to the south and north/west, respectively. Interaction from the east was simulated with a calculated average gradient that was held constant between Lake Wales and a pond at a sand mine east of Lake Wales. The observed gradient was relatively constant, for the period that data were available. Water levels at the sand mine gage were not measured long enough for direct use in the model.

ROMP 57 X Upper Floridan Monitor Well

The ROMP 57X Upper Floridan well was used to represent the potentiometric surface at the lake (Figures 3 and 4). There were, for some periods, multi-month gaps in the ROMP 57X Upper Floridan aquifer monitor well data. These gaps were infilled using estimated data generated by a linear regression of ROMP 57X Upper Floridan aquifer monitor well data with CL-1 Upper Floridan aquifer monitor well data. Simple linear data infill was not used due to the length of some of the data gaps. The CL-1 Upper Floridan aquifer monitor well (the well used for the regression) is located approximately 4.5 miles from Lake Wales (Figure 3).

ROMP 57x Surficial Aquifer Monitor Well

The ROMP 57X surficial aquifer monitor well data are generally daily, with the exception of a few data gaps and a period from November 1994 through October 2003 when data collection was monthly. Missing data were linearly infilled, because data gaps were shorter than those present in the ROMP 57X Upper Floridan aquifer monitor well record.

In addition to the ROMP 57X surficial aquifer monitor well, surface water levels in North Lake Wales and the gradient between Lake Wales and the South Mine Pond gage (Water Use Permit Number 5173, District ID 22) at a sand mine east of Lake Wales were used to simulate effects of the surficial aquifer in the water budget model (Figure 3). There were, for some periods, multi-month gaps in the North Lake Wales data. In addition, data collection started well after the model start date of January 1, 1988. These gaps were infilled using estimated data generated by a linear regression of North Lake Wales water level data with ROMP 57X surficial aquifer monitor well data. Simple linear data infill was not used due multi-month data gaps and missing data at the start of the model period.

South Mine Pond Staff Gage

The South Mine Pond staff gage is located just under a mile northeast of Lake Wales. Permittee-reported data for this gage were used to estimate the gradient in the surficial aquifer between the South Mine Pond and Lake Wales. The gradient used in the model was -0.0007, and the flow direction is from Lake Wales toward the South Mine Pond.

F. Water Budget Model Approach

The primary reason for the development of the water budget model was to estimate Historic lake stage exceedance percentiles that could be used to support development of Minimum and Guidance Levels for the lake. Model calibration was therefore focused on matching long-term percentiles based on measured water levels, rather than short-term high and low levels. Model calibration statistics that are reported are based on comparison of pairs of daily measured and modeled water levels.

Figure 16 presents the model calibration results. Table 3 presents a comparison of the percentiles of the measured data versus the model results. Table 4 presents the modeled water budget components for the calibration period.

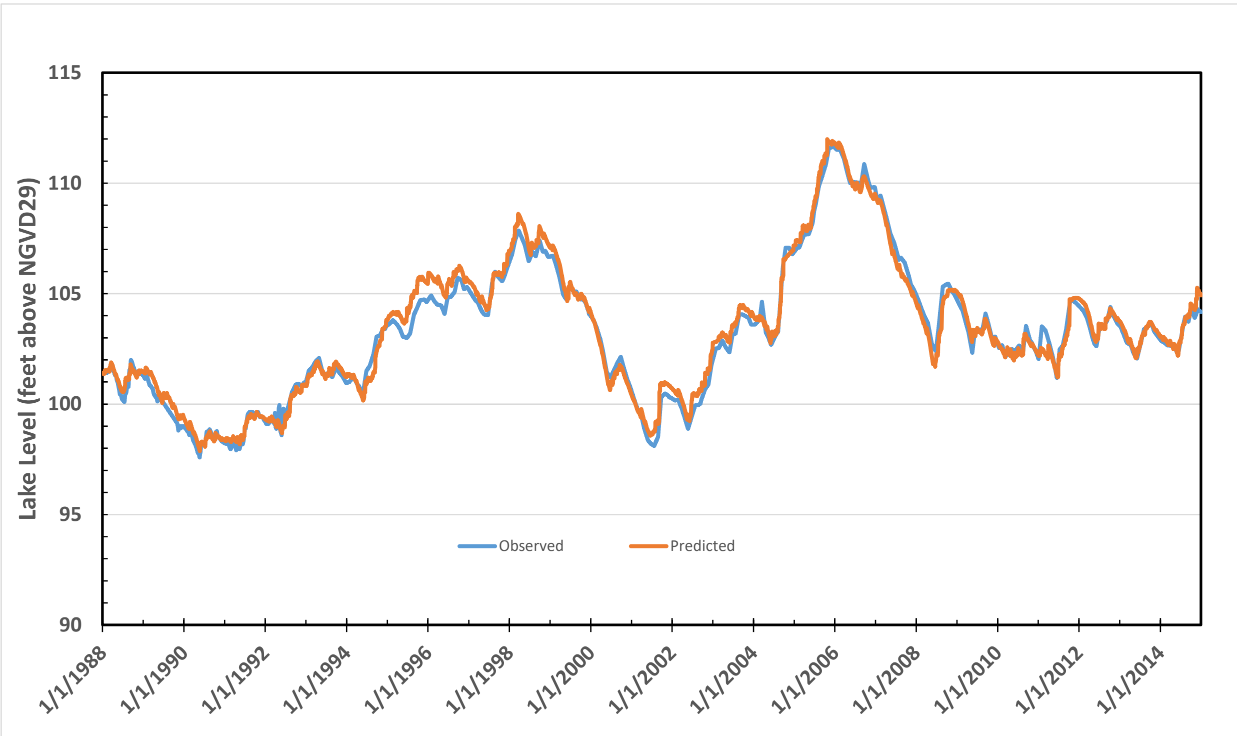

Figure 16. Modeled water levels predicted for the calibrated Lake Wales water budget (Predicted) and measured levels used for the model calibration (Data).

Table 3. Comparison of percentiles of measured lake level data compared to calibration percentiles from the model (all in feet NGVD 29).

	Data	Model
P10	106.4	106.4
P50	101.4	101.4
P90	98.4	98.5

Table 4. Lake Wales Water Budget (1988-2014)

Inflows	Rainfall	Surficial Aquifer Ground-water Inflow (North/ West)	Surficial Aquifer Ground-water Inflow (East)	Surficial Aquifer Ground-water Inflow (South)	Floridan Aquifer Ground-water Inflow	Runoff	DCIA Runoff	Inflow via channel	Total
In/yr	51.2	16.9	0.0	0.0	0.0	3.1	13.1	0.0	84.3
%	60.7	20.0	0.0	0.0	0.0	3.7	15.5	0.0	100.0
Outflows	**Evap-oration**	**Surficial Aquifer Ground water Outflow (North/ West)**	**Surficial Aquifer Ground-water Outflow (East)**	**Surficial Aquifer Ground-water Outflow (South)**	**Floridan Aquifer Ground-water Outflow**			**Outflow via channel**	**Total**
In/yr	57.9	0.0	6.8	2.5	15.7			0.0	82.8
%	69.8	0.0	8.2	3.0	18.9			0.0	100.0

G. Water Budget Model Calibration Discussion

Based on visual inspection of Figure 16 the model appears to be reasonably well calibrated. There are a few periods when the peaks or lows in the modeled hydrograph are higher or lower than the measured values, and these differences contributed to minor differences between the modeled and measured percentiles associated with the P90 percentile. Data limitations in the extreme ranges of the topography/bathymetry used to develop stage-volume estimates may also have contributed to the percentile difference.

A review of Table 3 shows no difference in the median (P50) and P10 percentiles and a difference of 0.1 feet in the P90 percentiles when comparing measured and modeled lake levels. This minor difference could be attributed to inaccuracies in rainfall estimates caused by the distance between rainfall gages and the lake during certain time periods or data collection frequency or issues.

The water budget model results are best viewed in terms of inches per year over the average lake area for the period of the model run, which can be difficult to comprehend at first. For example, runoff for the entire watershed is applied to the smaller lake area, which makes the value appear high until the differences in application area are considered. Leakage rates (and leakance coefficients), as another example, represent conditions below the lake base only, and may not be representative of the entire watershed. Professional judgement and decisions were used to match the modeled lake levels with observed data and arrive at the ultimate goal of developing a calibrated model. Even though data gaps as well as uncertainties in the values of model parameters have caused some differences between the model and observed data, the model is reasonably well calibrated and can be used to estimate the long term historic percentiles.

H. Water Budget Model Results

Groundwater withdrawals are not directly included in the Lake Wales water budget model, but are indirectly represented by their effects on water levels in the Upper Floridan aquifer. When a relationship between withdrawal rates and Upper Floridan aquifer potentiometric levels can be established, the effect of changes in groundwater withdrawals can be estimated by adjusting Upper Floridan aquifer levels in the model.

Determining the amount of Upper Florida aquifer drawdown that has occurred due to groundwater withdrawals involved the use of a regional groundwater model and analysis of water level data. The East-Central Florida Transient (ECFT) groundwater model (Sepulveda, et al., 2012 and CFWI, 2014) was used to quantify changes in water levels in response to changes in groundwater withdrawals. This was accomplished using a series of model runs whereby recent withdrawals and irrigation amounts were reduced by 25 percent, 50 percent, and 75 percent. This approach enabled the model to be used within the range of withdrawals that were used during the calibration phase. For the reassessment of minimum levels, the reduced pumping scenarios used a Reference Condition as a basis for comparing model reduction scenarios. The Reference Condition was based on the amount of groundwater withdrawals needed to meet the demands for water that existed as of 2005. Pumping amounts for each year and month of the 12 year transient model run were varied according to rainfall that occurred during each month. Based on the model scenarios it was estimated that modeled groundwater withdrawals have lowered Upper Floridan aquifer water levels about 7 feet beneath Lake Wales.

During evaluation of the reduced pumping scenarios, it was decided that an evaluation of long-term changes in water levels was needed to verify model results. For use in the evaluation of Lake Wales, long-term water levels in the ROMP 57X Upper Floridan aquifer well were extended back to the 1940s and 1950s time period using water levels from the Coley Deep well (SID 25339), located near the City of Frostproof; the ROMP 60 Upper Floridan aquifer abandoned (SID 17974) and replacement (SID 77757) wells located near the City of Mulberry; and the Claude Hardin Upper Floridan aquifer well (SID 17966), located near the City of Mulberry. This was done using water level data averaged over different periods, for example annual and monthly, and single months such as September, May and December. For each regression analysis, the regression parameters were determined using data for the period 1988 to 2014, which is the time period data is available for the ROMP 57X Upper Floridan aquifer well. These parameters were then used to estimate water levels for the period available for the respective independent well levels (Coley Deep and ROMP 60 Upper Floridan aquifer). For the regression analyses, estimates of long-term changes in groundwater levels ranged from about 3.5 feet to 6.8 feet. It was then determined that modeled drawdown amounts using the ECFT model would be modified and that a recovery level of 4.5 feet in Upper Floridan Aquifer levels would be used for the analysis. With respect to the surficial aquifer, the relationship between the leakance coefficient and the ratio of surficial aquifer to Upper Floridan aquifer drawdowns established for previous modeling efforts was used. From the water budget model, the leakance coefficient was 0.0008 feet/day/feet which resulted in a ratio of surficial to Upper Floridan drawdown of 0.5. The resulting recovery in the surficial aquifer was then estimated as the product of this ratio and the estimated Upper Floridan aquifer recovery amount (4.5 feet) or 2.25 feet.

Figure 17 presents the results of the calibrated water budget model for Lake Wales with and without the effects of groundwater withdrawals. Table 5 presents the percentiles based on the model output.

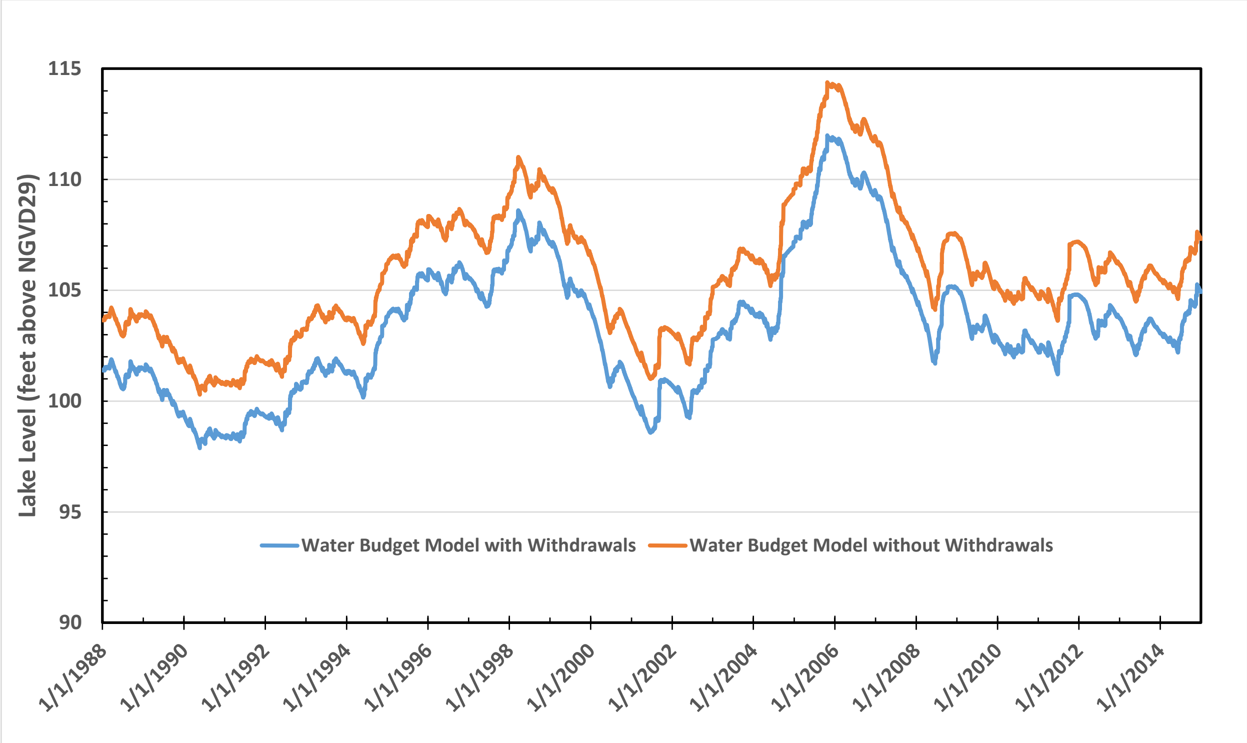

Figure 17. Calibrated Water Budget Model for Lake Wales with and without the effects of withdrawals.

Table 5. Lake level percentiles determined using the water budget model with withdrawal effects removed for the period 1988-2014 (feet NGVD 29).

Percentile	Elevation
P10	109.9
P50	105.6
P90	101.8

I. Rainfall Regression Model

In an effort to extend the period of record of water levels used to determine the Historic percentiles to be used in the development of the Minimum Levels, a line of organic correlation (LOC) was performed using the results of the water budget model and long-term rainfall data. The LOC is a linear fitting procedure that minimizes errors in both the x and y directions and defines the best-fit straight line as the line that minimizes the sum of the areas of right triangles formed by horizontal and vertical lines extending from observations to the fitted line (Helsel and Hirsch, 2002). LOC is preferable for this application since it produces a result that best retains the variance (and therefore best retains the "character") of the original data. By using this technique, the limited years of calibrated model water levels can be projected back to create a simulated data set representing over 60 years of lake levels, based on the relationship between modeled water levels and actual rainfall.

In this application, the simulated lake water levels representing Historic conditions were correlated with long-term rainfall data. For the rainfall regression analysis, additional representative rainfall records were added to the rainfall data used in the water budget model (1988-2014), extending the rainfall record back to 1930. The record consisted of daily rainfall measurements from the closest rain gage and, missing daily data values were infilled from the next closest gage with available data until all days were populated with rainfall data. The main gages used to build the Long-term rainfall series (Figure 18) were Lake Alfred Experimental Station NWS (SID 17616) and Mountain Lake NWS (SID 25147). Missing days were infilled with gaged rainfall at Blue Lake North Polk (SID 25160), Lake Starr Rain (SID 25149), Babson Park 1 ENE NWS (SID 24809), Winter Haven NWS (SID 24534), and Bartow NWS (SID 25164).

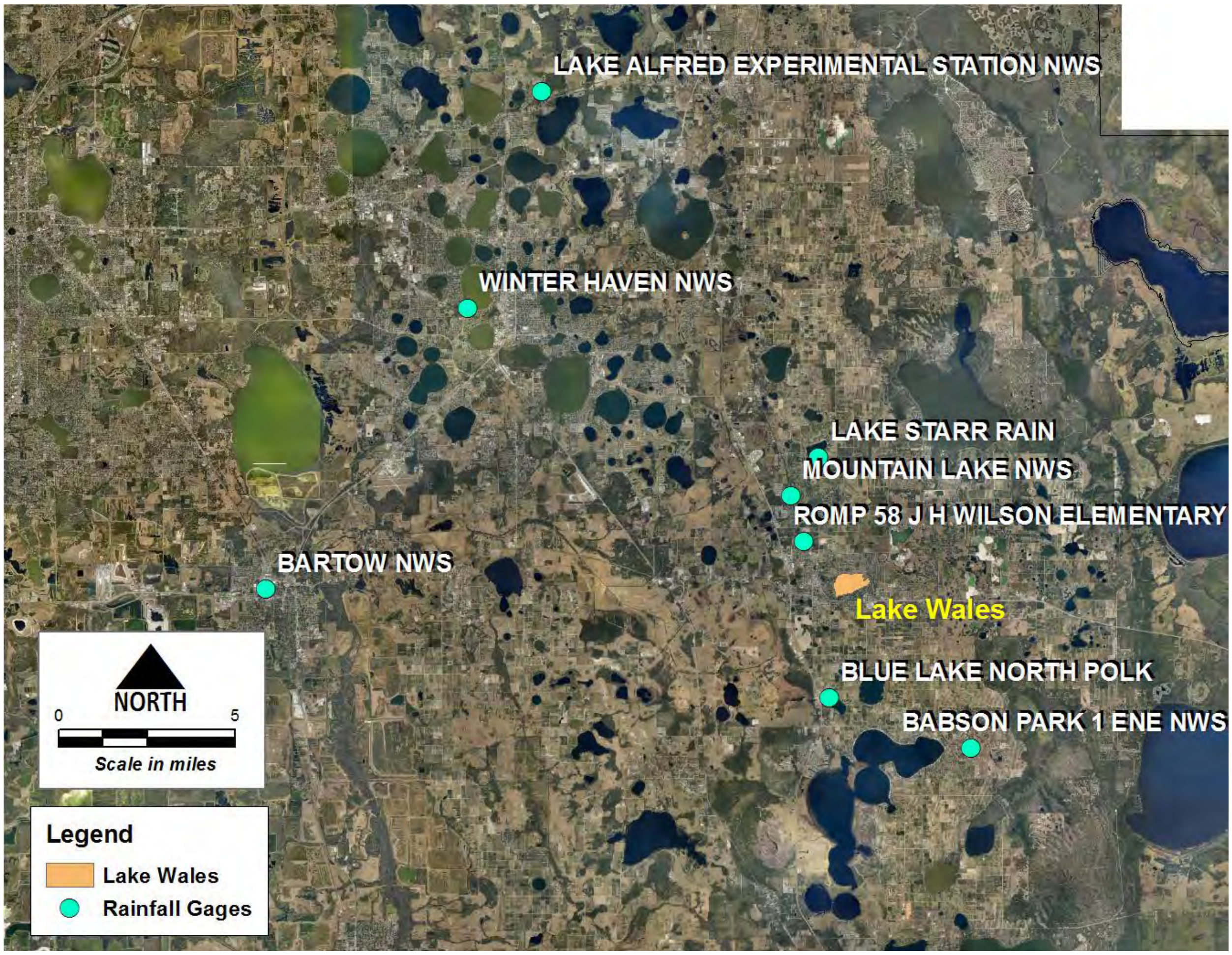

Figure 18. Rainfall Gages used for LOC Model.

Rainfall data were correlated to lake water level data by applying a linear inverse weighted sum to the rainfall using a concept described by Merritt (2001). The weighted sum gives higher weight to more recent rainfall and less weight to rainfall in the past. In this application, weighted sums varying from 6 months to 10 years were separately used, the results were compared, and the weighted rainfall series with the highest coefficient of determination (R^2) was chosen as the best model.

Rainfall was correlated to the water budget model results for the entire period used in the water budget model (1988-2014), and the results from 1946-2014 (69 years) were produced. The final 6-year weighted model had the highest coefficient of determination, with R^2 of 0.75. The results are presented in Figure 19.

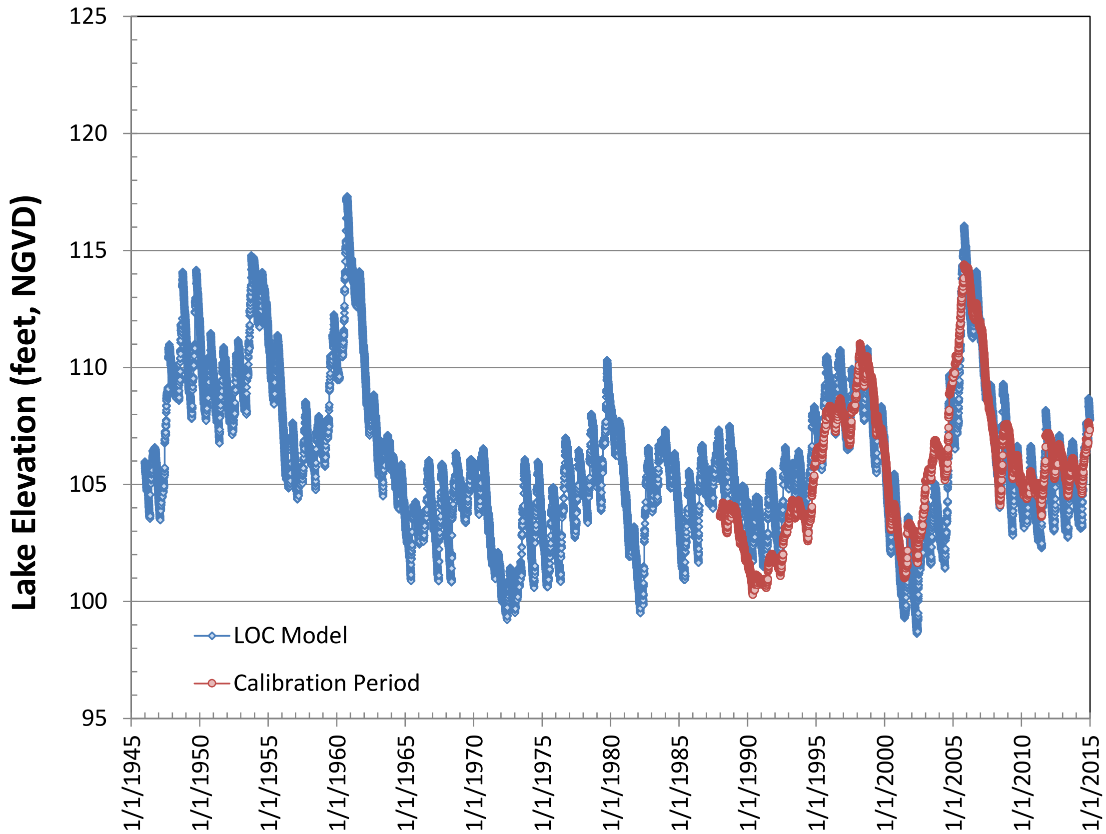

Figure 19. LOC model results for Lake Wales.

In an attempt to produce Historic percentiles that apply significant weight to the results of the water budget models, the rainfall LOC results for the period of the water budget model are replaced with the water budget model results. Therefore, the LOC rainfall model results are used for the period of 1946-1987, while the water budget results are used for the period of 1988-2014. These results are referred to as the "hybrid model." The resulting Historic percentiles for the hybrid model are presented in Table 6.

Table 6. Historic percentiles as estimated using the hybrid model from 1946 to 2014 (feet NGVD 29).

Percentile	Lake Wales
P10	110.6
P50	105.6
P90	101.8

J. Conclusions

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

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APPENDIX B

Draft Technical Memorandum

May 3, 2016

TO: Jerry L. Mallams, P.G., Manager, Water Resources Bureau

FROM: Tamera McBride, P.G., Senior Hydrogeologist, Water Resources Bureau
Yonas Ghile, Ph.D. Senior Environmental Scientist, Natural Systems and Restoration Bureau

Subject: Lake Wales Initial Minimum Levels Status Assessment

A. Introduction

The Southwest Florida Water Management District (District) is reevaluating adopted minimum levels for Lake Wales and is proposing revised minimum levels for the lake, in accordance with Section 373.042 and 373.0421, Florida Statutes (F.S). Documentation regarding development of the revised minimum levels is provided by McBride and Barcelo (2015) and Ghile and others (2015).

Section 373.0421, F.S. requires that a recovery or prevention strategy be developed for all water bodies that are found to be below their minimum flows or levels, or are projected to fall below the minimum flows or levels within 20 years. In the case of Lake Wales and other waterbodies with established minimum flows or levels in the Southern Water Use Caution Area (SWUCA), an applicable regional recovery strategy, referred to as the SWUCA Recovery Strategy, has been developed and adopted into District rules (Rule 40D-80.074, F.A.C.). One of the goals of the SWUCA Recovery Strategy is to achieve recovery of minimum flow and level water bodies such as Lake Wales. This document provides information and analyses to be considered for evaluating the status of the revised minimum levels proposed for Lake Wales and any recovery that may be necessary for the lake.

B. Background

Lake Wales is located in east-central Polk County, just northeast of the intersection of Alternate US Highway 27/State Road 17 and State Road 60 in the City of Lake Wales. (Figure 1). The lake is within the Peace Creek watershed.

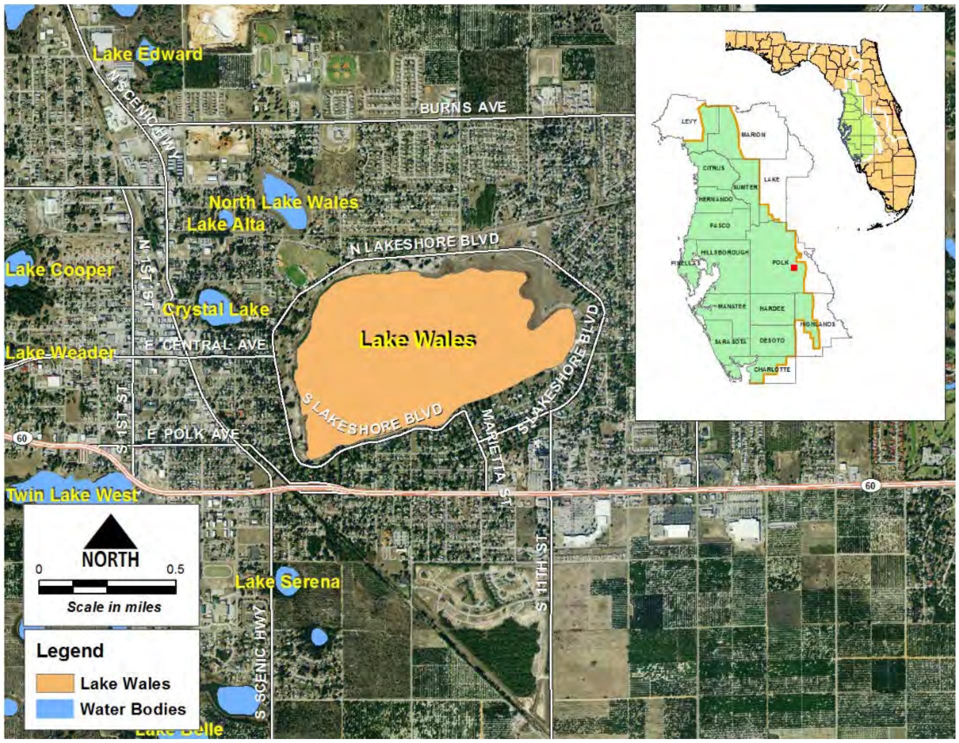

Figure 1. Location of Lake Wales in Polk County, Florida

C. Revised Minimum Levels Proposed for Lake Wales

Revised minimum levels proposed for Lake Wales are presented in Table 1 and discussed in more detail by Ghile and others (2015). Minimum levels represent long-term conditions that if achieved, are expected to protect water resources and the ecology of the area from significant harm that may result from water withdrawals. The Minimum Lake Level is the elevation that a lake's water levels are required to equal or exceed fifty percent of the time on a long-term basis. The High Minimum Lake Level is the elevation that a lake's water levels are required to equal or exceed ten percent of the time on a long-term basis. The Minimum Lake Level therefore represents the required 50th percentile (P50) of long-term water levels, while the High Minimum Lake Level represents the required 10^{th} percentile (P10) of long-term water levels. To determine the status of minimum levels for Lake Wales or minimum flows and levels for any other water body, long-term data or model results must be used.

Table 1. Proposed Minimum Levels for Lake Wales.

Proposed Minimum Levels	**Elevation in Feet** NGVD 29
High Minimum Lake Level	107.7
Minimum Lake Level	104.8

D. Status Assessment

The lake status assessment approach involves using actual lake stage data for Lake Wales from 1992 through 2014, which was determined to represent the “Current” period. The Current period represents a recent “Long-term” period when hydrologic stresses (including groundwater withdrawals) and structural alterations are reasonably stable. “Long-term” is defined as a period that has been subjected to the full range of rainfall variability that can be expected in the future. As demonstrated in McBride and Barcelo (2015), groundwater withdrawals during this period were relatively consistent. To create a data set that can reasonably be considered to be “Long-term”, a line of organic correlation (LOC) analysis was performed on the lake level data from the Current period. The LOC is a linear fitting procedure that minimizes errors in both the x and y directions and defines the best-fit straight line as the line that minimizes the sum of the areas of right triangles formed by horizontal and vertical lines extending from observations to the fitted line (Helsel and Hirsch, 2002). The LOC is preferable for this application since it produces a result that best retains the variance (and therefore best retains the "character") of the original data. This technique was used to develop the minimum levels for Lake Wales (McBride and Barcelo, 2015). By using this technique, the limited years of Current lake level data can be projected back to create a simulated data set representing over 60 years of lake levels, based on the current relationship between lake water levels and actual rainfall.

The same rainfall data set used for setting the minimum levels for Lake Wales was used for the status assessment. The best resulting correlation for the LOC model created with measured data was the 6-year weighted period (the best correlation for the LOC analyses created with Historic data to set the Lake Wales MFL was 6 years), with a coefficient of determination of 0.81. The resulting lake stage exceedance percentiles are presented in Table 2.

As an additional piece of information, Table 2 also presents the same percentiles calculated directly from the measured lake level data for Lake Wales for the period from 1992 through 2014. A limitation of these values is that the resulting lake stage exceedance percentiles are representative of rainfall conditions during only the past 23 years, rather than the longer-term rainfall conditions represented in the 1946 to 2014 LOC model simulations.

Table 2. Comparison of lake stage exceedance percentiles derived from the LOC results, exceedance percentiles of the 1992 to 2014 data, and the revised minimum levels proposed for Lake Wales.

Percentile	**LOC Model Current Withdrawal Scenario Results** Elevation in feet NGVD 29[a]	**1992 to 2014 Data** Elevation in feet NGVD 29[b]	**Proposed Minimum Levels** Elevation in feet NGVD 29
P10	107.8	107.5	107.7
P50	103.2	103.5	104.8

[a]Based on monthly average of daily model results

[b]Based on monthly average of available measured data

A comparison of the LOC model with the revised minimum levels proposed for Lake Wales indicates that the Long-term P10 is 0.1 foot higher than the proposed High Minimum Lake Level, and the Long-term P50 is 1.6 feet lower than the proposed Minimum Lake Level. The P10 elevation derived directly from the 1992 to 2014 lake data is 0.2 foot lower than the proposed High Minimum Lake Level and the P50 elevation is 1.3 feet lower than the proposed Minimum Lake Level. Differences in rainfall between the shorter 1992 to 2014 period and the longer 1946 to 2014 period used for the LOC modeling analyses likely contribute to the differences between derived and measured lake stage exceedance percentiles. Additionally, differences between actual withdrawal rates and those used in the models may have contributed to some of the differences in the percentiles.

E. Conclusions

Based on the information presented in this memorandum, it is concluded that Lake Wales water levels are currently below the revised Minimum Lake Level, and above the revised High Minimum Lake Level proposed for the lake. These conclusions are supported by comparison of percentiles derived from LOC modeled lake stage data with the proposed minimum levels.

Minimum flow and level status assessments are completed on an annual basis by the District and on a five-year basis as part of the regional water supply planning process. In addition, Lake Wales is included in the Recovery Strategy for the Southern Water Use Caution Area Recovery Strategy (40D-80.074, F.A.C). Therefore, the analyses outlined in this document for Lake Wales will be reassessed by the District as part of this plan.

F. References

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