Minimum and Guidance Levels for Lake Damon in Highlands County, Florida

May 30, 2018

Resource Evaluation Section
Water Resources Bureau
Southwest Florida
Water Management District

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Cover: Lake Damon December 2016 (Southwest Florida Water Management District).

Contents

Definitions

Category 1 Lakes	Lakes with lake-fringing cypress swamp(s) greater than 0.5 acre in size where Structural Alterations have not prevented the Historic P50 from equaling or rising above an elevation that is 1.8 feet below the Normal Pool elevation of the cypress swamp(s).
Category 2 Lakes	Lakes with lake-fringing cypress swamp(s) greater than 0.5 acre in size where Structural Alterations have prevented the Historic P50 from equaling or rising above an elevation that Is 1.8 feet below the Normal Pool and the lake fringing cypress swamp(s) remain viable and perform functions beneficial to the lake despite the Structural Alterations.
Category 3 Lakes	Lakes without lake-fringing cypress swamp(s) greater than 0.5 acre in size.
Control Point Elevation	The elevation of the highest stable point along the outlet profile of a surface water conveyance system that principally controls lake water level fluctuations
Current	A recent Long-term period during which Structural Alterations and hydrologic stresses are stable.
District	Southwest Florida Water Management District (SWFWMD)
Dynamic Ratio	The ratio of a lake's surface area (in square kilometers) to the mean depth of the lake (in meters). Used to determine at what water level a lake is susceptible to decreased water quality, i.e., turbidity, due to wave disturbance of bottom sediments.
F.A.C.	Florida Administrative Code

FDEP	Florida Department of Environmental Protection
F.S.	Florida Statutes
Guidance Levels	Water levels determined by the District and used as advisory information for the District, lake shore residents and local governments, or to aid in the management or control of adjustable structures.
High Guidance Level (HGL)	The expected Historic P10 elevation. Provided as an advisory guideline for the construction of lake shore development, water dependent structures, and operation of water management structures.
High Minimum Lake Level (HMLL)	The elevation that a lake's water levels are required to equal or exceed ten percent of the time on a Long-term basis
Historic	A Long-term period when there are no measurable impacts due to withdrawals, and Structural Alterations are similar to current conditions.
Historic P10	The expected Historic P10 elevation; *I.e.,* the elevation of the water surface of a lake or wetland that is expected to be equaled or exceeded ten percent of the time based on a Long-term period when there are or were no measurable impacts due to withdrawals, and Structural Alterations are similar to current conditions.
Historic P5O	The expected Historic P50 elevation; *I.e.,* the elevation of the water surface of a lake or wetland that is expected to be equaled or exceeded fifty percent of the time based on a Long-term period when there are or were no measurable impacts due to withdrawals, and Structural Alterations are similar to current conditions.

Historic P90	The expected Historic P90 elevation; *I.e.,* the elevation of the water surface of a lake or wetland that is expected to be equaled or exceeded ninety percent of the time based on a Long-term period when there are or were no measurable impacts due to withdrawals, and Structural Alterations are similar to current conditions.
Hydrologic Indicators	Biological and physical features, as listed In Section 373.4211(20), Florida Statutes, which are representative or indicative of previous water levels.
Leakance	Relative to groundwater movement, the ratio of the vertical hydrologic conductivity of the confining bed to the thickness of the confining bed (Anderson and Woessner, 2002); a measure of how easily water can pass through a confining unit.
Long-term	An evaluation period utilized to establish minimum flows and levels, to determine compliance with established minimum flows and levels, and to assess withdrawal impacts on established minimum flows and levels, that represents a period which spans the range of hydrologic conditions which can be expected to occur based upon historical records, ranging from high water levels to low water levels. In the context of a predictive model simulation, a Long-term simulation will be insensitive to temporal fluctuations in withdrawal rates and hydrologic conditions, so as to simulate steady-state, average conditions. In the context of an average water level, the average will be based upon the historic expected range and frequency of levels. relative to minimum level establishment and compliance, where there are six years or more of competent data, a minimum of a six-year evaluation period will be used; but the available data and reasonable scientific judgement will dictate whether a longer period is used. Where there are less than six years of competent data, the period used will be dictated by the available data and a determination, based on reasonable scientific

	Judgement, that the period is sufficiently representative of Long-term conditions.
Low Guidance Level (LGL)	The expected Historic P90. Provided as an advisory guideline for construction of water dependent structures, information for lakeshore residents, and operation of water management structures.
MFL	Minimum Flows and Levels
Minimum Lake Level (MLL)	The elevation that the lake's water levels are required to equal or exceed fifty percent of the time on a Long-term basis.
NAVD 88	North American Vertical Datum of 1988
NGVD 29	National Geodetic Vertical Datum of 1929
Normal Pool Elevation	An elevation approximating the P10 (see below) elevation which is determined based on hydrologic indicators of sustained inundation
Not Structurally Altered	Refers to a lake where the control point elevation equals or exceeds the Normal Pool elevation or the lake has no outlet
P10	The percentile ranking represented by the elevation of the water surface of a lake or wetland that is equaled or exceeded ten percent of the time as determined from a Long-term stage frequency analysis.
P50	The percentile ranking represented by the elevation of the water surface of a lake or wetland that Is equaled or exceeded fifty percent of the time as determined from a Long-term stage frequency analysis.

P90	The percentile ranking represented by the elevation of the water surface of a lake or wetland that Is equaled or exceeded ninety percent of the time as determined from a Long-term stage frequency analysis.
Reference Lakes	Lakes from a defined area which are not measurably impacted by water withdrawals. Reference lakes may be used to develop reference lake statistics, including the RLWR50, RLWR90, and the RLWR5090 (see below).
RLWR50	Reference Lake Water Regime 50. The median difference between the P10 and P50 elevations for reference lakes with historic data and similar hydrogeologic conditions as the lake of concern.
RLWR5090	Reference Lake Water Regime 5090. The median difference between the P50 and P90 elevations for reference lakes with historic data and similar hydrogeologic conditions as the lake of concern.
RLWR90	Reference Lake Water Regime 90. The median difference between the P10 and P90 lake stage elevations for reference lakes with historic data and similar hydrogeologic conditions as the lake of concern
SFWMD	South Florida Water Management District
SJRWMD	St. Johns River Water Management District
SWFWMD	Southwest Florida Water Management District

Introduction

Evaluation of Minimum Flows and Levels

This report describes the development of minimum and guidance levels for Lake Damon in Highlands County, Florida. These levels were developed based on the evaluation of historic water levels, including water budget models, and the applicable significant change standards, as discussed in detail in this report.

Following Governing Board approval on February 27, 2018, the levels became effective on May 30, 2018.

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 proposed MFLs and methods used for their development); 3) monitoring and MFLs status assessments, i.e., compliance evaluations; 4) development and implementation of recovery strategies; 5) MFLs compliance reporting; and 6) ongoing support for minimum flow and level regulatory concerns and prevention strategies. Many of these tasks are discussed or addressed in this Minimum Levels report; additional information on all tasks associated with the District's MFLs Program is summarized by Hancock *et al.* (2010).

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

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

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

Consideration of Changes and Structural Alterations and Environmental Values

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

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

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

The District has developed specific methodologies for establishing 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 rules (Chapter 40D-8, F.A.C.). The rules also provide 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 minimum levels. For Category 1 or 2 Lakes, a significant change standard, referred to as the Cypress Standard, is developed. The Cypress Standard is 1.8 feet below the normal pool elevation. For Category 3 lakes, six significant change standards are typically developed. Other available information, including potential changes in the coverage of herbaceous wetland and submersed aquatic plants, is also considered when establishing minimum levels for Category 3 Lakes. The standards and other available information are associated with the environmental values identified for consideration in Rule 62-40.473, F.A.C., when establishing MFLs (Table 1). The specific standards and other information evaluated to support development of minimum levels for Lake Damon are provided in subsequent sections of this report. More general information on the standards and other information used for consideration when developing minimum lake levels is available in the documents identified in the preceding sub-section of this report.

Table 1: Environmental values from the Water Resource Implementation Rule (62-40.473, F.A.C.), and the Significant Change Standards (and other information) associated with each that are considered when establishing minimum flows and levels.

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

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

Lake Classification

Lakes are classified as Category 1, 2, or 3 for Minimum Levels development. According to Rule 40D-8.624, F.A.C., Lake Damon meets the classification as a Category 3 lake, with less than 0.5 acre of fringing cypress wetlands. The standards associated with Category 3 lakes described below will also be developed in a subsequent section of this report.

Lake-specific significant change standards and other available information are developed for establishing Minimum Levels for Category 3 Lakes. The standards are used to identify thresholds for preventing significant harm to cultural and natural system values associated with lakes in accordance with guidance provided in the Florida Water Resource Implementation Rule (62-40.473, F.A.C.). Other information taken into consideration includes potential changes in the coverage of herbaceous wetland vegetation and aquatic plants.

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 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 (the Ski Elevation), and use of Historic lake stage data or region-specific Reference Lake Water Regime statistics where Historic lake data are not available.

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

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 Aesthetics Standard is established at the Low Guidance Level.

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

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

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

Herbaceous Wetland Information is also taken into consideration to determine the elevation at which changes in lake stage would result in substantial changes in potential wetland area within the lake basin (i.e., basin area with a water depth of four feet or less) (Butts *et al*. 1997). Similarly, changes in lake stage associated with changes in lake area available for colonization by rooted submersed or floating-leaved macrophytes are also evaluated, based on water transparency values. Using methods described in Caffrey (2006), mean secchi disk depth (SD) is used to calculate the maximum depth of colonization (MDC) for aquatic plants using regression equation log(MDC) – 0.66log(SD) + 0.30, where all values are represented in meters. The MDC depth is then used to calculate the total acreage at each lake stage that is available for aquatic plant colonization.

Minimum and Guidance Levels

Two Minimum Levels and two Guidance Levels are typically established for lakes. Upon completion of a public input/review process and, if necessary completion of an independent scientific review, either of which may result in modification of the proposed levels, the levels are then adopted by the District Governing Board into Chapter 40D-8, F.A.C. (see Hancock *et al.* 2010 for more information on the adoption process). The levels, which are expressed as elevations in feet above the National Geodetic Vertical Datum of 1929 (NGVD29), 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). While the NGVD29 datum is used for most elevation values included within this report, in some circumstances, notations are made for elevation data that was collected or reported relative to mean sea level or relative to NAVD88 and converted to elevations relative to NGVD29.

Development of Minimum and Guidance Levels for Lake Damon

Lake Setting and Description

Lake Damon (Figure 1) is located in Highlands County, Florida (Section 3, Township 33, Range 28; Section 4, Township 33, Range 28; Section 9, Township 33, Range 28; Section 10, Township 33, Range 28) in the Kissimmee River Basin within the Southwest Florida Water Management District.

Within the Kissimmee River primary basin, the lake's watershed (Figure 2) has a drainage area of approximately 684.5 acres, or 1.1 square miles. Lake Damon has one main inlet along the southern shore, a ditch that delivers water from both Lake Byrd and Lake Brentwood (Figure 3). The lake has one main outlet along the eastern shore, delivering water to Lake Pythias through three fixed culverts (Figure 3). Historically, Lake Damon also had an outlet along the northeast shore that discharged to Lake Trout, however that outlet has not existed since sometime after the 1970's. There are currently no surface water withdrawals from the lake permitted by the District. There are, however, several permitted groundwater withdrawals in the lake vicinity.

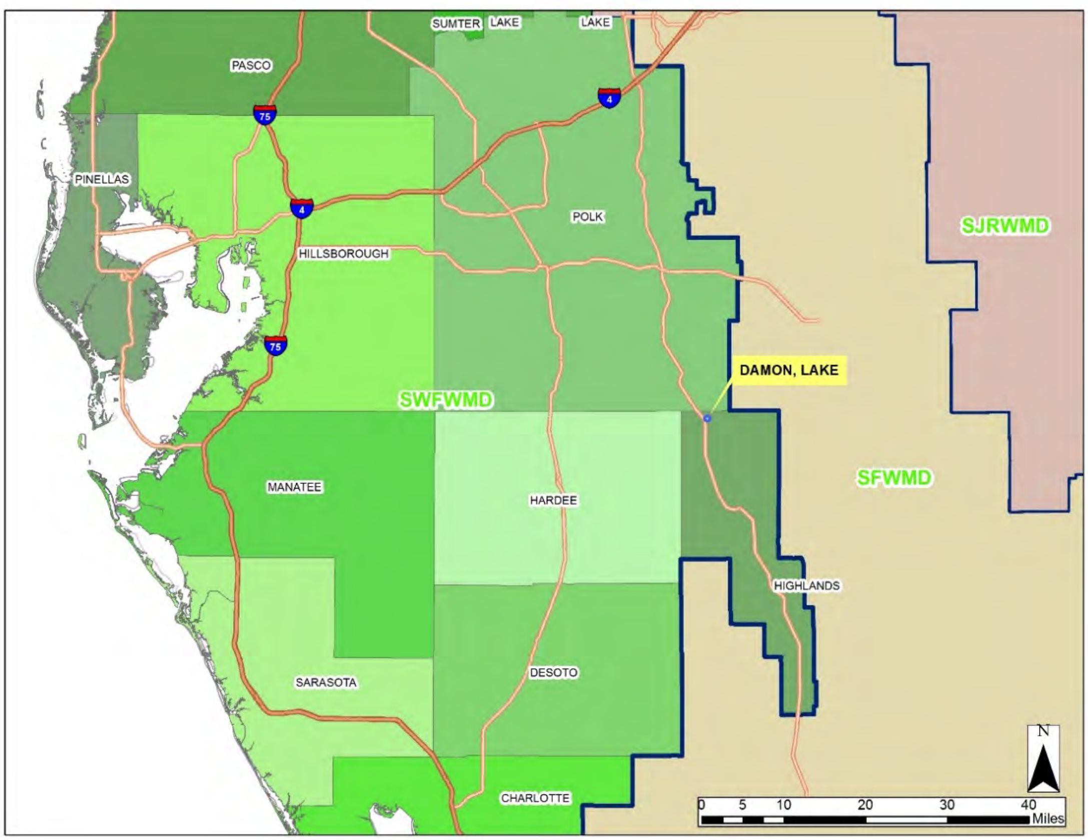

Figure 1: Location of Lake Damon in Highlands County, Florida.

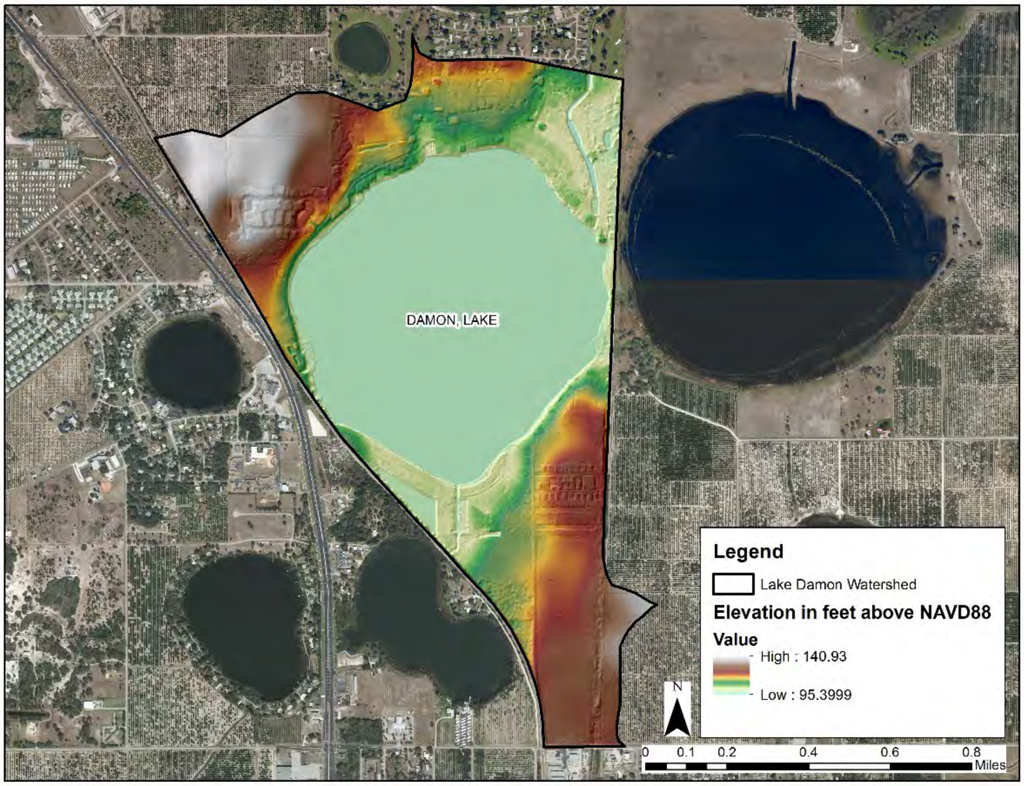

Figure 2: Watershed Delineation and Topography.

Figure 3: Location of Conveyance Systems and District Gage.

Land Use Land Cover

An examination of the 1990 and more current 2011 Florida Land Use, Cover, and Forms Classification System (FLUCCS) maps revealed that there has been some change to the landscape (specifically the dominant land forms) in the vicinity during this period (Figure 4 and Figure 5). In 1990 (Figure 4) the majority of the land surrounding Lake Damon was classified as either cropland and pastureland, tree crops, or low and medium density residential lands. By 2011 (Figure 5), much of the cropland had been replaced by open land in preparation of further development. In addition to a reduction in tree crops by 2011, there was also an increase in medium and high density residential areas. Figure 6 through Figure 11 aerial photography chronicles landscape changes to the area from 1941 through 2014. In the aerial photographs, it can be seen that there was once a railroad running between Lake Damon and Lake Pythias, which no longer exists.

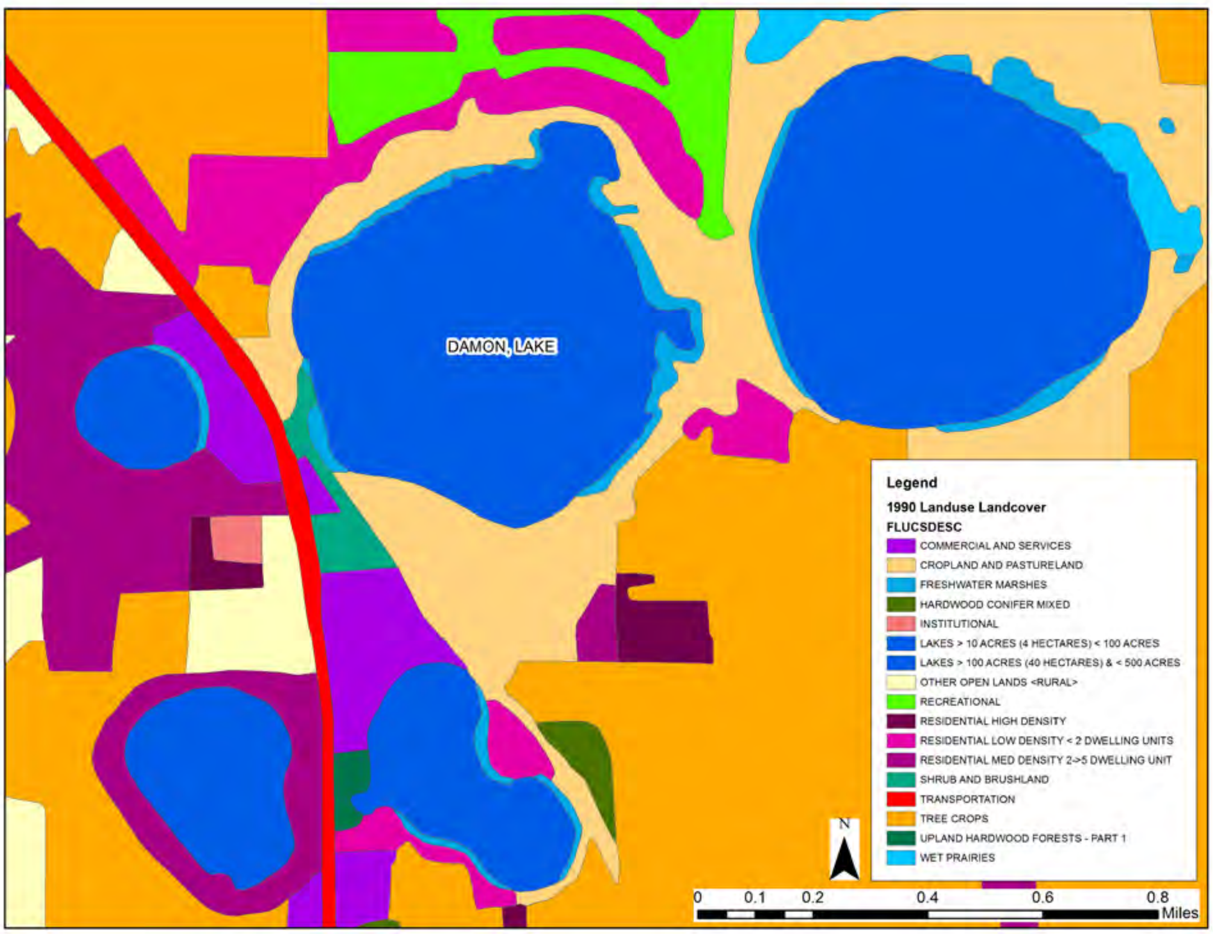

Figure 4: 1990 Land Use Land Cover Map of the Lake Damon Vicinity.

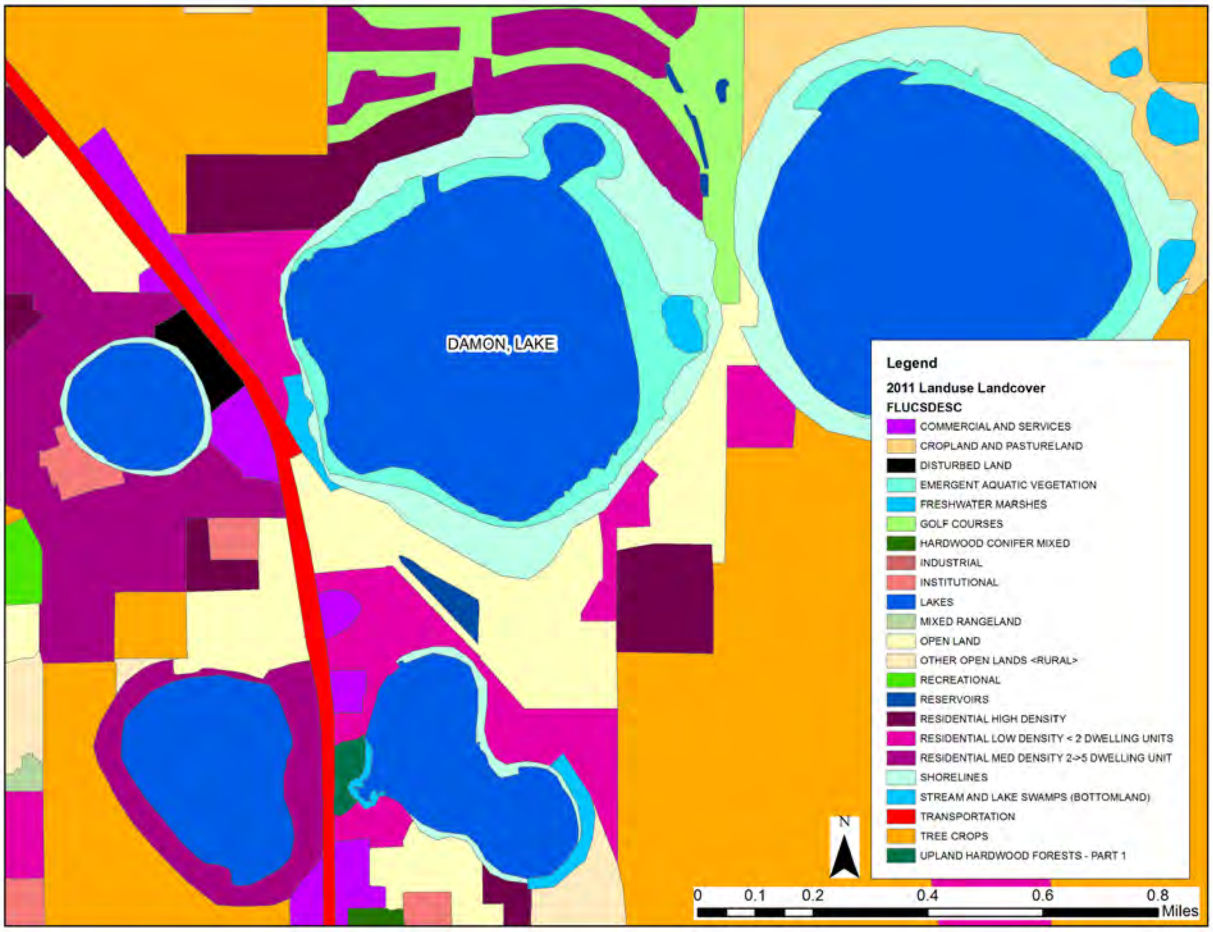

Figure 5: 2011 Land Use Land Cover Map of the Lake Damon Vicinity.

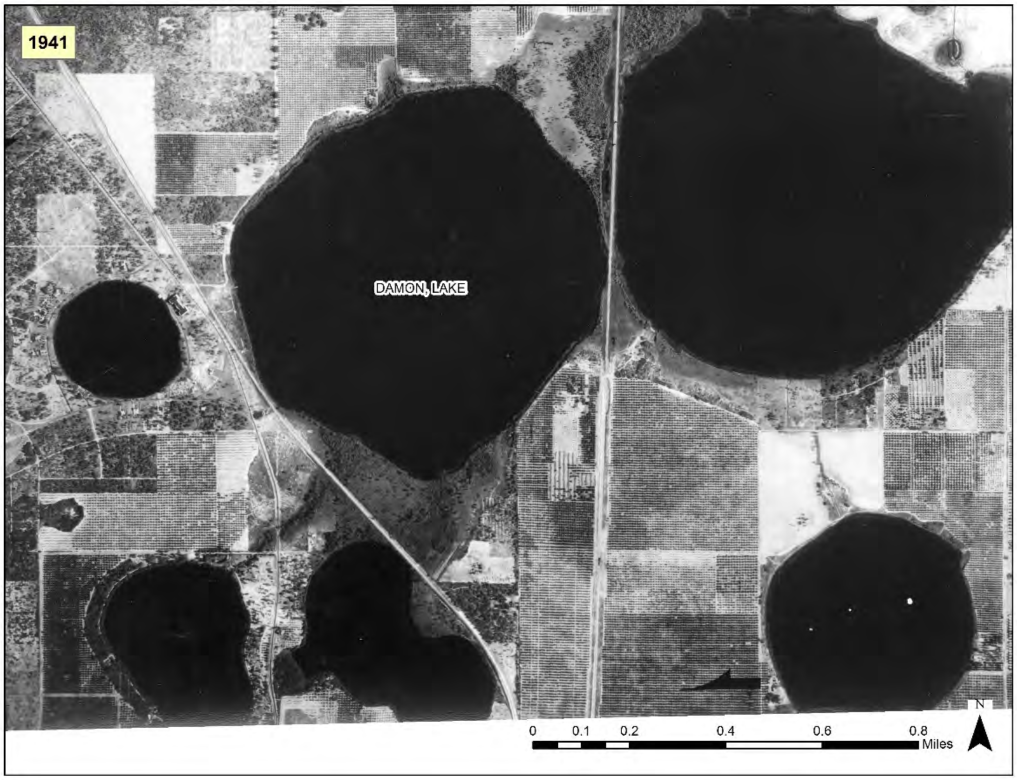

Figure 6: 1941 Aerial Photograph of Lake Damon

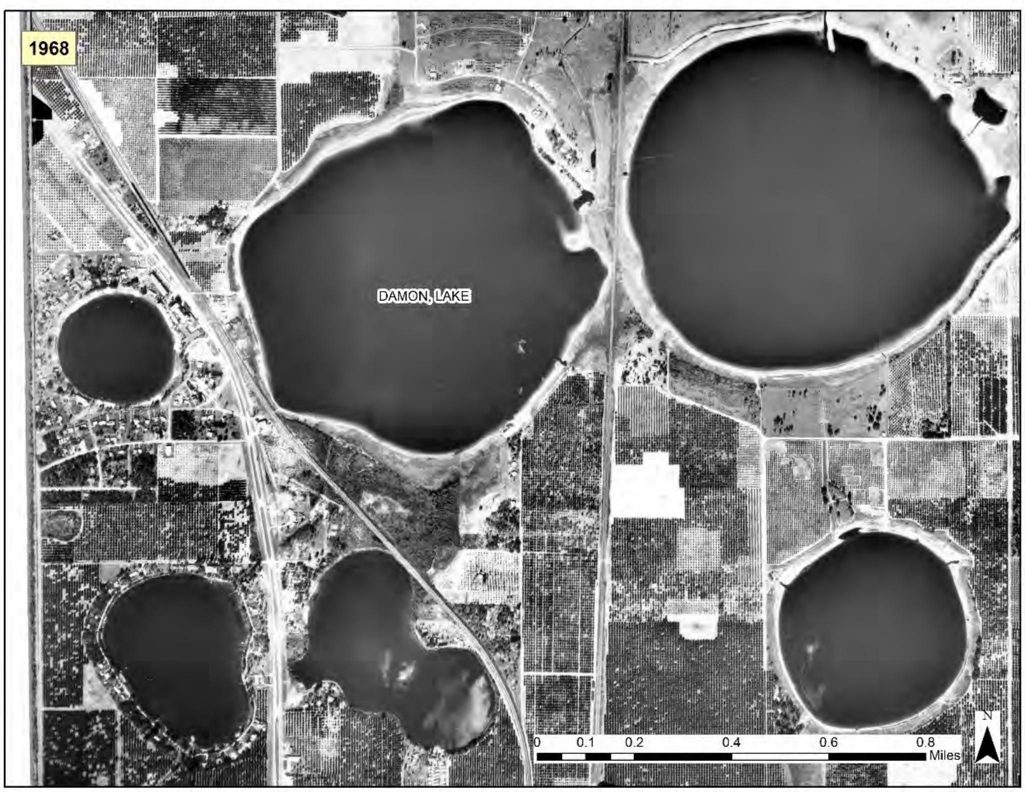

Figure 7: 1968 Aerial Photograph of Lake Damon

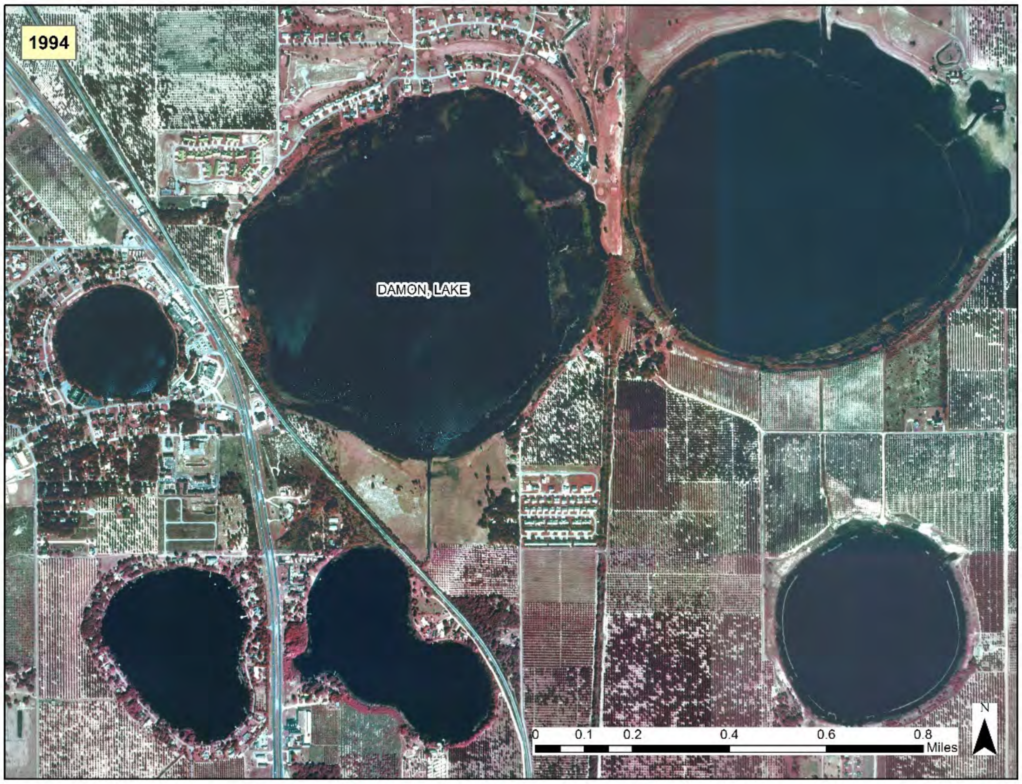

Figure 8: 1994 Aerial Photograph of Lake Damon

Figure 9: 2004 Aerial Photograph of Lake Damon

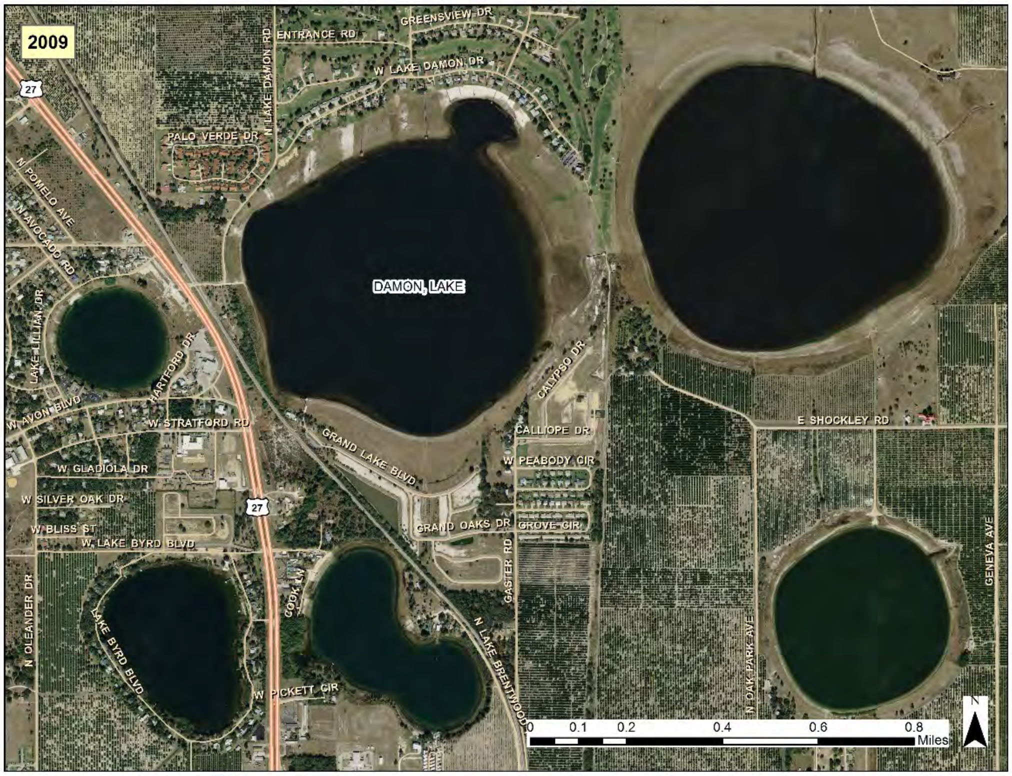

Figure 10: 2009 Aerial Photograph of Lake Damon

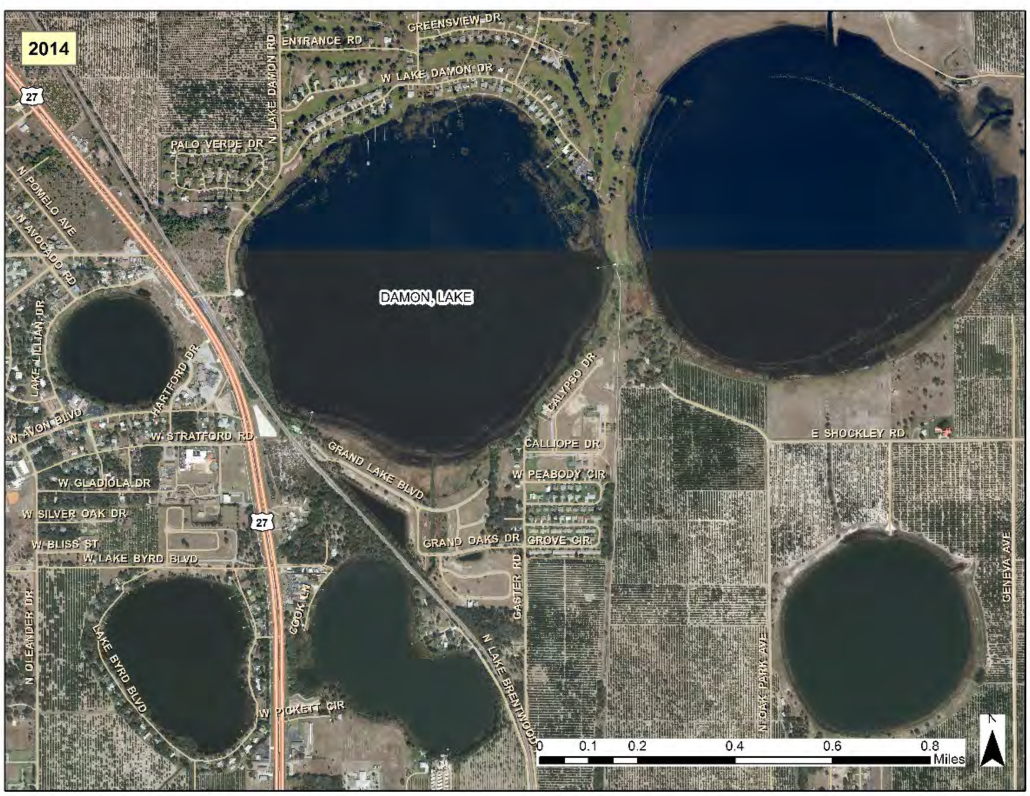

Figure 11: 2014 Aerial Photograph of Lake Damon

Bathymetry Description and History

Half-foot interval bathymetric data gathered from recent field surveys resulted in lake-bottom contour lines from 81 ft. to 101.5 ft. (Figure 12). These data revealed that the lowest lake bottom contour (81 ft.), or the deepest part of the lake, is located in the center of the lake. Additional morphometric or bathymetric information for the lake basin is discussed in the Methods, Results and Discussion section of this report.

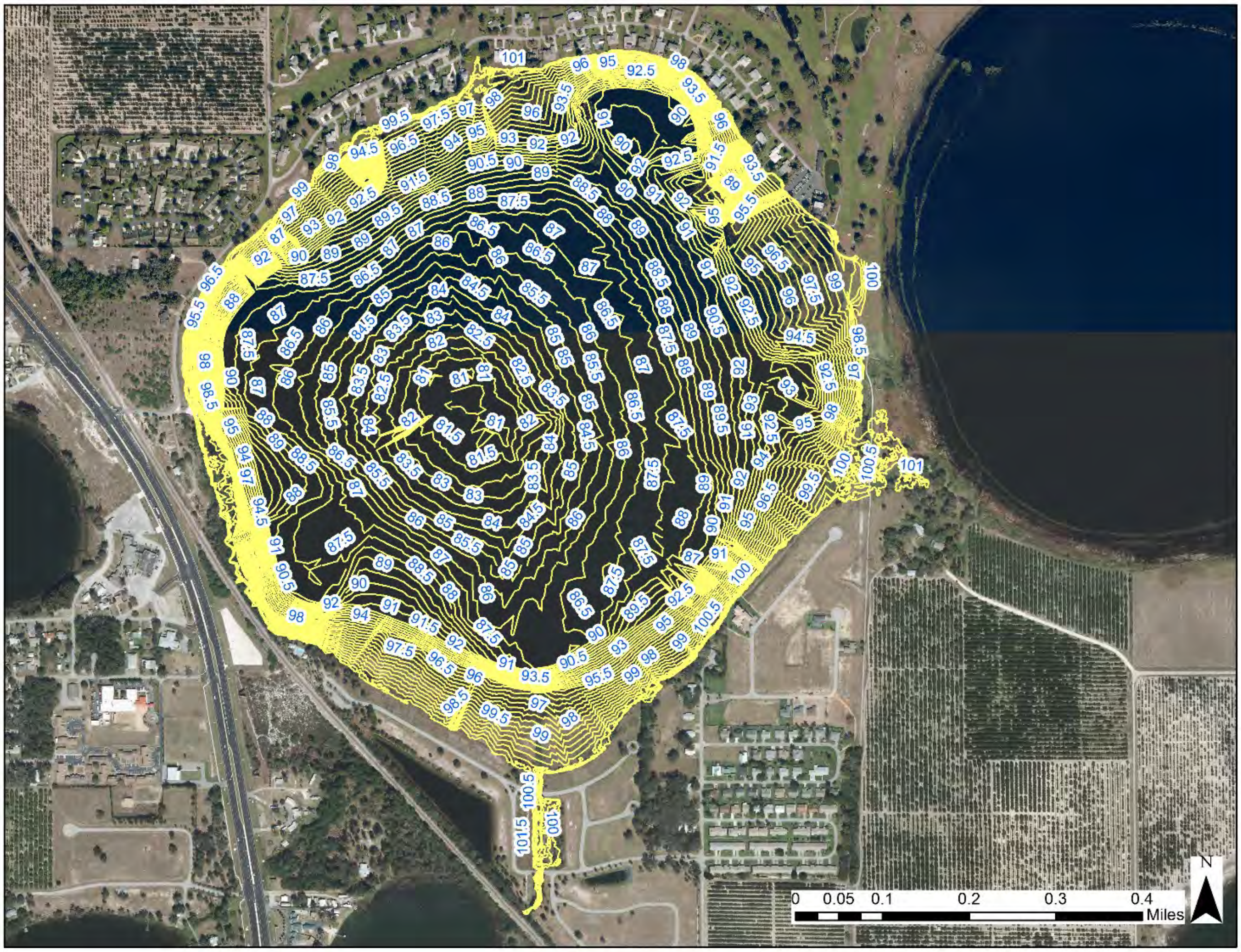

Figure 12: Lake Bottom Contours (ft., NGVD29) on a 2014 Natural Color Aerial Photograph

Water Level (Lake Stage) Record

Lake stage data, i.e., surface water elevations, are available for Lake Damon from the District's Water Management Information System (SID 23775) (Figure 13). Data collection began on July 22, 1981 and water elevations continue to be monitored, on a monthly basis, at the time of this report. On February 1, 2017 the gauge was adjusted from NGVD29 to NAVD88, with a measured shift of -1.01 ft. The highest lake stage elevation on record was 101.16 ft. and occurred on March 26, 1998. The lowest lake stage elevation on record was 89.53 ft. and occurred on May 18, 2009.

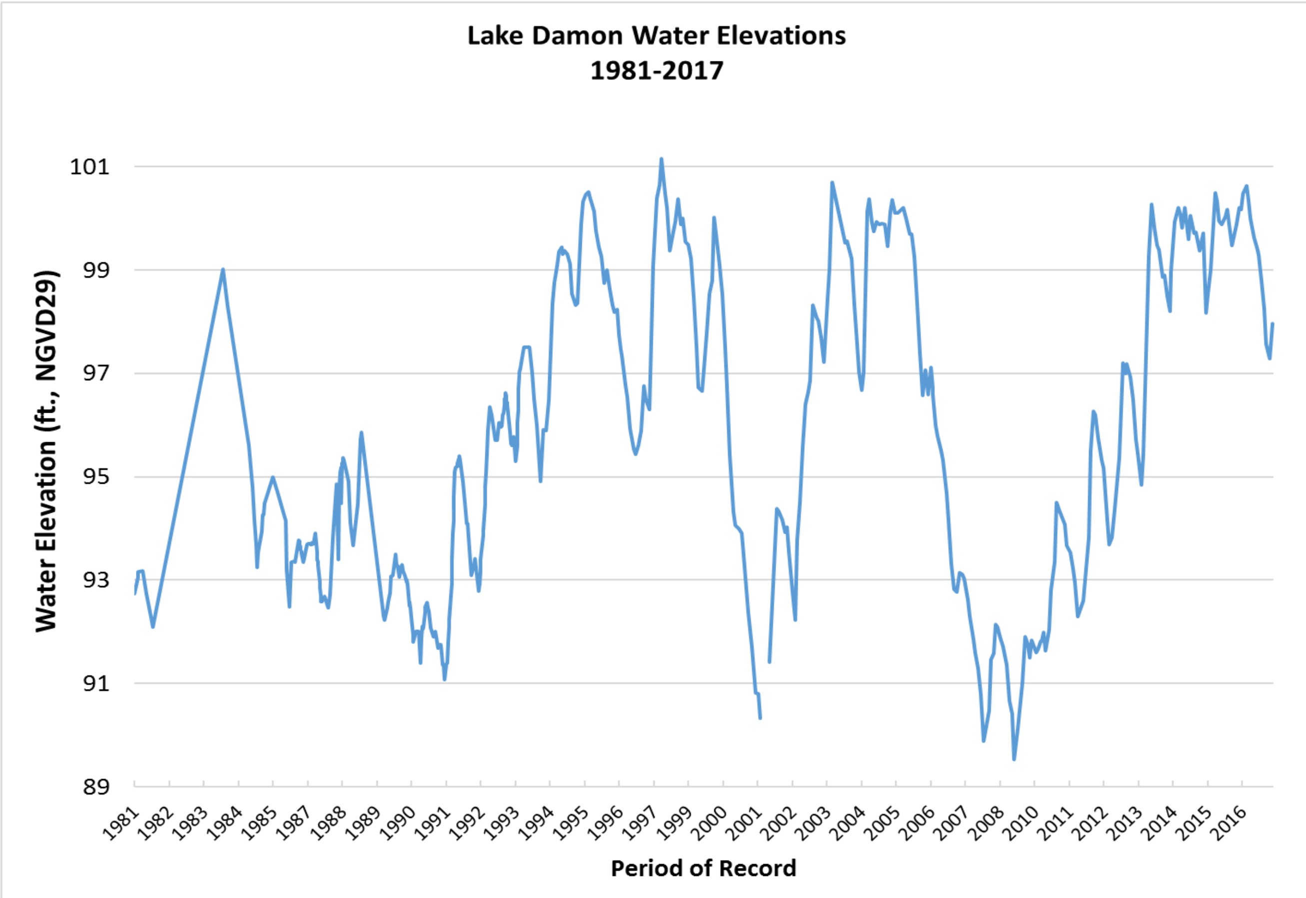

Figure 13: Lake Damon Period of Record Water Elevation Data (SID 23775)

Historic Management Levels

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

There are no previously adopted Minimum and Guidance levels for Lake Damon. Lake Damon does have Guidance Water Levels that were adopted by the District prior to August 7, 2000 which include a High Level of 101.00’, Low Level of 98.00’, and Extreme Low Level of 95.00’, all in feet above Mean Sea Level (msl).

Methods, Results and Discussion

The Minimum and Guidance Levels in this report were developed for Lake Damon using the methodology for Category 3 lakes described in Chapter 40D-8, F.A.C. Levels, Standards, and other information used for development of the levels, are listed in Table 2, along with lake surface area for each level. Detailed descriptions of the development and use of these data are provided in subsequent sections of this report.

Table 2: Lake Stage Percentiles, Normal Pool and Control Point Elevations, Significant Change Standards, and Minimum and Guidance Levels with associated surface areas for Lake Damon.

Levels	Elevation in Feet NGVD 29	Lake Area (acres)
Lake Stage Percentiles		
Historic P10 (1946 to 2016)	101.4	297
Historic P50 (1946 to 2016)	97.1	249
Historic P90 (1946 to 2016)	92.9	206
Normal Pool and Control Point		
Normal Pool	NA	NA
Control Point	99.1	270.2
Significant Change Standards		
Recreation/Ski Standard	92.7	203
Dock-Use Standard	101.6	297
Wetland Offset Elevation	96.3	241
Aesthetics Standard	92.9	206
Species Richness Standard	93.5	212
Basin Connectivity Standard	NA	NA
Lake Mixing Standard	89.5	155
Minimum and Guidance Levels		
High Guidance Level	101.4	297
High Minimum Lake Level	97.4	252
Minimum Lake Level	96.3	241
Low Guidance Level	92.9	206

NA - not appropriate

Bathymetry

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

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

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

The DEM created from the combined elevation data sets was used to develop topographic contours of the lake basin and to create a triangulated irregular network (TIN). The TIN was used to calculate the stage areas and volumes using a Python script file to iteratively run the Surface Volume tool in the Functional Surface toolset of the ESRI® 3D Analyst toolbox at one-tenth of a foot elevation change increments. Selected stage-area-volume results are presented in Figure 14.

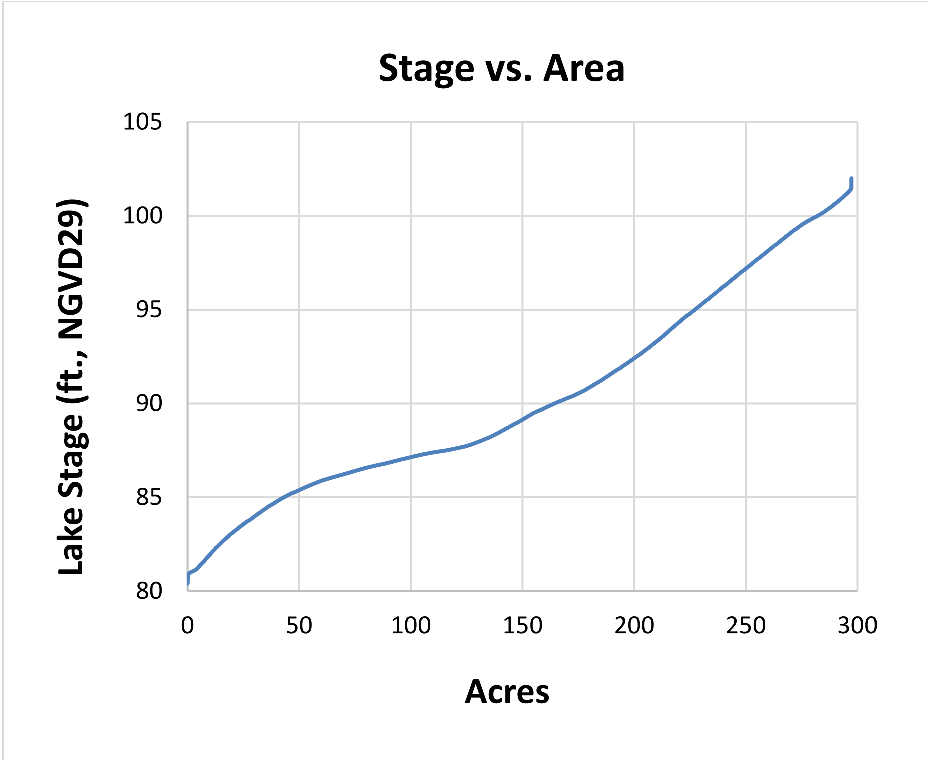

Figure 14: Lake Stage (Ft. NGVD29) to Surface Area (Acres) for Lake Damon.

Development of Exceedance Percentiles

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

Based on water-use estimates and analysis of lake water levels and regional ground water fluctuations, a modeling approach (see 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 developing a water budget model which incorporated the effects of precipitation, evaporation, overland flow, and groundwater interactions (Appendix A). Using the results of the water budget model, regression modeling for lake stage predictions was conducted using a linear line of organic correlation statistical model (LOC) (see Helsel and Hirsch 1992). The procedure was used to derive the relationship between daily water surface elevations for Lake Damon and composite regional rainfall.

A combination of model data produced a hybrid model which resulted in a 70-year (1946-2016) Historic water level record. Based on this hybrid data, the Historic P10 elevation, i.e., the elevation of the lake water surface equaled or exceeded ten percent of the time, was 101.4 ft. The Historic P50, the elevation the lake water surface equaled or exceeded fifty percent of the time during the historic period, was 97.1 ft. The Historic P90, the lake water surface elevation equaled or exceeded ninety percent of the time during the historic period, was 92.9 ft. (Figure 15 and Table 2).

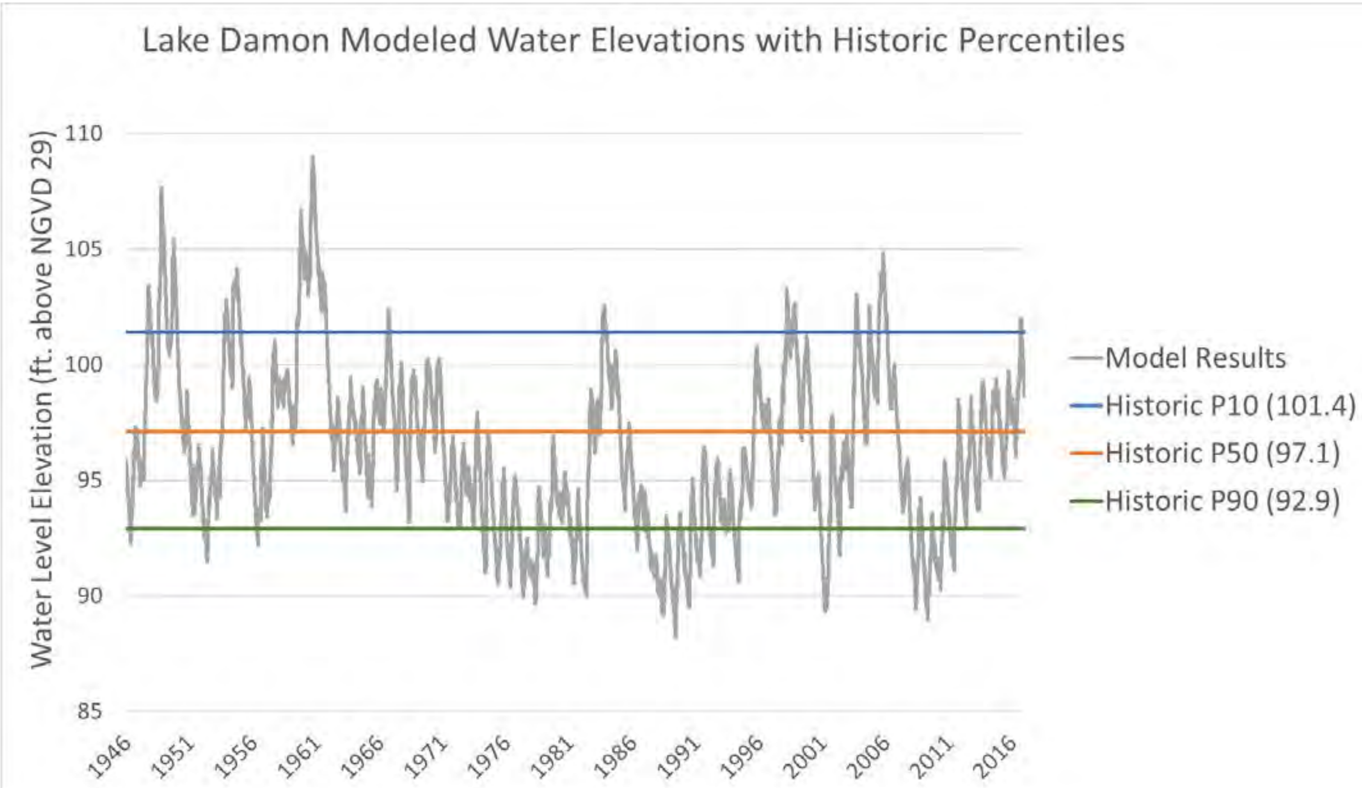

Figure 15: Historic Water Levels (hybrid) Used to Calculate Percentile Elevations Including P10, P50, and P90.

Normal Pool Elevation and Additional Information

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

Additional information to consider in establishing Minimum and Guidance Levels are the Control Point elevation and the lowest building floor (slab) elevation within the lake basin (determined by field survey data). The Control Point elevation is the elevation of the highest stable point along the outlet profile of a surface water conveyance system that can principally control the lake water level fluctuations at the high end. The Control Point for Lake Damon was determined at 99.1 ft., the bottom elevation of the lowest of three culverts connecting Lake Damon to Lake Pythias on the eastern shore. The lowest finished floor slab, based on survey reports from 2012, was established at 102.9 ft.

Guidance Levels

The High Guidance Level (HGL) is provided as an advisory guideline for construction of lakeshore development, water dependent structures, and operation of water management structures. The High Guidance Level is the expected Historic P10 of the lake, and is established using Historic data if it is available, or is estimated using the Current P10, the Control Point elevation and the Normal Pool elevation. Based on the availability of Historic data developed for Lake Damon, the High Guidance Level was established at the Historic P10 elevation, 101.4 ft. Recorded data indicate that the highest level on record was 101.16 ft. in March 1998.

The Low Guidance Level (LGL) 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 (RLWR) statistics. Based on the availability of Historic data for Lake Damon, the Low Guidance Level was established at the Historic P90 elevation, 92.9 ft. The recorded period of record indicates the lowest lake level elevation was 89.53 ft., below the Low Guidance Level, in May 2009 (Figure 13). The most recent record of the water level dropping below the Low Guidance Level was in July 2011, with a recorded level of 92.6 ft.

Significant Change Standards

Category 3 significant change standards were established for Lake Damon based on the stage-area-volume relationship which was developed. These standards include a Recreation/Ski Standard, Dock-Use Standard, Wetland Offset Elevation, Aesthetics Standard, Species Richness Standard, Basin Connectivity Standard, and Lake Mixing Standard. Each was evaluated for minimum levels development for Lake Damon and presented in Table 2.

- The **Recreation/Ski Standard** was established at an elevation of 92.7 ft. based on a ski elevation of 88.5 ft. and the difference between the Historic P50 and P90 of 4.2 ft.
- The **Dock-Use Standard** was established at an elevation of 101.6 ft. based on the elevation of lake sediments at the end of 13 docks on the lake, a 2-ft. clearance depth, and the difference between the Historic P50 and P90 of 4.2 ft.
- The **Wetland Offset Elevation** was established at 96.3 ft., or 0.8 ft. below the historic P50 elevation.
- The **Aesthetic Standard** was established at the Low Guidance Level elevation of 92.9 ft.
- The **Species Richness Standard** was established at 93.5 ft., based on a 15% reduction in lake surface area from that at the Historic P50 elevation.
- The **Basin Connectivity Standard** was not applicable as the lake does not have multiple basins.
- The **Lake Mixing Standard** was established at an elevation of 89.5 ft., where the dynamic ratio shifts from a value of less than 0.8 to greater than 0.8, indicating that potential changes in basin susceptibility to wind-induced sediment resuspension would not be of concern for minimum levels development (see Bachmann *et al.* 2000).

Review of changes in potential herbaceous wetland area associated with change in lake stage (Figure 16), and potential changes in area available for aquatic plant colonization (Figure 17) did not indicate that use of any of the identified standards would be inappropriate for minimum levels development. Figure 16 shows that as the lake stage increases, the acres available for herbaceous wetland area (acres < 4 ft.) also increase, up until around 90 ft. NGVD. The acres available for herbaceous wetlands then decrease as the lake becomes deeper. Similarly, the area available for aquatic plant colonization (acres < 9.2 ft.) follows the same trend of increasing until a threshold point, around 93 ft. NGVD (Figure 17). The changes in the slope of the lines reflects the variation in lake bottom contours and the area which it contains.

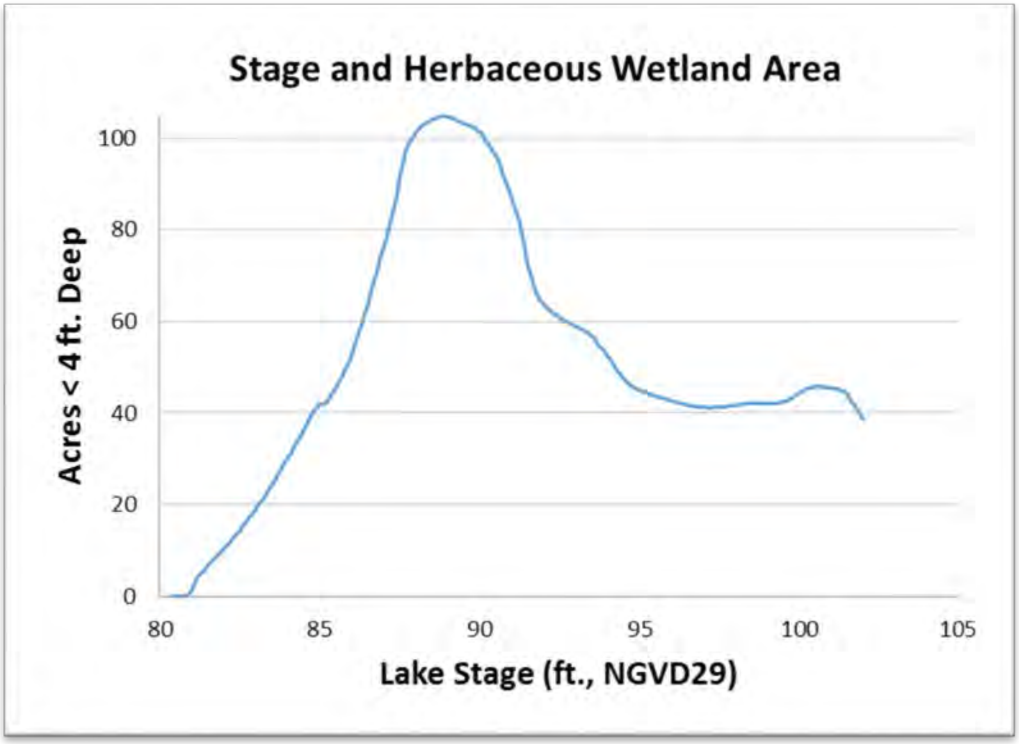

Figure 16: Lake Stage Compared to Available Herbaceous Wetland Area.

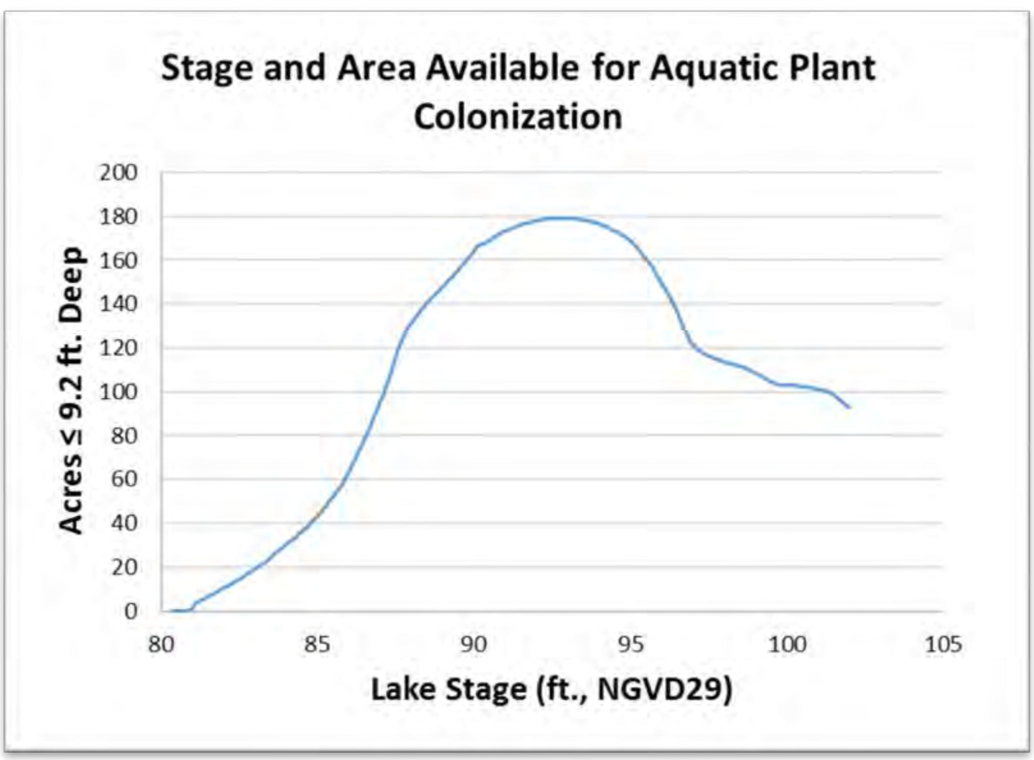

Figure 17: Lake Stage and Area Available for Aquatic Plant Colonization.

Minimum Levels

The Minimum Lake Level (MLL) is the elevation that a lake's water levels are ***required*** to equal or exceed fifty percent of the time on a long-term basis. For a Category 3 lake, the Minimum Lake Level is established using a process that considers applying professional experience and judgement, and the Standards previously listed. The MLL for Lake Damon is established at the Wetland Offset elevation of 96.3 ft.

The High Minimum Lake Level (HMLL) is the elevation that a lake's water levels are ***required*** to equal or exceed ten percent of the time on a long-term basis. For a Category 3 lake, Rule 40D-8.624, F.A.C. allows for the HMLL to be established using one of two methods. The High Minimum Lake Level is established at the elevation corresponding to the Minimum Lake Level plus the difference between the Historic P10 and the Historic P50, or alternatively, the HMLL is established at the elevation corresponding to the MLL plus the RLWR value. 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, P10 and P90, and P50 and P90 lake stage percentiles for a set of reference lakes. The HMLL for Lake Damon was established using the RLWR, in order to avoid potential flooding concerns with setting it too high, resulting in a HMLL of 97.4 ft. This elevation accounts for a natural fluctuation of lake levels.

Minimum and Guidance levels for Lake Damon are plotted on the recorded water level record (Figure 18). To illustrate the approximate locations of the lake margin when water levels equal the minimum levels, the levels are imposed onto a 2017 natural color aerial photograph in Figure 19.

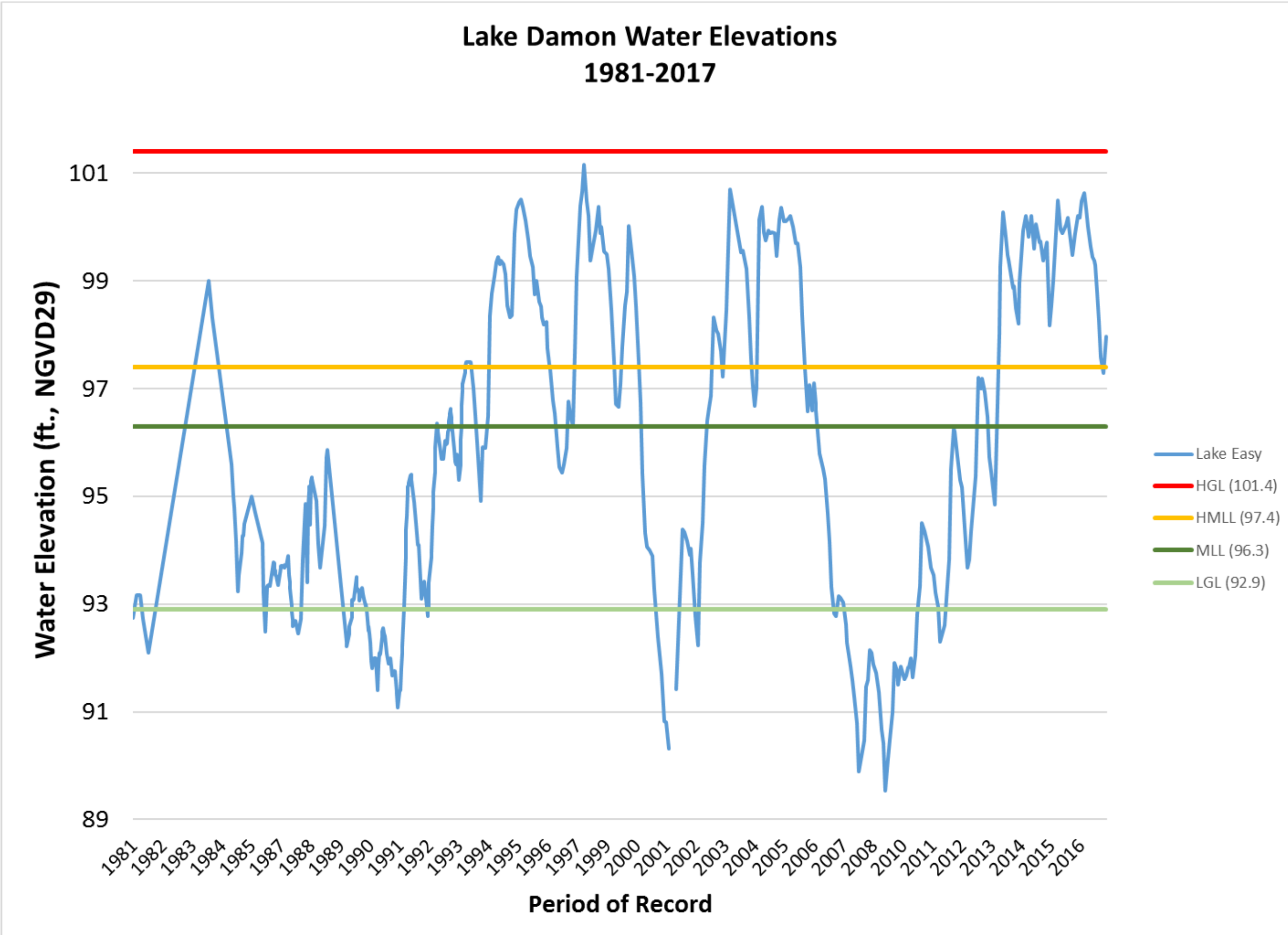

Figure 18: Recorded Water Level Elevations with Guidance and Minimum Lake Levels for Lake Damon.

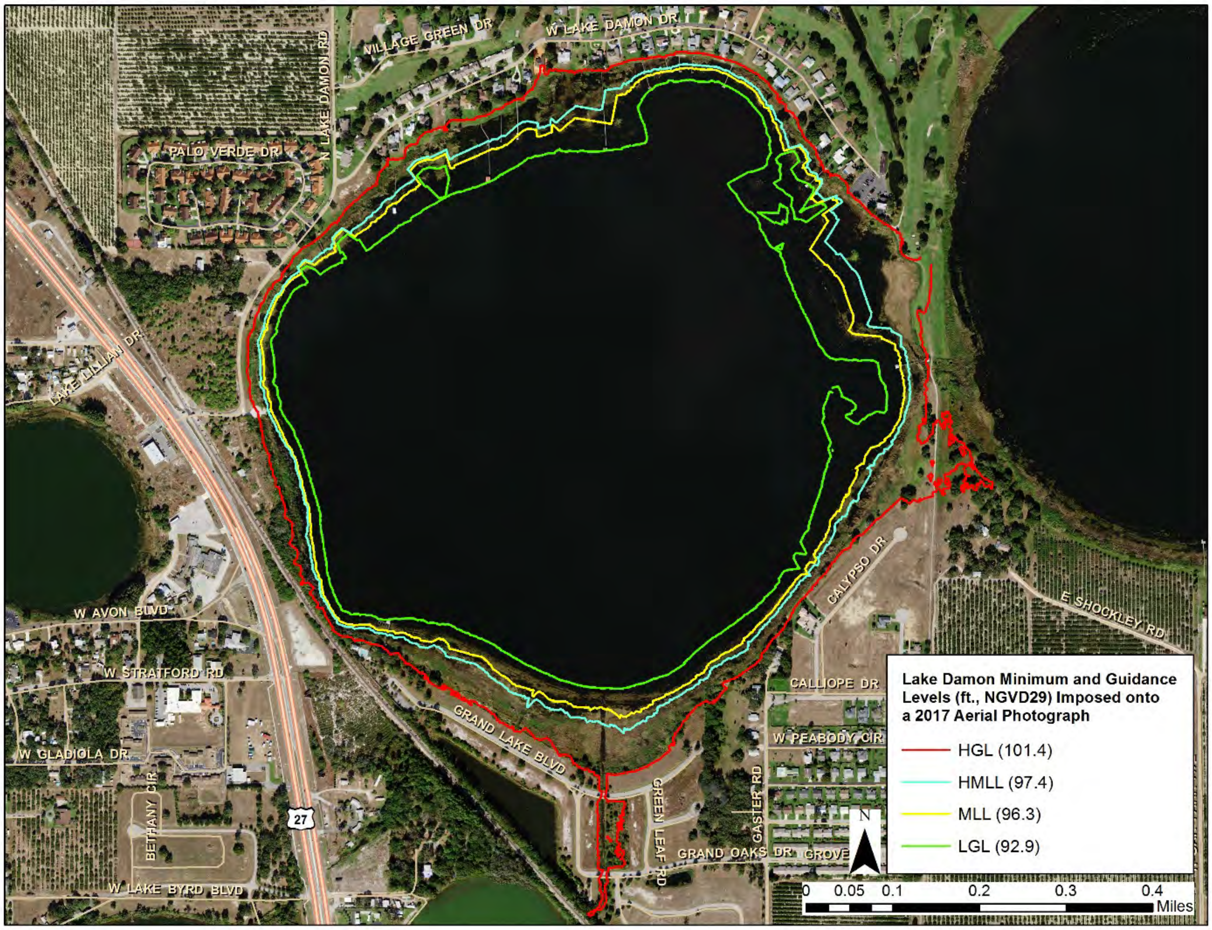

Figure 19: Lake Damon Minimum and Guidance Level Contour Lines Imposed onto a 2017 Natural Color Aerial Photograph.

Many federal, state, and local agencies, such as the U.S. Army Corps of Engineers, the Federal Emergency Management Agency, United States Geological Survey, and Florida's water management districts are in the process of upgrading from the National Geodetic Vertical Datum (NGVD29) standard to the North American Vertical Datum (NAVD88) standard. For comparison purposes, the MFLs for Lake Damon are presented in both datum standards (Table 3). The datum shift was calculated based on third-order leveling ties from vertical survey control stations with known elevations above the North American Vertical Datum on 1988. The NGVD29 datum conversion to NAVD88 is -1.01 ft. for SID 23775 on Lake Damon.

Table 3: Minimum and Guidance Levels for Lake Damon in NGVD29 and NAVD88.

Minimum and Guidance Levels	Elevation in Feet NGVD29	Elevation in Feet NAVD88
High Guidance Level	101.4	100.4
High Minimum Lake Level	97.4	96.4
Minimum Lake Level	96.3	95.3
Low Guidance Level	92.9	91.9

Consideration of Environmental Values

The minimum levels for Lake Damon 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.

The Wetland Offset Elevation was used for developing Minimum Levels for Lake Damon 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: fish and wildlife habitats and the passage of fish, transfer of detrital material, aesthetic and scenic attributes, filtration and absorption of nutrients and other pollutants, and water quality (Table 1).

In addition, the environmental value of maintenance of freshwater storage and supply is also expected to be protected by the minimum levels based on inclusion of conditions in water use permits that stipulate permitted withdrawals will not lead to violation of adopted minimum flows and levels.

Two environmental values identified in the Water Resource Implementation Rule were not considered relevant to development of minimum levels for Lake Damon. Estuarine resources were not considered relevant because the lake is not connected to an estuarine resource. Sediment loads were similarly not considered relevant for minimum levels development for the lake, because the transport of sediments as bedload or suspended load is a process typically associated with flowing water systems.

Minimum Levels Status Assessment

To assess if the Minimum and High Minimum Lake Levels are being met, observed stage data in Lake Damon were used to create a long-term record using a Line of Organic Correlation (LOC) model, similar to what was developed for establishing the Minimum Levels (Appendix A). For the status assessment, the lake stage data used to create the LOC must be from a period representing a time when groundwater withdrawals and structural alterations are reasonably stable, and represent current conditions, referred to as the “Current” period. Current stage data observed on Lake Damon were determined to be from 2002 through 2016. Using the Current stage data, the LOC model was created. The LOC model resulted in a 70-year long-term water level record (1946-2016).

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

The lake lies within the region of the District covered by an existing recovery strategy for the Southern Water Use Caution Area (Rule 40D-80.074, F.A.C.). The District plans to continue regular monitoring of water levels in Lake Damon 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.

Documents Cited and Reviewed

Anderson, M. P. and Woessner, W.W. 2002. Applied Groundwater Modeling Simulation of Flow and Advective Transport. Academic Press. San Diego, California.

Bachmann, R.W., Hoyer. M.V., and Canfield, D.E. Jr. 2000. The potential for wave disturbance in shallow Florida lakes. Lakes and Reservoir Management 16: 281-291.

Basso, R. and Schultz, R. 2003. Long-term variation in rainfall and its effect on Peace River flow in west-central Florida. Southwest Florida Water Management District, Brooksville, Florida.

Bedient, P., Brinson, M., Dierberg, F., Gorelick, S., Jenkins, K., Ross, D., Wagner, K., and Stephenson, D. 1999. Report of the Scientific Peer Review Panel on the data, theories, and methodologies supporting the Minimum Flows and Levels Rule for northern Tampa Bay Area, Florida. Prepared for the Southwest Florida Water Management District, the Environmental Confederation of Southwest Florida, Polk County, and Tampa Bay Water. Southwest Florida Water Management District. Brooksville, Florida.

Butts, D., Hinton, J. Watson, C., Langeland, K., Hall, D. and Kane, M. 1997 Aquascaping: planting and maintenance. Circular 912, Florida Cooperative Extension Service, University of Florida, Institute of Food and Agricultural Sciences, Gainesville, Florida.

Carr, D.W. and Rochow, T.F. 2004. Technical memorandum to file dated April 19, 2004. Subject: comparison of six biological indicators of hydrology in isolated *Taxodium acsendens* domes. Southwest Florida Water Management District. Brooksville, Florida.

Carr, D. W., Leeper, D. A., and Rochow, T. F. 2006. Comparison of Six Biologic Indicators of Hydrology and the Landward Extent of Hydric Soils

Caffrey, A.J., Hoyer, M.V. and Canfield, D.E., Jr. 2006. Factors affecting the maximum depth of colonization by submersed aquatic macrophytes in Florida lakes. University of Florida Institute of Food and Agricultural Sciences Department of Fisheries and Aquatic Sciences. Gainesville, Florida. Prepared for the Southwest Florida Water Management District. Brooksville, Florida.

Caffrey, A.J., Hoyer, M.V. and Canfield, D.E., Jr. 2007. Factors affecting the maximum depth of colonization by submersed aquatic macrophytes in Florida lakes. Lake and Reservoir Management 23: 287-297

Dierberg, F.E. and Wagner, K.J. 2001. A review of “A multiple-parameter approach for establishing minimum levels for Category 3 Lakes of the Southwest Florida Water Management District" Jun” 2001 draft by D. Leeper, M. Kelly, A. Munson, and R.Gant. Prepared for the Southwest Florida Water Management District, Brooksville, Florida.

Emery, S., Martin, D., Sumpter, D., Bowman, R., Paul, R. 2009. Lake surface area and bird species richness: analysis for minimum flows and levels rule review. University of South Florida Institute for Environmental Studies. Tampa, Florida. Prepared for the Southwest Florida Water Management District. Brooksville, Florida

Enfield, D. B., Mestas-Nunez, A. M., and Trimble, P. J. 2001. The Atlantic multi-Decadal oscillation and its relation to rainfall and river flow in the continental U. S. Geophysical Research Letters 28: 2077-2080.

Flannery, M.S., Peebles, E.B. and Montgomery, R.T. 2002. A percent-of-flow approach for Managing reductions in freshwater flows from unimpounded rivers to southwest Florida estuaries. Estuaries 25: 1318-1332.

Hancock, M. 2006. Draft memorandum to file, dated April 24, 2006. Subject: a proposed interim method for determining minimum levels in isolated wetlands. Southwest Florida Water Management District. Brooksville, Florida.

Hancock, M. 2007. Recent development in MFL establishment and assessment. Southwest Florida Water Management District, draft 2/22/2007. Brooksville, Florida.

Hancock, M.C. and R. Basso. 1996. Northern Tampa Bay Water Resource Assessment Project: Volume One. Surface-Water/Ground-Water Interrelationships. Southwest Florida Water Management District. Brooksville, Florida.

Hancock, M.C., Leeper, D.A., Barcelo, M.D. and Kelly, M.H. 2010. Minimum flows and levels development, compliance, and reporting in the Southwest Florida Water Management District. Southwest Florida Water Management District. Brooksville, Florida.

Helsel, D. R. and Hirsch, R. M. 1992. Statistical methods in water resources. Studies in Environmental Science 45. Elsevier. New York, New York.

Hoyer, M.V., Israel, G.D. and Canfield, D.E., Jr. 2006. Lake User's perceptions regarding impacts of lake water level on lake aesthetics and recreational uses. University of Florida Institute of Food and Agricultural Sciences Department of Fisheries and Aquatic Sciences and Department of Agricultural Education and Communication. Gainesville, Florida. Prepared for the Southwest Florida Water Management District. Brooksville, Florida.

Kelly, M. 2004. Florida river flow patterns and the Atlantic Multidecadal Oscillation. Southwest Florida Water Management District. Brooksville, Florida.

Leeper, D. 2006. Proposed methodological revisions regarding consideration of structural alterations for establishing Category 3 Lake minimum levels in the Southwest

Florida Water Management District, April 21, 2006 peer-review draft. Southwest Florida Water Management District. Brooksville, Florida.

Leeper, D., Kelly, M., Munson, A., and Gant, R. 2001. A multiple-parameter approach for establishing minimum levels for Category 3 Lakes of the Southwest Florida Water Management District, June14, 2001 draft. Southwest Florida Water Management District, Brooksville, Florida.

Mace, J. 2009. Minimum levels reevaluation: Gore Lake Flagler County, Florida. Technical Publication SJ2009003. St. Johns River Water Management District. Palatka, Florida.

Miller, J.A. 1986. Hydrogeologic framework of the Floridan aquifer system in Florida and parts of Georgia, Alabama, and South Carolina. U.S. Geological Survey Water-Resources Investigations Report.

Neubauer, C.P., Hall, G.B., Lowe, E.F., Robison, C.P., Hupalo, R.B., and Keenan, L.W. 2008. Minimum flows and levels method of the St. Johns River Water Management District, Florida, USA. Environmental Management 42: 1101-1114.

Poff N.L., B. Richter, A.H. Arthington, S.E. Bunn, R.J. Naiman, E. Kendy, M. Acreman, C. Apse, B.P. Bledsoe, M. Freeman, J. Henriksen, R.B. Jacobson, J. Kennen, D.M. Merritt, J. O'Keeffe, J.D. Olden, K. Rogers, R.E. Tharme & A. Warner. 2010. The Ecological Limits of Hydrologic Alteration (ELOHA): a new framework for developing regional environmental flow standards. *Freshwater Biology* 55:147-170.

Poff, N.L. and Zimmerman, K.H. 2010. Ecological responses to altered flow regimes: a literature review to inform science and management of environmental flows. Freshwater Biology 55: 194-205.

Postel, S. and Richter, B. 2003. Rivers for life: Managing water for people and nature. Island Press. Washington, D.C.

Schultz, Richard, Michael Hancock, Jill Hood, David Carr, and Theodore Rochow. Memorandum of file, dated July 21, 2004. Subject: Use of Biologic Indicators for Establishment of Historic Normal Pool. Southwest Florida Water Management District. Brooksville, Florida.

South Florida Water Management District. 2000. Minimum flows and levels for Lake Okeechobee, the Everglades and the Biscayne aquifer, February 29, 2000 draft. West Palm Beach, Florida.

South Florida Water Management District. 2006. Technical document to support development of minimum levels for Lake Istokpoga, November 2005. West Palm Beach, Florida.

Southwest Florida Water Management District. 1999a. Establishment of minimum levels for Category 1 and Category 2 lakes, *in* Northern Tampa Bay minimum flows and levels white papers: white papers supporting the establishment of minimum flows and levels for isolated cypress wetlands, Category 1 and 2 lakes, seawater intrusion, environmental aquifer levels and Tampa Bypass canal, peer-review final draft, March 19, 1999. Brooksville, Florida.

Southwest Florida Water Management District. 1999b. Establishment of minimum levels in palustrine cypress wetlands, *in* Northern Tampa Bay minimum flows and levels white papers: white papers supporting the establishment of minimum flows and levels for isolated cypress wetlands, Category 1 and 2 lakes, seawater intrusion, environmental aquifer levels and Tampa Bypass canal, peer-review final draft, March 19, 1999. Brooksville, Florida.

Suwannee River Water Management District. 2004. Development of Madison Blue Spring-based MFL technical report. Live Oak, Florida.

Suwannee River Water Management District. 2005. Technical report, MFL establishment for the lower Suwannee River & estuary, Little Fanning, Fanning & Manatee springs. Live Oak, Florida.

Wagner and Dierberg. 2006. A Review of a Multiple-Parameter Approach for Establishing Minimum Levels for Category 3 Lakes of the Southwest Florida Water Management District. SWFWMD, Brooksville, Fl.

Wantzen, K.M., Rothhaupt, K.O., Morti, M. Cantonati, M.G. Toth, L.G. and Fisher, P. (editors). 2008. Ecological effects of water-level fluctuations in lakes. Development in Hydrobiology, Volume 204. Springer Netherlands.

APPENDIX A

Draft Technical Memorandum

December 13, 2017

TO: Donna Campbell, Staff Environmental Scientist, Water Resources Bureau

THROUGH: Tamera McBride, P.G., Manager, Resource Evaluation Section

FROM: Jason G. Patterson, Hydrogeologist, Water Resources Bureau
Don Ellison, P.G., Senior Hydrogeologist, Water Resources Bureau

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

A. Introduction

Water budget and rainfall regression models were developed to assist the Southwest Florida Water Management District (District) in the assessment of minimum levels for Lake Damon, located in north-central Highlands County. A proposed minimum level for Lake Damon was scheduled to be established in FY 2017. This document will discuss the development of the Lake Damon models and use of the models for development of Historic lake stage exceedance percentiles using those models.

B. Background and Setting

Lake Damon is located in Northwest Highlands County, immediately south of U.S. Highway 27 just north of E. Old Bombing Range Rd. (Figure 1). The lake is located on the Lake Wales Ridge and is within the Kissimmee River watershed. There are two surface water systems, Lake Byrd and Lake Brentwood, draining into the lake basin and three culverts located between Lake Damon and Lake Pythias draining of out the lake basin. There are currently no permitted surface water withdrawals from the lake; however, there are numerous groundwater withdrawals in the vicinity.

Lake Damon has surface water inflow from Lake Byrd and Lake Brentwood. Both Byrd and Brentwood converge and flow into Lake Damon from the south. Discharge from the lake can occur to Lake Pythias via three culverts located on the east side of Lake Damon (Figure 2). Flow rates into and out of Lake Damon have not been measured, but have been observed.

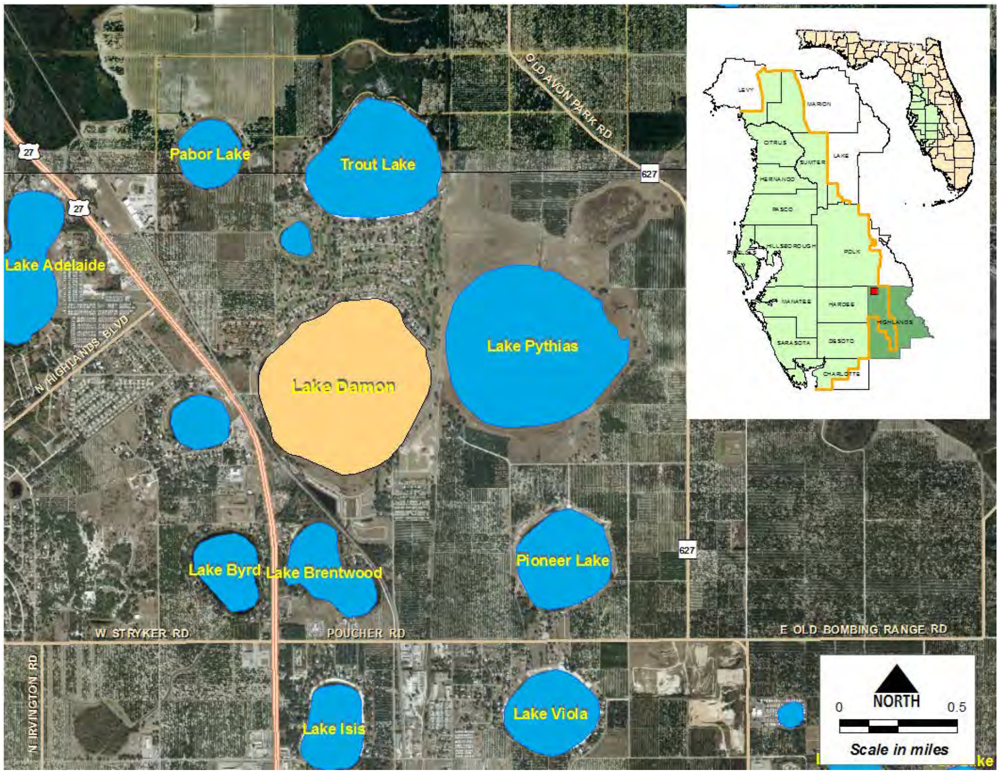

Figure 1. Location of Lake Damon in Polk County, Florida

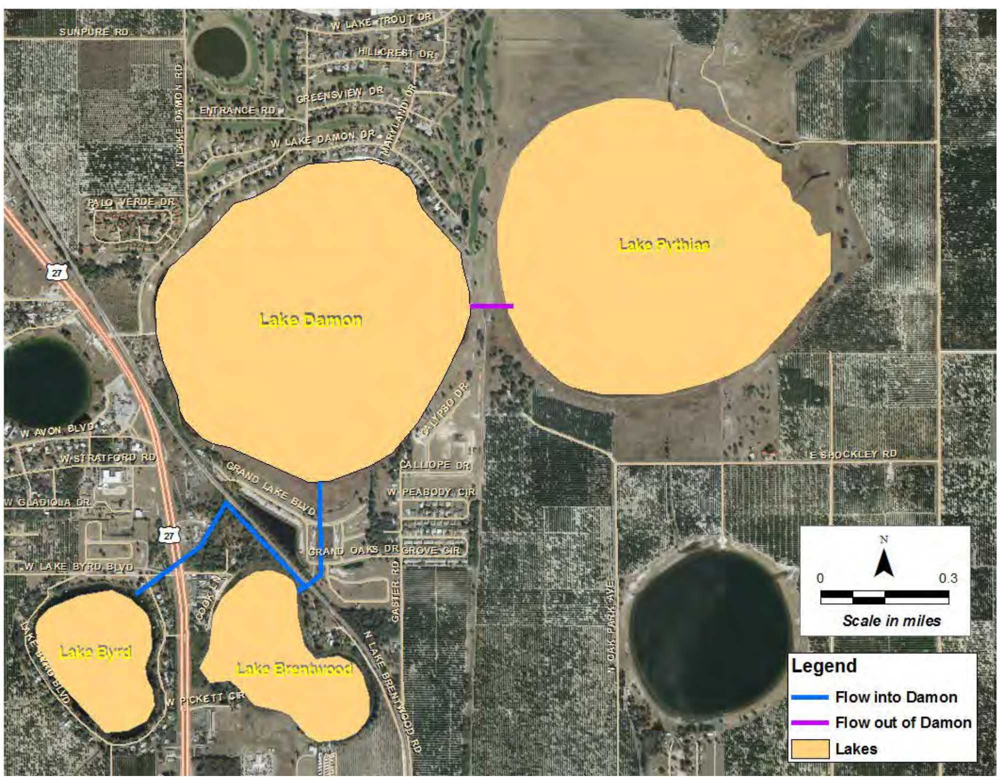

Figure 2. Flow into and out of Lake Damon

Physiography and Hydrogeology

Lake Damon is situated on a north-south oriented ridge (the Lake Wales Ridge) that is approximately 100 miles long and ranges from four to ten miles wide. The area surrounding the lake is categorized as the Eastern Complex of the Central Ridge in the Central Lake Physiographic District (Brooks, 1981).

It is a sub-region of the Lake Wales Ridge and contains residual high hills underlain by sand, gravel, and clayey sand that are deeply weathered. The Lake Wales Ridge area is predominantly well-drained and has internal drainage caused by numerous karst features; hence, it is the principal recharge area of the Floridan aquifer. Dissolution of the underlying limestone creates the relief seen in the Lake Wales Ridge. The Lake Wales Ridge Complex is a remnant of a broader upland that has been eroded and lowered by sea level fluctuations, fluvial erosion, and aeolian redistribution of sediments (Green et al., 2012). Elevations within the immediate watershed range from the lake edge at about 100 feet to 149 feet NGVD29 on the north side of the watershed. Drainage into the lake is a combination of channel inflow, overland flow, and percolation from the surficial aquifer.

The hydrogeology of the area includes a sand surficial aquifer; a clay confining unit perforated by karst features (sinkholes); and the thick carbonate Upper Floridan aquifer (Spechler and Kroening, 2007). The majority of lakes in the study area are sinkhole lakes that originated through collapse of solution-enlarged features in the underlying Floridan aquifer (Barcelo and others, 1990). Sinkholes can provide more direct avenues for water from the surficial aquifer to recharge the underlying Upper Floridan aquifer. Lateral movement of water through the surficial aquifer can be affected by individual lake basins because of the rolling topography, but there is also a sub-regional component to flows.

The surficial aquifer is recharged by area rainfall; however, much of the rain that falls drains into lakes or is lost to evapotranspiration. Other sources of recharge that are applied to land include wastewater, reclaimed water, septic effluent, and irrigation of agricultural land or landscape areas (Spechler and Kroening, 2007). In elevated areas, such as the Lake Wales Ridge, the water table generally is a subdued reflection of land-surface topography (Yobbi, 1996). The Intermediate confining unit (more recently referred to as the Hawthorn aquifer system) consists mostly of interbedded clay, silt, phosphate, and sand is present at Lake Damon and serves as a confining unit.

Stratigraphy near Lake Damon can be described by six well completion reports drilled for domestic supply, irrigation, and public supply within or near the Lake Damon watershed (figure 3). The surficial aquifer is present at all six sites ranging from 44 feet to as much as 160 feet below land surface datum (LSD). The stratigraphy at the well sites is typical of the area, as the surficial aquifer generally thickens toward the east, especially along the southern part of the Lake Wales Ridge where the thickness can exceed 200 feet. The surficial aquifer is considered the uppermost water-bearing unit and is recharged primarily by the infiltration of rainfall. Most rainfall within the area of Lake Damon drains into the lake or is lost to evapotranspiration. The remaining rainfall recharges the surficial aquifer by percolating through unsaturated surficial deposits (Spechler and Kroening, 2007).

Spechler and Kroening (2007) report that the intermediate confining unit, or Hawthorn aquifer system is present throughout much of Polk and northern Highlands County. The Hawthorn aquifer system was present at each of the six well sites. It was mostly described in the well completion reports as green/white clay and sandy clays. The unit typically displays low to moderate porosity values with low permeability values.

Below the Hawthorn aquifer system lies the limestone of the Upper Floridan aquifer system that ranges from approximately 300 feet thick in eastern Polk County to more than 1,200 feet thick in the southwestern part of the county (Spechler and Kroening, 2007). The top of the Floridan aquifer system, the principal source of water for this area, ranged from 220 feet below LSD to 304 feet below LSD according to the six well completion reports. The Floridan aquifer system here consisted mainly of calcarenitic limestone with some dolomite lenses.

Data

Water level data collection at Lake Damon began in 1981. Data was typically collected once a month since March 1985 to current (Figure 4). Data was collected less than monthly for only two years (2001 and 2003) since 1985.

ROMP 43XX Upper Floridan aquifer monitor well (SID 25532) was used for the water budget model for Lake Damon (Figure 5). The well is located approximately 2.3 miles southeast of Lake Damon. Data at ROMP 43XX was collected daily from July 1982 through current. Data gaps were infilled linearly for the duration of the water budget model. The largest data gap was 21 days from August 6, 2014 through August 26, 2014. An offset of -1.08 feet was applied and used to represent the Upper Floridan aquifer at the lake. This offset was calculated by finding the average difference between the potentiometric surface at the well and at the lake for May and September of each year from 2002 through 2011.

Ridge WRAP H-1 surficial aquifer monitor well (SID 23773) was used for the water budget model for Lake Damon (Figure 5).

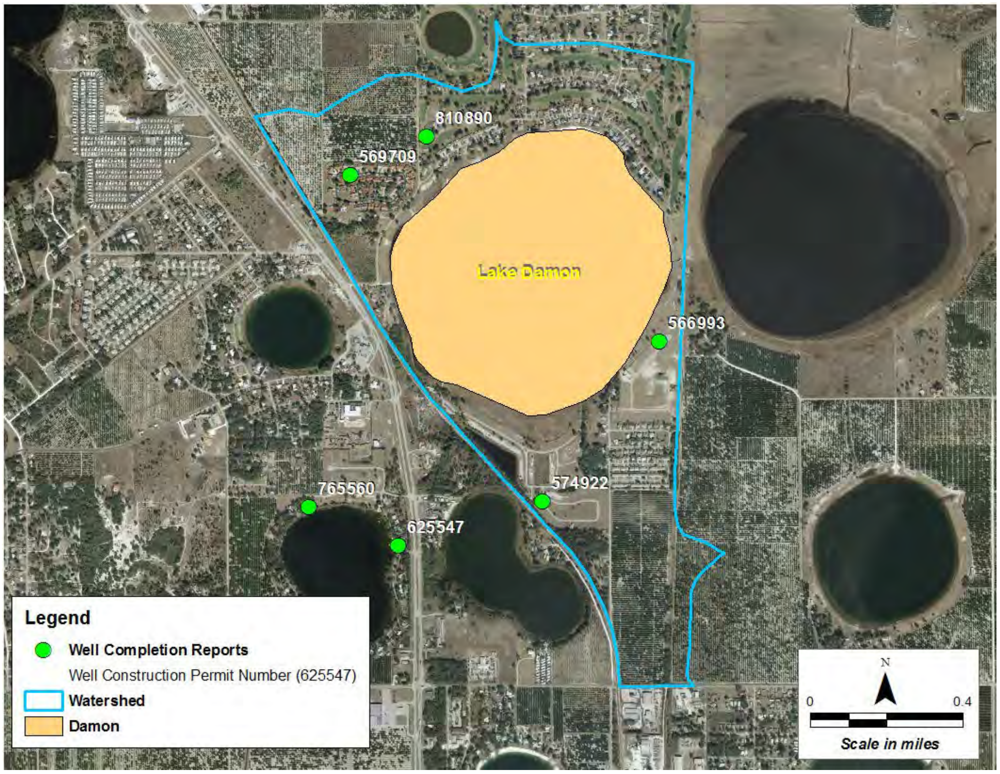

Figure 3. Well Construction Permit Locations

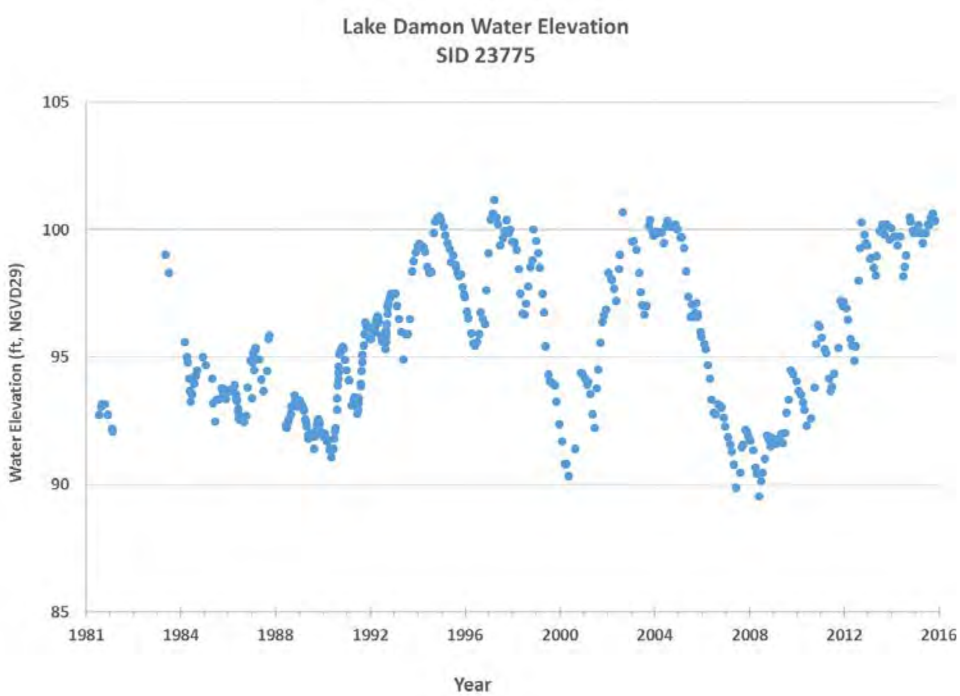

Figure 4. Lake Damon water levels

The well is located approximately 0.6 miles to the southwest of Lake Damon. Data collection began at Ridge WRAP H-1 on April 1991 and is typically collected monthly. During the water budget model period of 2002 through 2016, only five months of data are missing. Data between the missing months and monthly values were infilled linearly.

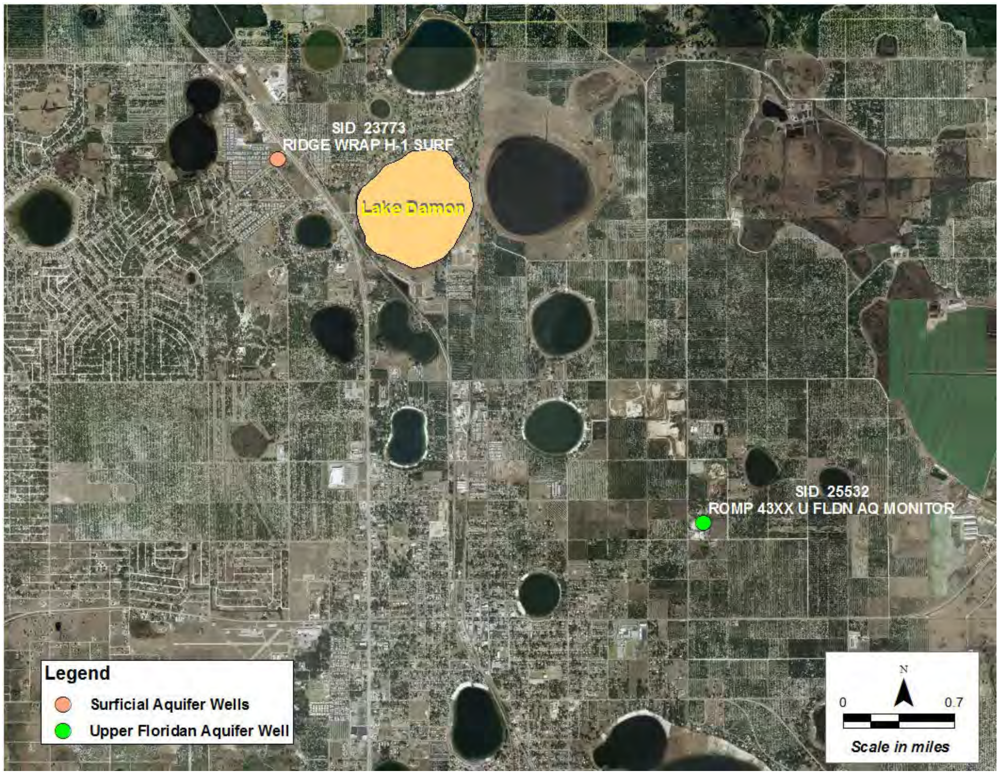

Figure 5. Location of monitoring wells near Lake Damon

Land and Water Use

Land and water use in the area of Lake Damon has changed over the years. Figure 4 shows the land use around Lake Damon in 1941 and Figure 5 shows 2011 land use/land cover with 2012 aerial imagery. Much of the land use in 1941 consisted of citrus groves, agriculture and very little residential development near the lake. Today, land use and water use have changed and is a mix of agriculture and residential (Figures 6 through 8, and Table 1). An estimated and metered water use database prepared annually by the District was used to estimate the groundwater use average from 2011 to 2015. The average estimated groundwater use within one mile of the lake is approximately 0.5 million gallons per day (mgd), of which almost all is agriculture use. Within 5 miles of the lake, the estimated average groundwater use is approximately 14.9 mgd, of which 86 percent is agricultural use and 12 percent is for public supply. Commercial/industrial, mining/dewatering and recreation uses are approximately 2 percent of the estimated total groundwater use average for the same time period.

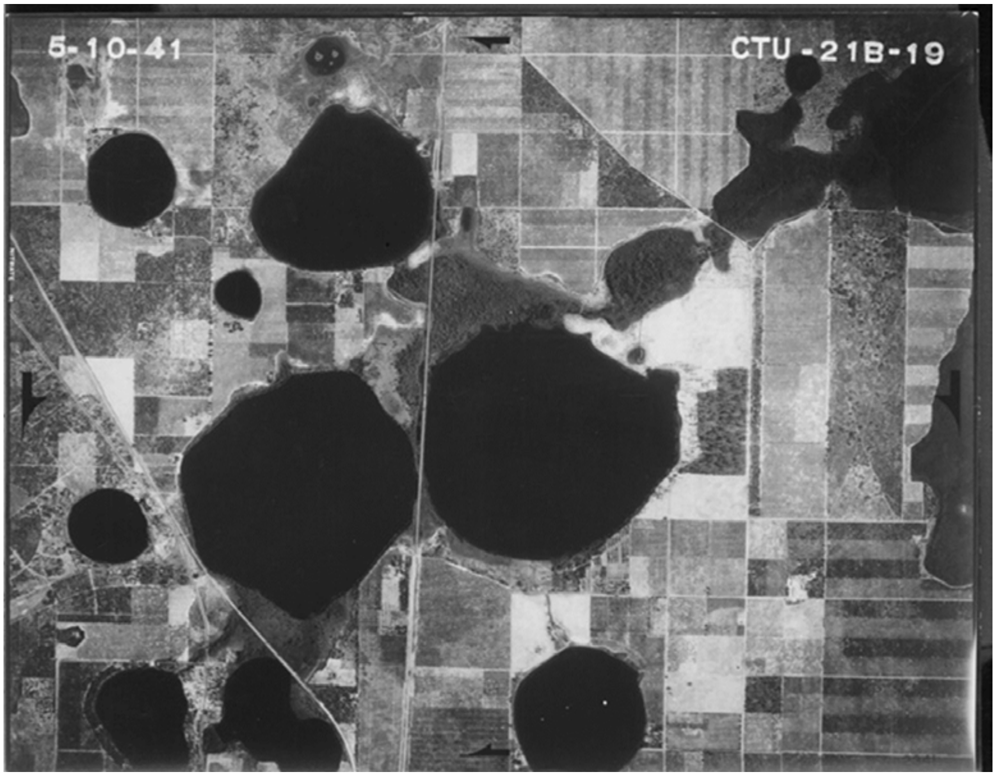

Figure 6. Land use around Lake Damon in 1941

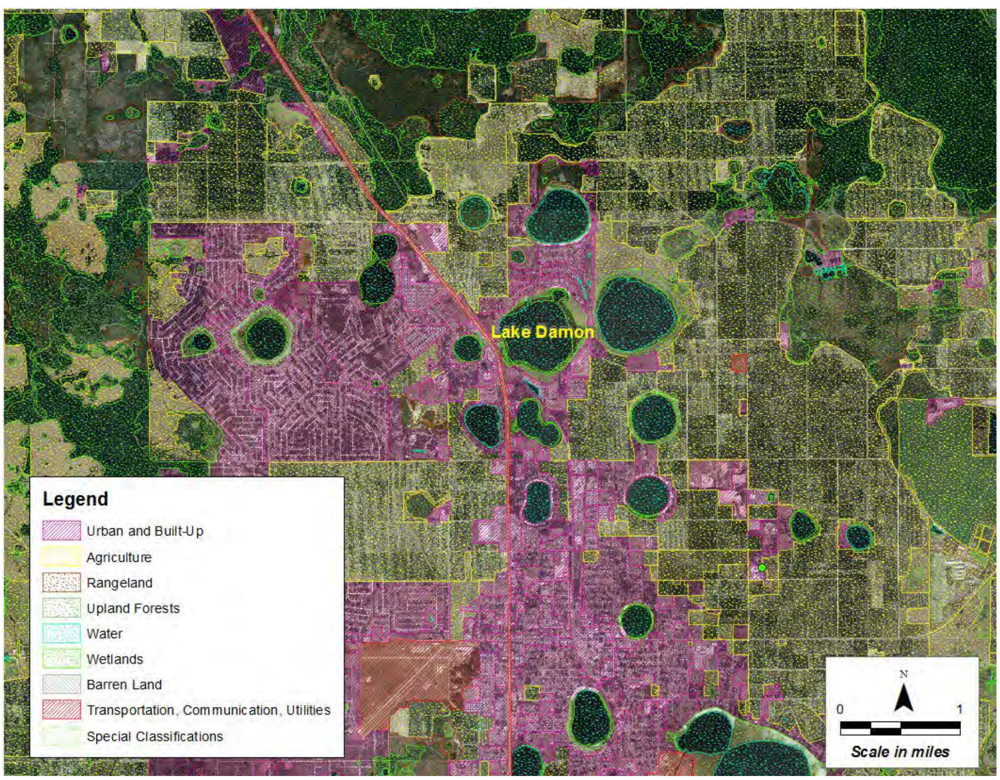

Figure 7. Land use/land cover in 2011 shown on 2012 aerial imagery

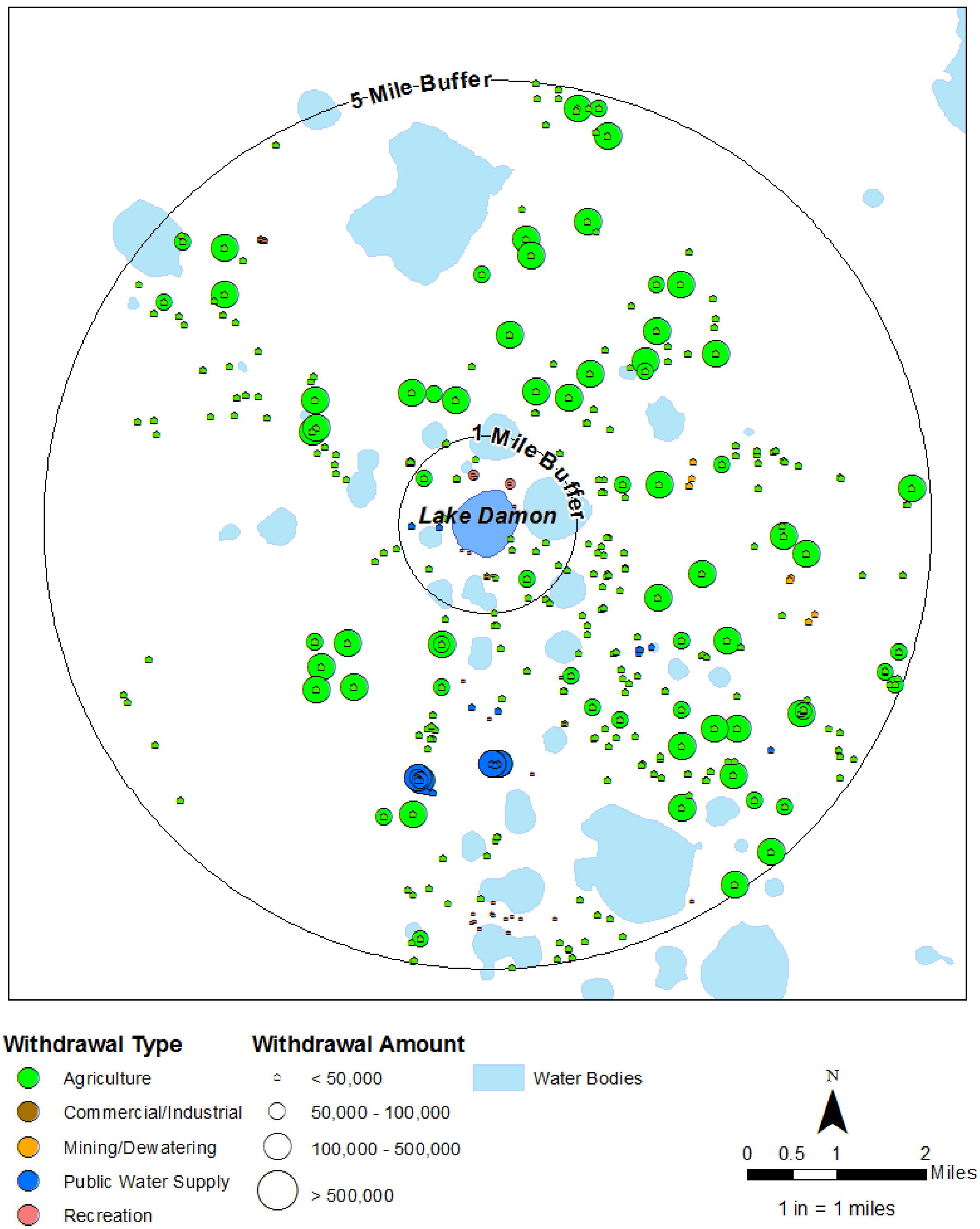

Figure 8. Lake Damon withdrawal locations

Table 1. Water Use in the Lake Damon area (2011-2015 average)

Water Use Within 1 Mile of Lake Damon (gpd)			
Use Type	**SW**	**GW**	**Total**
Agriculture	-	304,829	304,829
Commercial/Mining	-	-	-
Public Supply	-	2,129	2,129
Recreation	-	148,241	148,241
Total	-	455,199	455,199
Water Use Within 5 Mile of Lake Damon (gpd)			
Use Type	**SW**	**GW**	**Total**
Agriculture	162,189	12,652,976	12,815,165
Commercial/Mining	13,681	9,949	23,630
Public Supply	1,845	1,819,744	1,821,590
Recreation	802	257,550	258,352
Total	178,517	14,740,220	14,918,737

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 stage exceedance percentiles such as the P10, P50, and P90, which are, respectively, the water levels equaled or exceeded ten, fifty, and ninety percent of the time. If data representative of a Historic time period do not exist, or available Historic time period data is considered too short to represent long-term conditions, then a model is developed to approximate Long-term Historic data.

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

D. Water Budget Model Overview

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

The hydrologic processes in the water budget model include:

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

The water budget model uses a daily time step, and tracks inputs, outputs, and lake volume to calculate a daily estimate of lake levels. The water budget model for Lake Damon was calibrated for the period from 2002 to 2016. 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 10.2 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

Rainfall station and NEXRAD pixel data used to represent precipitation at the lake are presented in figure 9. The Avon Park 2W NWS rainfall station was the primary station used between January 2002 and December 2005. A few data gaps within this time period were infilled using rainfall data collected at Sebring.

For the period January 1, 2006 through December 31, 2016, an average of data for four NEXRAD pixels coinciding with the lake were used for the LOC model. NEXRAD is a network of 160 high-resolution Doppler weather radars controlled by the NWS, Air Force Weather Agency, and Federal Aviation Administration. The NEXRAD data were used for the water budget model because it resulted in a better calibration of the water budget model than using the average or individual results of the gages located near the lake or used for the earlier model period. NEXRAD data are expected to be available in the future, so they can be used for future status assessments.

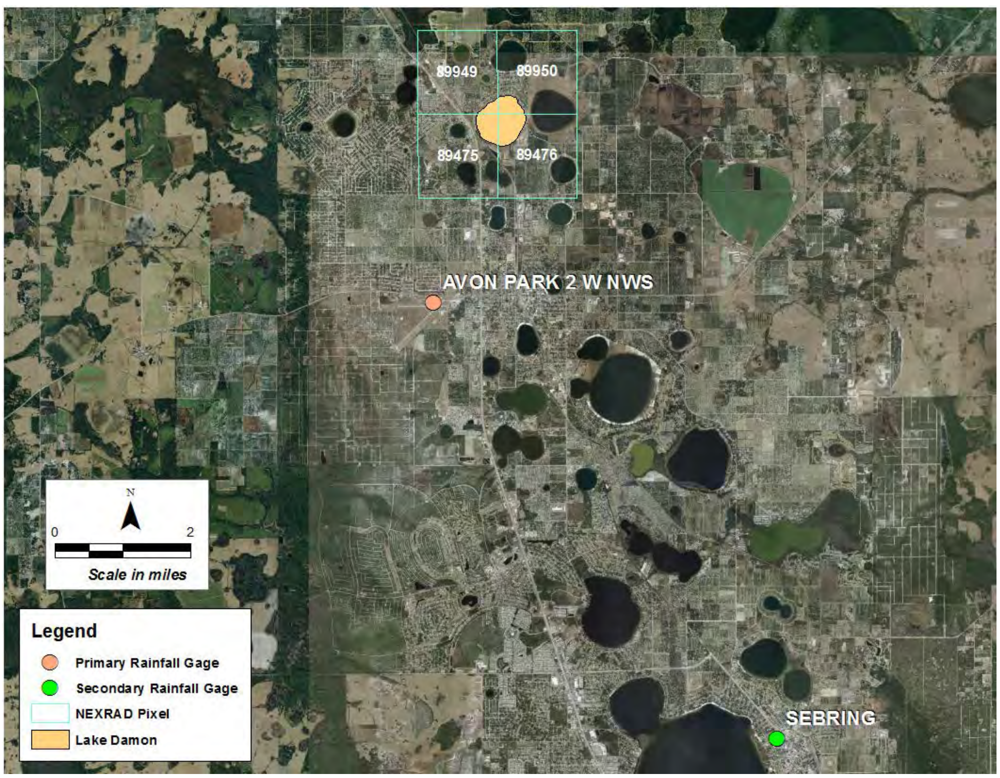

Figure 9. Rainfall stations and NEXRAD grids assessed in the Lake Damon water budget model

Lake Evaporation

Lake evaporation was estimated through use of monthly energy budget evaporation data collected by the U.S. Geological Survey (USGS) at Lake Starr in Polk County (Swancar et al., 2000) (Figure 10). Lake Starr is located approximately 22 miles to the north of Lake Damon. The data were collected from August of 1996 through July of 2011. Monthly Lake Starr evaporation data were used in the water budget model when available, and monthly averages for the period of record were used for those months when Lake Starr evaporation data were not available.

Jacobs (2007) produced daily potential evapotranspiration (PET) estimates on a 2-square kilometer grid for the entire state of Florida. The estimates began in 1995, and are updated annually. These estimates, available from the USGS, were calculated through 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.

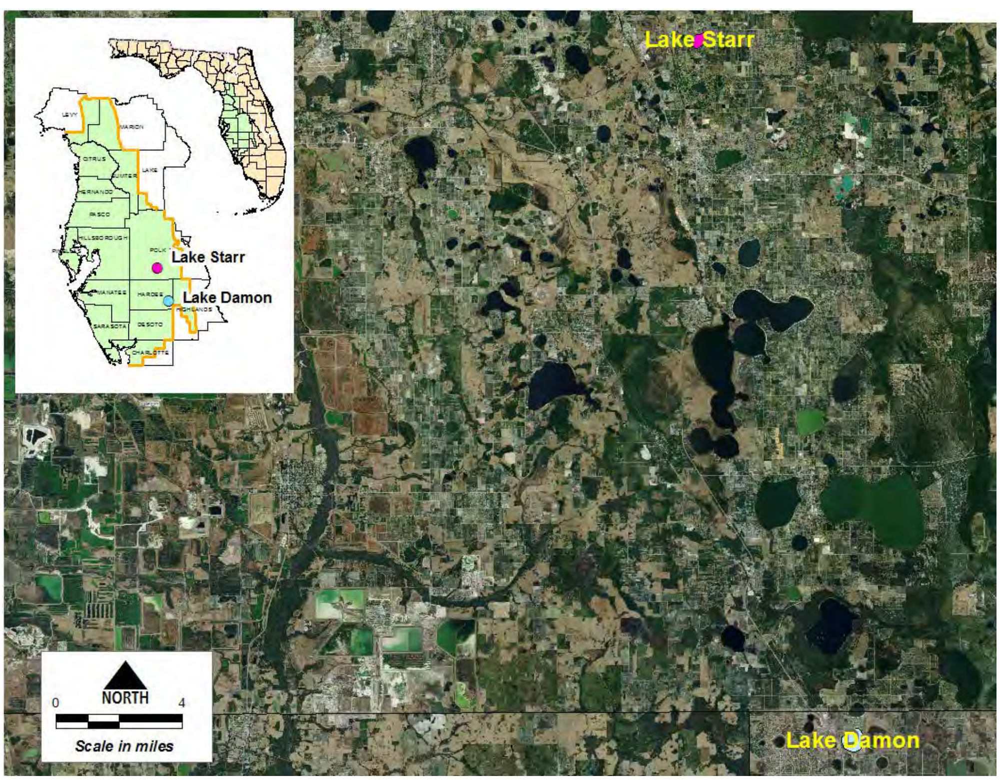

Figure 10. Location of Lake Damon and Lake Starr

Overland Flow

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

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

The lake is located on the central portion of the Lake Wales Ridge. 1-foot LiDAR-derived contours show land surface elevations within the watershed ranging from 149 feet at the southwest portion of the watershed to approximately 100 feet at the lake shore. LiDAR (Light Detection and Ranging) is a remote sensing method that measures variable distances to create three-dimensional information about the shape of the Earth's surface.

The watershed boundary was delineated using LiDAR data. Lake Damon has significant inflow from Lakes Byrd and Brentwood and outflow to Lake Pythias at water levels exceeding 99.13 ft NGVD29. Figure 12 shows the entire watershed for Lake Damon which consists of 427 acres (including the lake area of 258 acres).

The DCIA and SCS CNs used for the direct overland flow portion of the watershed are listed in Table 2. The soils in the immediate lake watershed are predominately "A" soils. The land use within the lake watershed is 44 percent residential (high, medium and low density), 23 percent tree crops, 11 percent golf courses, and the remaining land use (22 percent) are aquatic vegetation, shorelines and transportation.

A curve number (model calibration parameter) of 46 was used in the model and was considered reasonable given the local soil types, land use types and hydrologic conditions. The DCIA parameter was used in addition to the curve number parameter to account for connected impervious areas that provide direct runoff to the lake through storm water systems. It was estimated that 1 percent of the watershed (model calibration parameter) is directly connected impervious area, which was considered reasonable given current land use types.

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

Input Variable	Value
Overland Flow Watershed Size (acres)	427
SCS CN for watershed	46
Percent Directly Connected Area	1%
Upper Floridan Aquifer Monitor Well Used	ROMP 43XX U FLDN
Surficial Aquifer Monitor Well Used	Ridge WRAP H-1
Upper Floridan Aquifer Leakance Coefficient (ft/day/ft)	0.00029
Surficial Aquifer Leakance Coefficient (ft/day/ft)	0.0032
Outflow K Culvert 1 (24”)	0.002
Outflow Invert 1 (ft NGVD 29)	100.37
Outflow K Culvert 2 (36”)	0.003
Outflow Invert 2 (ft NGVD 29)	99.25
Outflow K Culvert 3 (36”)	0.003
Outflow Invert 2 (ft NGVD 29)	99.13
Inflow K Byrd	105.45
Inflow Invert Byrd (ft NGVD 29)	0.003
Inflow K Brentwood	100.23
Inflow Invert Brentwood (ft NGVD 29)	0.003

Figure 12. The Lake Damon watershed

Inflow and Discharge via Channels from Outside Watersheds

Inflows and outflows via channels and culverts from the watershed, or to the watershed (hence referred to as “channel flow”) occur and are incorporated into the water budget model. Channel inflow to Lake Damon occur from Lakes Byrd and Brentwood. The two channel inflows converge just south of Lake Damon and northeast of Lake Brentwood and flow north. Channel outflow via three culverts on the east side of Lake Damon allow flow into Lake Pythias (Figure 2).

Individual water budget models were developed for Lakes Byrd and Brentwood. Channel inflow from Byrd and Brentwood was determined by using the measured water levels from Byrd and Brentwood and the surveyed control points. The lake Byrd control point was surveyed at 105.45 ft. and Lake Brentwood at 100.23 ft. Channel inflow for each model was used to calibrate and remove the impacts from groundwater withdrawals and produce a new water level series for each lake reflective of the higher elevations and thus increase channel flow. The unimpacted water levels series were then used in each lake.

Channel outflow into Lake Pythias occurs at three culverts located on the east side of Lake Damon. One 24-inch and two 36-inch culverts were identified and surveyed as control points between the two lakes.

Flow from and into the surficial aquifer and Upper Floridan aquifer

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

ROMP 43XX Upper Floridan Monitor Well

The ROMP 43XX Upper Floridan aquifer well was used to represent the Upper Floridan aquifer fluctuation at the lake (Figures 45. During the water budget model calibration period data was collected daily with data gaps never exceeding 21 days. Missing data was infilled linearly. The well is located approximately 2.3 miles to the southeast of Lake Damon. Due to the distance from the well to the lake, an offset of 1.08 ft was subtracted to the data collected at the well. The offset was calculated by averaging the potentiometric surfaces in the Upper Floridan aquifer at the well and lake and taking the difference of the averages. The potentiometric surfaces were generated by the United States Geological Survey (USGS) on a biannual schedule of May and September in order to represent the wet and dry condition for each year. The USGS created potentiometric surfaces within the District annually from 1981 to 2011. Since the water budget model for Lake Damon extends back to 2002, only the 2002 through 2011 potentiometric surface maps were used to calculate the offset.

Surficial Aquifer

The RIDGE WRAP H-1 surficial aquifer monitor well is the closest surficial aquifer near the lake and is located approximately 0.6 miles northwest of Lake Damon (Figure 4). The well is the closest surficial monitoring well to Lake Damon. Although the well is in close proximity, the well is not within the Lake Damon watershed and is up gradient of the lake with higher water levels by approximately 33 feet. Due to the topographic gradient between the well and the lake an offset of 6.4 feet was subtracted from the well data to represent water levels in the surficial aquifer near Lake Damon.

F. Water Budget Model Calibration

The primary reason for the development of the water budget model is to estimate lake stage exceedance percentiles without groundwater impacts which can be used to extrapolated long-term Historic percentiles necessary to support development of Minimum and Guidance Levels for the lake. Model calibration was therefore focused on matching the longest period of measured water levels representing a current stable groundwater withdrawal regime.

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

Figures 13 through 15 presents the calibration results for Lakes Byrd, Brentwood, and Damon. Tables 3, 5, and 7 present a comparison of the percentiles of the measured data versus the model results. Tables 4, 6, and 8 presents the modeled water budget components for the calibration period.

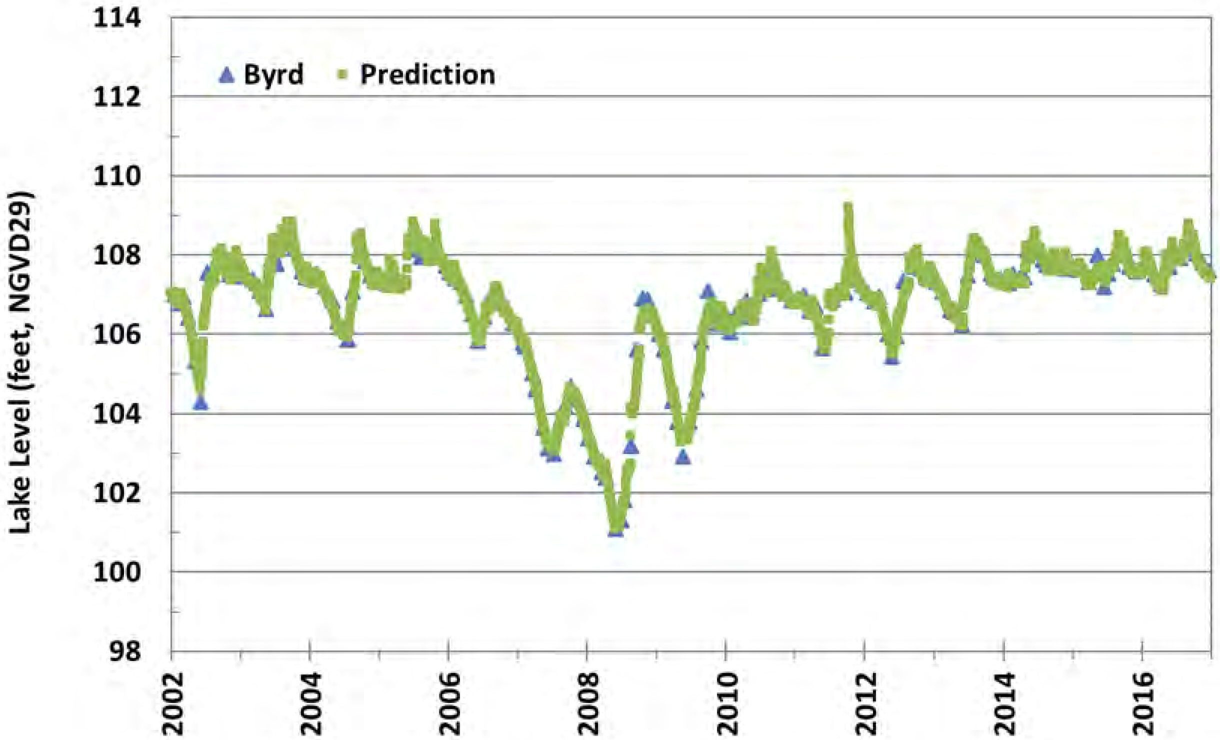

Figure 13. Modeled water levels predicted for the calibrated Lake Byrd water budget (Predicted) and measured levels used for the model calibration (Data)

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

	Data	Model
P10	107.2	107.2
P50	108.0	108.0
P90	104.3	104.4

Table 4. Lake Byrd Water Budget (2002-2016)

Inflows	Rainfall	Surficial Aquifer Ground-water Inflow	Floridan Aquifer Ground-water Inflow	Runoff	DCIA Runoff	Inflow via channel	Total
In/yr	52.7	21.0	0.0	6.7	29.6	0.0	110.0
%	47.9	19.1	0.0	6.1	26.9	0.0	100.0
Outflows	**Evap-oration**	**Surficial Aquifer Ground-water Outflow**	**Floridan Aquifer Ground-water Outflow**			**Outflow via channel**	**Total**
In/yr	58.3	21.7	14.4			15.2	109.7
%	53.2	19.8	13.2			13.9	100.0

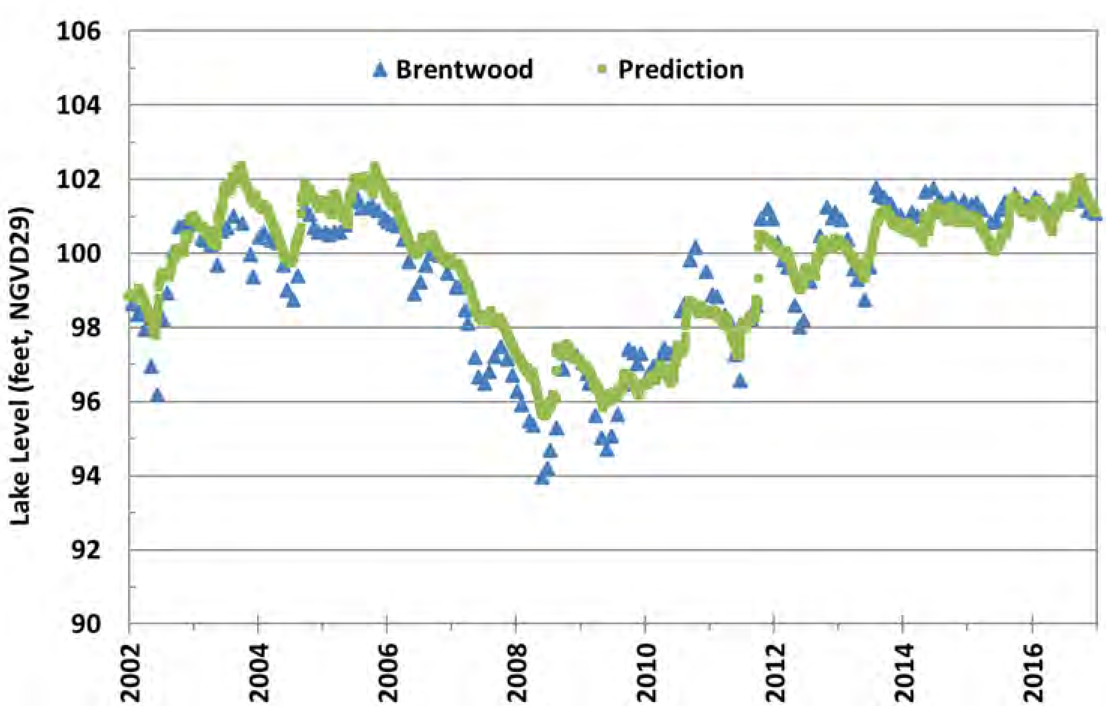

Figure 14. Modeled water levels predicted for the calibrated Lake Brentwood water budget (Predicted) and measured levels used for the model calibration (Data)

Table 5. Lake Brentwood comparison of percentiles of measured lake level data compared to calibration percentiles from the model (all in feet NGVD 29)

	Data	Model
P10	100.2	100.1
P50	101.4	101.4
P90	96.6	96.8

Table 6. Lake Brentwood Water Budget (2002-2016)

Inflows	Rainfall	Surficial Aquifer Ground-water Inflow	Floridan Aquifer Ground-water Inflow	Runoff	DCIA Runoff	Inflow via channel	Total
In/yr	53.0	25.3	0.0	5.5	4.3	0.0	88.1
%	60.2	28.7	0.0	6.2	4.9	0.0	100.0
Outflows	**Evap-oration**	**Surficial Aquifer Ground-water Outflow**	**Floridan Aquifer Ground-water Outflow**			**Outflow via channel**	**Total**
In/yr	58.3	0.1	11.9			15.9	86.3
%	67.6	0.2	13.7			18.5	100.0

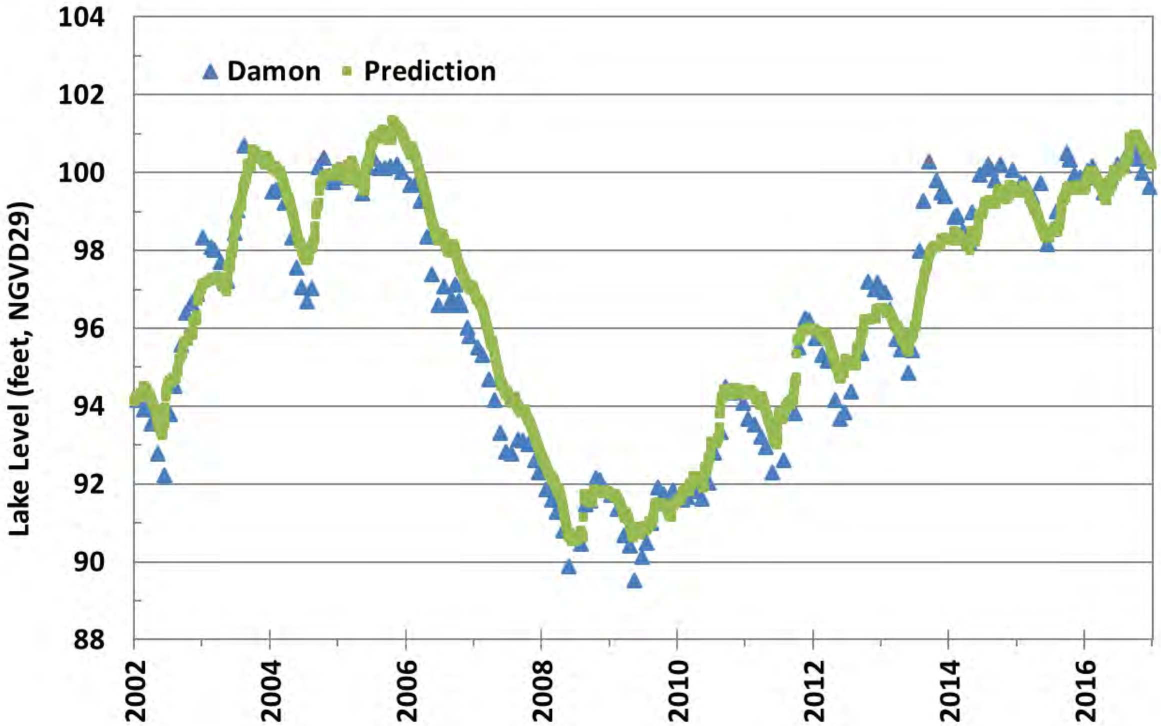

Figure 15. Modeled water levels predicted for the calibrated Lake Damon water budget (Predicted) and measured levels used for the model calibration (Data)

Table 7. Lake Damon comparison of percentiles of measured lake level data compared to calibration percentiles from the model (all in feet NGVD 29)

	Data	Model
P10	100.1	100.1
P50	96.7	96.7
P90	91.7	91.7

Table X. Lake Damon Water Budget (2002-2016)

Inflows	Rainfall	Surficial Aquifer Ground-water Inflow	Floridan Aquifer Ground-water Inflow	Runoff	DCIA Runoff	Inflow via channel	Total
In/yr	52.8	9.9	0.0	2.7	1.0	21.8	88.2
%	59.8	11.2	0.0	3.1	1.1	24.8	100.0

Outflows	Evap-oration	Surficial Aquifer Ground-water Outflow	Floridan Aquifer Ground-water Outflow			Outflow via channel	Total
In/yr	58.3	5.1	13.2			6.7	83.4
%	69.9	6.2	15.8			8.0	100.0

G. Water Budget Model Calibration Discussion

Based on visual inspection of Figures 15, 16, and 17 the models appear to be reasonably well calibrated. There are a few periods when the peaks or lows in the modeled hydrograph are slightly higher or lower than the measured values, and these differences contributed to minor differences between the modeled and measured percentiles associated with the P10 and P90 percentiles. Data limitations in the extreme ranges of the topography/bathymetry used to develop stage-volume estimates may also have contributed to the percentile difference. For Lake Damon, a review of Table 3 shows no differences in medians (P50), P10 percentiles and P90 percentiles between the data and model for the lake.

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

H. Water Budget Model Results

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

Determining the amount of Upper Floridan aquifer drawdown that has occurred due to groundwater withdrawals involved the use of a regional groundwater model and analysis of water level data. The East-Central Florida Transient (ECFT) groundwater model (Sepulveda, et al., 2012 and CFWI, 2014) was used to quantify changes in water levels in response to changes in groundwater withdrawals. This was accomplished using a series of model runs whereby recent withdrawals and irrigation amounts were reduced by 25 percent, 50 percent, and 75 percent. This approach enabled the model to be used within the range of withdrawals that were used during the calibration phase. For the reassessment of minimum levels, the reduced pumping scenarios used a Reference Condition as a basis for comparing model reduction scenarios. The Reference Condition was based on the amount of groundwater withdrawals needed to meet the demands for water that existed as of 2005. Pumping amounts for each year and month of the 12 year transient model run were varied according to rainfall that occurred during each month. As a result of the model scenarios it was estimated that modeled groundwater withdrawals have lowered Upper Floridan aquifer water levels about 2.6 feet beneath Lake Damon.

In addition to the reduced pumping scenarios, an assessment of long-term changes in groundwater levels was performed as a means of gaging model results. Because there is no long-term Upper Floridan aquifer monitor well at the Lake Damon location, the assessment focused on changes occurring at the Lake Alfred Deep well near Lake Alfred, Coley Deep, and the ROMP 60 sites (Figure 16). Average annual water level changes represented by the data were based on comparison of recent (1990 to 2014) levels to the period prior to and including 1960. For the Lake Alfred well, model results were 2.2 feet compared to 2.9 feet when looking at the data and for the Coley Deep well, the model indicated 7.4 feet compared to a change of 9.2 feet when looking at the data. These results are generally consistent, especially considering the data shows slightly more change which is likely due to the differences in rainfall recharge between the two periods that is not represented in the model. Results for the ROMP 60 well site are less certain and likely influenced by their locations relative to model boundaries.

For use in the water budget model, it was recommended that 2.6 feet of drawdown be used. This accounts for increases in pumping amounts that have occurred within one mile of the lake during and beyond the period used for the model. With respect to the surficial aquifer, the relationship between the Leakance coefficient and the ratio of surficial aquifer to Upper Florida aquifer drawdowns established for previous modeling efforts was used. From the water budget model, the Leakance coefficient was 0.0003 feet/day/feet which resulted in a ratio of surficial to Upper Florida drawdown of 0.2. The resulting recovery in the surficial aquifer was then estimated as the product of this ratio and the estimated Upper Florida aquifer recovery amount (2.6 feet) of 0.5 feet.

For Lakes Byrd and Brentwood, the same methodology was applied in order to determine surficial aquifer and Upper Floridan aquifer drawdowns. For Lake Byrd, the resulting recovery in the surficial aquifer was 0.4 feet and 2.8 feet for the Upper Floridan aquifer. Lake Brentwood recovery in the surficial aquifer was 0.6 feet and 2.9 feet for the Upper Floridan aquifer.

Figure 17 presents the results of the calibrated water budget models for Lake Damon with and without the effects of groundwater withdrawals. Table 9 presents the percentiles based on the model output for Lake Damon.

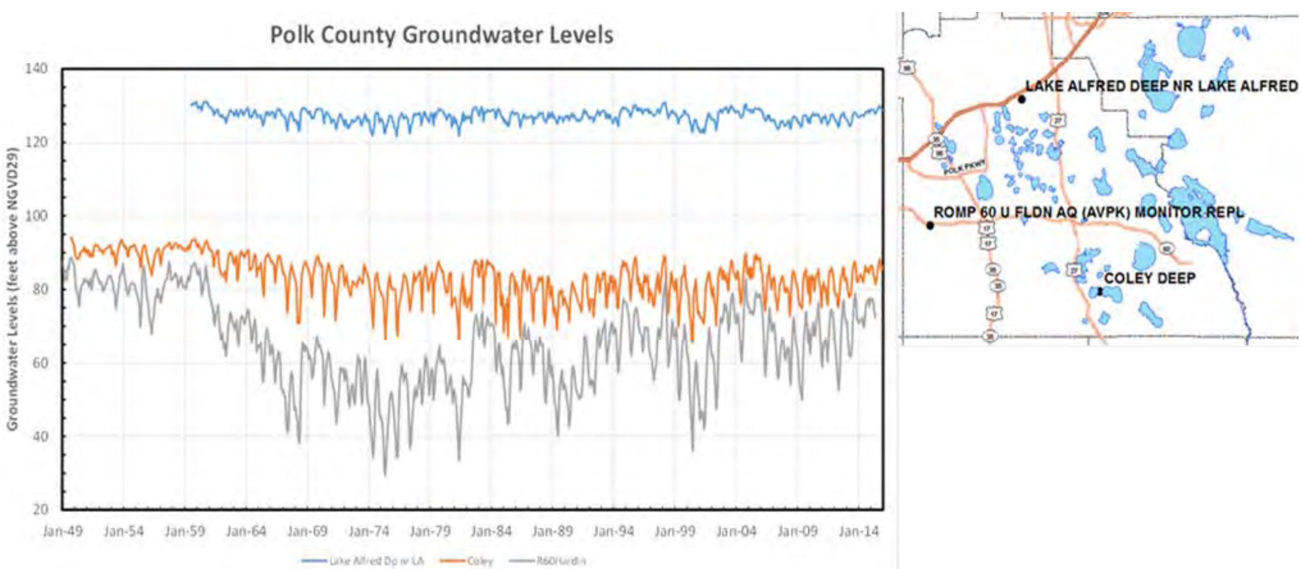

Figure 16. Long-term groundwater levels

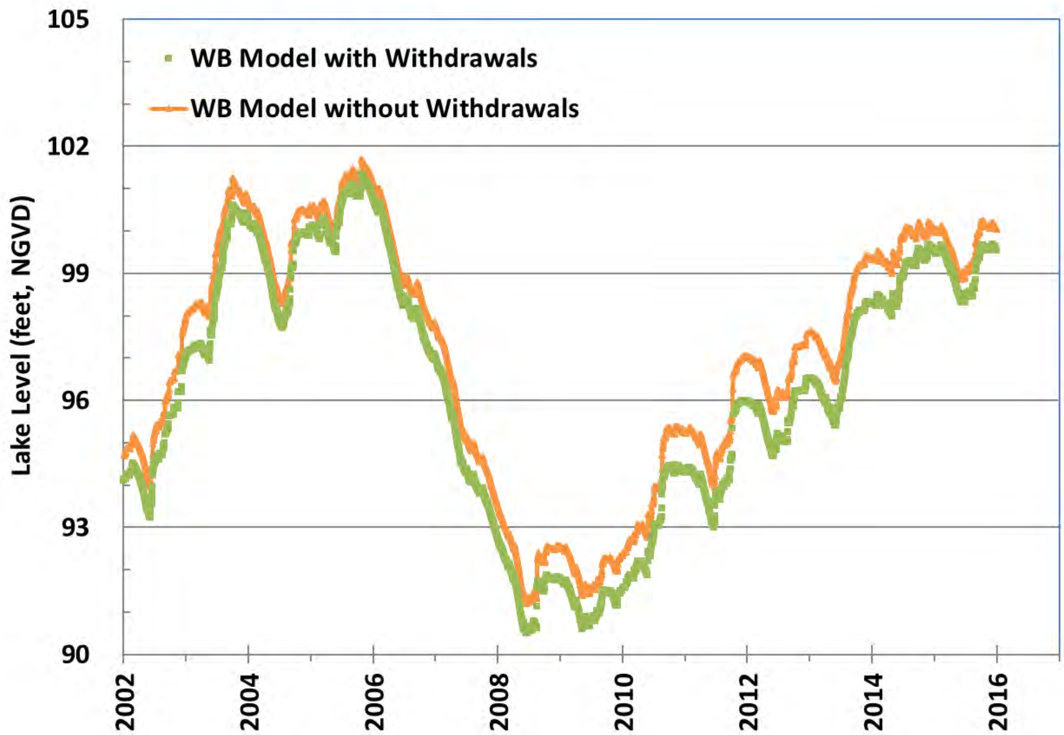

Figure 17. Calibrated Water Budget Model for Lake Damon with and without the effects of withdrawals

Table 9. Historical lake level percentiles determined using the water budget model (feet NGVD 29)

Percentile	Elevation
P10	100.5
P50	97.8
P90	92.5

J. Rainfall Regression Model

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

In this application, the simulated lake water levels representing Historic conditions were correlated with long-term rainfall data. For the rainfall regression analysis, additional representative rainfall records were added to the rainfall data used in the water budget model (2002-2016), extending the rainfall record back to 1946. The record consisted of daily rainfall measurements from the closest rainfall gage and missing daily data values were infilled from the next closest gage with available data until all days were populated with rainfall data. The main gage used to build the Long-term rainfall series (Figure 9) was Avon Park 2 W NWS NWS (SID 25508). Missing days were infilled with gaged rainfall at Sebring (SID 25178). NEXRAD data was used from 2006 through 2016.

Rainfall data were 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 (R2) was chosen as the best model.

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 and to represent the current structural operating schedule affecting the lake (Figure 17). Given the diverse and dispersed nature of groundwater withdrawals affecting the lake, it was difficult to determine a multi-period correction for groundwater impacts. The water budget model results used in the LOC model were limited to a period of relatively consistent groundwater impacts from 2003 through 2016. For this assessment, the final 5-year weighted model had the highest coefficient of determination, with R^2 of 0.82. The results are presented in Figure 18.

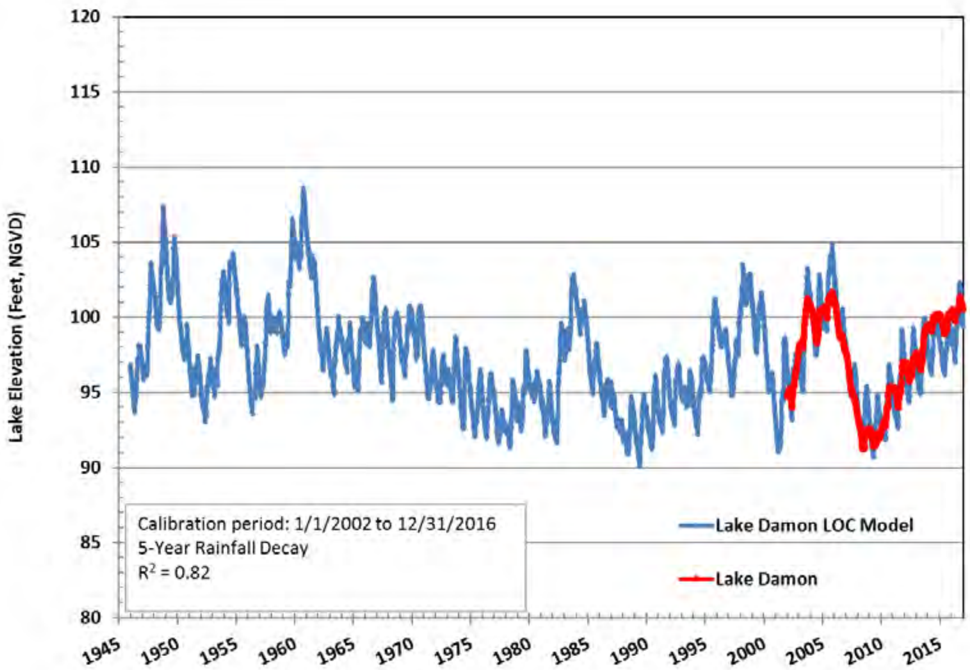

Figure 18. LOC model results for Lake Damon

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 1946-2016, while the water budget results are used for the period of 2002 through 2016. These results are referred to as the "hybrid model." The resulting Historic percentiles for the hybrid model are presented in Table 10. Note that the difference between the P10, P50, and P90 percentiles from the water budget model (Table 9) and those from the hybrid rainfall model (Table 10) for Lake Damon are 0.9, 0.7 and 0.4 for the P10, P50 and P90, respectively (with the hybrid rainfall model being higher for the P10 and P90).

Table 10. Historic percentiles as estimated using the hybrid rainfall model from 1946 through 2016 (feet NGVD 29).

Percentile	Lake Damoon
P10	101.4
P50	97.1
P90	92.9

J. Conclusions

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

K. References

Barcelo, M.D., Slonena, D.L., Camp, S.C., and Watson. J.D, 1990. Ridge II, A Hydrogeologic Investigation of the Lake Wales Ridge: Southwest Florida Water Management District, 14 p.

Brooks, H.K. 1981. Physiographic divisions of Florida: map and guide. Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, Florida.

CFWI (Central Florida Water Initiative) Hydrologic Analysis Team. August 29, 2014.

CH2MHILL. 2003. Local Runoff Prediction for the Lower Hillsborough River and Tampa Bypass Canal Watersheds. Draft Technical Memorandum. Prepared for Tampa Bay Water. Clearwater, Florida.

Helsel D.R. and R.M Hirsch. 2002. Statistical Methods in Water Resources. Techniques of Water-Resources Investigations of the United States Geological Survey. Book 4, Hydrologic Analysis and Interpretation. Chapter A3. U.S. Geological Survey.

Jacobs, J. 2007. Satellite-Based Solar Radiation, Net Radiation, and Potential and Reference Evapotranspiration Estimates over Florida: Task. 4. Calculation of Daily PET and Reference ET from 1995 to 2004. University of New Hampshire.

Sepulveda, N., C.R. Tiedeman, A.M. O'Reilly, J.B. Davis, and P. Burger. 2012. Groundwater Flow and Water Budget in the Surficial and Floridan Aquifer Systems in East-Central Florida: U.S. Geological Survey Open-File Report 2012-1132, 195 p., http://pubs.usgs.gov/of/2012/1132/.

Soil Conservation Service. 1972. National Engineering Handbook. August 1972.

Spechler, R.M. and S.E. Kroening. 2007. Hydrology of Polk County. Scientific Investigations Report 2006-5320. U.S. Geological Survey. Reston, Virginia.

Swancar, A., T.M. Lee, and T.M. O'Hare. 2000. Hydrogeologic Setting, Water Budget, and Preliminary Analysis of Ground-Water Exchange at Lake Starr, a Seepage Lake in Polk County, Florida. Water-Resources Investigations Report 00-4030. U.S. Geological Survey. Tallahassee, Florida.

Yobbi, D.K., 1996. Analysis and Simulation of Ground-Water Flow in Lake Wales Ridge and Adjacent Areas of Central Florida: U.S. Geological Survey Water-Resources Investigations Report 94-4254, 82 p.

Appendix B

Draft Technical Memorandum

December 1, 2017

TO: Tamera McBride, P.G., Manager, Water Resources Bureau

FROM: Jason G. Patterson, Hydrogeologist, Water Resources Bureau
Don Ellison, P.G., Senior Hydrogeologist, Water Resources Bureau
Donna Campbell, Staff Environmental Scientist, Water Resources Bureau

Subject: Lake Damon Initial Minimum Levels Status Assessment

A. Introduction

The Southwest Florida Water Management District (District) is adopting minimum levels for Lake Damon in accordance with Section 373.042 and 373.0421, Florida Statutes (F.S). Documentation regarding development of the minimum levels is provided by Patterson and Ellison (2017) and Campbell and others (2017).

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 lakes and other waterbodies with established minimum flows or levels in the Southern Water Use Caution Area (SWUCA), an applicable regional recovery strategy, referred to as the SWUCA Recovery Strategy, has been developed and adopted into District rules (Rule 40D-80.074, F.A.C.). One of the goals of the SWUCA Recovery Strategy is to achieve recovery of minimum flow and level water bodies such as Lake Damon. This document provides information and analyses to be considered for evaluating the status of the minimum levels proposed for Lake Damon and any recovery that may be necessary for the lake.

B. Background

Lake Damon is located in northwest Highlands County, immediately east of U.S. Highway 27 and north of E. Old Bombing Range road (Figure 1). The lake is within the Kissimmee watershed.

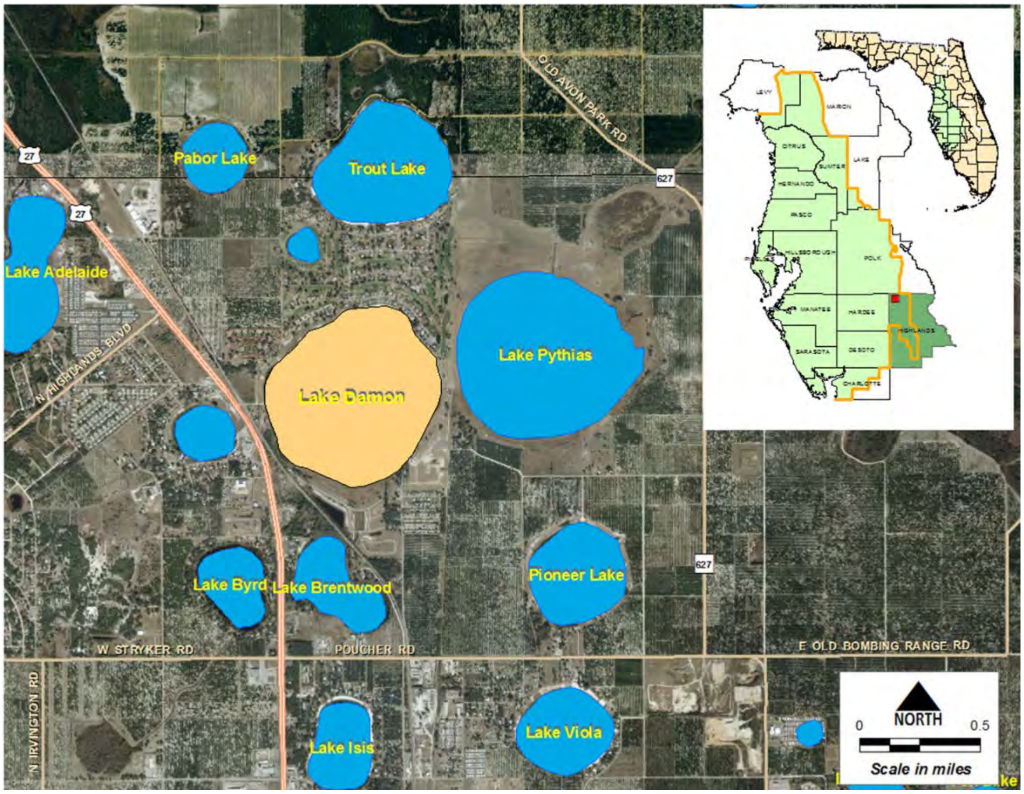

Figure 1. Location of Lake Damon in Polk County, Florida

C. Minimum Levels Proposed for Lake Damon

Minimum levels proposed for Lake Damon are presented in Table 1 and discussed in more detail by Campbell and others (2017). Minimum levels represent long-term conditions that if achieved, are expected to protect water resources and the ecology of the area from significant harm that may result from water withdrawals. The Minimum Lake Level is the elevation that a lake's water levels are required to equal or exceed fifty percent of the time on a long-term basis. The High Minimum Lake Level is the elevation that a lake's water levels are required to equal or exceed ten percent of the time on a long-term basis. The Minimum Lake Level therefore represents the required 50th percentile (P50) of long-term water levels, while the High Minimum Lake Level represents the required 10^{th} percentile (P10) of long-term water levels. To determine the status of minimum levels for Lake Damon, or minimum flows and levels for any other water body, long-term data or model results must be used.

Table 1. Proposed Minimum Levels for Lake Damon.

Proposed Minimum Levels	**Elevation in Feet** NGVD 29
High Minimum Lake Level	97.4
Minimum Lake Level	96.3

D. Status Assessment

The lake status assessment approach involves using actual lake stage data for Lake Damon from 2002 through 2016, 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. No structural alterations have occurred at the lake and groundwater withdrawals during this period were relatively consistent as demonstrated by Patterson and Ellison (2017). Therefore, 2002 through 2016 are considered to represent the "Current" period. "Long-term" is defined as a period that has been subjected to the full range of rainfall variability that can be expected in the future. To create a data set that can reasonably be considered to be "Long-term", a line of organic correlation (LOC) analysis was performed on the lake level data from the Current period. The LOC is a linear fitting procedure that minimizes errors in both the x and y directions and defines the best-fit straight line as the line that minimizes the sum of the areas of right triangles formed by horizontal and vertical lines extending from observations to the fitted line (Helsel and Hirsch, 2002). The LOC is preferable for this application since it produces a result that best retains the variance (and therefore best retains the "character") of the original data. This technique was used to develop the minimum levels for Lake Damon (Patterson and Ellison, 2017). By using this technique, the limited years of Current lake level data can be projected back to create a simulated data set representing over 60 years of lake levels, based on the current relationship between lake water levels and actual rainfall.

The same rainfall data set used for setting the minimum levels for Lake Damon was used for the status assessment. The best resulting correlation for the LOC model created with measured data was the 5-year weighted period (the best correlation for the LOC analyses created with Historic data to set the Lake Damon MFL was 5 years), with a coefficient of determination of 0.80. The resulting lake stage exceedance percentiles are presented in Table 2.

As an additional piece of information, Table 2 also presents the same percentiles calculated directly from the measured lake level data for Lake Damon for the period from 1993 through 2016. A limitation of these values is that the resulting lake stage exceedance percentiles are representative of rainfall conditions during only the past 24 years, rather than the longer-term rainfall conditions represented in the 1946 through 2016 LOC model simulations.

Table 2. Comparison of lake stage exceedance percentiles derived from the lake stage/LOC results, exceedance percentiles of the 2002 through 2016 data, and the minimum levels proposed for Lake Damon.

Percentile	**Lake Stage/LOC Model Current Withdrawal Scenario Results** Elevation in feet NGVD 29	**2002 to 2016 Data** Elevation in feet NGVD 29	**Proposed Minimum Levels** Elevation in feet NGVD 29
P10	101.2	100.1	97.4
P50	96.0	96.7	96.3

A comparison of the LOC model with the minimum levels proposed for Lake Damon indicates that the Long-term P10 is 3.8 feet above the proposed High Minimum Lake Level, and the Long-term P50 is 0.3 feet lower than the proposed Minimum Lake Level. The P10 elevation derived directly from the 2002 through 2016 lake data is 2.7 feet above the proposed High Minimum Lake Level and the P50 elevation is 0.4 feet above the proposed Minimum Lake Level. Differences in rainfall between the shorter 2002 through 2016 period and the longer 1946 to 2016 period used for the LOC modeling analyses likely contribute to the differences between derived and measured lake stage exceedance percentiles. Additionally, differences between actual withdrawal rates and those used in the models may have contributed to some of the differences in the percentiles.

E. Conclusions

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

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

F. References

Campbell, D., J. Patterson, D. Ellison. 2017. Proposed Minimum and Guidance Levels for Lake Damon in Polk County, Florida. Southwest Florida Water Management District. Brooksville, Florida.

Patterson, J., D. Ellison. 2017. Technical Memorandum to Mark Hurst, Subject: Lake Damon Water Budget Model, Rainfall Correlation Model, and Historic Percentile Estimations. Southwest Florida Water Management District. Brooksville, Florida.

Helsel D.R. and R.M Hirsch. 2002. Statistical Methods in Water Resources. Techniques of Water-Resources Investigations of the United States Geological Survey. Book 4, Hydrologic Analysis and Interpretation. Chapter A3. U.S. Geological Survey.