Minimum and Guidance Levels for Lake Lowery in Polk County, Florida

July 26, 2017

Resource Evaluation Section
Water Resources Bureau
Southwest Florida
Water Management District

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Cover: Photograph of Lake Lowery in December 2012 (Southwest Florida Water Management District files).

Contents

Introduction

Evaluation of Minimum Flows and Levels

This report describes the development of minimum levels for Lake Lowery in Polk County, Florida. These levels were approved by the Southwest Florida Water Management District (District) Governing Board in October 2016. These minimum levels for Lake Lowery were established to support ongoing District assessment of minimum flows and levels and the need for additional recovery 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.

Minimum Flows and Levels Program Overview

Legal Directives

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

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

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

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

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

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

Programmatic Description and Major Assumptions

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

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

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

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

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

Consideration of Changes and Structural Alterations and Environmental Values

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

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

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

The District has developed specific methodologies for establishing minimum flows or levels for lakes, wetlands, rivers, estuaries and aquifers, subjected the methodologies to independent, scientific peer-review, and incorporated the methods for some system types, including lakes, into its Water Level and Rates of Flow 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 Southwest Florida Water Management District (1999a, b) and Leeper *et al.* (2001). Additional information relevant to developing lake levels is presented by Schultz et al. (2004), Carr and Rochow (2004), Caffrey *et al.* (2006, 2007), Carr *et al.* (2006), Hoyer *et al*. (2006), Leeper (2006), Hancock (2006, 2007) and Emery *et al.* (2009). Independent scientific peer-review findings regarding the lake level methods are summarized by Bedient *et al.* (1999), Dierberg and Wagner (2001) and Wagner and Dierberg (2006).

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

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

Table 1. Environmental values identified in the state Water Resource Implementation Rule for consideration when establishing minimum flows and levels 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	NA[1]
Water quality	Cypress Standard, Wetland Offset, Lake Mixing Standard, Dock-Use Standard, Herbaceous Wetland Information, Submersed Aquatic Macrophyte Information
Navigation	Basin Connectivity Standard, Submersed Aquatic Macrophyte Information

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

Lake Classification

Lakes are classified as Category 1, 2, or 3 for the purpose of Minimum Levels development. According to Rule 40D-8.624, F.A.C., Lake Lowery meets the classification as a Category 3 lake: one that has "no lake-fringing cypress swamp(s) greater than 0.5 acre in size." Therefore, the appropriate significant change Standards were determined for Lake Lowery and used in the Minimum Levels development. The standards are used to identify thresholds for preventing significant harm to cultural and natural system values associated with lakes in accordance with guidance provided in the Florida Water Resources Implementation Rule (62-40.473, F.A.C.). The change Standards and other information associated with Category 3 lakes are described below and will be developed in a subsequent section of this report.

The <u>Recreation/Ski Standard</u> 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 5-foot deep ski corridor delineated as a circular area with a radius of 418 feet, or a rectangular ski corridor 200 feet in width and 2,000 feet in length, and use of Historic lake stage data or region-specific reference lake water regime statistics where Historic lake data are not available.

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

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

The <u>Aesthetics Standard</u> is developed to protect aesthetic values associated with the inundation of lake basins. The standard is intended to protect aesthetic values associated with the median lake stage from diminishing beyond the values associated with the lake when it is staged at the Low Guidance Level. The Aesthetic Standard is established at the Low Guidance Level. Water levels equal or exceed the standard ninety percent of the time during the Historic period, based on the Historic, composite water level record.

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

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

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

Herbaceous Wetland Information is also taken into consideration to determine the elevation at which changes in lake stage would result in substantial changes in potential wetland area within the lake basin (i.e., basin area with a water depth of four feet or less) (Butts *et al*. 1997). Similarly, changes in lake stage associated with changes in lake area available for colonization by rooted submersed or floating-leaved macrophytes are also evaluated, based on water transparency values. Note however, that as no water transparency data were available for Lake Lowery, macrophyte colonization was not determined.

Minimum Levels

Two Minimum Levels and two Guidance Levels are typically established for lakes. Upon completion of a public input/review process and, if necessary completion of an independent scientific review, either of which may result in modification of the levels, the levels are adopted by the District Governing Board into Chapter 40D-8, F.A.C. (see Hancock *et al.* 2010 for more information on the adoption process). The levels, which are expressed as elevations in feet above the National Geodetic Vertical Datum of 1929 (NGVD29), 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 (P10).

- 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 (P50).

- 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 (P90).

The District is in the process of converting from use of the NGVD29 datum to use of the North American Vertical Datum of 1988 (NAVD 88). While the NGVD29 datum is used for most elevation values included within this report, in some circumstances, notations are made for elevation data that was collected or reported relative to mean sea level or relative to NAVD88 and converted to elevations relative to NGVD29. All datum conversions were derived using the Corpscon 6.0 software distributed by the United States Army Corps of Engineers.

Development of Minimum and Guidance Levels for Lake Lowery

Lake Setting and Description

Drainage Basin and Watershed

Lake Lowery is an approximately 900-acre lake located at latitude 28°07‘43‘’ north and longitude 81°40’45” west in eastern Polk County, Florida, between the cities of Lake Alfred and Haines City (Figure 1). The lake is located in Sections 13, 14, 23 and 24, Township 27S, Range 26E. The lake is situated in the southernmost part of the Ocklawaha Basin on the border of the Peace River Basin (Figure 2). The "Gazetteer of Florida Lakes" (Florida Board of Conservation 1969, Shafer et al. 1986) lists the size of Lake Lowery as 903 acres when the lake level is at 130 feet above mean sea level. Lake Lowery is located within the Lake Lowery Outlet drainage sub-basin as delineated in accordance with the United States Geological Survey Hydrologic Unit Classification system (Figure 3). Surface water inputs to the lake include direct precipitation on the lake surface, contributions from the wetlands directly connected to the lake, and runoff from immediately adjacent upland areas. Figure 3 illustrates the surface water outflow conveyances from the lake. Although the lake is included in the Ocklawaha River watershed, surface flow from the lake may also drain to the Withlacoochee and Peace

River basins. Details of the outlets from the lake including survey elevations are discussed more in Appendix A.

Prior to the 1970s, Lake Lowery was within the boundaries of the Southwest Florida Water Management District. From the early 1970s to July 2003, the lake was in the St. Johns River Water Management District (Moore 2003) until the water management district boundary was revised again in 2003, putting the lake back in the Southwest Florida Water Management District.

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

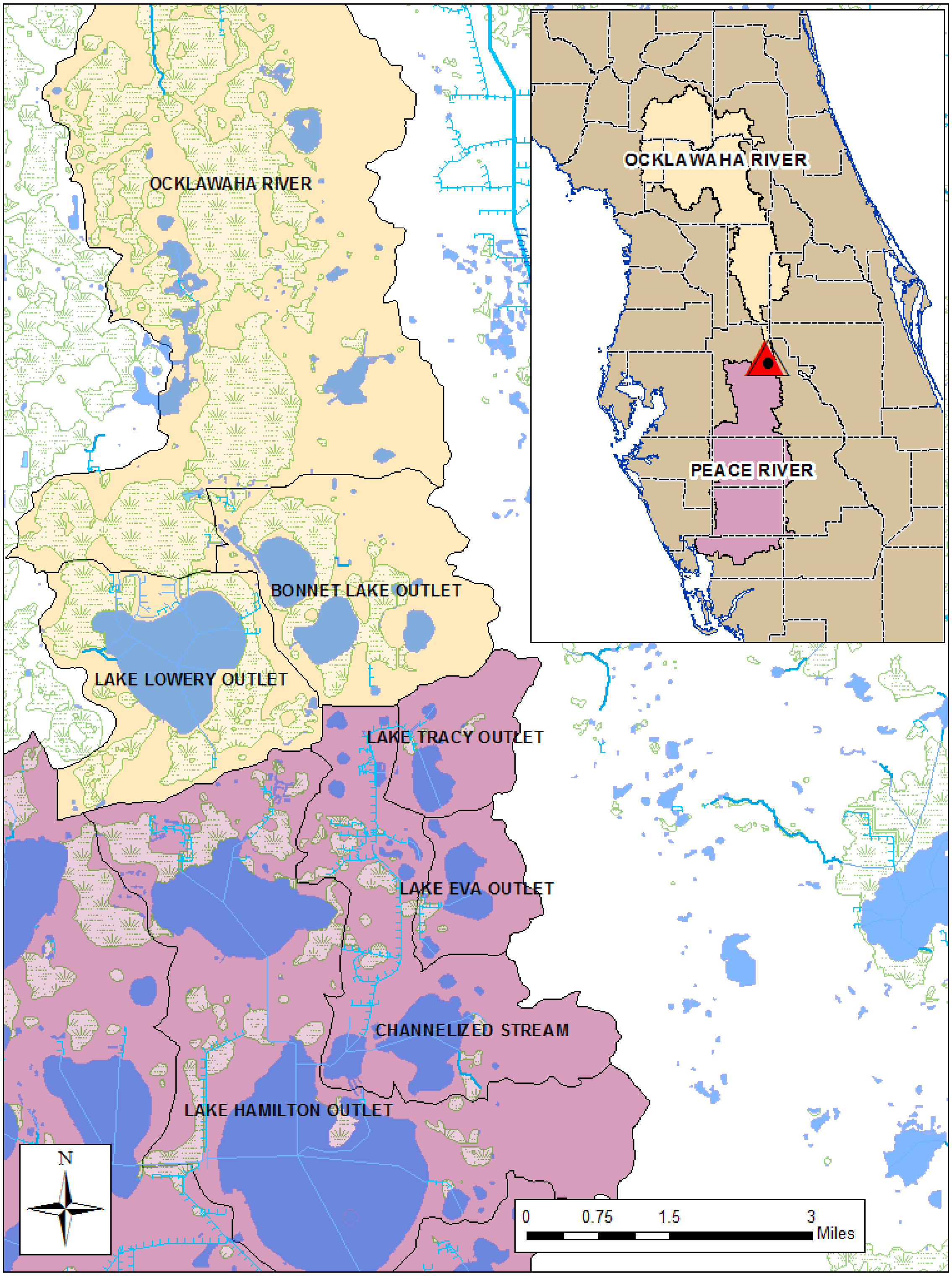

Figure 2. Drainage Basins to which Lake Lowery contributes.

Figure 3. Aerial photograph from 2008, showing surface water outflow paths from the Lake Lowery Outlet Drainage Basin.

Land Use Land Cover

An examination of 1941 aerial photography and more current 2011 Florida Land Use, Cover and Forms Classification System (FLUCCS) maps revealed that there have been considerable changes to the landscape in the vicinity of Lake Lowery during this period, primarily from agriculture or vacant uplands to residential. Specifically, land use in the vicinity of the lake in 1941 was primarily dominated by wetlands and citrus groves. By 2011, most of the groves had been replaced by residential development, however, much of the area around the lake remains Sawgrass (*Cladium jamaicense*) dominated wetlands (Figure 4). Figures 5 through 12 aerial photography chronicle landscape changes in the immediate Lake Lowery basin from 1941 to 2015.

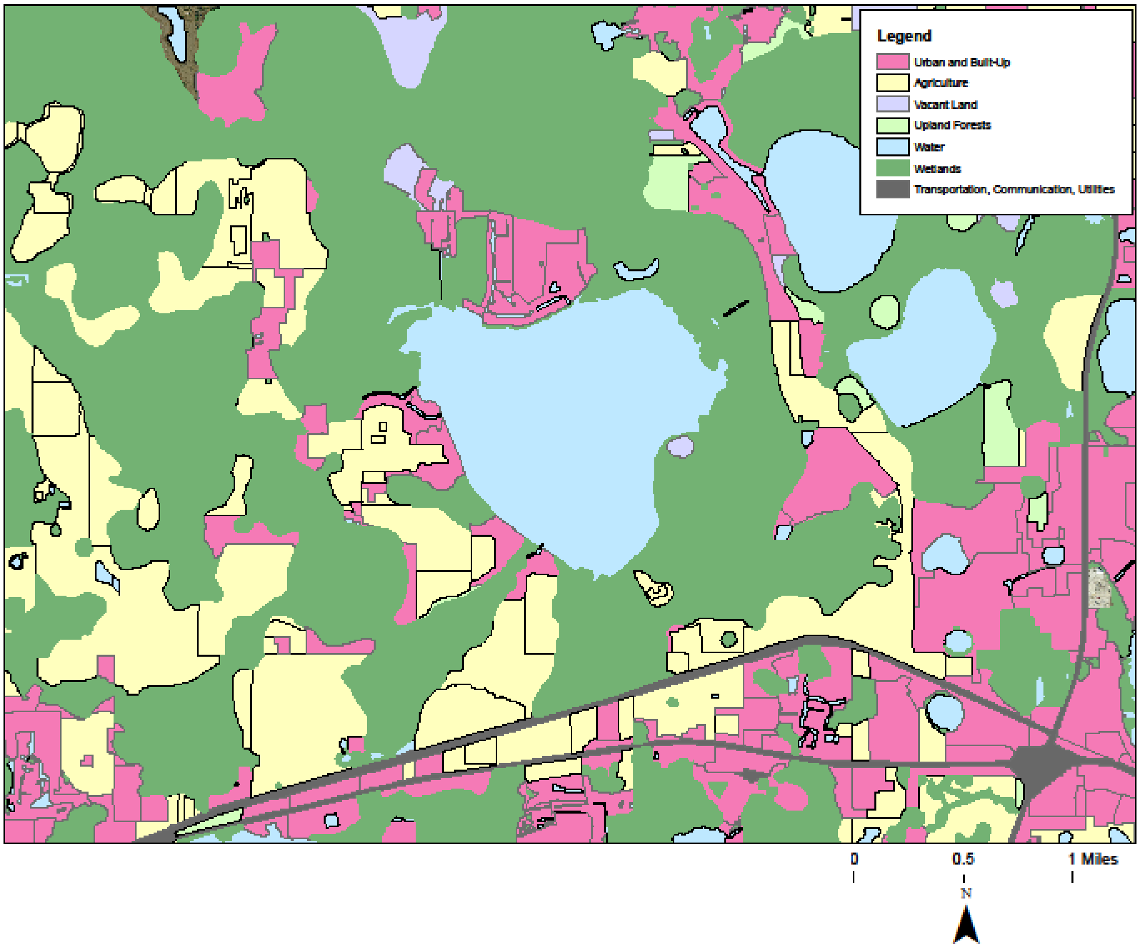

Figure 4. 2011 Land Use Land Cover Map of the Lake Lowery Vicinity.

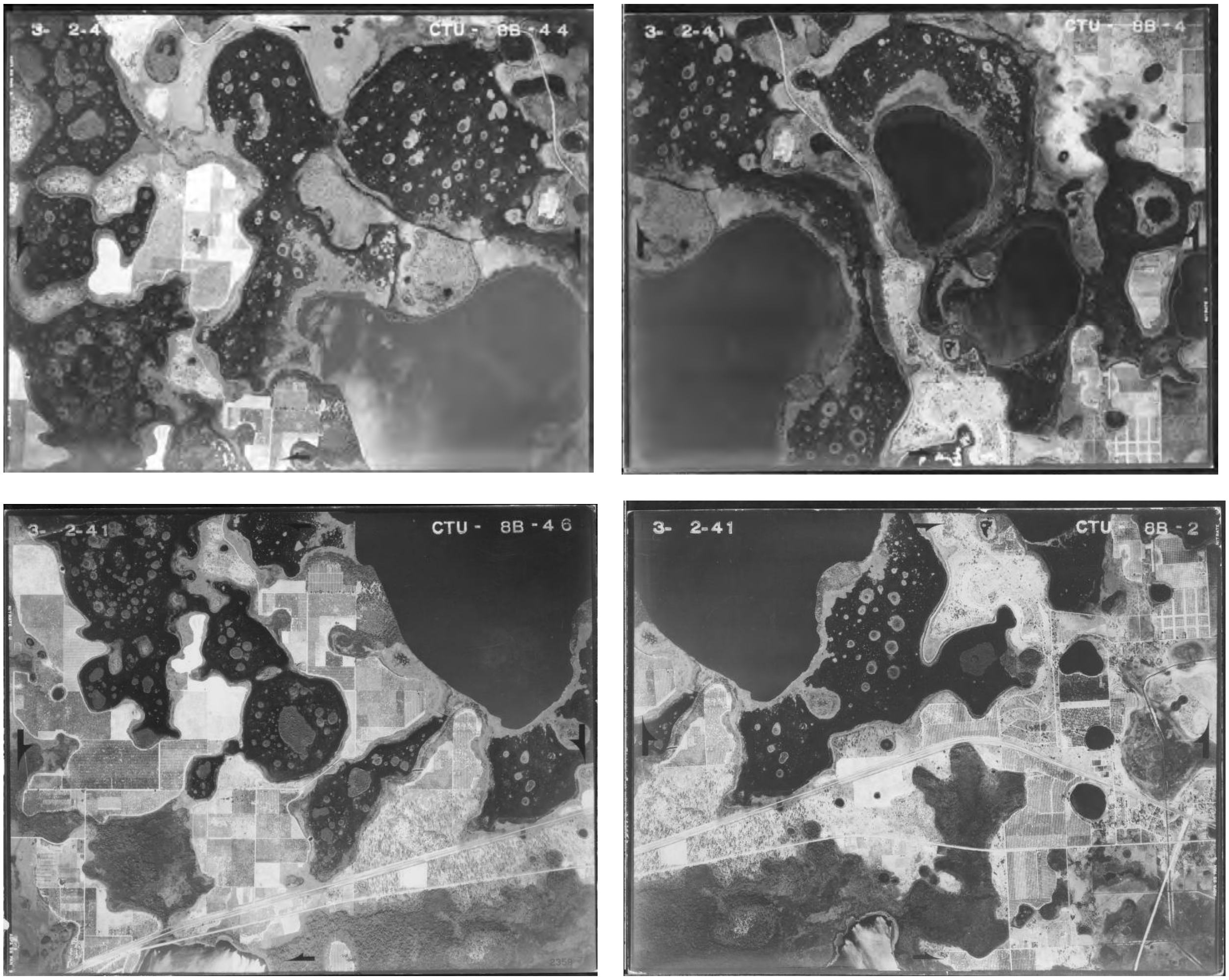

Figure 5. Aerial photographs of the Lake Lowery area in 1941 (United States Department of Agriculture 1941.)

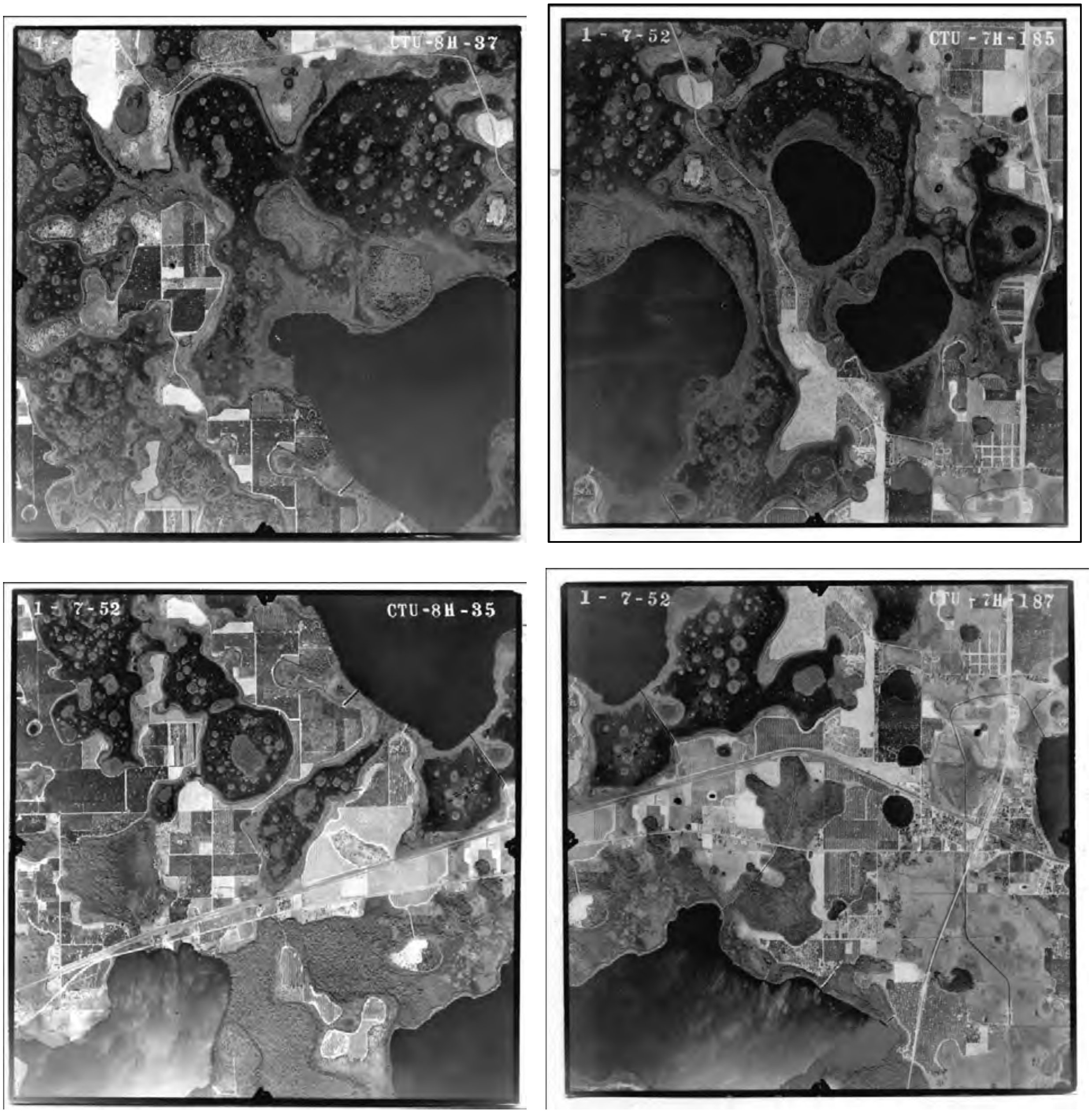

Figure 6. Aerial photographs of the Lake Lowery area in 1952 (United States Department of Agriculture 1952).

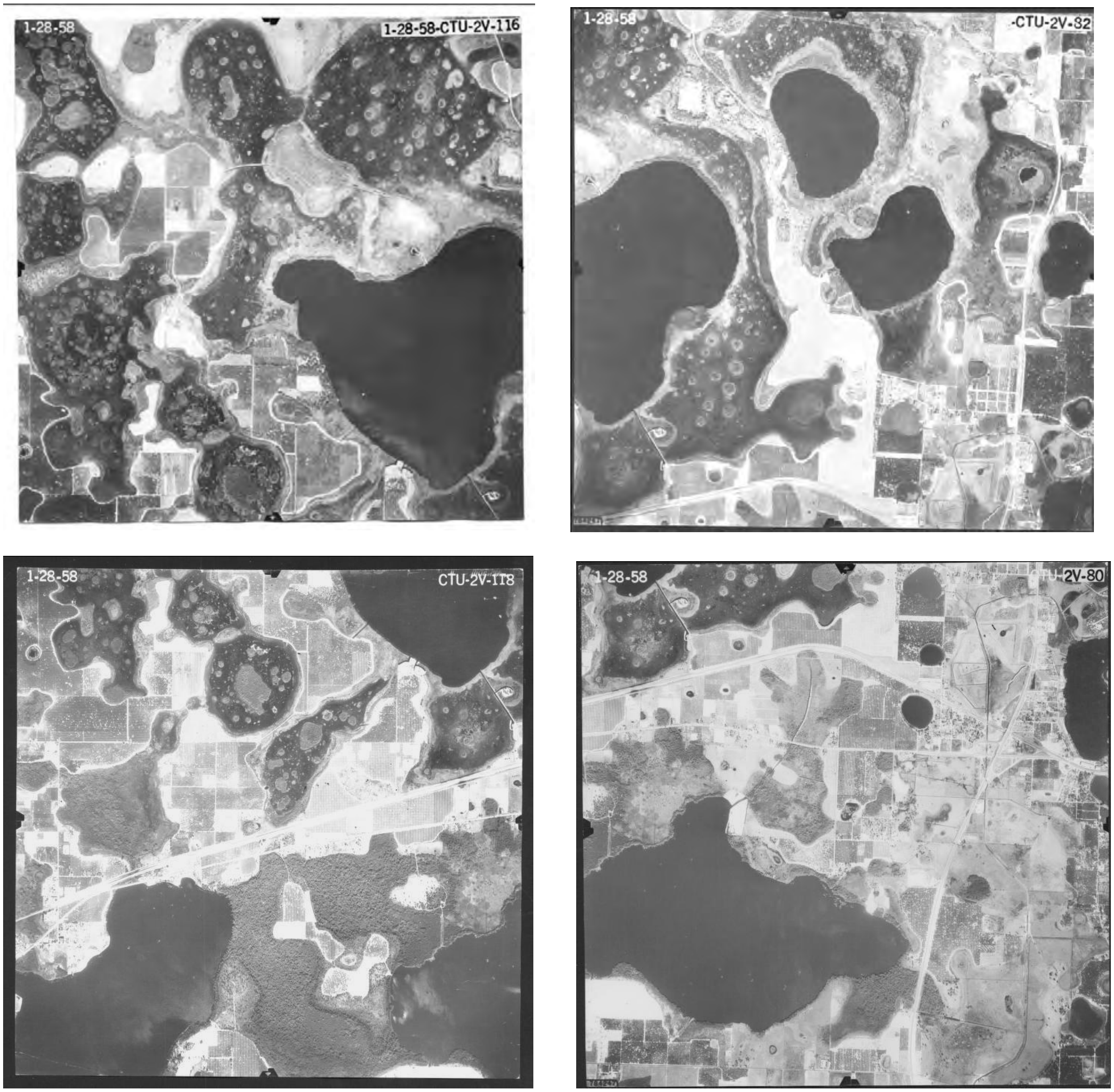

Figure 7. Aerial photographs of the Lake Lowery area in 1958 (United States Department of Agriculture 1958).

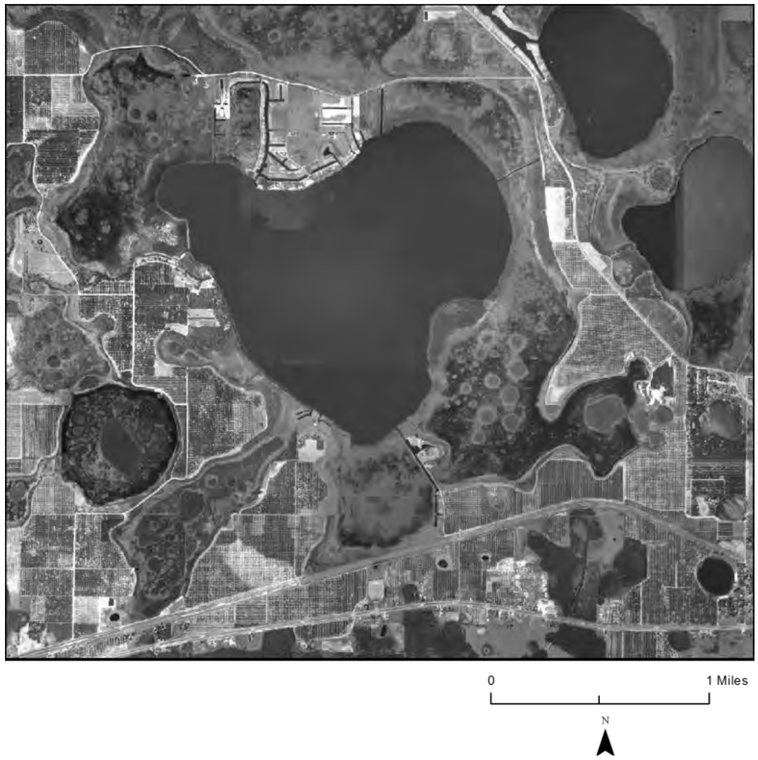

Figure 8. Aerial photograph of Lake Lowery in March 1971

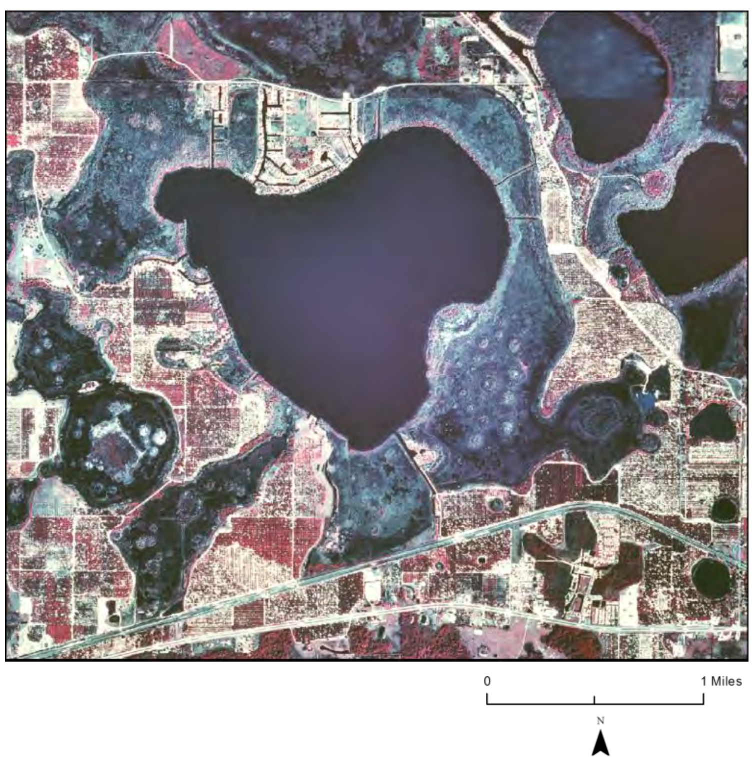

Figure 9. Aerial infrared photograph of Lake Lowery in 1984.

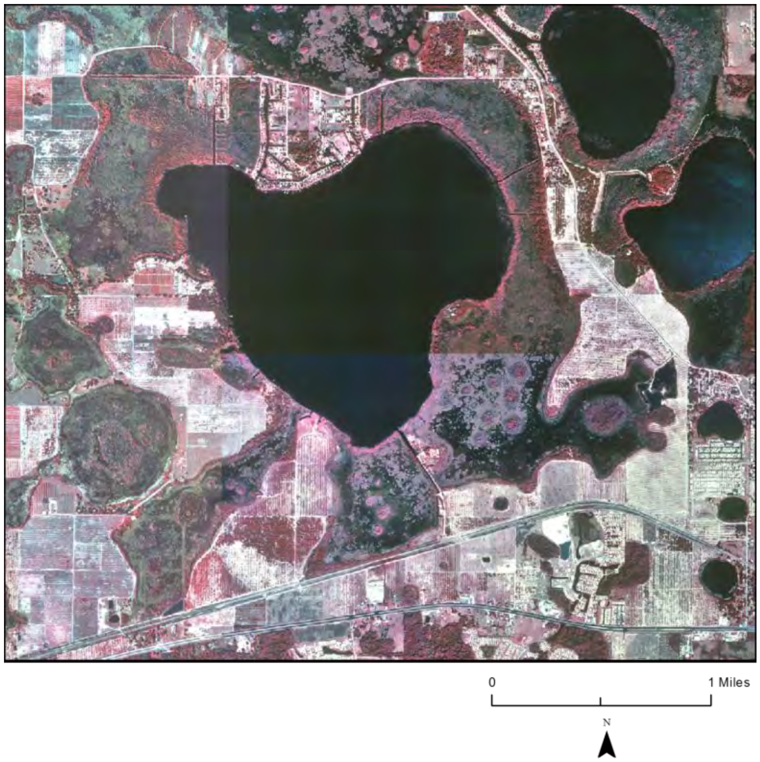

Figure 10. Aerial infrared photograph of Lake Lowery in 1994

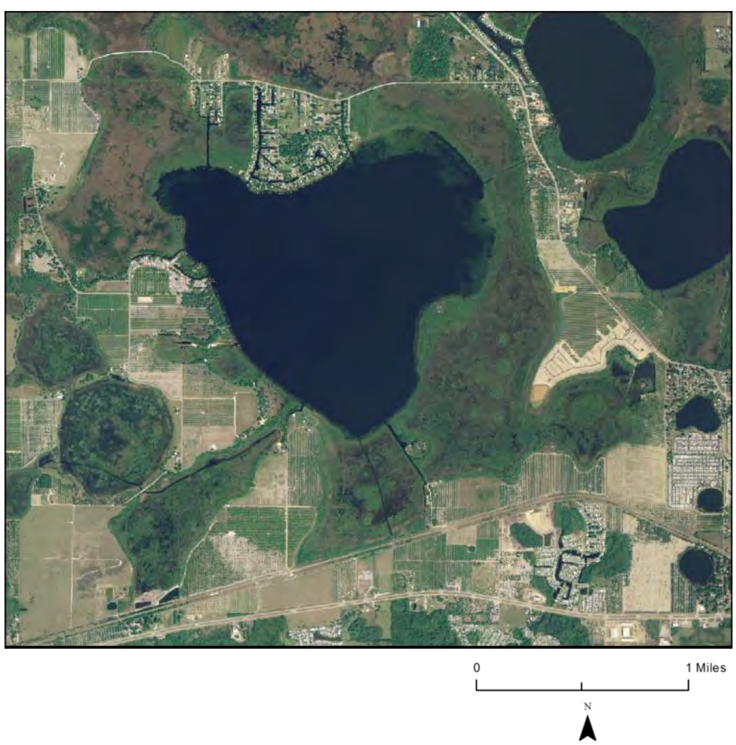

Figure 11. Aerial photograph of Lake Lowery in 2004

Figure 12. Aerial Photograph of Lake Lowery in 2015.

Bathymetry Description

One foot interval bathymetric data gathered from field surveys resulted in lake-bottom contour lines up to approximately 133 ft. (Figure 13). These data revealed that the lowest lake bottom contour (118 ft.) is located near the center of the lake and in pockets near the northeast side of the lake. Additional morphometric or bathymetric information for the lake basin is discussed in the Methods, Results and Discussion section of this report.

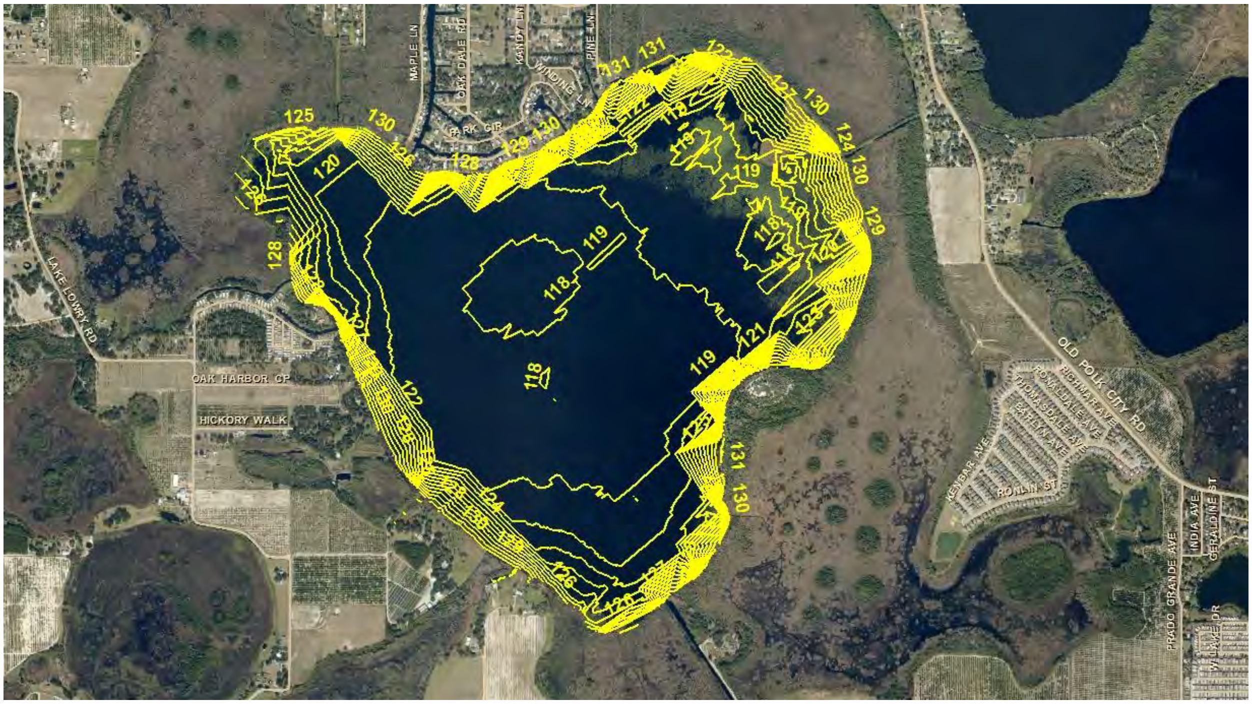

Figure 13. Lake Bottom Contours on a 2014 Natural Color Aerial Photograph

Water Level (Lake Stage) Record

Lake stage data, i.e., surface water elevations, are currently monitored and recorded at a District-maintained gage (Figure 14) located in a canal on the western lakeshore, and are available from the District's Water Management Information System (SID 17535) (Figure 15). Data have been collected continuously since June 1, 1960, originally from St. Johns River Water Management District's gage (SID 17710), which was then taken over by SWFWMD (SID 17535) in September 1998. The highest lake stage elevation on record is 133.32 ft. and occurred on September 11, 1960. The lowest lake stage elevation on record is 125.12 ft. and occurred on May 27, 1977. Figure 16 shows high water level (2004) and Figure 17 shows low water level (2009) historic aerial photographs of Lake Lowery. The District continues to monitor the water levels on a daily basis.

Figure 14. Lake Lowery Gage SID 17535 on September 11, 2008.

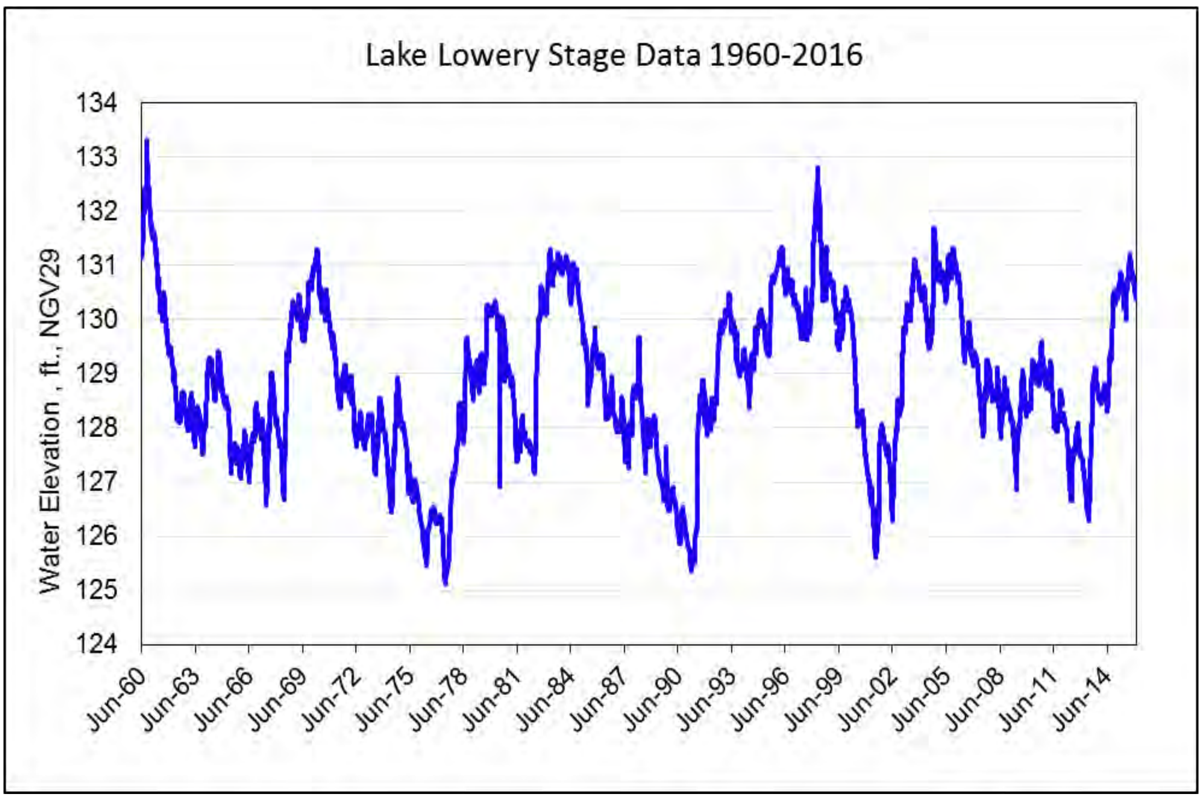

Figure 15. Lake Lowery Period of Record Stage Data (SID 17535 & 17710).

Figure 16. High Water Level (2004) Historic Aerial Photograph of Lake Lowery.

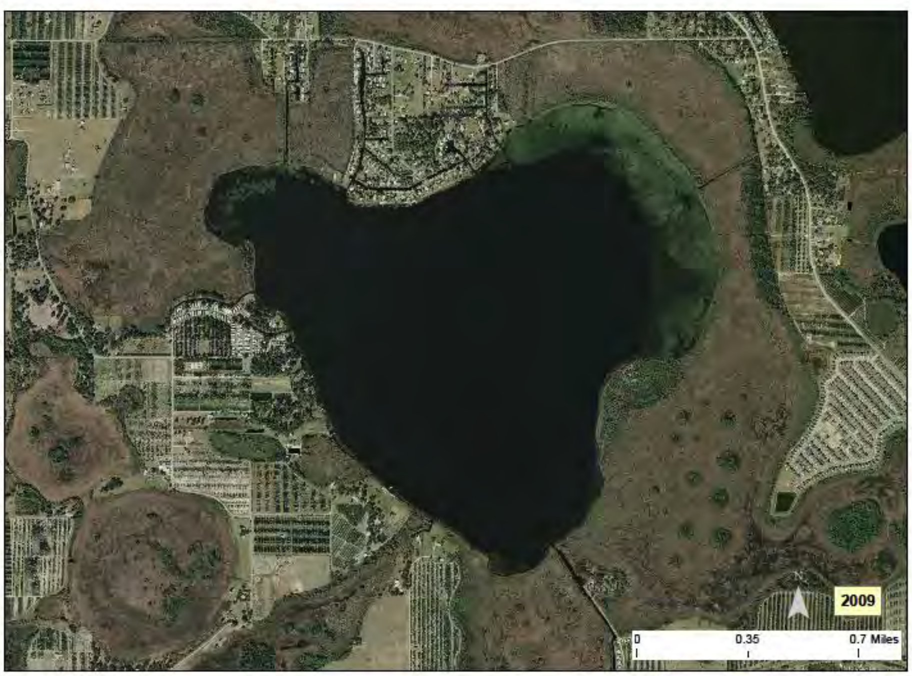

Figure 17. Low Water Level (2009) Historic Aerial Photograph of Lake Lowery

Historical and Current Management Levels

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

The Southwest Florida Water Management District has not previously adopted levels for Lake Lowery. However, the following minimum levels were approved by the St. Johns River Water Management District (SJRWMD) in December 2001. These levels (Table 2) were developed using different methods than were used by the SWFWMD to determine the current levels, and will not be discussed in this report.

Table 2. Minimum Levels Developed and Approved by SJRWMD and a brief description of each.

Levels	Elevation (NGVD29)	Hydroperiod Category
Minimum Infrequent High	130.0	Temporarily Flooded
Minimum Average	128.0	Typically Saturated
Minimum Frequent Low	126.5	Semi-permanently Flooded

Methods, Results and Discussion

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

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

Levels	Elevation in Feet NGVD29	Lake Area (acres)
Lake Stage Percentiles		
Historic P10 (1946 to 2015)	131.7	2,236
Historic P50 (1946 to 2015)	129.9	964
Historic P90 (1946 to 2015)	128.4	883
Normal Pool and Control Point		
Normal Pool	NA	NA
Control Point	127.6	1,111
Significant Change Standards		
Recreation/Ski Standard*	124.5	764
Dock-Use Standard*	131.4	1,900
Wetland Offset Elevation*	129.1	913
Aesthetics Standard*	128.4	883
Species Richness Standard*	126.4	821
Basin Connectivity Standard *	NA	NA
Lake Mixing Standard*	127.5	855
Minimum and Guidance Levels		
High Guidance Level	131.7	2,236
High Minimum Lake Level	129.7	950
Minimum Lake Level	127.9	868
Low Guidance Level	128.4	883

NA - not appropriate; * Developed for comparative purposes only; not used to establish Minimum Levels

Bathymetry

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

Stage-area-volume relationships were determined for Lake Lowery by building and processing a digital elevation model (DEM) of the lake basin and surrounding watershed. Elevations of the lake bottom and land surface elevations were used to build the model through a series of analyses using LP360 (by QCoherent) for ArcGIS, ESRI® ArcMap 10.2 software, the 3D Analyst ArcMap Extension, Python, and XTools Pro. The overall process involves merging the terrain morphology of the lake drainage basin with the lake basin morphology to develop one continuous 3D digital elevation model. The 3D digital elevation model is then used to calculate area of the lake and the associated volume of the lake at different elevations, starting at the largest size of the lake at its peak or flood stage, and working downward to the base elevation (deepest pools in the lake).

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

The DEM created from the combined elevation data sets was used to develop topographic contours of the lake basin and to create a triangulated irregular network (TIN). The TIN was used to calculate the stage areas and volumes using a Python script file to iteratively run the Surface Volume tool in the Functional Surface toolset of the ESRI® 3D Analyst toolbox at one-tenth of a foot elevation change increments. Stage-area results are presented in Figure 18.

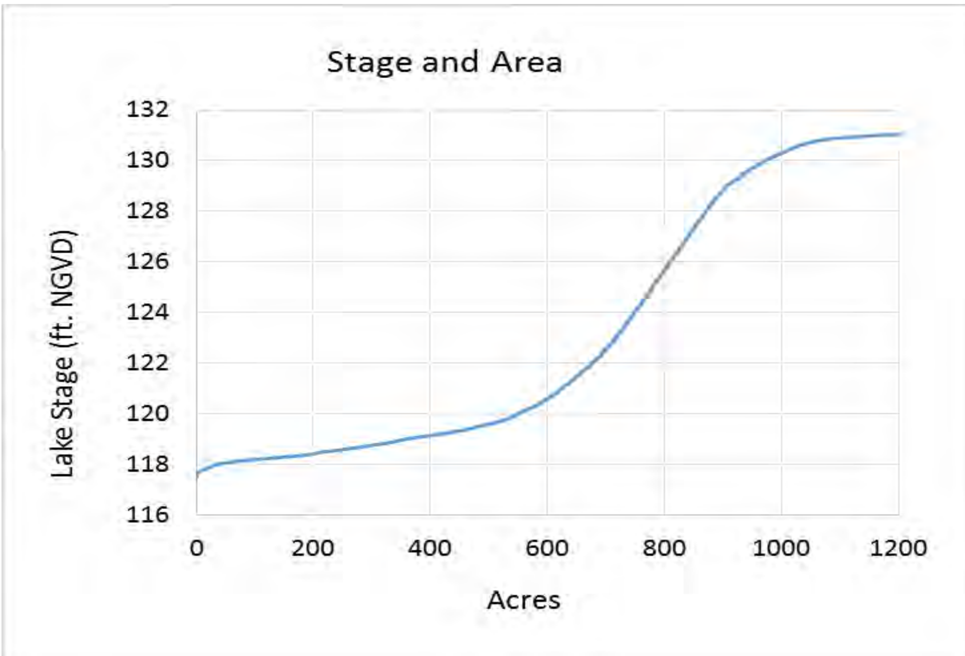

Figure 18. Lake Lowery surface area as a function of lake stage.

Development of Exceedance Percentiles

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

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

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

A combination of model data produced a hybrid model which resulted in a 70-year (1946-2015) Historic water level record. Based on this hybrid data, the Historic P10 elevation, i.e., the elevation of the lake water surface equaled or exceeded ten percent of the time, was 131.7 ft. The Historic P50, the elevation the lake water surface equaled or exceeded fifty percent of the time during the historic period, was 129.9 ft. The Historic P90, the lake water surface elevation equaled or exceeded ninety percent of the time during the historic period, was 128.4 ft. (Figure 19 and Table 3).

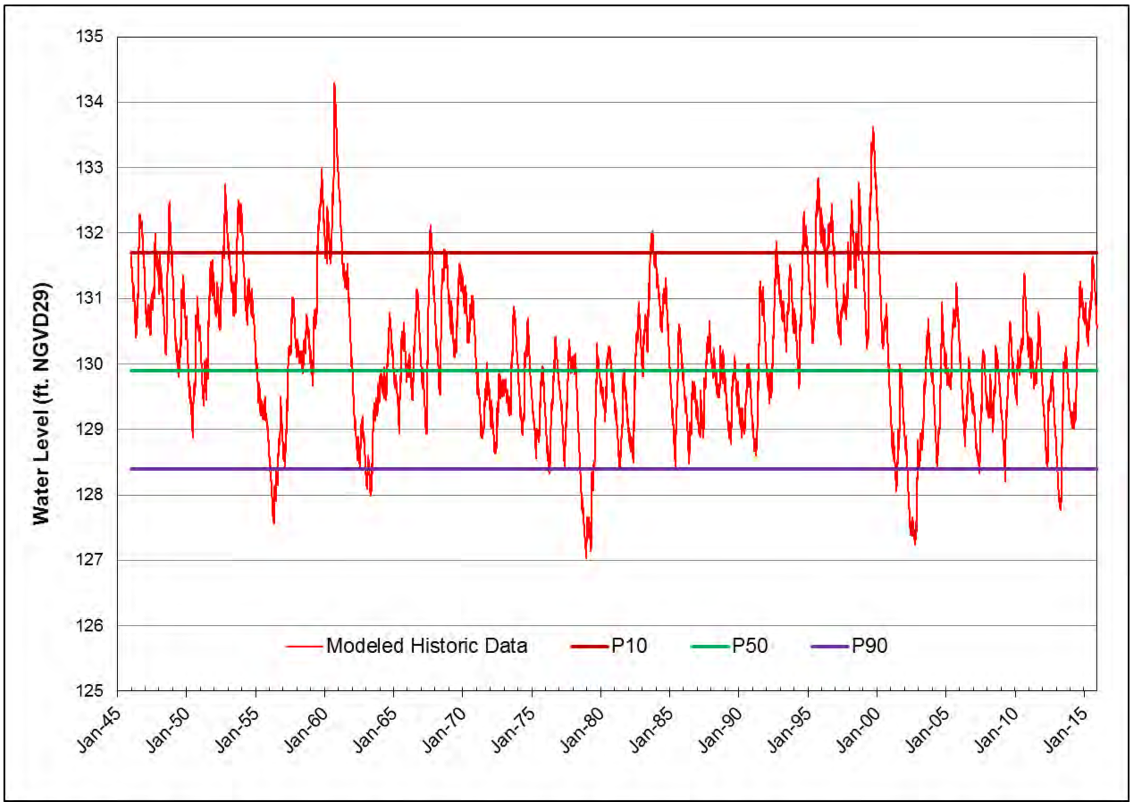

Figure 19. Lake Lowery Historic Water Levels (hybrid) Used to Calculate Percentile Elevations Including P10, P50, and P90.

Guidance Levels

The High Guidance Level is provided as an advisory guideline for construction of lakeshore development, water dependent structures, and operation of water management structures. The High Guidance Level is the expected Historic P10 of the lake, and is established using Historic data if it is available, or is estimated using the Current P10, the Control Point elevation, and the Normal Pool elevation. Based on the availability of Historic data developed for Lake Lowery, the High Guidance Level was established at the Historic P10 elevation, 131.7 ft. The High Guidance Level has been exceeded several times in the Historic data. The highest peak was 134.2 ft. occurring as a result of Hurricane Donna in 1960. In comparison, gaged period of record levels for the lake exceeded the High Guidance Level twice, once in September 1960 and then again in March 1998. The water level equaled the High Guidance Level in October 2004 (Figure 15).

Like the High Guidance Level, the Low Guidance Level is provided as an advisory guideline for water dependent structures, and as information for lakeshore residents and operation of water management structures. The Low Guidance Level is the elevation that a lake's water levels are expected to equal or exceed ninety percent of the time on a long-term basis. Based on the availability of Historic data for Lake Lowery, the Low Guidance Level was established at the Historic P90 elevation, 128.4 ft.

Significant Change Standards

The stage-volume relationships and Category 3 significant change standards were established for Lake Lowery, including a Lake Mixing Standard, a Dock-Use Standard, a Species Richness Standard, an Aesthetics Standard, and a Recreation/Ski Standard. In addition, Herbaceous Wetland Information and Submersed Aquatic Macrophyte Information were considered. Each standard and consideration was evaluated for minimum levels development for Lake Lowery and presented in Table 3.

- The **Lake Mixing Standard** (127.5 ft.) was established at the dynamic ratio (basin slope) shift as described in the rule, indicating that potential changes in basin susceptibility to wind-induced sediment re-suspension would not be of concern for minimum levels development.

- The **Dock-Use Standard** was established at 131.4 ft., derived from the elevation of lake sediments at the end of 93 docks on the lake (Table 4).

Table 4. Summary statistics and elevations associated with docks in Lake Lowery based on measurements made by District staff in April 2016. Exceedance percentiles (P10, P50, and P90) represent elevations exceeded by 10, 50 and 90 percent of the docks.

Summery Statistics	Statistics Value (N) or Elevation (ft.) of Sediments at Waterward End of Docks	Statistics Value (N) or Elevation (ft.) of Dock Platforms
N (number of docks)	93	93
10th Percentile (P90)	123.16	131.15
Median or 50th Percentile	125.50	131.75
90th Percentile (P10)	127.89	132.63
Maximum	129.89	133.29
Minimum	121.69	130.09

- The **Basin Connectivity Standard** was not applicable and was not established. Historical aerial photography and lake bathymetry indicate that the lake is a single basin.

- The **Species Richness Standard** was established at 126.4 ft., based on a 15% reduction in lake surface area from that at the Historic P50 elevation.

- An **Aesthetic Standard** for Lake Lowery was established at the Low Guidance Level elevation of 128.4 ft.

- The **Recreation/Ski Standard** was calculated at 124.5 ft. based on a ski elevation of 118 ft.

Review of changes in potential herbaceous wetland area associated with change in lake stage, and potential change in area available for aquatic macrophyte colonization did not indicate that use of any of the identified standards would be inappropriate for minimum levels development.

Additional information to consider in establishing Minimum and Guidance Levels are the Control Point elevation and the lowest building floor (slab) elevation within the lake basin (determined by field survey data). The Control Point elevation is the elevation of the highest stable point along the outlet profile of a surface water conveyance system that can principally control the lake water level fluctuations at the high end. There are three conveyance systems discharging water from the lake at different elevations. The control elevation, i.e., highest stable point, in the lowest of the three conveyance systems is culverts under Lake Lowery Road on the north side of the lake (Appendix A) and serves as the lake Control Point at elevation 127.6 ft. The lowest house slab in the drainage basin was surveyed at 131.7 ft.

Minimum Levels

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. Being that Lake Lowery is a Category 3 lake, one of the significant change standards would normally be used to set the High Minimum level, however in this case, the low floor slab was used to help prevent flooding. Therefore, the High Minimum Lake Level for Lake Lowery is established at 129.7 ft., 2 feet below the floor slab elevation.

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. For a Category 3 lake the Minimum Lake Level is established utilizing a process that considers applying professional experience and judgement, the eight Standards listed previously, and additional information mentioned above. Considering that the High Minimum Lake Level was established using the lowest floor slab, the Minimum Lake Level is 127.9 ft. This level was developed by subtracting the difference of the historic P10 and P50 from the High Minimum Level.

Minimum and Guidance levels for Lake Lowery are plotted on the Historic water level record (Figure 20) and the stage water level period of record (Figure 21).

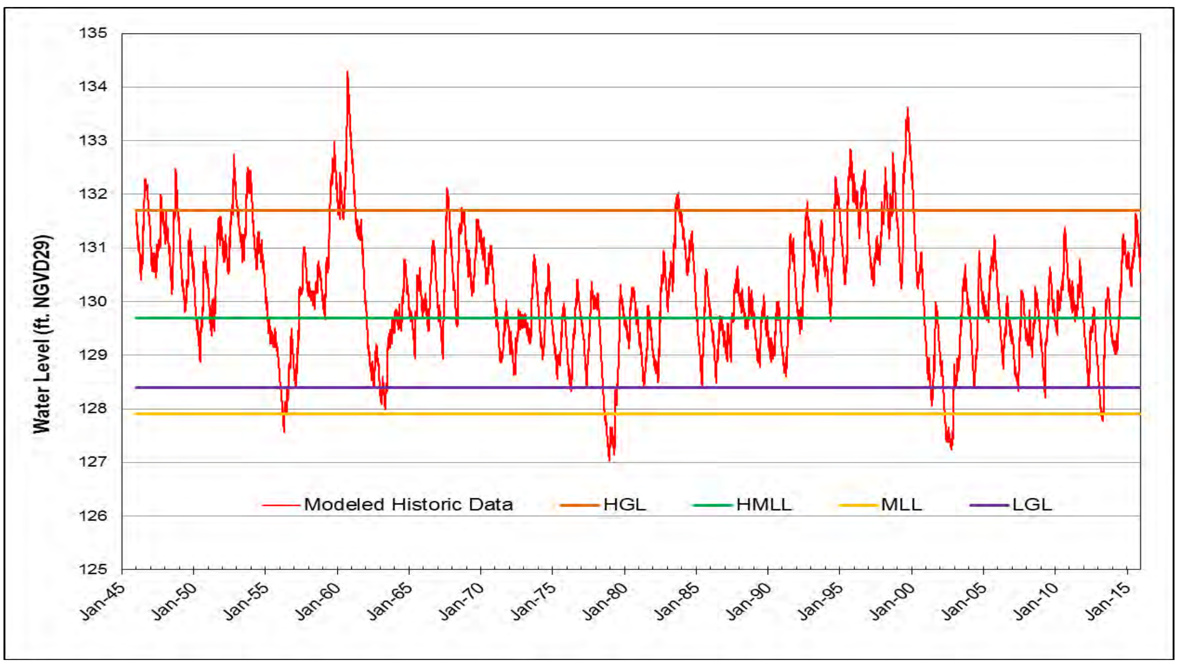

Figure 20. Lake Lowery Historic water levels (hybrid) used to calculate the Minimum and Guidance Levels. The levels include the High Guidance Level (HGL), High Minimum Lake Level (HMLL), Minimum Lake Level (MLL), and Low Guidance Level (LGL).

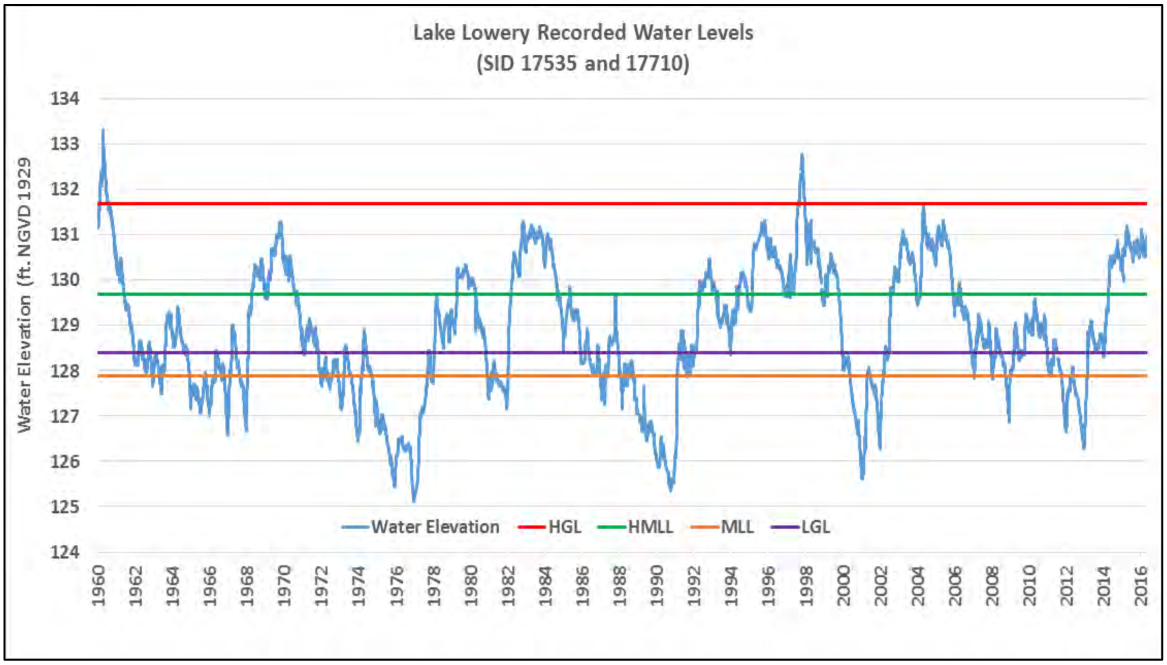

Figure 21. The High Guidance Level (HGL), High Minimum Lake Level (HMLL), Minimum Lake Level (MLL), and Low Guidance Level (LGL) with the lake stage water level period of record data.

Many federal, state, and local agencies, such as the U.S. Army Corps of Engineers, the Federal Emergency Management Agency, United States Geological Survey, and Florida's water management districts are in the process of upgrading from the National Geodetic Vertical Datum (NGVD29) standard to the North American Vertical Datum (NAVD88) standard. For comparison purposes, the MFLs for Lake Lowery are presented in both datum standards (Table 5). The datum shift was calculated based on third-order leveling ties from vertical survey control stations with known elevations above the North American Vertical Datum on 1988. The NGVD29 datum conversion to NAVD88 for SID 17535 is -0.87 ft.

Table 5. Minimum and Guidance Levels for Lake Lowery in NGVD29 and NAVD88.

Minimum and Guidance Levels	Elevation in Feet NGVD29	Elevation in Feet NAVD88
High Guidance Level	131.7	130.8
High Minimum Lake Level	129.7	128.8
Minimum Lake Level	127.9	127.0
Low Guidance Level	128.4	127.5

Consideration of Environmental Values

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

These levels serve to protect several environmental values identified in the Water Resource Implementation Rule, including: recreation in and on the water, fish and wildlife habitats and the passage of fish, transfer of detrital material, aesthetic and scenic attributes, filtration and absorption of nutrients and other pollutants, and water quality (refer to Table 1). Ultimately, Historic P50 and P10 elevations and the elevation of the lowest house slab were used for developing the minimum levels for Lake Lowery. Given that the minimum levels were established using Historic lake stage exceedance percentiles, the levels are as protective of relevant environmental values as they can be, given the existing low slab constriction. 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.

Minimum Levels Status Assessment

To assess if the Minimum and High Minimum Lake Levels are being met, observed stage data in Lake Lowery were used to create a long-term record using a Line of Organic Correlation (LOC) model, similar to what was developed for establishing the Minimum Levels (Appendix A). For the status assessment, the lake stage data used to create the LOC must be from a period representing a time when groundwater withdrawals and structural alterations are reasonably stable, and represent current conditions, referred to as the “Current” period. “Current” stage data observed on Lake Lowery were determined to be from 2014 through present. Using the Current stage data, the LOC model was created. The LOC model resulted in a 70-year long-term water level record (1946-2015).

For the status assessment, cumulative median (P50) and cumulative 10th percentile (P10) water elevations were compared to the Minimum Lake Level and High Minimum Lake Level to determine if long-term water levels were above the levels. Results from these assessments indicate that Lake Lowery water levels are currently above the Minimum Lake Levels and currently above the High Minimum Lake Levels (see Appendix B).

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APPENDIX A

Technical Memorandum

September 22, 2016

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

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

FROM: Donald L. Ellison, P.G., Senior Hydrogeologist, Water Resources Bureau
Mark Barcelo, P.E., Chief Engineer, Water Resources Bureau
Jason Patterson, Hydrogeologist, Water Resources Bureau
Corey Denninger, Senior GIS Analyst, Data Collection

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

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A. Introduction

Water budget and rainfall correlation models were developed to assist the Southwest Florida Water Management District (District) in the establishment of minimum and guidance levels for Lake Lowery, located in north-central Polk County. This document will discuss the development of the Lake Lowery models, as well as the development of the Historic percentiles using the models.

B. Background and Setting

Lake Lowery is located in north-central Polk County, northwest of Haines City, approximately half a mile north of U.S. Highway 17 and a third of a mile west of U.S. Highway 27 (Figure 1). The lake is situated in the southernmost part of the Ocklawaha Basin on the border of the Peace River Basin (Figure 2). The majority of the area surrounding Lake Lowery is rural and undeveloped. The development that has occurred around the lake consists of mostly residential growth and citrus groves (Figure 3). The potable and almost all of the irrigation water supply comes from the Upper Floridan aquifer.

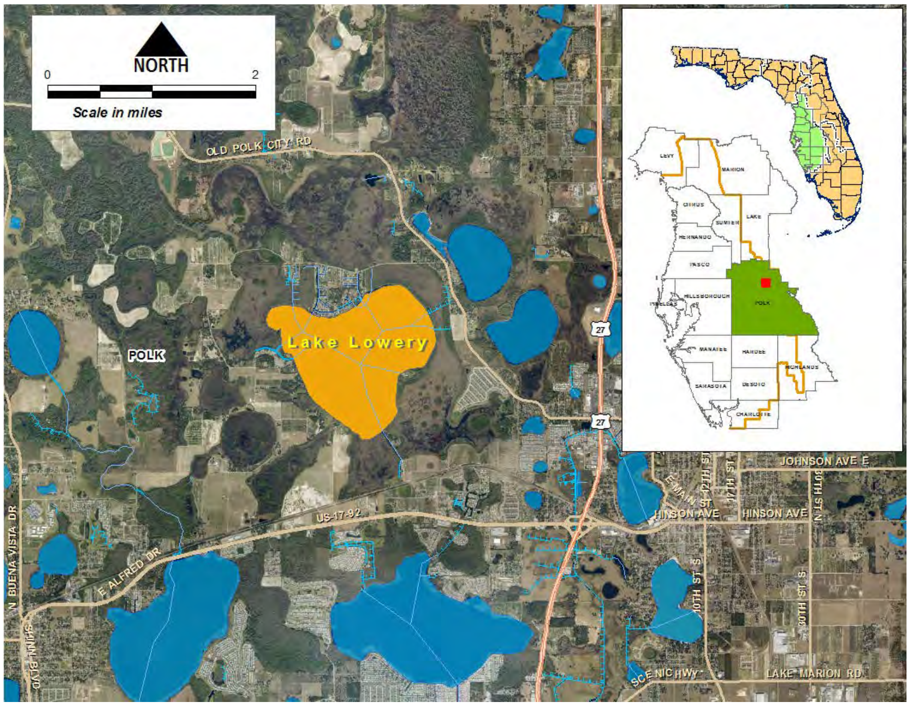

Figure 1. Location of Lake Lowery in Polk County, Florida.

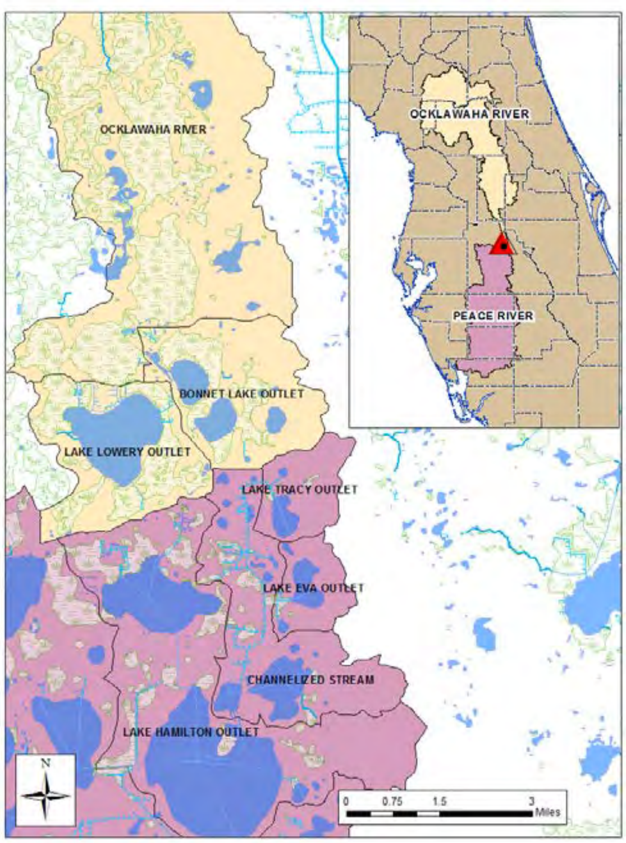

Figure 2. Drainage Basins Lake Lowery contributes to.

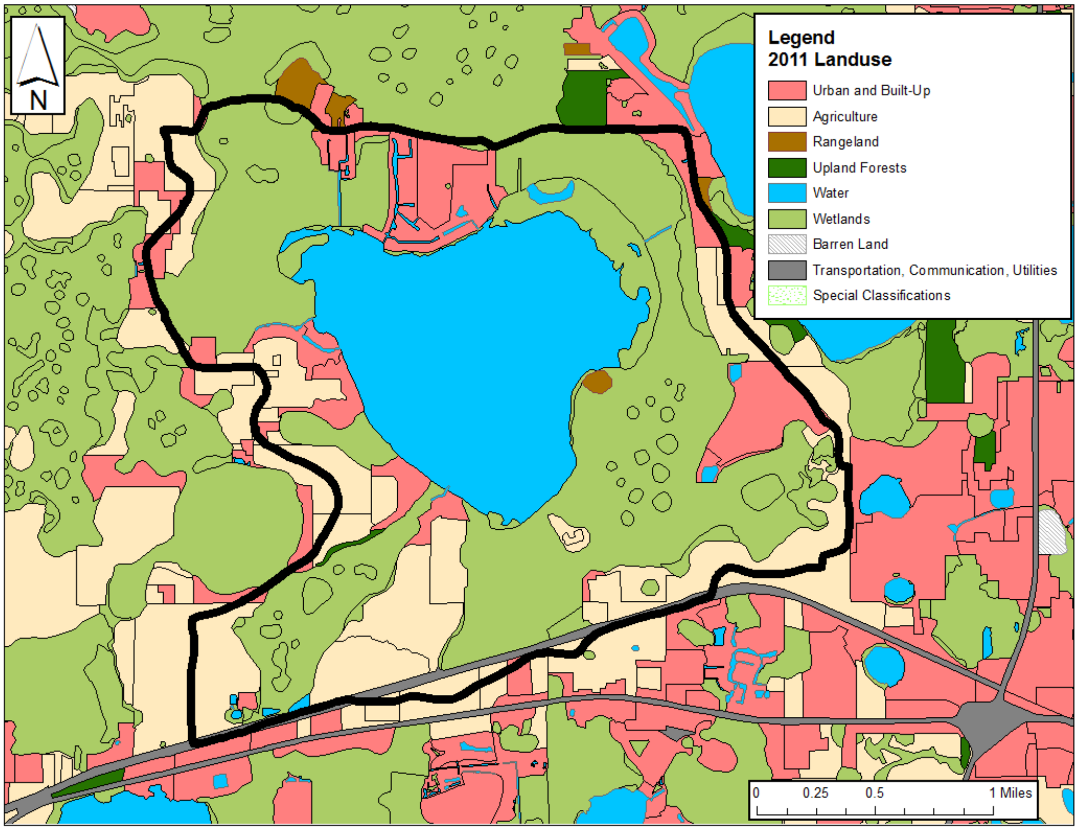

Figure 3. 2011 Land use map around Lake Lowery.

C. Drainage System

There are no channel inflows from other lakes to Lake Lowery, while discharge occurs via three outlets from the lake. Flooding of residential areas continues to be a concern, but modifications made to the drainage system in the time period between 2002 and 2004 aid in the reduction of flooding. Lake Lowery is located at the head of the Ocklawaha River Basin drainage basin and discharges primarily to the north. At high lake levels it also discharges to the south through two separate outlets. Flooding of residential areas adjacent to the lake is an issue and modifications to the drainage system flowing south have been made to allow to provide additional conveyance once a high level is reach. Between 2001 and 2003, these structures were reassessed and altered, with the bulk of the modification made in 2002. There are three control points on the lake (Figure 4). One discharges to the north and two to the south. Control Point 1 consists of two 46 inch reinforced concrete pipes capped by two flap gates to prevent water flowing from the north from entering the lake. The invert elevation is 127.6 ft. NGVD29 (Keith & Schnars, P.A. 2003). As of March 2016, these flap gates seemed to be non-functional due to sediment accumulation and vegetation growth.

Control Point 2 consists of an 18 ft. wide weir with a crest at 131.5 ft. NGVD29. There is also an 18" diameter plastic pipe off to the side of the weir with an invert of 129.73 ft. NGVD29. Control Point 3 consists of a drainage box and a 36 inch diameter outlet pipe with an initial invert elevation of 131.0 ft. NGVD29. There is a gate downstream of the structure that has to be opened for this structure to convey water. Polk County operates the structure and the operation schedule requires Lake Henry downstream to be at or below 126.0 ft. NGVD29.

Figure 4. Outlets from Lake Lowery.

Lake Lowery water levels are influenced indirectly by the surficial aquifer water levels which are affected by water levels in lakes Henry and Haines to the south and controlled by operable structures P-5 and P-6, respectively (Figure 5). These structures were operated by Lakes Region Lakes Management District (LRLMD) until 2013 when they were transferred to the District. Since the transfer the District has operated the structures with a new schedule. On May 29, 2014 the District completed the installation of a SCADA system on each structure providing remote operation control capabilities, and has since been operating in a manner to maintain the lakes near the Target

Conservation Level until weather patterns present a flooding concern and releases are made to create storage prior to the storm (Figures 6 and 7). The new operation guidelines appear to have increased levels in Lake Lowery (Figure 8) as well as the surficial aquifer (Figure 25) and to some degree the Upper Floridan Aquifer (Figure 23).

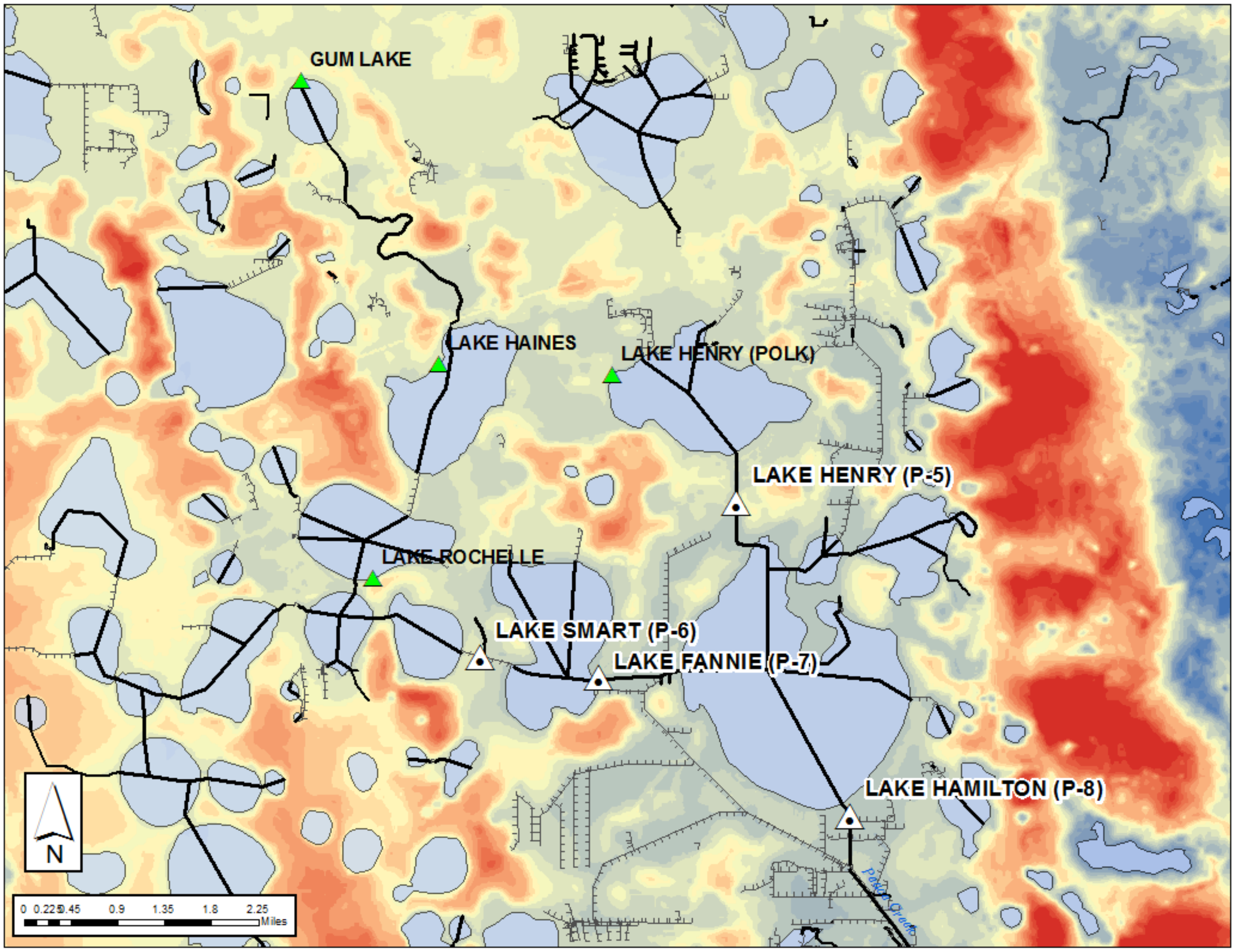

Figure 5. Locations of drainage structures in the area.

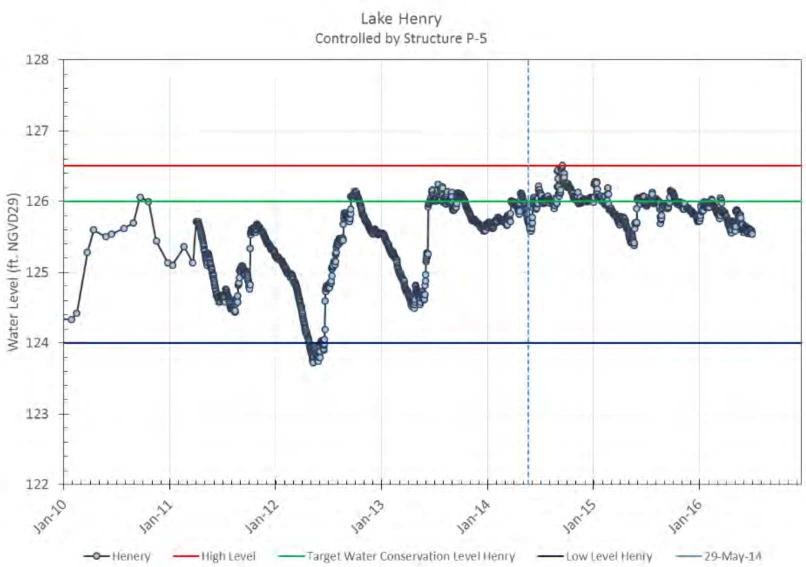

Figure 6. Lake Henry hydrograph.

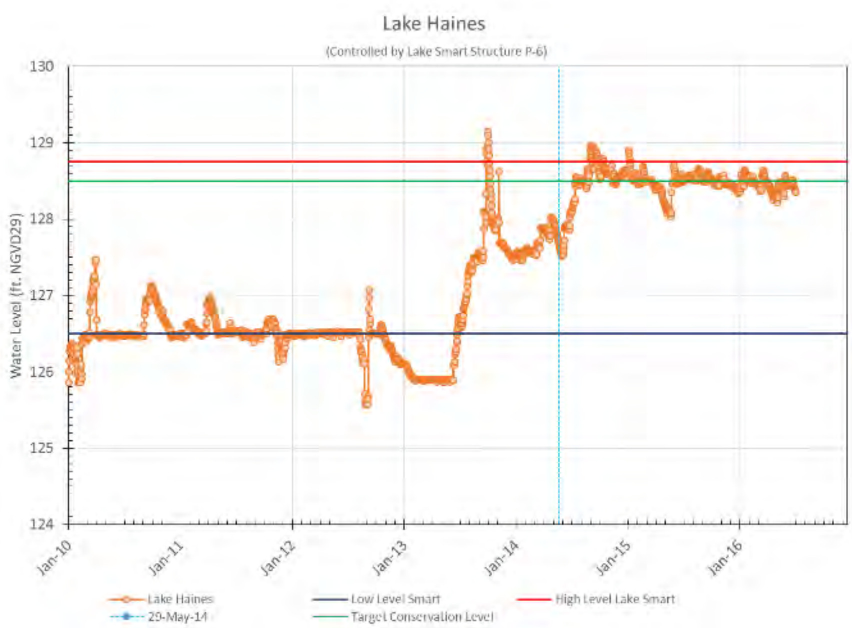

Figure 7. Lake Haines hydrograph.

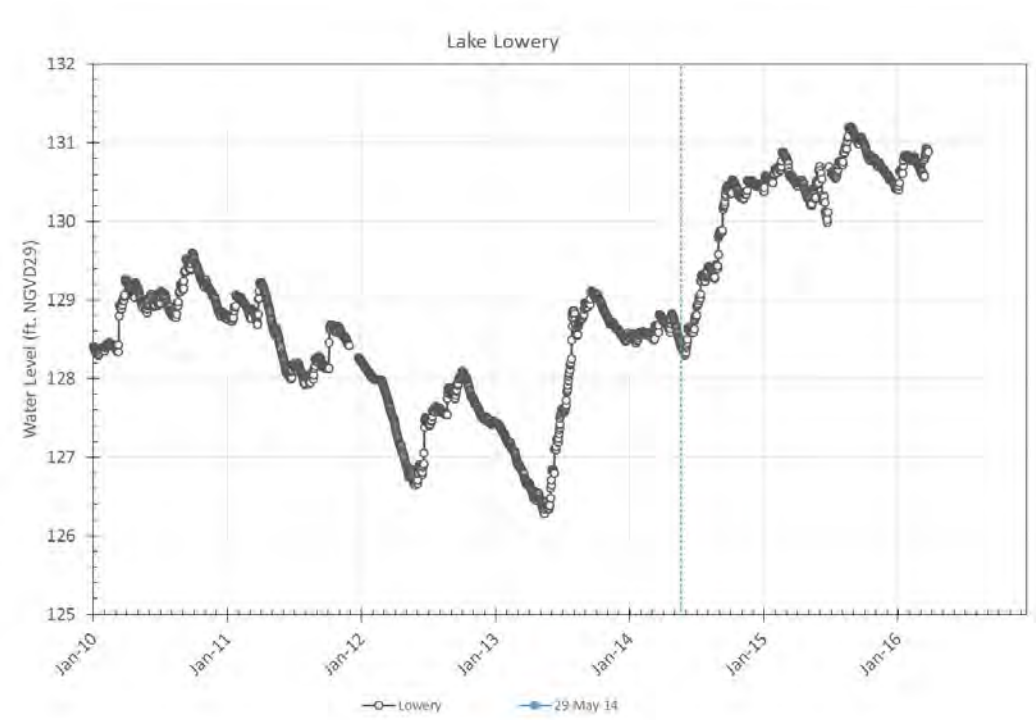

Figure 8. Lake Lowery hydrograph.

D. Physiography/Geology

White (1970) classified the physiographic area as the Polk Upland bordered to the east by the Lake Wales Ridge and to the west by the Winter Haven Ridge (Figure 9).The area surrounding the lake is categorized as the Winter Haven Karst (Brooks, 1981), a region of linearly oriented low sand hills and large solution lakes in an advanced stage of planation and many of the tops of hills are commonly 150 to 190 feet in elevation.

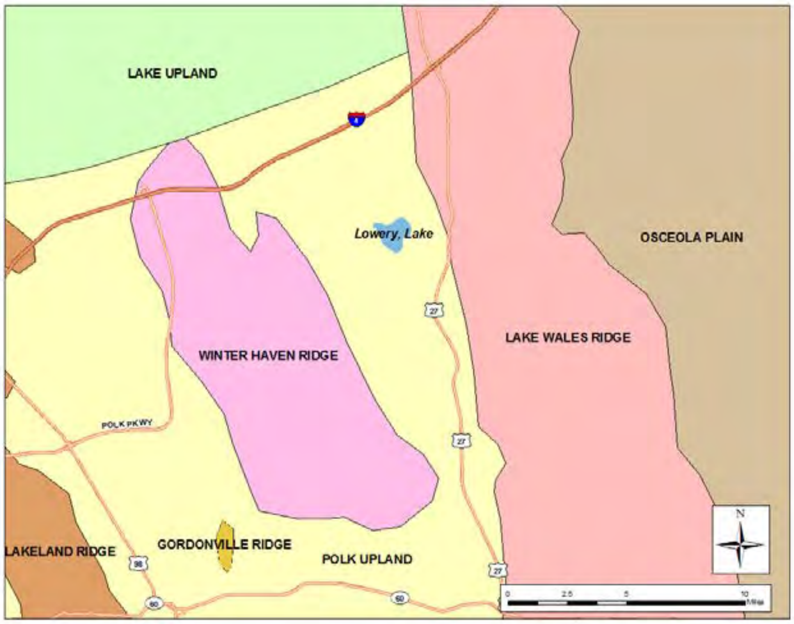

Figure 9. Physiographic provinces in the area of Lake Lowery (White 1970).

In general the hydrogeology of the area starting at landsurface includes an 80 foot thick unconsolidated surficial deposit of sand grading down to clay; a 30 foot confined intermediate aquifer system (IAS), which consists of a series of thin, interbedded limestone and phosphatic clays of generally low permeability; and finally the thick carbonate Upper Floridan aquifer (UFA). The base of the surficial aquifer (SA) consists of Pliocene age clays and clayey sands that form the top of the IAS. The IAS in this area is composed of the Hawthorn group which varies in thickness from 30 to 40 feet and forms an confinning unit. The UFA is a carbonate sequence comprised of the Suwannee Limestone, Ocala Limestone, and portions of the Avon Park Formation.The generalized hydrogeology of the lake Lowery area is depicted in a cross-section (Figures 10 and 11) based off of the top elevation of hydrostratigraphic units mapped by the Florida Geological Survey (FGS) (Arthur, 2008).

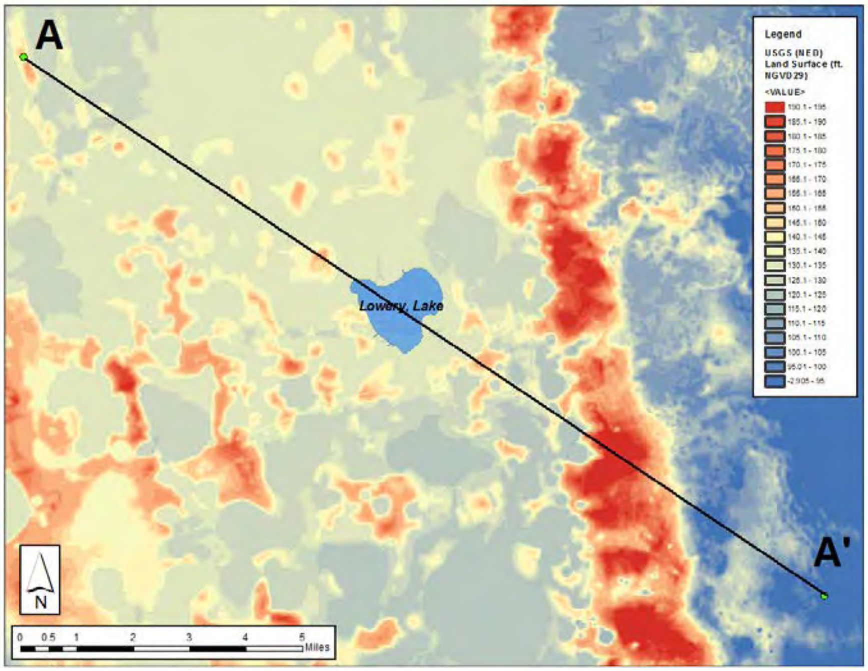

Figure 10. Alignment for geologic cross-section A-A’.

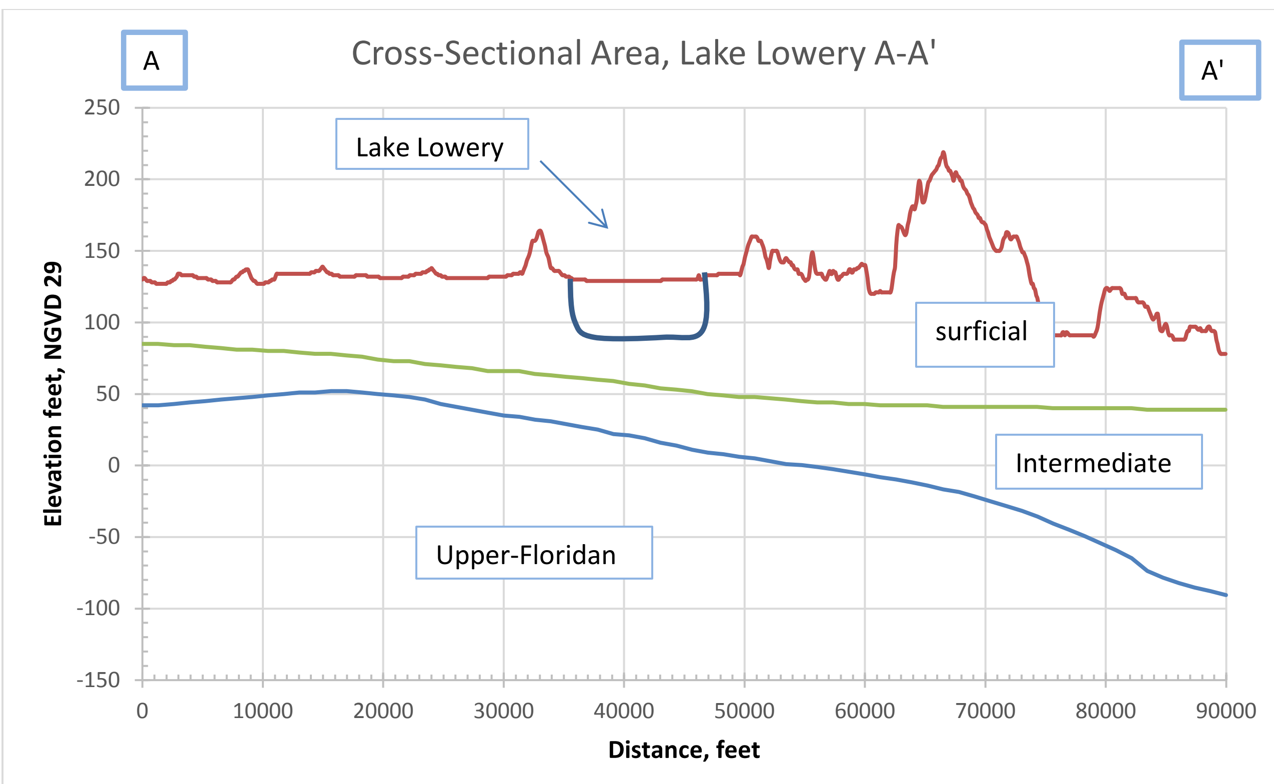

Figure 11. Generalized geologic cross-section through Lake Lowery based off of hydrostratigraphic units mapped by the Florida Geologic Survey (2008).

E. Water Use

Detailed water use near Lake Lowery was obtained from the District's annual estimated water use report. Estimated water use reports are available starting in 1992 and are current through 2012 (SWFWMD 2013). The water use data included in these reports are primarily from the District Water Use Permitting (WUP) database in the Water Management Information System (WMIS). The water quantity data is derived from metered withdrawal points and from estimates applied to unmetered withdrawal points. Population data is based on population numbers given by public supply permittees on the Public Supply Annual Report (PSAR) forms and functional BEBR population data. About 81 percent of the water use in this report is based on directly metered withdrawals. Since the total water use contains an element of estimation, the annual report is referred to as the "Estimated Water Use Report."

Individual withdrawal point locations near Lake Lowery are shown in Figure 12 and graphs depicting total water use within specified radial distances from a central point within the lake are presented in Figures 13 and 14. Water use within the first mile of the central point is close to zero, since a large percentage of this region is occupied by the lake. Water use for the area within two miles of the central point is less than 1 mgd in the beginning and increases to approximately 1.5 to 2.0 mgd. At three miles the water use ranges between 1 to 5 mgd with an average around 3 mgd. At five miles water use ranges from 4 to 18 mgd with an average around 7 mgd. At six miles the water use ranges from 6 to 24 mgd with an average around 12 mgd. From 2003 on water use has increased slightly.

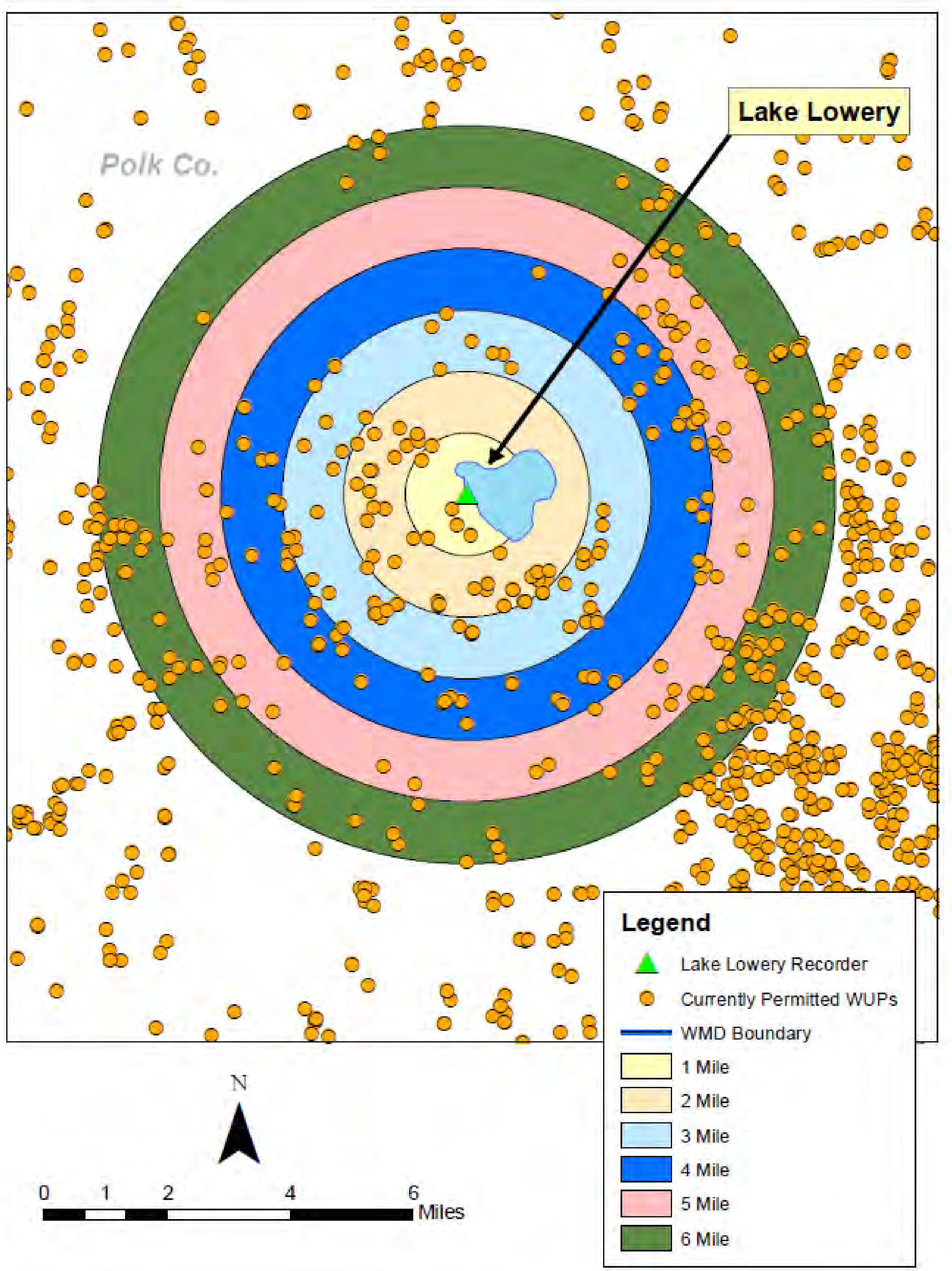

Figure 12. Individual withdrawal point locations near Lake Lowery.

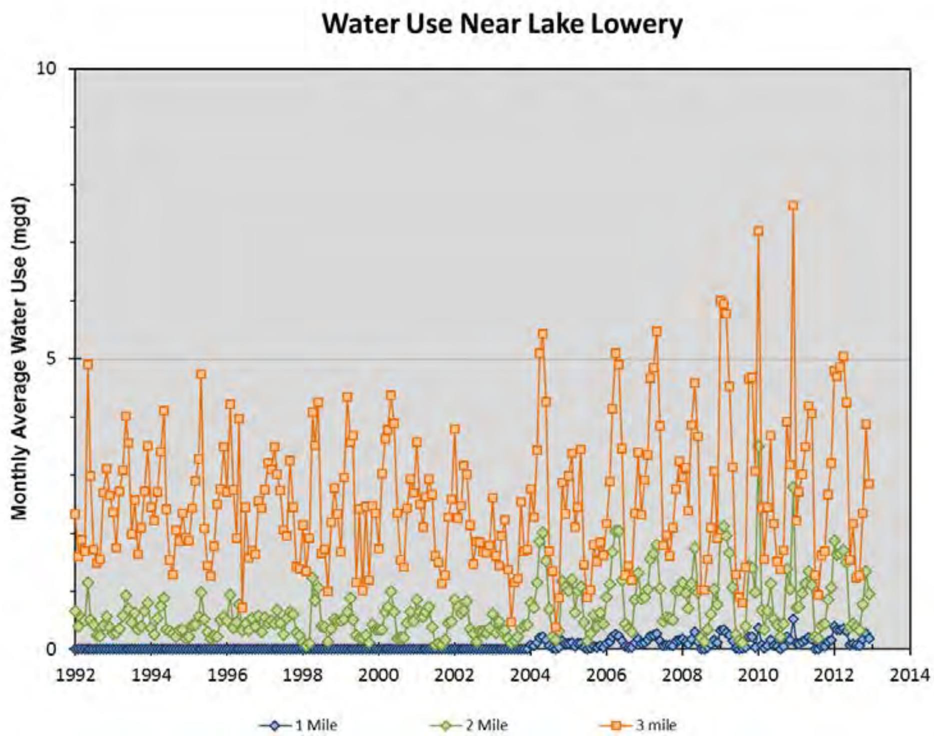

Figure 13. Metered and estimated water use within 1, 2 and 3 miles of Lake Lowery.

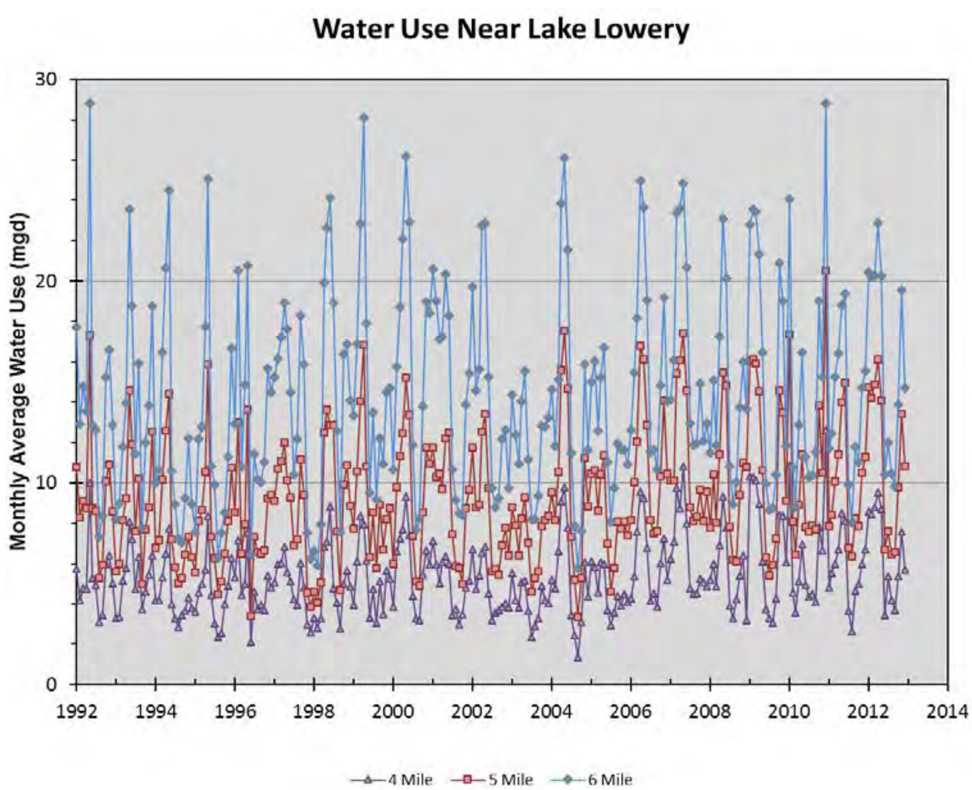

Figure 14. Metered and estimated water use within 4, 5 and 6 miles of Lake Lowery.

F. Evaluation of Groundwater Withdrawal Impacts

Impacts of groundwater withdrawals on the Lake Lowery area were evaluated through review of historic water levels and use of groundwater models. Lake Lowery is located in an area that has experienced moderate decreases in UFA groundwater levels over time. The lake is located at the edge of the Green Swamp potentiometric high near an area where the hydraulic gradient starts to increase to the east. Groundwater flow is generally from the north/northwest to the south/southeast across the lake (Figure 15 and 16). There is a downward head difference between the lake and UFA of approximately 7 to 9 feet indicating there are confining to leaky confining characteristics beneath the lake.

The groundwater models used to assess effects of withdrawals are the East-Central Florida Transient (ECFT) Model (USGS, 2012) and the District-wide Regulatory Model (DWRM). The two models were used because they include slightly different conceptualizations, and it was important to determine whether they would yield similar results. The ECFT model may be described as a quasi-integrated model that is supplied rainfall and irrigation, and calculates surface runoff and recharge to the water table, whereas in the DWRM, net recharge is determined externally and then applied directly to the water table. In order to estimate effects of groundwater withdrawals on the surficial and Upper Floridan aquifers, each model is run with a 50 percent reduction in groundwater withdrawals. This is done to avoid the potential problems that can occur with models when withdrawals are completely removed from the simulation, such as the occurrence of predicted water levels that are above land surface. These types of issues are especially of concern when the model is not calibrated to a “no-pumping” condition. The magnitude of water level recovery in the simulations was interpreted as the drawdown or change in water levels due to pumping a quantity equivalent to the 50 percent reduced pumping quantity. To estimate drawdown or change associated with all pumping, i.e., 100 percent of the current pumping quantities, values predicted for the 50 percent withdrawal reduction scenarios were doubled.

With respect to the UFA, water level changes at the center of the lake predicted for the 50 percent reduction scenarios using the ECFT model is in the 1.8 to 2.4 foot range; an estimated change of 4.4 feet was used in the modeling effort. For the SA, the ECFT model showed water level changes to be on the order of 0.22 feet; an estimated change of 0.44 feet was used in the modeling effort.

DWRM predicted 50 percent reduced pumping quantity drawdowns for the surficial aquifer on the order of 0.5 to 1.0 feet and approximately 2 feet for the Floridan aquifer. The results from the ECFT model are used in the water budget model; the DWMR results are presented for a comparison purpose.

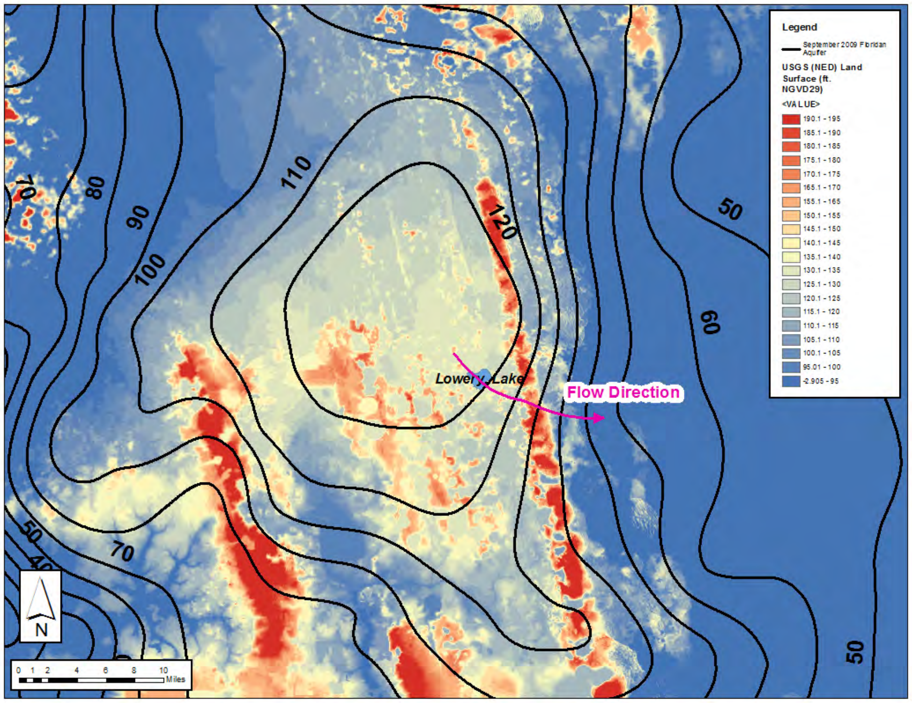

Figure 15. September 2009 potentiometric surface and flow direction through Lake Lowery.

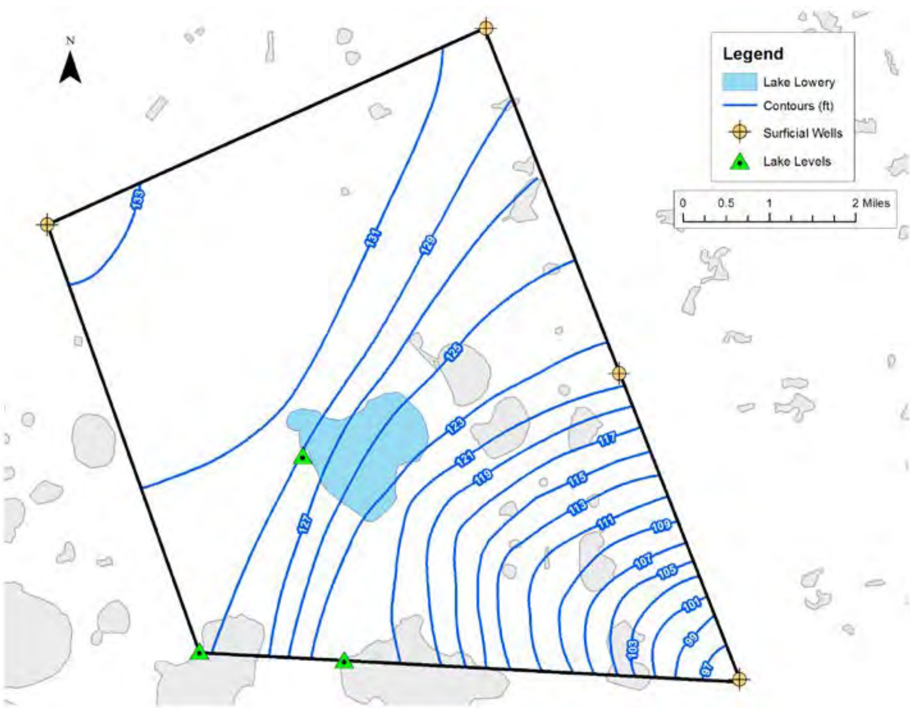

Figure 16. A generalized water table contour map using data from four surficial wells and three lake level staff gauges. Contours indicate the head difference at 2 foot intervals

G. Lake and Well Data.

Water level data collection at Lake Lowery began in June 1960 (Figure 17) and the record consists of two separate gauge locations (site identification numbers 26343 and 17535).   Data collection frequency has varied through time but is close to daily excluding gaps of missing data that occurred. Water level data are currently collected by the District. The values for the period of record maximum and the 10^{th}, 50^{th} and 90^{th} percentiles are listed in Table 1.

Table 1. Lake Lowery Period of Record Percentiles

Lake Lowery Observed Data Statistics (ft. NGVD29)	
Maximum	133.3
P10	130.8
P50	128.7
P90	127.3

The Upper Floridan aquifer monitoring well used in the model was the “Lake Alfred Deep Well Near Lake Alfred”, site identification number (SID) 17652, located 3.6 miles northwest of the lake (Figure 18). It was the only Upper Floridan aquifer well with a nearly continuous record in the area (Figure 19). The surficial aquifer well used to create data for the model is SID 1593179 from SJRWMD data base. This well is located approximately 2,300 feet west of the lake edge (Figure 20) and is the same well as District SID 17709 (Figures 21). Data for SID 1593179 is obtained from the SJRWMD data base.

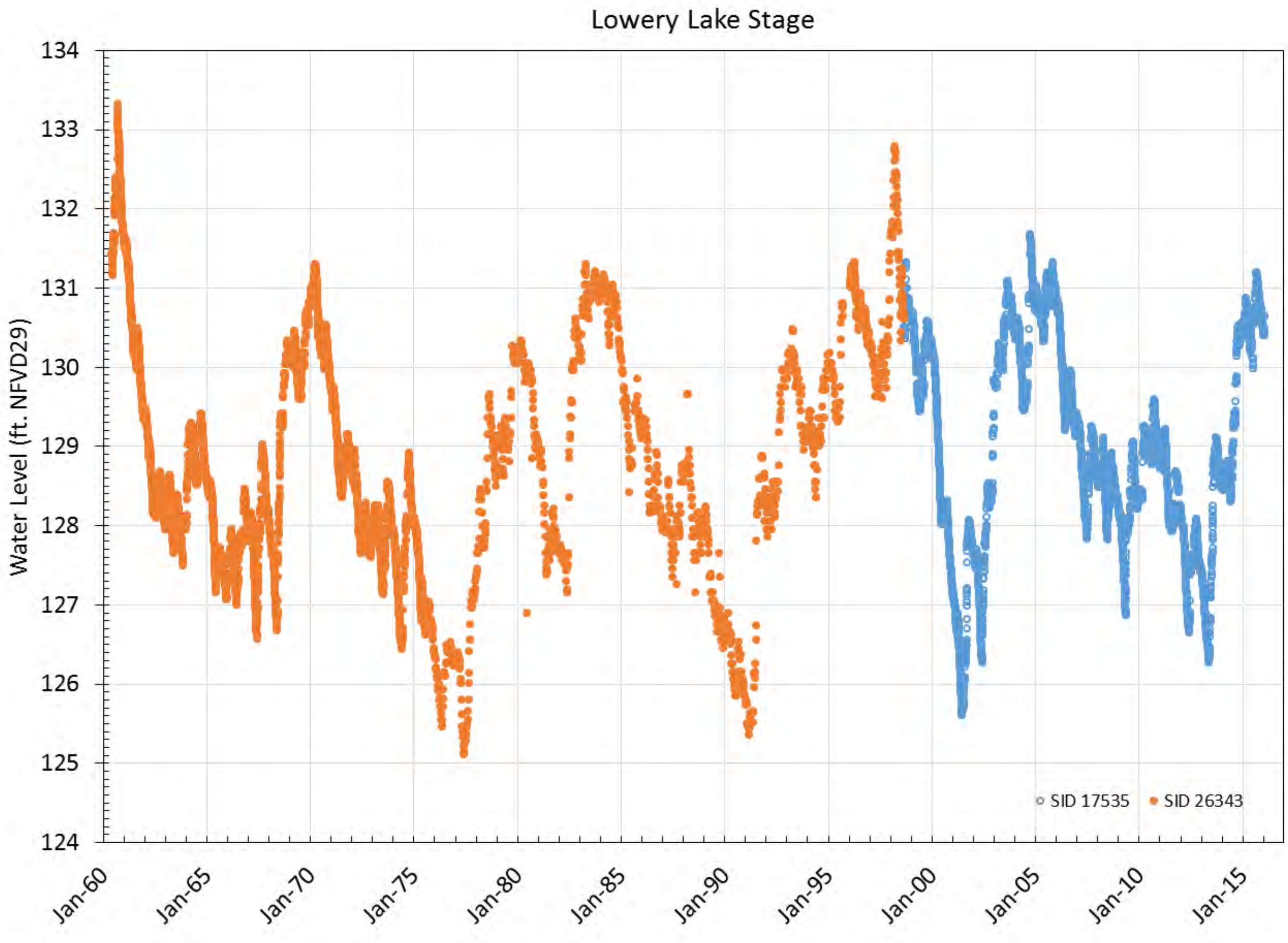

Figure 17. Lake Lowery water levels.

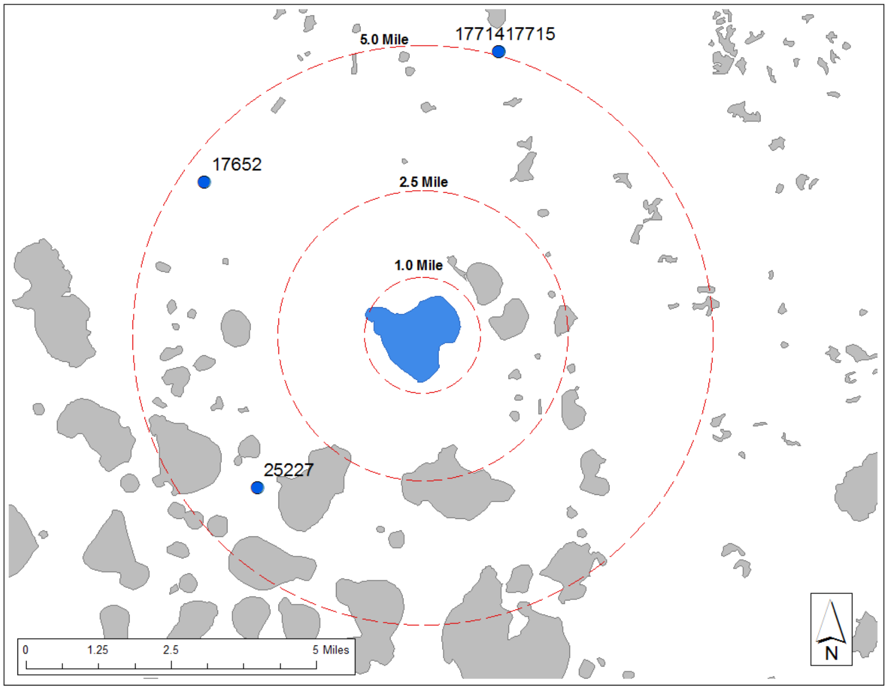

Figure 18. Location of Upper Floridan monitor wells near Lake Lowery.

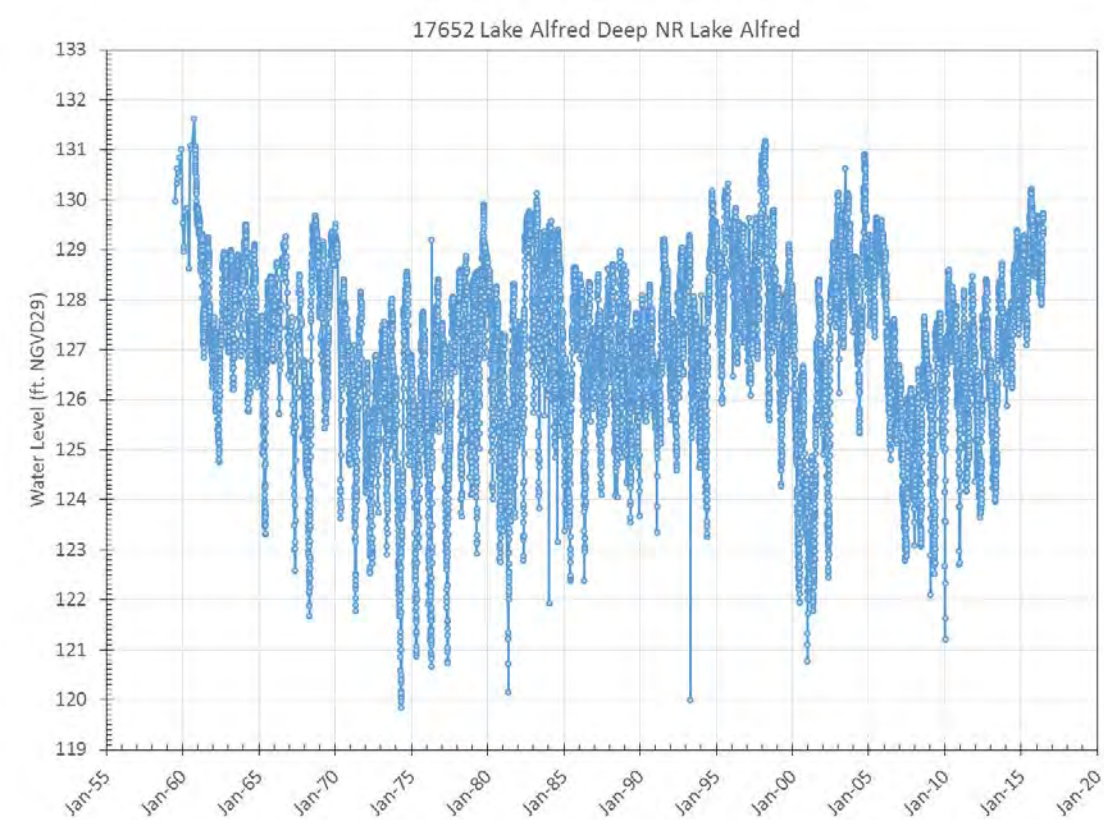

Figure 19. Water levels in the Lake Alfred Deep Upper Floridan aquifer monitor well.

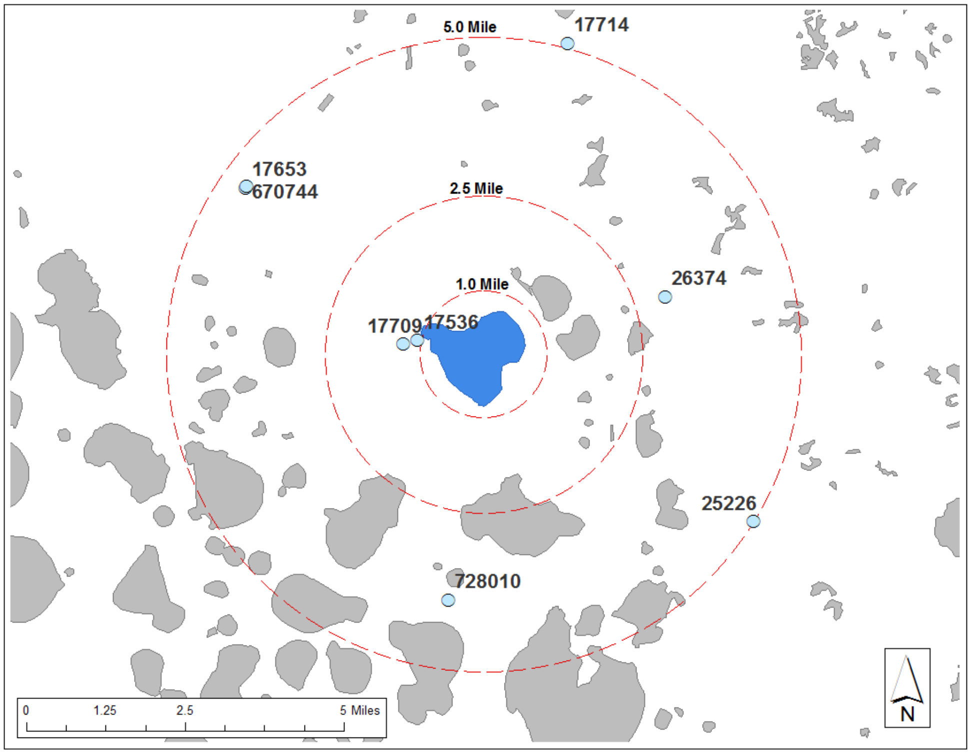

Figure 20. Location of surficial monitor wells near Lake Lowery.

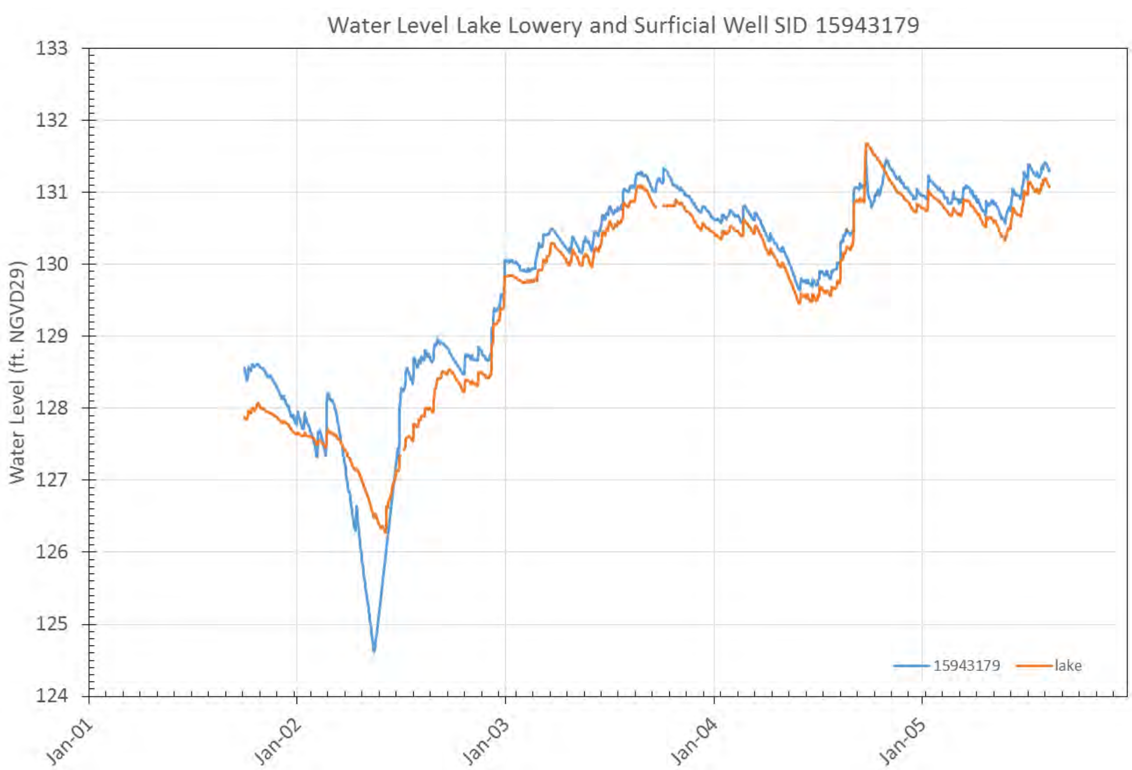

Figure 21. Water levels in Lake Lowery and SJRWMD Surficial Well 15943179 (same as SWFWMD SID 17709)

H. Purpose of Lake Models

Prior to establishment of Minimum Levels, long-term lake stage percentiles are developed to serve as the starting elevations for the determination of the lake's High Minimum Lake Level and the Minimum Lake Level. A critical task in this process is the delineation of a Historic time period. The Historic time period is defined as a period of time when there are little to no groundwater withdrawal impacts on the lake, and the lake's structural condition is similar or the same as present day. The existence of data from a Historic time period is significant, since it provides the opportunity to establish strong predictive relationships between rainfall, groundwater withdrawals, and lake stage fluctuation that represent the lake's natural state in the absence of groundwater withdrawals. This relationship can then be used to calculate long-term Historic lake stage exceedance percentiles such as the P10, P50, and P90, which are, respectively, the water levels expected to have been equaled or exceeded ten, fifty, and ninety percent of the time. If data representative of a Historic time period does not exist, or the 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 Lowery, review of groundwater use and hydrographs suggest that there is a potential for lake levels to be measurably impacted since 1965 (Ellison 2008). Early lake stage data pre-dating 1965 exists but the recent structural changes to the lake have created a new condition bringing into question the early data's representation of a period under similar structural conditions. There have also been substantial physical modifications to the drainage system over the years, with the most recent occurring in 2003. New operation schedules implemented on May 29, 2014 for structures P-5 and P-6 have appear to have resulted in a new condition. As a result, a water budget model (WBM) calibrated to recent structural conditions and recent water use was developed. The WBM was then used to generate data absent water use impacts by adjusting the UFA and surficial aquifer water levels according to drawdown estimates from numerical models. The result is a short period of simulated record without water use impacts but under the current structural conditions. These results were then coupled with a rainfall correlation model to estimate long-term (60 years) Historic percentiles representing current structural conditions without the impacts from water use through a full range of climatic conditions that capture the high rainfall periods of the 1960 and the low rainfall periods that have occurred since then.

I. Water Budget Model Overview

The Lake Lowery WBM 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. 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 may include:

a. Rainfall and evaporation
b. Overland flow
c. Augmentation from the Upper Floridan aquifer (not applicable for Lake Lowery)
d. Inflow via channels (not applicable for Lake Lowery)
e. Discharges via channels
f. Flow from and into the surficial aquifer
g. Flow from and into the Upper Floridan aquifer

The WBM uses a daily time-step, and tracks inputs, outputs, and lake volume to calculate a daily estimate of lake levels for the lake. The period of record for the Lake Lowery WBM started May 29, 2014 and extended through 2015. The starting date was chosen to coincide with the effects of recent changes in the P-5 and P-6 structure operation schedules.

Water Budget Model Components

Lake Stage/Volume

Lake stage area and stage volume estimates were determined by building a terrain model of Lake Lowery. Lake Lowery is isolated so no other lake basins were necessary for the stage volume analysis. Lake bottom and land surface elevations were used to build the model utilizing the software consisting of 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 Lake Lowery basin.

Precipitation

Rain data was compiled from rain gauges within a 10 mile radius, starting with the Lake Lowery gauge (SID 26344) located on the west side of the lake. Missing days of data were infilled using data from the next closest gauge if possible. There were short one to three day periods in the early periods (1935 to 1960) when data was missing from all the gages, these where infilled with zero values. The goal was to use the closest available data to the lake, as long as the data appeared to be high quality (Figure 22).

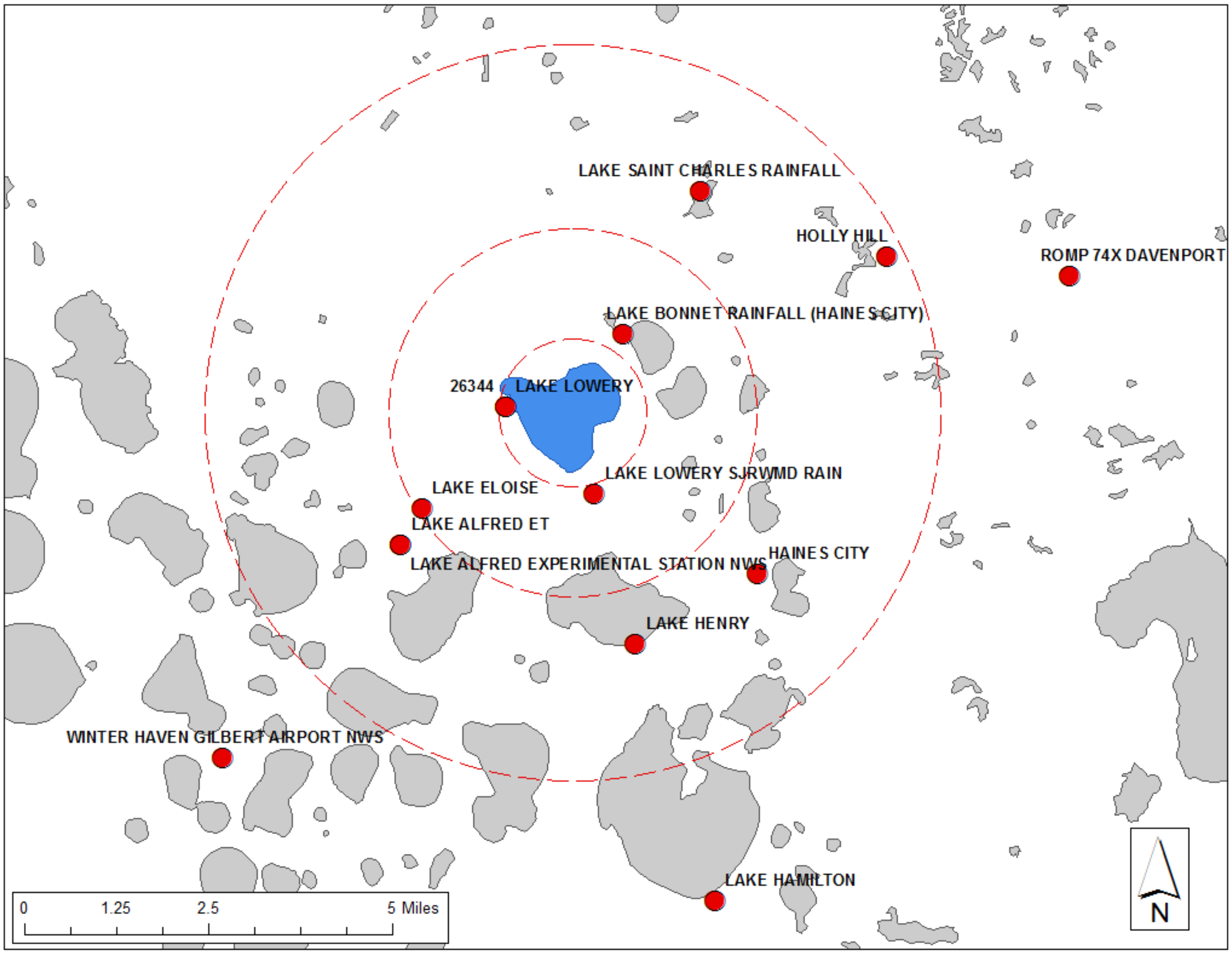

Figure 22. Rain gages used in the Lake Lowery water budget model.

__Lake Evaporation__

The evapotranspiration data was taken from an extensive study by the U.S Geological Survey (USGS) on Lake Starr, 12 miles SE of Lake Lowery (Figure 23). The USGS used the energy-budget method derived by E. R. Anderson 1954 (as cited by Swancar, Lee and O'Hare 2000). The data was collected from August of 1996 through July of 2011. Monthly Lake Starr evaporation data were used in the Lake Lowery water budget model when available, and monthly averages for the period of record were used for those months in the model 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 a website maintained by the USGS, were calculated through the 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 GOES data would increase model error more than using the Lake Starr data directly.

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 each 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 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 takes into account the amount of DCIA in the watershed that has been handled separately. Lake Lowery has an immediate watershed (approximately 3,410 acres) from which it receives direct overland flow (Figure 24).

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

The DCIA percent area and SCS curve number used for direct overland flow portion of the watershed are listed in Table 1. The soils in the area of the lake are A/D, B/D or D soils (Figure 24). The B/D and A/D soil type means that the characteristics of the soils are highly dependent on how well they are drained. For purposes of this model, taking into account the range of conditions experienced, a compromise was used for the CN. Additionally, approximately seven percent of the watershed is urban and built up (Figure 25) which drains directly to excavated canals, so the DCIA of the watershed was set to 0.07.

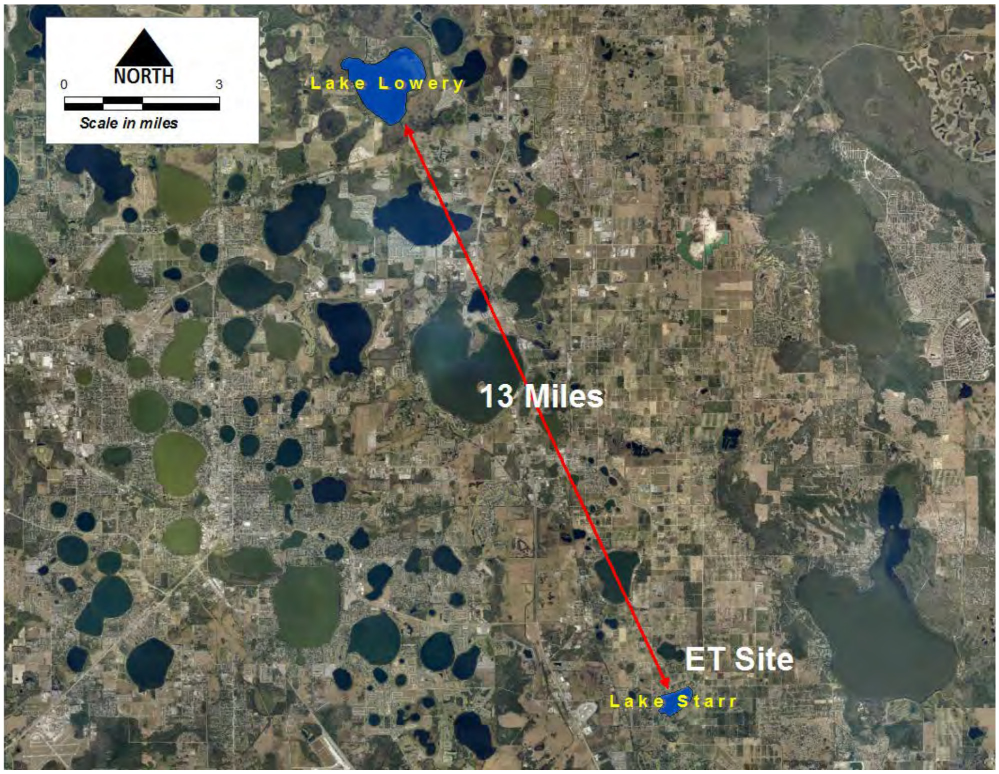

Figure 23. Location of Lake Starr ET site.

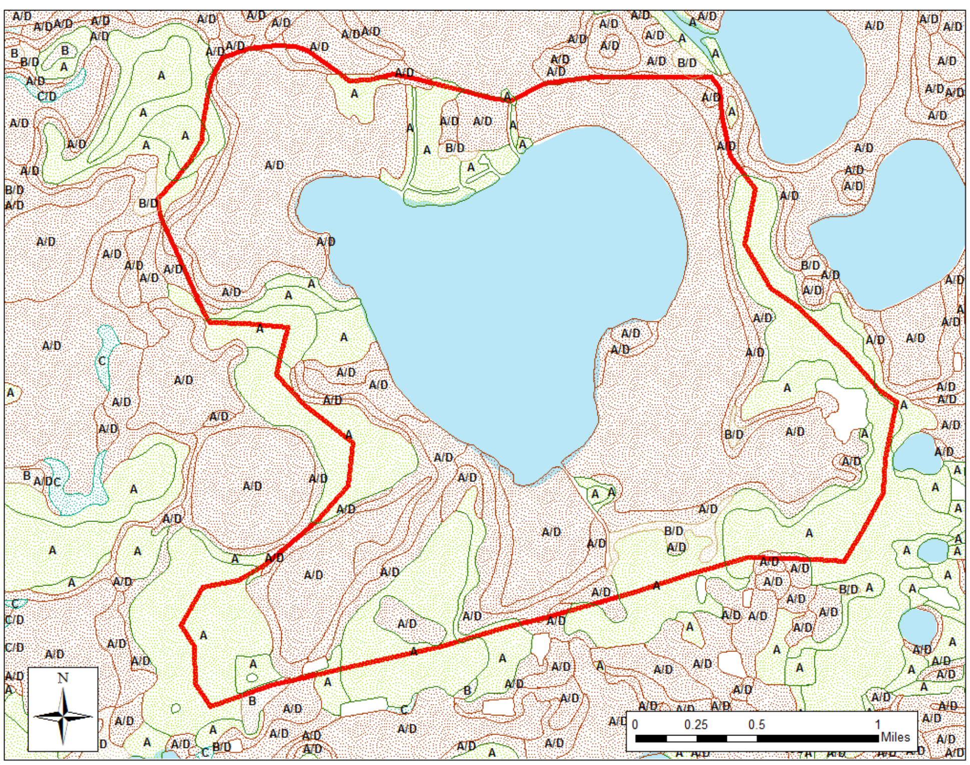

Figure 24. Direct overland flow portion and soil types.

Table 1. Model Inputs for the Lake Lowery model.

Input Variable	Value
Overland Flow Watershed Size (acres)	3410
SCS Curve Number of Watershed	75
Percent Directly Connected (DCIA)	7%
Floridan Well Site Identification No.	17652
Fl. Aq. Leakance Coefficient (ft/day/ft)	0.0002
Surf. Aq. Leakance Coefficient (ft/day/ft)	0.0013
Control Point 1 Elevation (ft, NGVD 29)	131.5
Control Point 1 Outflow K	0.1
Control Point 2 Invert (ft. NGVD 29)	131.0
Control Point 2 Outflow K	0.05
Control Point 3 Invert (ft, NGVD 29)	127.6
Control Point 3 Outflow K	0.00012

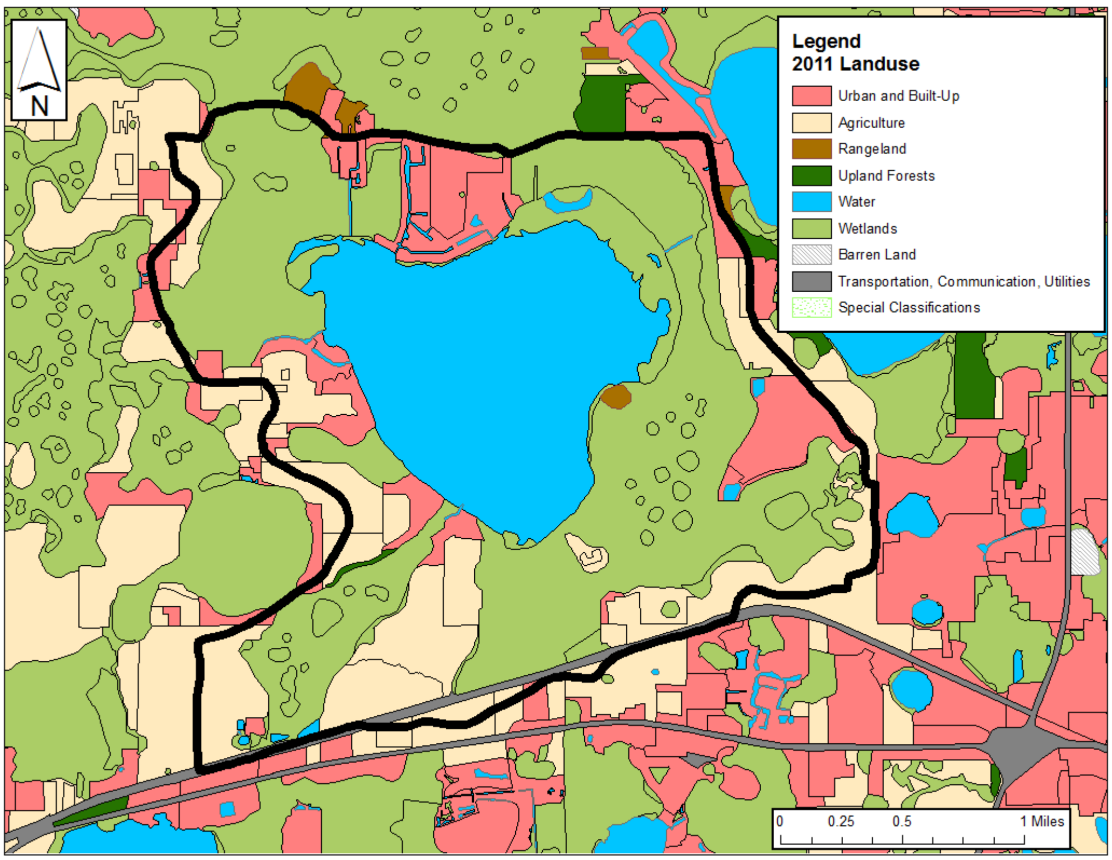

Figure 25. 2011 Landuse map.

Flow from and into the surficial aquifer

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

The nearest Upper Floridan aquifer monitor well with good data frequency is the Lake Alfred Floridan well (SID 17652) and was used to represent the potentiometric surface beneath the lake. The Lake Alfred well is located approximately 3.5 miles north of the lake. Potentiometric maps were used to estimate the Upper Floridan aquifer level beneath the lake, and based on the difference between the Lake Alfred well and the potentiometric surface, the well was adjusted by subtracting 7.0 ft. from the well water level record. Two surficial monitoring wells are located approximately 2,000 feet west of the lake. The period of record starts in 2001 and ends in 2006. To extend the record through 2015 an average difference of 0.5 ft. between the lake and well was added back to the lake record. Any missing daily water level values were in-filled using the previously recorded value.

C. Water Budget Model Components

The primary reason for the development of the water budget model is to estimate the 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 a period representative of current structural conditions.

Measured data from the lake were used for comparison with modeled water levels. Daily values are generated from the model, but only measured lake data points are used for the calibration.

Figure 26 presents the calibration results of the model. Table 2 presents a comparison of the percentiles of the measured data versus the model results. Table 3 presents the modeled water budget components for the model calibration.

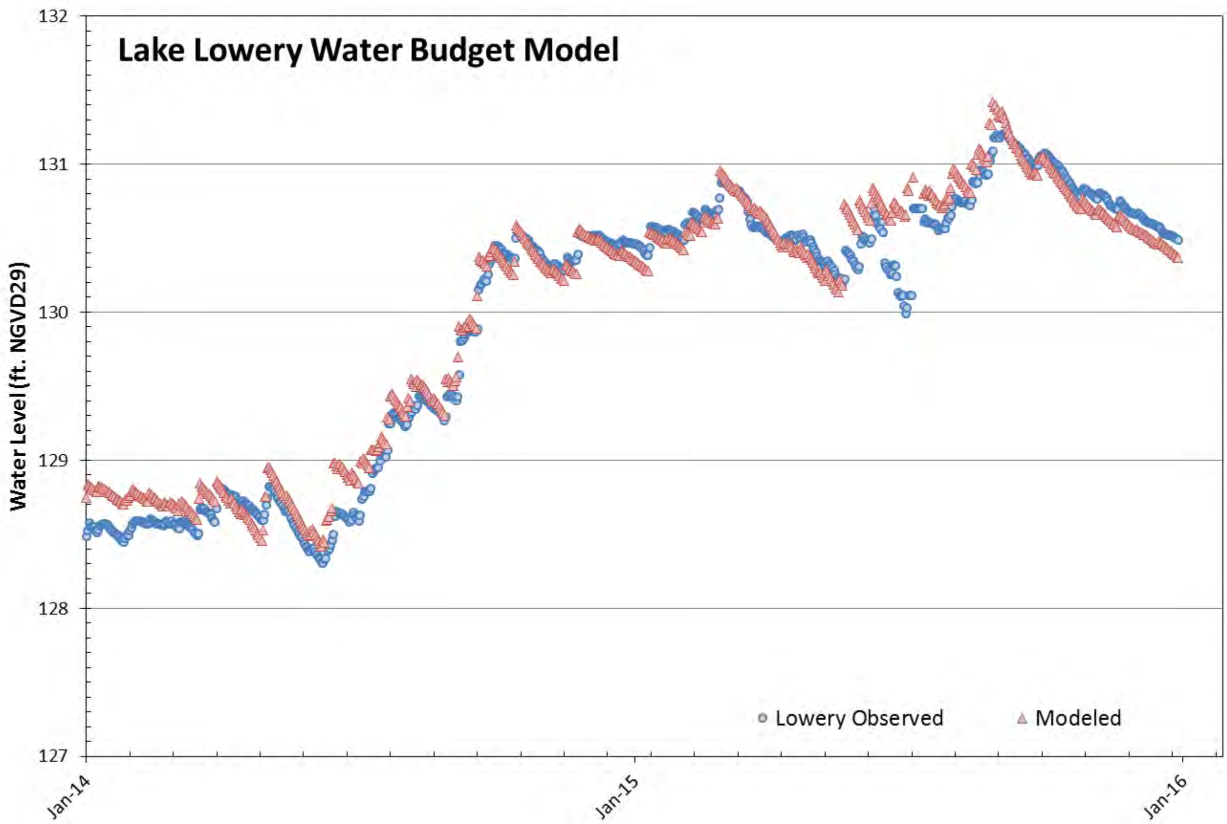

Figure 26. Modeled water levels predicted for the calibrated Lake Lowery water budget model (Model) and measured levels used for the model calibration (Data).

D. Water Budget Model Calibration Discussion

Based on a visual inspection of Figure 26, the model appears to be reasonably well calibrated. A review of Table 2 shows that the P10 and the P50 match the observed data percentiles. The model P90 within 0.1 feet of the observed data.

Table 2. Comparison of percentiles of measured lake level data compared to calibration percentiles from the model (all in feet NGVD29).

Percentile	Data	Model
P10	130.9	130.9
P50	130.5	130.5
P90	129.2	129.3

Table 3. Lake Lowery Water Budget (2014 through 2015).

Inflow	Rainfall	Surficial Aquifer Groundwater Inflow	Upper Floridan aquifer Groundwater Inflow	Runoff	DCIA Runoff	Channel Inflow	Total
In/year	59.62	2.32	0	16.41	8.08	0	86.43
%	68.98	2.69	0	18.98	9.35	0	100
Outflow	**Evap.**	**Surficial aquifer Outflow**	**Upper Floridan aquifer Groundwater Outflow**			**Channel Outflow**	**Total**
In/year	59.92	0.01	7.63			3.48	71.41
%	83.92	0.02	10.69			3.36	100

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

E. Water Budget Model Results

Groundwater withdrawals are not directly included in the Lake Lowery water budget model, but are indirectly represented by their effects on water levels in the Upper Floridan aquifer.

To estimate lake levels without the influence of groundwater withdrawals, the Upper Floridan aquifer and surficial aquifer wells in the water budget model were adjusted to represent zero withdrawals. For the May 29, 2014 through 2015 water budget model period, the adjustments made to each Upper Floridan aquifer and surficial aquifer well are found in Table 4.

Table 4. Aquifer water level adjustments to remove drawdown effects.

Well	Adjustment (feet) 2014 to 2016
Upper Floridan aquifer	4.2
Surficial aquifer	0.44

Figure 27 presents measured water level data for the lake along with the model-simulated lake levels in the lake absent groundwater withdrawals but with structural alterations similar to current conditions. Table 5 presents the resulting percentiles based on the model output.

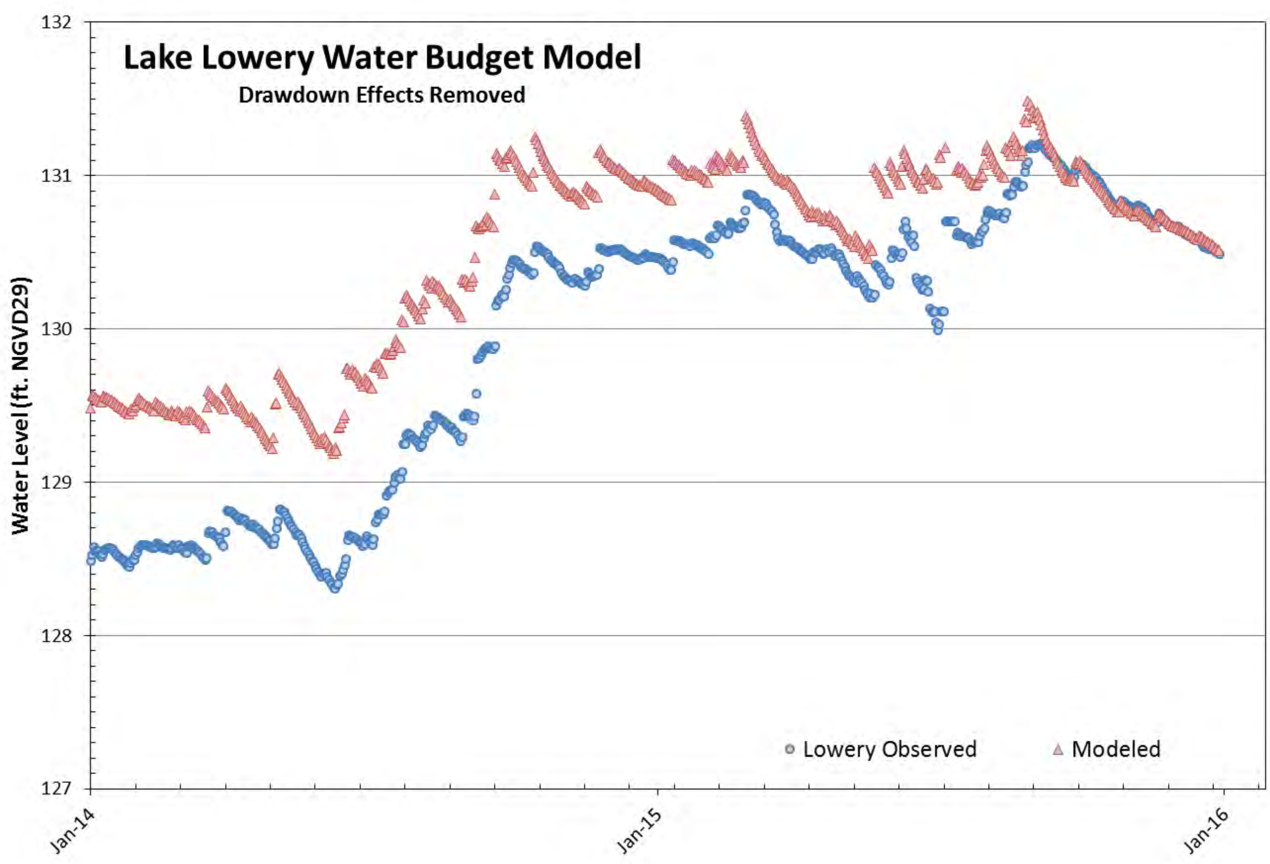

Figure 27. Measured lake levels (Data) and Historic water levels predicted with the calibrated Lake Lowery model (Model).

Table 5. Percentiles estimated using the Lake Lowery water budget model with drawdown effects removed (ft. NGVD29).

Percentile	Elevation
P10	131.1
P50	130.9
P90	130.1

I. Rainfall Correlation Model

In an effort to extend the period of record of the 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. 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, 1997). LOC is preferable for this application since it produces a result that best retains the variance (and therefore best retains the "character") of the original data.

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

Rainfall was correlated to the water budget model results for the entire period used in the water budget model (May 29, 2014 to 2016), and the results from 1946 through 2015 (70 years) were produced. For Lake Lowery, the 3-year weighted model had the highest correlation coefficient, with an R^2 of 0.75. The results are presented in Figure 28.

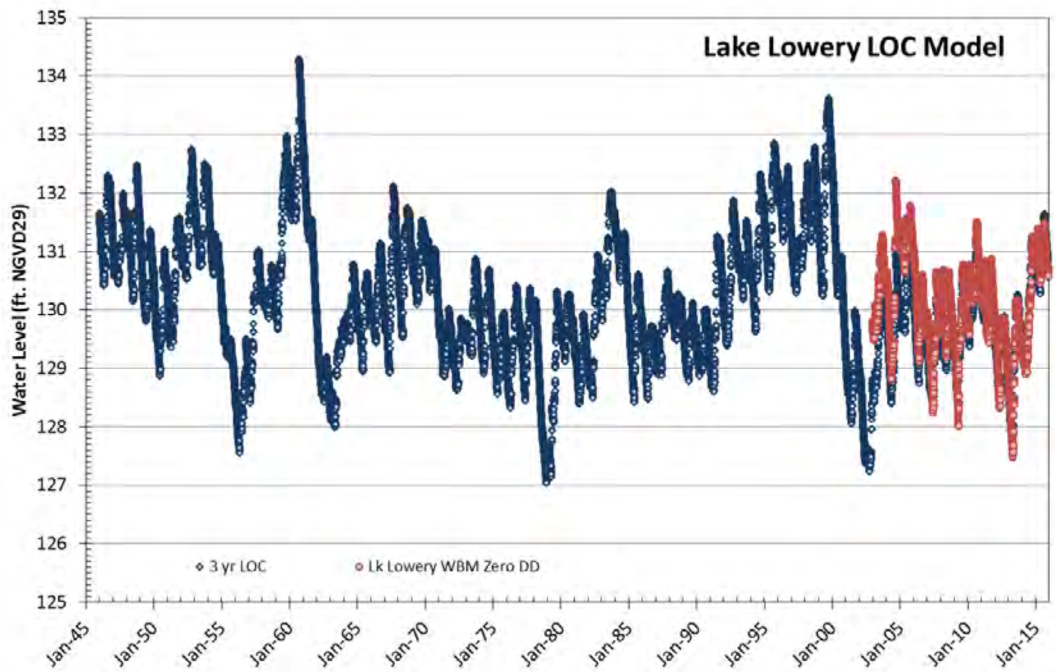

Figure 28. LOC model results for Lake Lowery.

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 to 2014, while the water budget results are used for the period of May 29, 2014 through 2015. 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 by the hybrid model from 1946 through 2015 (ft. NGVD29).

Percentile	Lake Lowery
P10	131.7
P50	129.9
P90	128.4

J. Conclusions

Based on the model results and the available data, the Lake Lowery 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.

K. References

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APPENDIX B

Technical Memorandum

September 19, 2016

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

FROM: Donald L. Ellison, P.G., Senior Hydrogeologist, Water Resources Bureau
David Carr, Staff Environmental Scientist, Water Resources Bureau

Subject: Lake Lowery Initial Minimum Levels Status Assessment

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A. Introduction

The Southwest Florida Water Management District (District) adopting minimum levels for Lake Lowery in accordance with Section 373.042 and 373.0421, Florida Statutes (F.S). Documentation regarding development of the revised minimum levels is provided by Ellison and others (2016) and Carr and others (2016).

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

B. Background

Lake Lowery is located in north-central Polk County, northwest of Haines City, approximately half a mile north of U.S. Highway 17 and a third of a mile west of U.S. Highway 27 (Figure 1). The lake is situated in the southernmost part of the Ocklawaha Basin on the border of the Peace River Basin (Figure 2). There are no channel inflows from other lakes to Lake Lowery, while discharge occurs via three outlets from the lake (Figure 3).

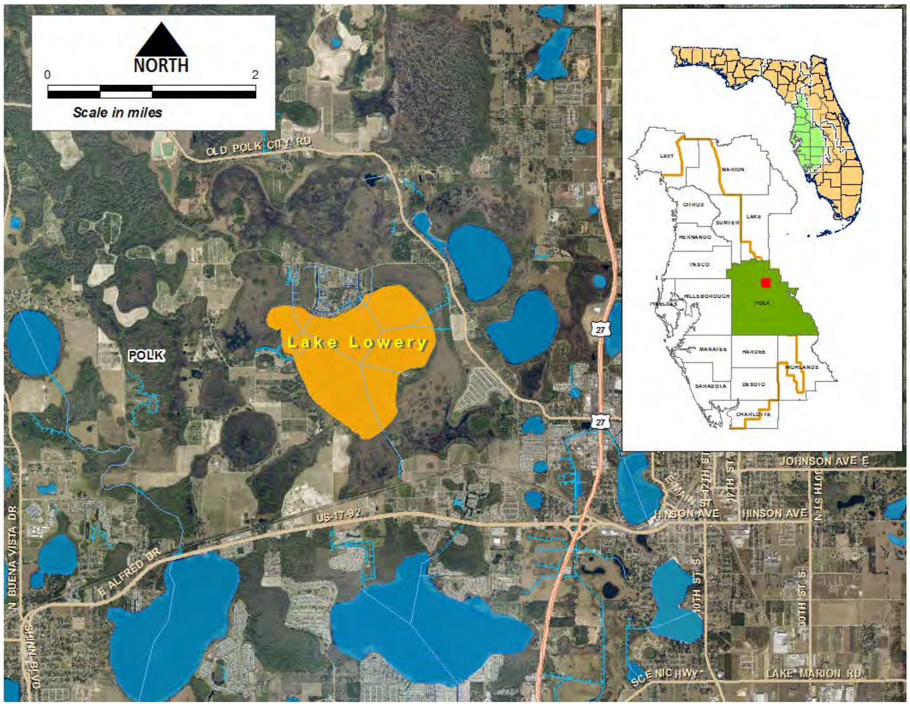

Figure 1. Location of Lake Lowery in Polk County, Florida.

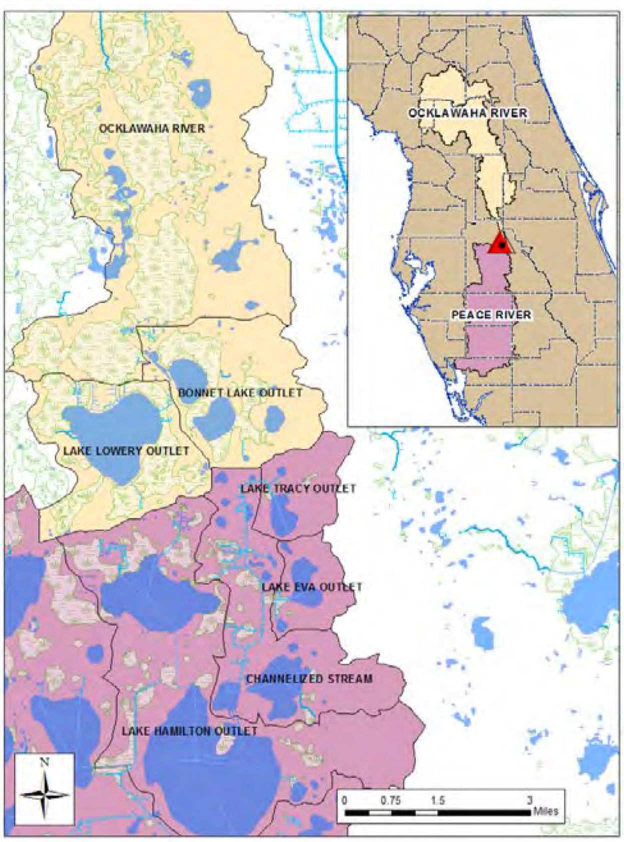

Figure 2. Drainage Basins Lake Lowery contributes to.

Figure 3. Outlets from Lake Lowery.

Individual withdrawal point locations near Lake Lowery are shown in Figure 4 and graphs depicting total water use within specified radial distances from a central point within the lake are presented in Figures 5 and 6. Water use within the first mile of the central point is close to zero, since a large percentage of this region is occupied by the lake. Water use for the area within two miles of the central point is less than 1 mgd in the beginning and increases to approximately 1.5 to 2.0 mgd. At three miles the water use ranges between 1 to 5 mgd with an average around 3 mgd. At five miles water use ranges from 4 to 18 mgd with an average around 7 mgd. At six miles the water use ranges from 6 to 24 mgd with an average around 12 mgd. From 2003 on water use has increased slightly.

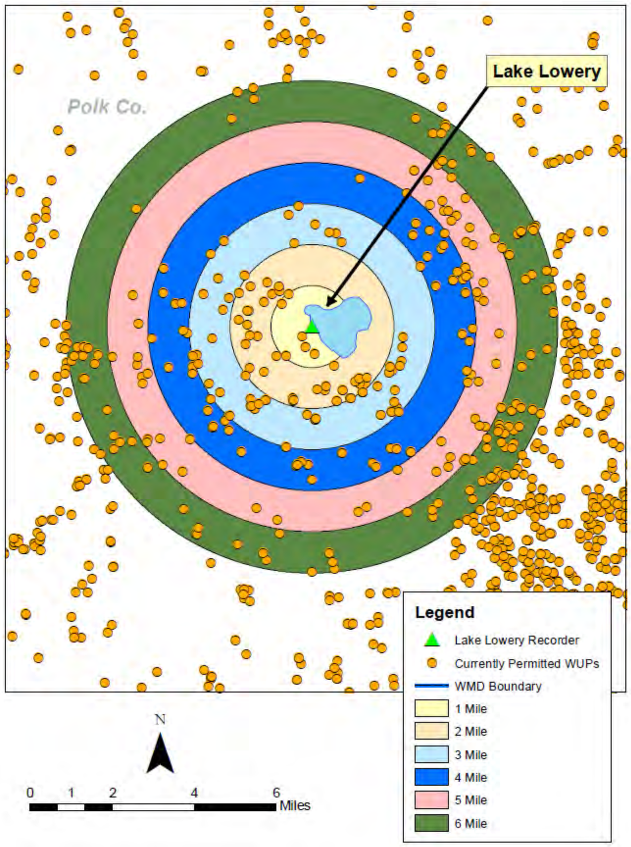

Figure 4. Individual withdrawal point locations near Lake Lowery.

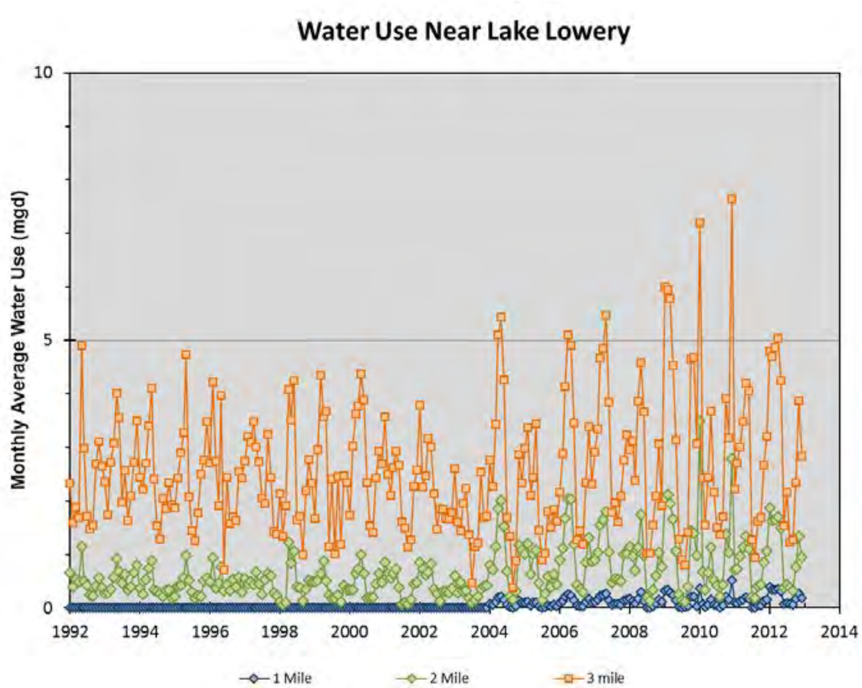

Figure 5. Metered and estimated water use within 1, 2 and 3 miles of Lake Lowery.

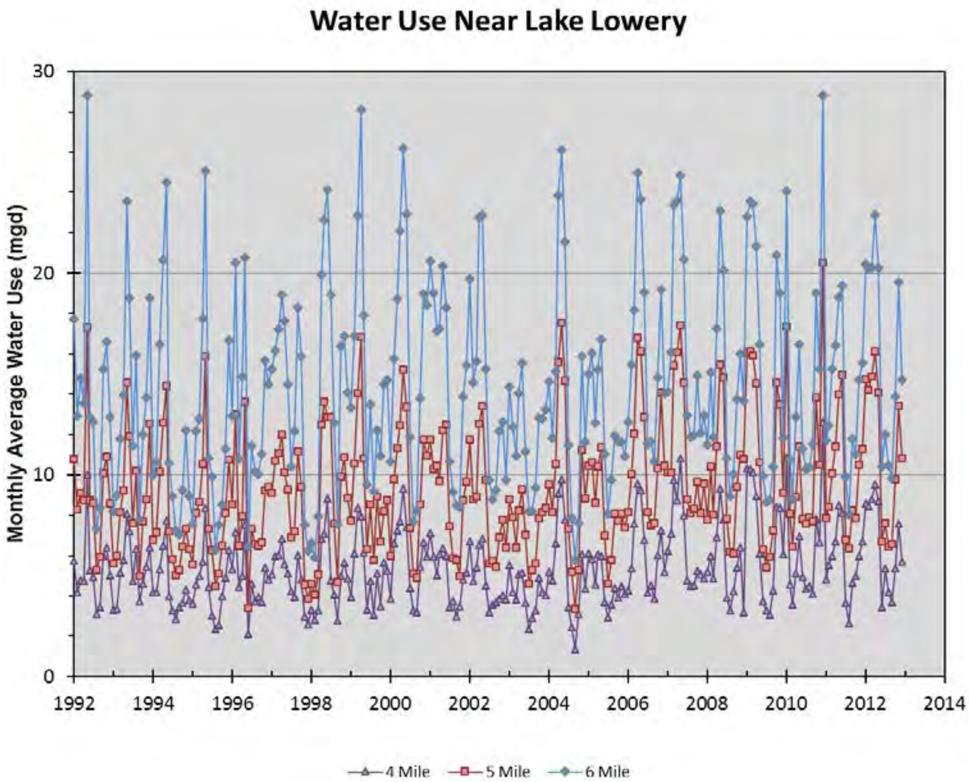

Figure 6. Metered and estimated water use within 4, 5 and 6 miles of Lake Lowery.

C. Revised Minimum Levels Proposed for Lake Lowery

Minimum levels proposed for Lake Lowery are presented in Table 1 and discussed in more detail by Hurst and others (2016). 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. Consideration can also be given to impacts on buildings and other structures in the basin. 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. “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 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 10th percentile (P10) of long-term water levels. To determine the status of minimum levels for Lake Lowery or minimum flows and levels for any other water body, long-term data or model results are used.

Table 1. Proposed Minimum Levels for Lake Lowery.

Proposed Minimum Levels	**Elevation in Feet** NGVD 29
High Minimum Lake Level	129.7
Minimum Lake Level	127.9

D. Status Assessment

The lake status assessment approach involves using actual lake stage data for Lake Lowery from a period representing “Current” structural conditions and hydrologic stresses (including groundwater withdrawals). Recent changes in the operation schedule for drainage control structures in the area of Lake Lowery have resulted in new hydrologic conditions that affect Lake lowery water levels and the Current period is defined as a period that coincides with this change that started on May 29, 2014 and extends to present time (Ellison and Others, 2016).

To create a data set that can reasonably be considered to be “Long-term”, a regression analysis using the line of organic correlation (LOC) method 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 Lowery (Ellison and Others, 2016). 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 Lowery was used for the status assessment (Ellison and Others, 2016). The best resulting correlation for the LOC model created with measured data (May 29, 2014 through 2016) was the 3-year weighted period, with a coefficient of determination of 0.75. The resulting lake stage exceedance percentiles are presented in Table 2.

As an additional piece of information, Table 2 also presents the percentiles calculated directly from the measured lake level data for Lake Lowery for the period from 2005 through 2015. A limitation of these values is that the resulting lake stage exceedance percentiles are representative of rainfall conditions during only the past 19 months, rather than the longer-term rainfall conditions represented in the 1946 through 2015 LOC model simulation.

Table 2. Comparison of lake stage exceedance percentiles derived from the lake stage/LOC results, exceedance percentiles of the May 29, 2014 through 2015 data, and the revised minimum levels proposed for Lake Lowery.

Percentile	**Long Term LOC Model Results 1946 through 2015** Elevation in feet NGVD 29*	**Measured Lake Levels for Current Period (May 29, 2014 through 2015)** Elevation in feet NGVD 29	**Proposed Minimum Levels** Elevation in feet NGVD 29
P10	132.0	130.9	129.7
P50	129.6	130.5	127.9

* LOC model based on Current Period and extended using rainfall for 1946 to 2015

A comparison of the LOC model with the revised minimum levels proposed for Lake Lowery indicates that the Long-term P10 is 2.3 feet above the proposed High Minimum Lake Level, and the Long-term P50 is 1.7 feet above the proposed Minimum Lake Level. The P10 elevation derived directly from the Current period measured lake data is 1.2 feet higher than the proposed High Minimum Lake Level, and the P50 elevation is 2.6 feet higher than the proposed Minimum Lake Level. Differences in rainfall between the shorter Current period and the longer 1946 to 2015 period used for the LOC modeling analyses likely contribute to the differences between derived and measured lake stage exceedance percentiles.

Conclusions

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

Minimum flow and level status assessments are completed on an annual basis by the District and on a five-year basis as part of the regional water supply planning process.

References

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