Revised Minimum and Guidance Levels for Eagle Lake, in Polk County, Florida

May 18, 2017

Resource Evaluation Section Water Resources Bureau

Southwest Florida Water Management District

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Table of Contents

Introduction

Reevaluation of Minimum Flows and Levels

This report describes the development of revised minimum and guidance levels for Eagle Lake in Polk County, Florida. These revised levels (Table 1) were developed using peer-reviewed methods for establishing lake levels within the Southwest Florida Water Management District (District) and are protective of all relevant environmental values identified for consideration in the Water Resource Implementation Rule when establishing minimum flows and levels (see Rule 62-40.473, Florida Administrative Code [F.A.C.]). Following a public input process, the minimum and guidance levels were approved by the District Governing Board on October 27, 2015 adopted into rule on January 24, 2017 and became effective on February 12, 2017. Rulemaking for these levels also included removal of previously adopted guidance levels for the lake from District rules.

Table 1. Revised Minimum and Guidance Levels for Eagle Lake

Minimum and Guidance Levels	Elevation in Feet NGVD29
High Guidance Level	131.6
High Minimum Lake Level	131.2
Minimum Lake Level	129.1
Low Guidance Level	127.9

Eagle Lake was selected for reevaluation based on development of modeling tools used to simulate natural water level fluctuations in lake basins that were not available when the previously adopted minimum levels for the lake were developed. Adopted levels for Eagle Lake were also reevaluated 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 revised 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 revised minimum level report; additional information on all tasks associated with the District's MFLs Program.

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), Hancock (2006), Hoyer *et al*. (2006), Leeper (2006), Hancock (2006, 2007) and Emery *et al.* (2009). Independent scientific peer-review findings regarding the lake level methods are summarized by Bedient *et al.* (1999), Dierberg and Wagner (2001) and Wagner and Dierberg (2006).

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

Categorical significant change standards and other available information are developed to identify criteria that are sensitive to long-term changes in hydrology and can be used for establishing minimum levels. For all lake categories, the most sensitive, appropriate criterion or criteria are used to develop 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 2). The specific standards and other information evaluated to support development of revised minimum levels for Eagle Lake 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 2. 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	Lake Mixing Standard, Cypress Standard, Herbaceous Wetland Information, Submersed Aquatic Macrophyte Information
Water quality	Cypress Standard, Wetland Offset, Lake Mixing Standard, Dock-Use Standard, Herbaceous Wetland Information, Submersed Aquatic Macrophyte Information
Navigation	Basin Connectivity Standard, Submersed Aquatic Macrophyte Information

NA[1] = Not applicable for consideration for most priority lakes;

NA[2] = Environmental value is addressed generally by development of minimum levels base on appropriate significant change standards and other information and use of minimum levels in District permitting programs

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 revised levels, the levels are adopted by the District Governing Board into Chapter 40D-8, F.A.C. Code (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.

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

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

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

The District is in the process of converting from use of the NGVD29 datum to use of the North American Vertical Datum of 1988 (NAVD 88). 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. All elevation values presented in this report are reported in the NGVD29 datum.

Lake Classification

Lakes are classified as Category 1, 2 or 3 for Minimum Levels development based on the presence or absence of fringing cypress wetlands greater than 0.5 acres in size. Eagle Lake does not have fringing cypress wetlands of any size and are therefore classified as a Category 3 Lake. The significant change standards for Category 3 lakes include a Lake Mixing Standard, a Dock-Use Standard, a Basin Connectivity Standard, a Species Richness Standard, an Herbaceous Wetland Standard, a Submerged Aquatic Macrophyte Standard, an Aesthetics Standard, and a Recreation/Ski Standard.

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

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

The 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 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.

Herbaceous Wetland Information is 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 or less feet). 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.

The Recreation/Ski Standard is developed to identify the lowest elevation within the lake basin that will contain an area suitable for safe water skiing. The standard is based on the lowest elevation (the Ski Elevation) within the basin that can contain a 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 Aesthetics Standard is developed to protect aesthetic values associated with the inundation of lake basins. The standard is intended to protect aesthetic values associated with the median lake stage from diminishing beyond the values associated with the lake when it is staged at the Low Guidance Level. The 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.

Lake Setting and Description

Location

Eagle Lake is in the Peace River Basin in Polk County, Florida (latitude 27 59 12, longitude 81 46 00) (Figure 1). The lake resides within the city of Eagle Lake about 10 miles southeast of Lakeland Florida. Eagle Lake is part of the census-designated Lakeland-Winter Haven Metropolitan area with a 2014 U.S. census estimated population of 634,638.

Physiology and Hydrology

Land form physiology or morphology of the nature or structure of the underlying geology in the region is primarily upland sand and deeper karst limestone. The area surrounding the lake is categorized as the Winter Haven Karst Region in the Central Lake Physiographic District (Brooks 1981); described as a region of sandhills with large circular lakes. As part of the Florida Department of Environmental Protection's Lake Bioassessment/Regionalization Initiative, the area has been identified as the Winter Haven region and described as an upland karst area of numerous alkaline, moderately hardwater eutrophic lakes with relatively high mineral content (Griffith *et al.* 1997).

The hydrogeology of the region includes three distinct aquifer systems: a surficial aquifer, an intermediate confining unit or intermediate aquifer system (IAS), and an Upper (UFAS) and Lower Floridan aquifer system (LFAS) (Spechler and Kroening, 2007 USGS). The surficial aquifer consists of sandy soils, is an unconfined layer generally tens of feet or less thick, and is rainfall driven. Water levels vary seasonally 1ft. – 5ft. within the surficial aquifer and regional horizontal conductivity ranges from 0.3 to 55 ft. per day (SWFWMD, 2000). The IAS has similar thickness and is part of the Hawthorn Group Stratigraphic Unit with a mosaic of sand, silt, clay, limestone and dolomite (O'Reilly et al., 2002). The IAS functions as an aquitard constraining movement of rainfall supplied groundwater in the surficial aquifer to the FAS (Scott, 2001). The UFAS consists of Ocala Limestone, and the Avon Park Formation (dolomite and dolomitic limestone); both characterized by cavernous porosity and solution cavities. The LFAS consists of the Avon Park, Oldsmar, and Cedar Keys Formations (limestone and dolomite), and characterized by abundant fractures. Public water supply withdrawals water from the LFAS.

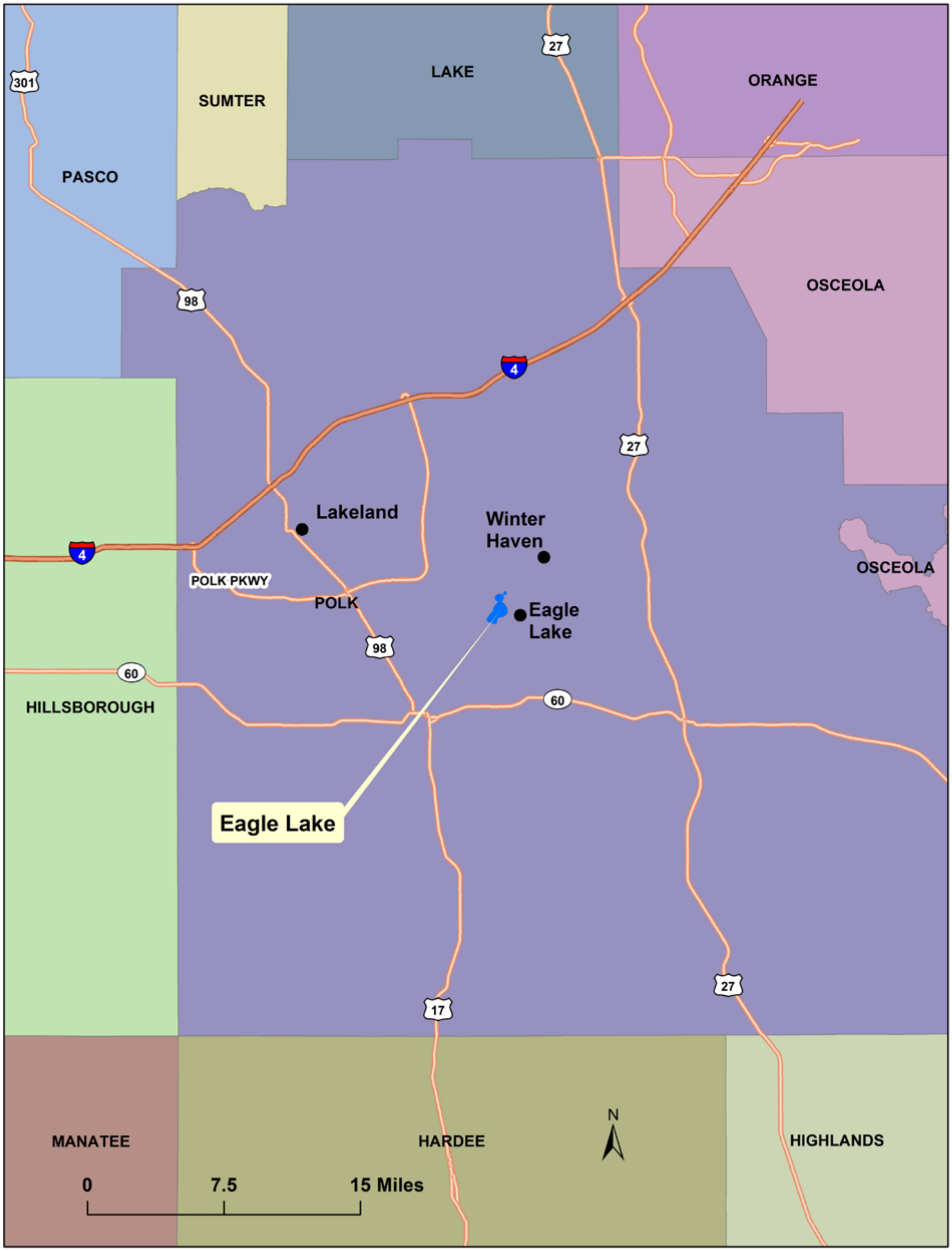


Figure 1. Eagle Lake Location Map.

Bathymetry and Basin/Watershed Description and History

One-foot interval bathymetric data gathered from recent field surveys resulted in lake-bottom contour lines (Figure 2). At the ten-year flood guidance levels established in 1988 and 2007 (131 feet, Tables 3 and 4), the lake surface area is 682 acres based on recent stage volume data calculated in support of minimum levels development. These data revealed that the lowest lake bottom contour (98 ft.) in the center of the lake is the deepest area at as much as 33 ft. deep. Additional morphometric or bathymetric information for the lake basin is discussed in the Methods, Results and Discussion section of this report and is also available in Florida Lakewatch (2001). There are no surface inflows to the lake, other than that from a few stormwater systems scattered throughout the basin. The lake outlet, which connects the lake to Millsite Lake to the south (Figure 3), is configured with a box culvert under Crystal Beach Road (Figure 4). The structure is slotted for use of stop logs, but none are currently in use.

Table 3. 1988 adopted guidance levels and associated surface areas for Eagle Lake, Polk County, Florida.

Level	Elevation (ft., NGVD)	Total Lake Area (acres)
Ten Year Flood Guidance Level	131.00	682
High Level	130.75	681
Low Level	128.50	665
Extreme Low Level	126.50	642

Table 4. 2007 adopted minimum levels, guidance levels and associated surface areas for Eagle Lake, Polk County, Florida.

Level	Elevation (ft., NGVD)	Lake Area (acres)
Ten Year Flood Guidance Level	131.30	682
High Guidance Level	129.60	675
High Minimum Lake Level	129.04	671
Minimum Lake Level	127.94	660
Low Guidance Level	127.15	651

NA = not available

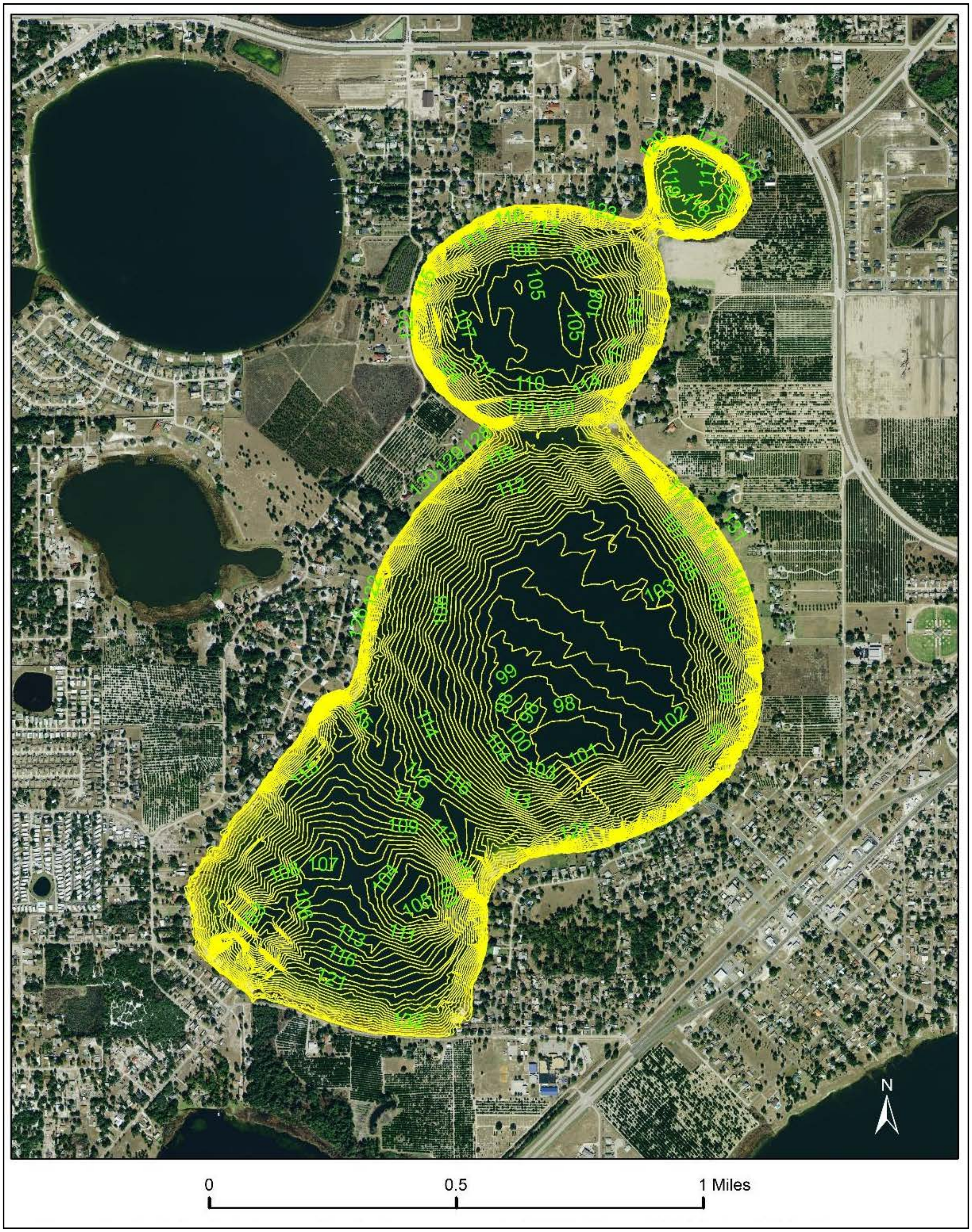


Figure 2. Lake Bottom Contours on a 2011 Natural Aerial Photograph.

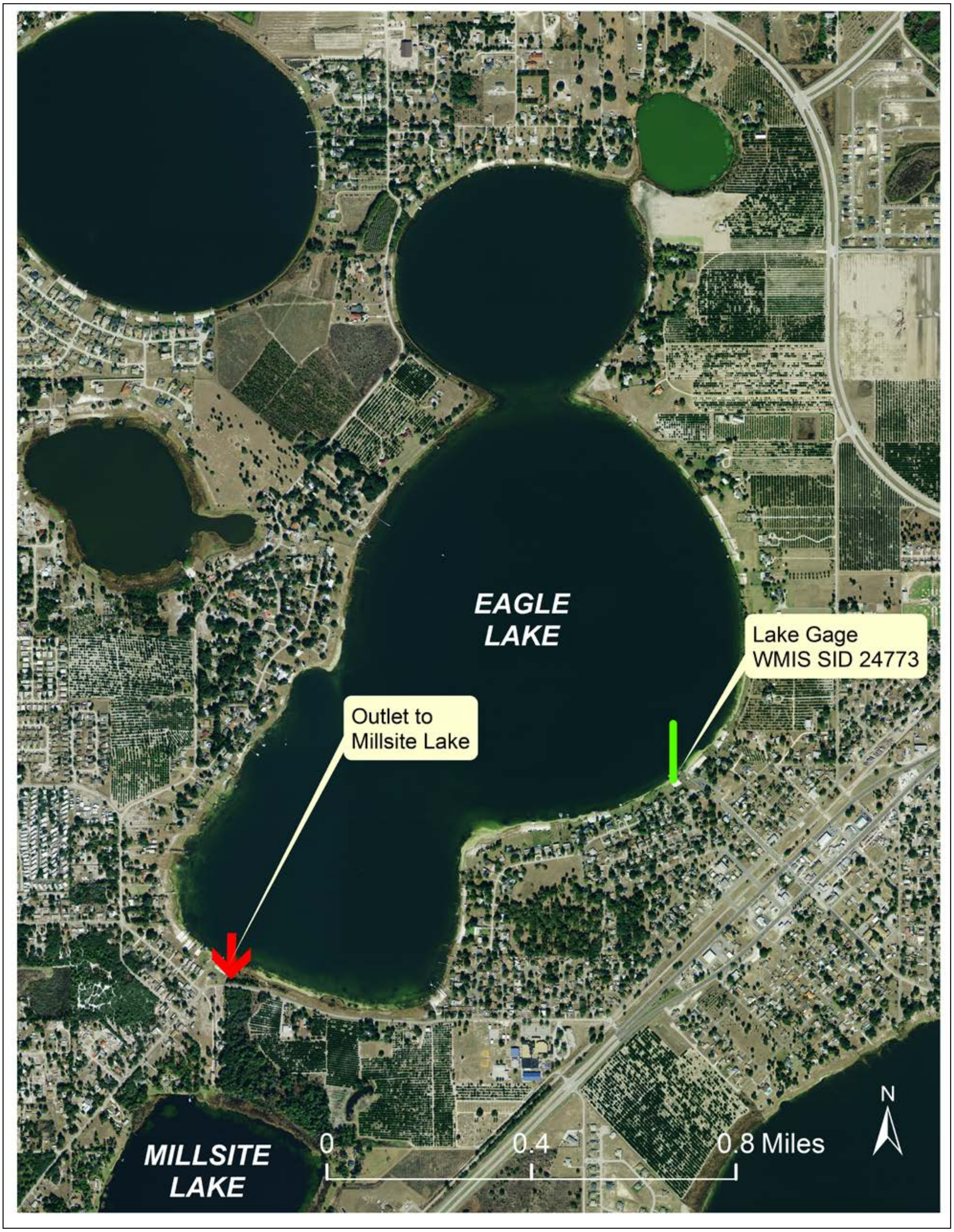


Figure 3. Location of the District Gage and Outlet Conveyance System.

Figure 4. Lake Outlet Structure at Crystal Beach Road.

The Eagle Lake basin/watershed land use has changed considerably from its pre-development times. Native vegetation historically included various species of trees including of *Pinus* (*palustris, elliottii, and clausa*), and Quercus (*laevis, marilandica, stellata, chapmanii and virginiana*), with understories of *Serenoa repens, Ilex glabra, Myrica cerifera, Aristida stricta, and Sorghastrum secundum*. This native vegetation are typical of the Tavares, Candler, Smyrna, Sparr and Pomello soils present in the lake basin (Ford et, al. 1990). Post-development land use changes include drainage modifications, agricultural activities, including citrus production and livestock grazing or pastureland use, and residential/urban development. Agricultural activities and constructed roads and more recently residential development are evident in the immediate lake basin in aerial photographs from the 1940s through recent times (Figures 5 through 10).

A comparison of the general shoreline exposure was made to current conditions by means of visual inspection of aerial photography (annually since 2014, 2011-2004, 1999, 1996, 1992, 1970's, and 1940's). Higher water levels on the mid-2000 photographs showed that there was an average 32 vertical feet less shoreline compared to recent times. Conversely, lower water levels on the 1970's photograph showed that there was an average 84 vertical feet more shoreline than the photographs from recent years (Figure 11).

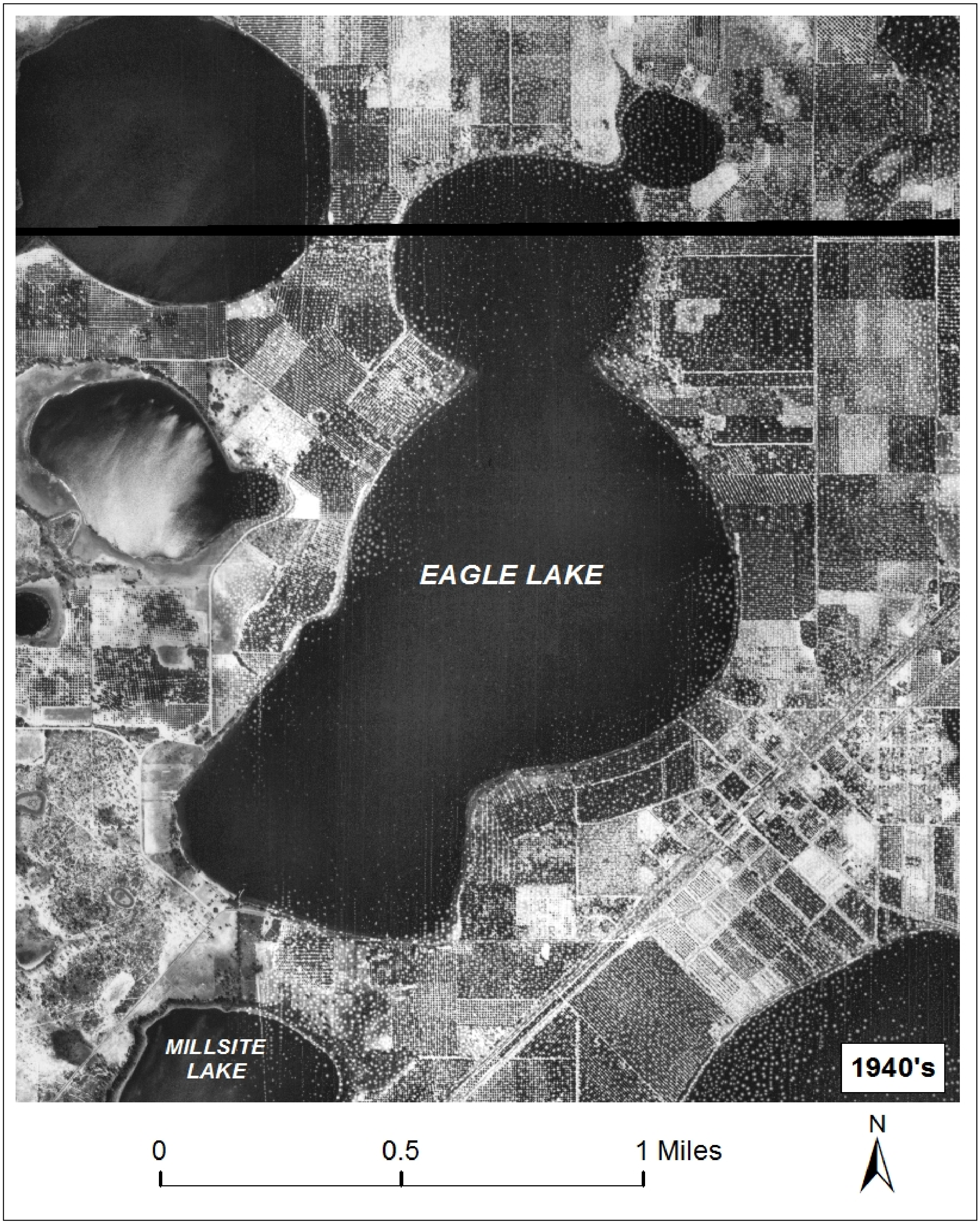


Figure 5. 1940’s Aerial Photograph of Eagle Lake.

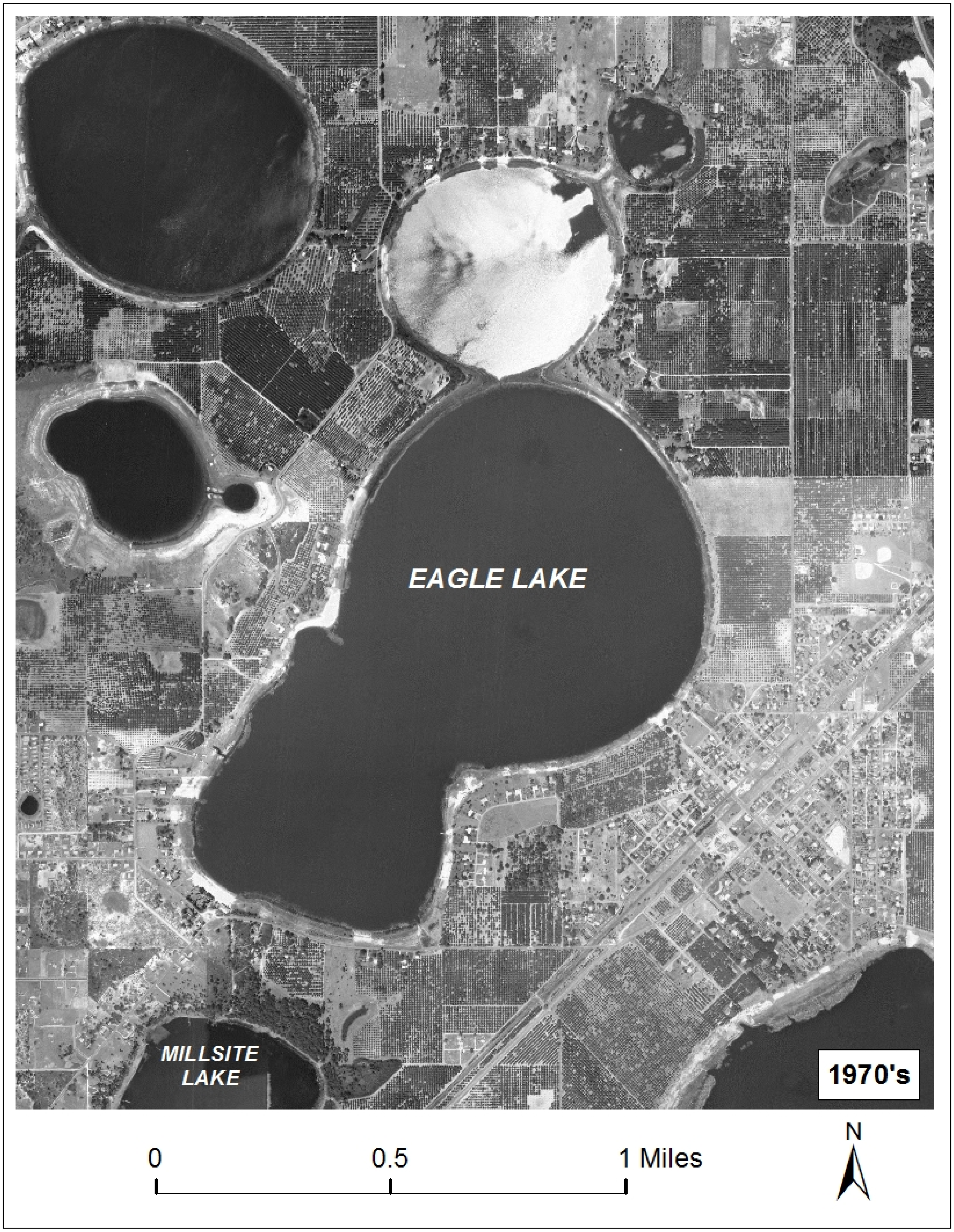


Figure 6. 1970's Aerial Photograph of Eagle Lake.

Figure 7. 2005 Aerial Photograph of Eagle Lake.

Figure 8. 2007 Aerial Photograph of Eagle Lake.

Figure 9. 2009 Aerial Photograph of Eagle Lake.

Figure 10. 2011 Aerial Photograph of Eagle Lake.

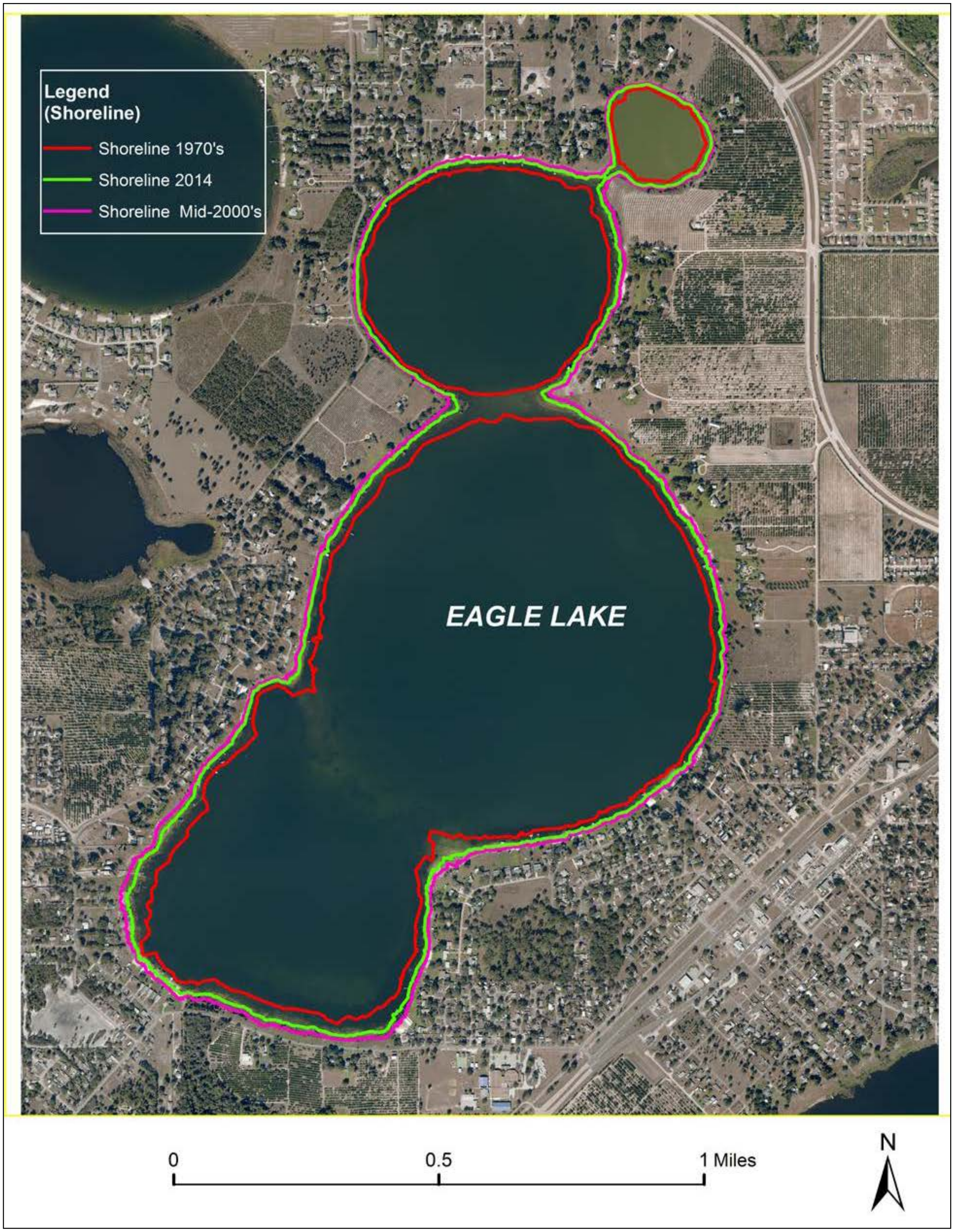


Figure 11. Approximate historic variability in the location of the shoreline on Eagle Lake.

Based on review the Florida Land Use, Cover and Forms Classification System (FLUCCS) 2011 map maintained by the District Mapping and GIS Section, the land area in the vicinity of Eagle Lake is currently nearly three-quarters residential (data not shown). Conversely, citrus held similar land cover as shown in the 1990 FLUCCS map. The current citrus groves are mostly smaller parcels in proximity to the lake (Figure 12). Wetlands associated with the lake include two areas of freshwater marsh along the lake margin. One resides on the east shore of the northernmost lobe and the other along the west shore of the middle lobe. Marshes make up approximately 15 percent of the lake margin with the remaining 85 percent residential development.

Hydrology

Lake stage data, i.e., surface water elevations collected are available for Eagle Lake from the District Water Management Information System (SID 24773) for the period from June 11, 1965 through the present time (Figure 13). See Figure 3 for the location of the District water level gauge.

The USGS frequently collected lake stage data on a daily or monthly basis prior to September 1983. The District took over monitoring in January 1984 and has since collected water level data on a monthly basis. The highest lake stage elevation on record was 131.5 ft. and occurred on September 23, 1998 near the end of a very strong El Nino period. The lowest lake stage elevation on record was 118.8 ft. and occurred on May 4, 1976 following a four-year long strong La Nina period.

Water Use

There are numerous permitted groundwater withdrawals in the area that may affect Eagle Lake water levels (Figure 14). Two public water supply wellfields are included in the withdrawals near Eagle Lake. The NE Lakeland and Lakeland Wellfields are both approximately 15 miles northwest, of the lake. An analysis of water use based on metered and estimated quantities for all water users in the area indicates that mean monthly water use within 1, 2, and 3 miles of Eagle Lake was 0.6, 1.8 and 4.7 mgd, respectively, for the 20-year period from 1992 through 2011 (Figure 15). Mean monthly water use within 5, 10 and 20 miles of the lake for the same period increased to 13.0, 51.7 and 197.8 mgd, respectively.

Historical Management Levels and Current Minimum and Guidance Levels Development

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.

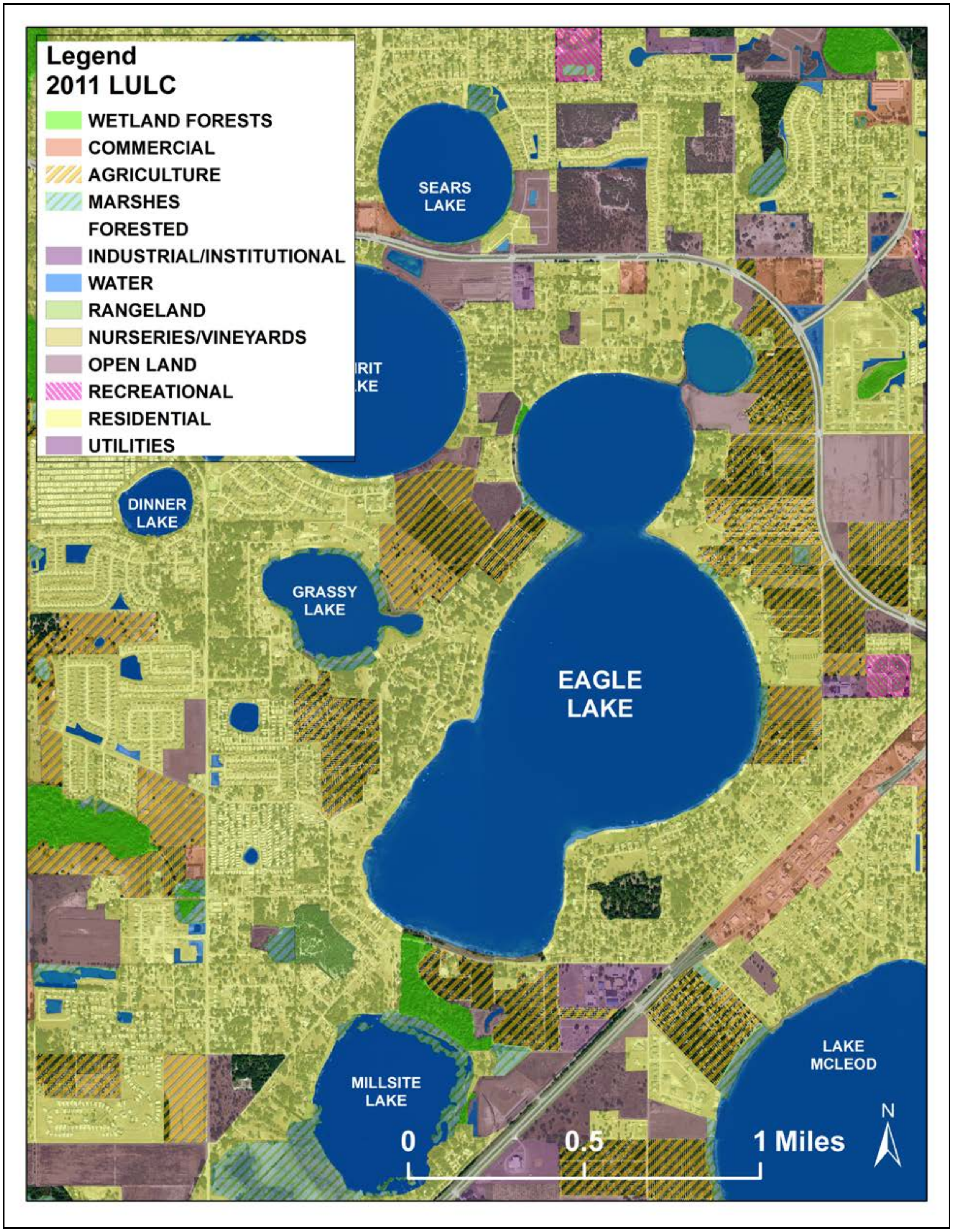


Figure 12. Land Use Land Cover Map of the Eagle Lake Vicinity.

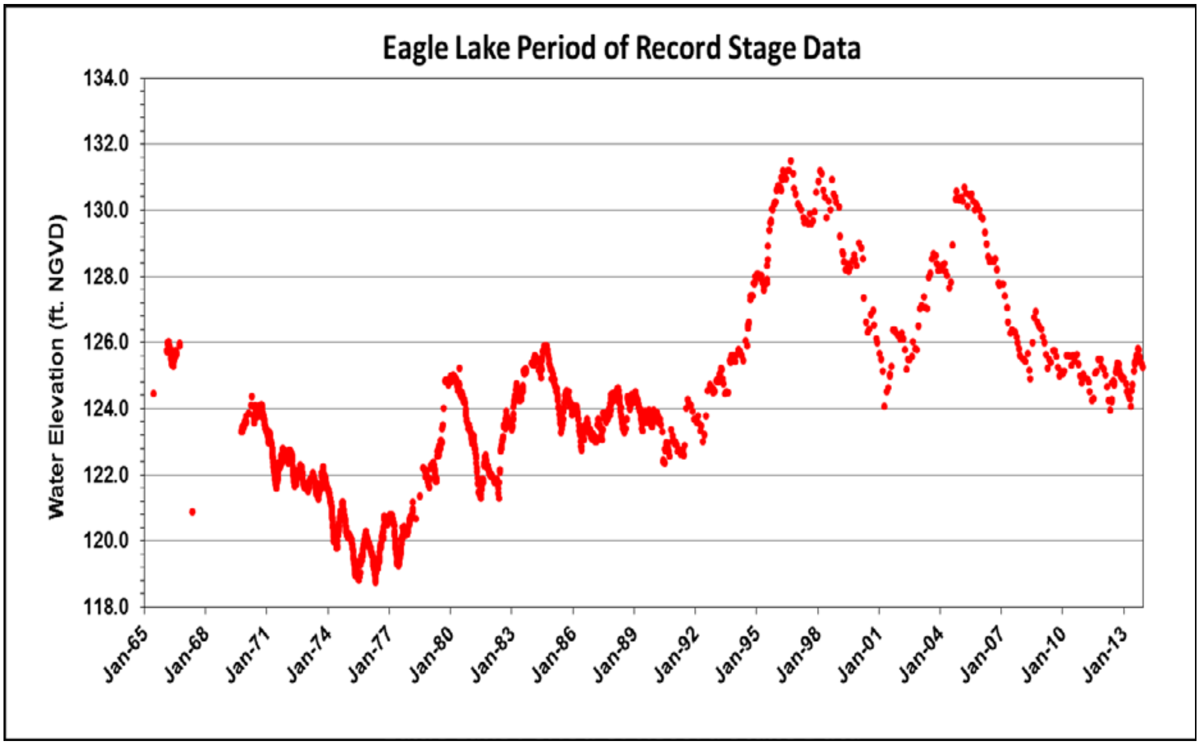


Figure 13. Eagle Lake Period of Record Stage Data (WMIS SID 24773)

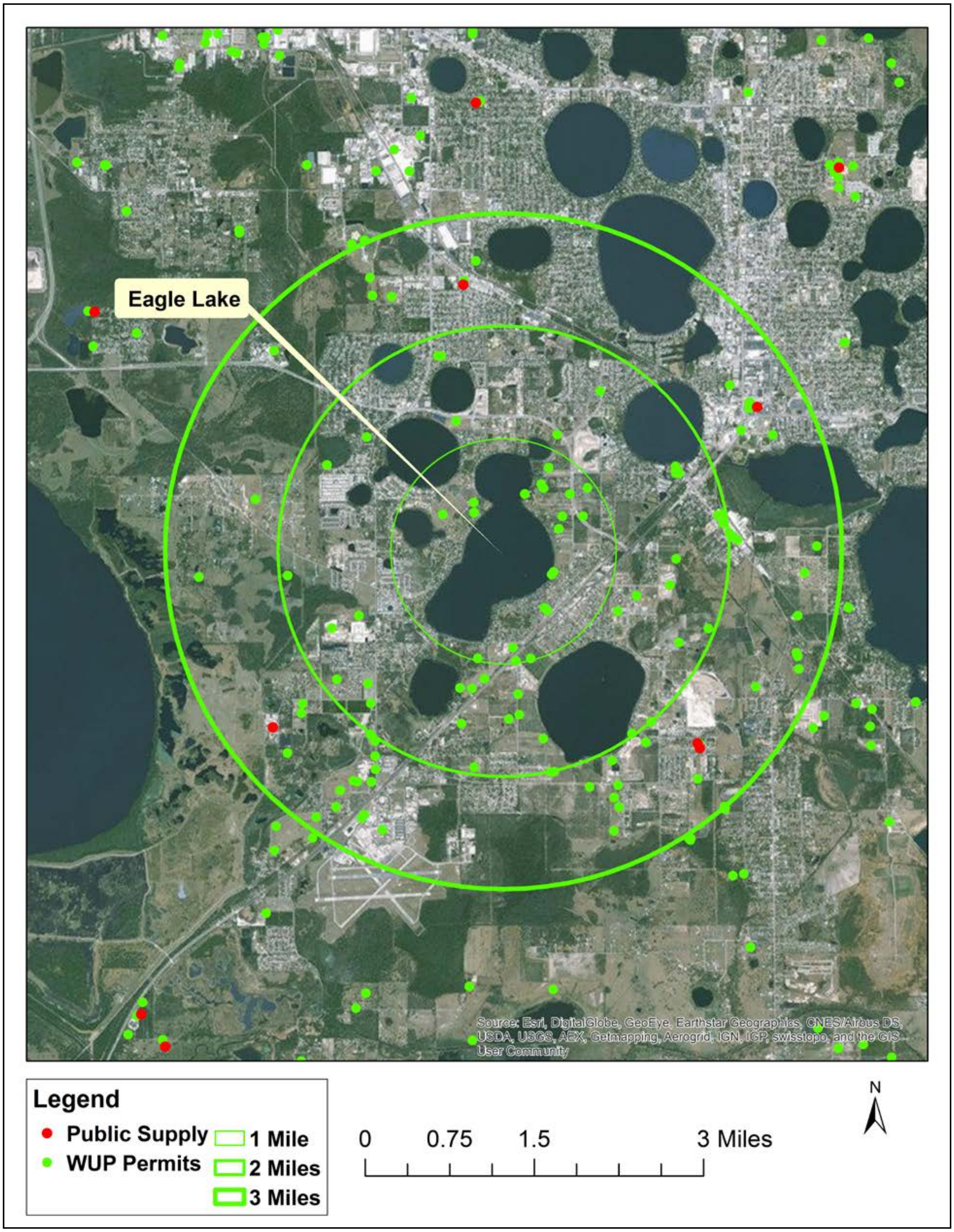


Figure 14. Permitted Groundwater Withdrawals Within a 1, 2, and 3 Mile Radius of Eagle Lake.

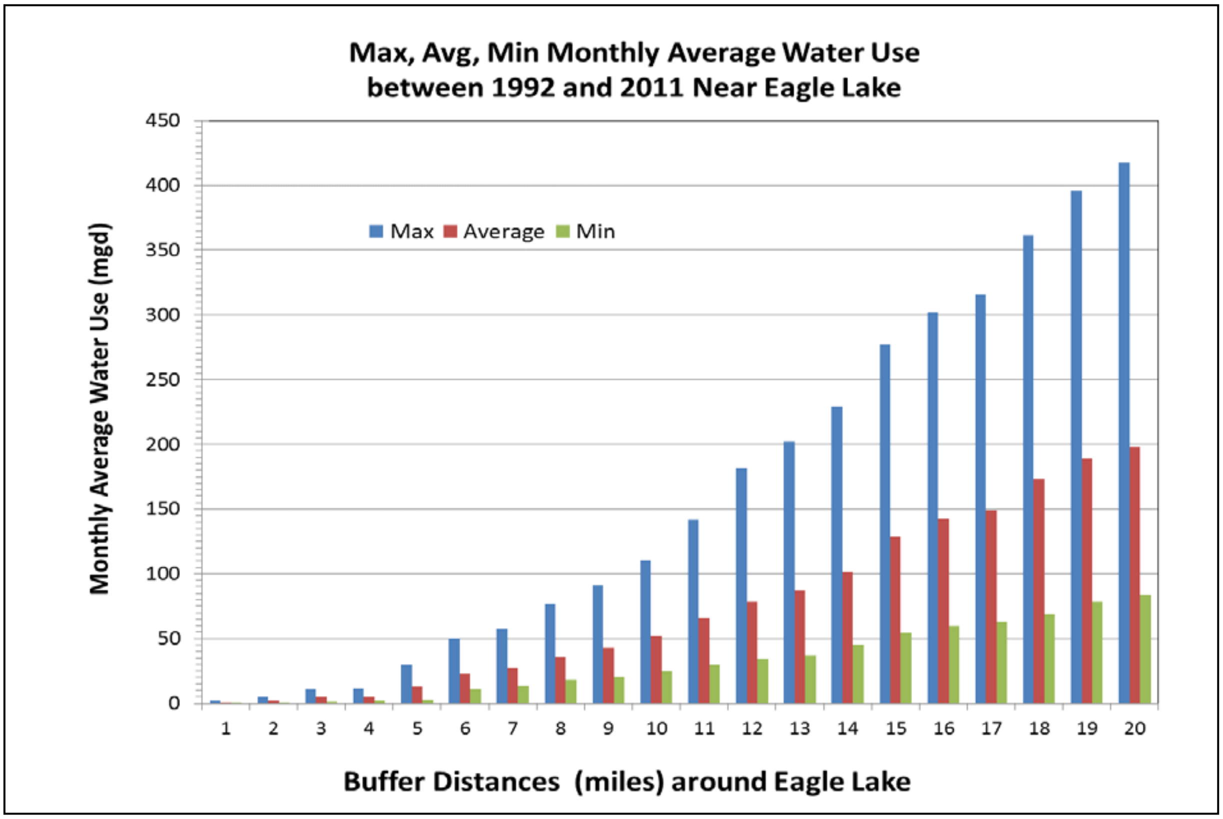


Figure 15. Monthly Average Water Use Within twenty miles of Eagle Lake.

Based on work conducted in 1988 (see SWFWMD 1996), the District Governing Board adopted management levels (currently referred to as Guidance Levels) into Chapter 40D-8, Florida Administrative Code for Eagle Lake in 1988 (Table 3). These previously adopted management levels for Eagle Lake were replaced by Minimum and Guidance Levels in December 12, 2006 using the methodology for Category 3 Lakes described in Leeper *et al.* (2001), in accordance with modifications outlined by Dierberg and Wagner (2001). The 2006 Minimum and Guidance Levels, along with area values for each water level are listed in Table 4.

Methods, Results and Discussion

Summary of Data and Analyses Supporting Development of the Revised Minimum and Guidance Levels

Revised Minimum and Guidance Levels were developed for Eagle Lake using the methodology for Category 3 lakes described in Chapter 40D-8, F.A.C. Revised levels along with lake surface area for each level are listed in Table 5 along with other information used for development of the revised levels. Detailed descriptions of the development and use of these data are provided in subsequent sections of this report.

Table 5. Elevation data and associated area values used for establishing minimum levels for Eagle Lake, Polk County, Florida.

Levels	Elevation (ft. NGVD)	Lake Area (acres)
Lake Stage Exceedance Percentiles		
Historic P10	131.6	681.8
Historic P50	129.5	664.3
Historic P90	127.9	646.4
Normal Pool and Control Point		
Normal Pool	132.3	687.4
Control Point	129.3	662.3
Low Floor Slab	133.3	697.9
Significant Change Standards		
Dock-Use Standard	128.2	649.9
Basin Connectivity Standard	129.1	660.3
Species Richness Standard	121.7	565.9
Aesthetic Standard	127.9	646.4
Recreation/Ski Standard	NA	NA
Mixing Standard	NA	NA
Wetland Offset	128.7	655.9
Revised Minimum and Guidance Levels		
High Guidance Level	131.6	681.8
High Minimum Lake Level	131.2	678.8
Minimum Lake Level	129.1	660.3
Low Guidance Level	127.9	646.4

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 Eagle Lake 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 Eagle Lake. 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). The with an LEI HS-WSPK transducer (operating frequency = 192kHz, cone angle = 20) mounted to a boat hull, a Lowrance LMS-350A sonar-based depth finder and the Trimble GPS Pathfinder Pro XR/Mapping System (Pro XR GPS Receiver, Integrated GPS/MSK Beacon Antenna, TDC1 Asset Surveyor and Pathfinder Office software).

The DEM created from the combined elevation data sets was used to develop topographic contours of the lake basin and to create a triangulated irregular network (TIN). The TIN was used to calculate the stage areas and volumes using a Python script file to iteratively run the Surface Volume tool in the Functional Surface toolset of the ESRI® 3D Analyst toolbox at one-tenth of a foot elevation change increments (selected stage-area-volume results are presented in Figure 16).

Classification of Lake Stage Data and Development of Exceedance Percentiles

A key part of establishing Minimum and Guidance Levels is the development of exceedance percentiles based on Historic water levels (lake stage data). For 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.

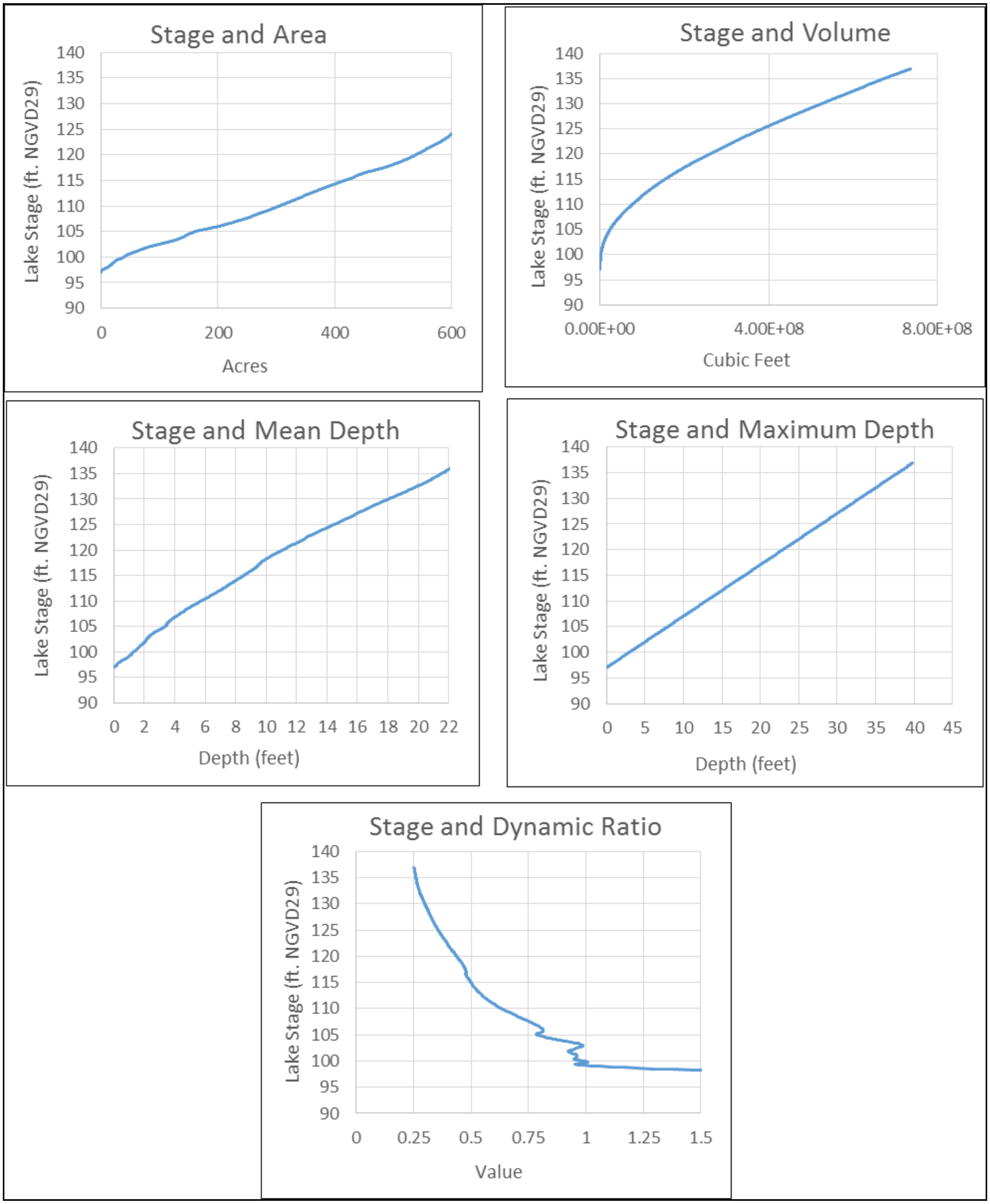


Figure 16. Surface area, volume, mean depth, maximum depth and dynamic ratio (basin slope) as a function of lake stage.

Based on water-use estimates and analysis of lake water levels and regional ground water fluctuations, no Historic lake stage data were available for Eagle Lake. 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 performing 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 fitting procedure known as the line of organic correlation (LOC) (see Helsel and Hirsch 1992). The procedure was used to describe the relationship between daily water surface elevations for Eagle Lake derived from measured data and various regional rainfall estimates determined from long-term rainfall stations in the lake vicinity.

A composite of both model data produced a hybrid model which resulted in a 67 year (1946-2013) Historic water level record. Based on this composite data, the Historic P10 elevation, i.e., the elevation the lake water surface equaled or exceeded ten percent of the time, was 131.6 ft. The Historic P50, the elevation the lake water surface equaled or exceeded fifty percent of the time during the historic period, was 129.5 ft. The Historic P90, the lake water surface elevation equaled or exceeded ninety percent of the time during the historic period, was 127.9 ft. (Figure 17 and Table 5).

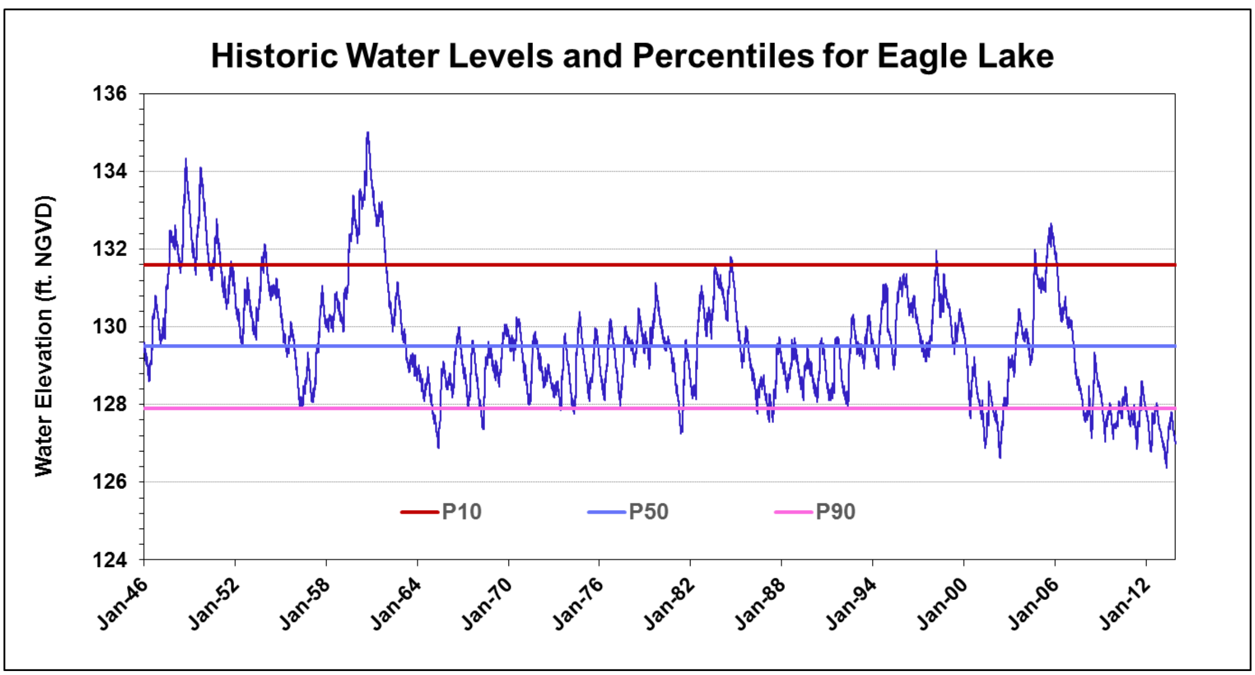


Figure 17. Historic Water Levels (hybrid) Used to Calculate Percentile Elevations Including P10, P50, and P90.

Revised 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 Eagle Lake, the revised High Guidance Level was established at the Historic P10 elevation, 131.6 ft. The High Guidance Level has been exceeded a few times in the Historic data. For example, the peak level during a large magnitude flood in 1960 associated with Hurricane Donna was approximately 135 ft. NGVD. Based on the recent gauging record for the lake, the water level reached the High Guidance Level on September 23, 1996 (Figure 13).

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. The level is established using Historic or Current lake stage data and, in some cases, reference lake water regime statistics. Reference lake water regime statistics are used when adequate Historic or current data are not available. These statistics represent differences between P10, P50 and P90 lake stage elevations for typical, regional lakes that exhibit little or no impacts associated with water withdrawals, i.e., reference lakes. Reference lake water regime statistics include the RLWR50, RLWR90 and RLWR5090, which are, respectively, median differences between P10 and P50, P50 and P90, and P10 and P90 lake stage percentiles for a set of reference lakes. Based on the availability of Historic data for Eagle Lake, the revised Low Guidance Level was established at the Historic P90 elevation, 127.9 ft.

Significant Change Standards and Other Information for Consideration

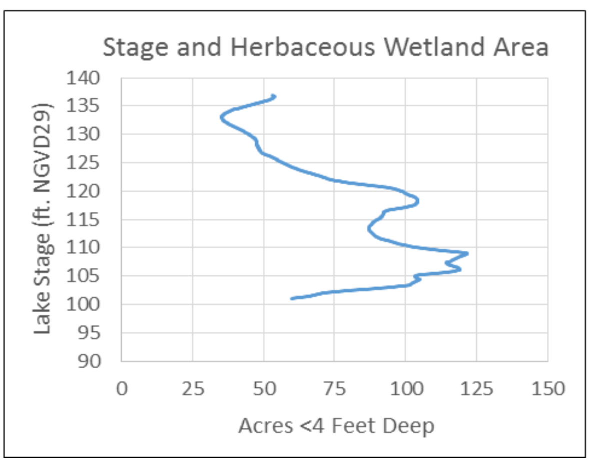
The stage-volume relationship developed and Category 3 significant change standards were established for Eagle Lake including a Lake Mixing Standard, a Dock-Use Standard, a Basin Connectivity Standard, a Species Richness Standard, an Herbaceous Wetland Standard, a Submerged Aquatic Macrophyte Standard, an Aesthetics Standard, and a Recreation/Ski Standard. Each were evaluated for minimum levels development for Eagle Lake and presented in Table 5.

The Mixing Standard was established at 107.6 ft., an elevation well below the Current P90 and Low Guidance Level elevations, 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 128.2 ft., based on 90 percent of the dock-end sediment elevations (124.6 ft.), developed from measurement of 39 docks (Table 6). Historical aerial photography and lake bathymetry reveal that the lake is potentially three separate basins depending on the water levels.

The Basin Connectivity Standard was established at 129.1 ft., based on the elevation of lake sediments at a critical high-spot between lake basins, clearance values for movement of aquatic biota or powerboats and other watercraft, and use of Historic lake levels. The Species Richness Standard was established at 121.7 ft., based on a 15% reduction in lake surface area from that at the Historic P50 elevation. 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 (Figure 18). An Aesthetic-Standard for Eagle Lake was established at the Low Guidance Level elevation of 127.9 ft. The Recreation/Ski Standard was calculated at 104.6 ft. based on a critical ski elevation of 98 ft., the standard was considered not applicable to the MFLs because it was considerably below the Historic P90 water level.

Table 6. Summary statistics and elevations associated with docks in Eagle Lake based on measurements made by District staff. 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 (feet) of Sediments at Waterward End of Docks	Statistics Value (N) or Elevation (feet) of Dock Platforms
N (number of docks)	39	39
10th Percentile (P90)	120.4	126.3
Median or 50th Percentile	122.4	129.7
90th Percentile (P10)	124.6	132.1
Maximum	125.3	133.3
Minimum	118.9	125.7



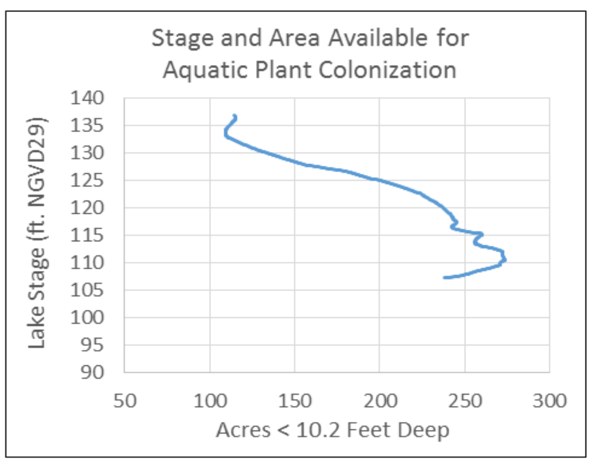


Figure 18. Potential herbaceous wetland area and area available for macrophyte colonization in Eagle Lake as a function of lake stage.

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. The Control Point elevation for Eagle Lake is 129.3.

Comparison of the Control Point elevation with the Normal Pool elevation is typically done for Category 1 and 2 Lake MFL development (SWFWMD 1999a, 1999b and Carr, *et al.* 2006). When appropriate, this comparison can identify that a lake is structurally altered and thus can determine the High Guidance Level. These indicators are absent at Eagle Lake. The low floor slab elevation was determined by field survey as 133.3 ft. (1.7 ft. higher than the HGL) and was not considered in establishing the Minimum and Guidance Levels. The low floor slab elevation was, however, exceeded 3 times in the Historic water level record (1948, 1949, and 1960) and was never exceeded in the stage dataset.

The most recent Ten Year Flood Guidance Level of 131.3 ft. was established in 2007 for Eagle Lake using the methodology for closed basin lakes described in current District rules (Chapter 40D-8, Florida Administrative Code). Although the lake has an outlet conveyance system (Figure 19) with an outlet control elevation of 129.3 ft. (Table 7), lake has rarely reached this level during most of the stage record. Peak flood stages are therefore related more to long-term rainfall and evaporation patterns than to single storm events, and the “closed basin lake” methodology is applicable.

Table 7. Summary of structural alteration / control point elevation information for Eagle Lake, Polk County, Florida. Numbers correspond to those shown in Figure 19.

No.	Description	Elevation (ft., NGVD)
1	**Control point**; invert at north end of box culvert under Crystal Beach Road	129.3
2	Invert at south end of box culvert under Crystal Beach Road	128.9
3	Highest channel bottom to Millsite Lake	128.6

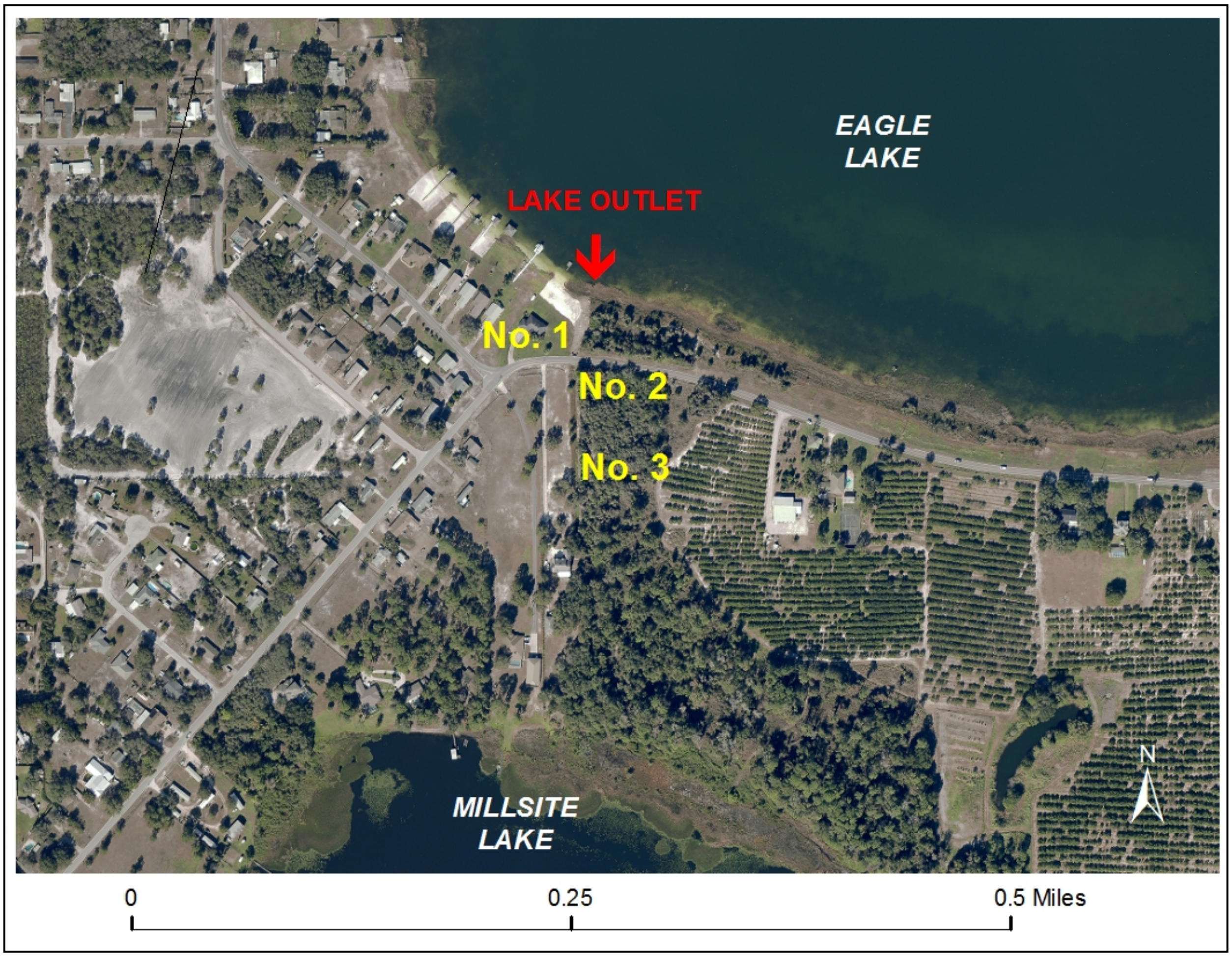


Figure 19. Outlet conveyance system and location of selected survey points for Eagle Lake on a 2014 aerial photograph.

Revised Minimum Levels

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 at the most conservative significant change standard. In the case of Eagle Lake, the revised minimum level is established by the Basin Connectivity Standard at 129.1 ft.

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. For Eagle Lake, a Category 3 lake with Historic data, the High Minimum Lake Level is established at the Minimum Lake Level elevation plus the difference between the Historic P10 and the Historic P50. Therefore, the revised high minimum level for Eagle Lake is established at 131.2 ft.

Revised Minimum and Guidance levels for Eagle Lake are plotted in Figure 20 along with the Historic water level record. The approximate locations of the lake margin when water levels equal the revised minimum levels are shown on a 2014 natural color photograph in Figure 21.

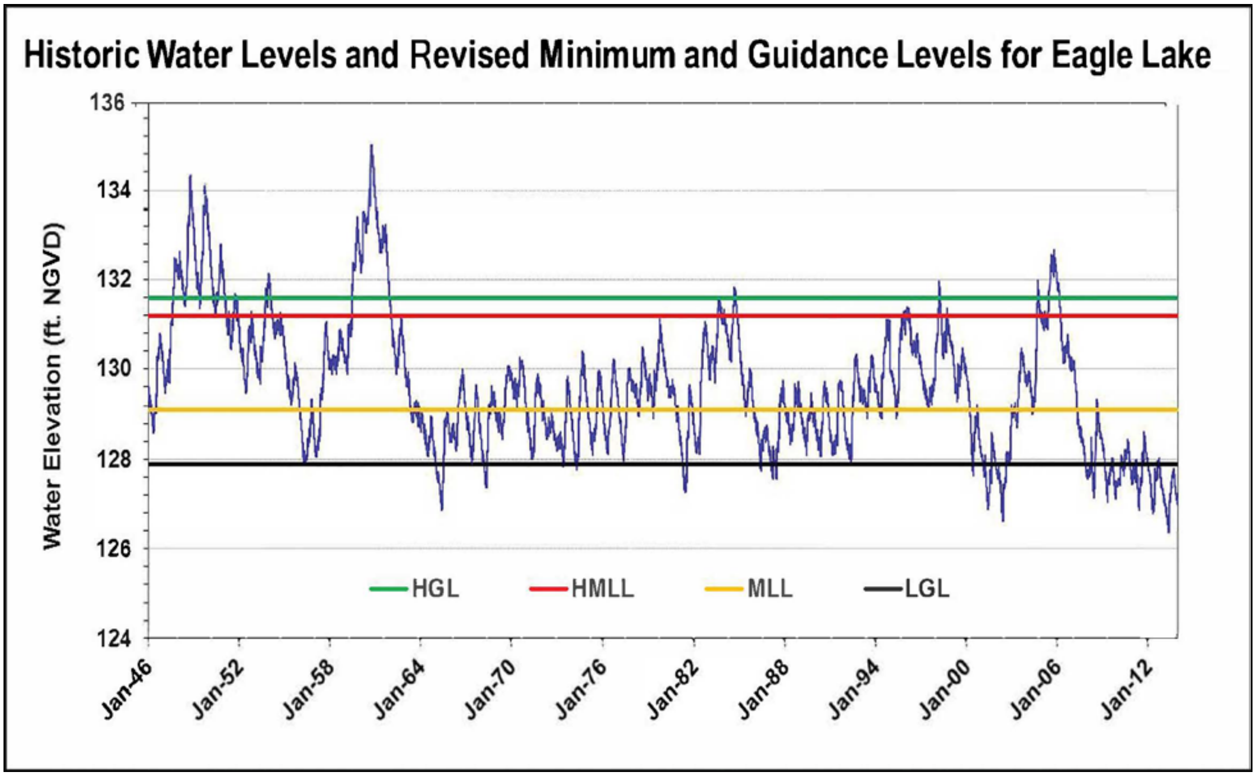


Figure 20. Historic water levels (hybrid) used to calculate the revised Minimum and Guidance Levels. The revised levels include the High Guidance Levels (HGL), High Minimum Lake Levels (HMLL), Minimum Lake Levels (MLL), and Low Guidance Levels (LGL).

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 revised MFLs for Eagle Lake are presented in both datum standards (Table 8). The datum shift (0.86) was calculated based on third-order leveling ties from vertical survey control stations with known elevations above the North American Vertical Datum on 1988.

Table 8. Revised Minimum and Guidance Levels for Eagle Lake in NAVD88.

Minimum and Guidance Levels	Elevation in Feet NGVD29	Elevation in Feet NAVD88
High Guidance Level	131.6	130.7
High Minimum Lake Level	131.2	130.3
Minimum Lake Level	129.1	128.2
Low Guidance Level	127.9	127.0

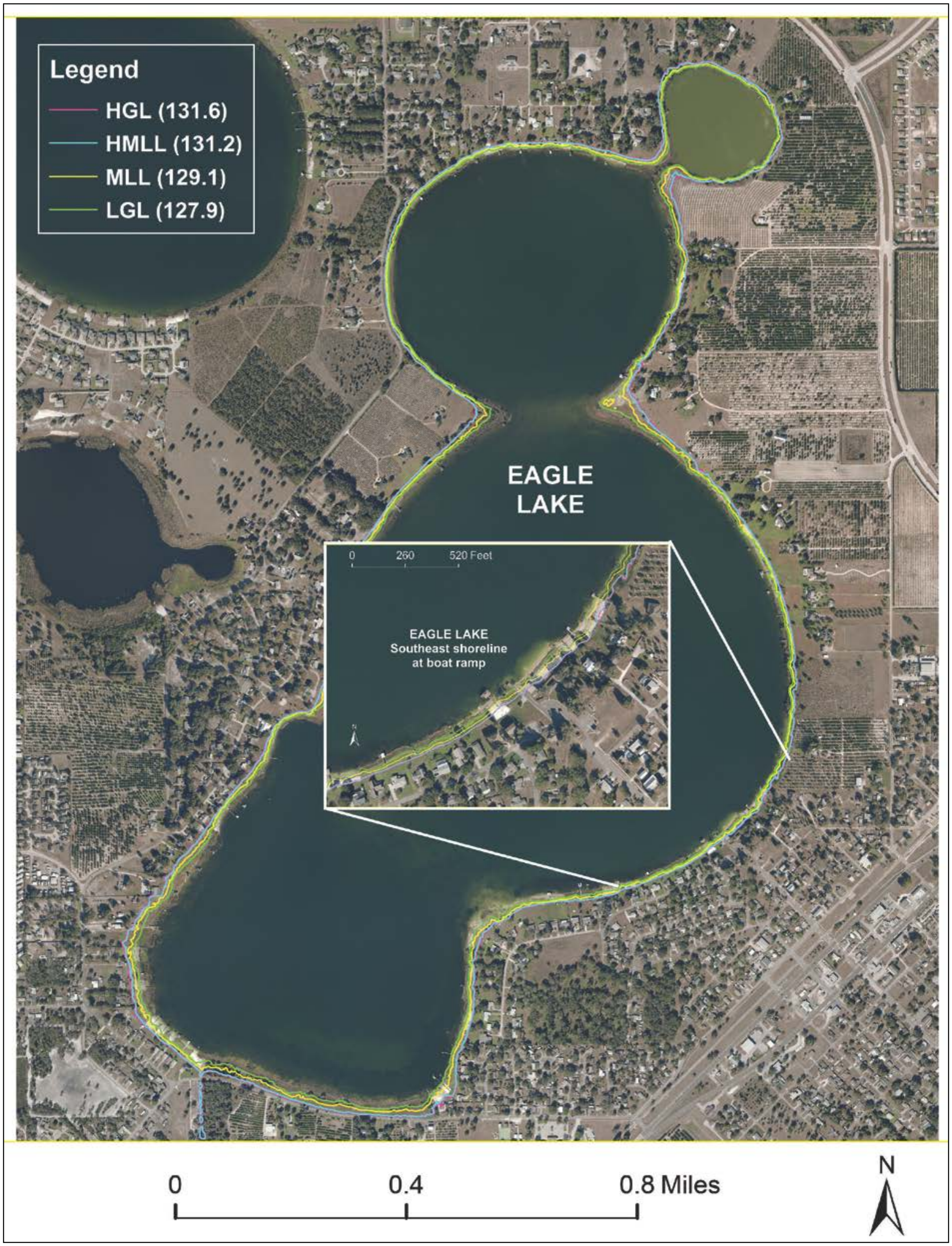


Figure 21. Eagle Lake Minimum and Guidance Level Contour Lines Imposed Onto a 2014 Natural Color Aerial Photograph.

Consideration of Environmental Values

The revised minimum levels for Eagle Lake 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. A Connectivity Standard was used for developing revised Minimum Levels for Eagle Lake based on its classification as a Category 3 lake. This standard is associated with protection of several environmental values identified in Rule 62-40.473, F.A.C., including: recreation in and on the water, fish and wildlife habitats and the passage of fish, transfer of detrital material and navigation (refer to Table 2).

The minimum levels revised is protective of four additional environmental values identified in Rule 62-40.473, F.A.C. Dock-Use, Species Richness, Aesthetics, and Wetland Offset standards are lower than the revised Minimum Level. The Recreation/Ski and Lake Mixing standards were considerably below the Historic P90 water level and deemed inappropriate. They are nevertheless, protective of the recreation in and on the water, transfer of detrital material, filtration and absorption of nutrients and other pollutants, sediment loads and water quality.

Two environmental value values identified in Rule 62-40.473, F.A.C., were not considered relevant to development of revised minimum levels for Eagle Lake. Estuarine resources were not considered relevant because the lake is not connected to an estuary. Sediment loads were similarly not considered relevant for minimum levels development for the lake, because the transport of sediments as bedload or suspended load is a phenomenon associated with flowing water systems.

The environmental value, maintenance of freshwater storage and supply is protected by the revised minimum levels based on the relatively modest potential changes in storage associated with the MFLs hydrologic regime as compared to the non-withdrawal impacted historic condition. Maintenance of freshwater supply is also expected to be protected by the revised minimum levels based on inclusion of conditions in water use permits that stipulate that permitted withdrawals will not lead to violation of adopted MFLs.

Comparison of Revised and Previously Adopted Levels

The revised High Guidance Level and Low Guidance Level for Eagle Lake are respectively, 2.0 feet and 0.7 feet higher than the previously adopted guidance levels. These differences are associated with application of a new modeling approach for characterization of Historic water level fluctuations within the lake, i.e., water level fluctuations that would be expected in the absence of water withdrawal impacts given existing structural conditions.

The revised High Minimum Lake Level for Eagle Lake is 2.2 feet higher than the previously adopted High Minimum Lake Level. The revised Minimum Lake Level is 1.2 feet higher than the previously adopted Minimum Lake Level. These differences are primarily due to the differences in the water level data used in Minimum and Guidance Level development.

Minimum Levels Status Assessment

To assess whether the revised Minimum Lake Levels are being met, a line of organic correlation (LOC) analysis was performed on “Current” lake level data to create a data set that can reasonably be considered “Long-term” (Appendix B). Measured lake stage data for Eagle Lake from 1995 through 2013 was determined to represent the “Current” period. The result of the analysis produces a 68-year long-term water level record (1946-2013) representing “Current” conditions, which can be compared to the revised Minimum Levels. Results from this assessment indicates that Eagle Lake water levels are currently above the revised High Minimum Lake Level, while currently below the revised Minimum Lake Level (see Appendix B).

The lake lies within the region of the District covered by an existing recovery strategy, the Comprehensive Environmental Resources Recovery Plan for the Southern Water Use Caution (Rule 40D80-073, F.A.C.). The District plans to continue regular monitoring of water levels in Eagle Lake and will also routinely evaluate the status of the lake’s water levels with respect to adopted minimum levels for the lake included in Chapter 40D-8, F.A.C.

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APPENDIX A

Technical Memorandum

September 10, 2015

TO: David Carr, Staff Environmental Scientist, Water Resources Bureau

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

FROM: Michael C. Hancock, P.E., Senior Professional Engineer, Water Resources Bureau
Mark D. Barcelo, P.E. Chief Professional Engineer, Water Resources Bureau

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

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A. Introduction

Water budget and rainfall regression models were developed to assist the Southwest Florida Water Management District (District) in the reassessment of minimum levels for Eagle Lake in central Polk County, southwest of Winter Haven. Eagle Lake currently has adopted minimum levels which are scheduled to be re-assessed in FY 2015. This document will discuss the development of the Eagle Lake models and use of the models for development of Historic lake stage exceedance percentiles.

B. Background and Setting

Eagle Lake is located in central Polk County, approximately 0.3 miles northwest of U.S. Highway 17 and immediately south of Winter Haven Road in the City of Eagle Lake (Figure 1). The lake lies within the Peace River watershed. Eagle Lake discharges along its southern shore via a 10 feet wide by 4 feet high box culvert under Crystal Beach Road. Once through the culvert, flow continues via a culvert and ditch system to Millsite Lake located approximately 0.25 miles south of Eagle Lake (Figure 2). Millsite Lake discharges to a ditch and canal system that eventually drains to the Peace River south of Lake Hancock. There are no significant natural or manmade inlets to the lake, although some of the development in the area directly drains to the lake.

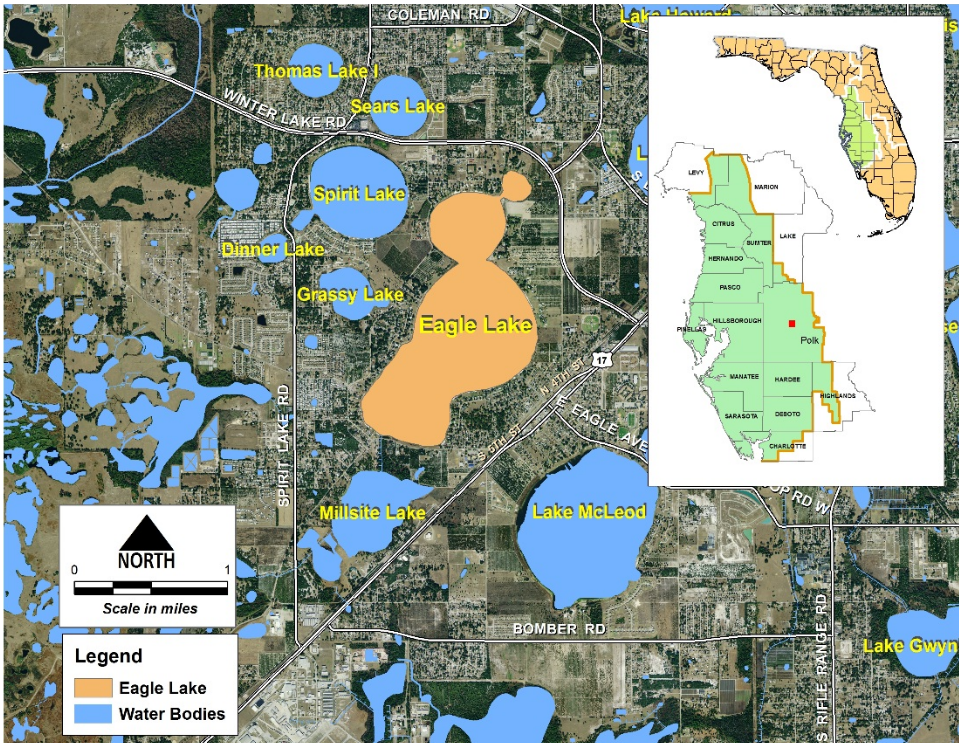

Figure 1. Location of Eagle Lake in Polk County, Florida.

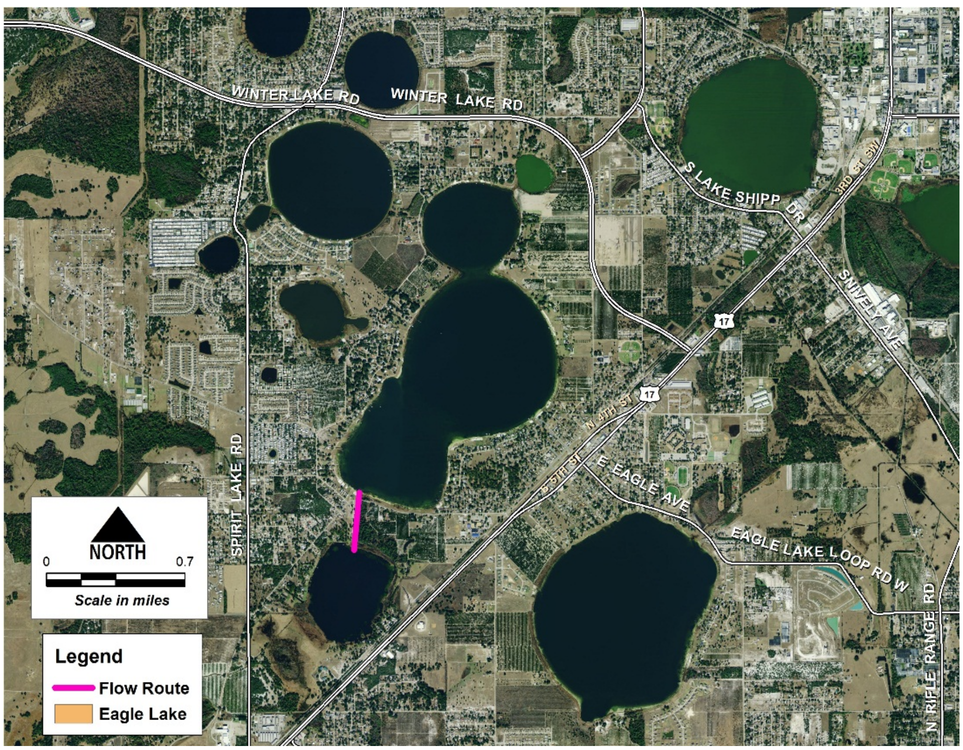

Figure 2. Flow route from Eagle Lake to Millsite Lake.

Physiography and Hydrogeology

The area surrounding the lake is categorized as the Winter Haven Karst in the Central Lake Physiographic District (Brooks, 1981); a region of sandhills with large circular lakes. The topography directly surrounding the lake is rolling, with elevations generally ranging from 140 to 160 feet NGVD 29. Drainage into the lake is a combination of overland flow and flow through drainage swales and minor conveyance systems.

The hydrogeology of the area includes a sand surficial aquifer; an intermediate clay confining/aquifer unit; and the thick carbonate Upper Floridan aquifer (Sinclair and Reichenbaugh, 1981, and Spechler and Kroening, 2007). Lateral movement of water through the surficial aquifer can be affected by individual lake basins because of the rolling topography, but there is also a subregional component to flows. Surficial aquifer water level data are sparse in the area of Eagle Lake. The surficial aquifer is generally 50 to 75 feet thick in the area of Eagle Lake, and surface drainage is poorly developed because of the highly pervious nature of the sandy soils (Sinclair and Reichenbaugh, 1981). Below the surficial aquifer is the intermediate confining unit and intermediate aquifer system (more recently referred to as the Hawthorne Aquifer System). The intermediate aquifer system is thought to end just north of Eagle Lake, so the unit in the area of the lake serves mostly as a confining unit. The combined system is estimated to be approximately 100 feet thick in the area of Eagle Lake (Spechler and Kroening, 2007). However, because the intermediate confining unit can be breached by sinkhole features, leakage from the surficial aquifer through the confining unit can be significant locally. Below the intermediate confining unit lies the limestone of the Upper Floridan aquifer that ranges from approximately 300 feet thick in eastern Polk County to more than 1,200 feet thick in the southwestern part of the county (Spechler and Kroening, 2007).

Data

Regular water level data collection at Eagle Lake (SID 24773) began in February 1966 (Figure 3), although one data point exists for June 1965. Data collection frequency occurred daily and weekly (with several large gaps) in the early part of the record (by the United States Geological Survey (USGS) and the District), and has been monthly since the early 1990s.

The nearest Floridan aquifer monitoring well with a significant period of water level data is the ROMP 73 Upper Floridan aquifer monitor well (SID 25370), with regular data collection beginning in February 1996 (although some data points exist from 1992) (Figures 4 and 5). ROMP 73 is located approximately 2 miles from Eagle Lake. Two other Upper Floridan aquifer monitor wells, ROMP 57 (SID 25343) and ROMP 59 (SID24838), are located a little over 10 miles to the southeast and southwest,

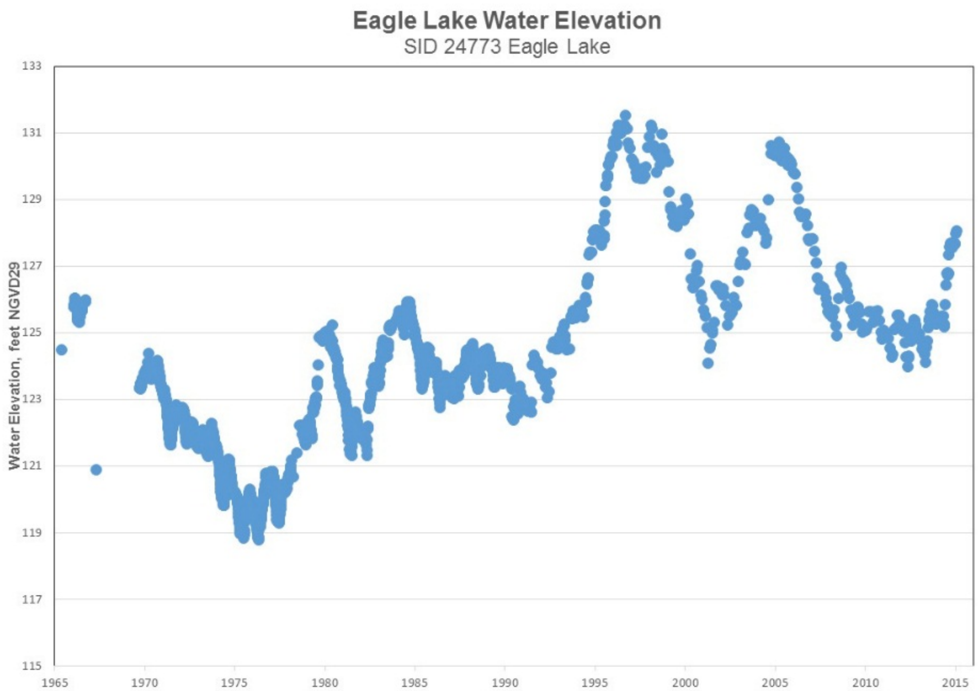

Figure 3. Eagle Lake water levels.

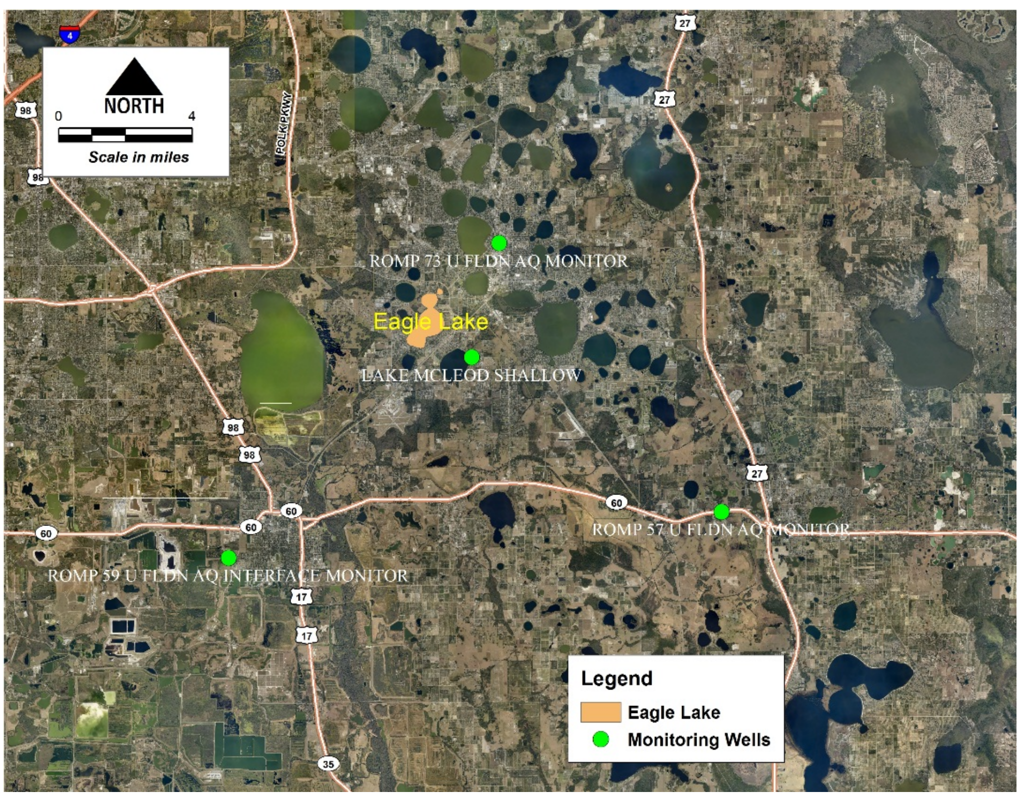

Figure 4. Location of monitor wells near Eagle Lake.

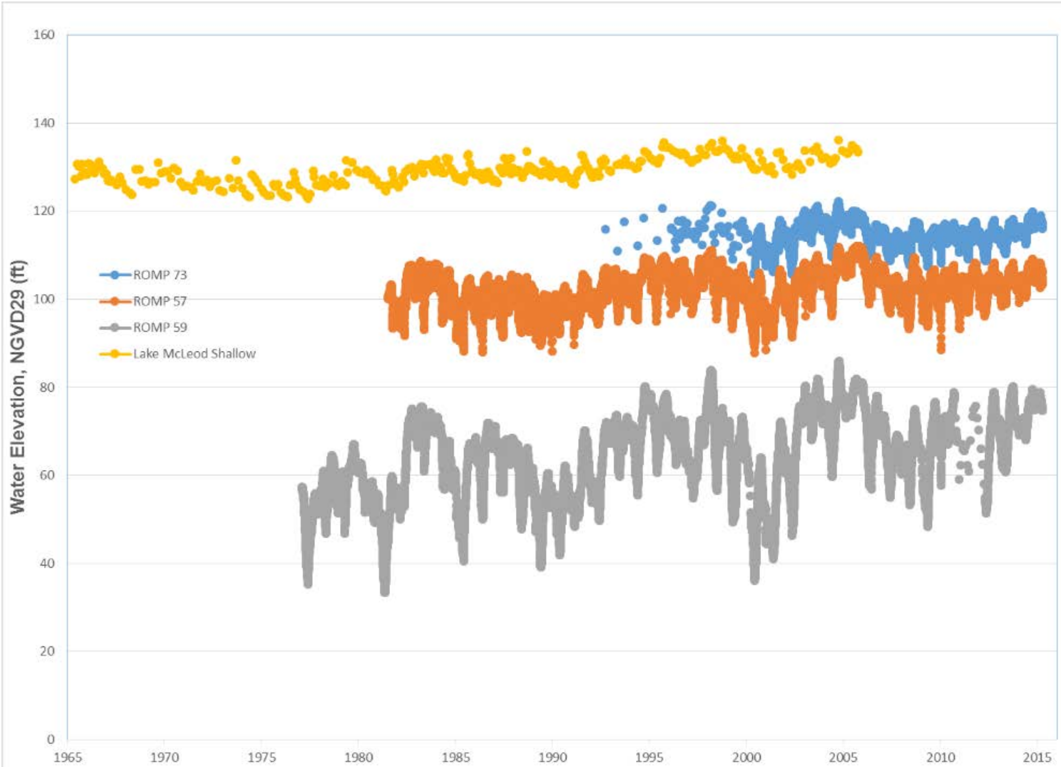

Figure 5. Water levels in monitoring wells near Eagle Lake.

respectively (Figures 4 and 5). Data for these two wells began in 1981 and 1977, respectively. The Lake McLeod Shallow well (SID 24749), located a little over 1 mile from the southeast shore of Eagle Lake (Figures 4 and 5), was the only surficial aquifer monitor well in the area with a long-term period of record. Unfortunately, the well was destroyed in 2005. Data for the well was consistently collected since 1965.

Land and Water Use

Water use in the area of Eagle Lake has changed over the years. Figure 6 shows the land use around Eagle Lake in 1968. Much of the land use at that time consisted of citrus groves. Irrigation of citrus groves became more prevalent in the 1960s when it was determined that efficient irrigation could greatly improve crop yield. Also, water use by the phosphate industry, centered in an area approximately 20 miles to the southwest of Eagle Lake, began to increase significantly throughout the late 1960s and 1970s. A ring of exposed lake bottom can be seen in Figure 6, possibly resulting from the effects of increased groundwater withdrawals and lower rainfall on the lake. Today, land use and water use have changed (Figure 2 and 7, and Table 1). Land use has become more rural and urban, replacing much of the citrus. The estimated total groundwater use average from 2008 to 2012 within one mile of the lake is approximately 471,000 gallons per day (gpd), of which 40 percent is agricultural use, and 57 percent is public supply use. Within 5 miles of the lake, the estimated total groundwater use average

Figure 6. Land use around Eagle Lake in 1968.

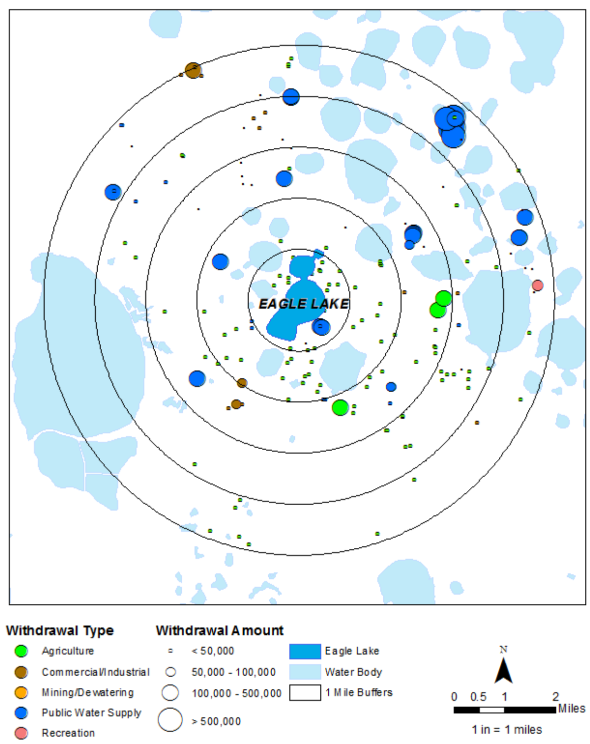

Figure 7. Average surface and groundwater withdrawals surrounding Eagle Lake from 2008 through 2012.

Table 1. Water Use in the Eagle Lake area (2008-2102 average).

Water Use Within 1 Mile of Eagle Lake (GPD)			
Use Type	**SW**	**GW**	**Total**
Agriculture	28,336	187,448	215,784
Commercial/Industrial			-
Mining/Dewatering			-
Public Supply		269,116	269,116
Recreation		14,555	14,555
Total	28,336	471,120	499,456
Water Use Within 5 Miles of Eagle Lake (GPD)			
Use Type	**SW**	**GW**	**Total**
Agriculture	93,177	1,672,225	1,765,402
Commercial/Industrial		339,031	339,031
Mining/Dewatering			-
Public Supply		8,193,147	8,193,147
Recreation		316,484	316,484
Total	93,177	10,520,887	10,614,064

from 2008 to 2012 is approximately 10.5 million gallons per day (mgd), of which 16.6 percent is agricultural use, and 77.2 percent public supply.

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

Figure 9 shows that the most recent 5-year period reflects reduced withdrawal amounts compared to earlier years shown in this figure. This is especially evident for agriculture and mining/dewatering uses. Public supply withdrawals, however, increased and peaked in 2006, but have returned to previous withdrawal levels. Factors that have been cited for declines in agricultural use include uncertainties associated with citrus greening and canker and increased urbanization, which is reflected in reductions in citrus acres in the county. The economic recession that began in 2006 is often cited as a potential influence in the more recent reductions in public supply withdrawals. Because permitted groundwater withdrawal quantities have remained fairly constant (with the exception of changes in how agriculture is permitted in the SWUCA since

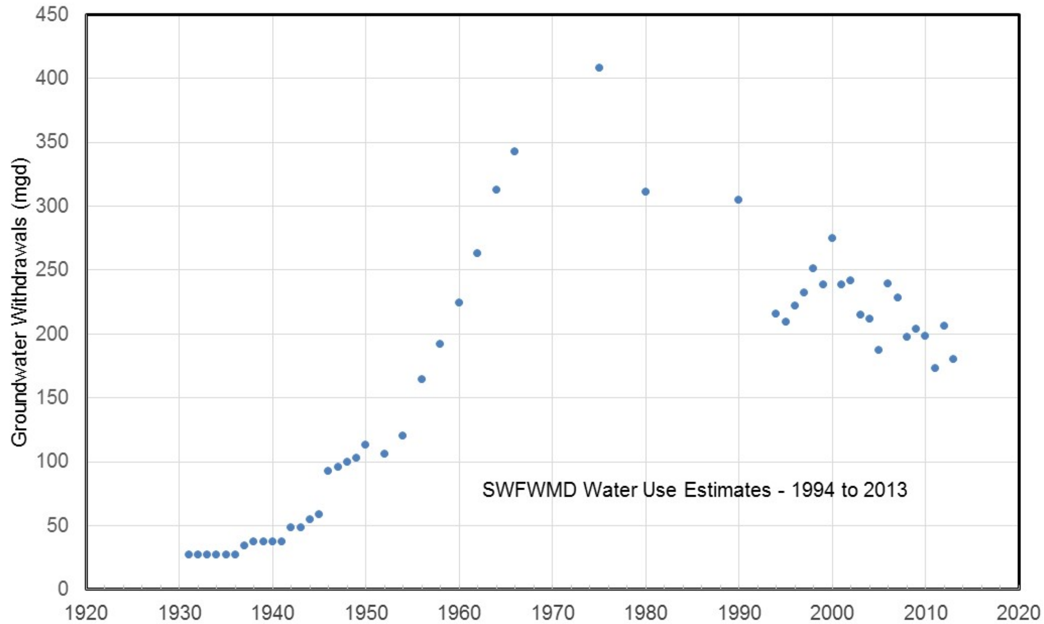

Figure 8. Total groundwater withdrawals in Polk County.

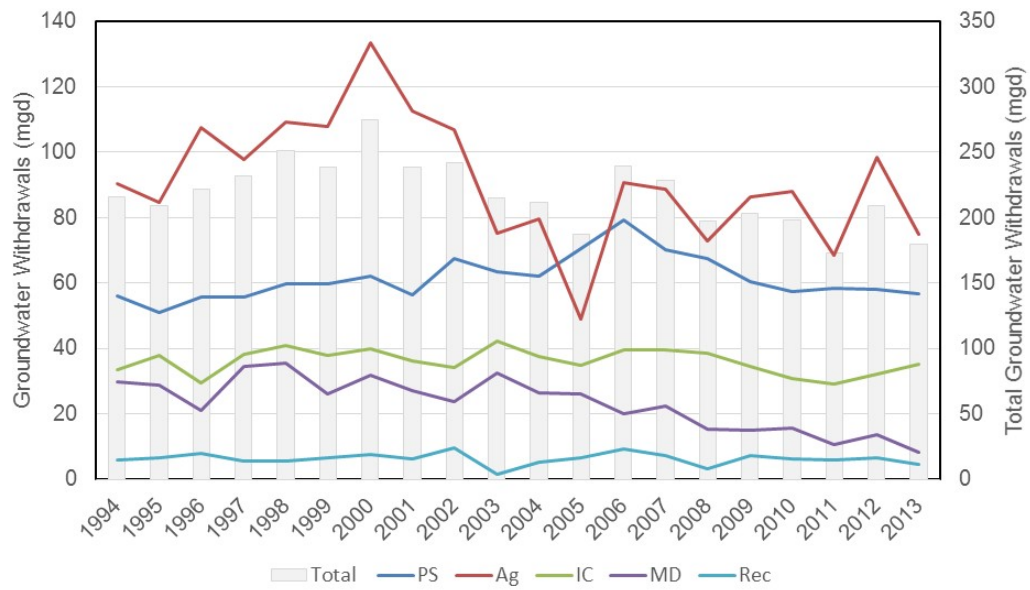

Figure 9. Estimated groundwater use in Polk County by use type (1994-2013)

2003), the permanancy of these declines is uncertain. However, the District continues to work with users to develop alternative supplies to meet water demands.

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

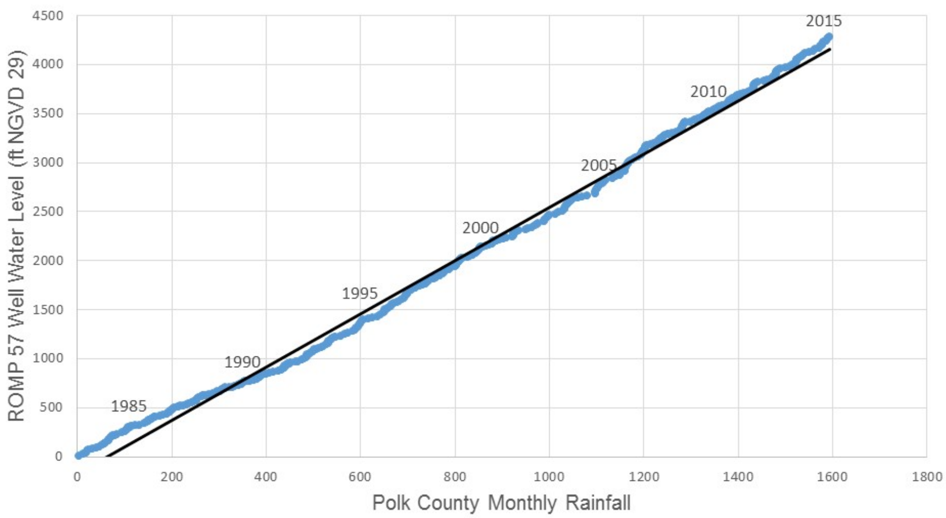

Figure 10. Cumulative double mass curve of ROMP 57 Upper Floridan aquifer monitoring well and Polk County-wide rainfall (1983 to 2014).

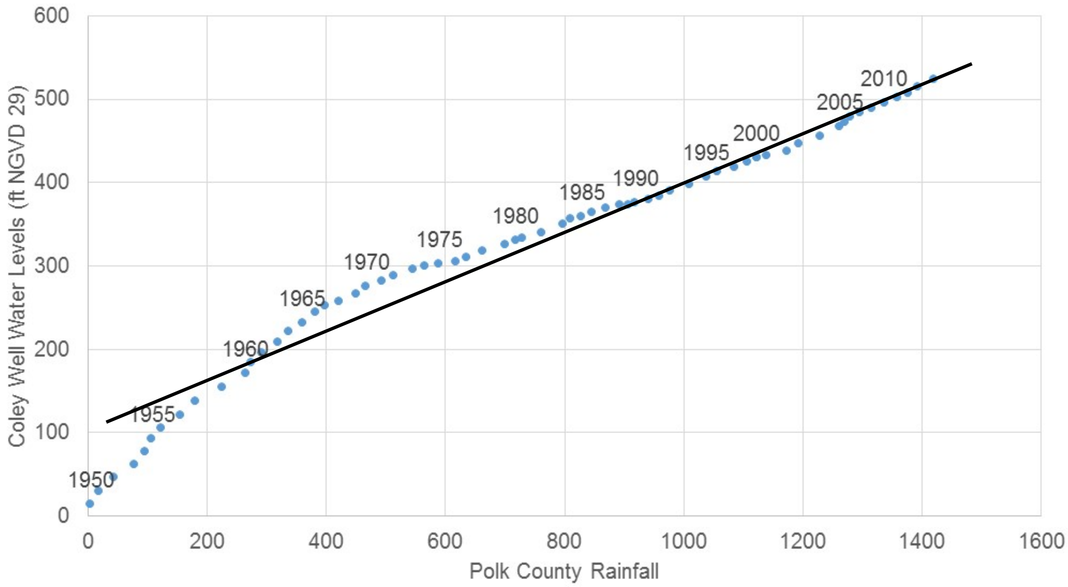

Figure 11. Cumulative double mass curve of the Coley Upper Floridan aquifer monitoring well and Polk County-wide rainfall (1950 to 2014).

C. Purpose of Models

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

In the case of Eagle Lake, withdrawals throughout the area have potentially affected water levels in the lake since the early 1940s. No data from Eagle Lake exists prior to the initiation of groundwater withdrawals. Therefore, the development of a water budget model coupled with a rainfall regression model of the lake was considered essential for estimating long-term Historic percentiles, accounting for changes in the lake's drainage system, and simulating effects of changing groundwater withdrawal rates.

D. Water Budget Model Overview

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

The hydrologic processes in the water budget model include:

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

The water budget model uses a daily time-step, and tracks inputs, outputs, and lake volume to calculate a daily estimate of lake levels. The water budget model for Eagle Lake was calibrated for the period from 1988 to 2013. This period provides the best balance of using available data for all components of the water budget and the desire to develop a long-term water level record.

E. Water Budget Model Components

Lake Stage/Volume

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

Precipitation

After a review of several rain gages in the area of Eagle Lake, a composite of the Winter Haven NWS station rainfall data and NEXRAD data in the District's WMIS database was used for the water budget model. The goal was to use the closest available data to the lake, as long as the data appeared to be high quality (Figure 12). Winter Haven NWS gage data (SID 24534), located about 1.5 miles from Eagle Lake, is available since 1941 collection, but was discontinued in 2008. However, the gage was said to have suspect data after being affected by the hurricanes of 2004, and possibly by previous storms. A replacement gage exists at the Winter Haven airport (Winter Haven Gilbert Airport NWS (SID 844099)), with data available from 1998 to current, but it is approximately 5 miles to the north of Eagle Lake. A third National Weather Service gage is available near Bartow (SID 25164), with available data from 1892 to current. This gage is located about 7.5 miles to the southwest of Eagle Lake. Finally, daily rainfall values estimated through the use of Doppler radar data (NEXRAD) are available in the District's WMIS database from December 29, 1995 to current. Other rain gages were also evaluated, but because of the concerns with later period data at the Winter Haven NWS station, NEXRAD data were used when available, with the Winter Haven NWS data used prior to December 1995. NEXRAD data are expected to be available into the future, so they can be used for future status assessments.

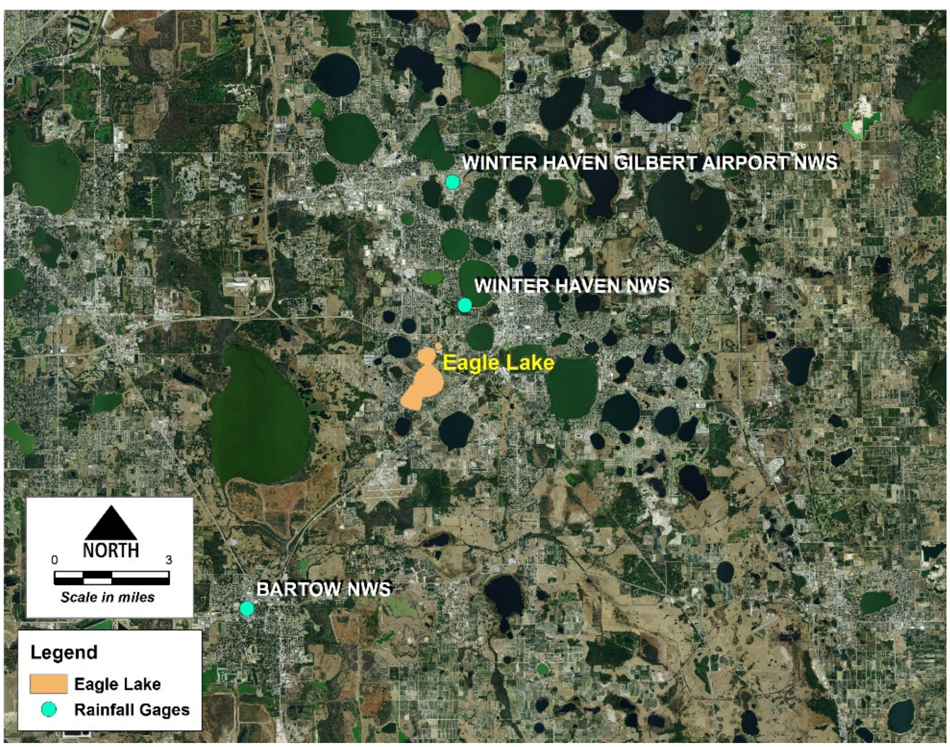

Figure 12. Rain gages assessed in the Eagle Lake water budget model.

Lake Evaporation

Lake evaporation was estimated through use of monthly energy budget evaporation data collected by the U.S. Geological Survey (USGS) at Lake Starr in Polk County (Swancar and others, 2000) (Figure 13). Lake Starr is located approximately 10 miles to the southeast of Eagle Lake. The data were collected from August of 1996 through July of 2011. Monthly Lake Starr evaporation data were used in the Eagle Lake water budget model when available, and monthly averages for the period of record were used for those months when Lake Starr evaporation data were not available.

Jacobs (2007) produced daily potential evapotranspiration (PET) estimates on a 2-square kilometer grid for the entire state of Florida. The estimates began in 1995, and are updated annually. These estimates, available from the USGS, were calculated through 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 the GOES data would increase model error more than using the Lake Starr data directly.

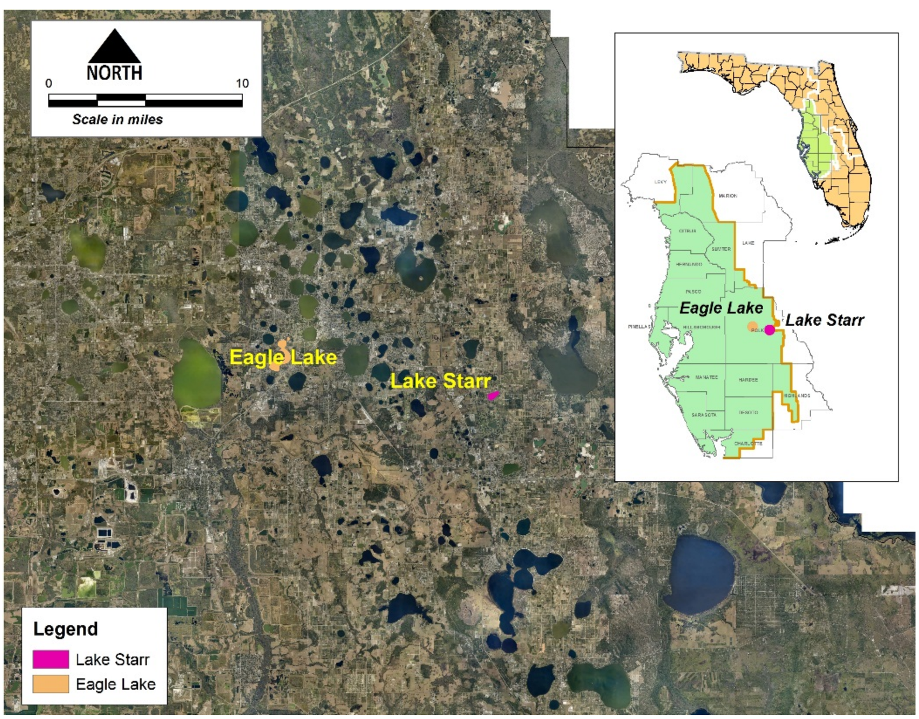

Figure 13. Location of Eagle Lake and Lake Starr (see map inset).

Overland Flow

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

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

The land surrounding Eagle Lake and other lakes in the area can be characterized as a plateau between the higher elevations of the Highlands Ridge to the east, and the Peace River valley to the west. Most of the lakes in the immediate area have relatively small watersheds, with sharp divides between the watersheds of each lake. Several slightly varying estimates of watershed boundaries have been performed in the past for different modeling efforts in the area. One of the most recent set of estimates was developed as part of an effort to model the Lake Hancock watershed for a recovery project in the area (BCI, 2006). The watershed area values developed by BCI were adopted for the Eagle Lake model (Table 2) after an independent check confirming that they are reasonable for modeling purposes (Figure 14). Eagle Lake has no significant inflow from other lakes, so the entire watershed is as shown in Figure 14, which consists of 1,551 acres (including the lake).

The DCIA and SCS CNs used for the direct overland flow portion of the watershed are listed in Table 2. The soils in the area of the lake are mostly A soils, with some C soils along the edge of the lake. Land use in the watershed is mostly low to medium density residential, with some areas of tree crops. A curve number of 48 was used in the model, which was also used for the project performed by BCI (2006). While there are no significant natural inflows to the lake, there are several directly connected drains for street and residential storm water, with no observed retention ponds. It was estimated that 24 percent of the watershed is directly connected impervious area, which again was consistent with the analysis performed by BCI.

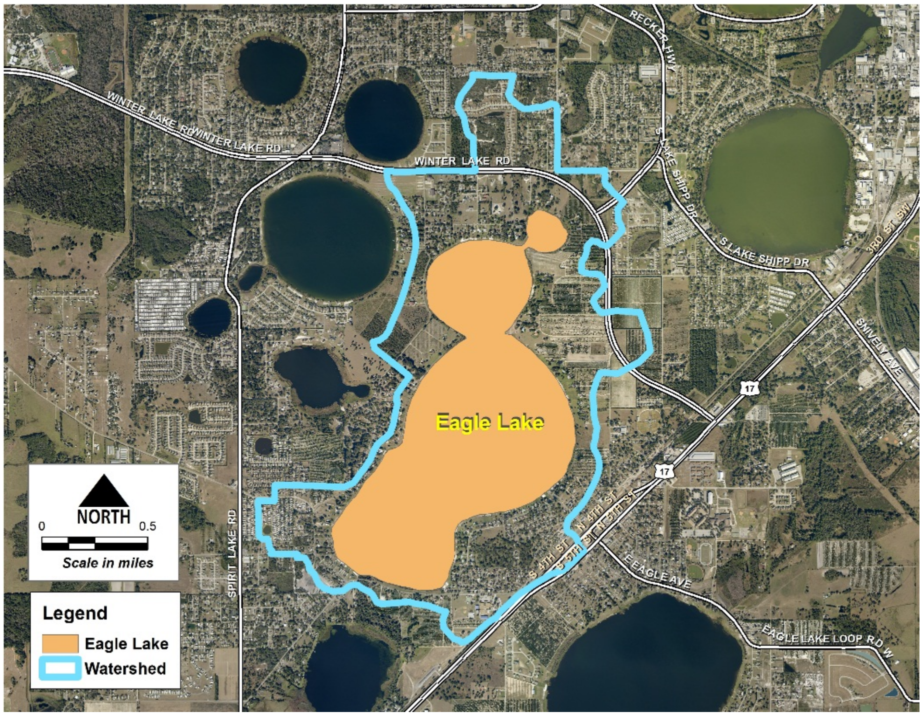

Figure 14. The Eagle Lake watershed.

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

Input Variable	Value
Overland Flow Watershed Size (acres)	1,551
SCS CN for watershed	48
Percent Directly Connected Area	24 percent
FL Monitor Well Used	ROMP 73 Floridan
Surf. Aq. Monitor Well(s) Used	Lake McLeod Shallow
FL Aq. Leakance Coefficient (ft/day/ft)	0.00026
Surf. Aq. Leakance Coefficient East (ft/day/ft)	0.001
Surf. Aq. Leakance Coefficient West (ft/day/ft)	0.0003
Outflow K	0.001
Outflow Invert (ft NGVD 29)	129.3
Inflow K	N/A
Inflow Invert (ft NGVD 29)	N/A

Inflow and Discharge via Channels from Outside Watersheds

While there are no significant surface water inflows via channels on Eagle Lake, there is a significant structured outflow from the lake's watershed (i.e. "channel flow"). To estimate flow out of Eagle Lake, the predicted elevation of the lake from the previous day is compared to the controlling elevation. Control elevations were determined based on professional surveying performed in the area. If the lake elevation is above the controlling elevation, the difference is multiplied by the current area of the lake and an "outflow coefficient." The coefficient represents a measure of channel and structure efficiency, and produces a rough estimate of volume lost from the lake. This volume is then subtracted from the current estimate of volume in the lake.

Discharge from Eagle Lake occurs via a concrete box culvert and ditch system on the southern end of the lake. The control elevation was determined to be the bottom of the culvert (129.3 feet NGVD29). The outflow then travels approximately 1,500 feet to Millsite Lake (Figure 2).

Flow from and into the surficial aquifer and Upper Floridan aquifer

Water exchange between Eagle Lake and the underlying aquifers is estimated using a leakance coefficient and the head difference between the lake and the aquifer levels. For each day of the simulation period, surficial aquifer and Upper Floridan aquifer leakage volumes were calculated independently. Leakance coefficients for each aquifer were then determined through calibration.

The ROMP 73 Floridan well is the closest Upper Floridan aquifer monitor well to Eagle Lake, and was used to represent the potentiometric surface at the lake (Figures 4 and 5). However, several adjustments to the data collected from ROMP 73 were made for purposes of the model. First, because regular data collection did not begin at ROMP 73 until 1996, and the starting year for the water budget model is 1988, a correlation between ROMP 73 and ROMP 57, the next closest Upper Floridan aquifer monitor well with characteristics similar to ROMP 73 (Figures 4 and 5), was performed to estimate water levels in ROMP 73 before data collection began at that well. Secondly, because the frequency of data collection at ROMP 57 has been regularly daily since data collection began at ROMP 57 (1981), the transformed data from ROMP 57 can also be used to infill data at ROMP 73 when data collection there was monthly, or when data is missing from the ROMP 73 records. When data does not exist at either well, a simple average between the last and next values is used. Finally, because the elevation of recent potentiometric surface maps at the lake appears to be approximately 6 feet lower than those at the ROMP 73 well, a 6-foot adjustment was made to the values of the infilled ROMP 73 record to better represent potentiometric levels in the area of the lake.

The only surficial well in the area with any significant data is the Lake McLeod Shallow well (Figures 4 and 5). Data at this well begin before the water budget model begins, but the well was destroyed in 2005. The land surface in the northeast area of the lake is generally 10 to 20 feet higher than that in the southwest area of the lake, suggesting a northeast to southwest flow pattern in the surficial aquifer. While the Lake McLeod Shallow well is a little more than one mile from the southeast shore of Eagle Lake, soils types and topographic elevations are similar, and it likely reasonably represents the characteristics of the surficial aquifer near Eagle Lake. Because the land surface elevation at the well is approximately the same as the elevation on the northeast shore of Eagle Lake, water levels collected from the well were used to represent the water table there. Water levels from 2005 to 2013 where simulated based on a regression between water levels in Lake McLeod and Lake McLeod Shallow. Water levels collected at Millsite Lake, into which Eagle Lake discharges, were used to represent the water table in the southwest area of the lake. However, the lake water levels were adjusted up 5 feet to maintain the head difference seen between the Lake McLeod Shallow well and Lake McLeod. The data from Lake McLeod Shallow and Millsite Lake are presented in Figure 15. A simple approach was used to fill in weekly or monthly data (or missing data) for both sets of data to create daily values by using the last recorded data value.

F. Water Budget Model Approach

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

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

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

G. Water Budget Model Calibration Discussion

Based on visual inspection of Figure 16, with the exception of a period in the late-1990s, most of the model appears to be reasonably well calibrated. The model does not reach as high as the field data for Eagle Lake during this period. A review of Table 3 shows that the differences in medians (P50) and P90 percentiles between the data and model for the lake are 0.0 and 0.4 feet, respectively, while the P10 is off by 1.4 feet (with the model lower).

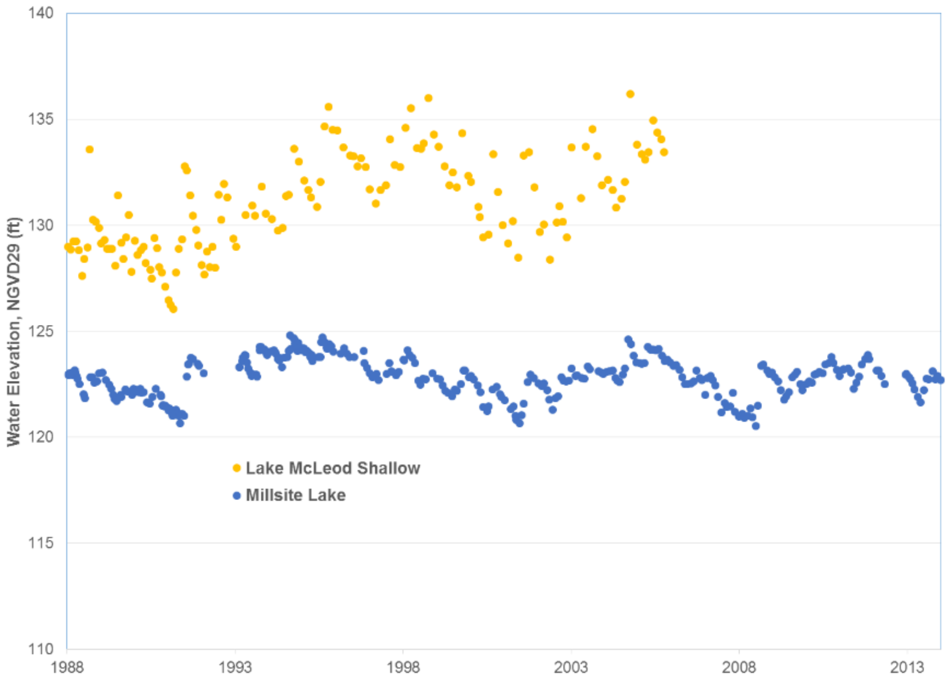

Figure 15. Water Level data from Lake McLeod Shallow monitor well and Lake Millsite from for the water budget model period.

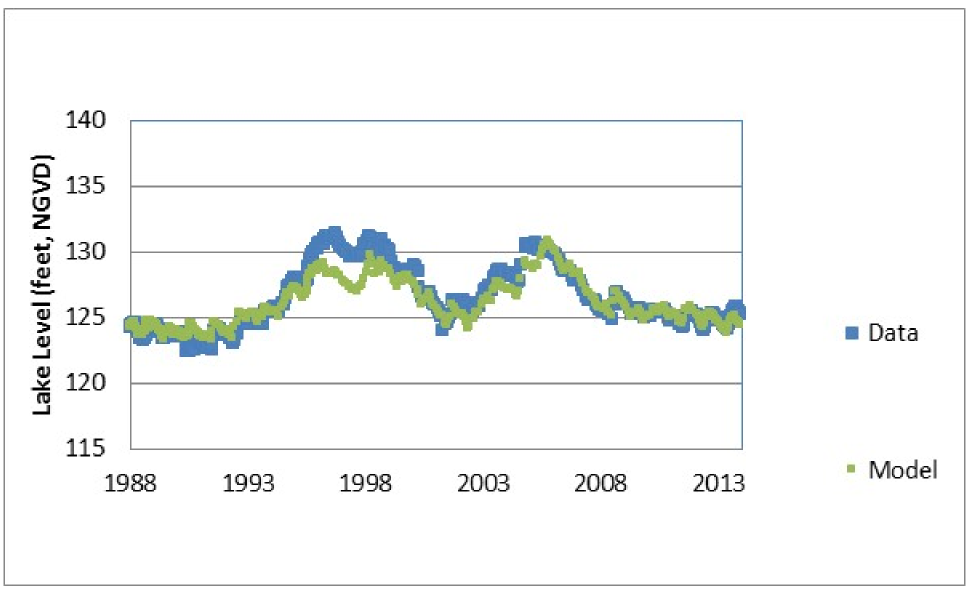

Figure 16. Modeled water levels predicted for the calibrated Eagle Lake water budget (Model) and measured levels used for the model calibration (Data).

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

	Data	Model
P10	130.1	128.7
P50	125.2	125.2
P90	123.4	123.8

Table 4. Eagle Lake Water Budget (1988-2013)

Inflows	Rainfall	Surficial Aquifer Ground water Inflow (West)	Surficial Aquifer Ground water Inflow (East)	Floridan Aquifer Ground water Inflow	Runoff	DCIA Runoff	Inflow via channel	Total
Inches/year	47.7	11.6	1.1	0.0	1.4	16.9	0.0	78.7
Percentage	60.6	14.7	1.4	0.0	1.8	21.5	0.0	100.0
Outflows	**Evaporation**	**Surficial Aquifer Ground water Outflow (West)**	**Surficial Aquifer Ground water Outflow (East)**	**Floridan Aquifer Ground water Outflow**			**Outflow via channel**	**Total**
Inches/year	58.1	0.0	0.1	20.2			0.2	78.6
Percentage	73.9	0.0	0.1	25.8			0.2	100.0

In an effort to achieve a better calibration, several alterations were assessed. Several alternative rain gages were tested, including the Winter Haven, Bartow, Lakeland, and Mountain Lake gages maintained by the National Weather Service (NWS). All resulted in a calibration very similar to that in Figure 16. An assessment of how runoff was generated in the model was performed, but no reasonable adjustments produced enough runoff to provide a better calibration. Sensitivity analysis was performed on the attributes of the outfall in an attempt to simulate possible backflow or clogging of the drainage system, but nothing that was tried could account for the volume needed to improve the calibration. Finally, an investigation into the possibility of other sources of water that might have entered the lake during that period was undertaken, but no evidence of additional flows was found.

Because of this, the calibration was reassessed without using the field water level data from 1996 through 1998, with the results presented below.

H. Water Budget Model Calibration Reassessment

With the data from 1996 through 1998 removed, only small changes in the input parameters (Table 5) were needed. The percentile comparison in Table 6 was achieved. The results are presented graphically in Figure 17. The revised water budget is presented in Table 7, although there are very little differences between Table 7 and Table 4.

Table 5. Model inputs for the Eagle Lake water budget model after reassessment.

Input Variable	Value
Overland Flow Watershed Size (acres)	1,551
SCS CN for watershed	48
Percent Directly Connected Area	24 percent
FL Monitor Well Used	ROMP 73 Floridan
Surf. Aq. Monitor Well(s) Used	Lake McLeod Surficial
FL Aq. Leakance Coefficient (ft/day/ft)	0.00024
Surf. Aq. Leakance Coefficient East (ft/day/ft)	0.001
Surf. Aq. Leakance Coefficient West (ft/day/ft)	0.0001
Outflow K	0.001
Outflow Invert (ft NGVD 29)	129.3
Inflow K	N/A
Inflow Invert (ft NGVD 29)	N/A

Table 6. Comparison of percentiles of measured lake level data compared to modified calibration percentiles from the model (all in feet NGVD 29, with the period from 1996-1998 not used).

	Data	Model
P10	128.5	128.1
P50	124.9	124.9
P90	123.4	123.7

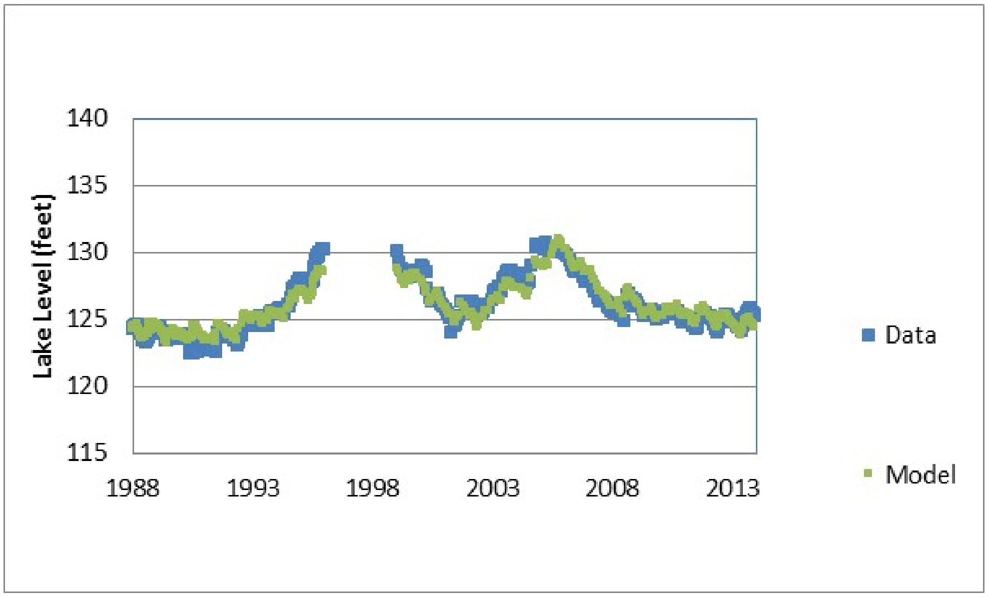

Figure 17. Modeled water levels predicted for the revised calibrated Eagle Lake water budget (Model) and measured levels used for the model calibration (Data).

Table 7. Modified Eagle Lake Water Budget (1988-2013)

Inflows	Rainfall	Surficial Aquifer Ground water Inflow (East)	Surficial Aquifer Ground water Inflow (West)	Floridan Aquifer Ground water Inflow	Runoff	DCIA Runoff	Inflow via channel	Total
Inches/year	47.7	11.7	0.0	0.0	1.4	16.9	0.0	77.7
Percentage	61.4	15.0	0.0	0.0	1.8	21.8	0.0	100.0
Outflows	Evaporation	Surficial Aquifer Ground water Outflow (East)	Surficial Aquifer Ground water Outflow (West)	Floridan Aquifer Ground water Outflow			Outflow via channel	
Inches/year	58.1	0.0	0.7	18.7			0.2	77.7
Percentage	74.8	0.0	1.0	24.1			0.2	100.0

A review of Table 6 shows that the differences in medians (P50) and P90 percentiles between the data and model for the lake are 0.0 and 0.3 feet, respectively, while the P10 is now only off by 0.4 feet (with the model higher).

I. Water Budget Model Results

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

Two hydrologic models available for the area of Eagle Lake were used for the analysis. The Peace River Integrated Model (PRIM) (HydroGeoLogic, Inc., 2011) is a transient integrated numerical model developed for the Peace River watershed. The PRIM model has the ability to account for groundwater, surface water, and rainfall/recharge, as well as the interactions between them. The East-Central Florida Transient Model (ECFT) (Sepulveda and others, 2012) is a groundwater flow model using the MODFLOW-2005 code (McDonald and Harbaugh, 1988), which uses model-independent estimates of partitioning rainfall into ET, streamflow, and aquifer recharge. The domain of both models includes the Eagle Lake area, and both represent the most current understanding of the hydrogeologic system in the area.

The PRIM was used to determine the drawdown in the surficial aquifer and Upper Floridan aquifer in response to groundwater withdrawals in the area. The base model run for the reduced withdrawal scenarios included rainfall and groundwater withdrawals that occurred during the period 1994 to 2006. Over this period, groundwater withdrawals within the entire Southern Water Use Caution Area (SWUCA) (Southwest Florida Water Management District, 2006) and the portion of Polk County within the SWUCA averaged about 630 mgd and 230 mgd, respectively. Two PRIM scenarios were run in order to quantify the response of Upper Floridan aquifer water levels to groundwater withdrawals. The scenarios included 25 percent and 50 percent reductions in groundwater withdrawals while maintaining all other parameters the same as in the base model run. This was done to avoid the potential problems that can occur with models when withdrawals are completely removed from the simulation, such as when water levels rise above land surface. Within Polk County, withdrawals were reduced by about 57.5 mgd and 115 mgd respectively for the two scenarios. As expected, the UFA water level response to the reductions was generally linear. Withdrawal reductions resulting from the 50 percent scenario (about 4.3 feet) were doubled (8.5 feet) to estimate total water level drawdown resulting from current withdrawals. This value was consistent with results of similar model scenarios run using both the ECFT and the District-wide Regulation Model (DWRM) (Rumbaugh, 2007), another model that covers the Eagle Lake area.

In the surficial aquifer, drawdowns were more spatially varied than in the Upper Floridan aquifer. At many cells, it was found that the responses of surficial water levels to changes in groundwater withdrawals were also generally linear. Based on this and comparison to results of the ECFT model, the surficial aquifer drawdown for the no-pumping scenario was estimated to be 1 foot.

Modifications to the Upper Floridan aquifer time series used in the water budget model were based on results of the ECFT groundwater flow model for a 50 percent reduction in groundwater withdrawals. Whereas the PRIM results provided the total change in water levels for the Historic period, the ECFT model provided information that was used to modify water levels on a monthly basis for use in the water budget model. Differences in water levels between the base model run and the 50 percent reduced groundwater withdrawals run were adjusted to achieve an overall average change of 8.5 feet as predicted using the PRIM. The adjusted differences were added to the base run to get a Historic water level time series. Monthly factors were then calculated (adjusted water level divided by base model water level) and used to modify the Upper Floridan aquifer time series used in the water budget model to estimate the Historic water level time series. The results are shown in Figure 18.

Figure 19 presents the results of the calibrated water budget model for Eagle Lake with and without the effects of groundwater withdrawals. Table 8 presents the percentiles based on the model output.

J. Rainfall Regression 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, 2002). LOC is preferable for this application since it produces a result that best retains the variance (and therefore best retains the "character") of the original data. By using this technique, the limited years of calibrated model water levels can be projected back to create a simulated data set representing over 60 years of lake levels, based on the relationship between modeled water levels and actual rainfall.

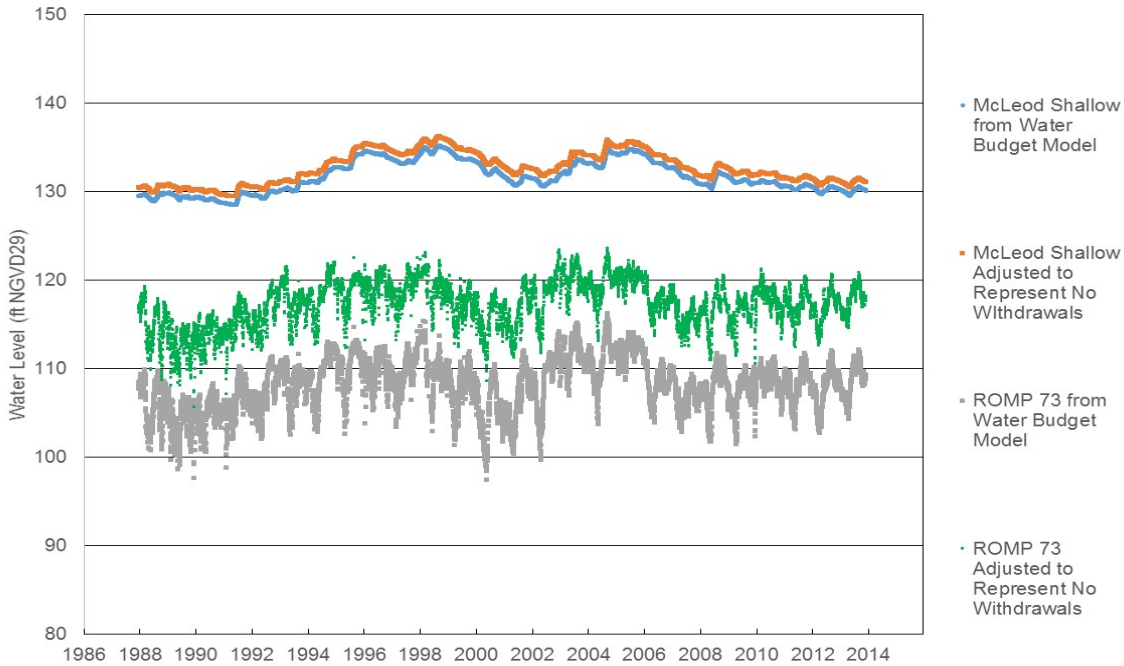

Figure 18. Adjusted water levels for the ROMP 73 and McLeod Shallow monitor wells, representing a “no withdrawals” scenario.

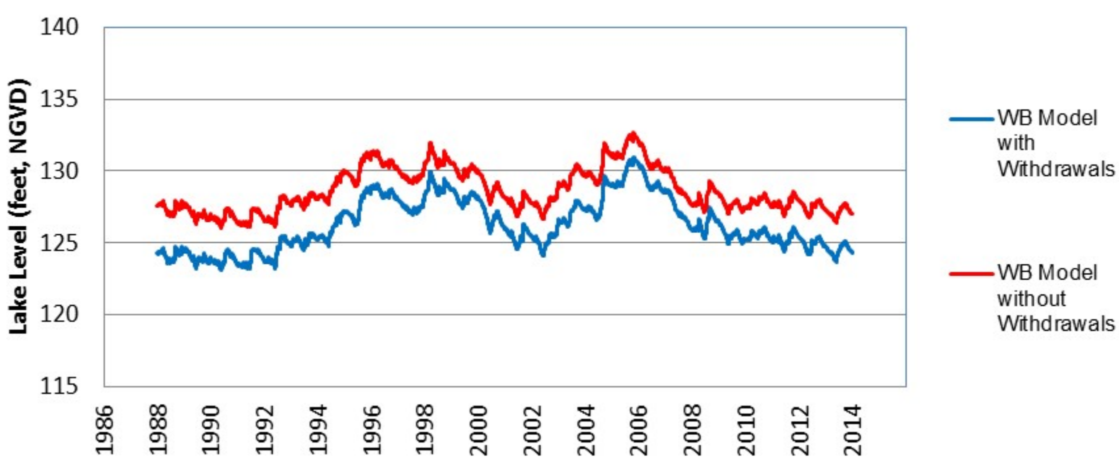

Figure 19. Calibrated Water Budget Model for Eagle Lake with and without the effects of withdrawals.

Table 8. Historical lake level percentiles determined using the water budget model (feet NGVD 29).

Percentile	Elevation
P10	130.9
P50	128.2
P90	126.9

In this application, the simulated lake water levels representing Historic conditions were correlated with long-term rainfall data. For the regression analysis, additional representative rainfall records were added to the rainfall data used in the water budget model (1988-2013). Rainfall data from the Winter Haven NWS gage were used to extend data from the calibration period back to January 1930.

Rainfall was 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 were separately used, the results were compared, and the weighted rainfall series with the highest coefficient of determination (R^2) was chosen as the best model.

Rainfall was correlated to the water budget model results for the entire period used in the water budget model (1988-2013), and the results from 1946-2013 (68 years) were produced. For Eagle Lake, the 6-year weighted model had the highest coefficient of determination, with an R^2 of 0.61. The results are presented in Figure 20.

In an attempt to produce Historic percentiles that apply significant weight to the results of the water budget models, the rainfall LOC results for the period of the water budget model are replaced with the water budget model results. Therefore, the LOC rainfall model results are used for the period of 1946-1987, while the water budget results are used for the period of 1988-2013. These results are referred to as the "hybrid model." The resulting Historic percentiles for the hybrid model are presented in Table 9. Note that the difference between the P10, P50, and P90 percentiles from the water budget model (Table 8) and those from the hybrid rainfall model (Table 9) for Eagle Lake are 0.9, 0.9, and 0.5 feet, respectively, with the hybrid model being higher in all cases. Therefore, there are relatively large differences in the Historic percentiles between the two models.

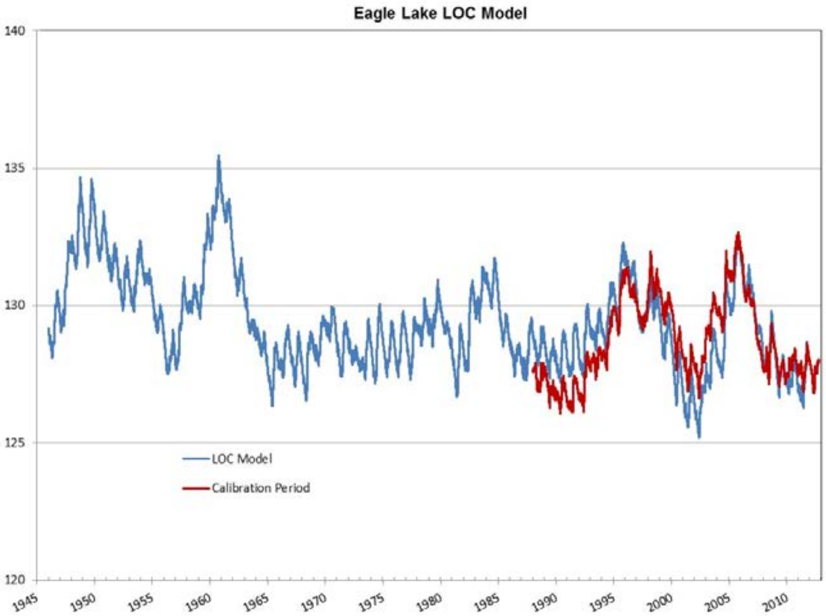

Figure 20. LOC model results for Eagle Lake.

Table 9. Historic percentiles as estimated using the hybrid model from 1946 to 2013 (feet NGVD 29).

Percentile	Eagle Lake
P10	131.8
P50	129.1
P90	127.4

J. Final Assessment

Following assessment of several lakes in the area of Eagle Lake, it was noticed that most lakes were experiencing poor correlation in the 1988 to 1995 period (approximately) of the LOC models (Figure 20). It is concluded that this may be the result of not being able to account for changing water use impacts over the entire water budget model period.

Analyses were performed to assess the LOC for a number of sub-periods of the 1988 to 2013 time range. It was found that the correlation during the early period was poor (as suspected), while other sub-periods correlated well. Through trial and error, it was found that the correlation improved significantly when data prior to the early to mid-1990s were removed from the LOC model, with the best results achieved when the 1988 through 1994 period was left out of the LOC model. As discussed in Section B earlier in this memorandum, assessment of Polk County-wide withdrawals and Upper Floridan aquifer levels provided strong evidence that groundwater withdrawal patterns appear to have changed sometime in the early to mid-1990s, and have remained reasonably consistent since that time. The results of the LOC are also consistent with this conclusion. The goal of this step in the analysis is to develop a LOC model that simulates Long-term water levels with the effects of groundwater pumping removed (Figures 18 and 19). Given the diverse and dispersed nature of groundwater withdrawals affecting the lake, it was difficult to determine a multi-period correction for groundwater impacts. For this reason, the water budget model results used in the LOC model were limited to a period of relatively consistent groundwater impacts from 1995 to 2013. For this assessment, the 5-year weighted model had the highest correlation coefficient, with an R^2 of 0.83. The results are presented in Figure 21.

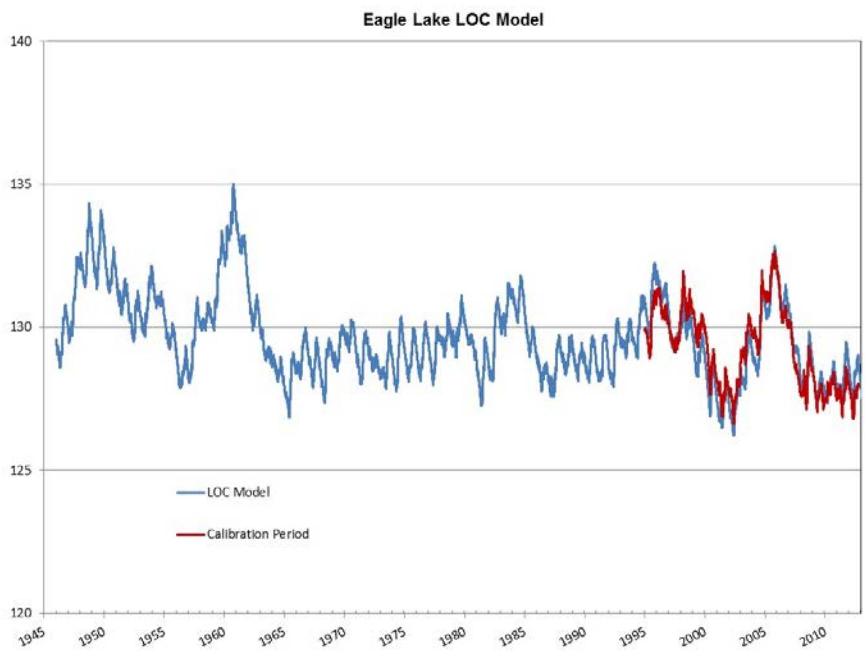

Figure 21. Revised LOC model results for Eagle Lake.

As before, 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 1946-1994, while the water budget results are used for the period of 1995-2013 (the “revised hybrid model”). The resulting Historic percentiles for the revised hybrid model are presented in Table 10. Note that the difference between the P10, P50, and P90 percentiles from the water budget model (Table 8) and those from the revised hybrid rainfall model (Table 10) for Eagle Lake are 0.7, 1.3, and 1.0 feet, respectively, with the revised hybrid model being higher in all cases. The difference between the P10, P50, and P90 percentiles from the original hybrid model (Table 9) and those from the revised hybrid rainfall model (Table 10) for Eagle Lake are 0.2, 0.4, and

0.5 feet, respectively, with the revised hybrid model being higher for the P50 and P90, and lower for the P10.

Table 10. Historic percentiles as estimated by the reassessed hybrid model from 1946 to 2013 (feet NGVD 29).

Percentile	Eagle Lake
P10	131.6
P50	129.5
P90	127.9

K. Conclusions

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

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APPENDIX B

Technical Memorandum

September 10, 2015

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

FROM: Michael C. Hancock, P.E., Senior Professional Engineer, Water Resources Bureau
David Carr, Staff Environmental Scientist, Water Resources Bureau

Subject: Eagle Lake Initial Minimum Levels Status Assessment

A. Introduction

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

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

B. Background

Eagle Lake is located in central Polk County, approximately 0.3 miles northwest of U.S. Highway 17 and immediately south of Winter Haven Road in the City of Eagle Lake (Figure 1). The lake lies within the Peace River watershed.

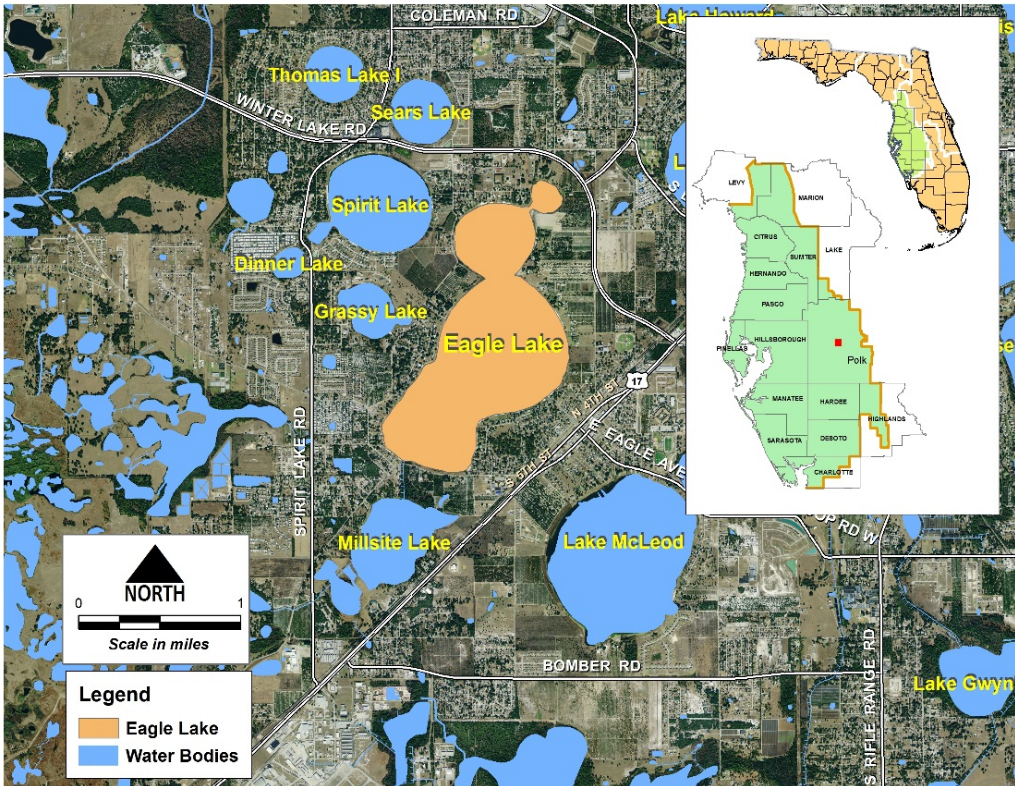

Figure 1. Location of Eagle Lake in Polk County, Florida.

C. Revised Minimum Levels Proposed for Eagle Lake

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

Table 1. Proposed Minimum Levels for Eagle Lake.

Proposed Minimum Levels	**Elevation in Feet** NGVD 29
High Minimum Lake Level	131.2
Minimum Lake Level	129.1

D. Status Assessment

The lake status assessment approach involves using actual lake stage data for Eagle Lake from 1995 through 2013, which was determined to represent the “Current” period. The Current period represents a recent “Long-term” period when hydrologic stresses (including groundwater withdrawals) and structural alterations are reasonably stable. “Long-term” is defined as a period that has been subjected to the full range of rainfall variability that can be expected in the future. As demonstrated in Hancock and Barcelo (2015), groundwater withdrawals during this period were relatively consistent. To create a data set that can reasonably be considered to be “Long-term”, a line of organic correlation (LOC) analysis was performed on the lake level data from the Current period. The LOC is a linear fitting procedure that minimizes errors in both the x and y directions and defines the best-fit straight line as the line that minimizes the sum of the areas of right triangles formed by horizontal and vertical lines extending from observations to the fitted line (Helsel and Hirsch, 2002). The LOC is preferable for this application since it produces a result that best retains the variance (and therefore best retains the "character") of the original data. This technique was used to develop the minimum levels for Eagle Lake (Hancock and Barcelo, 2015). By using this technique, the limited years of Current lake level data can be projected back to create a simulated data set representing over 60 years of lake levels, based on the current relationship between lake water levels and actual rainfall.

The same rainfall data set used for setting the minimum levels for Eagle Lake was used for the status assessment (Hancock and Barcelo, 2015). The best resulting correlation for the LOC model created with measured data was the 7-year weighted period (the best correlation for the LOC analyses created with Historic data to set the Eagle Lake MFL was 5 years), with a coefficient of determination of 0.75. The resulting lake stage exceedance percentiles are presented in Table 2.

Table 2. Comparison of lake stage exceedance percentiles derived from the lake stage/LOC results, exceedance percentiles of the 1995 to 2013 data, and the revised minimum levels proposed for Eagle Lake.

Percentile	**Lake Stage/LOC Model Current Withdrawal Scenario Results** Elevation in feet NGVD 29	**1995 to 2013 Data** Elevation in feet NGVD 29	**Proposed Minimum Levels** Elevation in feet NGVD 29
P10	131.3	130.5	131.2
P50	127.9	127.3	129.1

As an additional piece of information, Table 2 also presents the same percentiles calculated directly from the measured lake level data for Eagle Lake for the period from 1995 through 2013. A limitation of these values is that the resulting lake stage exceedance percentiles are representative of rainfall conditions during only the past 18 years, rather than the longer-term rainfall conditions represented in the 1946 to 2013 LOC model simulations.

A comparison of the LOC model with the revised minimum levels proposed for Eagle Lake indicates that the Long-term P10 is 0.1 feet higher than the proposed High Minimum Lake Level, and the Long-term P50 is 1.2 feet lower than the proposed Minimum Lake Level. The P10 elevation derived directly from the 1995 to 2013 lake data is 0.7 feet lower than the proposed High Minimum Lake Level and the P50 elevation is 1.8 feet lower than the proposed Minimum Lake Level. Differences in rainfall between the shorter 1995 to 2013 period and the longer 1946 to 2013 period used for the LOC modeling analyses likely contribute to the differences between derived and measured lake stage exceedance percentiles. Additionally, differences between actual withdrawal rates and those used in the models may have contributed to some of the differences in the percentiles.

E. Conclusions

Based on the information presented in this memorandum, it is concluded that Eagle Lake water levels are currently below the revised Minimum Lake Level, and above the revised High Minimum Lake Level proposed for the lake. These conclusions are supported by comparison of percentiles derived from 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. In addition, Eagle Lake is included in the Recovery Strategy for the Southern Water Use

Caution Area Recovery Strategy (40D-80.074, F.A.C). Therefore, the analyses outlined in this document for Eagle Lake will be reassessed by the District as part of this plan.

F. References

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