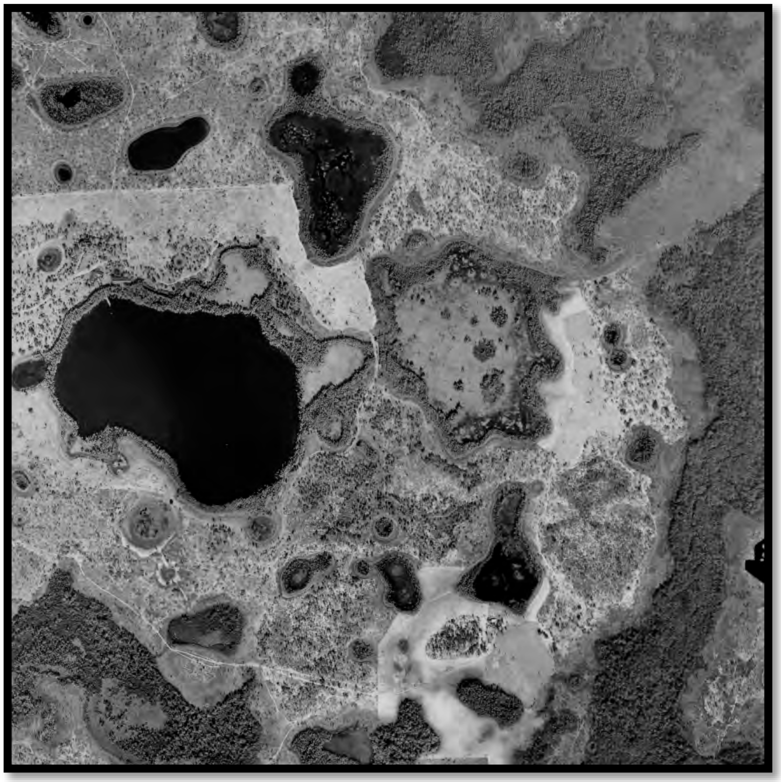
Revised Minimum and Guidance Levels for Moon Lake in Pasco County, Florida



June 17, 2015

Resource Evaluation Section
Water Resources Bureau

Southwest Florida Water Management District

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Cover Page: 1957 Historical aerial of Moon Lake and historical photos of Moon Lake Lodge (1920s). Aerial imagery provided by University of Florida George A. Smathers Libraries Aerial Photography: Florida Collection. Photos provided by State Archives of Florida, Florida Memory

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Executive Summary

This report describes the development of revised Minimum and Guidance levels for Moon Lake in Pasco County, Florida based on reevaluation of levels in Southwest Florida Water Management District rules that became effective in August 2000. Minimum levels are the levels at which further water withdrawals would be significantly harmful to the water resources of the area (Section 373.042(1)(b), F.S.). Adopted minimum levels are used to support water resource planning and permitting activities. Adopted guidance levels are used as advisory guidelines for construction of lakeshore development, water dependent structures, and operation of water management structures.

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

Revised Guidance and Minimum Levels for Moon Lake were developed using current District methods for establishing minimum levels for Category 1 Lakes, which are lakes that are contiguous with at least 0.5 acres of cypress-dominated wetlands. The revised Minimum Levels were developed with consideration of and are protective of all relevant environmental values identified for consideration in the Water Resource Implementation Rule when establishing minimum flows and levels (see Rule 62-40.473, F.A.C.). The revised levels are expressed as elevations in feet above the National Geodetic Vertical Datum of 1929 (NGVD29) that must be equaled or exceeded specified percentages of time on a long-term basis. Table ES-1 identifies these elevations and includes generic descriptions for the levels in District rules (Rule 40D-8.624, F.A.C). Differences between the revised and previously adopted levels are primarily associated with application of a new modeling approach for characterization of historic water level fluctuations within the lake, i.e., water level fluctuations that would be expected in the absence of water withdrawal impacts given existing structural conditions.

Based on these results, revision of the previously adopted Guidance and Minimum Levels for Moon Lake was recommended and determined to be necessary and approved by the District Governing Board. The revised Minimum and Guidance Levels identified in this report replaced the previously adopted levels for the lake included in District rules.

Based on available measured and modeled water level records, the revised minimum levels for Moon Lake are being met. In the event that levels are not met in the future recovery strategies outlined in the Comprehensive Environmental Resources Recovery

Plan for the Northern Tampa Bay Water Use Caution Area and the Hillsborough River Recover Strategy (Rule 40D-80.073, F.A.C) will apply for recovery of minimum levels for the lake.

Table ES-1. Revised Minimum and Guidance Levels for Lake Moon and level descriptions.

Minimum and Guidance Levels	Elevation (feet above NGVD29)	Level Descriptions
High Guidance Level	40.0	Advisory guideline for construction of lake shore development, water dependent structures, and operation of water management structures. The High Guidance Level is the elevation that a lake's water levels are expected to equal or exceed ten percent of the time on a long-term basis.
High Minimum Lake Level	39.6	Elevation that a lake's water levels are required to equal or exceed ten percent of the time on a long-term basis.
Minimum Lake Level	38.2	Elevation that the lake's water levels are required to equal or exceed fifty percent of the time on a long-term basis.
Low Guidance Level	36.3	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.

	High Guidance Level	High Minimum Level	Minimum Lake Level	Low Guidance Level
NGVD 29[a]	40.0	39.6	38.2	36.3
NAVD 88[b]	39.2	38.8	37.3	35.4

[a] National Geodetic Vertical Datum of 1929
[b] North American Vertical Datum of 1988

Introduction

Reevaluation of Minimum and Guidance Levels

This report describes the development of revised minimum and guidance levels for Moon Lake in Pasco County, Florida. The revised levels were developed based on the reevaluation of minimum and guidance levels approved by the Southwest Florida Water Management District Governing Board for the lake in November 2003 (see Southwest Florida Water Management District 1999) and adopted into District rules with an effective date of August 2004. The revised minimum and guidance levels represent needed revisions to the previously adopted levels.

Moon Lake was selected for reevaluation based on development of modeling tools for simulating lake level fluctuations that were not available when the previously adopted levels were developed. The previously adopted lake levels were also reevaluated to support ongoing assessments of minimum flows and levels in the northern Tampa Bay Water Use Caution Area, a region of the District where recovery strategies are being implemented to support recovery to minimum flow and level thresholds.

Minimum Flows and Levels Program Overview

Legal Directives

Section 373.042, Florida Statutes (F.S.) directs the Department of Environmental Protection or the water management districts to establish minimum flows and levels (MFLs) for lakes, wetlands, rivers and aquifers. Section 373.042(1)(a), F.S., states that “the minimum flow for a given watercourse shall be the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area." Section 373.042(1)(b), F.S., defines the minimum water level of an aquifer or surface water body as "…the level of groundwater in an aquifer and the level of surface water at which further withdrawals would be significantly harmful to the water resources of the area." Minimum flows and levels are established and used by the 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 “if the existing flow or level in a water body is below, or is projected to fall within 20 years below, the applicable minimum flow or level established pursuant to S. 373.042.” Section 373.0421(2)(a), F.S., requires that recovery or prevention strategies be developed to: "(a) achieve recovery to the established minimum flow or level as soon as practicable; or (b) prevent the existing flow or level from falling below the established minimum flow or level." Periodic reevaluation and, as necessary, revision of established MFLs are required by Section 373.0421(3), F.S.

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

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

Development of Minimum Lake Levels

Programmatic Description and Major Assumptions

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

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

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

Support for these assumptions is provided by a large body of published scientific work addressing relationships between hydrology, ecology and human-use values associated with water resources (e.g., see reviews and syntheses by Postel and Richer 2003, Wantzen *et al.* 2008, Poff *et al.* 2010, Poff and Zimmerman 2010). This body of knowledge 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;
- support status assessments for water bodies with proposed or established MFLs (*i.e.*, determine whether the flow and/or water level are below, or are projected to fall below the applicable minimum flow or level); and

- support development of lake guidance levels (described in the following paragraph).

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

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

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

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

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

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

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

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

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

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

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

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

Data and Analyses Supporting Development of Revised Minimum and Guidance Levels

Lake Setting and Description

Moon Lake (Figure 1) is located in the Coastal Rivers Basin of the Southwest Florida Water Management District (SWFWMD or District) in Pasco County, Florida (Sections 21 & 28, Township 25S, Range 17E). The area surrounding the lake is categorized as the Land-O-Lakes subdivision of the Tampa Plain in the Ocala Uplift Physiographic District (Brooks 1981). The subdivision is a region of many lakes on a moderately thick plain of silty sand overlying Tampa Limestone. As part of the Florida Department of Environmental Protection's Lake Bioassessment/Regionalization Initiative, the area has been identified as the Weeki Wachee Hills lake region, and described as a region of Pleistocene sand dunes with numerous solution basins containing clear-water lakes with circumneutral pH, low alkalinity and low nutrient levels (Griffith *et al.* 1997).

Uplands surrounding the lake have been cleared and are currently used for residential development (Figure 2). Forested wetlands contiguous with the lake have been dredged or filled. A public boat ramp and swimming beach are maintained along the northeastern lakeshore by the Pasco County Parks and Recreation Department. The Southwest Florida Water Management District maintains a regulatory water-level gauge along the lake's west shore.

The 1954 United States Geological Survey 1:24,000 Fivay, Fla. and the 1954 (photorevised 1988) Fivay Junction quadrangle maps include a water level elevation of 41 ft above NGVD for Moon Lake. The "Gazetteer of Florida Lakes" (Florida Board of Conservation 1969, Shafer *et al.* 1986) lists the lake area as 99 acres at this elevation. Based on the most recent map of the basin generated in support of minimum levels development, the lake extends over 144 acres when it reaches a stage of 41.8 ft above NGVD (Figure 3). Data used for production of the topographic and bathymetric maps were obtained from LiDAR land surface elevation data collected in 2008 and field surveys conducted in 2002 through 2003.

Moon Lake is located in the Pithlachascotee River drainage basin, and has a drainage area of 0.3 square miles (Florida Board of Conservation 1969). Inlets include a ditch/culvert/canal system that connects the lake to a large cypress-dominated wetland (95 acres) east of the lake. A series of ditches and culverts initiating along the lakes south shore drain the lake through several wetland ponds, and ultimately to the Pithlachascotee River.

The lake is connected to the cypress wetland at an elevation of 38.3 NGVD (elevation of main inflow culvert, see Figure 2). Based on the data for the period of record for the lake (January1965 – March 2015), the lake and large cypress wetland are connected 49% of the time indicating frequent connectivity (Figure 3). Historical imagery indicates that a raised road was constructed between the lake and wetland, reducing the frequency of the connection to what it is today. A broader natural connection was likely historically in place prior to the road construction and the wetland and lake likely formed one continuous basin. Due to semi-permanent connection between the lake and the cypress wetland, biological indicators of both the lake and connected wetland were evaluated for the development of the normal pool elevation.

There are no surface water withdrawals from the lake currently permitted by the District. There are, however, several permitted groundwater withdrawals in the area, including major withdrawals associated with Tampa Bay Water's operation of the Starkey and North Pasco Wellfield (Figure 4). Monthly average water withdrawals from 1992 – 2011 within a two-mile radius were 111,000 gallons and within a three mile radius were 5.9 million gallons per day (mgd) (Figure 4).

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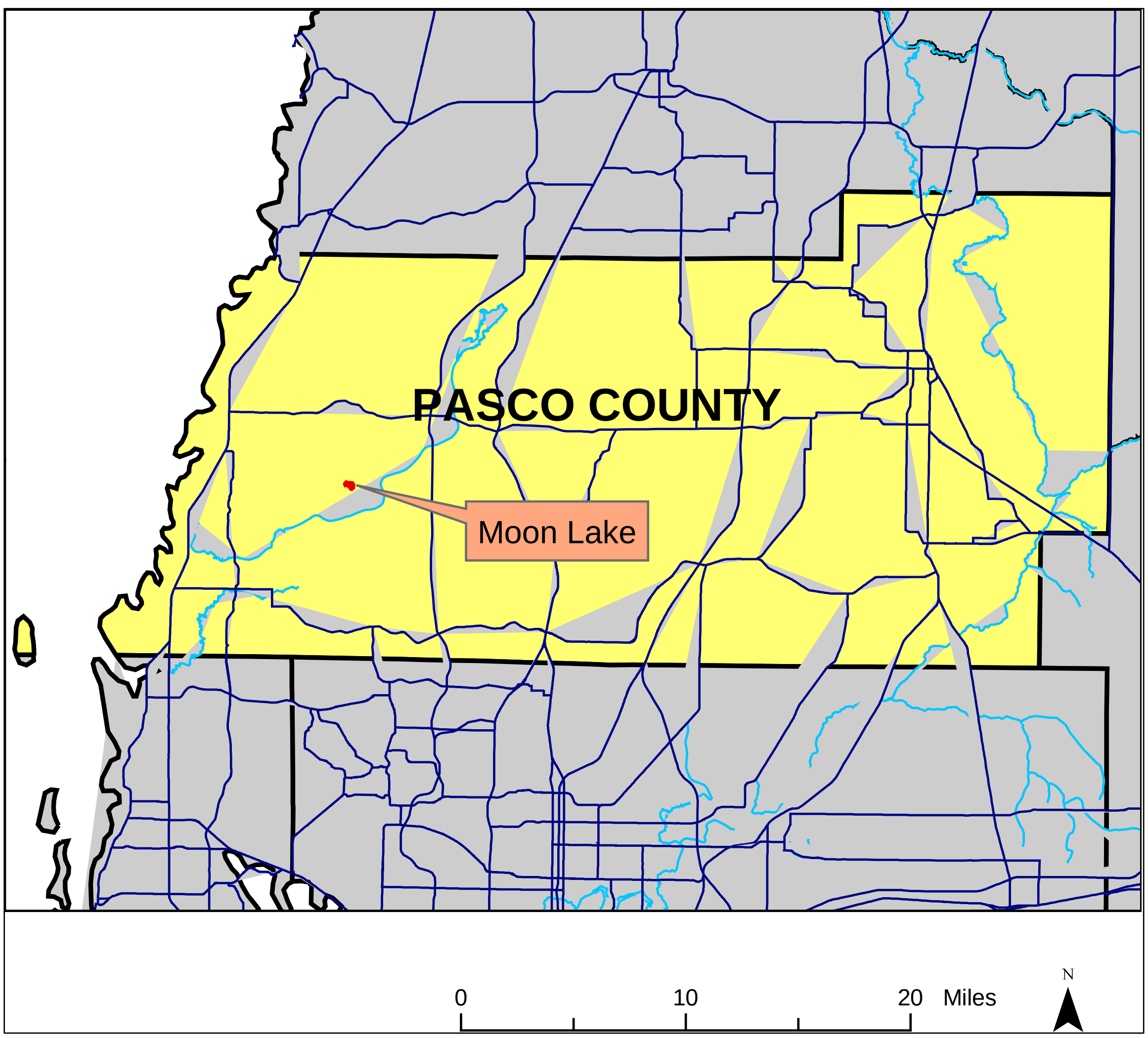


Figure 1. Location of Moon Lake in Pasco County, Florida.

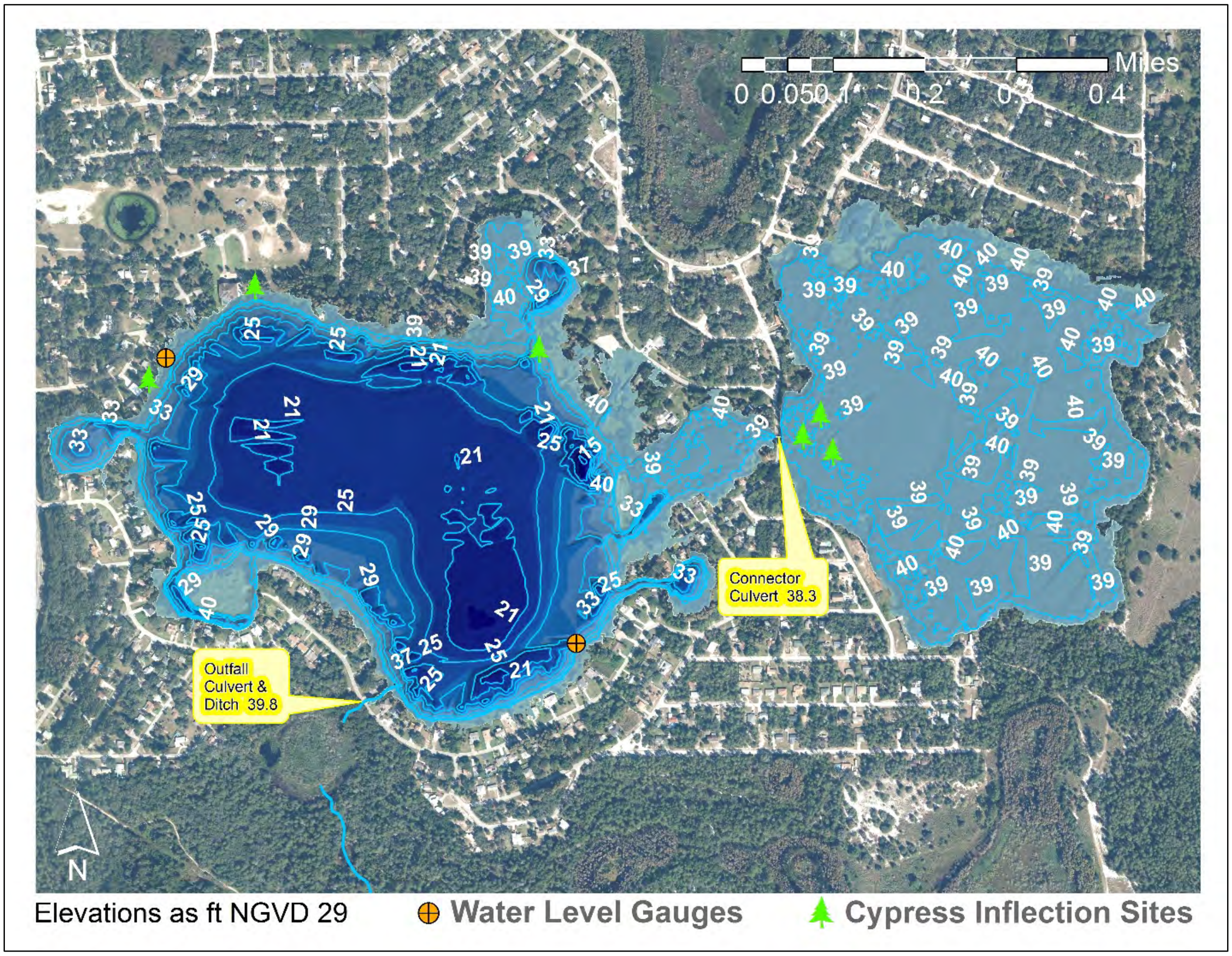


Figure 2. The water level gage is located on the northeastern side of the lake. The ditch located on the southern side of the lake serves as the lake outflow.

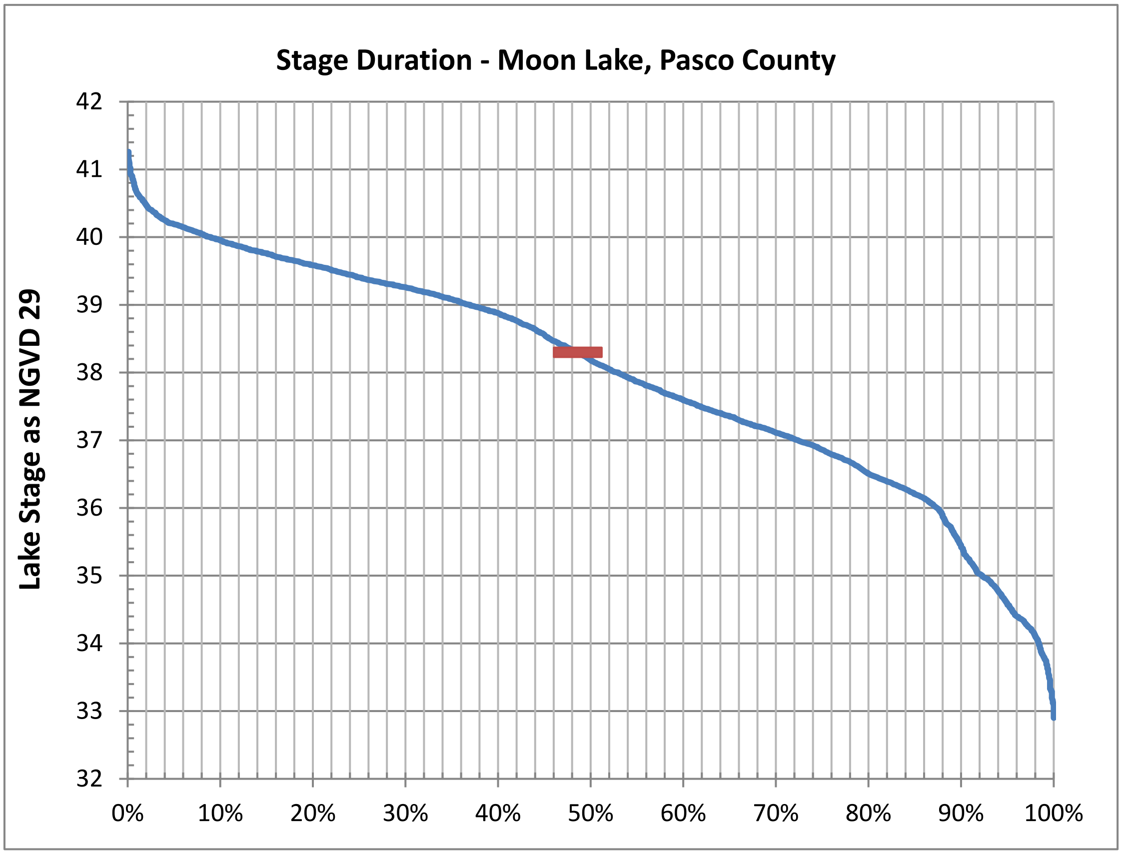


Figure 3. Stage duration (data period January 1965 – March 2015) plot for Moon Lake, Pasco County shown with the elevation of the connection to large cypress wetland to the east.

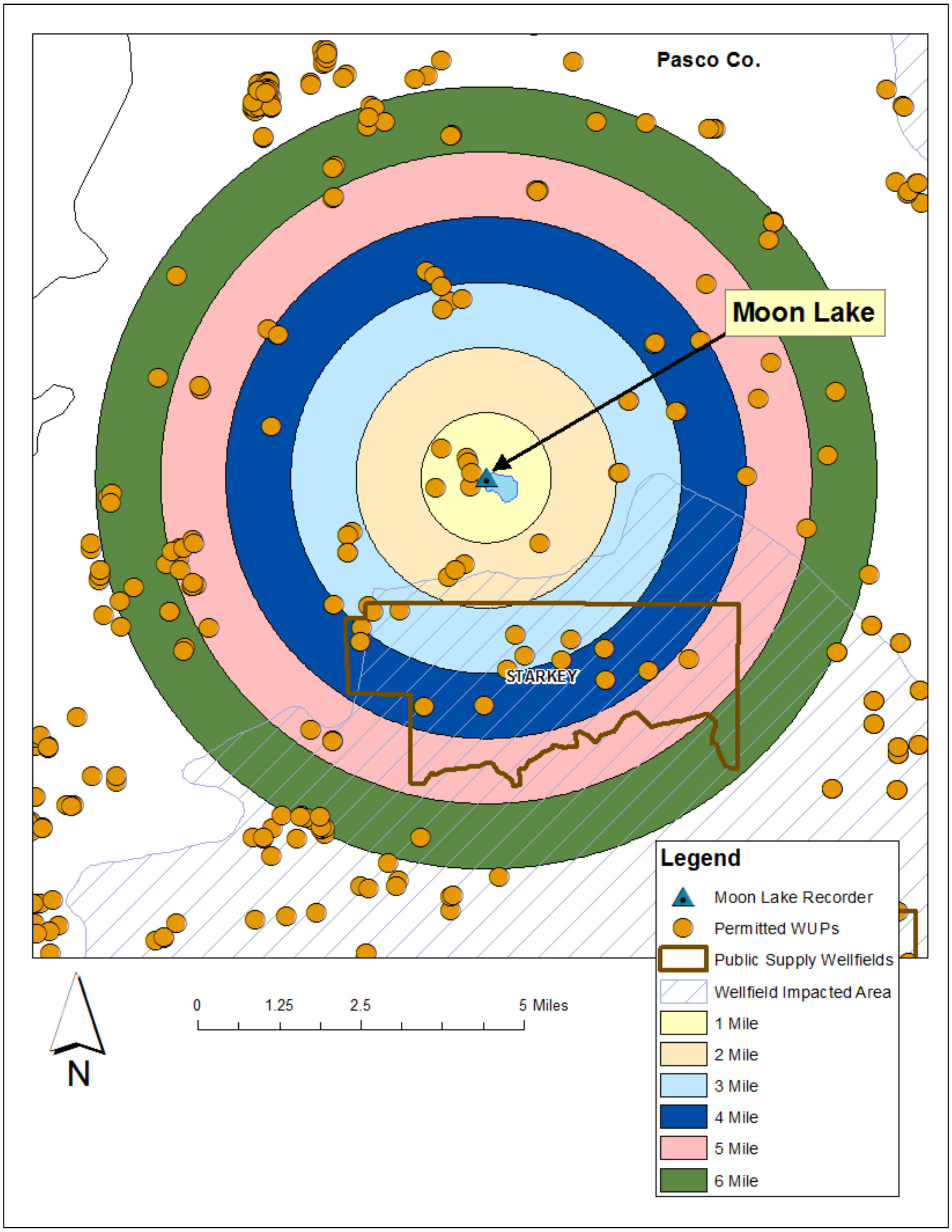


Figure 4. Permitted groundwater withdrawals within a one six-mile radius of Moon Lake.

Previously Adopted Minimum and Guidance Levels

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

Based on work conducted in the 1980s (see SWFWMD 1996a), the District adopted management levels, including minimum and flood levels, for Moon Lake in November 1984 (Table 2) and incorporated the levels into its Water Levels and Rates of Flow Rules (Chapter 40D-8, F.A.C.). As part of the work leading to the adoption of management levels, a Maximum Desirable Level of 40.00 feet above mean sea level was also developed for the lake, but was not adopted by rule.

Based on changes to sections of the Florida Statutes that address minimum flows and levels in 1996 and 1997, and the development of new approaches for establishing MFLs, District Water Levels and Rates of Flow rules were modified in 2000. The modifications included incorporation of rule language addressing MFLs development and the renaming of established levels as Guidance Levels, as indicated for Moon Lake in Table 2. Subsequent revisions to District rules incorporated additional rule language associated with developing minimum lake levels.

Based on the approaches for establishing MFLs developed in the late 1990s and early 2000s, the District adopted recommended Guidance and Minimum Levels for Moon Lake (Leeper 2003) into its Water Levels and Rates of Flow rules in September 2004 (Table 3), and removed the previously adopted management levels for the lake from District rules. A Ten-Year Flood Guidance Level of 71.5 feet above NGVD that was adopted for the lake along with the other levels in September 2004 was subsequently removed from Chapter 40D-8, F.A.C., in 2007, when the Governing Board determined that flood-stage elevations should not be included in the District's Water Levels and Rates of Flow rules.

The previously adopted Minimum and Guidance Levels for Moon Lake (Table 2) were developed using a methodology that differs from the current approach for establishing Minimum and Guidance Levels (SWFWMD 1999a). The levels do not, therefore, necessarily correspond with the revised levels developed using current methods. The revised Minimum and Guidance Levels developed using current methods have replaced previous Guidance Levels following adoption by the District Governing Board into Chapter 40D-8, F.A.C. In 2007, one of the management levels, a Ten-Year Flood Guidance Level of 41.7 ft., was removed from Chapter 40D-8, when the District Governing Board determined that flood-stage elevations should not be included in the District's Water Levels and Rates of Flow rules.

Ongoing development of methods for establishing MFLs has led the District to develop revised Minimum and Guidance Levels for Moon Lake, as outlined in this report. Because the previously adopted Minimum and Guidance Levels were developed using methods that differ from those now in use, they do not necessarily correspond with the revised levels presented in this report. Following adoption by the Governing Board, Minimum and Guidance Levels developed using existing methods have replaced the previously adopted levels.

Table 2. Previously adopted management and Guidance Levels for Moon Lake.

Management Levels (as originally adopted)	Guidance Levels [a]	Elevation (feet above Mean Sea Level)
Ten (10) Year Flood Warning Level	Ten Year Flood Guidance Level	41.00
Minimum Flood Level	High Level	40.50
Minimum Low Management Level	Low Level	37.50
Minimum Extreme Low Management Level	Extreme Low Level	35.50

[a] Adopted management levels within District rules were renamed as Guidance Levels in 2000.

Table 2. Previously Adopted Minimum and Guidance Levels for Moon Lake as listed in Table 8-2 of subsection 40D-8.624, F.A.C.

Minimum and Guidance Levels	Elevation in Feet NGVD 29
High Guidance Level	39.9
High Minimum Level	39.9
Minimum Level	38.3
Low Guidance Level	36.2

Methods, Results and Discussion

Summary Data Used for Revised Minimum and Guidance Levels Development

Revised Minimum and Guidance Levels for Moon Lake were developed using the methodology for Category 1 Lakes described in Rule 40D-8.624, F.A.C. Revised levels and additional information are listed in Table 3, along with lake surface areas for each level or feature/standard elevation. Detailed descriptions of the development and use of these data are provided in the subsequent sections of this report.

Table 4. Revised Minimum and Guidance Levels, lake stage exceedance percentiles, normal pool, control point, significant change standards and associated surface areas for Moon Lake.

Levels	**Elevation in Feet NGVD 29**	**Lake Area (acres)**
Lake Stage Exceedance Percentiles		
Period of Record (POR) P10 (1965 to 2014)	39.9	196
Period of Record (POR) P50 (1965 to 2014)	38.2	104
Period of Record (POR) P90 (1965 to 2014)	35.4	97
Historic P10 (1946 to 2014)	40.0	198
Historic P50 (1946 to 2014)	38.3	105
Historic P90 (1946 to 2014)	36.3	98
Normal Pool and Structural Elevations		
Normal Pool (see Table 5)	40.0	198
Control Point (Outfall Pipe)	39.8	193
Inflow Connection	38.26	104
Low Floor Slab	42.0	> 235
Low Road	42.4	> 235
Significant Change Standards		
Cypress Standard	38.2	104
Basin Connectivity Standard *	41.3	224
Dock-Use Standard*	39.2	158
Wetland Offset Elevation*	37.5	102
Aesthetics Standard*	36.3	99
Species Richness Standard *	32.9	89
Recreation/Ski Standard*	32.3	88
Lake Mixing Standard*	22.6	32
Minimum and Guidance Levels		
High Guidance Level	40.0	200
High Minimum Lake Level	39.6	193
Minimum Lake Level	38.2	105
Low Guidance Level	36.3	99

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

Bathymetry

Relationships between lake stage, inundated area and volume can be used to evaluate expected fluctuations in lake size that may occur in response to climate, other natural factors, and anthropogenic impacts such as structural alterations or water withdrawals. Long term reductions in lake stage and size can be detrimental to many of the environmental values identified in the Water Resource Implementation Rule for consideration when establishing MFLs. A long term reduction in lake stage and size can be detrimental to both the lake ecology and the fringing wetlands through the reduction of habitat needed for fisheries, waterfowl, and wading birds. 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 Moon Lake by building and processing a digital elevation model (DEM) of the lake basin and surrounding watershed. Lake bottom elevations 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 Moon Lake. Light Detection and Ranging Data (LiDAR) was processed with LP360 for ArcGIS and merged with bathymetric data collected with both sonar and mechanical (manual methods). The with an LEI HS-WSPK transducer (operating frequency = 192kHz, cone angle = 20) mounted to a boat hull, a Lowrance LMS-350A sonar-based depth finder and the Trimble GPS Pathfinder Pro XR/Mapping System (Pro XR GPS Receiver, Integrated GPS/MSK Beacon Antenna, TDC1 Asset Surveyor and Pathfinder Office software).

The DEM created from the combined elevation data sets was used to develop topographic contours of the lake basin (Figure 2) 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 10).

Lake Stage Data and Development of Exceedance Percentiles

Period of record (POR) lake stage data, *i.e.,* surface water elevations for Moon Lake relative to NGVD 29 were obtained from the District's Water Management Information System (WMIS) data base, Site Identification (SID) number 20798 and 759472 (Figure 2). Surface water level data have been recorded since January 1965 (Figure 5). Data through 2014 were used for modeling analyses.

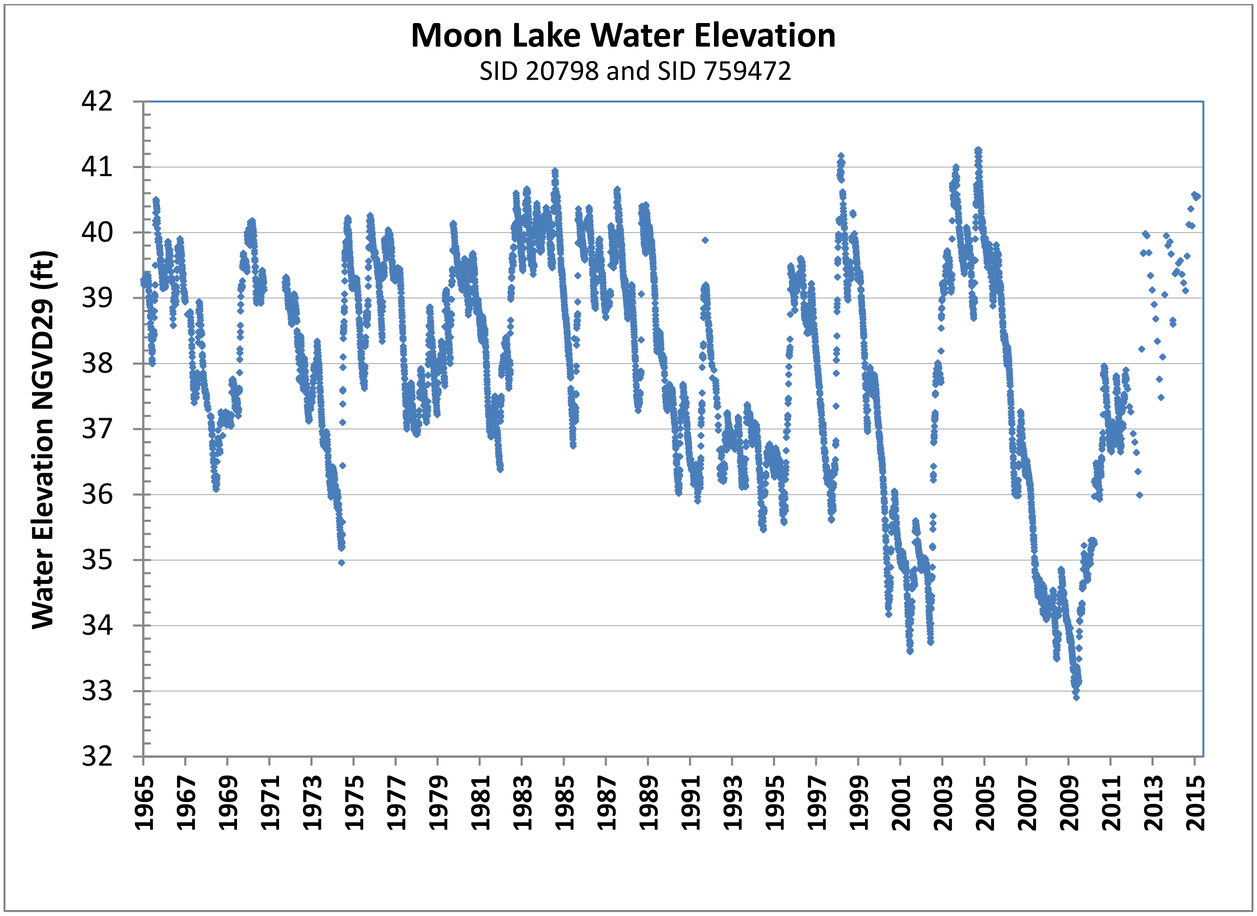


Figure 5. Moon Lake period of record stage data – 1965 through Dec. 2015.

Record high water levels were above 41 ft (NGVD 29) in March 1998 during the El Nino period and in September-October 2004 August during the 2004 hurricane season. The extreme low water level was 32.9 NGVD 29 and occurred on May 18, 2009. The approximate contour lines of the extreme high and low water level are shown on a 2011 aerial photograph (Figure 6).

For the purpose of Minimum Levels determination, lake stage data are classified as "Historic" for long-term periods when there are no measurable impacts due to water withdrawals, and impacts due to structural alterations are similar to existing conditions. In the context of Minimum Levels development, "structural alterations" means man's physical alteration of the control point, or highest stable point along the outlet conveyance system of a lake, to the degree that water level fluctuations are affected. Lake stage data are classified as "Current" when hydrologic stresses due to water withdrawals and structural alterations are stable, and are representative of the current situation.

A Long-term Historic lake stage record is critical for establishing Minimum and Guidance Levels. Although Historic data is available from 1966 to 1974 prior to the withdrawal period of the Starkey and North Pasco wellfields, this time period was too short to be considered Long-term Historic. Although the original MFL developed for Moon Lake (Leeper 2003) classified the entire period of record lake stage data as Historic, specific information was not available at that time regarding the estimated drawdown in the surficial and Upper Floridan aquifer in response to groundwater withdrawals in the vicinity of Moon Lake. This information is now available through the use of the Integrated Northern Tampa Bay (INTB) model (Geurink and Basso, 2013) with the results of the model showing an average predicted drawdown of 0.3 ft in the surficial aquifer near Moon Lake from 1989-2000 and 0.2 ft from 2000 forward (Patterson 2014).

Although these modeled effects of groundwater withdrawals are considered light, the development of Minimum and Guidance levels requires a Historic data record in the absence of these effects. A water budget model was therefore developed to simulate an unimpacted Historic water level record for the lake (Appendix A). The LOC model was then used to predict the lake stage for the long-term Historic time period of 1946 to 2014 which resulted in a correlation coefficient of determination (r^2) equal to 0.83. This hybrid water level record (Figure 7) represents Historic conditions.

The modeled hybrid Historic lake stage record was used to calculate Historic P10, P50, and P90 lake stage exceedance percentile elevations (Figure 8, Table 4). The Historic P10 elevation, the elevation the lake water surface equaled or exceeded ten percent of the time during the Historic period based was 40.0 ft. The Historic P50 elevation, the elevation the lake water surface equaled or exceeded fifty percent of the time during the Historic period based on the water budget model, was 38.3 ft. The Historic P90 elevation, the elevation the lake water surface equaled or exceeded 90 percent of the time during the Historic period was 36.3 ft.

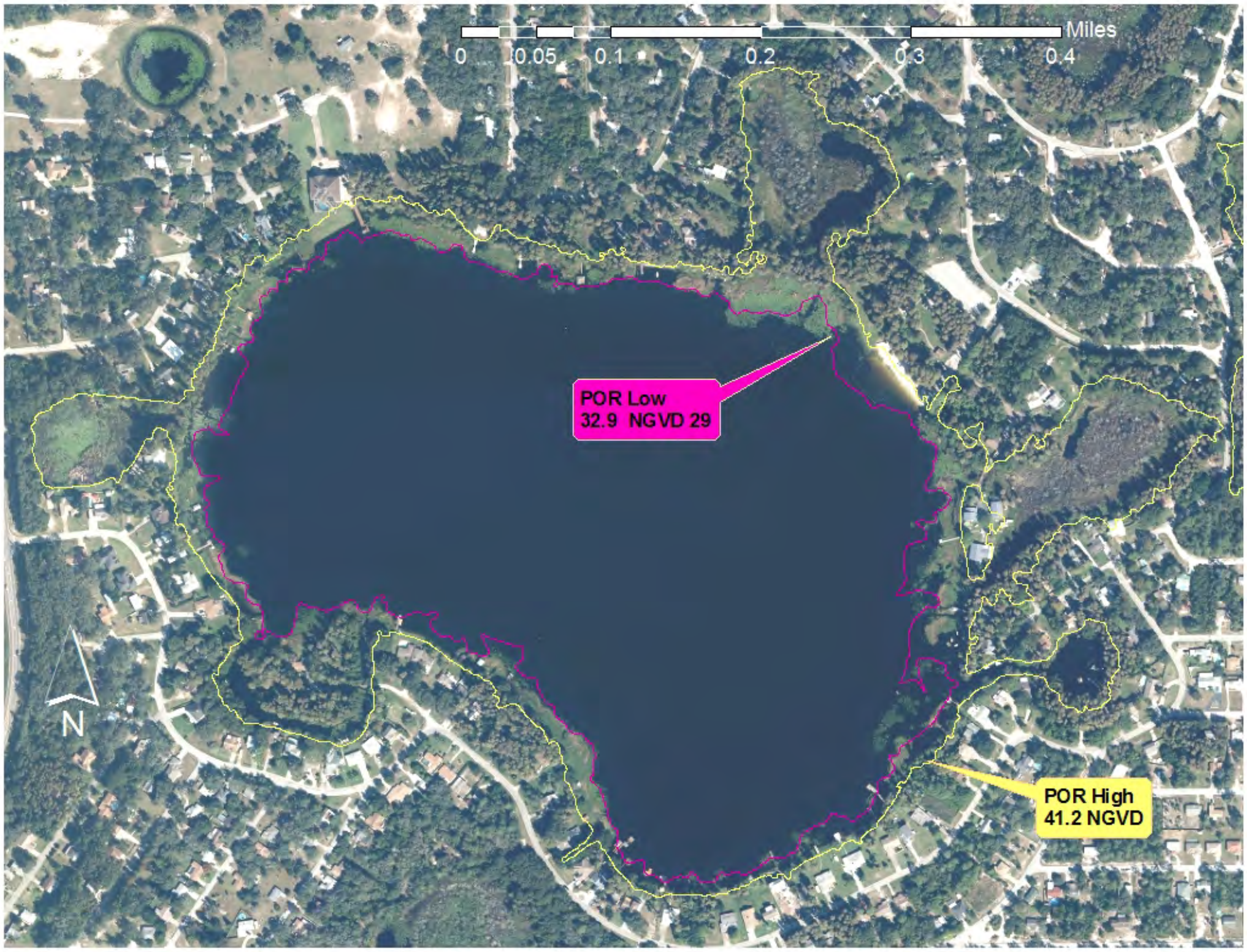


Figure 6. POR high (41.2 NGVD 29) and low (32.9 NGVD 29) water level contours for Moon Lake imposed on the January 2011 aerial imagery.

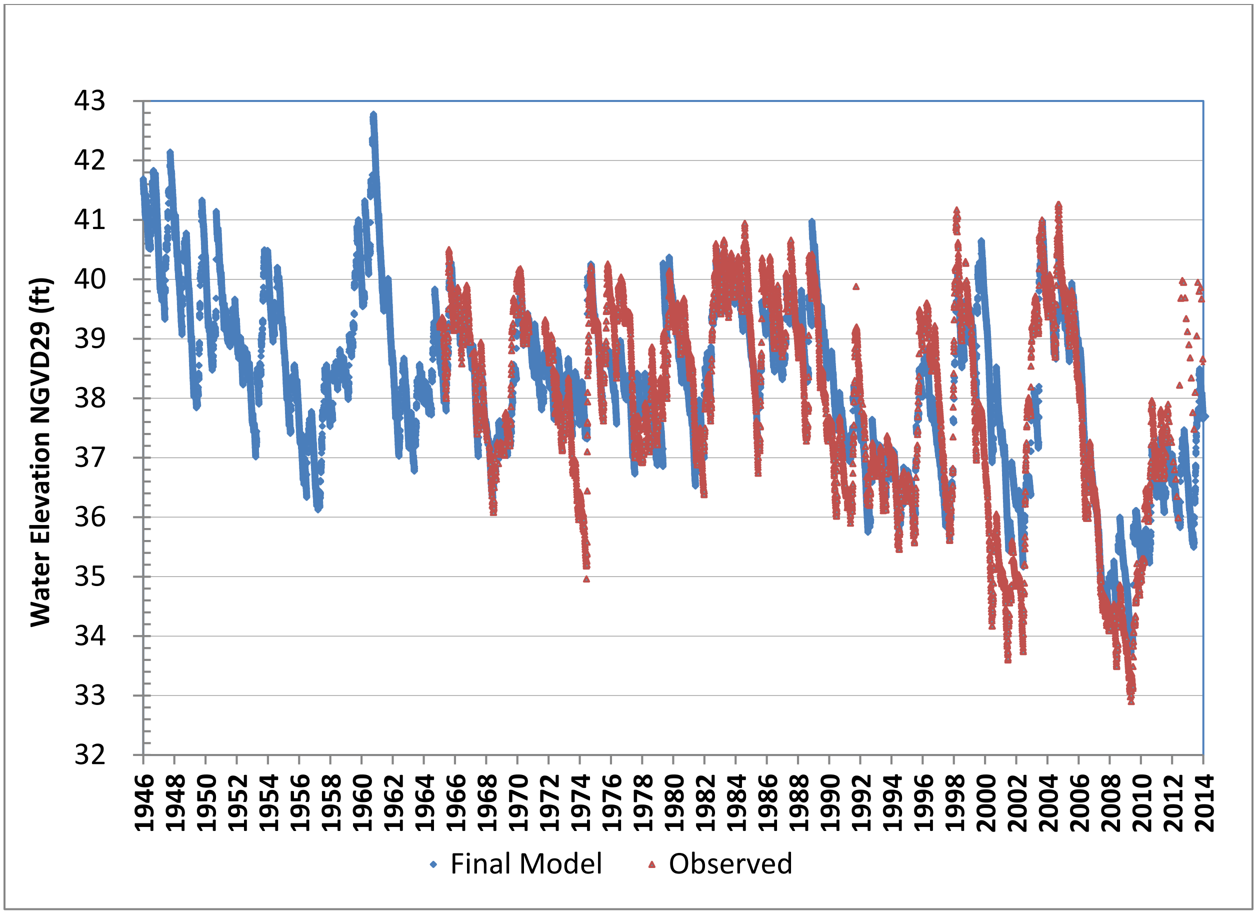


Figure 7. Observed and predicted long-term Historic water levels at Moon Lake for a calibration period from November 1988-December 2013 (water budget model period).

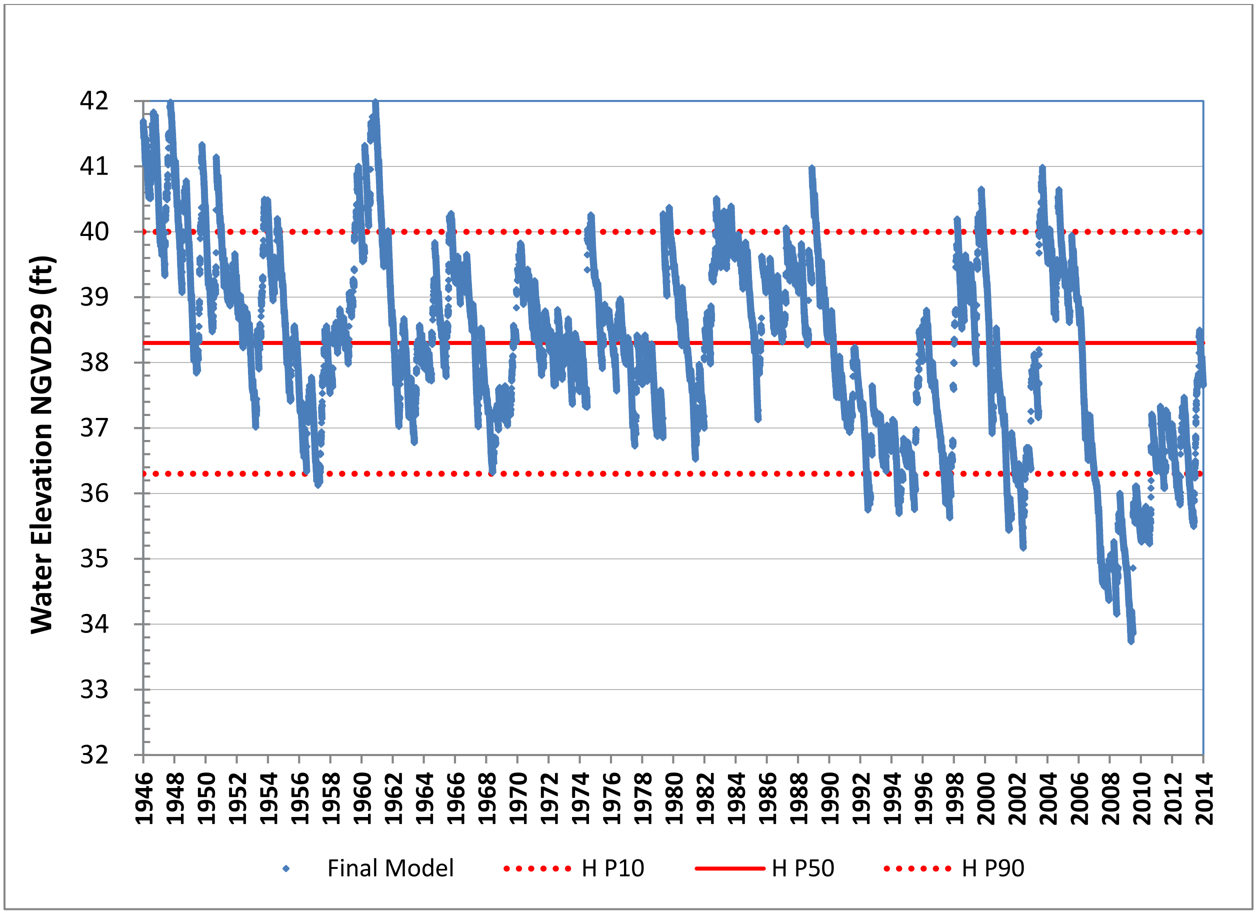


Figure 8. Historic water levels (hybrid results) used to calculate percentile elevations for Moon Lake. Historic P10, P50, and P90 are depicted as horizontal lines.

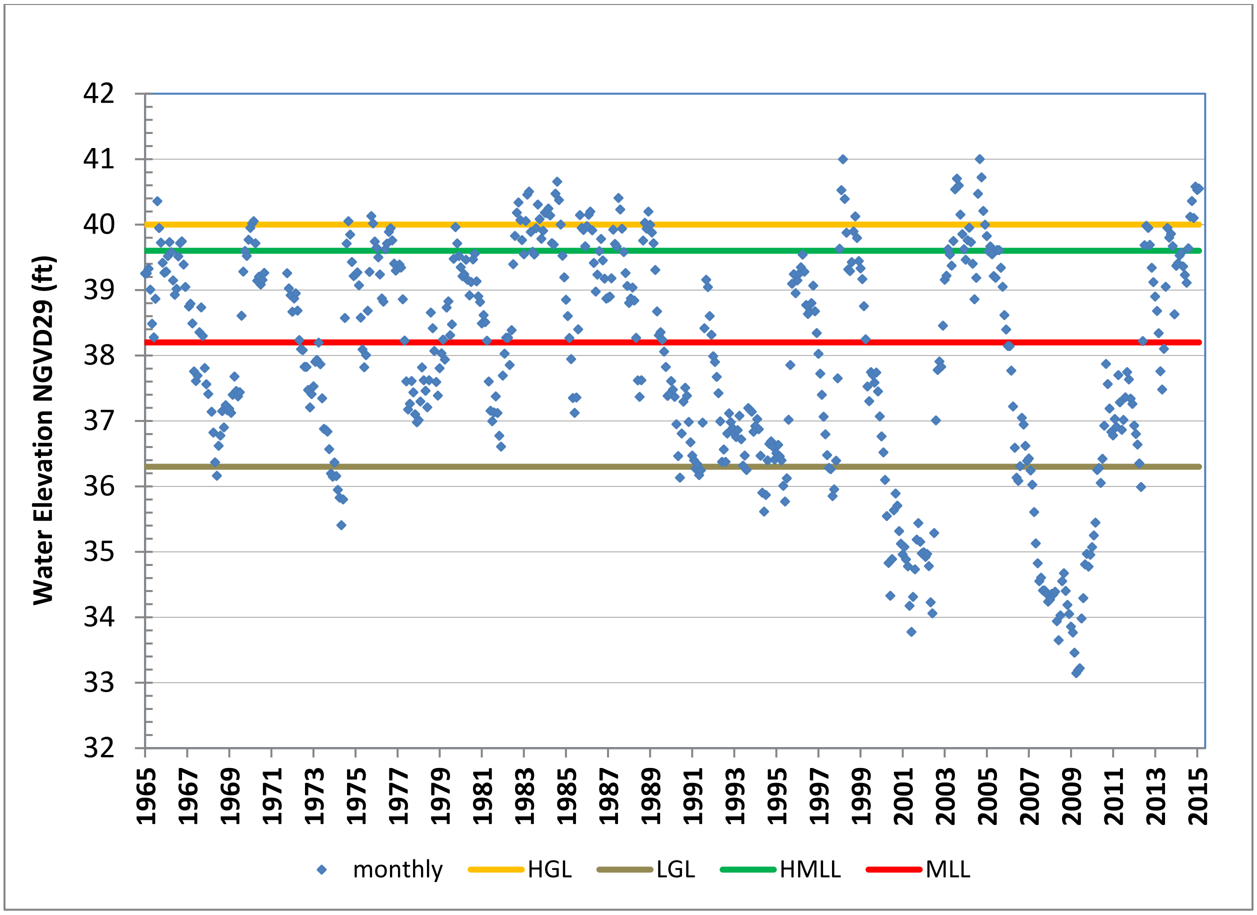


Figure 9. Observed monthly water levels and revised Minimum and Guidance Levels for Moon Lake. Revised levels include the High Guidance Level (HGL), High Minimum Lake Level (HMLL), Minimum Lake Level (MLL), and the Low Guidance Level (LGL).

Normal Pool Elevation, Control Point Elevation, and Structural Alteration Status

The **Normal Pool** elevation, a reference elevation used for development of minimum lake and wetland levels, is established based on the elevation of hydrologic indicators of sustained inundation. The buttress inflection points on the trunks of *Taxodium* sp. have been shown to be reliable biologic indicators of hydrology at an approximation of the historic P10 (Carr, et al. 2006). Nine examples of *Taxodium* sp. buttresses were measured on the lake from December 2013 to January 2014 with four measured within the lake and five measured within the connected cypress wetland (see Figure 2). Cypress within the wetland were measured due to the semi-permanent connection with the lake and also to supplement the limited number of cypress found on the lake. Low numbers of inflection points were found on the lake due to shoreline development, mainly fill activities that took place in the 1960s and 1970s. The standard deviations for both populations (lake and wetland) was 0.3 ft and indicates consistency of measured normal pool elevations. Based on the survey of these biologic indicators, the Normal Pool elevation was established at **40.0 ft**. (Table 5), which is the average of the medians of the two populations measured (lake and wetland).

Table 5. Summary statistics for elevations of cypress (*Taxodium sp*.) buttress inflection points of lakeshore and wetland used for establishing normal pool elevations for Moon Lake (elevations as ft NGVD 29).

	Lakeshore	Connected Wetland	Average
N	4	5	
Median	39.58	40.33	40.0
Mean	39.68	40.47	
Minimum	39.38	40.13	
Maximum	40.18	40.83	
std	0.35	0.32	

The **Control Point** elevation is the elevation of the highest stable point along the outlet profile of a surface water conveyance system (*e.g.,* weir, conservation structure, ditch, culvert, or pipe) that is the principal control of water level fluctuations in the lake. In the case of Moon Lake, the outlet conveyance is located along the south shore of the lake which begins with a drainage ditch and 24 inch by 40.5 foot long culvert under Lacey Road. Downstream of the culvert the ditch meanders through a series of wetlands until flow eventually reaches the Pithlachascotee River. The control point established during development of the originally adopted MFL was determined to be a high spot within the upper reach of the outfall ditch, upstream of the culvert with a surveyed elevation of measured at 39.8 ft NGVD. The invert elevation of the culvert under Lacey Road is 39.01 ft NGVD 29.

Structural Alteration Status is determined to support development of Minimum and Guidance Levels and the modeling of Historic lake stage records. In addition to identification of outlet conveyance system modifications, comparison of the Control Point elevation and Normal Pool elevation is typically used to determine if a lake has been structurally altered. If the Control Point elevation is below the Normal Pool, the lake is classified as a structurally altered system. If the Control Point elevation is above the Normal Pool or the lake has no outlet, then the lake is not considered to be structurally altered. Based on the existence of the outflow conveyance system and given that the Normal Pool elevation (40.0 ft.) is higher than the Control point elevation (39.8 ft.), Moon Lake was classified as structurally altered.

Revised Guidance Levels

The **High Guidance Level** is provided as an advisory guideline for construction of lake-shore development, water dependent structures, and operation of water management structures. The High Guidance Level is the expected Historic P10 of the lake and is established using historic lake stage data if it is available, or is estimated using the Current P10, the Control Point, and the Normal Pool elevation. Based on long-term Historic model results, the revised High Guidance Level for Moon Lake was established at **40.0 ft.** (Figure 9, Table 3). The lowest residential floor slab within the immediate lake basin (42.0 ft.) is 2 feet higher than the revised High Guidance Level.

The **Low Guidance Level** is provided as an advisory guideline for water dependent structures, information for lake shore residents, and operation of water management structures. The Low Guidance Level is the elevation that a lake's water levels are expected to equal or exceed ninety percent of the time (P90) on a long-term basis. The level is established using historic or current lake stage data, and in some cases, reference lake water regime statistics, which are differences between selected lake stage percentiles for a set of reference lakes. Based on long-term Historic model results, the revised Low Guidance Level for Moon Lake was established at **36.3 ft**. (Figure 9, Table 3).

Lake Classification

Lakes are classified as Category 1, 2, or 3 for the purpose of Minimum Levels development. Systems with fringing cypress wetlands greater than 0.5 acres in size where water levels regularly rise to an elevation expected to fully maintain the integrity of the wetlands (*i.e.*, the Historic P50 is equal to or higher than an elevation 1.8 feet below the Normal Pool elevation) are classified as Category 1 Lakes. Category 2 lakes are also lakes with fringing cypress wetlands greater than 0.5 acres in size, but where structural alterations have prevented the Historic P50 from equaling or rising above an elevation that is equal to an elevation 1.8 ft. below normal pool. Despite the structural alterations, the lake-fringing cypress swamp(s) remain viable and perform functions beneficial to the lake. Lakes without fringing cypress wetlands or with less than 0.5 acres of fringing cypress wetlands are classified as Category 3 Lakes. Based on the presence of lake-fringing cypress wetlands of 0.5 acre or more in size within the lake basin, and because the Historic P50 (38.3 ft.) is less than 1.8 ft. below the Normal Pool elevation (40.0 - 38.3 = 1.7), Moon Lake was classified as a Category 1 lake.

Significant Change Standards and Other Information for Consideration

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

For Category 1 or 2 Lakes, a significant change standard is established 1.8 feet below the normal pool elevation. This standard identifies a desired median lake stage that if achieved, may be expected to preserve the ecological integrity of lake-fringing wetlands. Although not identified by name in the District's Minimum Flows and Levels rule, the elevation 1.8 feet below normal pool is typically referred to as the **Cypress Standard** in District documents pertaining to minimum levels development. For Moon Lake, the Cypress Standard was established at **38.2 ft.** Based on the Historic water level record for the lake, the standard was equaled or exceeded 54 percent of the time, *i.e.*, the standard elevation corresponds to the Historic P54.

Six significant change standards for Category 3 lakes, including a Dock-Use Standard, a Basin Connectivity Standard, an Aesthetics Standard, a Recreation/Ski Standard, a Species Richness Standard, and a Lake Mixing Standard are developed. These standards identify desired median lake stages that if achieved, are intended to preserve various environmental values (see Table 1). Although Moon Lake is a Category 1 Lake, Category 3 Lake standards were developed for comparative purposes. These standards were not, however, used to establish the revised Minimum Levels.

The **Basin Connectivity Standard** is developed to protect surface water connections between lake basins or among sub-basins within lake basins to allow for movement of aquatic biota, such as fish, and support recreational lake-use. The standard is based on the elevation of lake sediments at a critical high-spot between lake sub-basins, clearance water depths for movement of aquatic biota or powerboats and other watercraft, and use of historic lake stage data or region-specific reference lake water regime statistics. A review of historical aerial imagery for years 1938 and 1970 indicates that Moon Lake is composed on one main basin connected to a large cypress stand located to the east of the lake. Although a navigable connection between the lake and cypress wetland is not apparent the basin connectivity standard was applied to the connected wetland using the elevation of the large flow through culvert. The Basin Connectivity Standard was established at 41.3 ft, based on the critical high-spot elevation of 33.6 ft (culvert invert Figure 2), plus one foot needed for movement of biota and the 2.0 ft difference between the Historic P50 and P90 (2.0 feet). Based on the Historic water level record for the lake, the standard was equaled or exceeded 1.7 percent of the time. The elevation exceeds the highest lake elevation recorded for the lake during the period of record (1965-2015) and is not applicable as a management level.

The **Dock-Use** Standard is developed to provide for sufficient water depth at the end of existing docks to permit mooring of boats and prevent adverse impacts to bottom - dwelling plants and animals caused by boat operation. The standard is based on the elevation of lake sediments at the end of existing docks, a clearance water depth value for boat mooring, and use of historic lake stage data. The dock standard was established during development of the originally adopted MFL in 2002. The Dock-Use Standard for Moon Lake was established at **39.2 ft.**, based on the elevation of sediments at the end of ninety percent of the 10 docks within the lake (35.2 ft., Table 6), a two-foot water depth based on use of powerboats in the lake, and the 2 ft difference between the Historic P50 and Historic P90. Based on the Historic water level record for the lake, the standard was equaled or exceeded 28.2 percent of the time, *i.e.*, the standard elevation corresponds to the Historic P28.

Table 6. Summary statistics and elevations associated with docks in Moon Lake based on measurements made by District staff in April 2002. Exceedance percentiles (P10, P50, P90) represent elevations exceeded by 10, 50 and 90 percent of the docks.

Summery Statistics	Statistics Value (N) or Elevation (feet) of Sediments at Waterward End of Docks	Statistics Value (N) or Elevation (feet) of Dock Platforms
N (number of docks)	36	36
10th Percentile (P90)	31.9	40.0
Median or 50th Percentile	34.2	41.2
90th Percentile (P10)	35.2	41.8
Maximum	36.0	43.6
Minimum	31.2	39.2

The **Aesthetics Standard** is developed to protect aesthetic values associated with the inundation of lake basins. The standard is intended to protect aesthetic values associated with the median lake stage from becoming degraded below the values associated with the lake when it is staged at the Low Guidance Level. The Aesthetic Standard is established at the Low Guidance Level, which is **36.3 ft.** for Moon Lake. Because the Low Guidance Level was established at the Historic P90 elevation, water levels equaled or exceeded the Aesthetics Standard 90 percent of the time during the Historic period.

The **Species Richness Standard** is developed to prevent a decline in the number of bird species that may be expected to occur at or utilize a lake. Based on an empirical relationship between lake surface area and the number of birds expected to occur at Florida lakes, the standard is established at the lowest elevation associated with less than a 15 percent reduction in lake surface area relative to the lake area at the Historic

P50 elevation. The Species Richness Standard for Moon Lake is established at **32.9 ft.** (see Figure 10 for a plot of lake stage versus lake surface area). Based on the Historic water level record for the lake, the standard was equaled or exceeded 100 percent of the time and would not be appropriate as a management level since it is well outside the normal range of level fluctuation.

The **Recreation/Ski Standard** is developed to identify the lowest elevation within the lake basin that will contain an area suitable for safe water skiing. The standard is based on the lowest elevation (the Ski Elevation) within the basin that can contain a five-foot deep ski corridor delineated as a circular area with a radius of 418 ft., or as used in this case, a rectangular ski area 200 ft. in width and 2,000 ft. in length, and use of historic lake stage data. The Recreation/Ski Standard was established at 32.3 ft NGVD, based on the sum of the elevation at which the lake could provide an area suitable for safe skiing (30.3 ft NGVD 29) and the difference between the Historic P50 and P90 (2 ft).

Based on the Historic water level record for the lake, the standard was equaled or exceeded 100 percent of the time. This standard would not be appropriate as a management level since it is well outside the normal low range of level fluctuation. The lowest recorded lake level for Moon Lake was 32.9 NGVD.

The **Lake Mixing Standard** is developed to prevent significant changes in patterns of wind-driven mixing of the lake water column and sediment re-suspension. The standard is established at the highest elevation at or below the Historic P50 elevation where the dynamic ratio (see Bachmann *et al.* 2000) shifts from a value of <0.8 to a value >0.8, or from a value >0.8 to a value of <0.8. The dynamic ratio shift across the 0.8 threshold occurred at 22.6 NGVD (Figure 10). Based on the Historic water level record for the lake, the standard was equaled or exceeded 100 percent of the time. This standard would not be appropriate as a management level since it is well outside the normal low range of level fluctuation. The lowest recorded lake level for Moon Lake was 32.9 NGVD.

Because herbaceous wetlands are common within the Moon Lake basin, it was determined that an additional measure of wetland change should be considered for minimum levels development. Based on a review (Hancock 2006) of the development of minimum level methods for cypress-dominated wetlands, it was determined that up to an 0.8 foot decrease (or Wetland Offset) in the Historic P50 elevation would not likely be associated with significant changes in the herbaceous wetlands occurring within lake basins. A Wetland Offset elevation of 37.5 NGVD was therefore established for Moon Lake by subtracting 0.8 feet from the Historic P50 elevation. The wetland offset elevation was equaled or exceeded 70.3 percent of the time during the Historic period and therefore corresponds to the Historic P70.3.

Information on herbaceous wetlands is taken into consideration when determining the elevation at which changes in lake stage would result in substantial changes in potential wetland area within the lake basin (*i.e.*, basin area with a water depth of four or less feet). Similarly, changes in lake stage associated with changes in lake area available for colonization by rooted submersed or floating-leaved macrophytes are also evaluated, based on water transparency values (*i.e.*, basin area with a water depth of 9.2 feet or less feet).

Review of changes in potential herbaceous wetland area in relation to change in lake stage relative to the wetland area of the Historic P50 did not indicate that there would be a significant increase or decrease in the area of herbaceous wetland vegetation associated with use of the applicable significant change standards below the Historic P50 which includes the Cypress Standard (38.2 NGVD), Wetland Offset Standard (37.5 NGVD), and the Aesthetics Standard (36.3 NGVD) (Figure 11).
Review of changes in area available for submersed aquatic plant colonization relative to the area available at the Historic P50 change in lake stage also did not indicate that there would be a significant increase or decrease in the area of submersed aquatic plant vegetation at the elevation of the Cypress Standard, Wetland Offset Standard, or Aesthetics Standard (Figure 11).

Although the Species Richness Standard, Ski Standard, and Mixing Standard were determined not to be appropriate as minimum low management levels since their respective elevations fell well below the normal low level fluctuation (lower than the 10^{th} percentile or P90), the potential changes in herbaceous wetland area was also determined. This estimation was completed to help document the expected habitat changes that could potentially occur if the lake dropped to these unusually low levels for a long duration. Based on the increase in the area of the lake with depth less than 4 feet, the potential increase in herbaceous wetland area relative to the Historic P50 elevation would be 64 percent at the Species Richness Standard, 71 percent at the Ski Standard, and 165 percent at the mixing standard. These significant increases in herbaceous wetland area would impact recreational uses of the lake due to the reduction in available open water. This information further supports why the use of these standards would not be appropriate for establishment of a minimum low level.

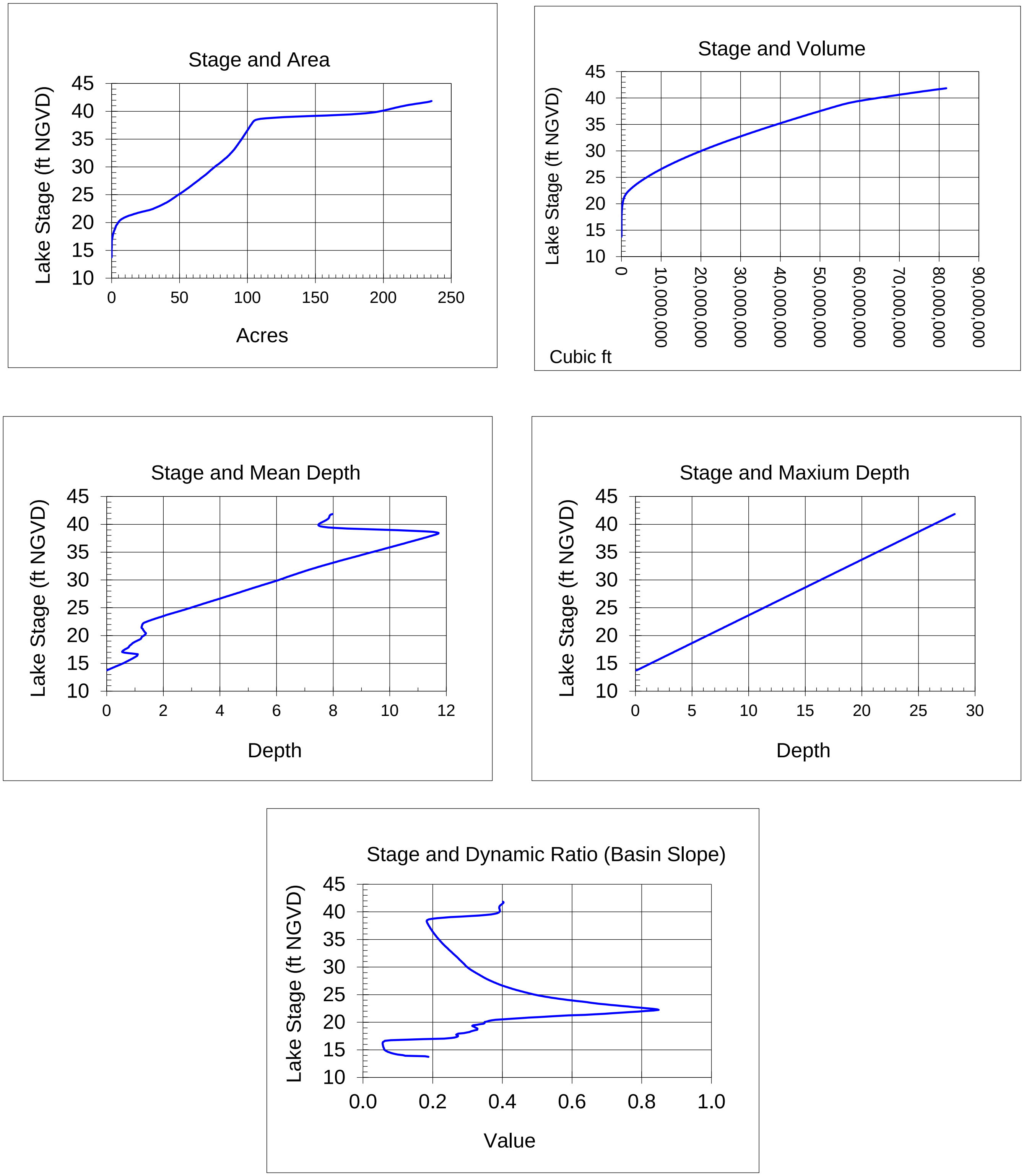
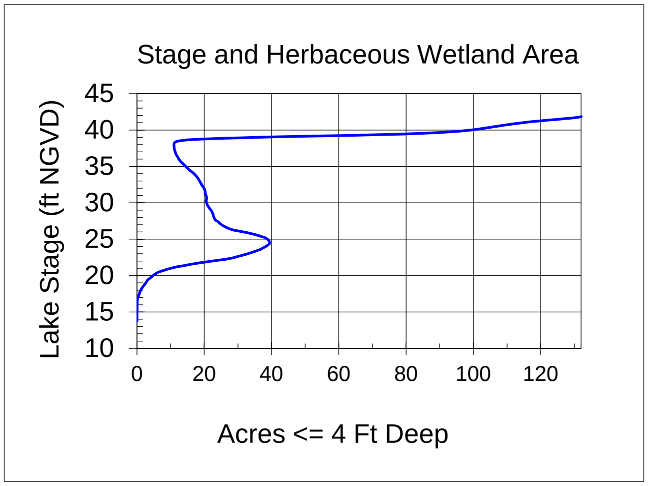


Figure 10. Mean depth, maximum depth, surface area volume, stage volume, and dynamic ratio (basin slope) in feet for Moon Lake.



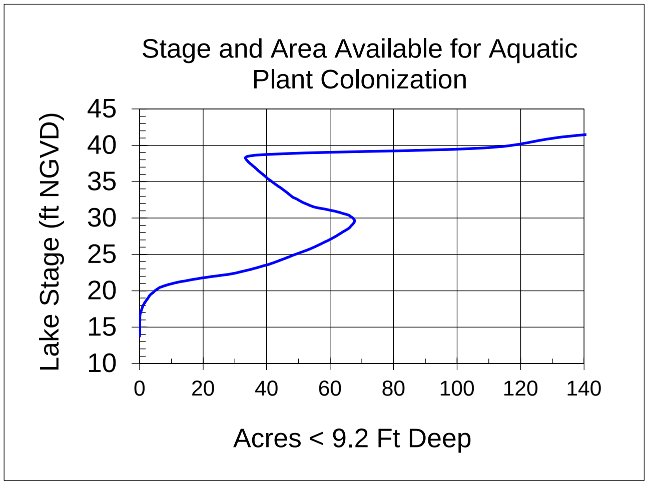


Figure 11. Area available for submersed macrophyte colonization and potential herbaceous wetland area in Moon Lake as a function of lake stage (water surface elevation).

Revised Minimum Levels

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

The **Minimum Lake Level (MLL)** is the elevation that a lake's water levels are required to equal or exceed fifty percent of the time on a long-term basis. The Minimum Lake Level is established at the elevation that the lake's water levels are required to equal or exceed fifty percent of the time on a long-term basis. The revised Minimum Lake Level for Moon Lake is **38.2 ft**.

The **High Minimum Lake Level** is the elevation that a lake's water levels are required to equal or exceed ten percent of the time on a long-term basis. For Category 2 Lakes, the High Minimum Lake Level is established at the High Guidance Level, which is the expected Historic P10. The revised High Minimum Lake Level for Moon Lake is **39.6 ft**.

The revised Minimum and Guidance levels for Moon Lake are shown in Figure 9 along with lake stage elevation. The MLL and HMLL levels are also shown as contour lines on the 2014 aerial imagery (Figure 12).

Many federal, state, and local agencies, such as the U.S. Army Corps of Engineers, the Federal Emergency Management Agency, United States Geological Survey, and Florida’s water management districts are in the process of upgrading from the National Geodetic Vertical Datum (NGVD29) standard to the North American Vertical Datum (NAVD88) standard. For comparison purposes, the revised MFLs for Moon Lake are presented in both datum standards (Table 7). The NGVD29 datum was converted to NAVD88 using the Corpscon conversion of 0.846 ft.

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

Revised Minimum and Guidance Levels	Feet NGVD29	Feet NAVD88
High Guidance Level	40.0	39.2
High Minimum Lake Level	39.6	38.8
Minimum Lake Level	38.2	37.3
Low Guidance Level	36.3	35.4

Consideration of Environmental Values

The revised minimum levels for Moon Lake are protective of all relevant environmental values identified for consideration in the Water Resource Implementation Rule when establishing MFLs (see Rule 62-40.473, F.A.C.). When developing MFLs, the District evaluates the categorical significant change standards and other available information as presented above. The purpose is to identify criteria that are sensitive to long-term changes in hydrology and represent significant harm thresholds. The Cypress Standard was used for developing revised Minimum Levels for Moon Lake based on its classification as a Category 1 Lake. This standard was identified to support development of revised minimum levels for Moon Lake based on the occurrence of lake-fringing cypress wetlands of one-half an acre or greater in size. The large cypress wetland located on the east side of lake comprises roughly 95 acres (see Figure 3). The Cypress 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, sediment loads and water quality (refer to Table 1).

Two additional environmental value identified in Rule 62-40.473, F. A. C., are also protected by the revised minimum levels for Moon. The environmental value, recreation in and on the water is associated with the Aesthetic Standard developed for the lake. This standard is associated with an elevation lower than the Cypress Standard elevation (36.3 NGVD vs 38.2 NGVD) indicating that it will be achieved at a higher frequency than the Cypress Standard. The environmental value, maintenance of freshwater storage and supply is protected by the revised minimum levels based on the relatively modest potential changes in storage associated with the minimum flows hydrologic regime as compared to the non-withdrawal impacted historic condition. Maintenance of freshwater supply is also expected to be protected by the revised minimum levels based on inclusion of conditions in water use permits that stipulate that permitted withdrawals will not lead to violation of adopted minimum flows and levels.

Two environmental values identified in Rule 62-40.473, F.A.C., were not considered relevant to development of revised minimum levels for Moon Lake. Estuarine resources were not considered relevant because the lake is only remotely connected to the estuarine resources associated with the downstream receiving waters of Tampa Bay, and water level fluctuations in the lake are expected to exert little effect on the ecological structure and functions of the bay. Sediment loads were similarly not considered relevant for levels development for the lake, because the transport of sediments as bedload or suspended load is a phenomenon associated with flowing water systems.

Assessment of the Moon Lake Minimum Level Condition

The revised Minimum Lake Level and High Minimum Lake Level were evaluated for compliance using the same predictive models that were used to develop the long-term Historic exceedance percentiles (Appendix B). The models were used to evaluate whether Moon Lake water levels were previously above or below the revised Minimum Lake Level and revised High Minimum Lake Level for the lake. Previous levels were determined to be at or above the revised Minimum Lake Level and High Minimum Lake Level.

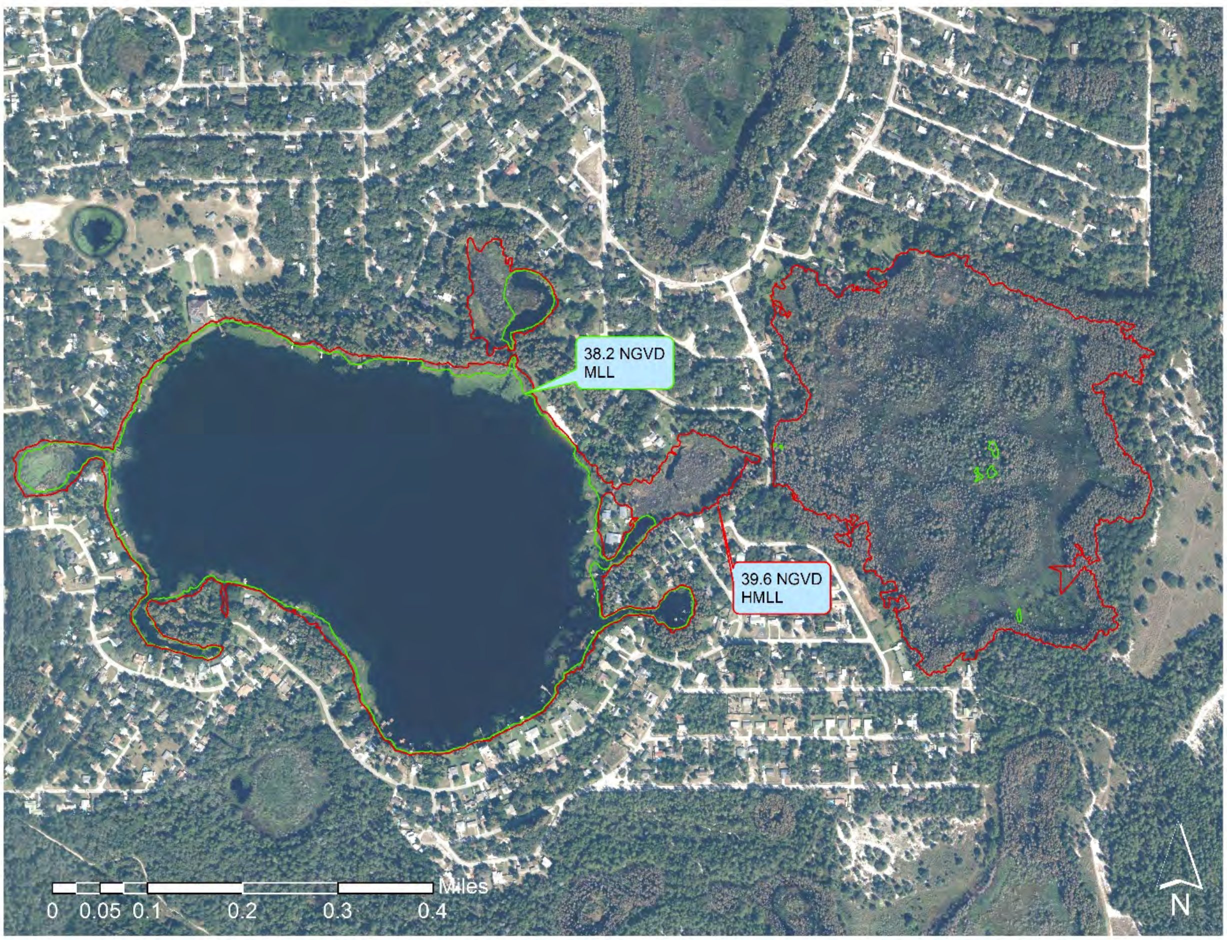


Figure 12. Approximate location of water level (i.e., shoreline) associated with the revised Minimum Lake Level (MLL) and High Minimum Lake Level (HMLL) for Moon Lake relative to conditions in October 2013. The approximate lake level elevation was 48.2 ft. NGVD when the imagery was taken.

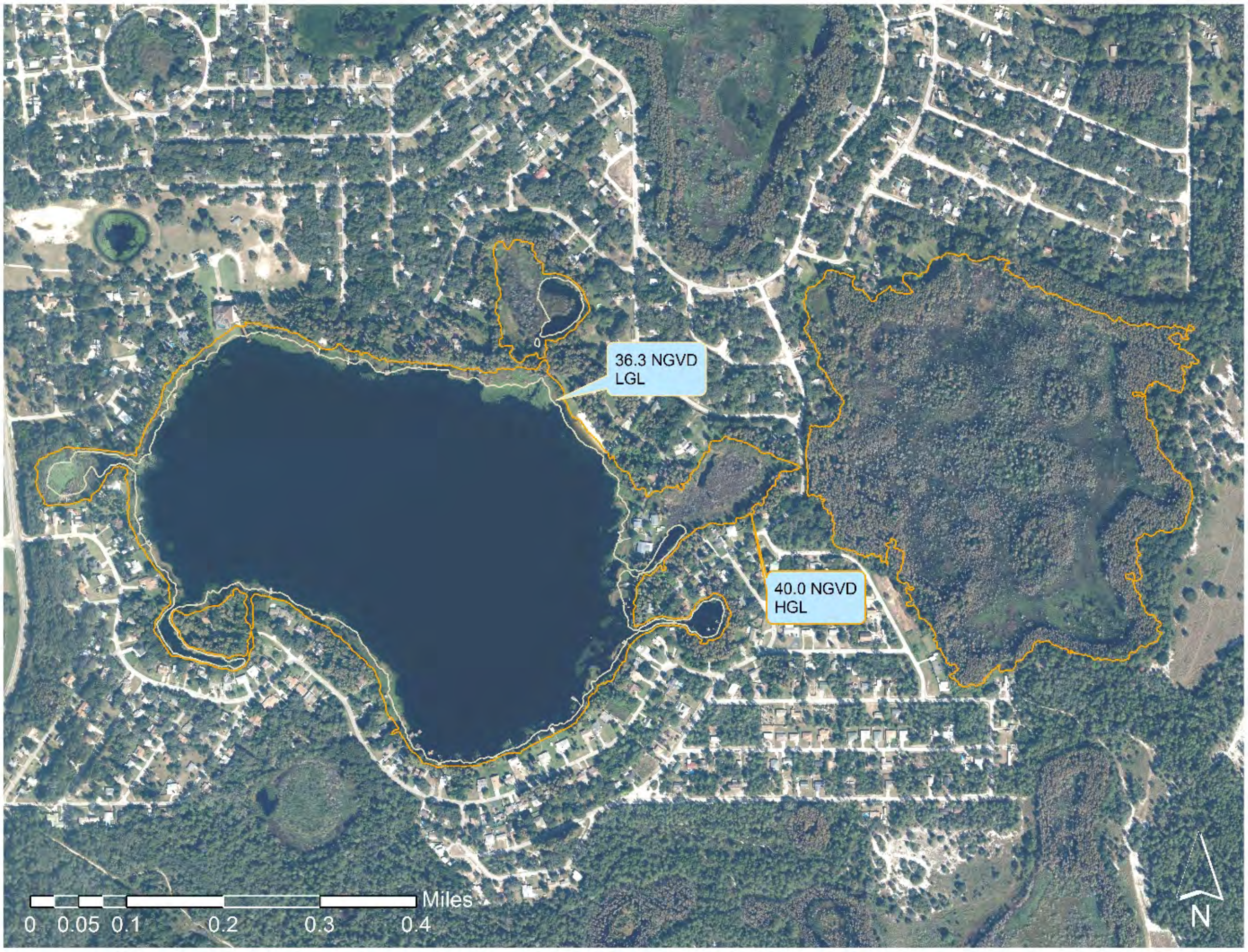


Figure 13. Approximate location of water level (i.e., shoreline) associated with the revised Low Guidance Level (LGL) and High Guidance Level (HGL) for Moon Lake relative to conditions during October 2013.

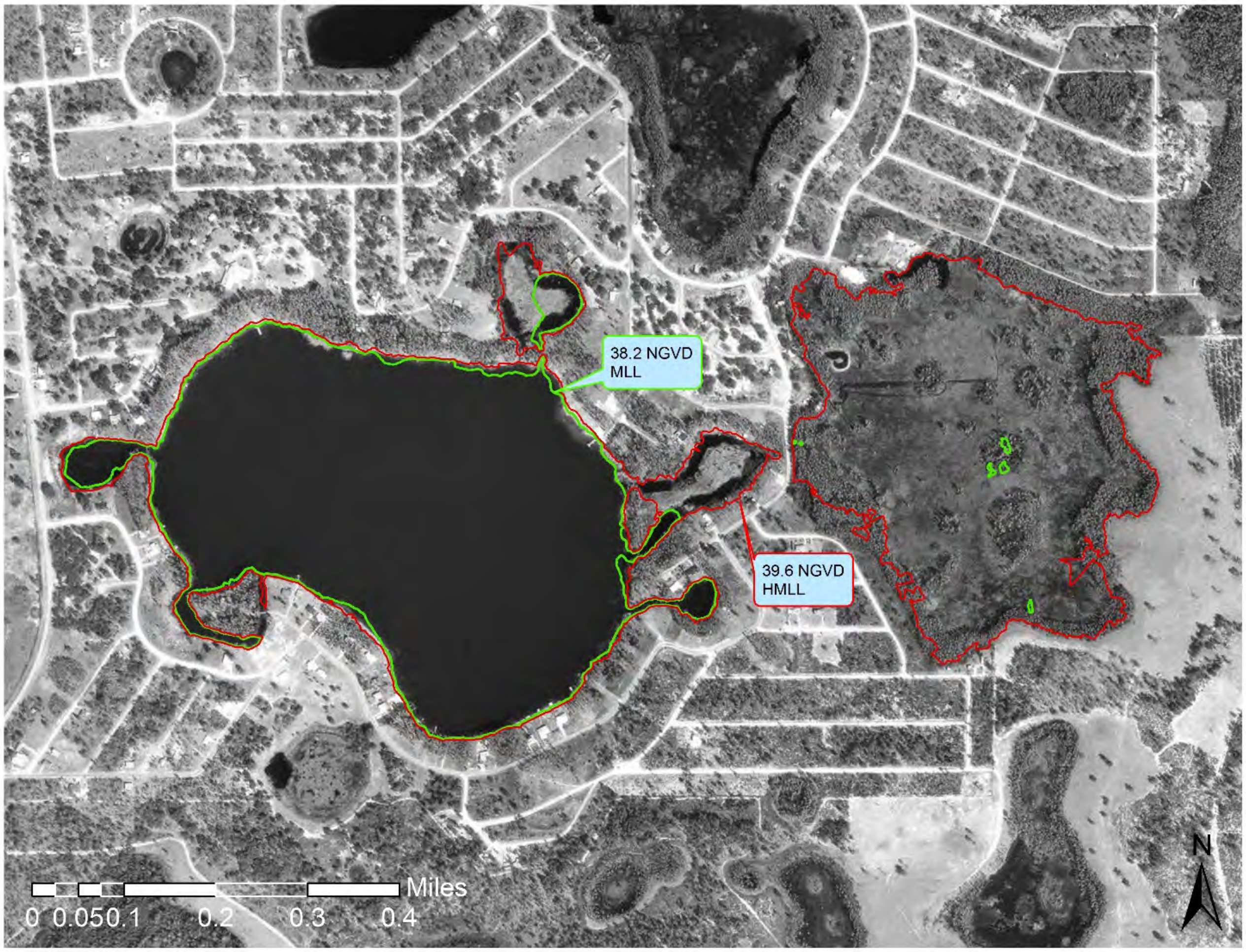


Figure 14. Approximate location of water level (i.e., shoreline) associated with the revised Minimum Lake Level (MLL) and High Minimum Lake Level (HMLL) for Moon Lake relative to conditions in 1970.

Documents Cited and Reviewed

Bachmann, R. W., Hoyer, M. V., and Canfield, D. E., Jr. 2000. The potential for wave disturbance in shallow Florida lakes. Lake 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, Hillsborough County, and Tampa Bay Water. Southwest Florida Water Management District. Brooksville, Florida.

Brenner, M., T. J. Smoak, D. Leeper, M. Streubert, and S. Baker. 2007. Radium-226 Accumulation in Florida Freshwater Mussels. Limnol. Oceanogr. 52:4, 2007:1614-1623

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.

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

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 in West-central Florida, USA Cypress Domes. Wetlands 26:4 1012–1019 pp.

Dickinson, D.E., P.L. Brezonik, W.C. Huber, and J.P. Heaney. 1982. Gazetteer of Florida Lakes, Publication No. 63. Department of Environmental Engineering Sciences. University of Florida, Gainesville, Florida.

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” June 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-Nuez, A., and Trimble, P.J. 2001. The Atlantic Multidecadal Oscillation and Its Relation to Rainfall and River Flows in the Continental U.S. Geophysical Research Letters, 28:10 2077-2080 pp.

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.

Florida Board of Conservation. 1969. Florida lakes, part III: gazetteer. Division of Water Resources. Tallahassee, Florida.

Florida Department of Environmental Protection. 2001. Basin Status Report: Tampa Bay. Florida Department of Environmental Protection, Tallahassee, Florida.

Florida Freshwater Fish and Game Commission. Date Unknown. Summary report on Moon Lake fish sampling. Tallahassee, Florida.

Florida Lakewatch. 2001. Florida Lakewatch data report 2000. University of Florida Institute of Food and Agricultural Sciences, Department of Fisheries and Aquatic Sciences, Gainesville, Florida.

Griffith, G. E., Canfield, D. E., Jr., Horsburgh, C. A., Omernik, J. M., and Azevedo, S. H. 1997. Lake regions of Florida (map). United States Environmental Protection Agency, University of Florida Institute of Food and Agricultural Sciences, Florida Lakewatch, Florida Department of Environmental Protection, and the Florida Lake Management Society. Gainesville and Tallahassee, Florida.

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., 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.

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.

Hyde, A. G., Law, L., Weatherspoon R. L., Cheyney, M. D., and Eckenrod, J. J. 1977. Soil Survey of Hillsborough County, Florida. USDA Soil Conservation Service in cooperation with the University of Florida Institute of Food and Agricultural Sciences, Agricultural Experiment Stations, Soil Science Department. USDA Soil Conservation Service, Washington, D.C.

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.

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.

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

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, Richer, B.D., Arthington, A.H., Bunn, S.E., Naiman, R.J., Kendy, E., Acreman, M., Apse, C., Bledsoe, B.P., Freeman, M.C., Henriksen, J., Jacobson, R.B., Kennan, J.G., Merritt, D.M., O'Keefe, J.H., Olden, J.D., Rogers, K., Tharme, R.E. and Warner, A. 2010. The ecological limits of hydrologic alteration (ELOHA): a new framework for developing regional 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 Richer, B. 2003. Rivers for life: Managing water for people and nature. Island Press. Washington, D.C.

Romie, K. 2000. Water chemistry of lakes in the Southwest Florida Water Management District. Brooksville, Florida.

Sacks, L.A. 2002. Estimating ground-water inflow to lakes in central Florida using the isotope mass-balance approach. Water Resources Investigations Report 02-4192. U.S. Geological Survey, Tallahassee, Florida.

Schultz, R., Hancock, M., Hood, J., Carr, D. and Rochow, T. 2005. Technical memorandum to File, NTB II. Subject: use of biological indicators for the establishment of historic normal pool. Southwest Florida Water Management District. Brooksville, Florida.

Shafer, M. D., Dickinson, R. E., Heaney, J. P., and Huber, W. C. 1986. Gazetteer of Florida lakes. Publication no. 96, Water Resources Research Center, University of Florida. Gainesville, Florida.

Southwest Florida Water Management District. 1996. Lake Levels Program lake data sheets / 1977-1996, Coastal Rivers Basin – 15. 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. 1996. Lake Levels Program lake data sheets / 1977-1996, Coastal Rivers Basin – 15. Brooksville, 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.

Southwest Florida Water Management District. 2001. Special purpose survey, Section 28, Township 25 South, Range 17 East, Pasco County; Coastal Rivers Basin, Minimum Flows & Levels, Moon Lake. Brooksville, Florida.

Southwest Florida Water Management District. 2001. Survey Section Field Book 15.54, pages 34-48. 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.

United States Geological Survey. 1954. Fivay quadrangle, Florida-Pasco Co., 7.5 minute series (topographic) map; Fivay, Fla., N2815-W8230/7.5, 1954, AMS 4440 SE-Series V847. Department of Interior. Washington, D.C.

United States Geological Survey. 1988. Fivay Junction quadrangle, Florida-Pasco Co., 7.5 minute series (topographic) map; Fivay Junction, Fla., 28082-C5-Tf-024, 1954, photorevised 1988, DMA 4440 I SE-Series V847. Department of Interior. Washington, D.C

Wagner, K. J. and Dierberg, F. E. 2006. A review of “Proposed methodological revisions regarding consideration of structural alterations for establishing Category 3 Lake Minimum Levels in the Southwest Florida Water Management District” by D. Leeper, 2006. Prepared for the Southwest Florida Water Management District, Brooksville, Florida.

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 Hydrobiologiy, Volume 204. Springer Netherlands.

White, W. A. 1970. The Geomorphology of the Florida Peninsula. Florida Geological Survey Bulletin 51. Bureau of Geology, Division of Interior Resources, Florida Department of Natural Resources, Tallahassee, FL.

Appendix A

May 25, 2015

Technical Memorandum

TO: Keith Kolasa, Senior Environmental Scientist, Water Resources Bureau

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

FROM: Jason G. Patterson, Hydrogeologist, Water Resources Bureau
Michael C. Hancock, P.E., Senior Prof. Engineer, Water Resources Bureau

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

A. Introduction

Water budget and rainfall correlation models were developed to assist the Southwest Florida Water Management District (District) in the reassessment of minimum levels in Moon Lake, located in southwest Pasco County. Moon Lake has previously adopted minimum levels, which were reevaluated in FY 2014. This document will discuss the development of the Moon Lake models, as well as the development of the Historic percentiles using the models.

B. Background and Setting

Moon Lake is located in the Coastal Rivers Basin of the District in southwest Pasco County, east of Moon Lake Rd near New Port Richey (Figure 1). The lake is approximately 1.5 miles north of the Starkey wellfield and 1.2 miles west of North Pasco wellfield, which are two of eleven regional water supply wellfields operated by Tampa Bay Water.

Moon Lake is located in the Pithlachascotee River drainage basin. Surface water inflow to the lake occurs as overland flow from the lake's small drainage basin, and as overflow from a wetland to the east of the lake connected by a culvert. The drainage area of the lake is approximately 0.7 square miles (Florida Board of Conservation 1969). Discharge from the lake occurs along the south shore of the lake through a series of ditches and culverts, then through several wetland ponds, and ultimately to the Pithlachascotee River (Figure 2).

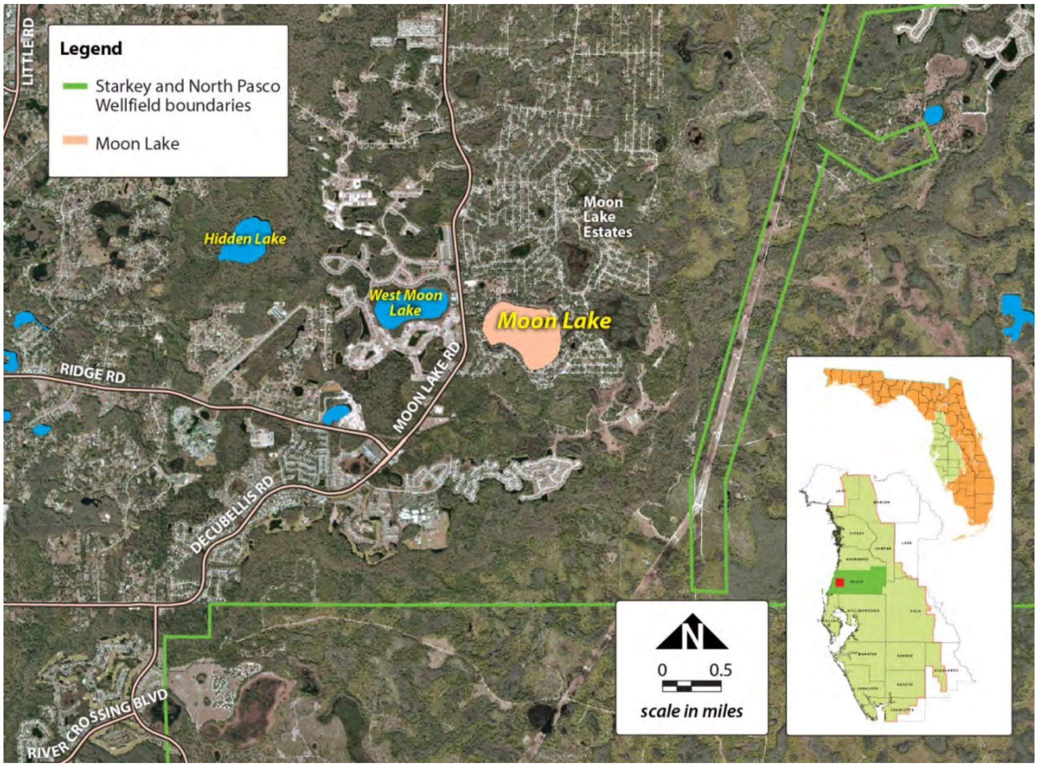


Figure 1. Location of Moon Lake in Pasco County, Florida

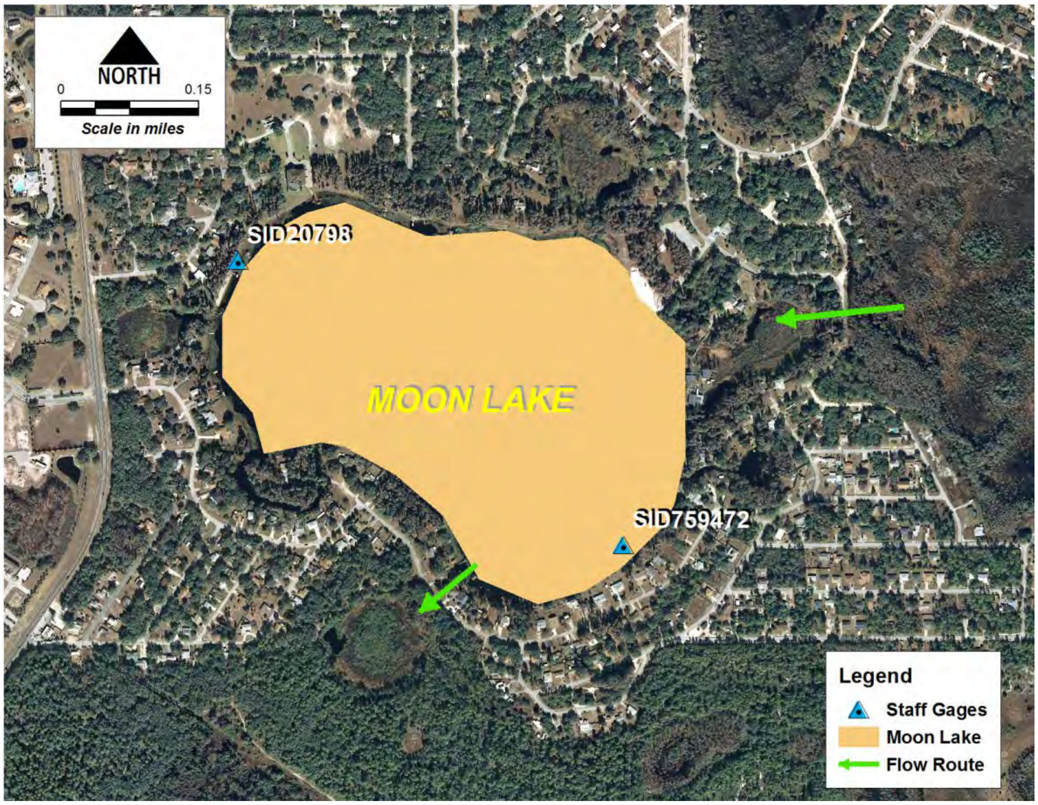


Figure 2. Location of inlet, outlet and District lake-level gages

The area surrounding the lake is categorized as the Land-O-Lakes subdivision of the Tampa Plain in the Ocala Uplift Physiographic District (Brooks 1981). The subdivision is a region of many lakes on a moderately thick plain of silty sand overlying limestone. As part of the Florida Department of Environmental Protection’s Lake Bioassessment/Regionalization Initiative, the area has been identified as the Weeki Wachee Hills lake region, and described as a region of Pleistocene sand dunes with numerous solution basins containing clear-water lakes with circumneutral pH, low alkalinity and low nutrient levels (Griffith et al. 1997).

Uplands surrounding the lake have been cleared and are currently used for residential development. Forested wetlands contiguous with the lake have been dredged or filled. A public boat ramp and swimming beach exists along the northeast lakeshore and are maintained by the Pasco County Parks and Recreation Department (Leeper 2003).

The hydrogeology of the area includes a sand surficial aquifer; a discontinuous, intermediate clay confining unit; and the thick carbonate Upper Floridan aquifer. In general, the surficial aquifer in the study area is in good hydraulic connection with the underlying Upper Floridan aquifer because the clay confining unit is generally thin, discontinuous, and breeched by numerous karst features. The surficial aquifer is generally ten to thirty feet thick and overlies the limestone of the Upper Floridan aquifer that averages nearly one thousand feet thick in the area (Miller, 1986).

There are no surface water withdrawals from the lake currently permitted by the District. There are several permitted groundwater withdrawals in the area including withdrawals from the Starkey and North Pasco wellfields (Figure 3). Starkey wellfield began pumping groundwater in 1974 and North Pasco in 1992. From 1974 to 2013, the wellfields combined averaged approximately 9 million gallons per day (mgd). However, withdrawals have not been consistent through time. From 1974 through 1982, Starkey wellfield pumped approximately 2.3 mgd, and from 1983 through 2007, the wellfield averaged approximatetly 11.3 mgd, and from 2008 to current, the wellfield averaged roughly 4.0 mgd. From 1992 through 2006, the North Pasco wellfield average withdrawals were approximately 2.2 mgd. From 2007 through current, the North Pasco wellfield withdrawal average was roughly 0.2 mgd (Figure 4). Additional groundwater withdrawals within two miles of the lake average approximately 0.3 mgd between 1992 and 2011.

Water level data collection for Moon Lake began in 1965, which predates the withdrawals at the Starkey and North Pasco wellfields. The frequency of data collection has been relatively consistent over the years. Historically, five staff gages have been used to collect water level data at the lake. Water level data from staff gage site identification number (SID) 759472 and SID 20798 were used to represent lake water levels. SID 759472 was used to collect water level data from 1965 to10/3/2011 and SID 20798 has been used to collect water level data from 9/18/1990 to current.

The Moon Lake Deep Upper Floridan aquifer monitoring well is located approximately one-half mile southwest of Moon Lake. Through examination of various interpolated potentiometric surface maps prepared by the U.S. Geologic Survey (USGS), the well is less than five ft. below the potentiometric contour surrounding the lake (Figure 6). Also, through examination of potentiometric drawdown results from the Integrated Northern Tampa Bay (INTB) model (Geurink and Basso, 2013), both the lake and the Moon Lake Deep well appear to have experienced very similar drawdowns (within 0.2 of a foot) over time. Water level data collected from the Moon Lake Deep well is recorded hourly by SCADA and has a period of record from1965 through current (Figure 7).

Moon Lake Shallow surficial aquifer monitor well is located approximately 20 feet from Moon Lake Deep, about one-half mile southwest of the lake. Water level data collected from the Moon Lake Shallow well is recorded hourly by SCADA and has a period of record from 1965 through current (Figure 8).

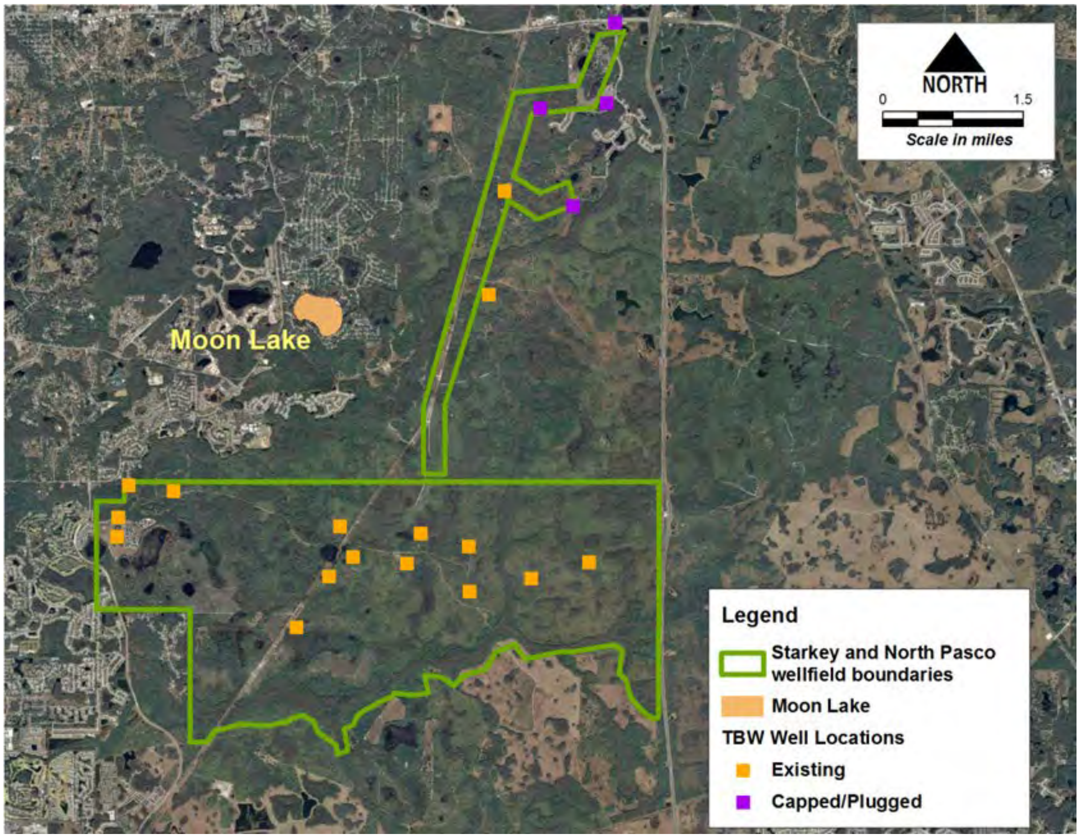


Figure 2. Starkey and North Pasco wellfield configuration

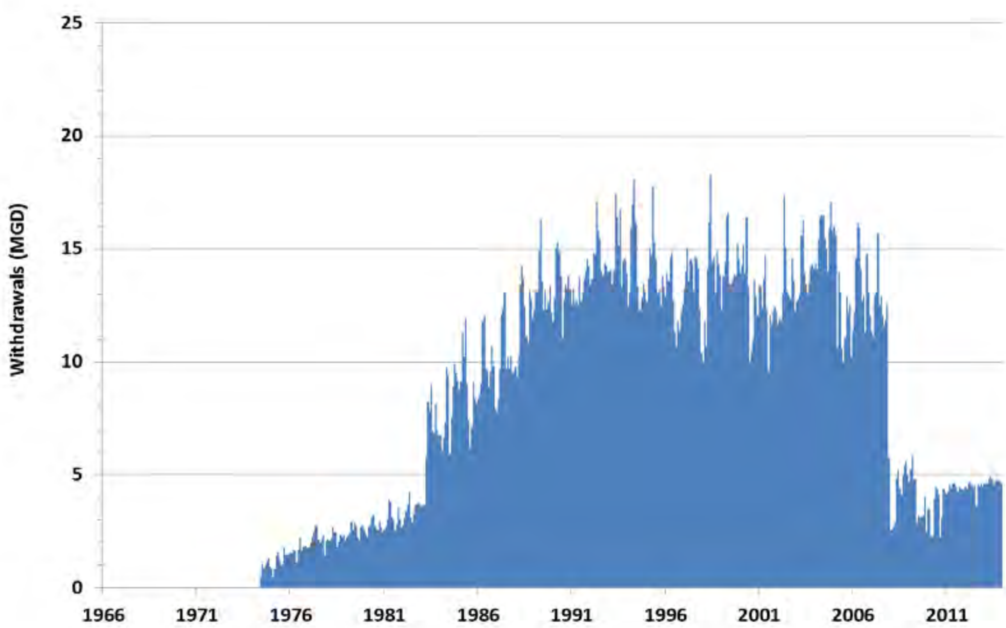


Figure 3. Starkey and North Pasco wellfield withdrawals

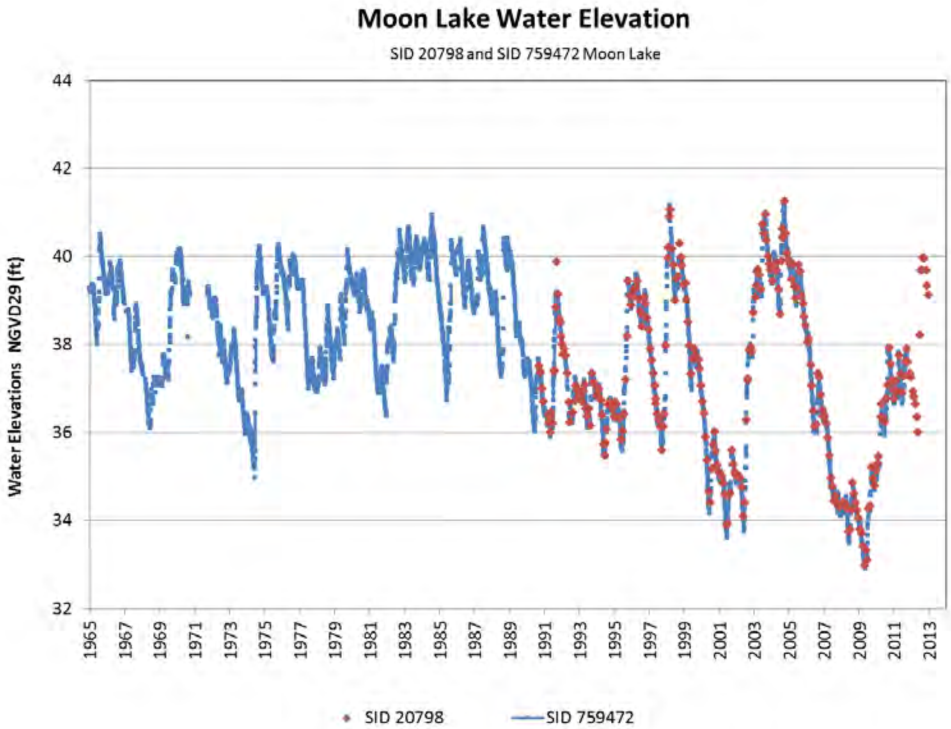


Figure 4. Moon Lake water levels

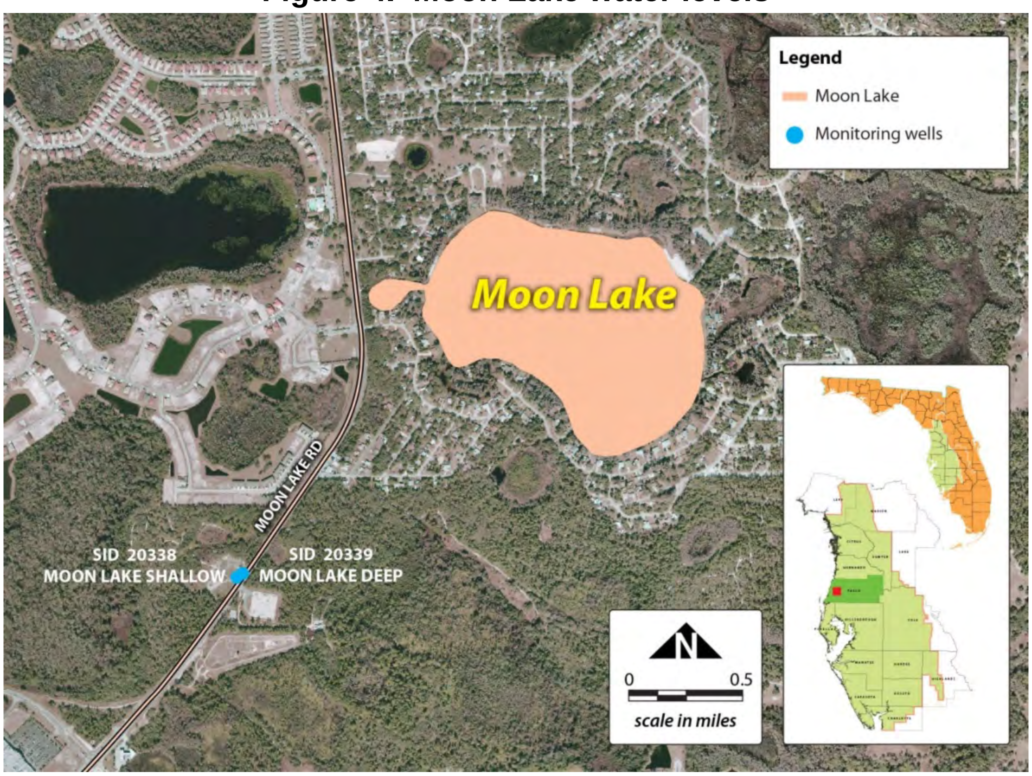


Figure 6. Locations of monitor wells near Moon Lake

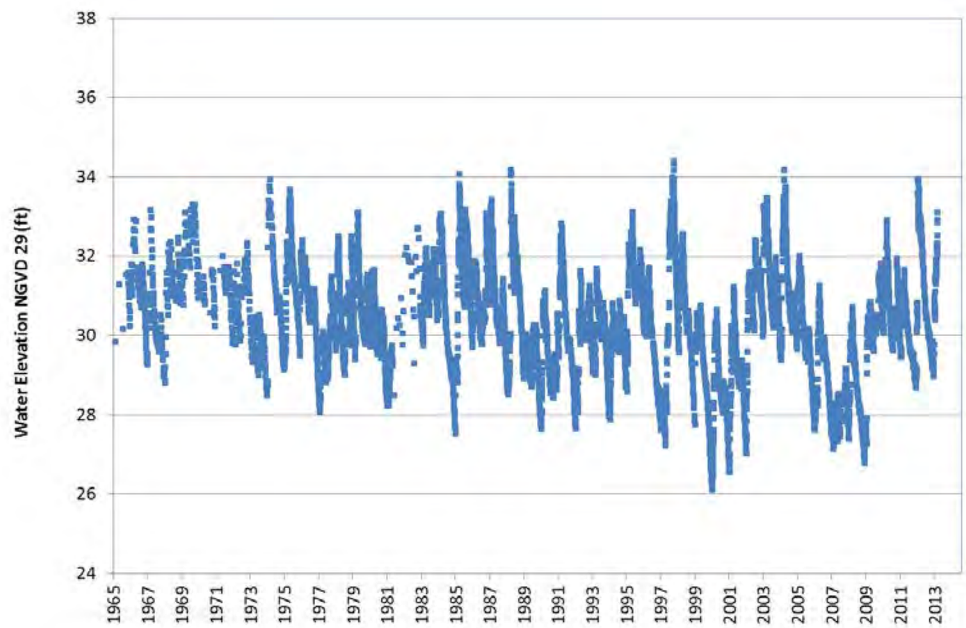


Figure 7. Water levels Moon Lake Deep Floridan aquifer monitor well

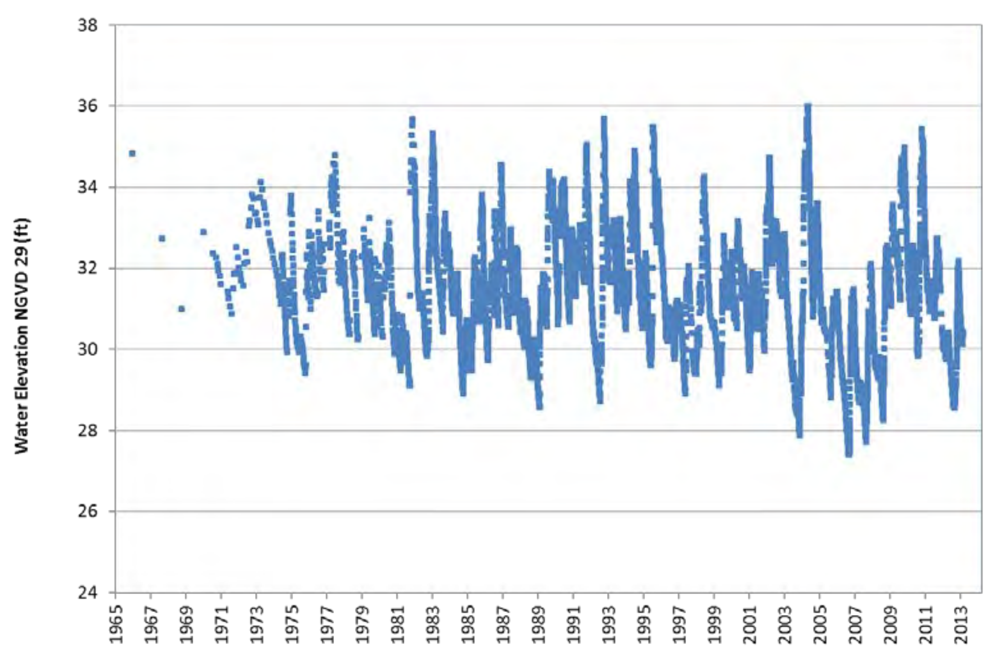


Figure 8. Water levels in Moon Lake Shallow surficial well

Water level data for Moon Lake and the accumulated pumping amounts between the Starkey and South Pasco wellfields are shown in figure 10. The water levels on the lake reached a low for the recorded period during 2009 and a high in 2004. The low value in 2009 can be attributed to extended drought conditions in the NTB region and the 2004 high is likely caused by a highly active 2004 hurricane season. However, it should be noted that during the time of maximum pumping within the wellfields, the lake water levels tended to have slightly more fluctuation.

C. Purpose of Models

Prior to establishment of Minimum Levels (ML), long-term lake stage percentiles are developed to serve as the starting elevations for the determination of the lake's High Minimum Lake Level (HMLL) and the Minimum Lake Level (MLL). 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 then be used to calculate a long-term Historic P50 (or median) and P10 for the lake.

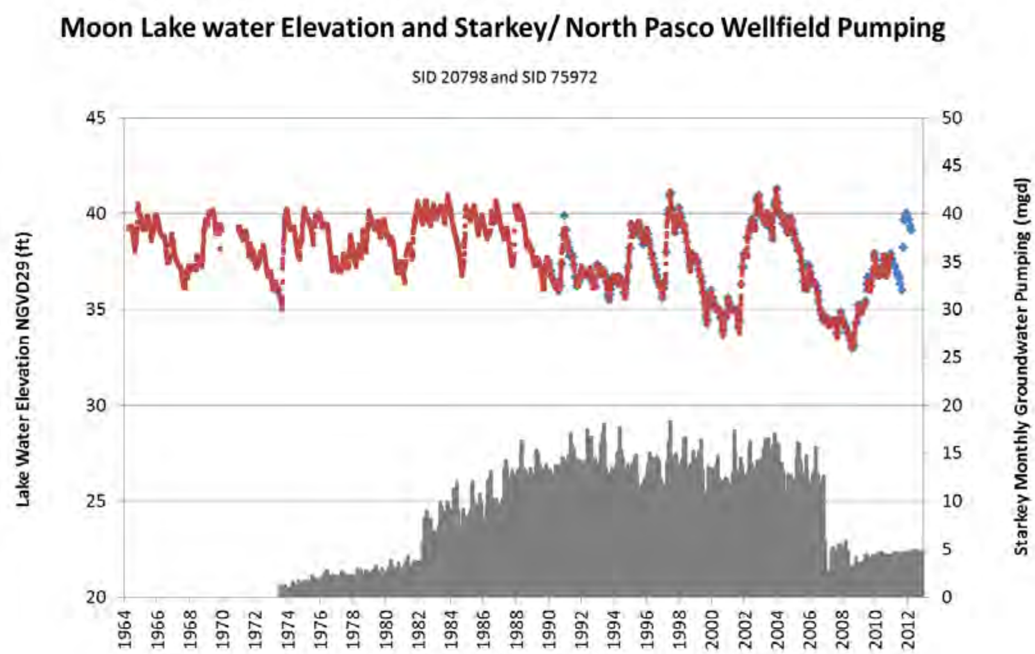


Figure 9. Water levels in Moon Lake

D. Water Budget Model Overview

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

The hydrologic processes in the Moon Lake model include:

a. Rainfall and Evaporation
b. Overland flow
c. Inflow and Discharge via channels
d. Flow from and into the surficial aquifer
e. Flow from and into the Upper Floridan aquifer

The model uses a daily time-step, and tracks inputs, outputs, and lake volume to calculate a daily estimate of lake levels for the lake. The water budget model is calibrated from 1966 to 2011, which provides a period of time that is considered long-term for purposes of determining Historic percentiles. This period also provides the best balance of using available data for all parts of the water budget and the desire to have a long-term period.

E. Model Components

Lake Stage/Volume

Stage area and stage volumes were determined by building a terrain model of the lakes and surrounding watersheds. Lake bottom elevations and land surface elevations were used to build the model through a series of analyses using LP360 (by QCoherent) for ArcGIS, ESRI's ArcMap 10.1 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 underlying 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 flood stage and working downward to the base elevation.

Precipitation

A line of organic correlation (LOC) model was previously performed for Moon Lake. The LOC is a linear fitting procedure that minimizes errors in both the x and y directions and defines the best-fit straight line as the line that minimizes the sum of the areas of right triangles formed by horizontal and vertical lines extending from observations to the fitted line (Helsel and Hirsch, 1997).

Because an LOC model was performed for Moon Lake, the same rainfall data assembled for that model was used and updated through 2014. Daily data from St. Leo NWS, located approximately 21 miles to the east of the lake was used to represent precipitation over the area of Moon Lake from January 1, 1966 through December 31, 1991. From January 1, 1992 through December 31, 2011 the Summer Tree rain gage, located slightly less than 3 miles to the north of the lake was used to represent precipitation over the area of Moon Lake. From January 1, 2012 to the end of the calibration period (December 31, 2014), the Kent Grove rain gage, located approximately 6 miles to the northeast of the lake was used to represent precipitation over the area of Moon Lake (Figure 11). Missing data points in the rainfall data set between 1992 and the end of the calibration period was infilled using data points collected at the Saint Leo NWS rain station.

Lake Evaporation

Lake evaporation was estimated through use of monthly energy budget evaporation data collected by the U.S. Geological Survey (USGS) at Lake Starr in Polk County (Swancar and others, 2000) (Figure 12). The data was 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 in the water budget model when Lake Starr evaporation data were not available.

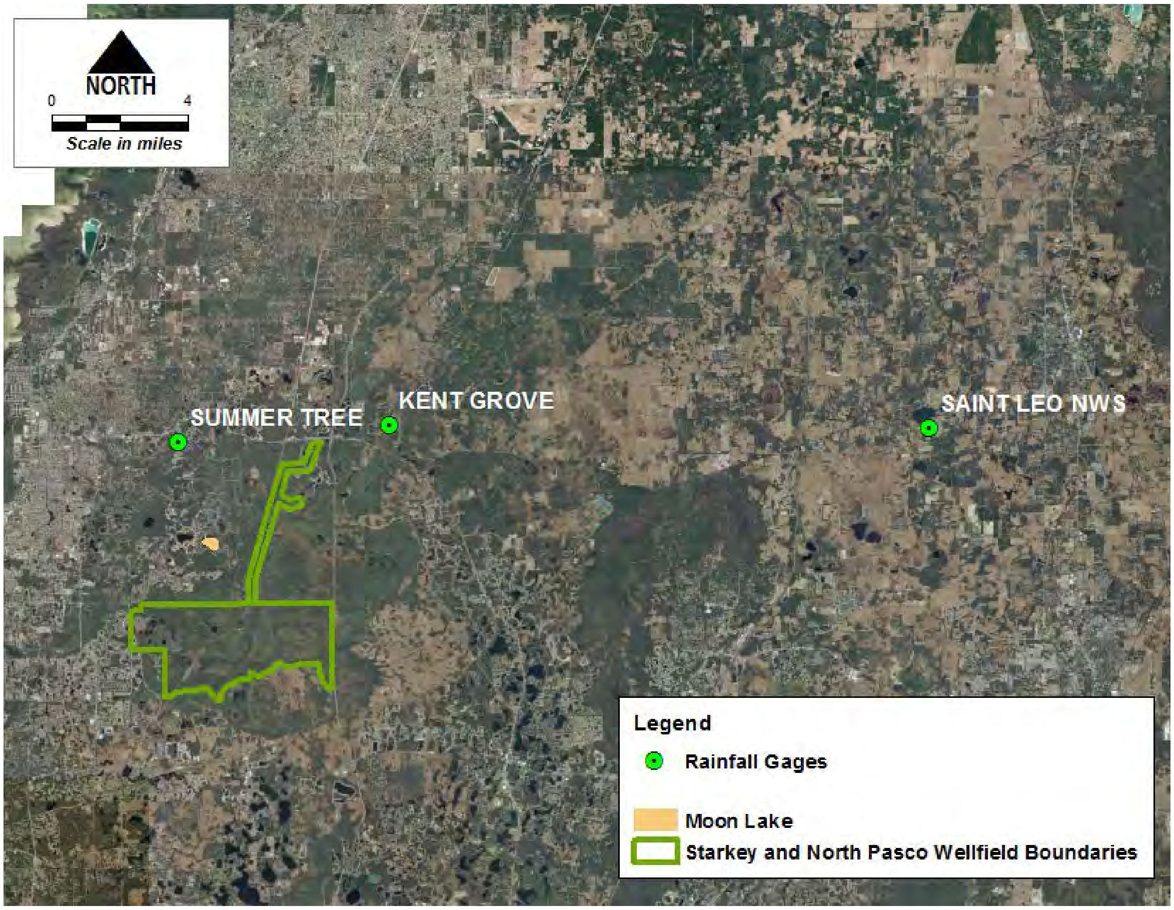


Figure 10. Rain gages used in the Moon Lake Model

A recent study compared monthly energy budget evaporation data collected from both Lake Starr and Calm Lake (Swancar, 2011, personal communications). Calm Lake is located less than 10 miles to the south of Moon Lake (Figure 12). The assessment concluded that the evaporation rates between the two lakes were essentially the same, with small differences attributed to measurement error and monthly differences in latent heat (due to differences in lake depth).

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 on the USGS website, 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 lakes was considered. A decision was made to use the Lake Starr 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 this would introduce more error than using the Lake Starr data directly.

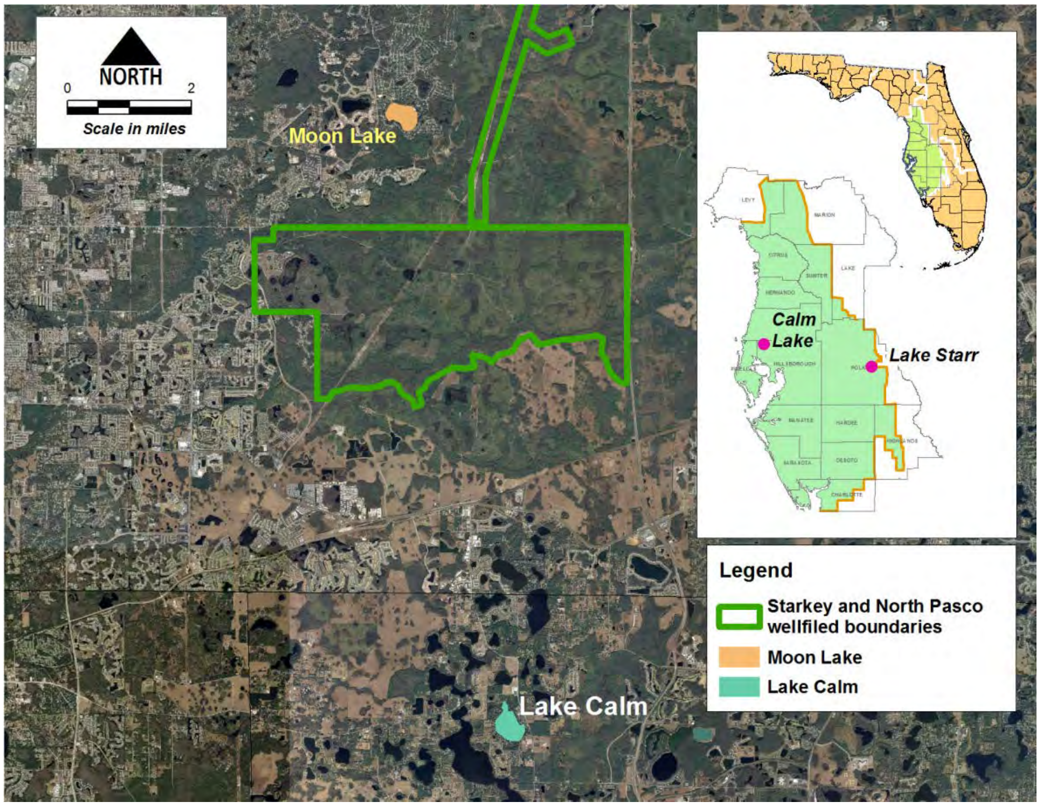


Figure 11. Location of Lakes Starr and Calm

Overland Flow

The 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 (DCIA) calculations. The free water area of each lake was subtracted from the total watershed area at each time step to estimate the watershed area contributing to surface runoff. The directly connected impervious area is subtracted from the watershed for the SCS calculation, and then added to the lake water budget separately. Additionally, a curve number (CN) chosen for the watershed of the lake take into account the amount of DCIA in the watershed that has been handled separately.

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

The topography in the area of Moon Lake is relatively flat, so determining watersheds based on relatively subtle divides can be challenging. Several slightly varying estimates of watershed boundaries have been performed in the past for different modeling efforts in the area. The most recent estimates were performed as part of an effort to model the Bear Creek and Pithlachascotee River watersheds (Ardaman & Associates, Inc., 2013). These values were adopted for this model (Table 1). An independent check produced watershed areas within a couple acres of those found in the previous effort, confirming that they are reasonable.

The Moon Lake watershed was derived from a recent flood modeling effort (Ardaman & Associates, Inc., 2013) and used for this model (Figure 13). The watershed for the lake is 440.6 acres. The watershed is relatively flat, and flow from the watershed into the Pithlachascotee River basin occurs only during large rainfall events.

The DCIA and SCS CN used the lake is listed in Table 1. Curve numbers were difficult to assess. The soils in the area, with exception to a large cypress wetland located east of the lake, are classified as A, C or B/D soilswhich means that the area ranges from low runoff potential “A” to high runoff potential “D”.The characteristics of the B/D soils are highly dependent on how well they are drained. A “D” soil will generally have a higher amount of runoff per quantity of rain than an “A”, “B” or “C” soil. The cypress wetland soil is listed as “W” with a FLUCCS code of 6150. This indicates that the water within the wetland does not runnoff into the lake until the water table reaches the inlet to the lake at 38.3 ft. For purposes of this model an SCS number of 56 was used. The DCIA of the watershed is essentially zero, and is modeled as such.

Table 1. Model Inputs

	Moon
Total Watershed Size (acres)	440.6
SCS CN of watershed	56
Percent Directly Connected	0
FL Monitor Well Used	Moon Lake Deep
Surf. Aq. Monitor Well(s) Used	Moon Lake Shallow
Surf. Aq. Leakance Coefficient (ft/day/ft)	1.0X10-3
Fl. Aq. Leakance Coefficient (ft/day/ft)	1.4X10-4
Outflow K	0.02
Outflow Invert (ft NGVD)	39.8
Inflow K	N/A
Inflow Invert (ft NGVD)	N/A

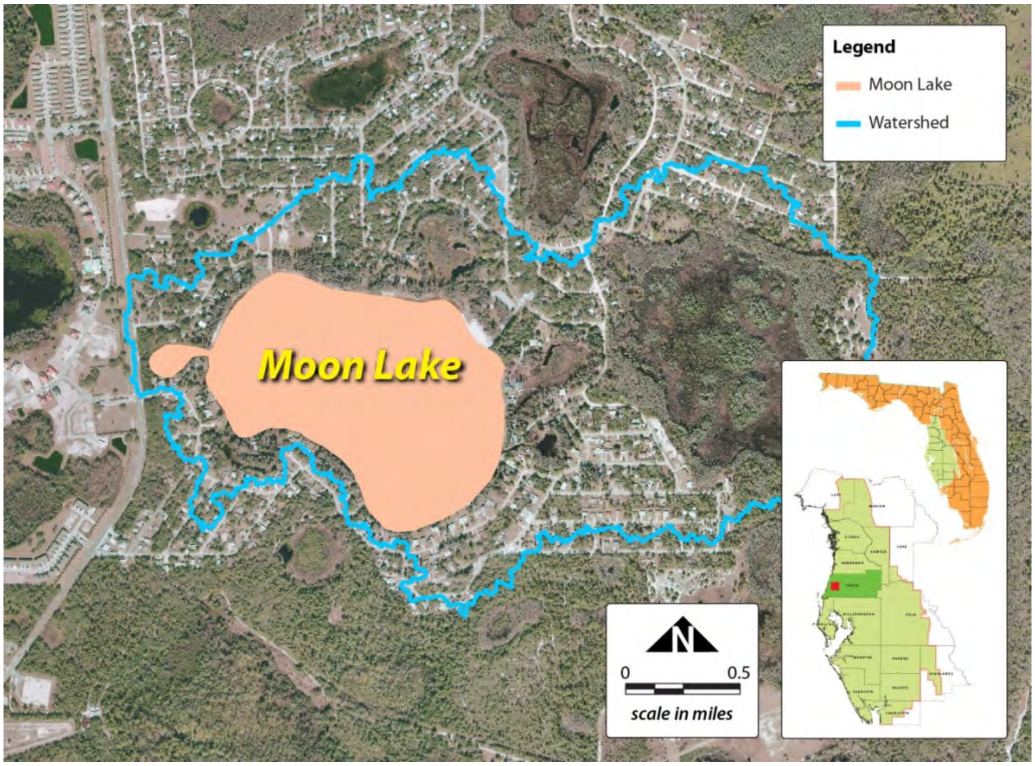


Figure 12. Watershed of Moon Lake

Inflow and Discharge Via Channels from Outside Watersheds

Inflow and outflow via channels from or to outside individual lakes' watersheds (hence referred to as "channel flow") is a relatively small component of the water budget in Moon Lake since water levels rarely reach elevations that allow discharge. Because the channel flow component is small, and detailed surveys and dimensions of structures and channels were not available, a simplified approach was used.

To estimate flow out of the lake, the predicted elevation of the lake from the previous day is compared to the controlling elevation. If this value is a positive number, the difference is multiplied by the current area of the lake and an "outflow coefficient." The coefficient represents a measure of channel and structure efficiency, and produces a rough estimate of volume lost from the lake. This volume is then subtracted from the current estimate of volume. As long as the volumes remain a small component of the lake water budget, it was thought that a significant amount of error would not be introduced to the model results. To estimate flow into the lake, the same approach was applied, using data and information from a donating water body to determine availability of water.

Moon Lake has one channel/inlet draining into the lake. The inlet connects the lake to the cypress dominated wetland east of the lake when the water elevation in the lake or wetland exceeds about 38.3 ft above NGVD29. For modeling purposes, the stage volume and watershed were considered part of the lake for stage volume and watershed.

A series of ditches and culverts exist along the lakes south shore and drain the lake through several wetland ponds, and ultimately to the Pithlachascotee River. A low floor slab elevation, extent of structural alteration and the control point elevation (39.8 ft above NGVD) were determined using available one-foot contour interval aerial maps and field survey data (Leeper, 2003).

Flow from and into the surficial aquifer and Upper Floridan aquifer

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

The Moon Lake Deep Floridan aquifer monitoring well (Figure 6), located roughly one-half mile to the southwest of Moon Lake, was used to represent the Upper Floridan aquifer. The well has a period of record starting in 1965 to current. A simple approach was used to fill in missing data by using the last recorded data value until a new value was recorded. Water levels were not adjusted for the Upper Floridan aquifer well because the potentiometric surface contours created by the U.S. Geological Survey shows less than a five-foot difference between the Upper Floridan aquifer well used and the lake.

The Moon Lake Shallow well, located adjacent to the Moon Lake Deep well, was used to represent the surficial aquifer. The period of record for the well is 1965 to present. Missing data for the surficial well was infilled using the same approach as described above for the Upper Floridan well. Through examination of topographic maps and land surface elevation data prepared by the USGS, it was noted that the well is approximately seven feet below the land surface elevation surrounding the lake. Therefore, a downward adjustment of seven feet was made to the well in order to better estimate the groundwater within the vicinity of the lake.

F. Water Budget Model Approach

The primary reason for development of the Moon Lake model is to estimate the Historic percentiles for the lake. More specifically of importance is the P50 (median), which is used to determine several elevations that are considered as part of the minimum level determination process. Therefore, the calibration focused on matching the long-term percentiles of the lakes, rather than short-term highs and lows.
Actual data from the lake was used to compare to the modeled water levels. Water level data for Moon Lake has been collected monthly since 1965 (with some periods of more or less frequent data collection). Daily values are generated from the model, so data was filled-in using the same approach used to fill-in the well data.

Figure 13 presents the calibration result of the model. Table 2 presents a comparison of the percentiles of the data versus the model results. Tables 3 and 4 present the modeled water budget breakdown for the model calibration period for the lake.

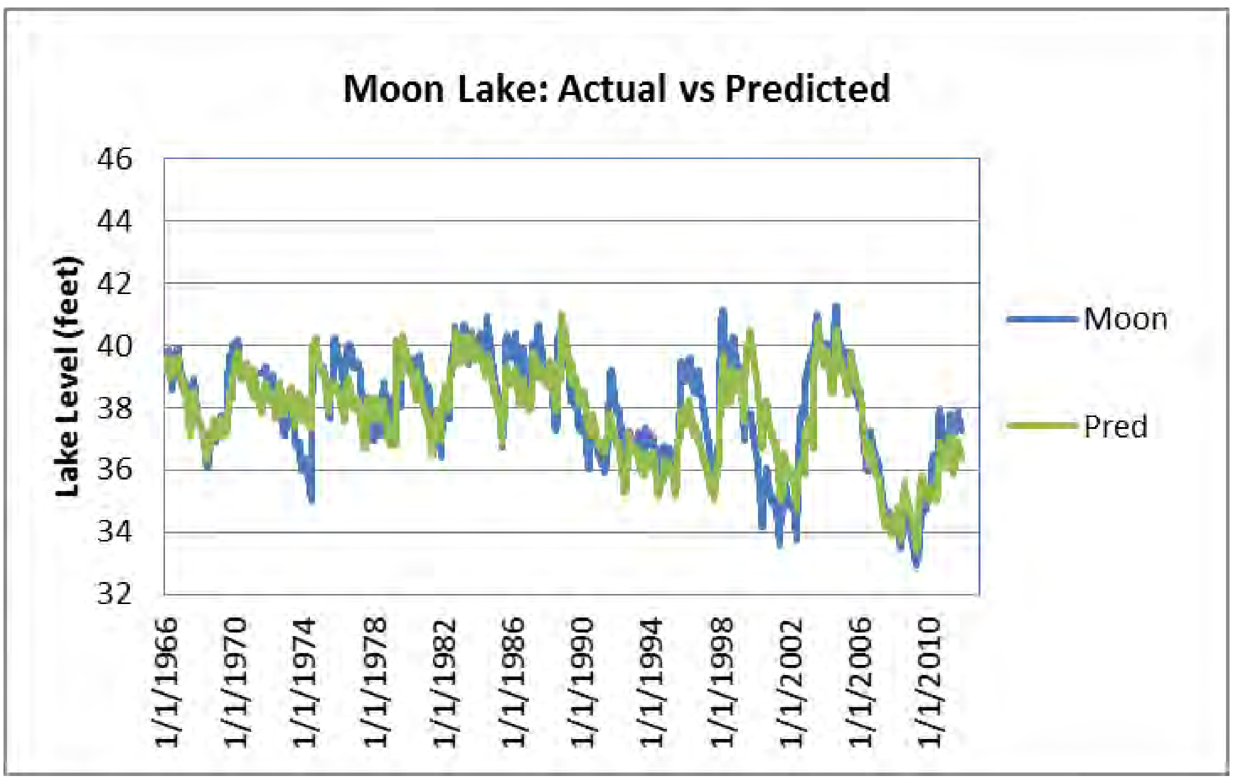


Figure 13. Moon Lake Calibration in the Moon Lake model.

Table 2. Long-term percentiles of water level data compared to long-term calibration percentiles from the model (all in feet NGVD).

	Moon Lake Data	Moon Lake Model
P10	39.9	39.6
P50	38.0	38.0
P90	35.3	35.6

Table 3. Moon Lake Water Budget from the model (1966-2011).

Inflows	Rainfall	SURF GW Inflow	FL GW Inflow	Runoff	DCIA Runoff	Inflow via channel	Total
Inches/year	53.2	3.7	0.0	10.7	0.0	0.0	67.7
Percentage	78.7	5.5	0.0	15.8	0.0	0.0	100.0

Outflows	Evaporation	SURF GW Outflow	FL GW Outflow			Outflow via channel	Total
Inches/year	57.8	1.2	7.3			1.2	67.5
Percentage	85.7	1.8	10.8			1.7	100.0

G. Water Budget Model Calibration Discussion

Based on a visual inspection of Figure 13, the calibration of the model appears to be reasonable. There are a few periods when the peaks or lows in the modeled hydrograph are a bit low or high, but the overall representation of the data is reasonable.

A review of Table 2 shows that the difference in median percentiles (P50) is within 0.1 ft, the P10 and P90 percentile between the data and the lake model are within 0.3 feet.

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

H. Water Budget Model Results

Groundwater withdrawals are not directly included in the Moon Lake model, but are indirectly represented by their effects on water levels in the Upper Floridan aquifer. Metered groundwater withdrawal rates from the Starkey and North Pasco wellfield are available from 1974 to current for the period of the calibrated model, so if 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.

The Integrated Northern Tampa Bay (INTB) model (Geurink and Basso, 2013) is an integrated model developed for the northern Tampa Bay area using the Integrated Hydrologic Model (IHM) code (Geurink and others, 2013). The IHM code combines the groundwater model MODFLOW (McDonald and Harbaugh, 1988), and the surface-water model HSPF (Johanson and others, 1984) to create a model code that can be used to represent the complete groundwater/surface-water system. The domain of the INTB application includes the Starkey and North Pasco wellfield area, and represents the most current understanding of the hydrogeologic system in the area.

The INTB was used to determine the drawdown in the surficial aquifer and Upper Floridan aquifer in response to groundwater withdrawals in the area. However, Starkey wellfield did not begin withdrawing groundwater until 1974 and North Pasco until 1992. Drawdown in both aquifers was calculated for two withdrawal rates representing the effects of Tampa Bay Water's regional wellfields before and after cutbacks from approximately 150 mgd to 90 mgd.

From 1966 to 1974, Starkey and North Pasco wellfield were not withdrawing groundwater. The pre-cutback period in the model is from 1974 to 2008, while the post-cutback period is 2008 to 2011. The model results allowed the drawdowns associated with all permitted withdrawals to be calculated before and after wellfield cutbacks (assuming all other withdrawals are consistent with the modeled period). The INTB model was run from 1996 to 2006 using a daily integration step. Drawdown amounts were calculated by running the model with and without groundwater withdrawals, and were calculated for each node in the model. The INTB model uses a one-quarter mile grid spacing in the area of the wellfields. Groundwater withdrawal rates from the Starkey and North Pasco wellfield in each scenario were 14 mgd and 4 mgd, respectively.

Results from the scenarios showed that there is a fairly linear relationship between Upper Floridan aquifer drawdown and withdrawal rates at the Starkey and North Pasco wellfiels., Because of the leaky nature of the confining unit in the area of the lake, and because the water table in the Moon Lake model is also not active, the relationship between groundwater withdrawals in the Upper Floridan and water levels in the surficial was also of interest. The same scenarios described above showed that for one mgd of groundwater withdrawals results in approximately 0.04 feet of drawdown in the water table at the lake. Using the drawdowns determined through the INTB model, the Upper Floridan aquifer and surficial monitor well data in the model can be adjusted to reflect changes in groundwater withdrawals.

To estimate lake levels without the influence of groundwater withdrawals, the Upper Floridan aquifer and surficial aquifer wells in the model were adjusted to represent zero withdrawals. For the 1966 to 2011 water budget model period, three periods of adjustment were used to reflect the pumping/cutbacks that took place at the Starkey and North Pasco wellfield. The adjustments to each Upper Floridan aquifer and surficial aquifer well are found in Table 4. Figure 15 presents actual water level data for each lake along with the model's forecast for water levels in the lake under Historic condition (no groundwater withdrawals). Table 5 presents the Historic Percentiles as estimated by the water budget model.

Table 4. Aquifer water level adjustments to the Moon Lake model to represent Historic percentiles

Well	Adjustment (feet) 1974 to 1983	Adjustment (feet) 1984 to 2008	Adjustment (feet) 2008 to 2011
Moon Lake Deep (Floridan aquifer)	0.12	0.85	0.25
Moon Lake Shallow (surficial aquifer)	0.1	0.6	0.2

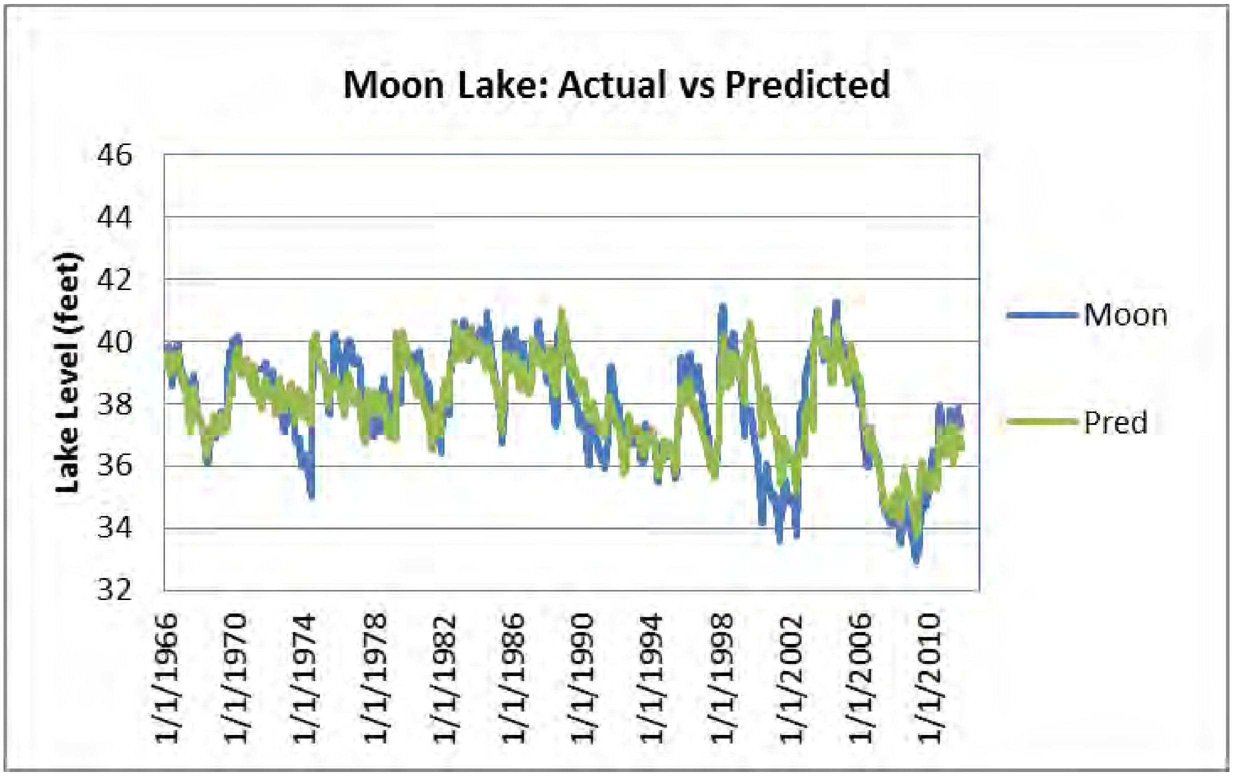


Figure 14. Historic percentile scenario for Moon Lake

Table 5. Historic percentiles as estimated by the Moon Lake model (in feet NGVD).

Percentile	Moon Lake
P10	39.7
P50	38.1
P90	36.1

Historic normal pools are elevation datums established to standardize measured water levels and facilitate comparison among wetlands and lakes. The historic normal pool elevation is commonly used in the design of wetland storm water treatment systems (Southwest Florida Water Management District, 1988). This level can be consistently identified in cypress swamps or cypress-ringed lakes based on similar vertical locations of several indicators of inundation (Hull, et al, 1989; Biological Research Associates, 1996). Historic normal pools have been used as an estimate of the P10 in a natural wetland, based on observation of many control sites in the northern Tampa Bay area.

Historic normal pools were determined on Moon Lake based on cypress indicators of inundation. The historic normal pools for the lake are shown in Table 6.

Table 6. Field determined Historic normal pool for Moon Lake.

Lake	Historic Normal Pool (feet NGVD)
Moon	40.2

While the Historic normal pool and natural P10 in lakes and wetlands in the northern Tampa Bay area may differ by several tenths of a foot in many cases, the P10 of the model's estimates for Moon Lake are 0.4 feet lower than the respective Historic normal pool elevations for the lake. The differences likely are caused by rainfall or structural alterations at the lake.

I. Rainfall Correlation Model

In an effort to extend the period of record of the water levels used to determine the Historic Percentiles to be used in the development of the lakes' Minimum Levels, an LOC was performed using the results of the water budget model and long-term rainfall. LOC is preferable for this application since it produces a result that best retains the variance (and therefore best retains the "character") of the original data.

In this application, the simulated lake water levels representing Historic conditions were correlated with Long-term rainfall. For the correlation, additional representative rainfall records were added to the rainfall records used in the water budget model (1966-2014). Rainfall data from the Saint Leo NWS gage were used to extend the data back to 1946. Although The Saint Leo NWS gage is located roughly 21 miles northeast of the lake, it is one of only a few rain gages in the vicinity with data preceding 1966. Summer Tree rainfall station began collecting rainfall data at the beginning of 1992 and was used to extend the rainfall data through 2011. From 2012 through 2014, the Kent Grove rainfall station was used.

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

Rainfall was correlated to the water budget model results for the entire period used in the water budget model (1966-2011), and the results from 1946-2014 (69 years) were produced. The 4 year weighted model had the highest correlation coefficient, with an R^2 of 0.83. Previous correlations for lakes in the northern Tampa Bay area have consistently had best correlation coefficients in the 2 to 5 year range. The results are presented in Figure 15.

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 result are used for the period of 1946-1965 and 2012-2014, while the water budget results are used for the period of 1966-2011. These results are referred to as the “hybrid model”. The resulting Historic percentiles for the hybrid model are presented in Table 7. Note that the difference between the P10, P50, and P90 percentiles from the water budget model (Table 5) and those from the hybrid rainfall model (Table 7) for Moon Lake are 0.3, 0.2, and 0.2 feet, respectively. Therefore, there are very small changes to the Historic percentiles between the two models for the lake. The results of the hybrid model and observed water levels at Moon Lake are presented in Figure 16.

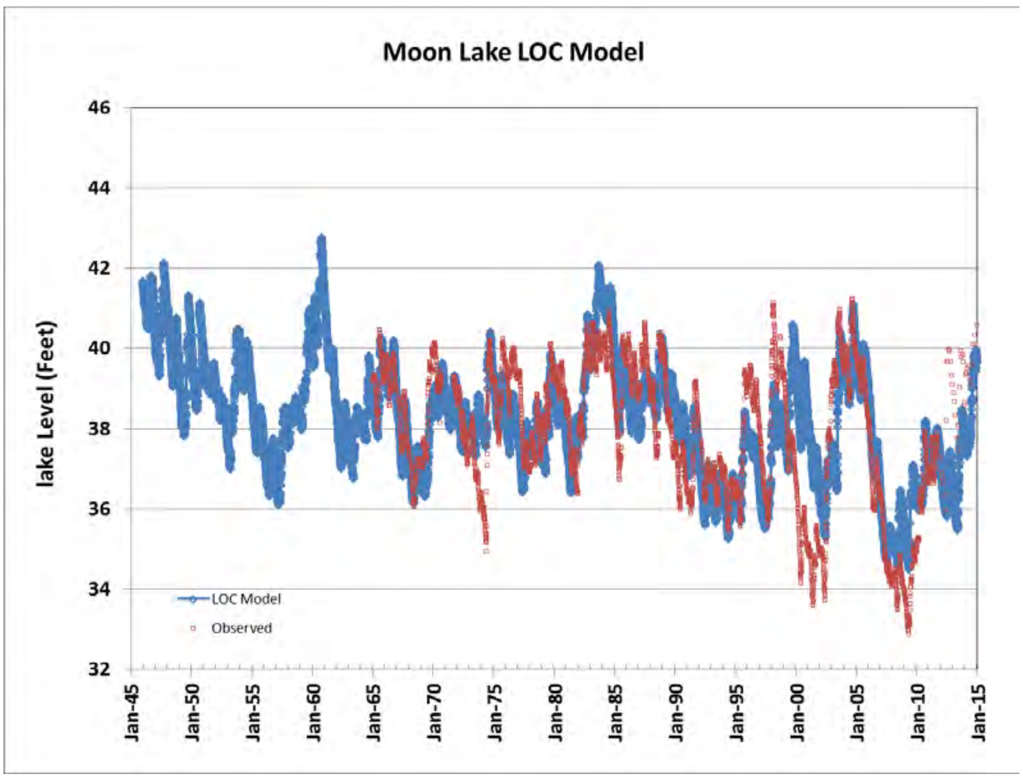


Figure 15. LOC model results for Moon Lake

Table 7. Historic percentiles as estimated by the hybrid model from 1946 to 2014 (in feet NGVD).

Percentile	Moon Lake
P10	40.0
P50	38.3
P90	36.3

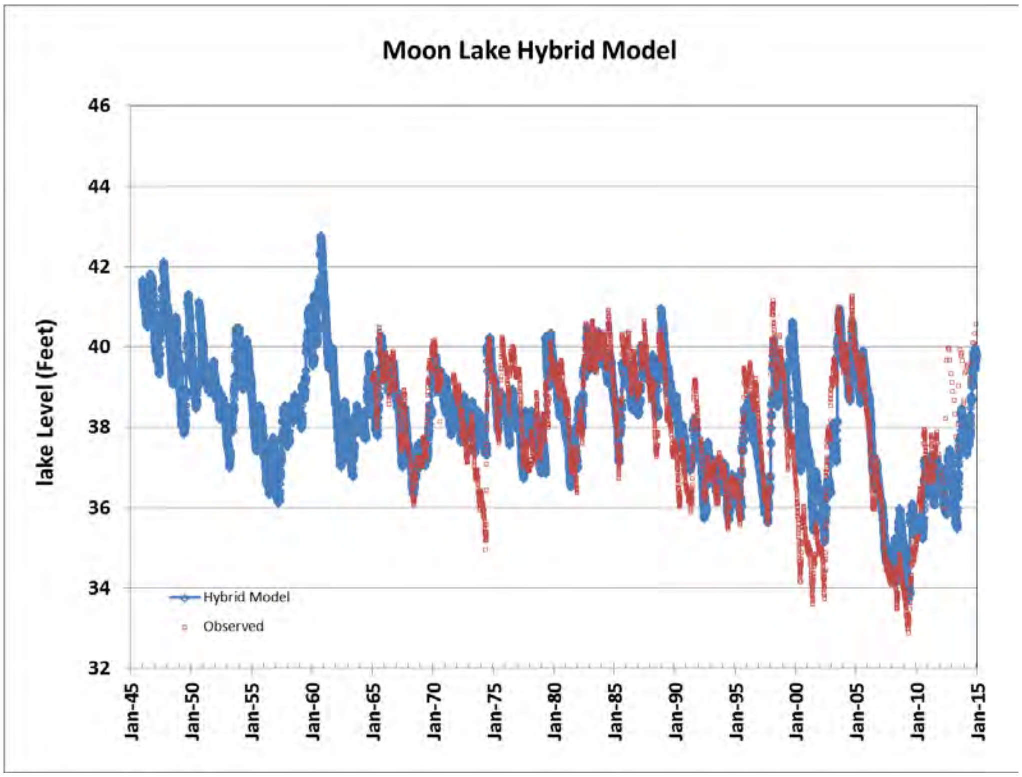


Figure 16. LOC model results and observed data for Moon Lake

J. Conclusions

Based on the model results and the available data, the Moon Lake water budget and LOC rainfall models are useful tools for assessing long-term percentiles in the lake. Based on the same information, the percentiles produced via this process appear to be reasonable estimates for Historic conditions.

K. References

Ardaman & Associates, Inc. 2011. Floodplain Justification Report for the Bear Creek and Pithlachascotee River Watersheds within Pasco and Hernando County, Florida. Prepared for Southwest Florida Water Management District. May 2013.

Berryman and Henigar, Inc. 2005. Rocky Creek Lake Enhancement Project Phase 1 Final Report. Prepared for Tampa Bay Water. September 2005.

Biological Research Associates. 1996. Use of lasting indicators of historic inundation patterns in isolated wetlands as reference elevations to determine areal extent and intensity of reduced water levels near areas of groundwater withdrawals. Report submitted to the West Coast Regional Water Supply Authority. November 1996.

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.

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

Florida Board of Conservation. 1969. Florida lakes, part III: gazetteer. Division of water Resources. Tallahassee, Florida.

Geurink, J.S. and R. Basso. 2013. Development, Calibration, and Evaluation of the Integrated Northern Tampa Bay Hydrologic Model. Prepared for Tampa Bay Water and Southwest Florida Water Management District. March 2013

Geurink, J.S. *et al.* 2013. User Manual for the Integrated Hydrologic Model. Tampa Bay Water, Clearwater FL.

Griffith, G., Canfield, D., Jr., Horsburgh, C., Omernik, and J. Azevedo, S. 1997. Lake Regions of Florida (map). United States Environmental Protection Agency, University of Florida Institute of Food and Agricultural Sciences, Florida Lakewatch, Florida Department of Environmental Protection, and the Florida Lake Management Society. Gainesville and Tallahassee, Florida.

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

Hancock, M.C. and T.S. McBride. 2013. Memorandum: Lakes Horse/Raleigh/Rogers Water Budget (HRR) Model and Historic Percentile Estimation. Southwest Florida Water Management District. July 9, 2013.

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.
Hull, H.C., J.M. Post Jr., M. Lopez, and R.G. Perry. 1989. Analysis of water level indicators in wetlands: Implications for the design of surface water management systems. In Wetlands: Concerns and Successes. Proceeding of the American Water Resources Association, Tampa. D. Fisk (ed.), pages 195-204.

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.

Leeper, Doug. 2003. Memorandum: Proposed minimum and guidance levels for Moon Lake in Pasco County, Florida. Southwest Florida Water Management District. November 14, 2003.

Johanson, R.C., J.C. Imhoff, J.L. Kittle, and A.S. Donigian. 1984. Hydrological Simulation Program – FORTRAN (HSPF): User's Manual for Release 8.0. U.S. Environmental Protection Agency. Athens, Georgia

McDonald, M. G., and A.W. Harbaugh. 1988. A three-dimensional finite-difference groundwater model." *Open File Report 83-875,* U.S. Geological Survey.

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

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

Southwest Florida Water Management District. 1988. Basis of Review for Surface Water Permit Applications in the Southwest Florida Water Management District.

Southwest Florida Water Management District. 2003. Lake Pretty Water Transfer Project. Operations Department.

Swancar, A. personal communications, 2011.

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.

Appendix B

Technical Memorandum

April 25, 2015

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

FROM: Jason Patterson, Hydrogeologist, Water Resources Bureau
Keith Kolasa, Senior Environmental Scientist, Water Resources Bureau

Subject: Moon Lake Initial Minimum Levels Status Assessment

L. Introduction

The Southwest Florida Water Management District (District) reevaluated adopted minimum levels for Moon Lake in accordance with Section 373.042 and 373.0421, Florida Statutes (F.S). Documentation regarding development of the revised minimum levels was provided by Patterson and Hancock (2014) and Kolasa (2015).

Section 373.0421, F.S. requires that a recovery or prevention strategy be developed for all water bodies that are found to be below their minimum flows or levels, or are projected to fall below the minimum flows or levels within 20 years. In the case of Moon Lake and other water bodies with established minimum flows or levels in the northern Tampa Bay area, an applicable regional recovery strategy, referred to as the "Comprehensive Plan", has been developed and adopted into District rules (Rule 40D-80.073, F.A.C.). One of the goals of the Comprehensive Plan is to achieve recovery of minimum flow and level water bodies such as Moon Lake that are located in the area affected by the Consolidated Permit wellfields (i.e., the Central System Facilities) operated by Tampa Bay Water. This document provides information and analyses to be considered for evaluating the status (i.e., compliance) of the revised minimum levels for Moon Lake and any recovery that may be necessary for the lake.

M. Background

Moon Lake is located in the Coastal Rivers Basin of the District in southwest Pasco County, east of Moon Lake Rd near New Port Richey. The lake is approximately 1.5 miles north of the Starkey wellfield and 1.2 miles west of North Pasco wellfield, which are two of eleven regional water supply wellfields operated by Tampa Bay Water (Figure 1).

From 2002 to 2005, a cutback in the withdrawal rates at most Central System Facility wellfields occurred in response to the development of several alternative water supply sources. As a whole, the wellfields were reduced from approximately 158 million gallons per day (mgd) to 90 mgd, although the timing and amount of reduction at each wellfield was variable. These cutbacks are evident in the withdrawal rates reported for the Starkey and North pasco Wellfields (Figures 2 and 3).

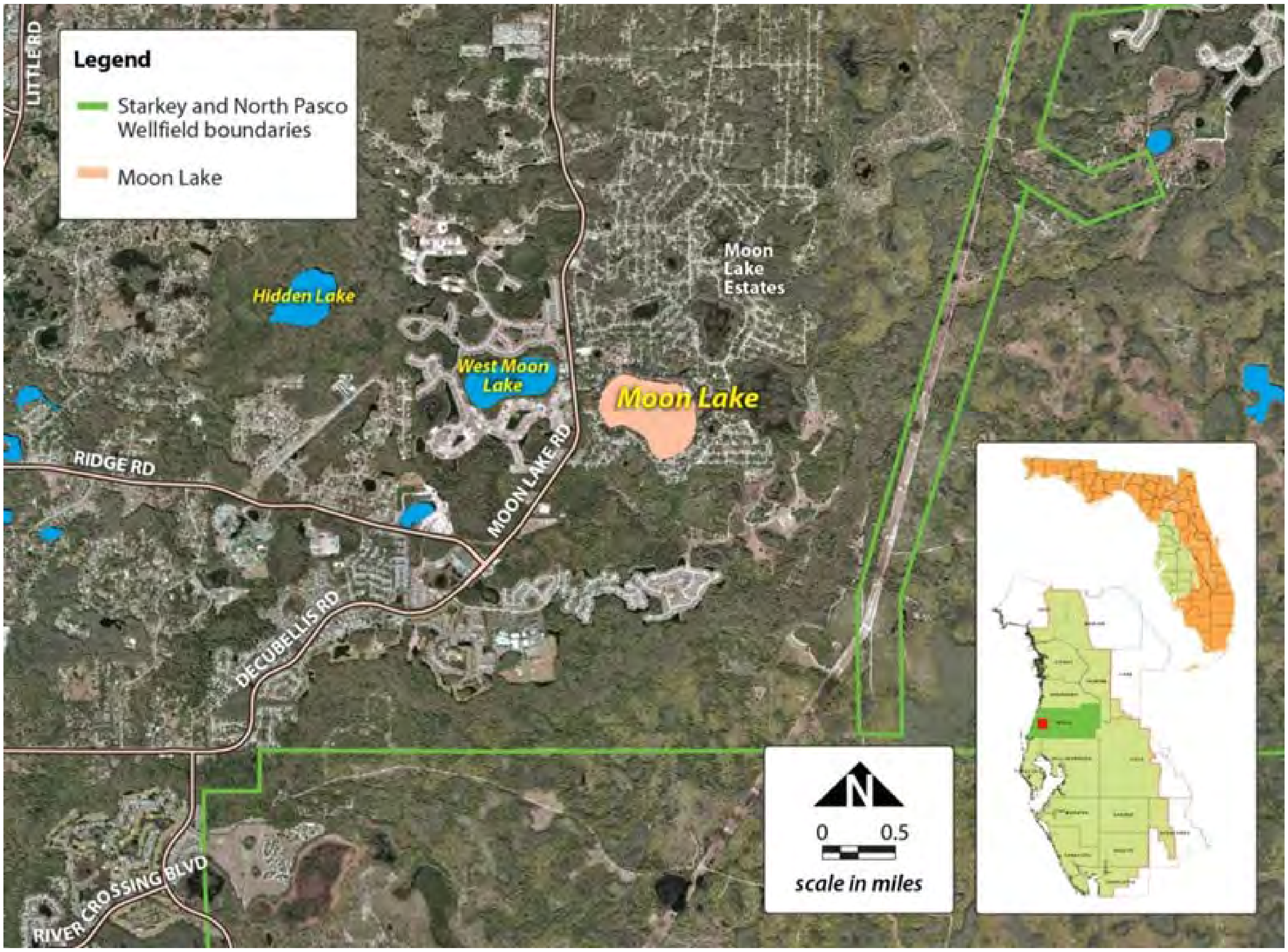


Figure 5. Location of Moon Lake and the Starkey and North Pasco Wellfield.

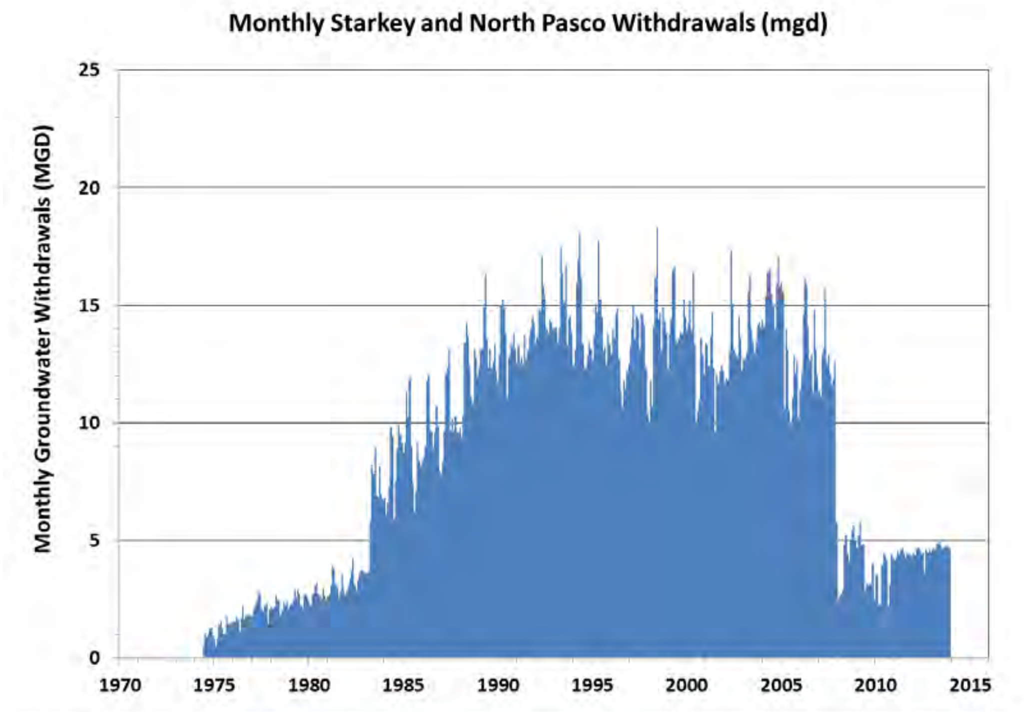


Figure 2. Section 21 Wellfield withdrawals in million gallons per day (MGD).

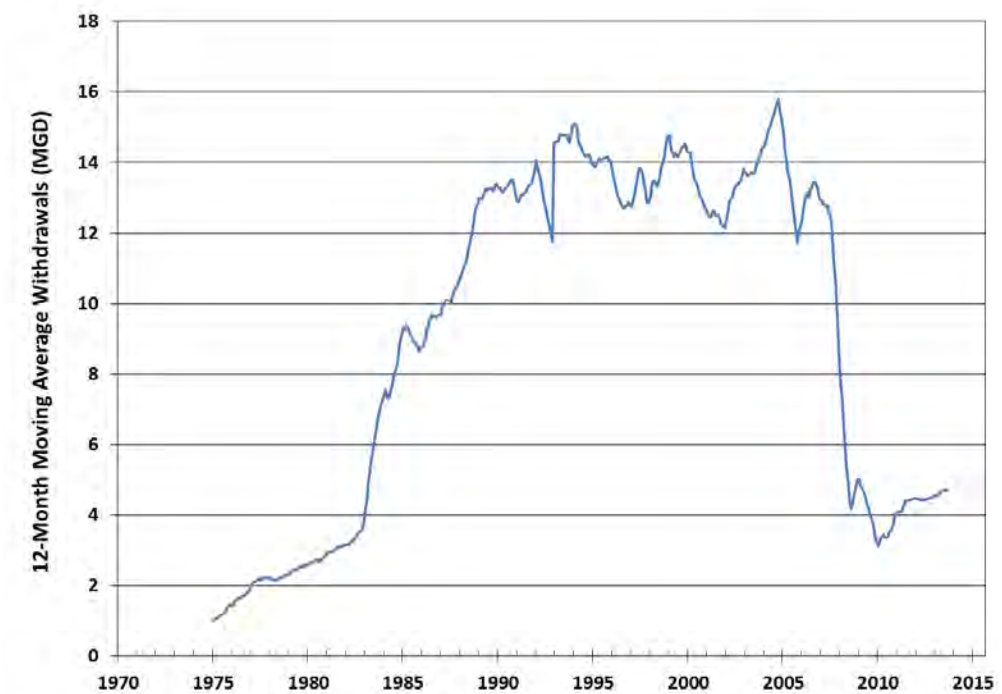


Figure 3. 12-month moving average of Starkey and North Pasco Wellfield withdrawals in million gallons per day (MGD).

N. Revised Minimum Levels for Moon Lake

Revised minimum levels for Moon Lake are presented in Table 3 and discussed in more detail by Kolasa (2015). Minimum levels represent long-term conditions that, if achieved, are expected to protect water resources and the ecology of the area from significant harm that may result from water withdrawals. The Minimum Lake Level is the elevation that a lake's water levels are required to equal or exceed fifty percent of the time on a long-term basis. The High Minimum Lake Level is the elevation that a lake's water levels are required to equal or exceed ten percent of the time on a long-term basis. The Minimum Lake Level therefore represents the required 50th percentile (P50) of long-term water levels, while the High Minimum Lake Level represents the required 10th percentile (P10) of long-term water levels. To determine the status of minimum levels for Moon Lake or minimum flows and levels for any other water body, long-term hydrologic data or model results must be used.

Table 1. Revised Minimum Levels for Moon Lake.

Revised Minimum Levels	**Elevation in Feet** NGVD 29
High Minimum Lake Level	39.6
Minimum Lake Level	38.2

O. Status Assessment

Three models were used in this assessment, including the Integrated Northern Tampa Bay (INTB) model (Geurink and Basso, 2013), the Moon Lake Water Budget model (Patterson and Hancock, 2014), and the Moon Lake Line of Organic Correlation (LOC) model (Patterson and Ellison, 2014). Using these models, three approaches were used to assess the status of Moon Lake (described below).

Use of the Integrated Northern Tampa Bay (INTB) model

The Integrated Northern Tampa Bay (INTB) model was used in the development of the minimum levels (Patterson and Hancock, 2014) and in this MFL status assessment to estimate drawdowns in the surficial and Upper Floridan aquifers in response to various rates of groundwater withdrawals. All INTB model simulations were performed for an 11-year period corresponding to conditions from 1996 through 2006 using a daily integration step. Average pre-cutback wellfield withdrawals for an initial simulation were represented by the actual 1997 distribution and quantity of withdrawals for the eleven Central System Facility wellfields, which represented pre-cutback withdrawal rates. Post-cutback wellfield withdrawals for a second simulation were represented by the actual 2008 distribution and quantities of withdrawals for the eleven Central System Facility wellfields. The 2008 distribution and quantities were considered representative of forecasted long-term average withdrawal conditions for the post-cutback period. These withdrawal distributions and quantities were repeated for each year of the 11-year simulations. All other area withdrawals not associated with the Central System Facilities were included in the simulations, based on their actual quantities and distributions from 1996 through 2006 Results for the two simulations were compared to an 11-year INTB model run with no withdrawals to estimate drawdown. The pre- and post-cutback withdrawal rates used for the Section 21 Wellfield for the two simulations are presented in Table 2. The modeled drawdowns in the surficial aquifer and Upper Floridan aquifer systems in the vicinity of Moon Lake for the two simulations are presented in Table 3.

Table 2. Withdrawal rates used for pre- and post-cutback withdrawal INTB simulations.

Wellfield	Pre-cutback Withdrawal Rate (MGD)	Post-cutback Withdrawal Rate (MGD)
North Pasco	1.3	0.3
Starkey	12.3	4.1

MGD = million gallons per day

Table 3. Resulting drawdown at Moon Lake from pre- and post-cutback withdrawal INTB simulations.

Well	Pre-Cutback Drawdown (feet) 1974 to 1983	Pre-Cutback Drawdown (feet) 1984 to 2008	Post-Cutback Drawdown (feet) 2008 to 2012
Floridan aquifer	0.12	0.85	0.25
Surficial aquifer	0.1	0.6	0.2

Use of the Moon Lake Water Budget and Line of Organic Correlation (LOC) Models

The Moon Lake Water Budget and LOC models were created as part of the development of the revised minimum levels for Moon Lake. The Moon Lake Water Budget model (Patterson and Hancock, 2014) is a spreadsheet-based tool that includes natural hydrologic processes and engineered alterations acting on the control volume of the lake. 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 Moon Lake was calibrated from November 1966 through 2011. This period provided the best balance between using available data for all parts of the water budget and the desire to model a long-term period. The calibrated model can be used to assess the effect of changes in the various water budget components on lake water levels. Assistance

The Moon Lake LOC model (Patterson and Hancock, 2014) was developed to extend the period of record of the water levels produced by various simulations of the water budget model. The LOC model is a linear fitting procedure that minimizes errors in both the x and y directions and defines the best-fit straight line as the line that minimizes the sum of the areas of right triangles formed by horizontal and vertical lines extending from observations to the fitted line (Helsel and Hirsch, 1997). An LOC model is a preferred method for developing long-term water level records, since it results in predictions that retain the variance (and therefore best retains the "character") of the original data. Through this process, rainfall is correlated with the water budget model results, and long-term lake levels were then estimated using long-term rainfall data. In this application, lake levels are simulated using rainfall data collected in the region back to 1946, allowing assessment of a relatively long period that takes into account lake level variability caused by a variation in rainfall conditions.

Moon Lake Status Assessment

First Approach

The first lake status assessment approach involved three steps, including: 1) adjusting the Upper Floridan and surficial aquifer levels in the Moon Lake Water Budget model to represent expected long-term post-cutback average wellfield withdrawal rates, 2) use of the LOC model to estimate lake levels associated with the withdrawal rates over a long period of time, and 3) development of a composite or “hybrid” long-term water level (i.e., stage) record based on output from the water budget and LOC models.

For the first step in the analysis, the water budget model was run for the January 1, 1966 to 2011 period based on drawdown in the Upper Floridan aquifer associated with the post-cutback wellfield withdrawal rates estimated with the INTB model. These interim results are provided in Table 4. Next, these results were correlated with rainfall through the LOC model to develop a 69-year stage record (1946 through 2014) to represent lake levels subjected to the post-cutback withdrawal rates. The correlation lag-period with the best correlation coefficient was 4 years. The correlation coefficient for the 4-year lag was 0.82. Finally, to apply significant weight to the period of the water budget model results, the LOC lake stage values for the period of the water budget simulation were replaced with the results of the water budget simulation. The LOC rainfall model results were therefore used for the period from 1946 through January 1, 1966, while the water budget model results were used for the period from January 1, 1966 through 2011. The resulting composite lake stage series is referred to as the Moon Lake "hybrid" results. Lake stage exceedance percentiles calculated from these results are provided in Table 5. The results of this analysis are compared to the revised Minimum Levels for Moon Lake in Table 6.

Table 4. Lake stage exceedance percentiles for Moon Lake derived using the Moon Lake Water Budget Model. Percentiles include lake stage values equaled or exceeded ten (P10), fifty (P50) and ninety (P90) percent of the time.

Percentile	**Water Budget Model Post-Cutback Wellfield Withdrawal Scenario Results** Elevation in feet NGVD 29
P10	39.6
P50	38.0
P90	35.9

Table 5. Lake stage exceedance percentiles for Moon Lake based on the Moon Lake hybrid results.

Percentile	**Water Budget/LOC Model Hybrid Post-Cutback Wellfield Withdrawal Scenario Results** Elevation in feet NGVD 29
P10	40.0
P50	38.3
P90	36.2

Differences in exceedance percentiles presented in Tables 4 and 5 are likely attributable to differences in rainfall between the 1946-2014 period used to derive the Moon Lake hybrid model results and the November 1, 1966-2011 period used to develop the Moon Lake Water Budget model results.

Table 6. Comparison of hybrid lake stage exceedance percentiles from the models and the revised minimum levels for Moon Lake. Percentiles as described in Table 4.

Percentile	**Water Budget/LOC Model Hybrid Post-Cutback Wellfield Withdrawal Scenario Results** Elevation in feet NGVD 29	**Revised Minimum Levels** Elevation in feet NGVD 29
P10	40.0	39.6
P50	38.3	38.2

Second Approach

The second lake status assessment approach involved using actual lake stage data for Moon Lake from January 2008 through December 2013 (representing the period of wellfields near Moon Lake cutbacks) to develop an LOC model, combining the LOC and lake stage data into a hybrid result, and comparing the hybrid results to the revised minimum levels. This analysis was intended for development of a long-term model (1946-2013) based on measured lake levels. The model was calibrated to the post-cutback period (2008-2013), which integrated effects of withdrawal rates that occurred during this period, rather than pre-cutback withdrawal rates, which were higher.

The best resulting correlation was for the 2-year weighted period, with a correlation coefficient of 0.86. As before, “hybrid” results were created by replacing the rainfall LOC results with the actual Moon Lake data for the period of January 2008 to December 2013. However, because the measured data was recorded on a monthly, rather than a daily basis, the calculated stage exceedance percentiles from the direct LOC results and the “hybrid” results were similar. The resulting stage exceedance percentiles are presented in Table 7.

Table 7. Comparison of lake stage exceedance percentiles derived from the lake stage/LOC hybrid results and the revised minimum levels for Moon Lake.

Percentile	**Lake Stage/LOC Model Hybrid Post-Cutback Wellfield Withdrawal Scenario Results** Elevation in feet NGVD 29	**Revised Minimum Levels** Elevation in feet NGVD 29
P10	40.2	39.6
P50	38.3	38.2

Third Approach

The third approach involved a comparison of lake stage exceedance percentiles based directly on measured lake level data for Moon Lake for the period from January 2008 through December 2013 with the revised minimum levels. No models were used for this approach. A limitation of this analysis is that the resulting lake stage exceedance percentiles are representative of rainfall conditions during only the past 6 years, rather than the longer-term rainfall conditions represented in the 1946 to 2014 LOC model simulations. Results for the third approach are presented in Table 8.

Table 8. Comparison of lake stage exceedance percentiles derived from measured water level records at Moon Lake from January 2008 through December 2013 and the revised minimum levels for the lake.

Percentile	**January 2008 to December 2013 Data** Elevation in feet NGVD 29	**Revised Minimum Levels** Elevation in feet NGVD 29
P10	39.8	39.6
P50	37.6	38.2

Discussion

Table 9 is a summary of the results of all three approaches.

Table 9. Comparison of lake stage exceedance percentiles derived from each approach compared to the revised minimum levels for the lake.

Percentile	**Approach 1[a]** Elevation in feet NGVD 29	**Approach 2[b]** Elevation in feet NGVD 29	**Approach 3[c]** Elevation in feet NGVD 29	**Revised Minimum Levels** Elevation in feet NGVD 29
P10	40.0	40.2	39.8	39.6
P50	38.3	38.3	37.6	38.2

[a] Water budget/LOC hybrid model post-cutback wellfield withdrawal scenario results
[b] Lake stage/LOC hybrid model results based on post-cutback data
[c] Measured lake stage results based on post-cutback data

A comparison of the water budget/LOC hybrid results (Approach 1) with the revised minimum levels for Moon Lake indicates that the hybrid long-term P10 is 0.4 feet higher than the revised High Minimum Lake Level and the hybrid long-term P50 is 0.1 feet higher than the revised Minimum Lake Level.

The P10 for the second MFL status assessment approach is 0.6 feet higher than the revised High Minimum Level and the P50 is 0.1 feet above the revised Minimum Lake Level. The P50 for approach 1 and 2 are the same and the P10 for Approach 2 is higher than Approach 1.

The P10 elevation derived from the third approach was 0.2 feet higher than the revised High Minimum Lake Level and the P50 elevation was 0.7 feet lower than the revised Minimum Lake Level. Differences in rainfall between the shorter January 2008 to December 2013 period and the longer (1946 to 2013) period used for the LOC modeling analyses likely contribute to the differences in derived lake stage exceedance percentiles as compared to the first two approaches. Additionally, differences between actual withdrawal rates and those used in the models for the first two options likely contributed to the differences.

P. Conclusions

Based on the information presented in this memorandum, it is concluded that Moon Lake water levels are currently above the revised Minimum Lake Level and revised High Minimum Lake Level for the lake. These conclusions are supported by comparison of long-term modeled lake stage exceedance percentiles with the revised minimum levels. The modeling analyses were based on expected post-cutback withdrawal rates from the Central System Facilities. Other analyses presented show that if more recent low withdrawal rates continue, the revised Minimum Level for the lake will continue to be met.

Minimum flow and level status assessments are completed on an annual basis by the District and on a five-year basis as part of the regional water supply planning process. In addition, Moon Lake is included in the Comprehensive Environmental Resources Recovery Plan for the Northern Tampa Bay Water Use Caution Area (40D-80.073, F.A.C). Therefore, the analyses outlined in this document for Moon Lake will be reassessed by the District and Tampa Bay Water as part of this plan, and, as part of Tampa Bay Water's Permit Recovery Assessment Plan (required by Chapter 40D-80, F.A.C. and the Consolidated Permit (No. 20011771.001)).

Q. References

Kolasa, K. 2015. Proposed Minimum and Guidance Levels for Moon Lake in Hillsborough County, Florida. Southwest Florida Water Management District. Brooksville, Florida.

Geurink, J.S. and R. Basso. 2013. Development, Calibration, and Evaluation of the Integrated Northern Tampa Bay Hydrologic Model. Prepared for Tampa Bay Water and Southwest Florida Water Management District. March 2013.

Patterson, J. and M.C. Hancock, 2015. Technical Memorandum to Keith Kolasa, Subject: Moon Lake Water Budget Model, Rainfall Correlation Model, and Historic Percentile Estimations. Southwest Florida Water Management District. Brooksville, Florida

Appendix C

Technical Memorandum

November 20, 2014

TO: Keith Kolasa, Senior Environmental Scientist, Resource Evaluation Section

FROM: Jason Patterson, Hydrogeologist, Resource Evaluation Section

Subject: Evaluation of Groundwater Withdrawal Impacts to Moon Lake

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1.0 Introduction

Moon Lake is located in west-central Pasco County in west-central Florida (Figure 1). Prior to establishment of a Minimum Level (ML), an evaluation of hydrologic changes in the vicinity of the lake is necessary to determine if the water body has been significantly impacted by groundwater withdrawals. The establishment of the ML for Moon Lake is not part of this report. This memorandum describes the hydrogeologic setting near the lake and includes the results of two numerical model scenarios of groundwater withdrawals in the area.

2.0 Hydrogeologic Setting

The hydrogeology of the area includes a surficial sand aquifer system; a discontinuous, intermediate clay confining unit, a thick carbonate Upper Floridan aquifer, a low permeable confining unit and a Lower Floridan aquifer. In general, the surficial aquifer system is in good hydraulic connection with the underlying Upper Floridan aquifer because the clay confining unit is generally thin, discontinuous, and breeched by numerous karst features. The surficial sand aquifer is generally a few tens of feet thick and overlies the limestone of the Upper Floridan aquifer that averages nearly 1,000 feet thick in the area (Miller, 1986). In between these two aquifers is the Hawthorn Group clay that varies between a few feet to as much as 25 feet thick. Because the clay unit is breached by buried karst features and has previously been exposed to erosional processes, preferential pathways locally connect the overlying surficial aquifer to the Upper Floridan aquifer resulting in moderate-to-high leakage to the Upper Floridan aquifer (SWFWMD, 1996). Thus, the Upper Floridan aquifer is defined as a leaky artesian aquifer system.

The base of the Upper Floridan aquifer generally occurs at the first, persistent sequence of evaporitic minerals such as gypsum or anhydrite that occur as nodules or discontinuous thin layers in the carbonate matrix. This low permeability unit is regionally extensive and is generally referred to as middle confining unit II (Miller, 1986).

3.0 Evaluation of Groundwater Withdrawal Impacts to Moon Lake

A number of regional groundwater flow models have included the area around Moon Lake in west-central Pasco County. Ryder (1982) simulated the entire extent of the Southwest Florida Water Management District. In 1993, the District completed the Northern Tampa Bay groundwater flow model that covered a 2,000 square mile area of Hillsborough, Pinellas, Pasco, and Hernando Counties (SWFWMD, 1993). In 2002, the USGS simulated the entire Florida peninsula in their Mega Model of regional groundwater flow (Sepulveda, 2002). The most recent and advanced simulation of southern Pasco County and the surrounding area is the Integrated Northern Tampa Bay (INTB) model (Geurink and Basso, 2012). The construction and calibration of this model was part of a cooperative effort between the SWFWMD and Tampa Bay Water (TBW), a regional water utility that operates 11 major wellfields. The Integrated Northern Tampa Bay Model covers a 4,000 square-mile area of the Northern Tampa Bay region (Figure 2).

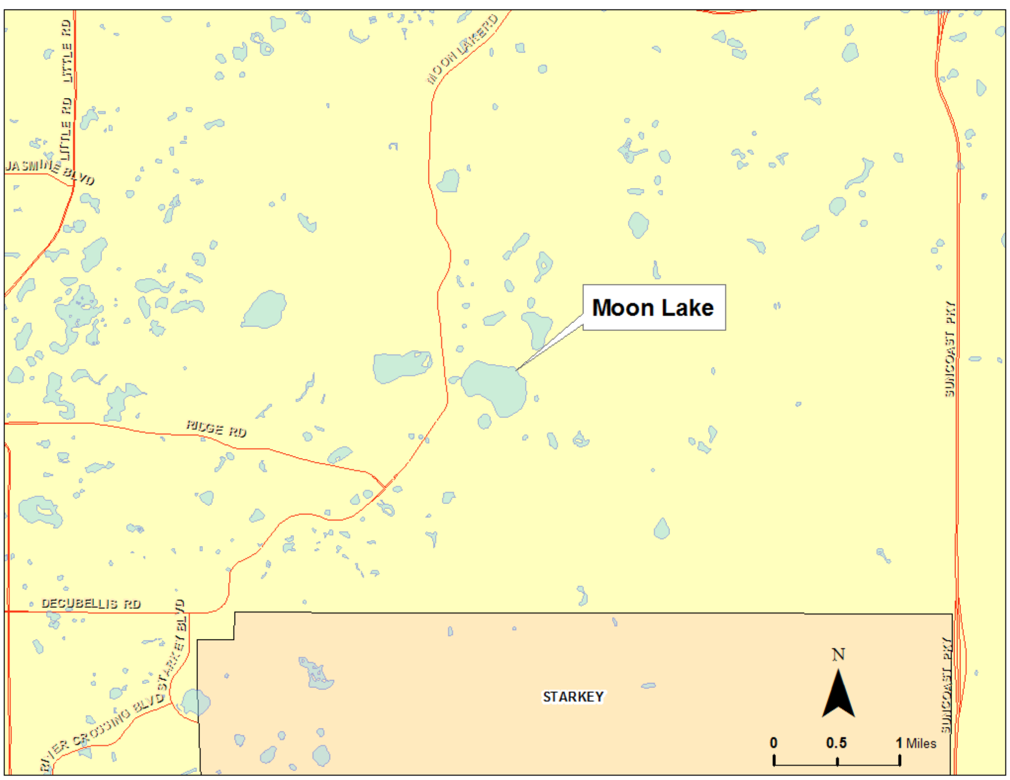

Figure 1. Location of Moon Lake.

An integrated model represents the most advanced simulation tool available to the scientific community in water resources investigations. It combines the traditional ground-water flow model with a surface water model and contains an interprocessor code that links both systems. One of the many advantages of an integrated model is that it simulates the entire hydrologic system. It represents the “state-of-art” tool in assessing changes due to rainfall, drainage alterations, and withdrawals.

The model code used to run the INTB simulation is called the Integrated Hydrologic Model (IHM) which combines the HSPF surface water code and the MODFLOW ground-water code using interprocessor software. During the INTB development phase, several new enhancements were made to move the code toward a more physically-based simulation. The most important of these enhancements was the partitioning of the surface into seven major land use segments: urban, irrigated land, grass/pasture, forested, open water, wetlands, and mining/other. For each land segment, parameters were applied in the HSPF model consistent with the land cover, depth-to-water table, and slope. Recharge and ET potential were then passed to each underlying MODFLOW grid cell based on an area weighted-average of land segment processes above it. Other new software improvements included a new ET algorithm/hierarchy plus allowing the model code to transiently vary specific yield and vadose zone storages.

The INTB model contains 172 subbasin delineations in HSPF (Figure 3). There is also an extensive data input time series of 15-minute rainfall from 300 stations for the period 1989-1998, a well pumping database that is independent of integration time step (1-7 days), a methodology to incorporate irrigation

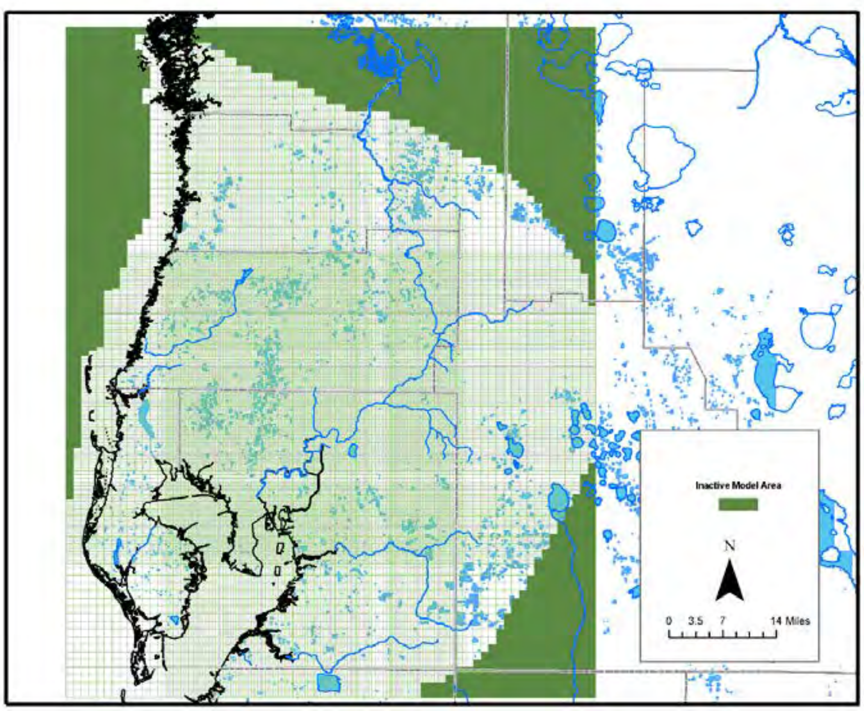

Figure 2. Groundwater grid used in the INTB model.

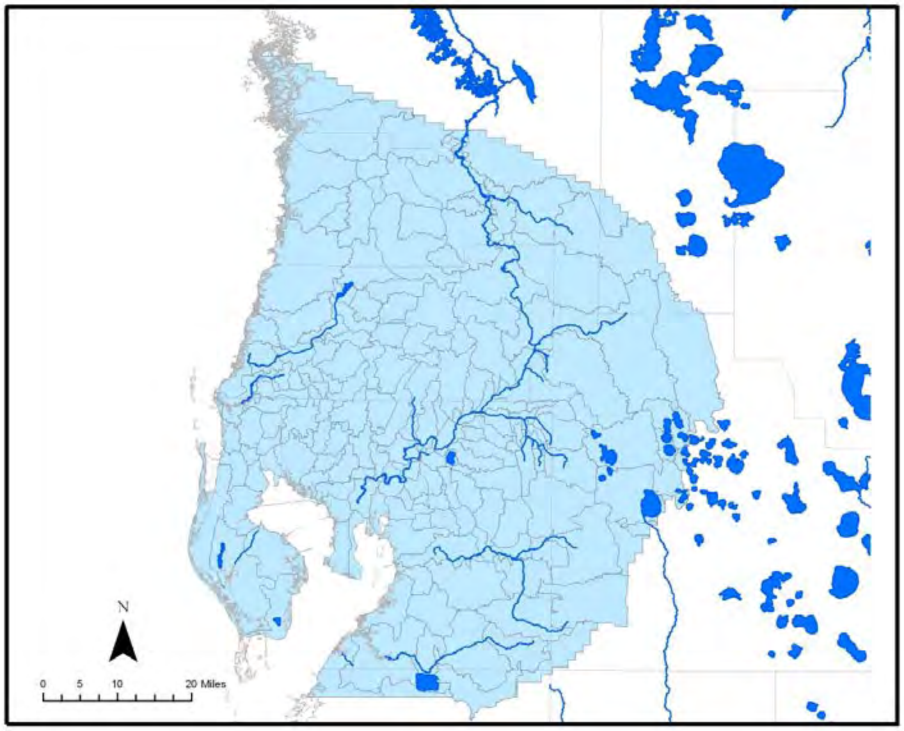

Figure 3. HSPF subbasins in the INTB model.

flux into the model simulation, construction of an approximate 150,000 river cell package that allows simulation of hydrography from major rivers to small isolated wetlands, and GIS-based definition of land cover/topography. An empirical estimation of ET was also developed to constrain model derived ET based on land use and depth-to-water table relationships.

The MODFLOW gridded domain of the INTB contains 207 rows by 183 columns of variable spacing ranging from 0.25 to one mile. The groundwater portion is comprised of three layers: a surficial aquifer (layer 1), an intermediate confining unit or aquifer (layer 2), and the Upper Floridan aquifer (layer 3). The model simulates leakage between layers in a quasi-3D manner through a leakance coefficient term.

The INTB model is a regional simulation and has been calibrated to meet global metrics. The model is calibrated using a daily integration step for a transient 10-year period from 1989-1998. A model Verification period from 1999 through 2006 has recently been added. Model-wide mean error for all wells in both the surficial and Upper Floridan aquifers is less than 0.2 feet during both the calibration and verification periods. Mean absolute error was less than two feet for both the surficial and Upper Floridan aquifer. Total stream flow and spring flow mean error averaged for the model domain is each less than 10 percent. More information summarizing the INTB model calibration can be found in Geurink and Basso (2012).

3.1 INTB Model Scenarios

Three different groundwater withdrawal scenarios were run with the INTB model. The first scenario consisted of simulating all groundwater withdrawn within the model domain from 1989 through 2000. The second scenario consisted of eliminating all pumping in the Central West-Central Florida Groundwater Basin (Figure 4). Total withdrawals within the Central West-Central Florida Groundwater Basin averaged 239.4 mgd during the 1989-2000 period. TBW central wellfield system withdrawals were simulated at their actual withdrawal rates during this period. The third scenario consisted of reducing TBW central wellfield system withdrawals to their mandated recovery quantity of 90 mgd from the 11 central system wellfields. For TBW only, the 2008 pumping distribution was adjusted slightly upward from 86.9 mgd to 90 mgd to match recovery quantities.

Taking the difference in simulated heads from the 1989-2000 pumping to non-pumping runs, the average predicted drawdown in the surficial aquifer near Moon Lake was 0.3 ft and 0.5 ft in the Upper Floridan aquifer (Figure 5 and 6). Taking the difference in modeled heads from the TBW recovery pumping to non-pumping runs, the average predicted drawdown in the surficial aquifer near Moon Lake was 0.2 ft and 0.5 in the Upper Floridan aquifer (Figure 7 and 8). Table 1 presents the predicted drawdown in the surficial aquifer based on the INTB model results.

Table 1. INTB model results for Moon Lake.

Lake Name	**Predicted Drawdown (ft) in the Surficial Aquifer due to 1989-2000 Withdrawals***	**Predicted Drawdown (ft) in the Surficial Aquifer with TBW Withdrawals reduced to 90 mgd***
Moon	0.3	0.2
Lake Name	**Predicted Drawdown (ft) in the Upper Floridan Aquifer due to 1989-2000 Withdrawals***	**Predicted Drawdown (ft) in the Upper Floridan Aquifer with TBW Withdrawals reduced to 90 mgd***
Moon	0.5	0.3

* Average drawdown from model cells intersecting lake

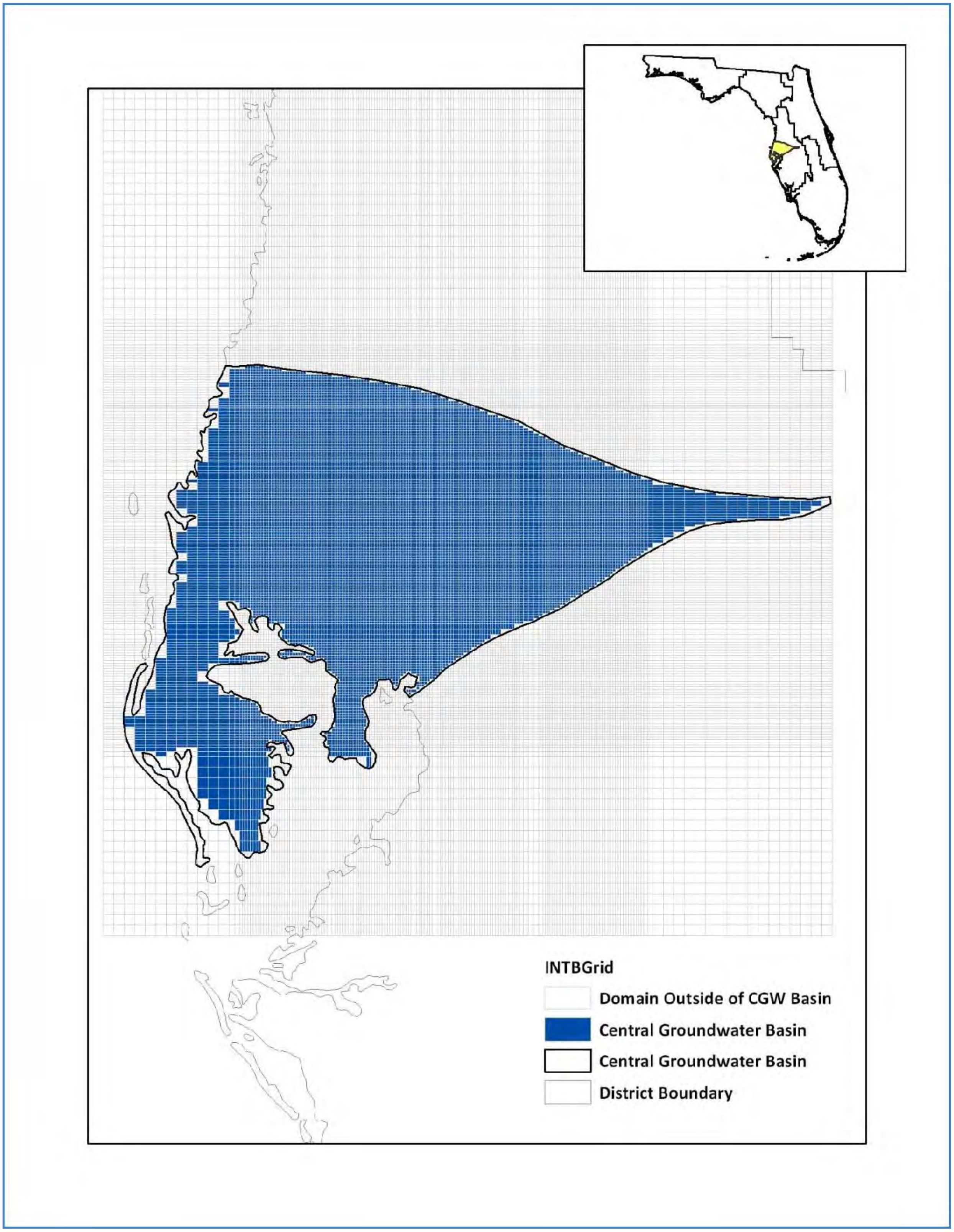

Figure 4. INTB scenarios where impacts to the hydrologic system were simulated due to groundwater withdrawals in the Central West-Central Florida Groundwater Basin.

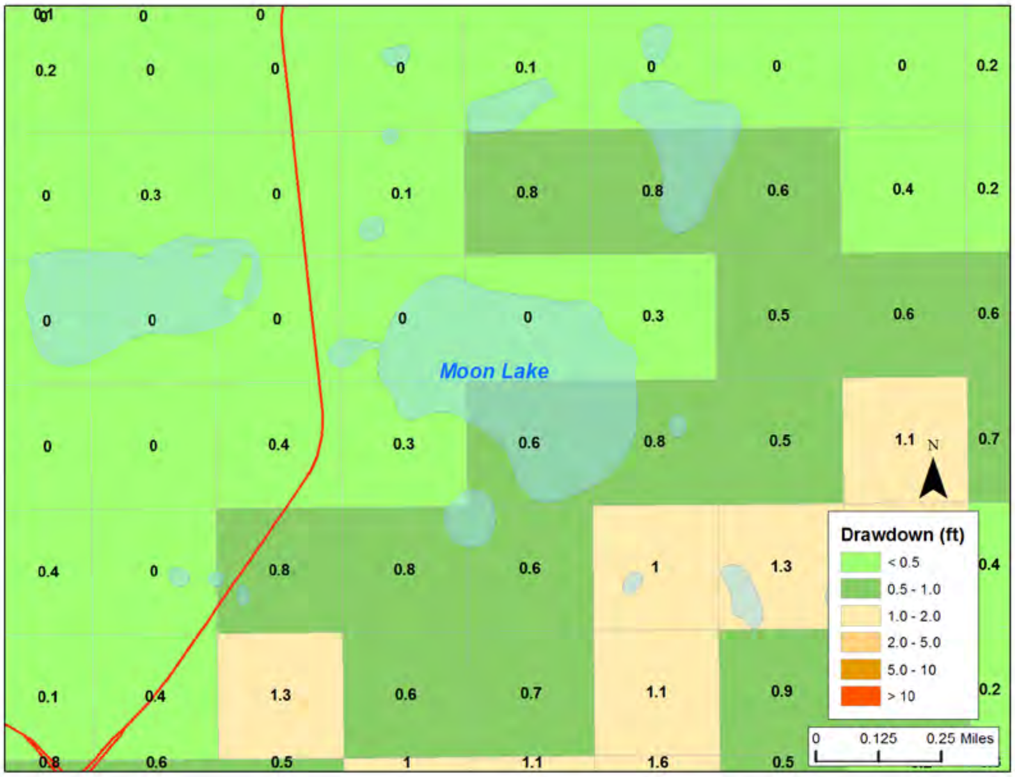

Figure 5. Predicted mean drawdown in the surficial aquifer due to 1989-2000 groundwater withdrawals.

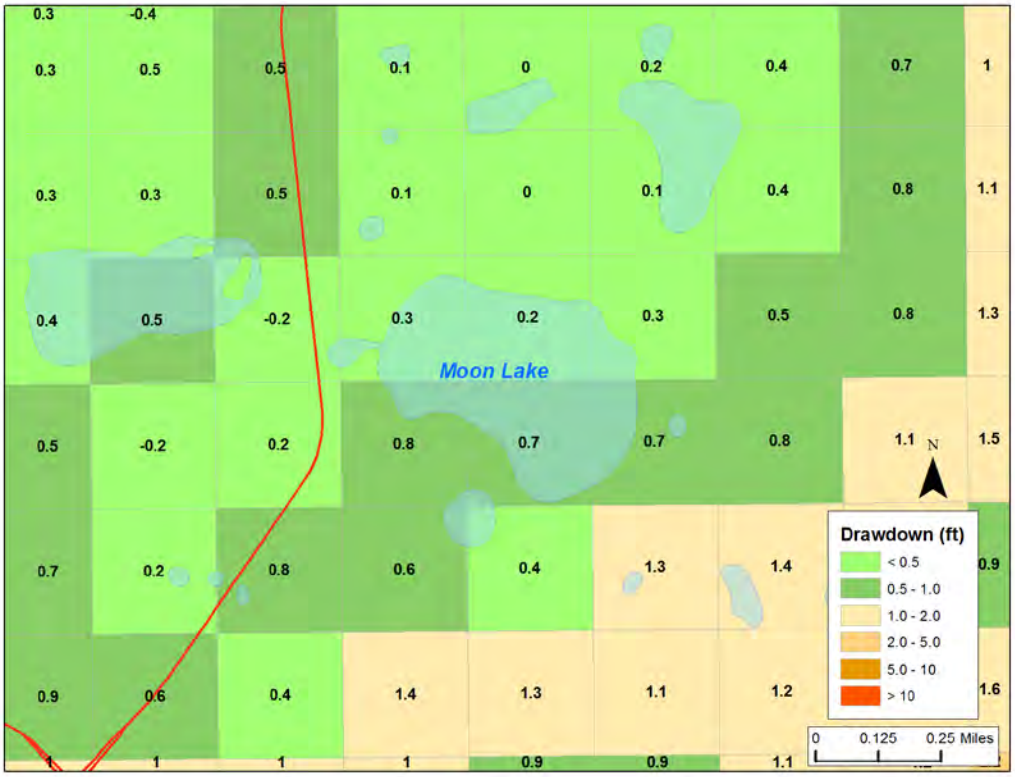

Figure 6. Predicted mean drawdown in the Upper Floridan aquifer due to 1989-2000 groundwater withdrawals.

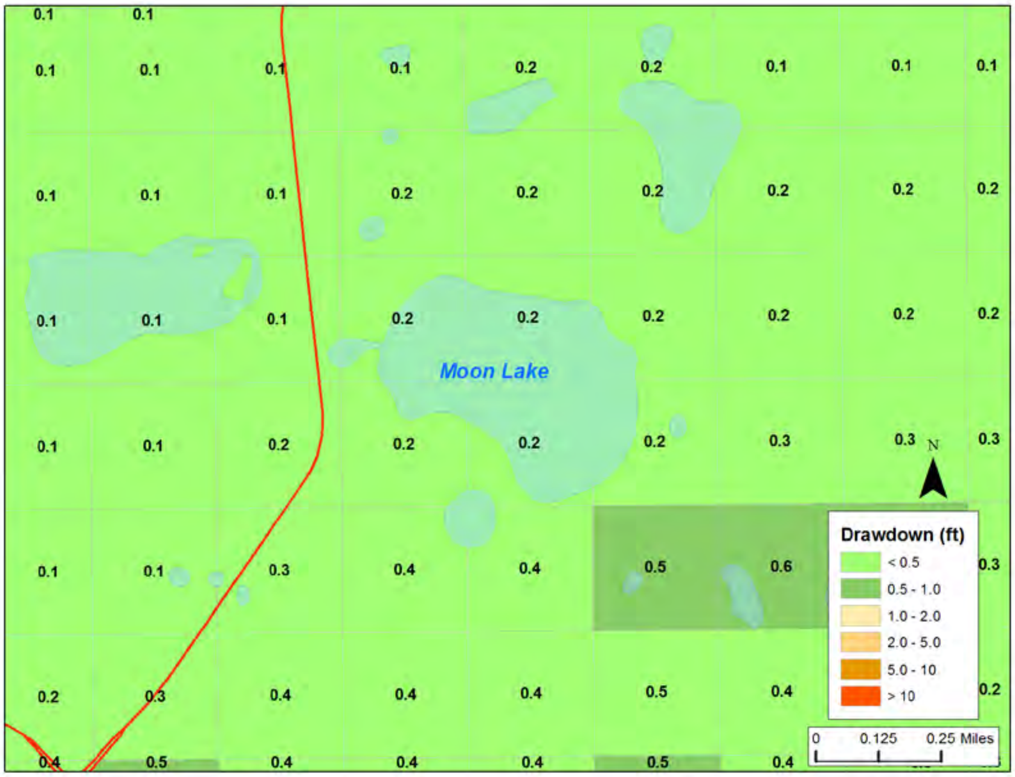

Figure 7. Predicted mean drawdown in the surficial aquifer due to TBW 90 mgd groundwater withdrawals.

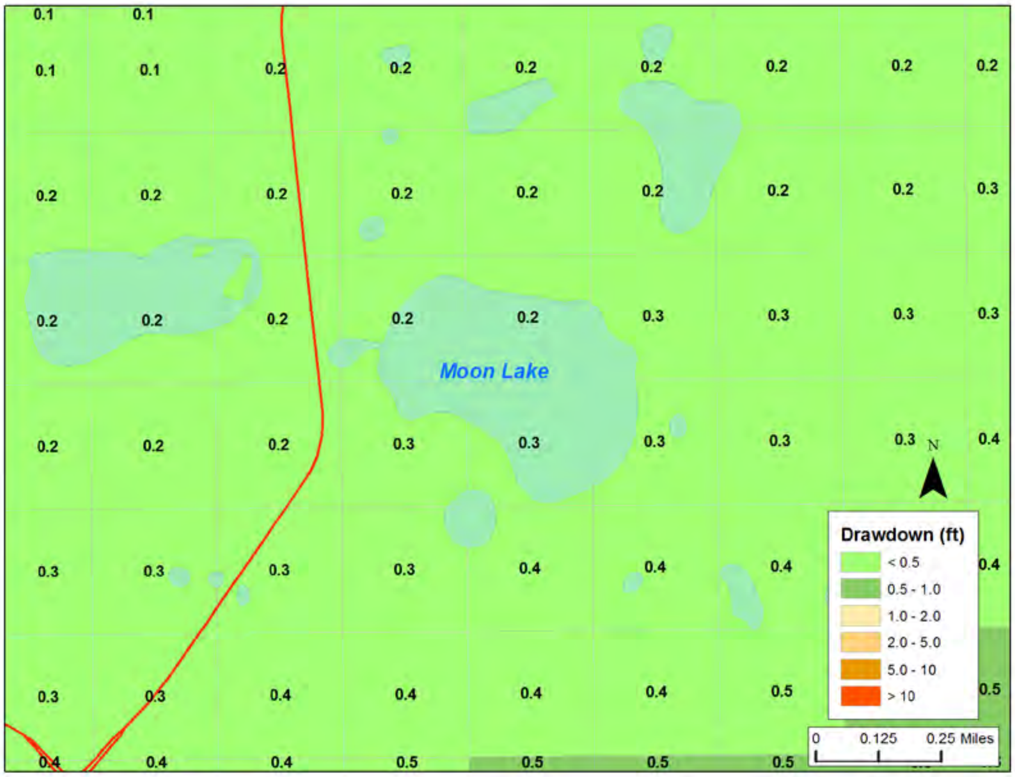

Figure 7. Predicted mean drawdown in the surficial aquifer due to TBW 90 mgd groundwater withdrawals.

References

Geurink, J., and Basso, R., 2012. Development, Calibration, and Evaluation of the Integrated Northern Tampa Bay Model: An Application of the Integrated Hydrologic Model Simulation Engine, Tampa Bay Water and the Southwest Florida Water Management District.

Miller, J.A. 1986. Hydrogeologic framework of the Floridan aquifer system in Florida and in parts of Georgia, Alabama, and South Caroline: U.S. Geological Survey Water-Resources Investigations Report 84-4135, 69 p.

Ryder, P., 1982. Digital Model of Predevelopment Flow in the Tertiary limestone (Floridan) Aquifer System in West-Central Florida, U.S. Geological Survey Water-Resources Investigations Report 81-54.

Sepulveda, N. 2002. Simulation of Ground-Water Flow in the Intermediate and Floridan Aquifer Systems in Peninsular Florida, U.S. Geological Survey WRI Report 02-4009, 130 p.

Southwest Florida Water Management District, 1993, Computer Model of Ground-water Flow in the Northern Tampa Bay Area, 119 p.