Minimum and Guidance Levels For Crystal Lake in Hillsborough County, Florida

August 28, 2015

Resource Evaluation Section
Water Resources Bureau
Southwest Florida
Water Management District

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Cover Page: Aerial District file photograph of Crystal Lake in 1979.

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Executive Summary

This report describes the development of Minimum and Guidance levels for Crystal Lake, a.k.a., South Crystal Lake, in Hillsborough 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. Crystal Lake was selected for reevaluation based on development of modeling tools for simulating lake level fluctuations that were not available when levels currently adopted for the lake were developed. The 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 Crystal Lake were developed using current District methods for establishing minimum levels for Category 2 Lakes, which are lakes that are not contiguous with at least 0.5 acres of cypress-dominated wetlands. The Minimum Levels were developed with consideration of and are protective of all relevant environmental values identified for consideration in the Water Resource Implementation Rule when establishing minimum flows and levels (see Rule 62-40.473, F.A.C.). The levels are expressed as elevations in feet above the National Geodetic Vertical Datum of 1929 (NGVD29) that must be equaled or exceeded specified percentages of time on a long-term basis. Table ES-1 identifies these elevations and includes generic descriptions for the levels in District rules (Rule 40D-8.624, F.A.C). Differences between the current 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 Crystal Lake was recommended and approved by the District Governing Board on April 28, 2015. The Minimum and Guidance Levels identified in this report replaces the previously adopted levels for the lake included in District rules.

Based on available measured and modeled water level records, the minimum levels for Crystal Lke are not currently being met. 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. Modeling analyses suggest that if recent, lowered groundwater withdrawal rates from the Tampa Bay Water Central System Facilities that impact the lake's water levels continue, the Minimum Level may be met. Tampa Bay Water, in cooperation with the District, will assess the specific needs for recovery in Crystal Lake and other water bodies affected by groundwater withdrawals from the Central System Facilities and by 2020, if not sooner, an alternative recovery project will be proposed if Crystal Lake is found to not be meeting its adopted minimum levels.

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

Minimum and Guidance Levels	Elevation (feet above NGVD29[a])	Level Descriptions
High Guidance Level	60.4	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	60.4	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	59.0	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	56.9	Advisory guideline for water dependent structures, information for lakeshore residents and operation of water management structures. The Low Guidance Level is the elevation that a lake's water levels are expected to equal or exceed ninety percent of the time on a long-term basis.

[a] National Geodetic Vertical Datum of 1929

[b] North American Vertical Datum of 1988

Introduction

Reevaluation of Minimum and Guidance Levels

This report describes the development of minimum and guidance levels for Crystal Lake, a.k.a., South Crystal Lake in Hillsborough County, Florida. The 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 October 1998 (see Southwest Florida Water Management District 1999) and adopted into District rules with an effective date of August 7, 2000. The minimum and guidance levels represent needed revisions to the previously adopted levels.

Crystal Lake was selected for reevaluation based on development of modeling tools for simulating lake level fluctuations that were not available when the currently adopted levels were developed. The 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 “[t]he minimum flow for a given watercourse shall be the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area." Section 373.042(1)(b), F.S., defines the minimum water level of an aquifer or surface water body as "…the level of groundwater in an aquifer and the level of surface water at which further withdrawals would be significantly harmful to the water resources of the area." Minimum flows and levels are established and used by the Southwest Florida Water Management District (SWFWMD or District) for water resource planning, as one of the criteria used for evaluating water use permit applications, and for the design, construction and use of surface water management systems.

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

Minimum flows and levels are to be established based upon the best information available, and when appropriate, may be calculated to reflect seasonal variations (Section 373.042(1), F.S.). Also, establishment of MFLs is to involve consideration of, and at the governing board or department’s discretion, may provide for the protection of nonconsumptive uses (Section 373.042(1), F.S.). Consideration must also be given to "…changes and structural alterations to watersheds, surface waters and aquifers, and the effects such changes or alterations have had, and the constraints such changes or alterations have placed, on the hydrology of the affected watershed, surface water, or aquifer…", with the requirement that these considerations shall not allow significant harm caused by withdrawals (Section 373.0421(1)(a), F.S.). Sections 373.042 and 373.0421 provide additional information regarding the prioritization and scheduling of MFLs, the independent scientific review of scientific or technical data, methodologies, models and scientific and technical assumptions employed in each model used to establish a minimum flow or level, and exclusions that may be considered when 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 "[m]inimum flows and levels should be expressed as multiple flows or levels defining a minimum hydrologic regime, to the extent practical and necessary to establish the limit beyond which further withdrawals would be significantly harmful to the water resources or the ecology of the area as provided in Section 373.042(1), F.S." It further notes that, "…a minimum flow or level need not be expressed as multiple flows or levels if other resource protection tools, such as reservations implemented to protect fish and wildlife or public health and safety, that provide equivalent or greater protection of the hydrologic regime of the water body, are developed and adopted in coordination with the minimum flow or level." The rule also includes provision addressing: protection of MFLs during the construction and operation of water resource projects; the issuance of permits pursuant to Section 373.086 and Parts II and IV of Chapter 373, F.S.; water shortage declarations; development of recovery or prevention strategies, development and updates to a minimum flow and level priority list and schedule, and peer review for MFLs establishment.

Development of Minimum Lake Levels

Programmatic Description and Major Assumptions

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

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

The District's MFLs Program is implemented based on a 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 is/are sensitive to long-term changes in hydrology and can be used for establishing minimum levels. For all lake categories, the most sensitive, appropriate criterion or criteria are used to develop recommend minimum levels. For Category 1 or 2 Lakes, a significant change standard, referred to as the Cypress Standard, is developed. For Category 3 Lakes, six significant change standards, 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 minimum levels for Crystal Lake are provided in subsequent sections of this report.

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.

Table 1. Environmental values identified in the state Water Resource Implementation Rule for consideration when establishing MFLs and 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 Standard 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 Standard 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 Standard Aesthetics Standard Species Richness Standard Herbaceous Wetland Information Submersed Aquatic Macrophyte Information
Filtration and absorption of nutrients and other pollutants	Cypress Standard Wetland Offset Standard Lake Mixing Standard Herbaceous Wetland Information Submersed Aquatic Macrophyte Information
Sediment loads	Lake Mixing Standard Cypress Standard Herbaceous Wetland Information Submersed Aquatic Macrophyte Information
Water quality	Cypress Standard Wetland Offset Standard 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] = Based on appropriate significant change standards and other information and use of minimum levels in District permitting programs

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 Minimum and Guidance Levels for, Crystal Lake

Lake Setting and Description

Crystal Lake is located in Hillsborough County, Florida (Sections 14, Township 27, Range 18) (latitude 28 08 01 longitude 82 28 34) within the Tampa Bay Planning Region of the Southwest Florida Water Management District (Figure 1). The lake is also known as South Crystal Lake, the name used to identify the water body on the 1974 (photo-revised 1987) United States Geological Survey 1:24,000 Lutz, Fla. quadrangle map. White (1970) classified the physiographic area of west-central Florida containing Crystal Lake as the Northern Gulf Coastal Lowlands region (Figure 2). Crystal Lake was estimated to be 19 acres (USF, 1998). Crystal Lake is located in the Rocky/Brushy Creek watershed and was estimated at 55 square miles (Hillsborough County, 2007). From prior to the 1930s through the 1950s land use/land cover immediately adjacent to Crystal Lake was Cypress Swamp, with citrus groves dominating the landscape beyond the wetlands (Figure 3). The first signs of residential development were in the 1960s. By the 1990s, residential development replaced nearly all of the groves and significantly reduced the Cypress Swamp (especially to the west).

As part of the Florida Department of Environmental Protection's Lake Bioassessment Regionalization Initiative and SWFWMD's water quality sampling program, Crystal Lake is within the Southwestern Florida Flatwoods region and the Land O' Lakes region respectively (Griffith *et al.* 1997 and Romie, 2000). Each of these regions was described as having mostly low total suspended solids, clear water, circumneutral-pH lakes and a moderately low alkalinity and nutrient levels. The soils surrounding the lake are mostly Basinger, Holopaw, and Samsula depressional soils, and Myakka fine sand (Hyde et al. 1977).

Crystal Lake is located in the Rocky/Brushy Creek watershed which has an estimated area of 55 square miles (Hillsborough County 2007). The immediate watershed area from which Crystal Lake receives overland flow is approximately 100 acres (including the lake) (Appendix A). The single inlet to the lake is located along the northern shore of the lake and receives water from Strawberry Lake under Crystal Lake Road (Figure 3). The single outlet from the lake is a dredged canal located along the western side of the lake. Water flows northwestward through this canal back under Crystal Lake Road, and into a large wetlands/lake system.

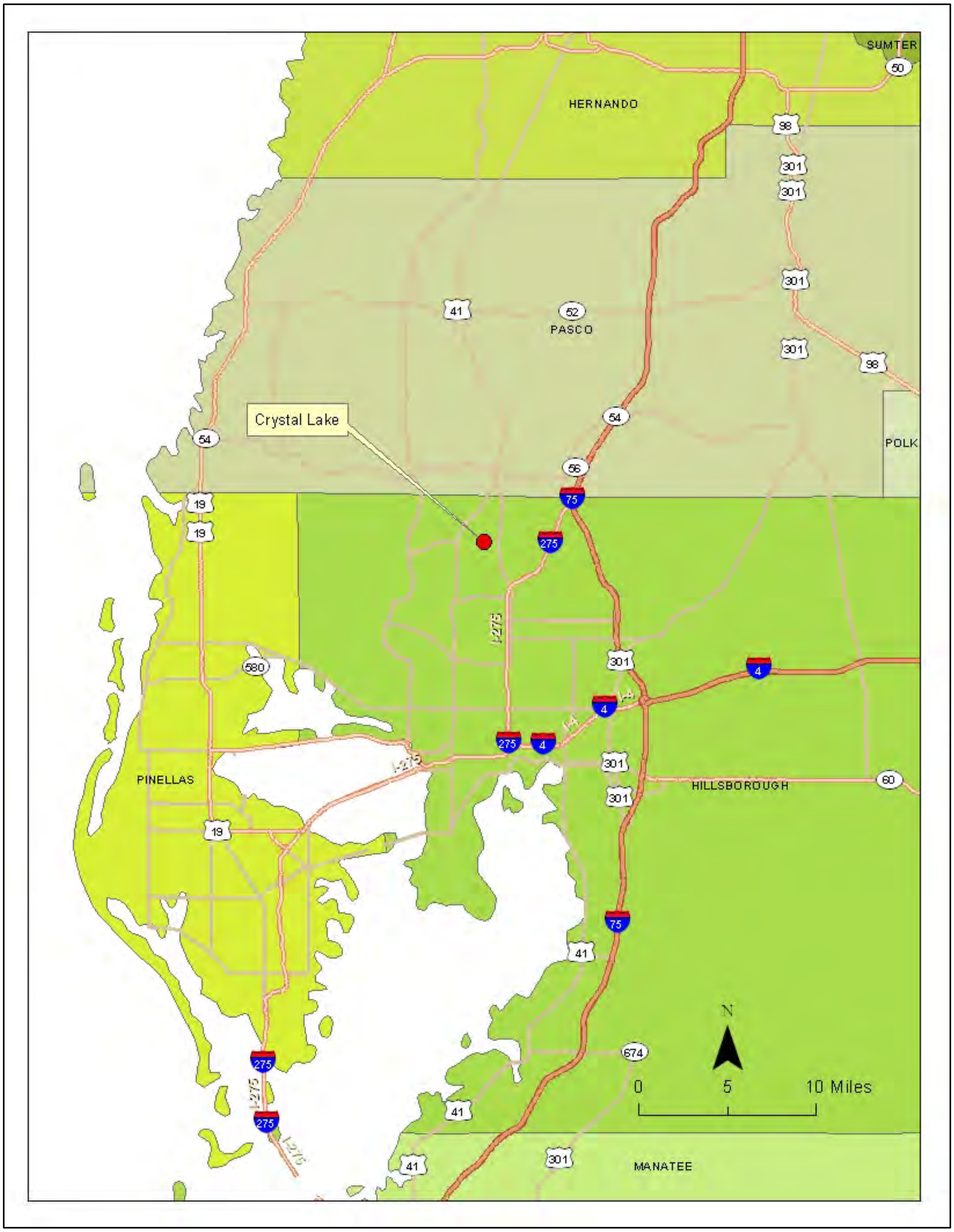

Figure 1. Location of Crystal Lake in Hillsborough County, Florida.

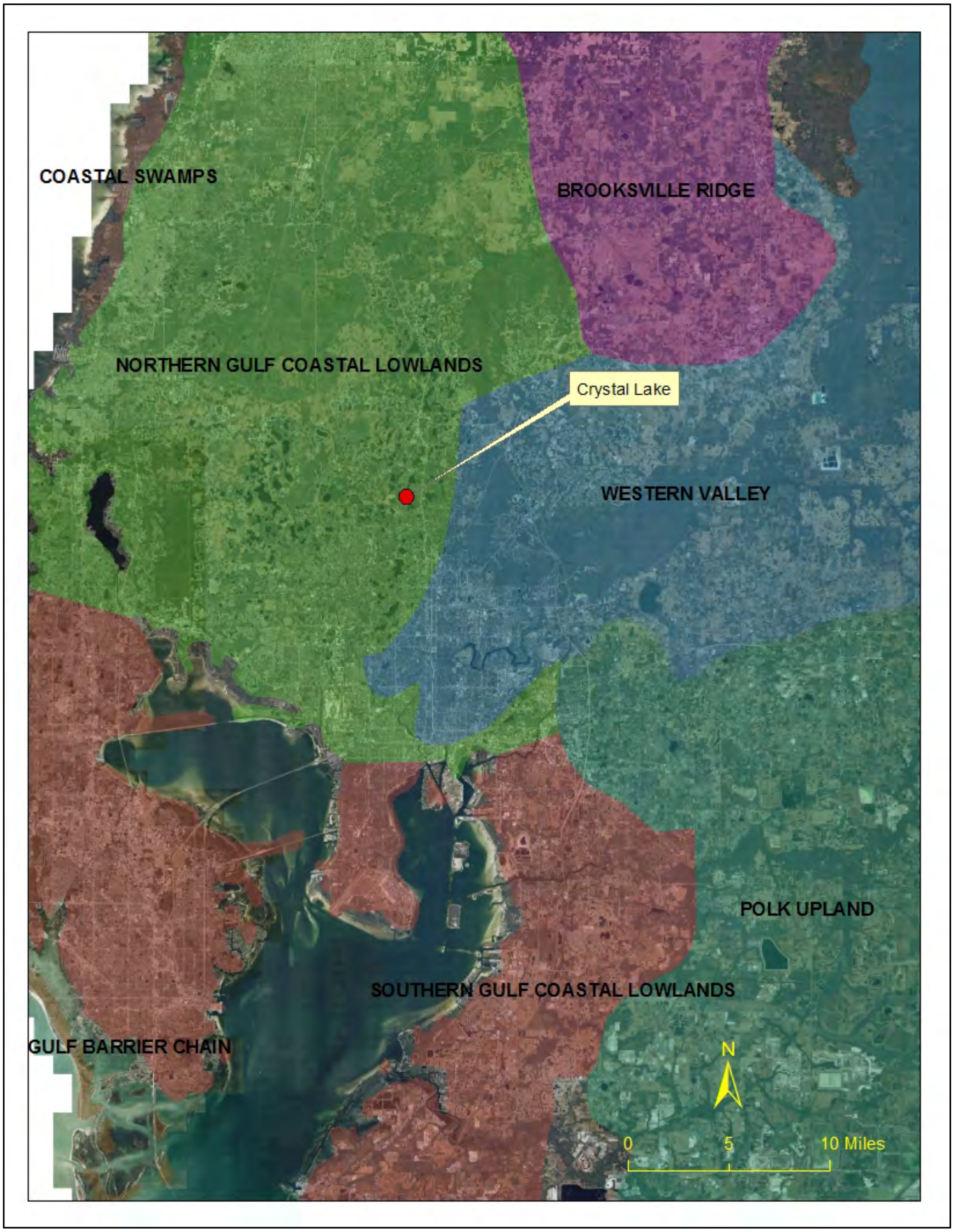

Figure 2. Physiographic regions of the Crystal Lake area.

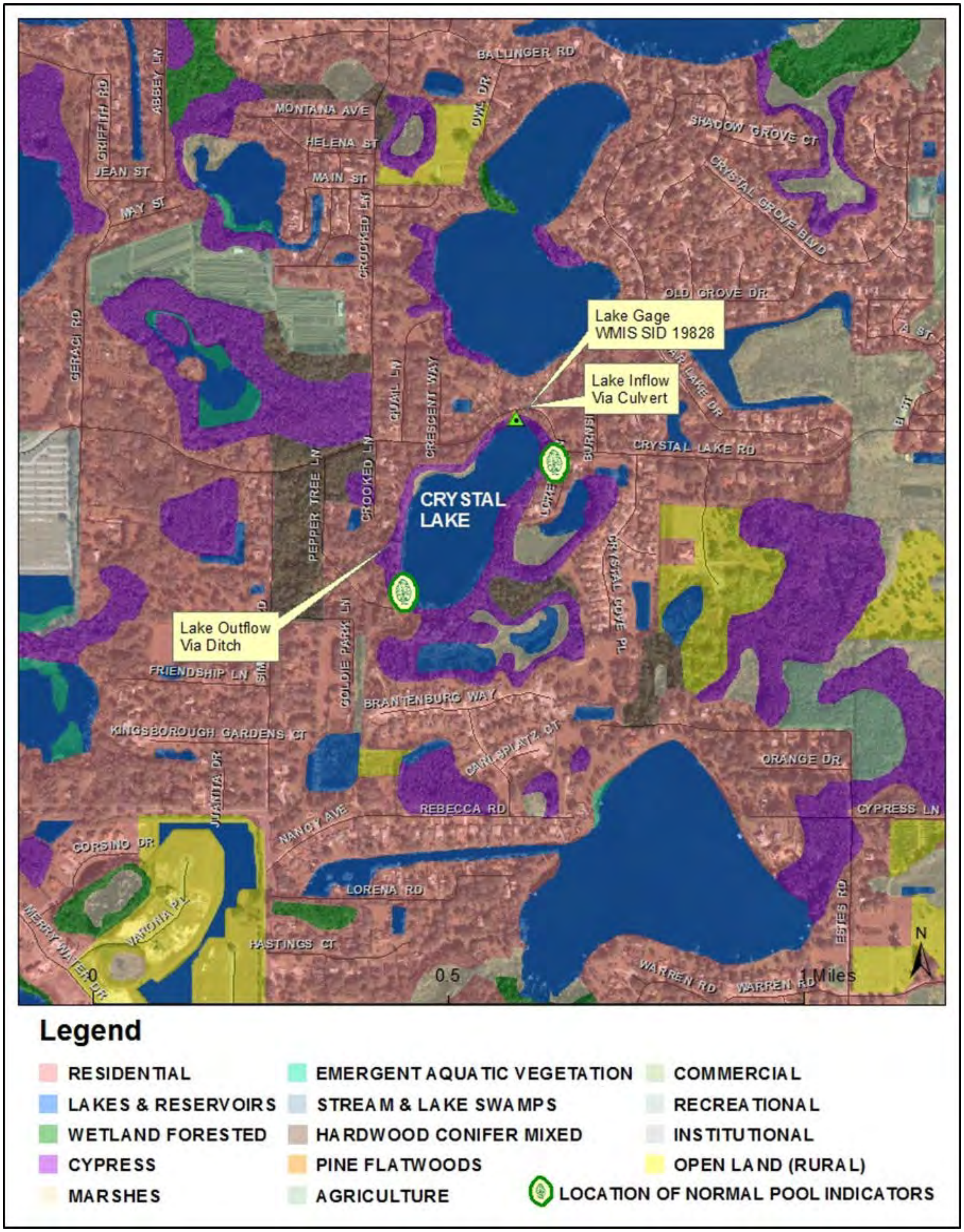

Figure 3. 2011 Florida Land Use and Cover Classification features in proximity to Crystal Lake overlying a January 7, 2011 natural color aerial photograph. Water level gage is located on the northern side of the lake near the lake inflow. The ditch located at the end of Crooked Lane serves as the lake outflow.

In 1973, due to concerns of low lake levels, lakefront homeowners began augmenting the lake with water withdrawn from the Floridan aquifer. In 1977, the District issued a permit to the homeowners for a maximum rate of 432,000 gallons per day (gpd), to a maximum elevation of 59.0 ft. NGVD. The permit was renewed in 1983 at an average annual rate of 114,000 gpd and maximum of 504,000 gpd, and required metering of withdrawals. The most recent renewal was in 1994 (with an extension to 2017 given in 1998), with an average annual rate of 60,000 gpd and maximum of 252,000 gpd. However, no augmentation has been reported since 2003, and it is understood that no augmentation has occurred since that year. Lakes that are augmented with groundwater withdrawn from the Floridan aquifer (including Crystal Lake) typically experience a shift from low to high calcium-bicarbonate (hardness) concentrations and increase in pH (Brenner et al.).

The hydrogeologic setting of the lake basin includes potential withdrawal impacts (Appendix C), and the history of lake augmentation from the aquifer artificially affected surface water levels. Monthly average water withdrawals from 1992 – 2011 within this three mile radius were 8.6 million gallons per day (mgd). Eighty percent of these withdrawals (6.9 mgd) were from the public supply wells at the Section 21 Wellfield (Figure 4).

Currently Adopted Guidance Levels

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

The previously adopted Minimum and Guidance Levels for Crystal Lake were adopted on October 1998 (Table 2). These levels were developed using a methodology that differs from the current approach for establishing Minimum and Guidance Levels. The levels do not, therefore, necessarily correspond with levels developed using current methods. The Minimum and Guidance Levels developed using current methods replaces Guidance Levels adopted by the District Governing Board into Chapter 40D-8, F.A.C. One of the management levels, a Ten Year Flood Guidance Level of 62.1 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.

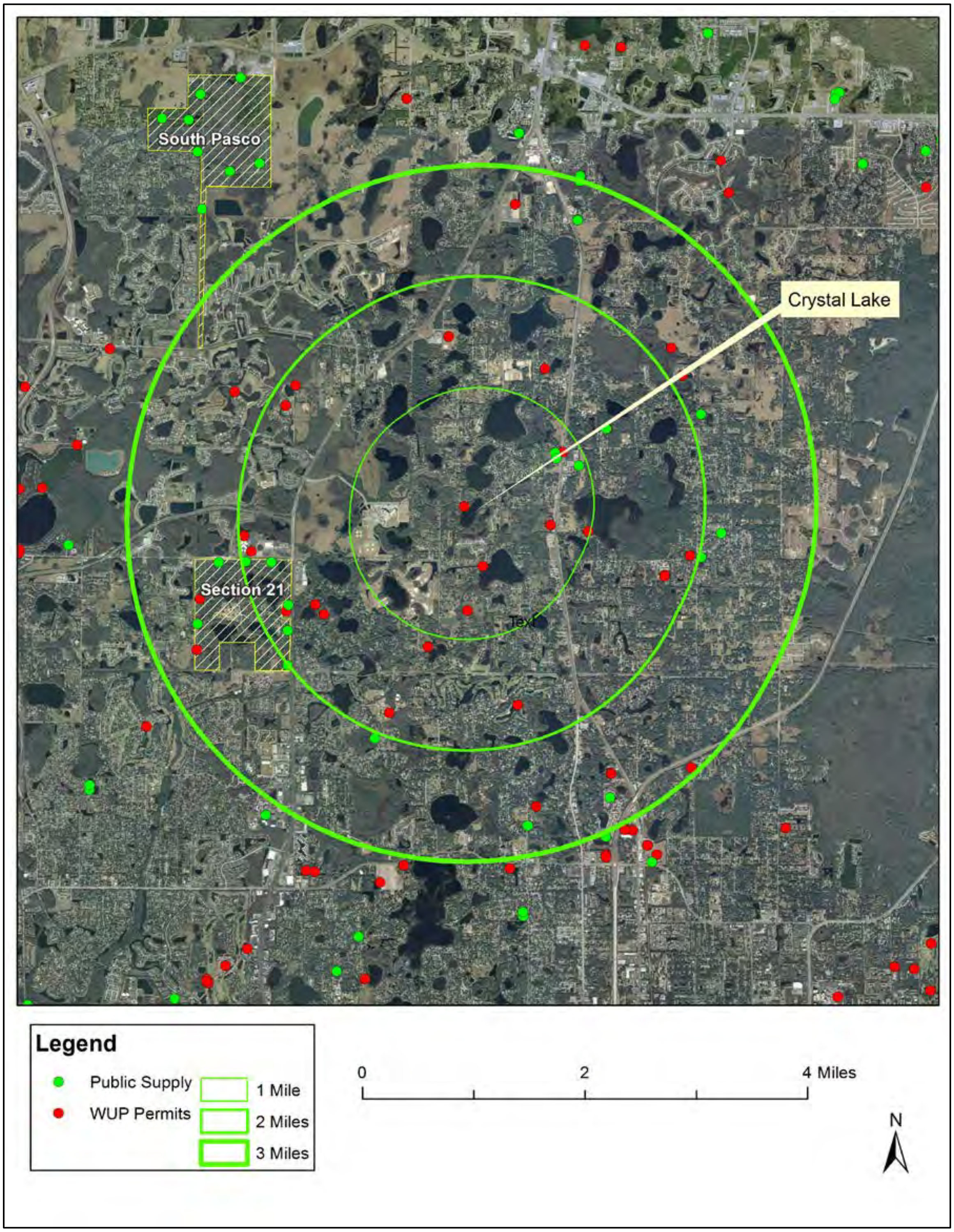

Figure 4. Permitted Groundwater withdrawals within a one, two and three mile radius of Crystal Lake.

Table 2. Previously adopted Minimum and Guidance Levels for Crystal 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	59.8
High Minimum Lake Level	59.8
Minimum Lake Level	58.8
Low Guidance Level	57.7

Annually since 1991, a list of stressed lakes has been developed to support the District's consumptive water use permitting program as referenced in the District's Water Use Permit (WUP) Handbook (Part B) dated May 19, 2014. This reference defines a stressed condition for a lake" as "chronic fluctuation below the normal range of lake level fluctuations". For lakes with District-established management levels, a stressed condition is a chronic fluctuation below the minimum low management level. A stressed condition is based on continuous monthly data for the most recent five-year period, with the latest readings being within the past 12 months, and two-thirds of the values are at or below the adopted minimum low management level. For those lakes without established management levels, stressed conditions shall be determined on a case-by-case basis through site investigation by District staff during the permit evaluation process. Although Crystal Lake was not listed as stressed during recent years, it was designated as stressed during 1992-1998 (based on pre-established management levels) and 2002-2003 (annual District technical memos).

Summary Data Used for Minimum and Guidance Levels Development

Minimum and Guidance Levels for Crystal Lake were developed using the methodology for Category 2 Lakes described in Rule 40D-8.624, F.A.C. These 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.

Lake Stage Data and Exceedance Percentiles

Period of record (POR) lake stage data, *i.e.,* surface water elevations for Crystal Lake relative to NGVD 29 were obtained from in the District's Water Management Information System (WMIS) data base. Gage data were collected at two gage sites. Gage data were collected at Site Identification (SID) number 19827 from July 1972 until it was discontinued in April 2005. Gage data were collected at SID 19828 from July 1999 to present. See Figure 3 for the current location of the SWFWMD water level gage. POR gage data were collected weekly in the early part of the record by the United States Geological Survey (USGS) and monthly by the District since April 2005 and are graphed in Figure 5.

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

Levels	Elevation in Feet NGVD 29	Lake Area (acres)
Lake Stage Exceedance Percentiles		
Period of Record (POR) P10 (1972 to 2013)	60.4	39.3
Period of Record (POR) P50 (1972 to 2013)	58.8	19.3
Period of Record (POR) P90 (1972 to 2013)	55.7	16.4
Current P10 (2005 to 2013)	60.4	39.3
Current P50 (2005 to 2013)	58.4	18.9
Current P90 (2005 to 2013)	55.8	16.5
Historic P10 (1946 to 2013)	60.6	40.5
Historic P50 (1946 to 2013)	59.0	20.0
Historic P90 (1946 to 2013)	56.9	17.7
Normal Pool and Control Point		
Normal Pool	62.7	>54.2
Control Point	59.0	20
Low Floor Slab	63.9	>54.2
Significant Change Standards		
Cypress Standard	60.9	42.5
Species Richness Standard*	56.3	17.1
Wetland Offset Elevation*	58.2	18.8
Aesthetics Standard*	56.9	17.7
Dock-Use Standard*	59.8	34.8
Basin Connectivity Standard *	NA	NA
Recreation/Ski Standard*	NA	NA
Lake Mixing Standard*	NA	NA
Minimum and Guidance Levels		
High Guidance Level	60.4	39.3
High Minimum Lake Level	60.4	39.3
Minimum Lake Level	59.0	20.0
Low Guidance Level	56.9	17.7

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

Record high water levels were generally above 61 ft. and occurred seven times (Figure 5). The extreme high water level was 62.7 ft. and occurred in September 1979 (the lowest house slab/finished floor is one foot higher at 63.9 ft.). Record low water levels were generally below 55 ft. and occurred eleven times; these lows mostly occurred since 1994. The extreme low water level was 53 ft. and occurred in June 2000. The average horizontal distance from the base (shoreline) of most docks to the record low water level of 53 ft. is shown on the latest available aerial photography (Figure 6) is 60 ft.

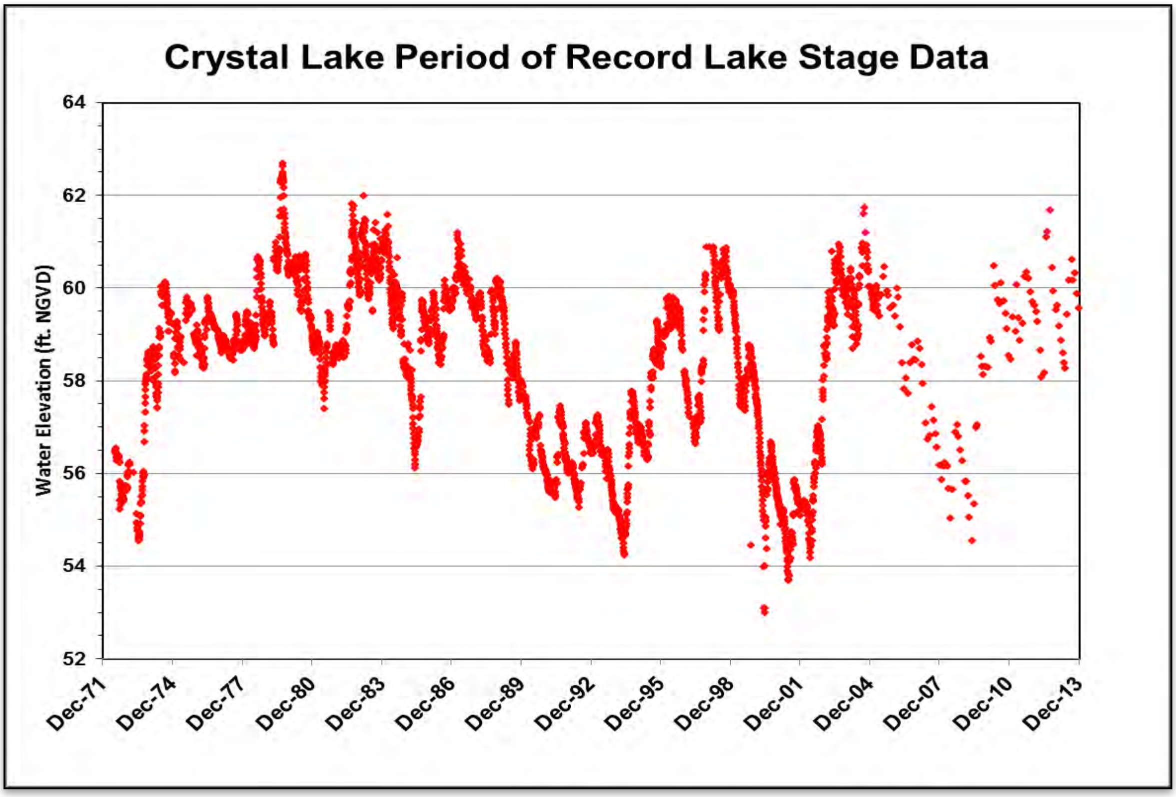

Figure 5. Period of record (POR) data collected July 1972 – December 2013.

For the purpose of Minimum Levels determination, lake stage data are classified as "Historic" for 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" hydrologic stresses due to water withdrawals and structural alterations are stable.

A Long-term Historic lake stage record is a critical step to establish Minimum and Guidance Levels. No measured Historic data are available for Crystal Lake because effects from groundwater withdrawals from the nearby Section 21 Wellfield predate the lake level record. A water budget model was therefore developed to simulate Historic water levels for the lake (Appendix A). Once the water budget model produced historic daily lake stage records, it was then coupled with Line of Organic Correlation (LOC) model of the lake to produce a composite or "hybrid" long-term lake level record estimate (Appendix A). The hybrid model was then used to predict the lake stage for the long-term Historic time period of 1946 to 2013 which resulted in a correlation coefficient of determination (r^2) equal to 0.51. This hybrid water level record (Figure 7) represents Historic conditions.

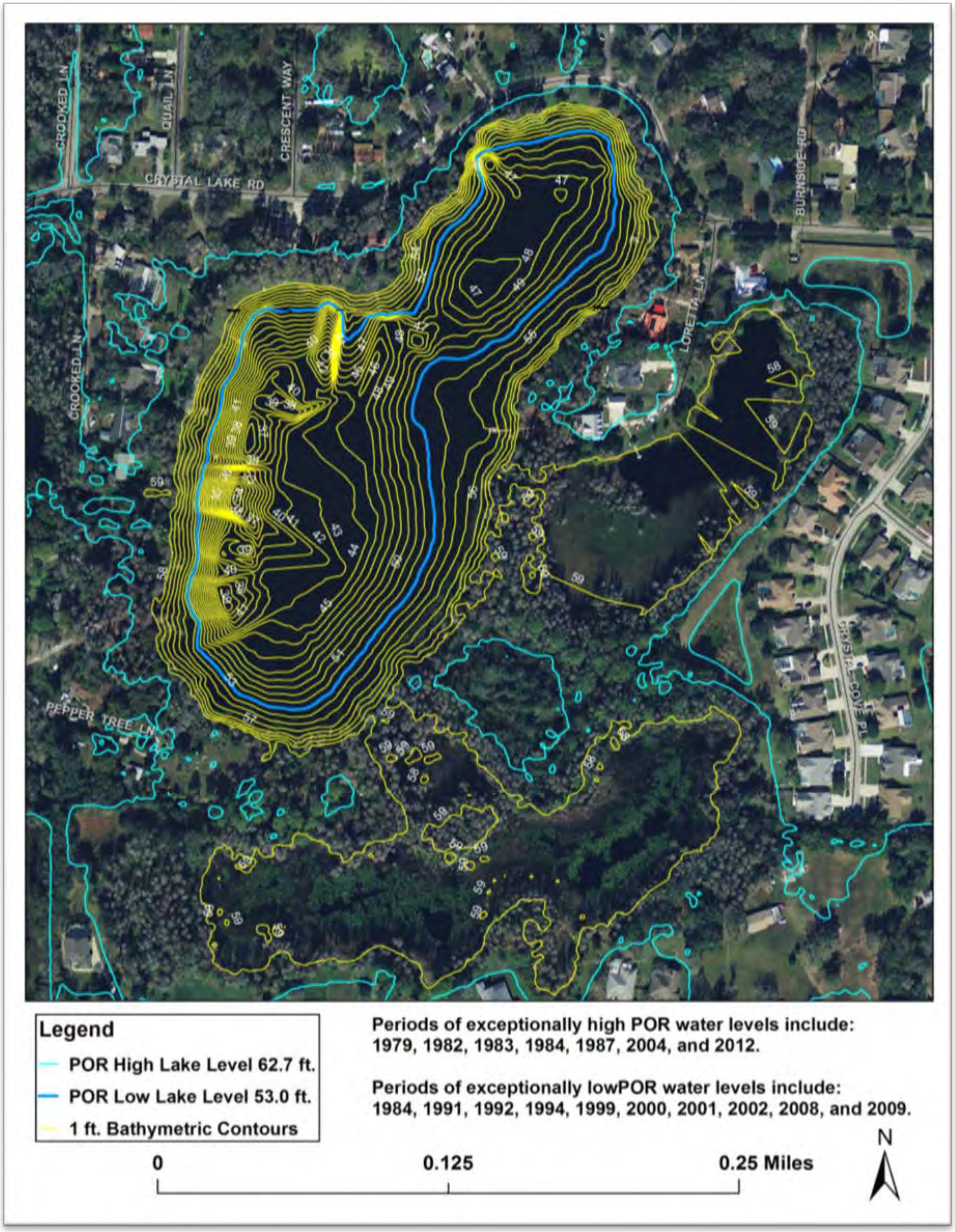

Figure 6. Bathymetric map showing POR extreme high and extreme low water level contours for Crystal Lake. These contours are compared with the lake level on a January 2012 aerial imagery.

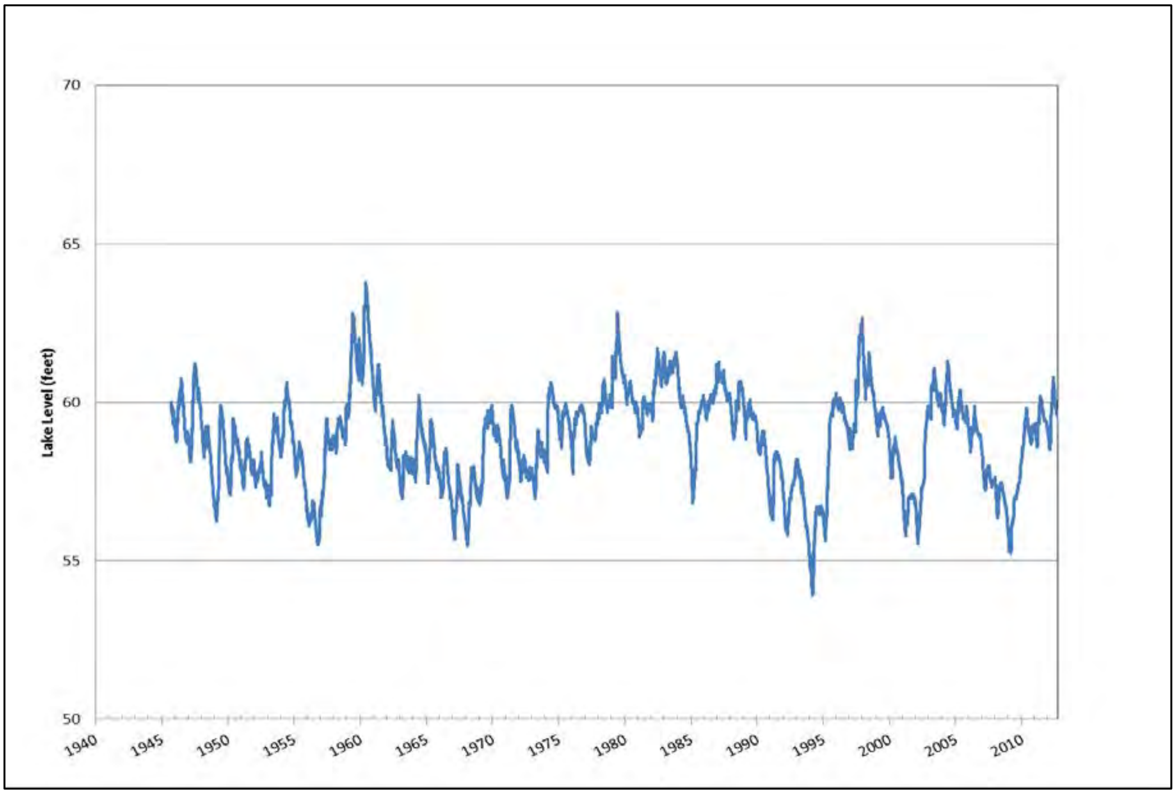

Figure 7. Hybrid model predicted long-term Historic water levels at Crystal Lake for a calibration period from July 1972 – December 2013.

The modeled hybrid Historic lake stage data set was used to calculate Historic P10, P50, and P90 lake stage percentile elevations (Figure 8, Table 3). The Historic P10 elevation, the elevation the lake water surface equaled or exceeded ten percent of the time during the Historic period, was 60.6 ft. The Historic P50 elevation, the elevation the lake water surface equaled or exceeded fifty percent of the time during the historic period, was 59.0 ft. The Historic P90 elevation, the elevation the lake water surface equaled or exceeded 90 percent of the time during the historic period, was 56.9 ft.

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). Eleven examples of *Taxodium* sp. buttresses were measured on the lake in February 2013 at various points along the shoreline in the Cypress wetlands adjacent to the lake (see Figure 3). Based on the survey of these biologic indicators, the Historic Normal Pool elevation was established at the median, **62.7 ft**. (Table 4).

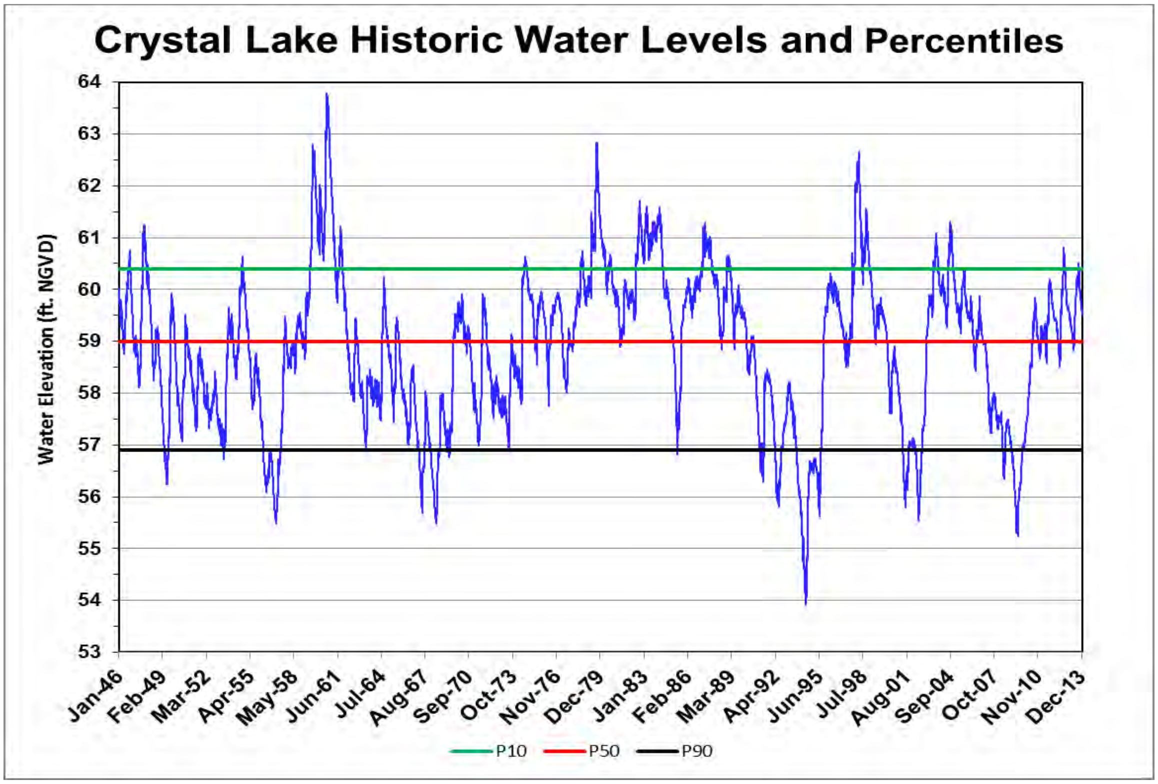

Figure 8. Long-term Historic (hybrid) water levels used to calculate percentile elevations for Crystal Lake. Historic P10, P50, and P90 are depicted as horizontal lines.

Table 4. Summary statistics for hydrologic indicator measurements (elevations buttress inflection points of lakeshore *Taxodium sp*.) used for establishing Normal Pool elevation for Crystal Lake.

N	11
Median	62.7
Mean	62.4
Minimum	59.8
Maximum	63.3

The **Control Point** elevation is the elevation of the highest stable point along the outlet profile of a surface water conveyance system (*e.g.,* weir, conservation structure, ditch, culvert, or pipe) that is the principal control of water level fluctuations in the lake. A high spot within the outflow conveyance system of the lake near Crystal Lake Road with an **elevation of 59.0 ft.** was identified as the lake control point. The control point previously identified for the lake was set at an elevation of 59.8 ft. at the crest of what was a poorly maintained and constructed weir located near the lake edge at the mouth of the outflow conveyance system. This weir no longer exists.

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 Normal Pool elevations 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 (62.7 ft.) is higher than the Control point elevation (59.0 ft.), Crystal Lake was classified as structurally altered.

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. It can be established using the best available information, including hydrologic data (modeled or measured Historic P10), hydrologic indicators (Normal Pool elevation), the effectiveness of structural alterations, and other information indicative of previous water levels. If the best available information indicates that a different elevation is more representative of the expected Historic P10, Chapter 40D-8.624(4)(c) allows other information to be used to establish the High Guidance Level.

It was determined in this case that other information should be used to established the High Guidance Level, rather than the Historic P10 predicted by the water budget model (60.6 ft NGVD) Because the P10 exceedance percentile can be significantly affected by drainage and control structures, the accuracy of the P10 as derived by water budget models can have more error than the lower percentiles (such as the P90 and P50). In the case of Lake Crystal, the outflow to the lake has a manmade control structure in significant disrepair, and a control point that consists of a high point in a ditch bottom. Changes in the control structure and control point over time introduced uncertainty in the water budget model Historic P10, and it was decided that the model-derived Historic P10 may not be representative of the expected Historic P10. Chapter 40D-8.624(4)(c) allows for establishment of the High Guidance Level at the Current P10 if certain criteria are met. A review of Table 3 shows that both the “Current” P10 (as estimated via the water budget/LOC modeling process) and the period of record P10 (as calculated by the field data) are 60.4 feet NGVD29. Both of these values are 0.2 feet less than the model-derived Historic P10 of 60.6 feet NGVD29. Therefore, based on all of this information, including a likely high level of uncertaintly in the modeled Historic P10, the High Guidance Level for Crystal Lake is **60.4** feet NGVD. (Figure 9, Table 3). The lowest residential floor slab within the immediate lake basin (63.9 ft.) is 3.5 feet higher than the 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 Low Guidance Level for Crystal Lake is established at **56.9 ft.** (Figure 9, Table 3).

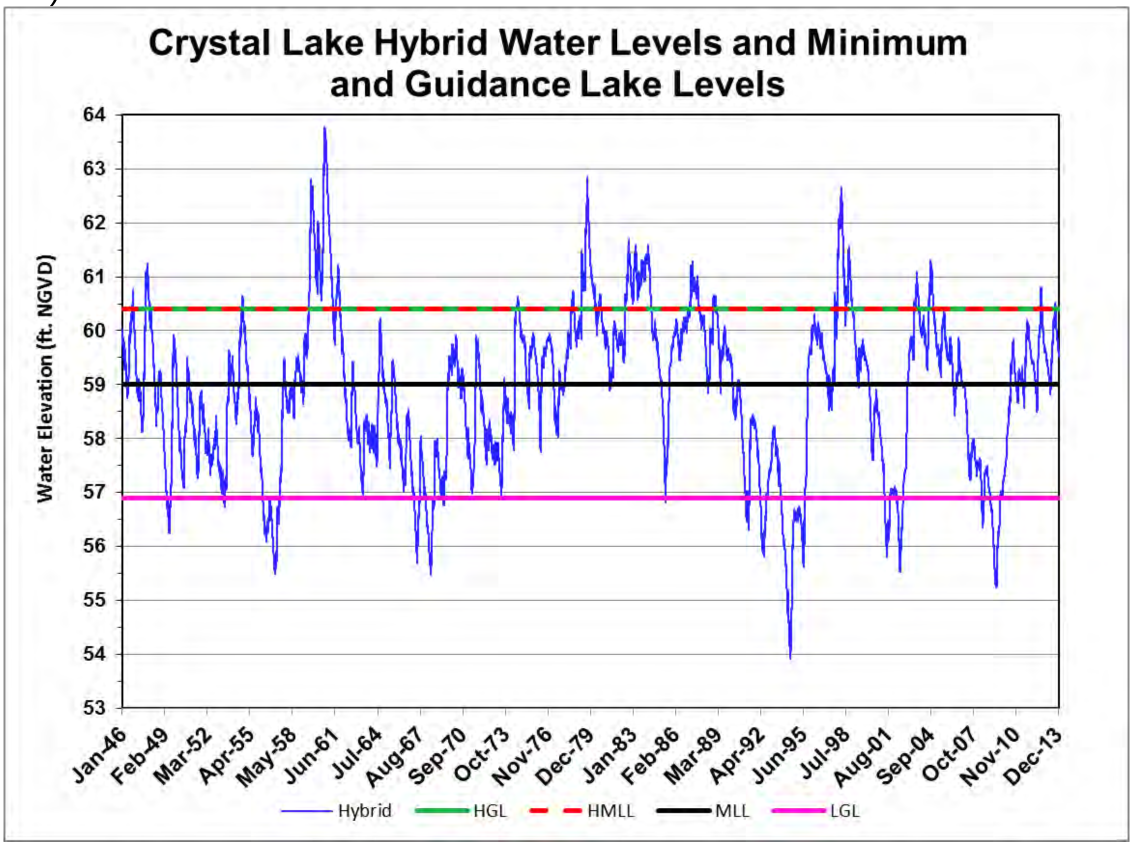

Figure 9. Historic water levels (hybrid results) and Minimum and Guidance levels for Crystal Lake. Levels include the High Guidance Level (HGL), High Minimum Lake Level (HMLL), Minimum Lake Level (MLL), and the Low Guidance Level (LGL).

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 currently 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 ft. below the Normal Pool elevation) are classified as Category 1 Lakes. Lakes with fringing cypress wetlands greater than 0.5 acres in size that have been structurally altered such that the Historic P50 elevation is less than 1.8 ft. below the Normal Pool elevation are classified as Category 2 Lakes. 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 (59.0 ft.) is more than 1.8 ft. below the Normal Pool elevation (62.7 ft.), Crystal Lake was classified as a Category 2 Lake.

Significant Change Standards and Other Information for Consideration

Lake-specific significant change standards and other available information are developed for establishing minimum levels. The standards are used to identify thresholds for preventing significant environmental values associated with lakes 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 Crystal Lake, the **Cypress Standard** was established at 60.9 ft. Based on the Historic water level record for the lake, the standard was equaled or exceeded seven percent of the time, *i.e.*, the standard elevation corresponds to the Historic P7.

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 lake values. Although Crystal Lake is a Category 2 Lake, Category 3 Lake standards were developed for comparative purposes. These standards were not, however, used to establish the Minimum Levels.

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 **56.9 ft.** for Crystal Lake. Because the Low Guidance Level was established at the Historic P90 elevation, water levels equaled or exceeded the Aesthetics Standard ninety 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 established for Crystal Lake is established at **56.3 ft.** (Figure 10).

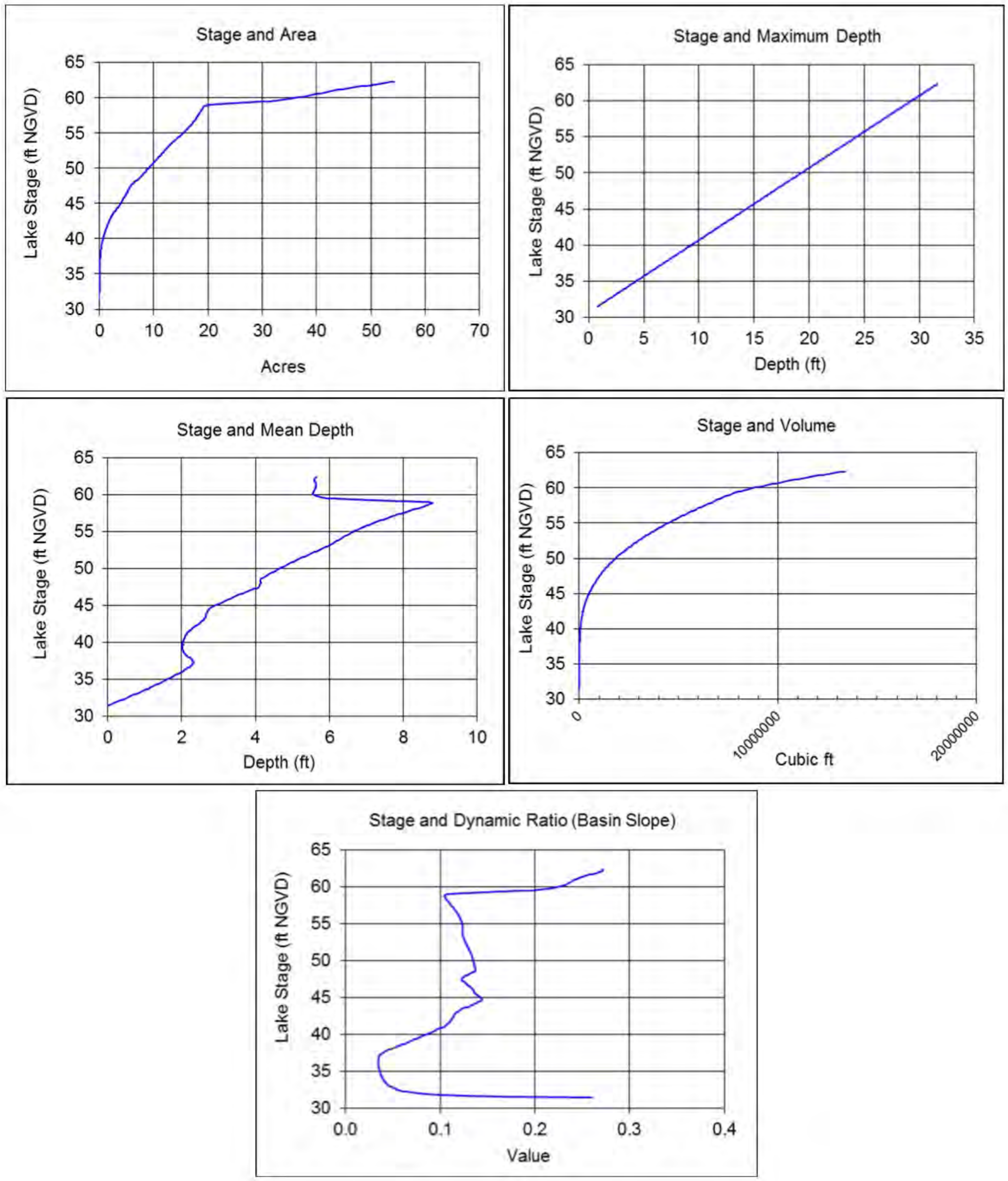

Figure 10. Surface area, maximum depth, mean depth, volume, dynamic ratio (basin slope) in feet for Crystal Lake.

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 a rectangular ski area 200 ft. in width and 2,000 ft. in length. Crystal Lake did not meet the minimum size requirements suitable for safe water skiing. Therefore, a Recreation/Ski Standard was not established.

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-Use Standard for Crystal Lake was established at **59.8 ft.**, based on the elevation of sediments at the end of ninety percent of the 12 docks on the lake (55.7 ft., Table 5), a two-foot water depth based on use of powerboats in the lake, and the 2.1 ft. difference between the Historic P50 and Historic P90.

Table 5. Summary statistics and elevations associated with docks in Crystal Lake based on measurements made by District staff in February 2013. Percentiles (10th, 50th and 90th) represent the percentage of docks at or below the corresponding elevation.

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)	12	12
Median	54.4	62.1
10^{th} Percentile (P90)	51.0	61.6
50^{th} Percentile	54.4	62.1
90^{th} Percentile (P10)	55.7	62.5
Maximum	56.9	63.2
Minimum	49.6	61.3

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. Lake sub-basins were not identified for Crystal Lake therefore a Basin Conductivity Standard was not developed.

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 shifts from a value of <0.8 to a value >0.8, or from a value >0.8 to a value of <0.8 (Bachmann *et al.* 2000). Development of a Lake Mixing Standard was not appropriate for Crystal Lake based on consideration of dynamic range values for all water surface elevations that may be expected within the basin (refer to Figure 10).

Information pertaining to **Herbaceous Wetlands** in the lake basin is taken under consideration to determine the elevation at which the change in lake stage would result in substantial change in potential wetland area within the lake basin (*i.e*., basin area with a water depth less than or equal to four feet). Review of changes in potential herbaceous wetland area in relation to change in lake stage 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 (Figure 11). Also considered is the elevation at which change in lake stage would result in substantial change in the area available for colonization by **Submersed Aquatic Plants** (i.e., basin area with a water depth of 10.9 ft. or less), based on water clarity values. Review of this stage vs. area data did not indicate that there would be a significant increase or decrease in the area of submersed aquatic plant vegetation associated with use of the applicable standards (Figure 11).

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** is the elevation that a lake's water levels are required to equal or exceed fifty percent of the time on a long-term basis. For Category 2 Lakes, the Minimum Level is established at the Historic P50 elevation. The Minimum Lake Level for Crystal Lake was therefore established at **59.0 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. The High Minimum Lake Level for Crystal Lake was therefore established at **60.4 ft.**

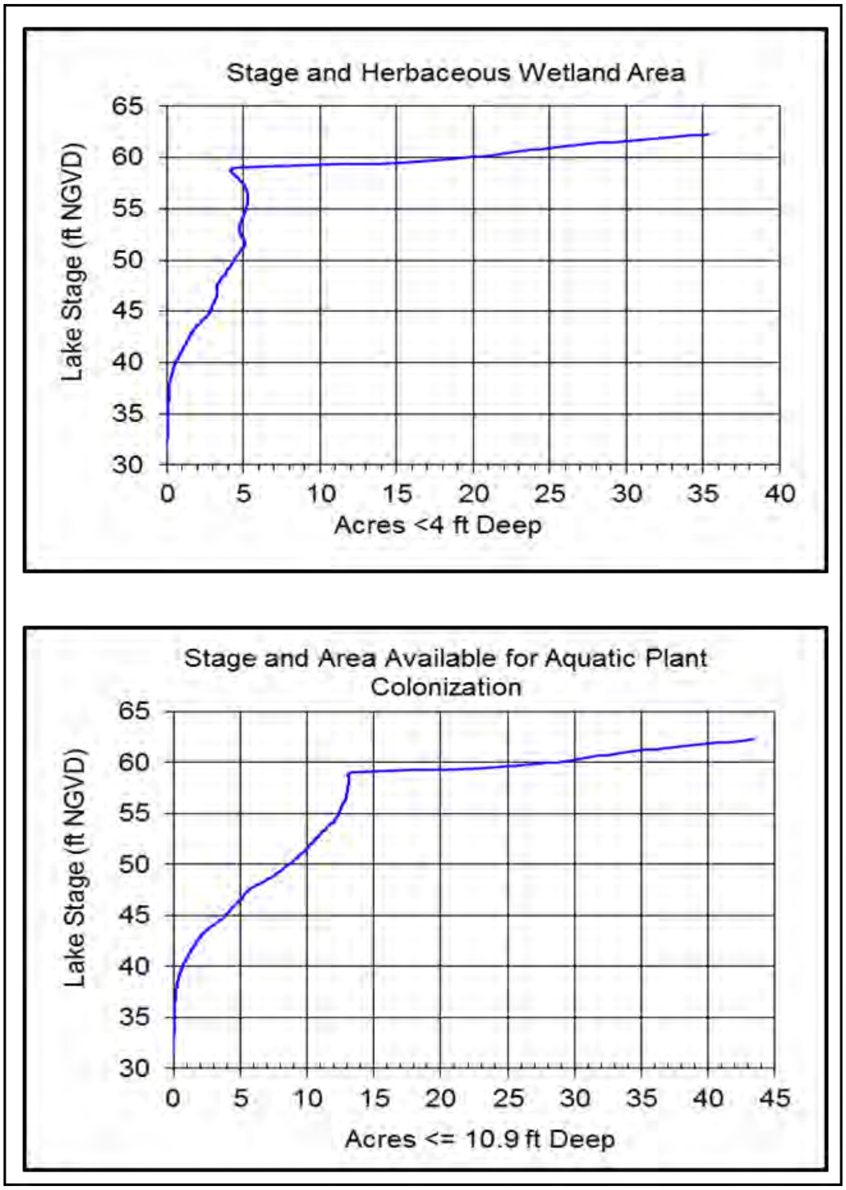

Figure 11. Potential herbaceous wetland area and area available for submersed macrophyte colonization in Crystal Lake as a function of lake stage (water surface elevation).

The MLL, HMLL and lake stage water levels are shown as contour lines on historic aerial photographs (Figures 12 – 14). Figure 12 presents the MLL and HMLL contour lines with an estimate of the 1973 water level based on a visual examination of the contour line that best matched the shoreline. Figure 13 presents the MLL and HMLL contour lines with the estimated (POR) water level on January 9, 2007 which illustrates it’s similarity to the HMLL. Figure 14 presents the MLL and HMLL contour lines with the estimated (POR) water level on January 6, 2010.

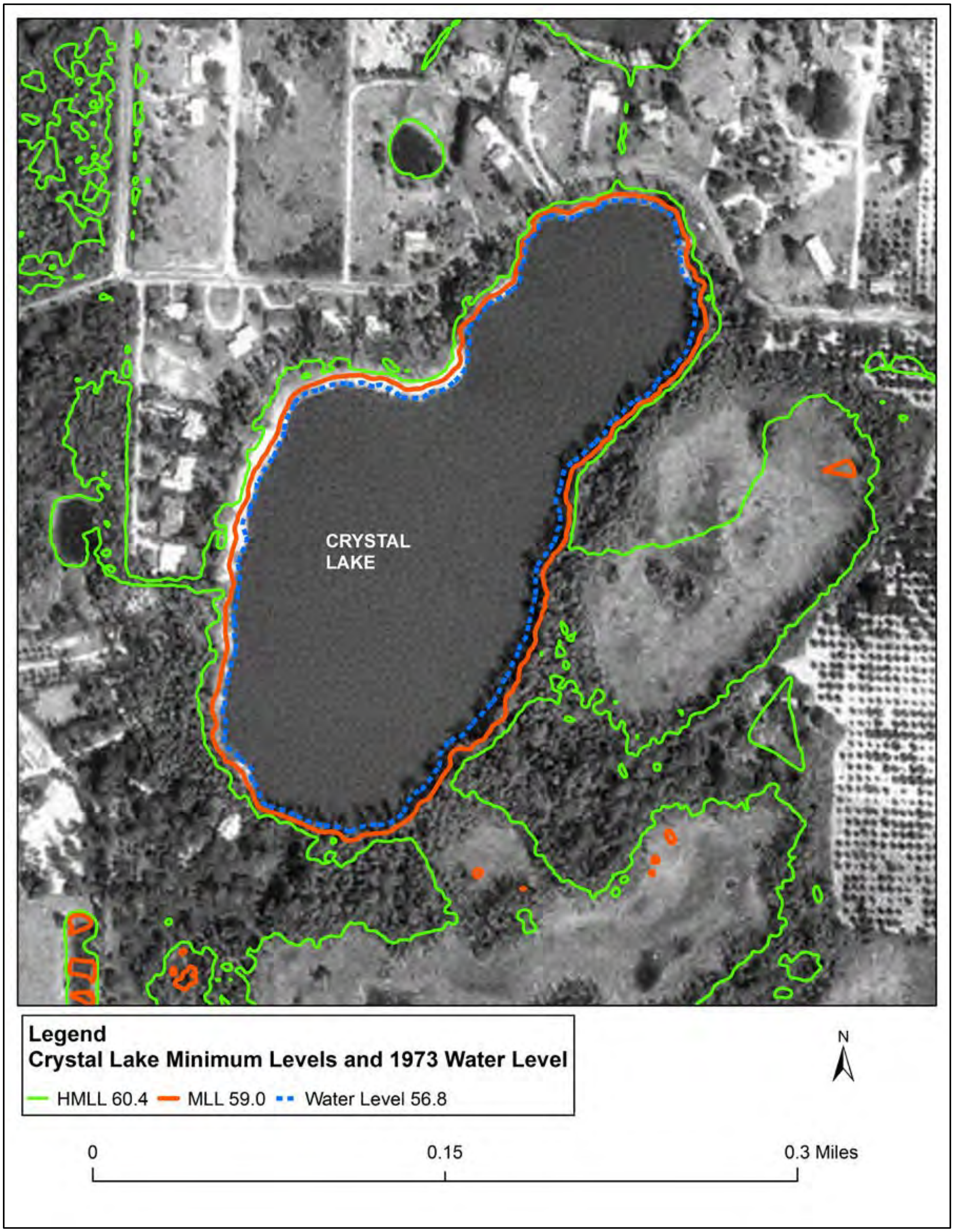

Figure 12. Approximate location of water level associated with the Minimum Lake Level (MLL) and High Minimum Lake Level (HMLL) for Crystal Lake relative to conditions on February 15, 1973. Based on interpretation of contour lines at the lake edge, the lake stage was estimated at 56.8 ft.

Figure 13. Approximate location of water level associated with the Minimum Lake Level (MLL) and High Minimum Lake Level (HMLL) for Crystal Lake relative to conditions on January 09, 2007. Based on gage readings, the lake stage was 58.9 ft., essentially equal to the MLL.

Figure 14. Approximate location of water level associated with the Minimum Lake Level (MLL) and High Minimum Lake Level (HMLL) for Crystal Lake relative to conditions on January 06, 2010. Based on gage readings, the lake stage was 58.3 ft. on the date of the imagery.

Many federal, state, and local agencies, such as the US Army Corps of Engineers, the Federal Emergency Management Agency, U.S. Geological Survey, and Florida's water management districts are in the process of upgrading from the National Geodetic Vertical Datum (NGVD29) standard to the North American Vertical Datum (NAVD88) standard. For comparison purposes, the Minimum and Guidance levels for Crystal Lake are presented in both datum standards (Table 6). The NGVD29 datum was converted to NAVD88 using the Corpscon conversion of 0.827 ft.

Table 6. Minimum and Guidance Levels for Crystal Lake relative to NGVD29 and NAVD88.

Minimum and Guidance Levels	Feet NGVD29	Feet NAVD88
High Guidance Level	60.4	59.6
High Minimum Lake Level	60.4	59.6
Minimum Lake Level	59.0	58.2
Low Guidance Level	56.9	56.1

Consideration of Environmental Values

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 Historic P50 elevation was used for developing Minimum Levels for Crystal Lake based on its classification as a Category 2 Lake. This elevation is associated with protection of the environmental values identified in Rule 62-40.473, F.A.C. (refer to Table 1). The Minimum Levels for Crystal 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.).

A Cypress Standard was identified to support development of minimum levels for Crystal Lake based on the occurrence of lake-fringing cypress wetlands of one-half an acre or greater in size. The standard is associated with protection of several environmental values identified in the rule, including: fish and wildlife habitats and the passage of fish, transfer of detrital material, aesthetic and scenic attributes, filtration and absorption of nutrients and other pollutants, and water quality. Ultimately, the Historic P50 elevation and High Guidance Level/Historic P10 were used for developing the minimum levels for Crystal Lake based on existing structural alterations and its classification as a Category 2 Lake. Given that the Minimum Levels were established using historic lake stage exceedance percentiles, the levels are as protective of all relevant environmental values as they can be, given existing structural alterations. In addition, the environmental value, maintenance of freshwater storage and supply is also expected to be protected by the minimum levels based on inclusion of conditions in water use permits that stipulate that permitted withdrawals will not lead to violation of adopted minimum flows and levels.

Two environmental values identified in Rule 62-40.473, F.A.C., were not considered relevant to development of minimum levels for Crystal 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 minimum 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 Crystal Lake Minimum Level Condition

The 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 Crystal Lake water levels are currently above or below the Minimum Lake Level and High Minimum Lake Level for the lake. Current levels were determined to be below the Minimum Lake Level and High Minimum Lake Level.

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Appendix A

Technical Memorandum

November 10, 2014

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

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

FROM: Michael C. Hancock, P.E., Senior Prof. Engineer, Water Resources Bureau

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

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A. Introduction

Water budget and rainfall correlation models were developed to assist the Southwest Florida Water Management District (District) in the reassessment of minimum levels for Crystal Lake in northwest Hillsborough County. Crystal Lake currently has adopted minimum levels which are scheduled to be re-assessed in FY 2014. This document will discuss the development of the Crystal Lake models and use of the models for development of Historic lake stage exceedance percentiles.

B. Background and Setting

Crystal Lake (also known as South Crystal Lake) is located in northwest Hillsborough County, approximately 0.8 miles west of U.S. Highway 41 and immediately south of Crystal Lake Road in Lutz (Figure 1). The lake lies within the Brushy Creek watershed. Brushy Creek is a tributary to Rocky Creek. Surface-water inflow occurs from Strawberry Lake (also known as North Crystal Lake) to the north (Figure 2). Two large wetlands to the east and south of the lake flow to and from the lake at high water levels. Discharge from Crystal Lake occurs via a ditch on the southwest quadrant of the lake, which flows north along Crooked Lane (on the western side of the lake), and passes under Crystal Lake Road to the west of the lake inlet (Figure 2).

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), a region of many lakes on a moderately thick plain of silty sand overlying limestone. The topography is very flat, and drainage in to the lake is a combination of overland flow and flow through drainage swales and minor conveyance systems.

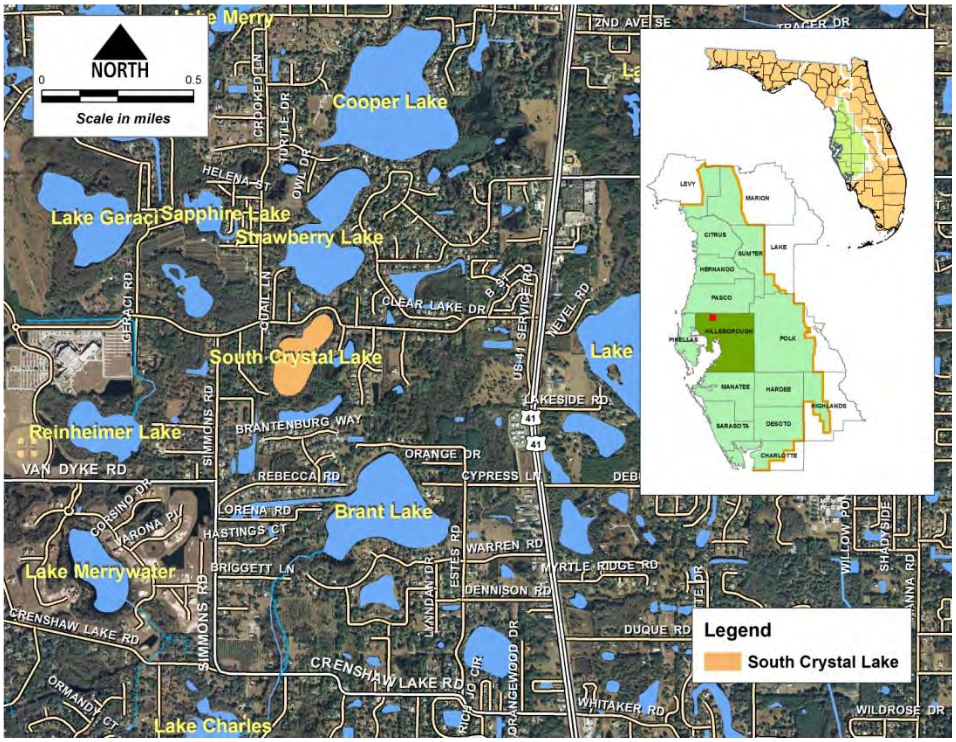

Figure 1. Location of Crystal Lake in Hillsborough County, Florida.

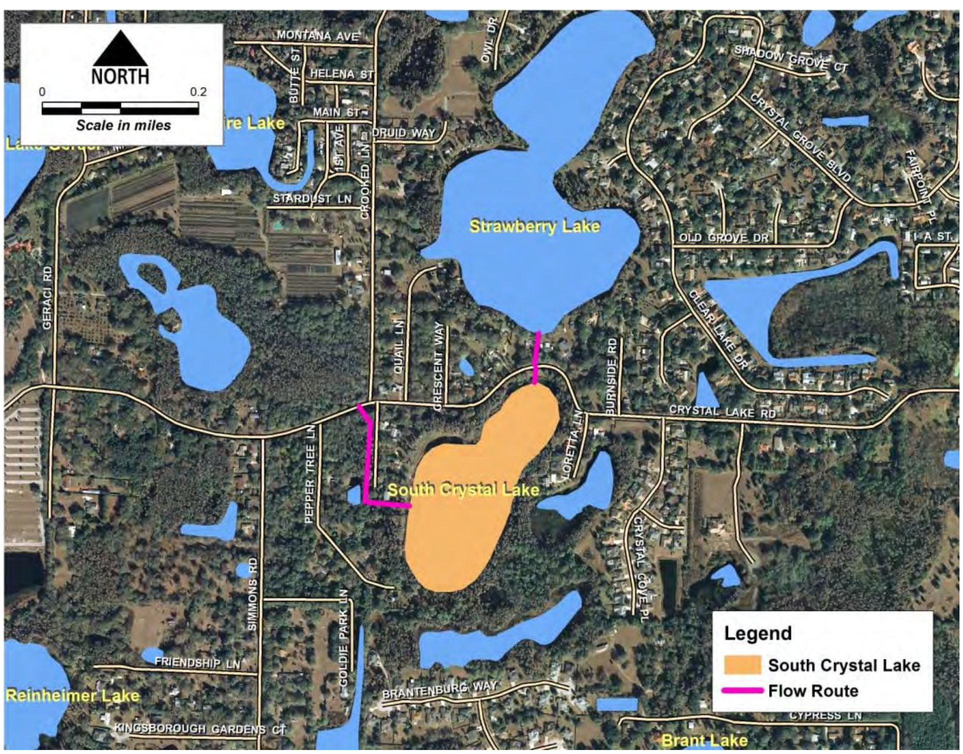

Figure 2. Flow between Strawberry Lake and Crystal Lake.

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). 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 (Hancock and Basso, 1996).

Crystal Lake is located approximately 1.5 miles northeast of the Section 21 Wellfield, one of eleven regional water supply wellfields operated by Tampa Bay Water (Figure 3). Groundwater withdrawals began at the Section 21 Wellfield in 1963 and steadily climbed to nearly 20 million gallons per day (mgd) in 1967 (Figure 4). With the development of the South Pasco Wellfield in 1973, withdrawal rates at the Section 21 Wellfield were reduced to approximately 10 mgd. Withdrawal rates since 2005 have averaged a little over 3 mgd, with several extended periods when the wellfield was shut down completely.

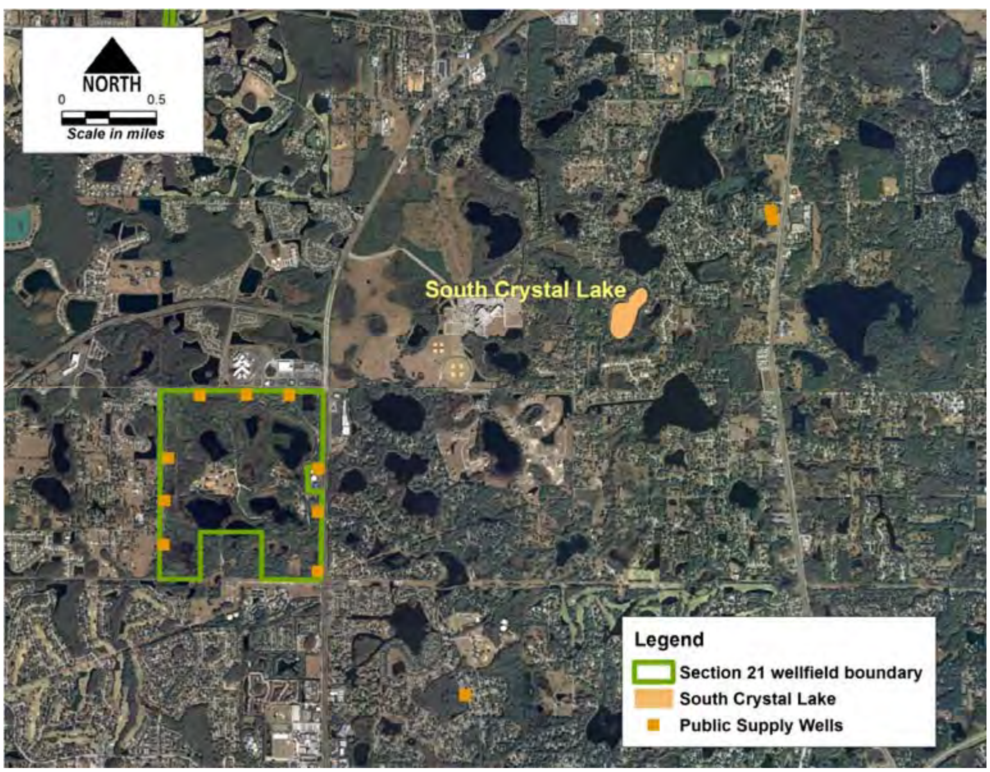

Figure 3. Crystal Lake and the Section 21 Wellfield.

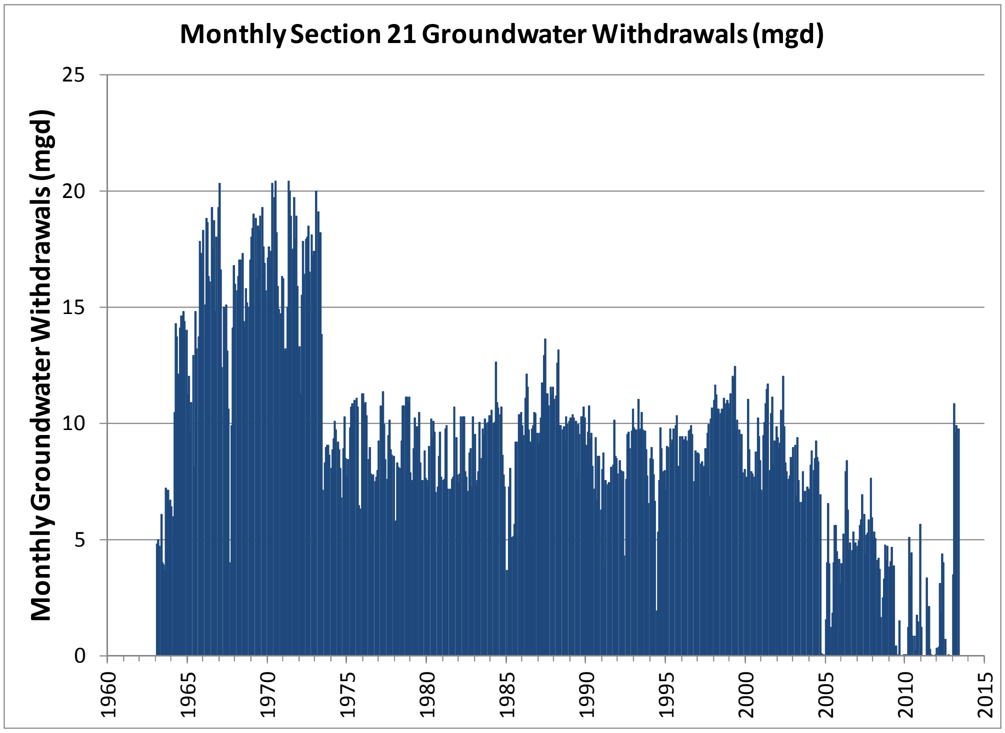

Figure 4. Section 21 Wellfield withdrawals.

Water level data collection at Crystal Lake began in July 1972 (Figure 5). Data collection frequency has occurred weekly in the early part of the record (by the United States Geological Survey (USGS) and the District), and has been monthly since April 2005.

Water levels from the Debuel Road Deep Floridan aquifer and Debuel Road Shallow surficial aquifer monitor wells are available beginning in August 1965, making them two of the longest term monitor wells in Hillsborough County (Figures 6 and 7). The wells are located approximately 1.5 miles to the southeast of Crystal Lake. The data collection frequency began as weekly, and became daily in the mid-1970s (Figure 7).

Water levels in many lakes in the Section 21 Wellfield area dropped significantly since public supply groundwater withdrawals began (Hancock and Basso, 1996). Because Crystal Lake water level data collection did not begin until well after the beginning of withdrawals from the wellfield (Figure 8), the correlation between ground-water withdrawals and lake level cannot be easily made from the comparison of data. Lake recovery during the period of recent reductions in groundwater withdrawals can be seen in Figure 8. A review of aerial photography (Figure 9) shows that signs of lowered lake level after the commencement of groundwater withdrawals at the Section 21 Wellfield are somewhat obvious in the 1968 photograph. It is also interesting to note that a relatively large cypress wetland to the immediate west of the lake was filled sometime between 1938 and 1968.

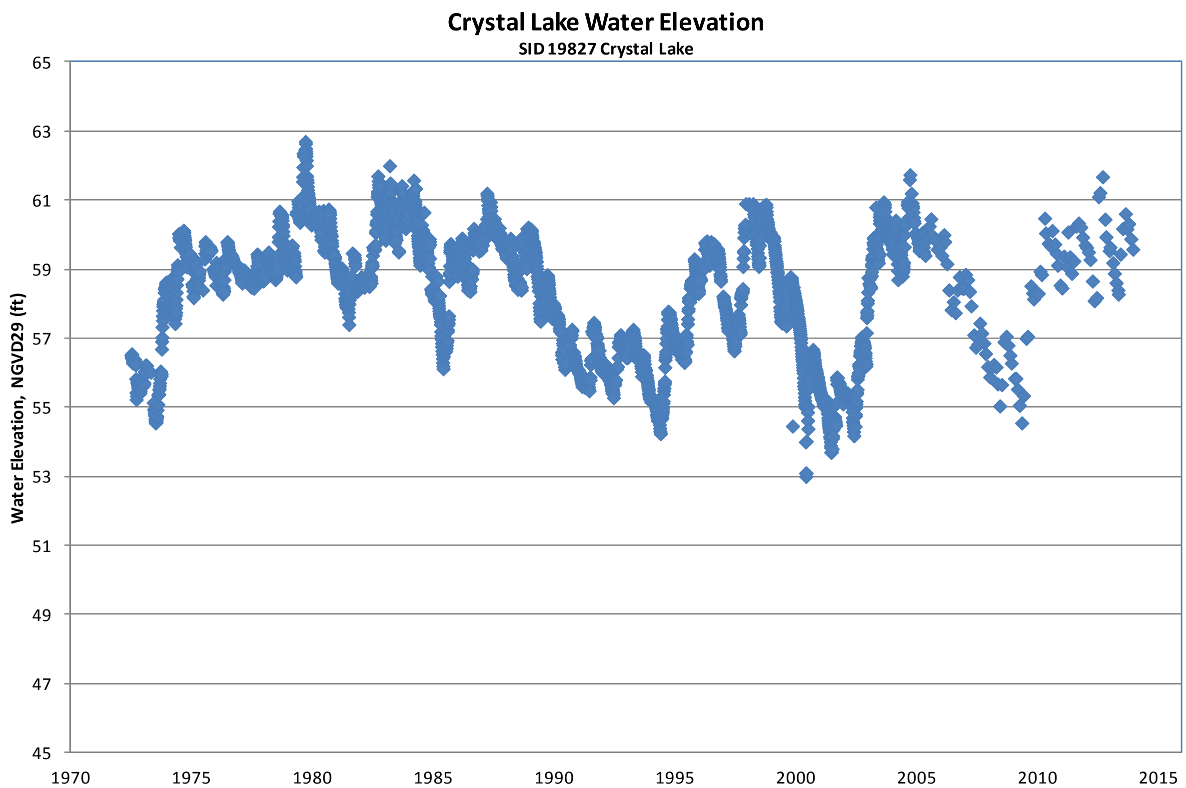

Figure 5. Crystal Lake water levels.

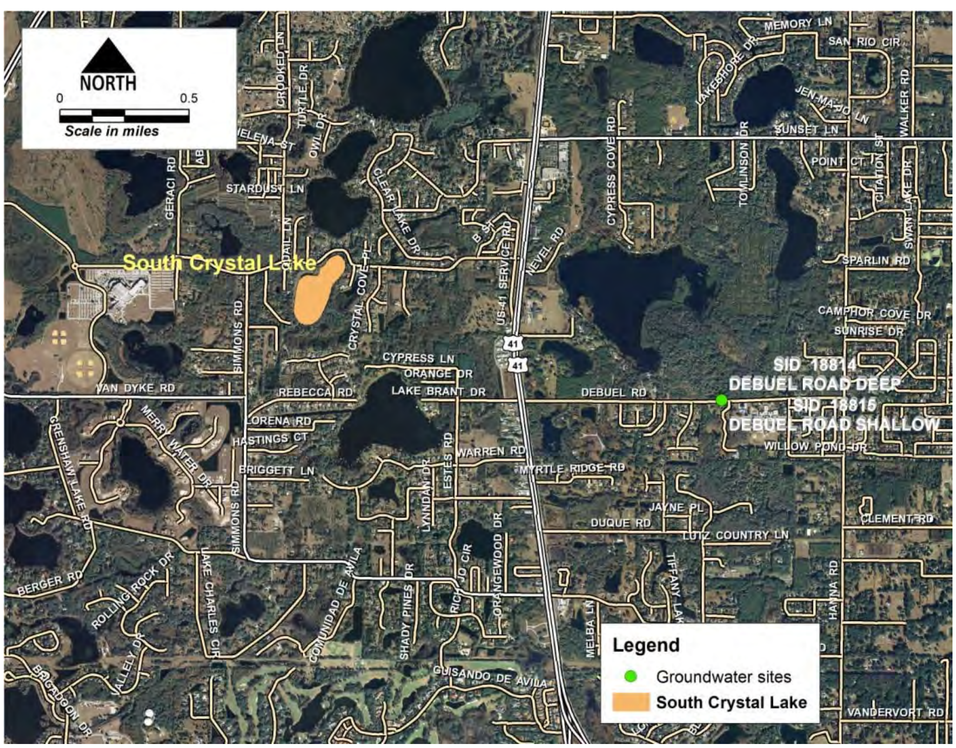

Figure 6. Location of monitor wells near Crystal Lake.

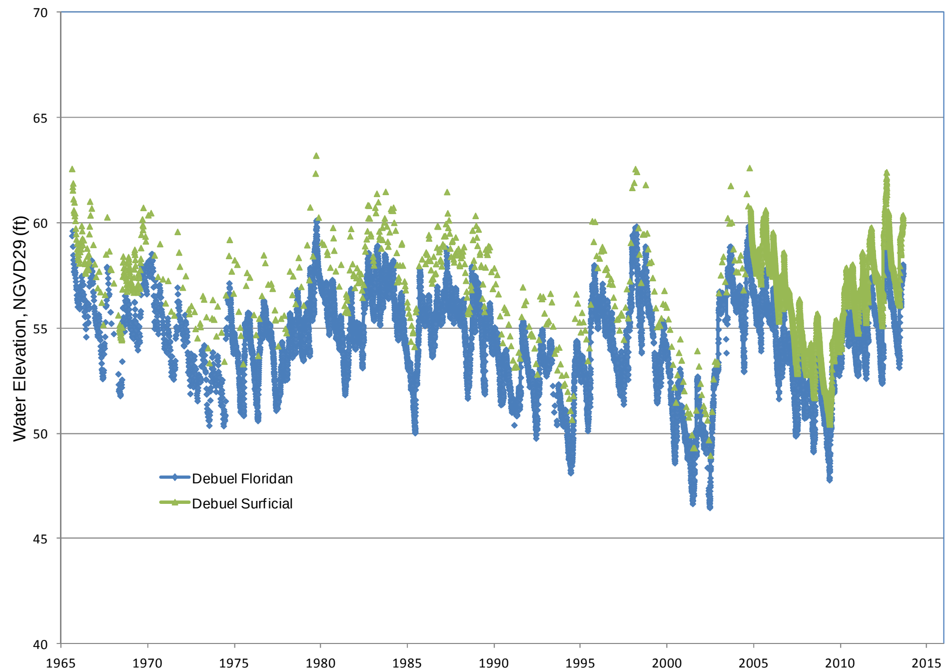

Figure 7. Water levels in the Debuel Road Surficial and Floridan aquifer monitor wells.

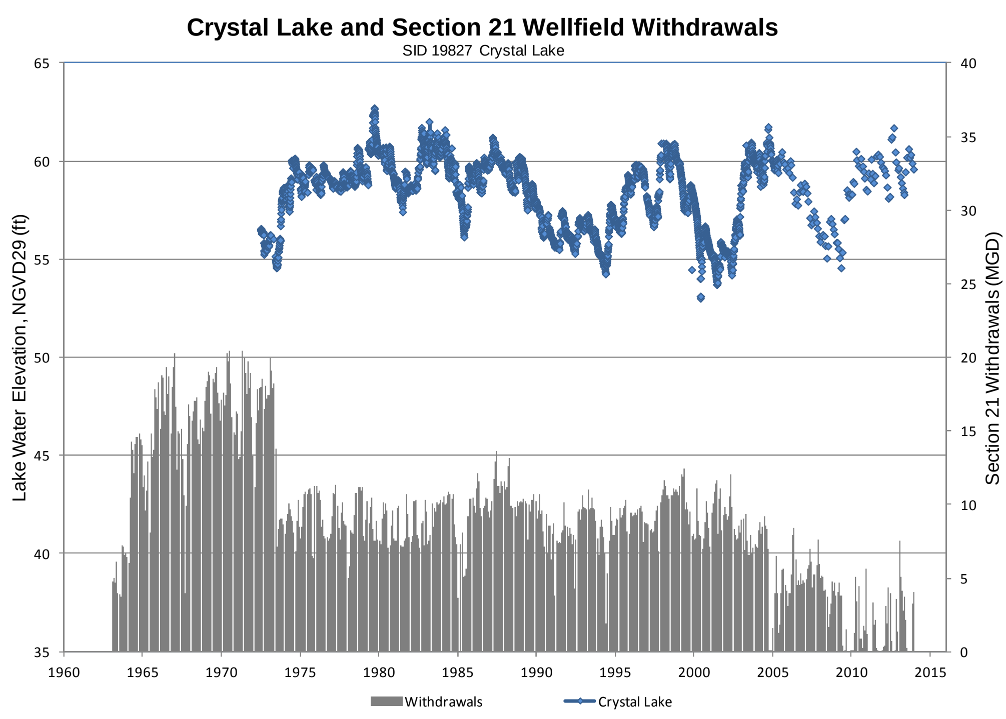

Figure 8. Water levels in Crystal Lake and Groundwater Withdrawals at the Section 21 Wellfield.

Figure 9. Water level changes in Crystal Lake.

In 1973, due to concerns of low lake levels, lakefront homeowners began augmenting the lake with water withdrawn from the Floridan aquifer. In 1977, the District issued a permit to the homeowners for a maximum rate of 432,000 gallons per day, to a maximum elevation of 59.0 feet NGVD 29. The permit was renewed in 1983 at an average annual rate of 114,000 gpd and maximum of 504,000 gpd, and required metering of withdrawals. The most recent renewal was in 1994 (with an extension to 2017 given in 1998), with an average annual rate of 60,000 gpd and maximum of 252,000 gpd. However, no augmentation has been reported since 2003, and it is understood that no augmentation has occurred since that year. Figure 10 presents the metered augmentation withdrawals.

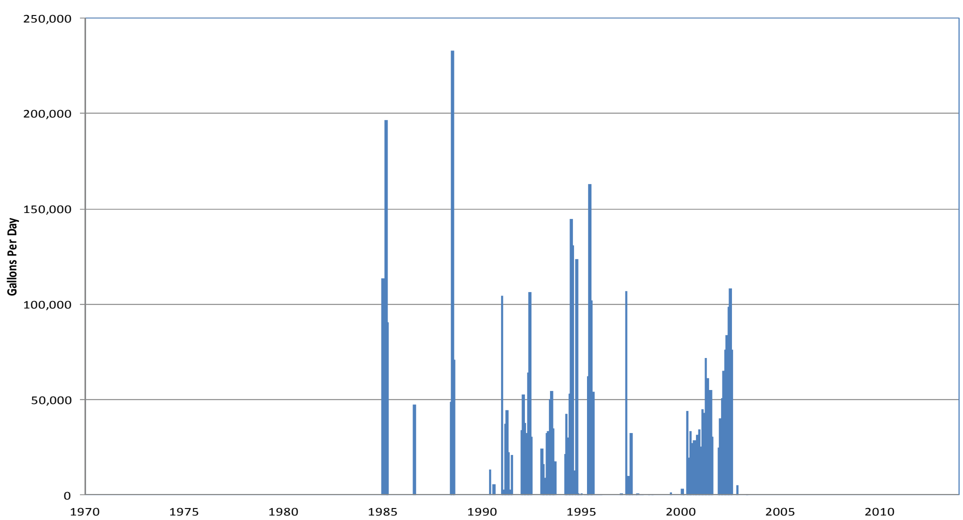

Figure 10. Metered augmentation withdrawals at Crystal Lake.

C. Purpose of Models

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

In the case of Crystal Lake, the Section 21 Wellfield has potentially affected water levels in the lake since early 1963. Other groundwater withdrawals (including other wellfields) in the area could also affect levels, but the effect of such withdrawals would be much smaller and less consistent. No data from Crystal Lake exists prior to the initiation of groundwater withdrawals from the Section 21 Wellfield. Therefore, the development of a water budget model coupled with a rainfall correlation model of the lake was considered essential for estimating long-term Historic percentiles, accounting for changes in the lake's drainage system, and simulating effects of changing groundwater withdrawal rates.

D. Water Budget Model Overview

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

The hydrologic processes in the water budget model include:

a. Rainfall and evaporation
b. Overland flow
c. Inflow and discharge via channels

d. Flow from and into the surficial aquifer
e. Flow from and into the Upper Floridan aquifer

The water budget model uses a daily time-step, and tracks inputs, outputs, and lake volume to calculate a daily estimate of lake levels for each lake. The water budget model for Crystal Lake is calibrated from 1974 to 2013. This period provides the best balance of using available data for all parts of the water budget and the desire to develop a long-term water level record.

E. Water Budget Model Components

Lake Stage/Volume

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

Precipitation

After a review of several rain gages in the area of Crystal Lake, a composite of several stations was used for the water budget model. The goal was to use the closest available data to the lake, as long as the data appeared to be high quality (Figure 11). A rain gage was located on the north shore of Crystal Lake (SID 19829) from May 1986 through April 2005. Rainfall data from the Crenshaw Lake gage (SID 20005), located about one mile to the southwest of the lake was used from January 1974 to May 1986 and to in-fill missing dates during the time period of data collection at the Crystal Lake gage. Data collection at the Crenshaw Lake gage ended in May 2005. The Whalen gage (SID 19492), located approximately one mile to the south of Crystal Lake, was used for the remainder of 2005 (when the Whalen gage was terminated). The St. Pete Jackson 26A gage (SID 19550), located approximately 2.5 miles to the southwest of the lake, was used for the remainder of the model period (through 2013). All rainfall stations used are maintained by the District.

Figure 11. Rain gages used in the Crystal Lake water budget model.

Lake Evaporation

Lake evaporation was estimated through use of monthly energy budget evaporation data collected by the U.S. Geological Survey (USGS) at Lake Starr in Polk County (Swancar and others, 2000) (Figure 12). The data was collected from August of 1996 through July of 2011. Monthly Lake Starr evaporation data were used in the Crystal Lake water budget model when available, and monthly averages for the period of record were used for those months in the model when Lake Starr evaporation data were not available.

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 approximately 6.1 miles to the west of Crystal Lake (Figure 12). The assessment concluded that the evaporation rates between the two lakes were nearly the same, with small differences attributed to measurement error and monthly differences in latent heat associated with 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 from a website maintained by the USGS, were calculated through the use of solar radiation data measured by a Geostationary Operational Environmental Satellite (GOES). Because PET is equal to lake evaporation over open water areas, using the values derived from the grid nodes over the modeled lake was considered. A decision was made to instead use the Lake

Starr evaporation data since the GOES data nodes typically include both upland and lake estimates, with no clear way of subdividing the two. It was thought that using the daily PET estimates based on the GOES data would increase model error more than using the Lake Starr data directly.

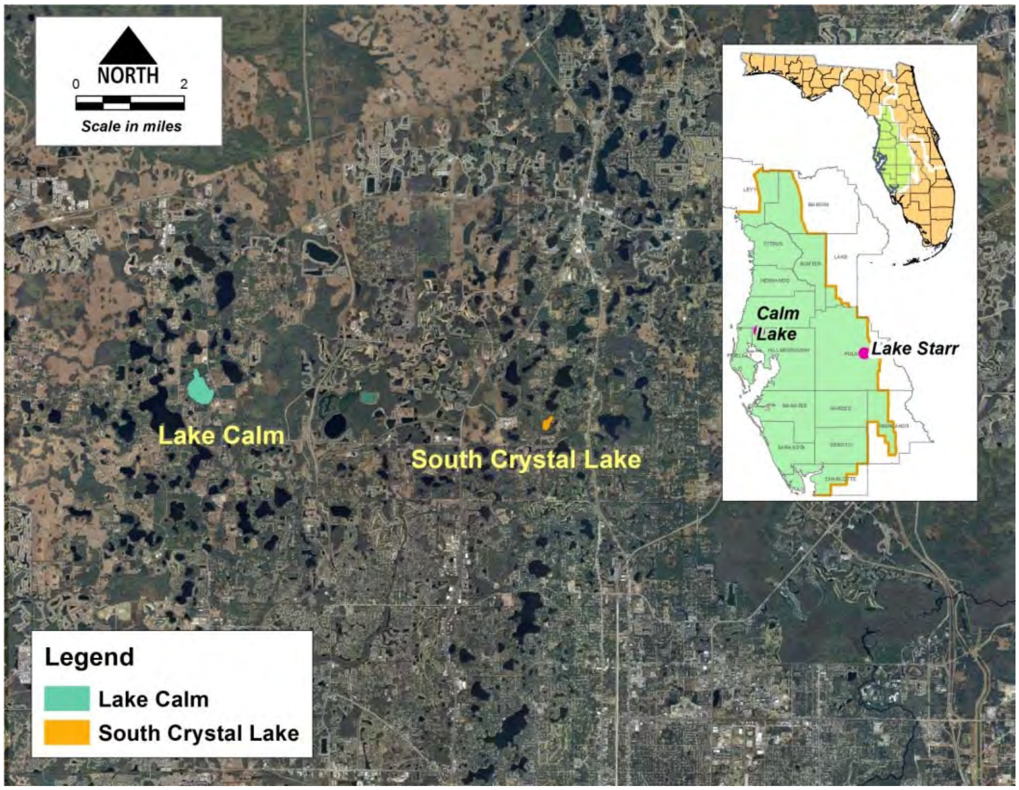

Figure 12. Location of Crystal Lake, Lake Calm and Lake Starr (see map inset).

Augmentation withdrawn from the Upper Floridan aquifer

When applicable, augmentation quantities withdrawn from the Upper Floridan aquifer were added to the lake on a daily basis, based on the available metered values (Figure 10). Because monthly totals are all that is required for the permit issued by the District, an assumption was made that the monthly total was distributed evenly each day of the month for which augmentation was reported. Most of the reported augmentation occurred from the late 1980s through the early 2000s. While the homeowners on the lake had a permit to augment the lake prior to the mid-1980s, metered use was not required to be reported to the District. Since the original permitted quantity was not large, it is not likely that any applied augmentation would have significantly altered the long-term water budget of the lake, and therefore no estimates of unmetered augmentation were included in the model.

Overland Flow

The water budget model was set up to estimate overland flow via a modified version of the U.S. Department of Agriculture, Soil Conservation Service (SCS) Curve Number method (SCS, 1972), and via directly connected impervious area calculations. The free water area of each lake was subtracted from the total watershed area at each time step to estimate the watershed area contributing to surface runoff. The directly connected impervious area (DCIA) is subtracted from the watershed for the SCS calculation, and then added to the lake water budget separately. Additionally, the curve number (CN) chosen for the watershed of the lake takes into account the amount of DCIA in the watershed that has been handled separately.

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 Crystal 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. One of the most recent set of estimates was developed as part of an effort to model the Rocky Creek watershed for flood assessment purposes (Parsons, 2010). The watershed area values developed by Parsons were adopted for the Crystal Lake model (Table 1) after an independent check confirming that they are reasonable for modeling purposes.

Crystal Lake has an immediate watershed from which it receives overland flow, and a contributing watershed to the north from which it can receive channel flow from Strawberry Lake (Figure 13). The entire area of the contributing watersheds includes much of the northern section of the Rocky/Brushy Creek watershed, while the area of the overland flow watershed is approximately 100.5 acres (including the lake).

Because Crystal Lake has a direct overland flow basin and contributing basins, it can be modeled as one large basin using the modified SCS method, or by modeling the overland flow portion of the contributing basin using the modified SCS method, and modeling the contributing basin using lake stage at Strawberry Lake and a control elevation. Both variations were evaluated, but the latter was chosen since it was believed that modeling the lake using both channel and overland flow was more realistic, and would allow the model to be used to evaluate effects of variations in structure alterations to assist with potential recovery project assessments.

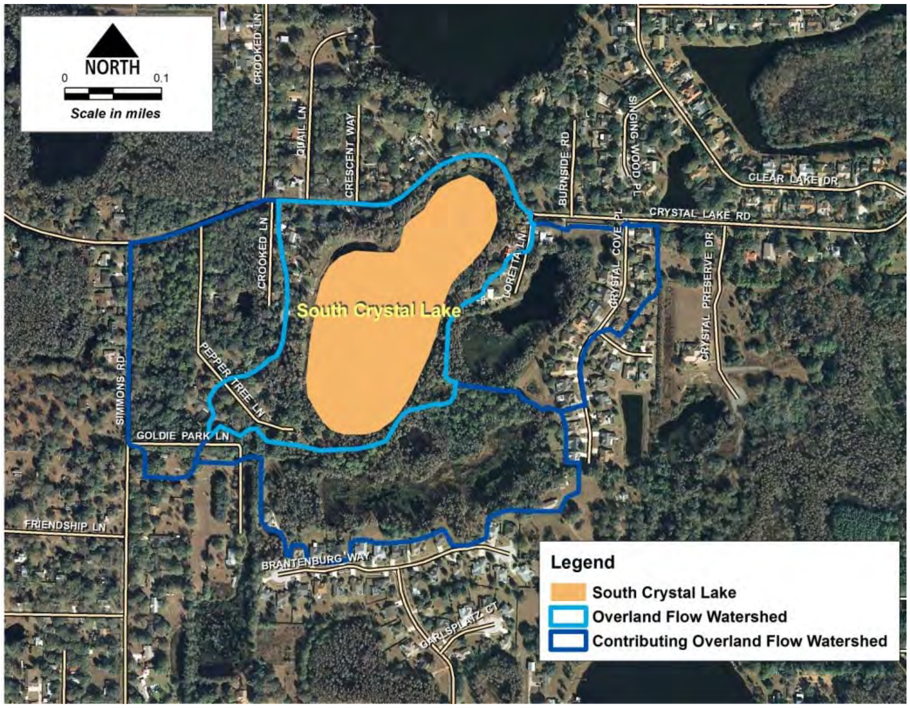

Figure 13. Direct overland flow portion of the Crystal Lake watershed.

The DCIA and SCS CN used for the direct overland flow portion of the watershed are listed in Table 1. Curve numbers were difficult to assess. The soils in the area of the lake are B/D or D soils. The B/D soil type means that the characteristics of the 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 a “B” soil. Because of the proximity of the wellfields to the area being modeled, water levels have been historically lowered by the withdrawals, and therefore the soils in the area may have had lower runoff rates during that time (characteristic of a “B” soil). Groundwater withdrawals during the period of calibration were, however, significantly reduced relative to historic withdrawal rates, so the soils in the area may have begun to exhibit runoff properties more characteristic of “D” soils.

Additionally, much of the contributing watershed via overland flow contains wetlands and open water. The watershed to the east and south of the lake contain relatively large open waterbodies that do not connect to the lake until elevations of 59 feet NGVD 29 are reached (which is control elevation). Therefore, the large storage available in these areas greatly limits the flow to Crystal Lake.

For purposes of this model, taking into account the range of conditions experienced, a compromise was used for the CN. No direct discharges to the lake were identified, so the DCIA of the watershed is zero.

Table 1. Model inputs for the Crystal Lake water budget model.

Input Variable	Value
Overland Flow Watershed Size (acres)	100.5
SCS CN of watershed	45
Percent Directly Connected	0
FL Monitor Well Used	Debuel Road Deep
Surf. Aq. Monitor Well(s) Used	Debuel Road Shallow
Fl. Aq. Leakance Coefficient (ft/day/ft)	0.0025
Surf. Aq. Leakance Coefficient (ft/day/ft)	0.002
Outflow K	0.016
Outflow Invert (ft NGVD 29)	59.0
Inflow K	0.009
Inflow Invert (ft NGVD 29)	57.6

Inflow and Discharge via Channels from Outside Watersheds

Inflow and outflow via channels from or to the lake's watershed (i.e. "channel flow") is an important component of the Crystal Lake water budget, although the gradients of the channels are relatively flat, and the inflows to the lake likely occur only during high rainfall events.

To estimate flow out of Crystal Lake, the predicted elevation of the lake from the previous day is compared to the controlling elevation. Control elevations were determined based on professional surveying performed in the area. If the lake elevation is above the controlling elevation, the difference is multiplied by the current area of the lake and an "outflow coefficient." The coefficient represents a measure of channel and structure efficiency, and produces a rough estimate of volume lost from the lake. This volume is then subtracted from the current estimate of volume in the lake. To estimate flow into the lake, the same approach was applied. Monthly lake stage data from Strawberry Lake (infilled to daily) was included in the model, and the elevation of Strawberry Lake each day was compared to the controlling elevation of a 38 by 60 inch reinforced concrete pipe under Crystal Lake Road from Strawberry Lake to Crystal Lake. If the Strawberry Lake elevation is above the controlling elevation, the difference is multiplied by the current area of Crystal Lake and an outflow coefficient. The resulting volume is then added to the current estimate of volume in Crystal Lake.

Discharge from Strawberry Lake flows through a vegetated ditch, under Crystal Lake Road, and into the north end of Crystal Lake (Figure 2). Discharge from Crystal Lake occurs via a ditch on the western side of the lake. The ruins of a structure are found at the lake, although no information on the history of the structure exists. The ditch curves to the north, running northward parallel to the lake. Runoff in the ditch passes through a 38 by 60 inch reinforced concrete pipe under Crystal Lake Road. The controlling elevation was determined to be a high point in the ditch bottom before passing under Crystal Lake Road (59.0 ft NGVD 29).

Flow from and into the surficial aquifer and Upper Floridan aquifer

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

The Debuel Road Deep well is the closest Upper Floridan aquifer monitor well to Crystal Lake, and was used to represent the potentiometric surface at the lake (Figure 6). Because the elevation of recent potentiometric surface maps appears to be within one foot between the lake and the well, no adjustments were made to the water levels of this well for modeling purposes. The Debuel Lake Shallow surficial aquifer monitor well was used to represent the water table elevation near the lake (Figure 6). Since no significant differences in topography exist between the lake and well, no adjustments were made for modeling purposes. A simple approach was used to fill in weekly or monthly data (or missing data) to create daily values by using the last recorded data value.

F. Water Budget Model Approach

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

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

Figure 14 presents the calibration results of the model. Table 2 presents a comparison of the percentiles of the measured data versus the model results. Table 3 presents modeled water budget components for the model calibration period.

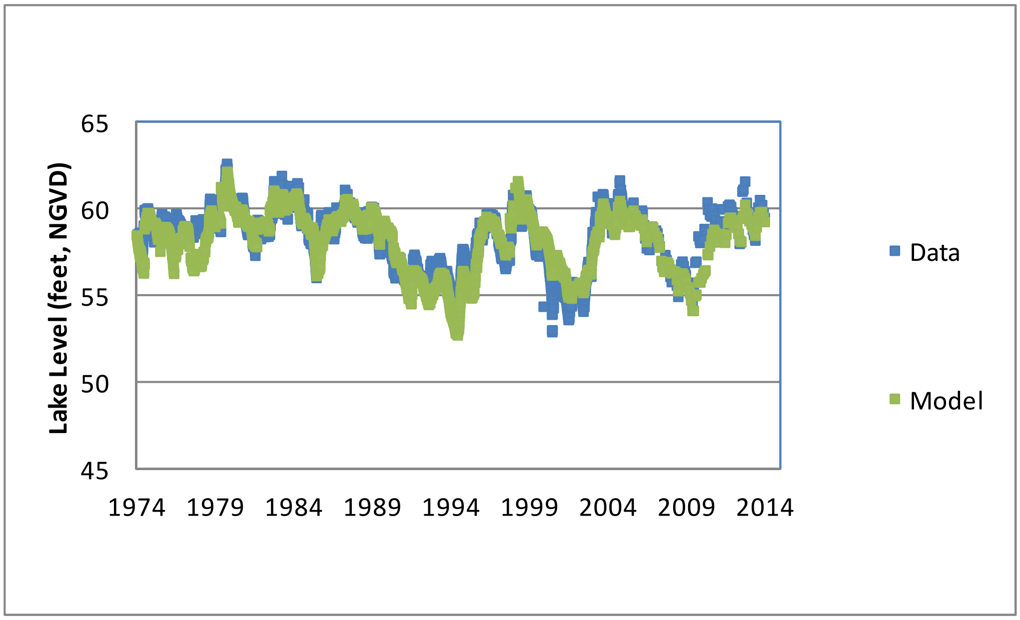

Figure 14. Modeled water levels predicted for the calibrated Crystal Lake water budget (Model) and measured levels used for the model calibration (Data).

Table 2. Comparison of percentiles of measured lake level data compared to calibration percentiles from the model (all in feet NGVD 29).

	Data	Model
P10	60.4	60.3
P50	58.8	58.8
P90	55.8	55.5

Table 3. Crystal Lake Water Budget (1974-2013)

Inflows	Rainfall	Surficial Aquifer Ground water Inflow	Floridan Aquifer Ground water Inflow	Runoff	DCIA Runoff	Aug.	Inflow via channel	Total
Inches/year	56.7	0.6	0.0	4.9	0.0	6.8	70.9	139.9
Percentage	40.6	0.4	0.0	3.5	0.0	4.9	50.6	100.0
Outflows	**Evaporation**	**SURF GW Outflow**	**FL GW Outflow**				**Outflow via channel**	**Total**
Inches/year	58.1	14.6	44.1				22.9	139.7
Percentage	41.6	10.5	31.6				16.3	100.0

G. Water Budget Model Calibration Discussion

Based on a visual inspection of Figure 14, the model appears to be reasonably well calibrated. There are a few periods when the peaks in the modeled hydrograph are higher or lower than the measured values, and these differences contributed to minor differences between the modeled and measured percentiles associated with higher and lower lake levels, i.e., the P10 and P90 percentiles. Reduced precision in the higher and lower ranges of the stage-volume relationships for the lake may also have contributed to the percentile differences.

A review of Table 2 shows that the differences in median (P50) and P10 percentiles between the data and model for the lake are the same within 0.1 feet, while the P90 is off by 0.3 feet (with the model lower). Attempts at better calibration of the P90 resulted in larger differences between the medians. Some of the differences at the higher and lower percentiles may be due to less detail in the higher and lower stage-volume relationships.

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

H. Water Budget Model Results

Groundwater withdrawals are not directly included in the Crystal Lake water budget model, but are indirectly represented by their effects on water levels in the Upper Floridan aquifer. Metered groundwater withdrawal rates from the Section 21 Wellfield are available for the model calibration period, 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. The INTB model has the ability to account for groundwater and surface-water, as well as the interaction between them. The domain of the INTB application includes the Crystal Lake 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. 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. The pre-cutback period in the model is from 1974 through 2004, while the post-cutback period is 2005 through 2013. The model results allowed the drawdowns associated with all permitted withdrawals to be calculated before and after wellfield cutbacks, assuming changes in all other withdrawals are consistent with the modeled period.

The INTB model was run for each withdrawal scenario from 1996 to 2006 using a daily integration step. Drawdown values in feet 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 Section 21 Wellfield in each scenario were 8.9 mgd and 4.2 mgd, respectively.

Results from the INTB modeling scenarios showed that there is a fairly linear relationship between Upper Floridan aquifer drawdown and withdrawal rates at the wellfields. Because of the leaky nature of the confining unit in the area of Crystal Lake, and because the water table in the model is not active, the relationship between groundwater withdrawals in the Upper Floridan and water levels in the surficial aquifer was also of interest. 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 water budget model were adjusted to represent zero withdrawals. For the 1974 to 2013 water budget model period, two periods of adjustment were used to reflect the cutbacks that took place at the Section 21 Wellfield. Adjustments to each Upper Floridan aquifer and surficial aquifer well and the associated adjustment periods are found in Table 4.

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

Well	**Adjustment (feet) 1974 to 2004**	**Adjustment (feet) 2005 to 2013**
Upper Floridan aquifer	3.6	1.5
Surficial aquifer	1.7	0.6

Additionally, because Crystal Lake has experienced a significant amount of augmentation during the modeled period, the augmentation was removed from the model for the scenario runs. This allows the results to represent the hydrology of the lake with no man-made effects (with the exception of permanent structures).

Figure 15 presents measured water level data for the lake along with the model's simulated lake levels under Historic conditions, i.e. in the absence of groundwater withdrawals with structural alterations similar to current conditions. Table 5 presents the Historic percentiles based on the model output.

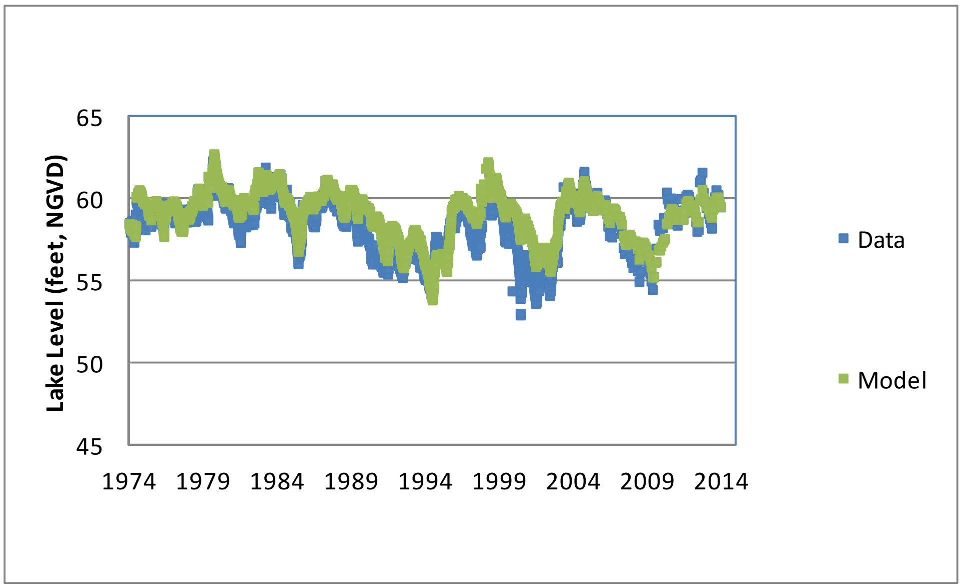

Figure 15. Measured lake levels (Data) and Historic water levels predicted with the calibrated Crystal Lake model (Model).

Table 5. Historic percentiles estimated by the Crystal Lake water budget model (in feet NGVD 29).

Percentile	Elevation
P10	60.8
P50	59.6
P90	56.8

Historic normal pool elevations are established for lakes, ponds and wetlands 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). The normal pool 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 Historic P10 in natural wetlands and lakes, based on observation of many control sites in the northern Tampa Bay area.

Historic normal pools were determined for Crystal Lake based on inflection points of remaining cypress trees. The historic normal pool for Crystal Lake was determined to be 62.7 feet NGVD 29. 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 model's estimate of the Historic P10 for Crystal Lake is approximately 1.9 feet lower than the field determined Historic normal pool. The difference is likely caused by the structural alterations of the lake, since the control point is 3.7 feet lower than the Historic normal pool.

I. Rainfall Correlation Model

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

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 (1974-2013). Rainfall data from the Cresent Lake gage was used to extend data back to January 1972, and the Cosme rain gage (located on the Cosme Wellfield) was used to extend the rain data back to 1945. Finally, rainfall data from the St. Leo gage (Figure 16) were used to extend the data back to 1930. Although the St. Leo gage is approximately 19 miles from Crystal Lake, it is one of only a few rain gages in the vicinity with data preceding 1945, and in this case, is only used in the first few years of the correlation.

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 (1974-2013), and the results from 1946-2013 (68 years) were produced. For Crystal Lake, the 3-year weighted model had the highest correlation coefficient, with an R^2 of 0.51. 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 17.

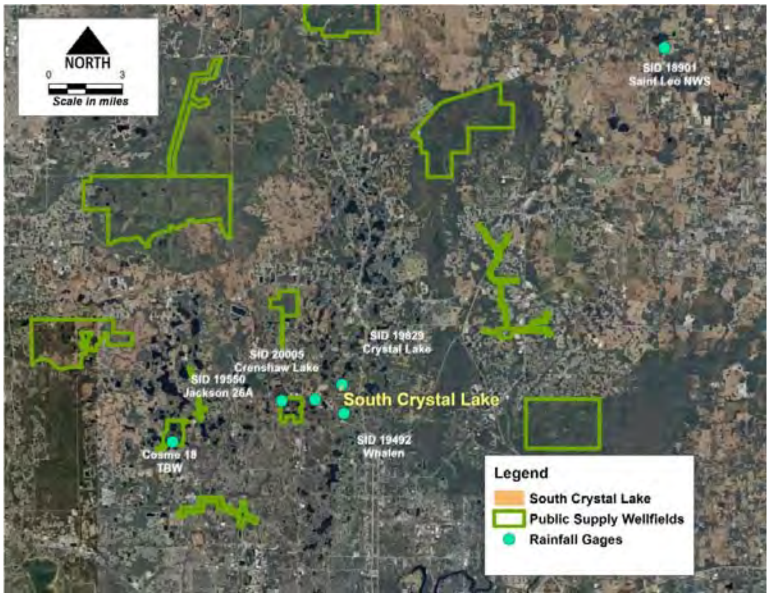

Figure 16. Location of rain stations used for the rainfall correlation model.

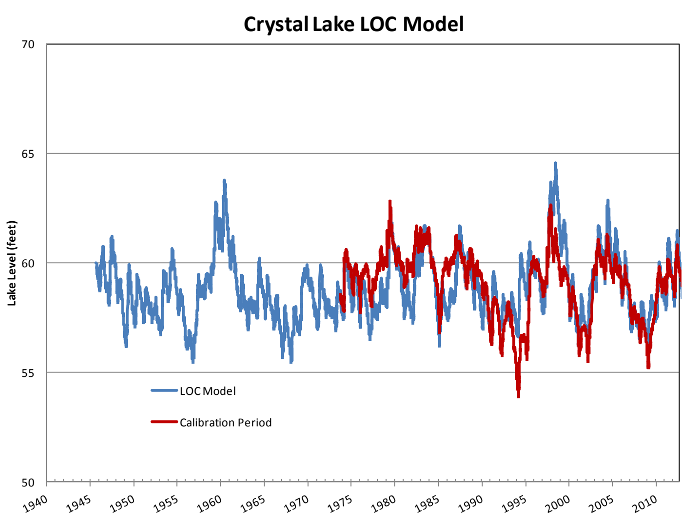

Figure 17. LOC model results for Crystal Lake.

In an attempt to produce Historic percentiles that apply significant weight to the results of the water budget models, the rainfall LOC results for the period of the water budget model are replaced with the water budget model results. Therefore, the LOC rainfall model results are used for the period of 1946-1973, while the water budget results are used for the period of 1974-2013. These results are referred to as the "hybrid model." The resulting Historic percentiles for the hybrid model are presented in Table 6. 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 6) for Crystal Lake are 0.2, 0.6, and 0.1 feet, respectively. Therefore, there are relatively small changes to the Historic percentiles between the two models.

Table 6. Historic percentiles as estimated by the hybrid model from 1946 to 2013 (feet NGVD 29).

Percentile	Crystal Lake
P10	60.6
P50	59.0
P90	56.9

J. Conclusions

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

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Appendix B

Technical Memorandum

March 27, 2015

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

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

Subject: Crystal Lake Initial Minimum Levels Status Assessment

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A. Introduction

The Southwest Florida Water Management District (District) is reevaluating adopted minimum levels for Crystal Lake and is proposing revised minimum levels for the lake, in accordance with Sections 373.042 and 373.0421, Florida Statutes (F.S). Documentation regarding development of the revised minimum levels is provided by Hancock (2014) and Carr (2014).

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 Crystal 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 Crystal 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 proposed for Crystal Lake and any recovery that may be necessary for the lake.

B. Background

Crystal Lake (also known as South Crystal Lake) is located in Hillsborough County approximately 1.5 miles to the northeast of the Section 21 Wellfield, one of the eleven regional water supply wellfields comprising the Central System Facilities (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 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 Section 21 Wellfield (Figures 2 and 3).

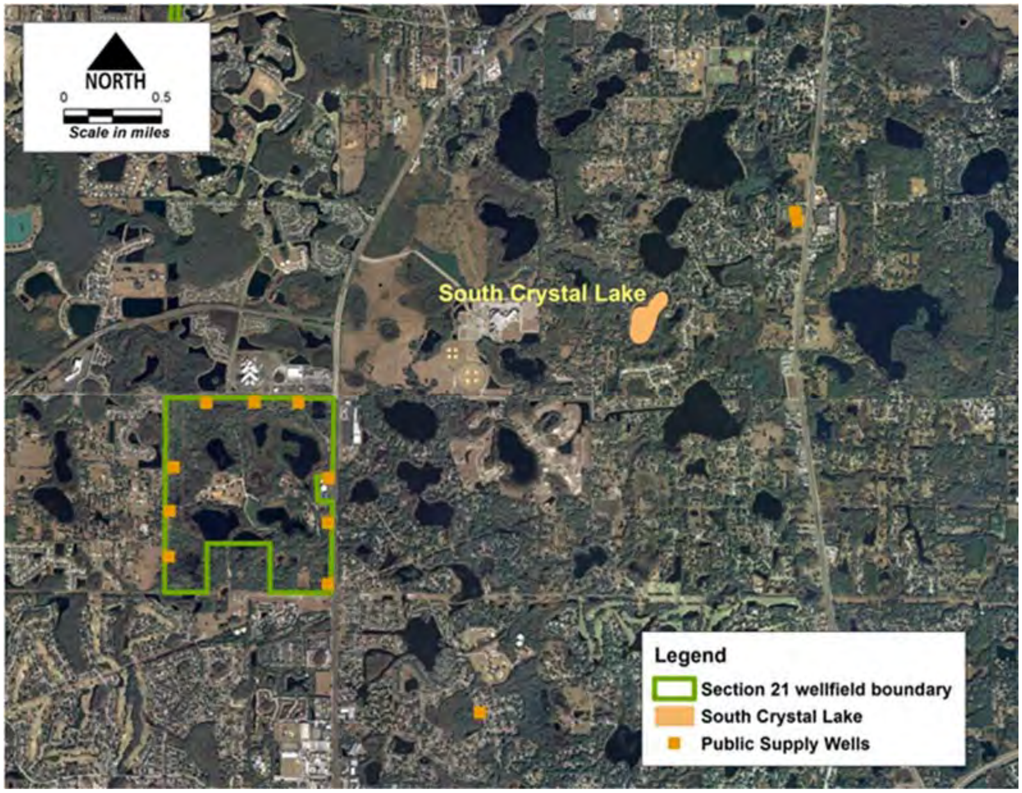

Figure 1. Location of Crystal Lake and the Section 21 Wellfield.

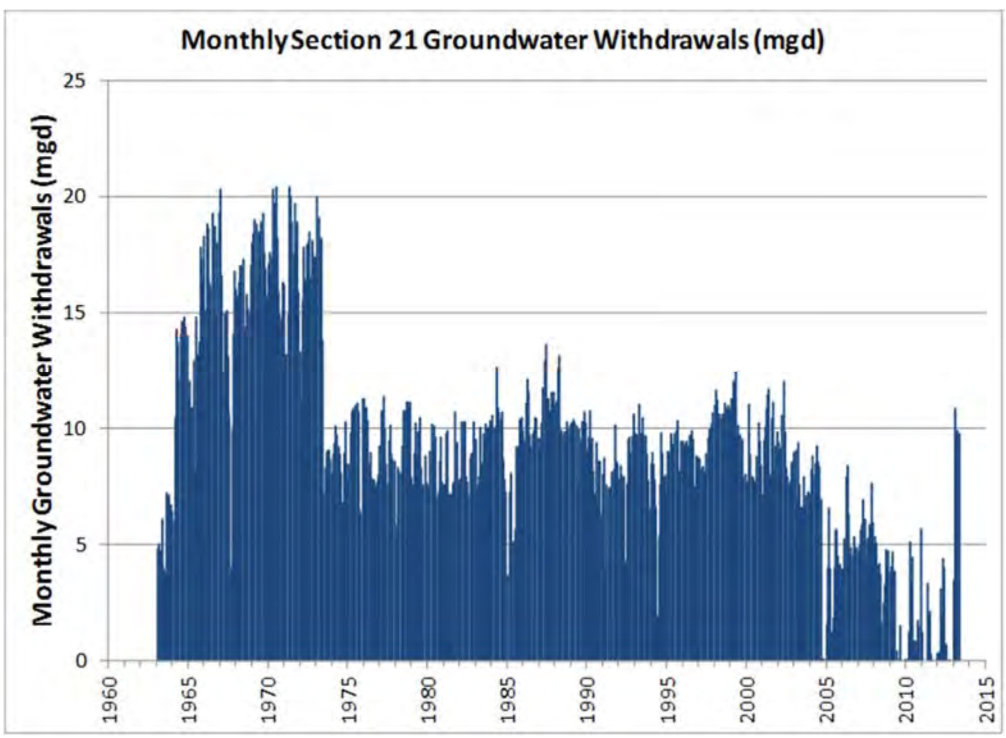

Figure 2. Section 21 Wellfield withdrawals in million gallons per day (MGD).

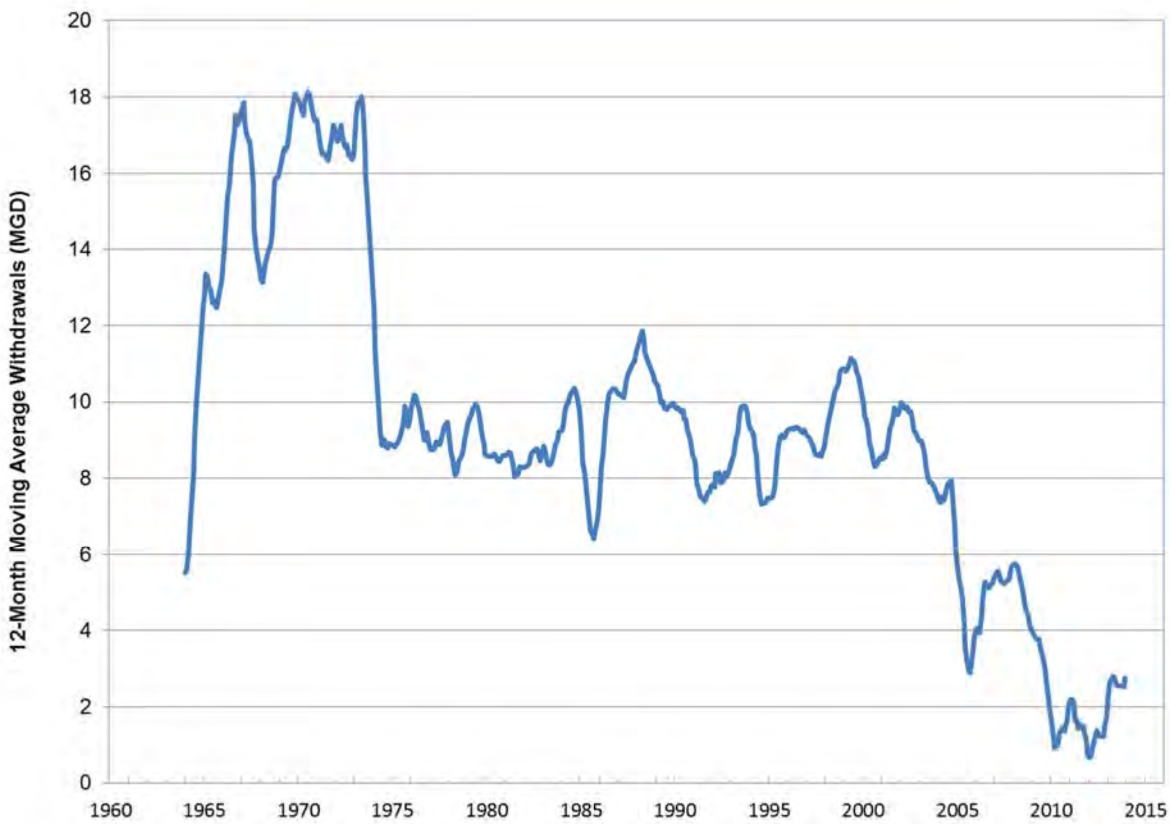

Figure 3. 12-month moving average of Section 21 Wellfield withdrawals in million gallons per day (MGD).

In 1973, due to concerns of low lake levels, lakefront homeowners began augmenting the lake with water withdrawn from the Floridan aquifer (Hancock, 2014). The most recent renewal for the water use permit associated with the augmentation occurred in 1994 (with an extension to 2017 given in 1998), with an average annual rate of 60,000 gpd and maximum of 252,000 gpd. However, no augmentation has been reported since 2003, and it is understood that no augmentation has occurred since that year.

C. Revised Minimum Levels Proposed for Crystal Lake

Revised minimum levels proposed for Crystal Lake are presented in Table 1 and discussed in more detail by Carr (2014). 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 Crystal Lake or minimum flows and levels for any other water body, long-term hydrologic data or model results must be used.

Table 1. Proposed Minimum Levels for Crystal Lake.

Proposed Minimum Levels	**Elevation in Feet** NGVD 29
High Minimum Lake Level	60.4
Minimum Lake Level	59.0

D. Status Assessment

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

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 for Crystal Lake (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 withdrawal rate 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 Crystal Lake (calculated as the average of the drawdown in the model cells on which Crystal Lake is located) 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)
Section 21	8.9	4.2

MGD = million gallons per day

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

Simulation	Surficial Aquifer Drawdown (feet)	Upper Floridan Aquifer Drawdown (feet)
Pre-cutback	1.7	3.6
Post-cutback	0.6	1.5

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

The Crystal Lake Water Budget and LOC models were created as part of the development of the revised minimum levels for Crystal Lake. The Crystal Lake Water Budget model (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 Crystal Lake was calibrated from 1974 through 2013. 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.

The Crystal Lake LOC model (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 are then estimated using long-term rainfall data. In this application, lake levels were 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 variation in rainfall conditions.

Crystal 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 Crystal 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 1974 through 2013 period based on drawdown in the Upper Floridan aquifer associated with the post-cutback wellfield withdrawal rates estimated with the INTB model. Because there is an active water use permit for augmentation of Crystal Lake, the analysis was performed with and without inclusion of reported the augmentation quantities. These interim results are provided in Table 4. Next, these results were correlated with rainfall through the LOC model to develop a 68-year stage record (1946 through 2013) to represent lake levels subjected to the post-cutback withdrawal rates. This analysis was done using the water budget model scenarios with and without augmentation. The correlation lag-period with the best correlation coefficient for the scenario with augmentation was 4 years. The correlation coefficient for the 4-year lag was 0.51. The correlation lag-period with the best correlation coefficient for the scenario without augmentation was also 4 years, with a correlation coefficient of 0.55. Finally, to apply significant weight to the period of the water budget model results, the LOC lake stage values for the period of each 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 1973, while the water budget model results were used for the period from 1974 through 2013. The resulting composite lake stage series is referred to as the Crystal Lake “hybrid” results. Lake stage exceedance percentiles calculated from these results are provided in Table 5. The results of this analysis are compared to revised Minimum Levels proposed for Crystal Lake in Table 6.

Differences in exceedance percentiles presented in Tables 4 and 5 are likely attributable to differences in rainfall between the 1946-2013 period used to derive the Crystal Lake hybrid model results and the 1974-2013 period used to develop the Crystal Lake Water Budget model results.

Table 4. Lake stage exceedance percentiles for Crystal Lake derived using the Crystal 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 without Augmentation** Elevation in feet NGVD 29	**Water Budget Model Post-cutback Wellfield Withdrawal Scenario Results with Augmentation** Elevation in feet NGVD 29
P10	60.6	60.6
P50	59.3	59.4
P90	55.8	57.0

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

Percentile	**Water Budget/LOC Model Hybrid Post-cutback Wellfield Withdrawal Scenario Results without Augmentation** Elevation in feet NGVD 29	**Water Budget/LOC Model Hybrid Post-cutback Wellfield Withdrawal Scenario Results with Augmentation** Elevation in feet NGVD 29
P10	60.4	60.4
P50	58.4	58.6
P90	55.8	56.6

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

Percentile	**Water Budget/LOC Model Hybrid Post-cutback Wellfield Withdrawal Scenario Results without Augmentation** Elevation in feet NGVD 29	**Water Budget/LOC Model Hybrid Post-cutback Wellfield Withdrawal Scenario Results with Augmentation** Elevation in feet NGVD 29	**Proposed Minimum Levels** Elevation in feet NGVD 29
P10	60.4	60.4	60.4
P50	58.4	58.6	59.0

Second Approach

The second lake status assessment approach involved using actual lake stage data for Crystal Lake from 2005 through 2013 (representing the period of wellfield cutbacks) to develop an LOC model, combining the LOC and lake stage data into a hybrid result, and comparing the hybrid results to the proposed 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 (2005-2013), which integrated effects of withdrawal rates that occurred during this period, rather than pre-cutback withdrawal rates, which were higher. Note also that any augmentation of the lake during this period would also be reflected in the lake data, but records show that augmentation did not occur during the 2005-2013 period.

The best resulting correlation was for the 3-year weighted period, with a correlation coefficient of 0.74. As before, “hybrid” results were created by replacing the rainfall LOC results with the actual Crystal Lake data for the period of 2005 to 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” data were the same to one-tenth of a foot. 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 proposed for Crystal Lake.

Percentile	**Lake Stage/LOC Model Hybrid Post-cutback Wellfield Withdrawal Scenario Results** Elevation in feet NGVD 29	**Proposed Minimum Levels** Elevation in feet NGVD 29
P10	60.7	60.4
P50	58.3	59.0

Third Approach

The third approach involved comparison of lake stage exceedance percentiles based directly on measured lake level data for Crystal Lake for the period from 2005 through 2013 with the proposed 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 11 years, rather than the longer-term rainfall conditions represented in the 1946 to 2013 LOC model simulations. As with the second approach, the data would reflect any augmentation that had taken place, but, as noted previously, there was no augmentation during this time period. 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 Crystal Lake from 2005 through 2013 (post-cutback) and the revised minimum levels proposed for the lake.

Percentile	**2005 to 2013 Data** Elevation in feet NGVD 29	**Proposed Minimum Levels** Elevation in feet NGVD 29
P10	60.2	60.4
P50	59.4	59.0

Discussion

Table 9 summarizes the results of all three approaches:

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

Percentile	**Approach 1[a] Without Augmentation** Elevation in feet NGVD 29	**Approach 1[a] With Augmentation** Elevation in feet NGVD 29	**Approach 2[b]** Elevation in feet NGVD 29	**Approach 3[c]** Elevation in feet NGVD 29	**Proposed Minimum Levels** Elevation in feet NGVD 29
P10	60.4	60.4	60.7	60.2	60.4
P50	58.4	58.6	58.3	59.4	59.0

[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 proposed for Crystal Lake indicates that the hybrid long-term P10 with or without augmentation is equal to the proposed High Minimum Lake Level. The hybrid long-term P50 with augmentation is 0.4 feet lower than the proposed Minimum Lake Level, while the hybrid long-term P50 without augmentation is 0.6 feet lower than the proposed Minimum Lake Level. Note that no augmentation has occurred since 2003, so the model runs with augmentation don't necessarily represent future augmentation rates. Also note that because augmentation is typically applied during periods when the lake is low, augmentation typically has the greatest effect on the P90, can have some effect on the P50 (depending on the quantities and timing of augmentation), and usually has minimal effect on the P10.

The P10 for the second MFL status assessment approach is 0.3 feet higher than the proposed High Minimum Level, while the P50 is 0.7 feet lower than the proposed Minimum Level. While the P10 is higher using Approach 2 as compared to either variation of Approach 1, the opposite is true for the P50.

The P10 elevation derived from the third approach is 0.2 feet lower than the proposed High Minimum Level, but the P50 elevation is 0.4 feet higher than the proposed Minimum Level. Differences in rainfall between the shorter 2005 to 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 likely contributed to the differences. While the actual average withdrawals from the Section 21 Wellfield from 2005 through 2013 were approximately 3.1 mgd (not greatly different than the 4.2 mgd used in the ITNB model), the average withdrawals from the Section 21 Wellfield for the past 5 years (2009 through 2013) were only 1.8 mgd.

E. Conclusions

Based on the information presented in this memorandum, it is concluded that Crystal Lake water levels are currently below the revised Minimum Lake Level, but a close to or above the revised High Minimum Lake Level proposed for the lake. These conclusions are supported by comparison of long-term modeled lake stage exceedance percentiles with the proposed 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 proposed for the lake may 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, Crystal 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 Crystal 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)). Tampa Bay Water, in cooperation with the District, will assess the specific needs for recovery in Crystal Lake and other water bodies affected by groundwater withdrawals from the Central System Facilities. By 2020, if not sooner, an alternative recovery project will be proposed if Crystal Lake is found to not be meeting its adopted minimum levels. The draft results of the Permit Recovery Assessment Plan are due to the District by December 31, 2018.

F. References

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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.

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Appendix C

Draft Technical Memorandum

June 19, 2014

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

FROM: Jason Patterson, Hydrogeologist, Resource Evaluation Section

Subject: Evaluation of Groundwater Withdrawal Impacts to Crystal Lake

1.0 Introduction

Crystal Lake is located in northwest Hillsborough 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 Crystal 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 Crystal Lake

A number of regional groundwater flow models have included the area around Crystal Lake in northwest Hillsborough 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).

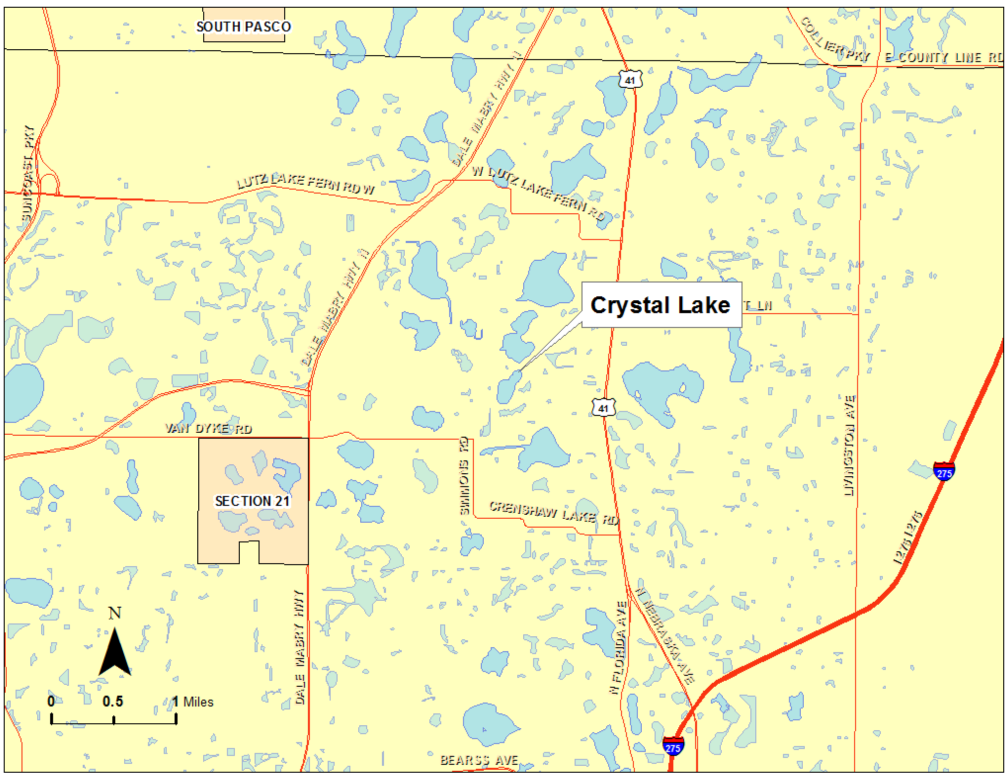

Figure 1. Location of Crystal Lake.

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

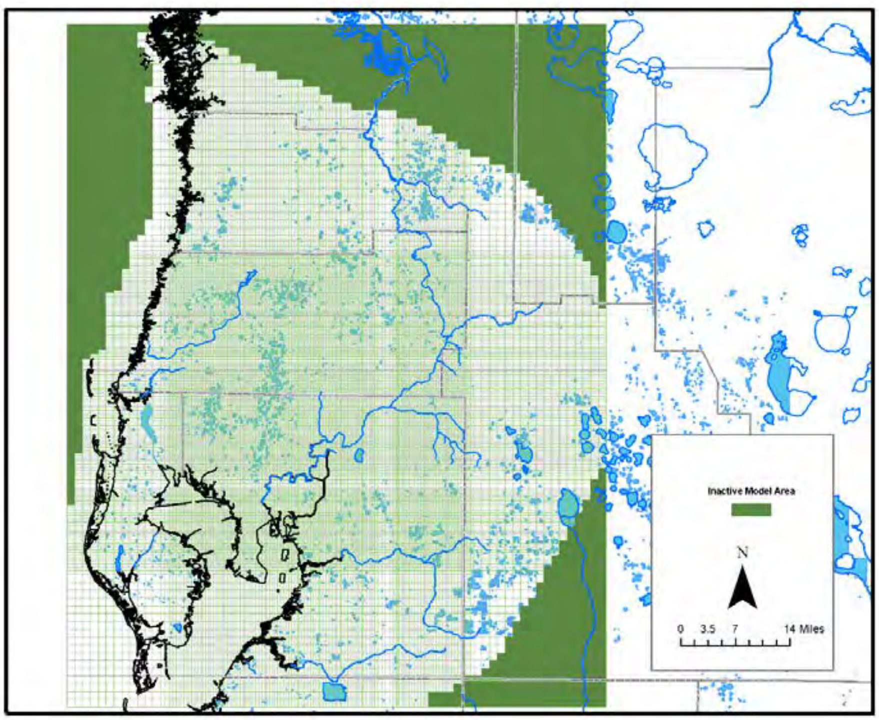

Figure 2. Groundwater grid used in the INTB model

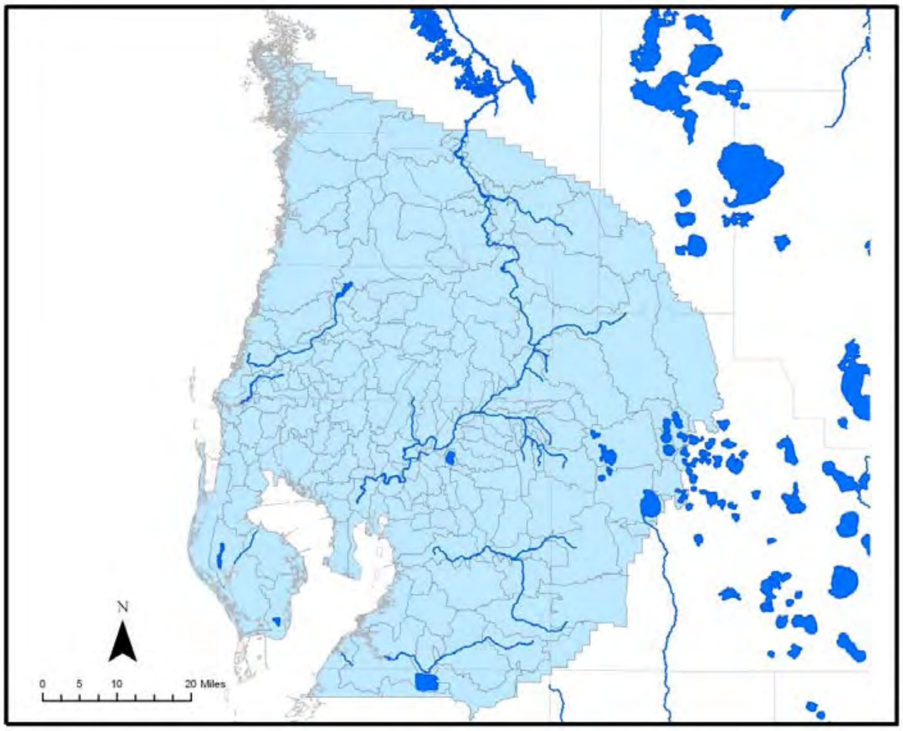

Figure 3. HSPF subbasins in the INTB model.

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 Crystal Lake was 1.3 ft and 4.4 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 Crystal Lake was 0.6 ft. and 1.5 ft. 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 Crystal 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***
Crystal	1.3	0.6
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***
Crystal	4.4	1.5

* Average drawdown from model cells intersecting lake

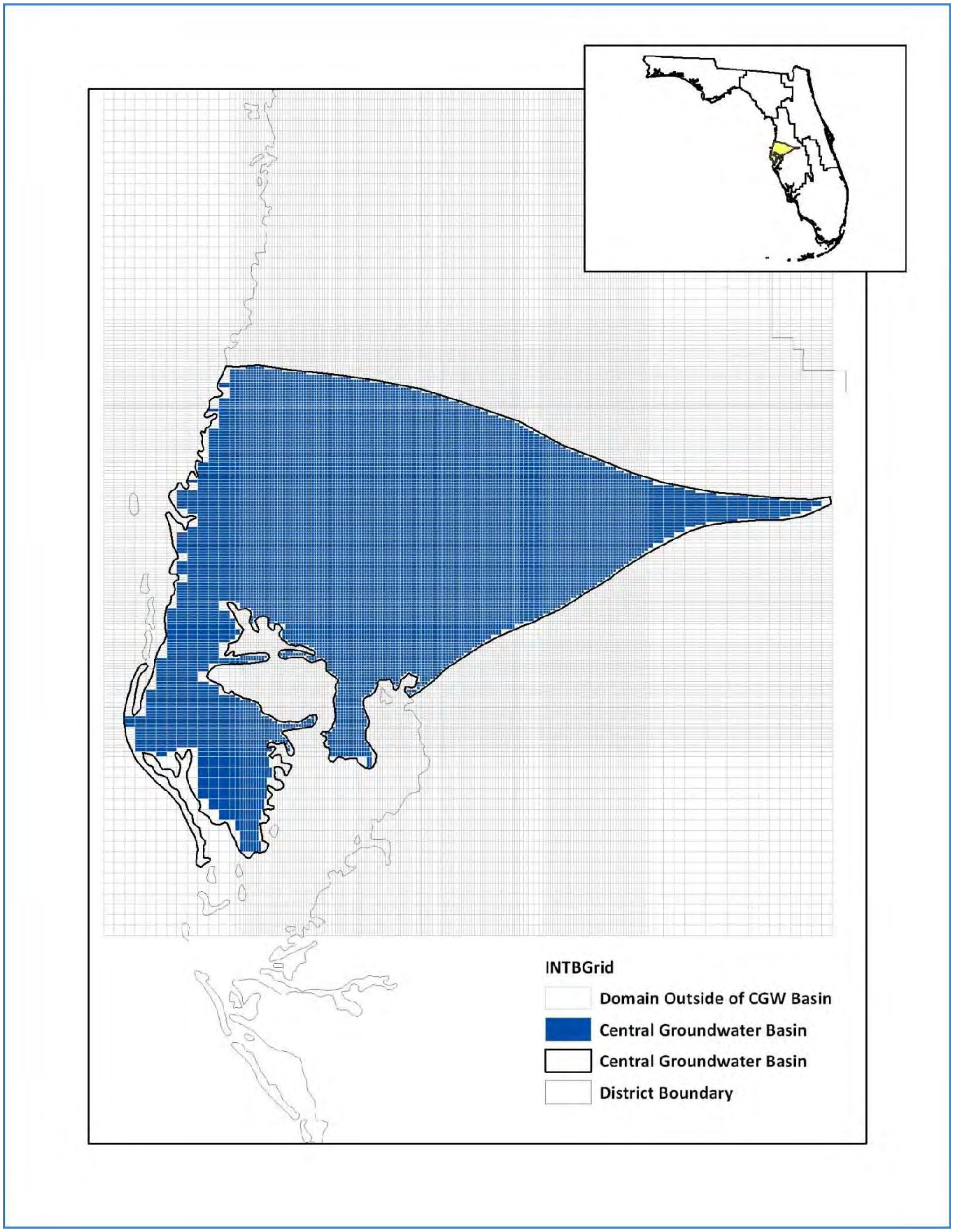

Figure 4. INTB scenarios where impacts to the hydrologic system were simulated due to groundwater withdrawals in the Central West-Central Florida Groundwater Basin.

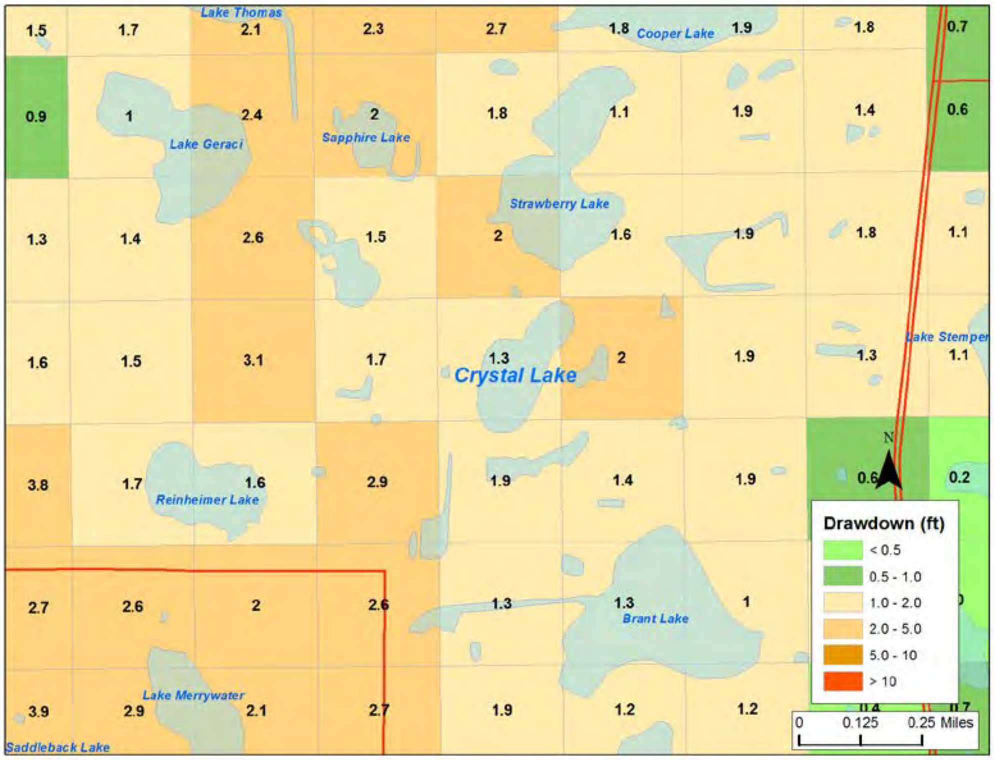

Figure 5. Predicted mean drawdown in the surficial aquifer due to 1989-2000 groundwater withdrawals.

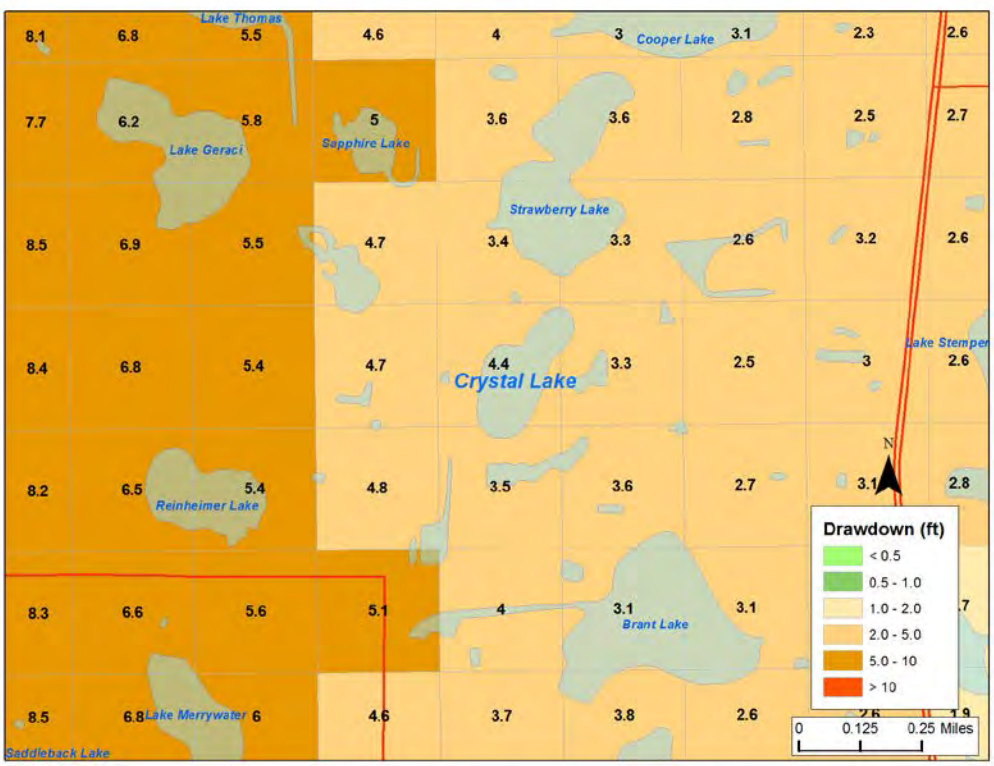

Figure 6. Predicted mean drawdown in the Upper Floridan aquifer due to 1989-2000 groundwater withdrawals.

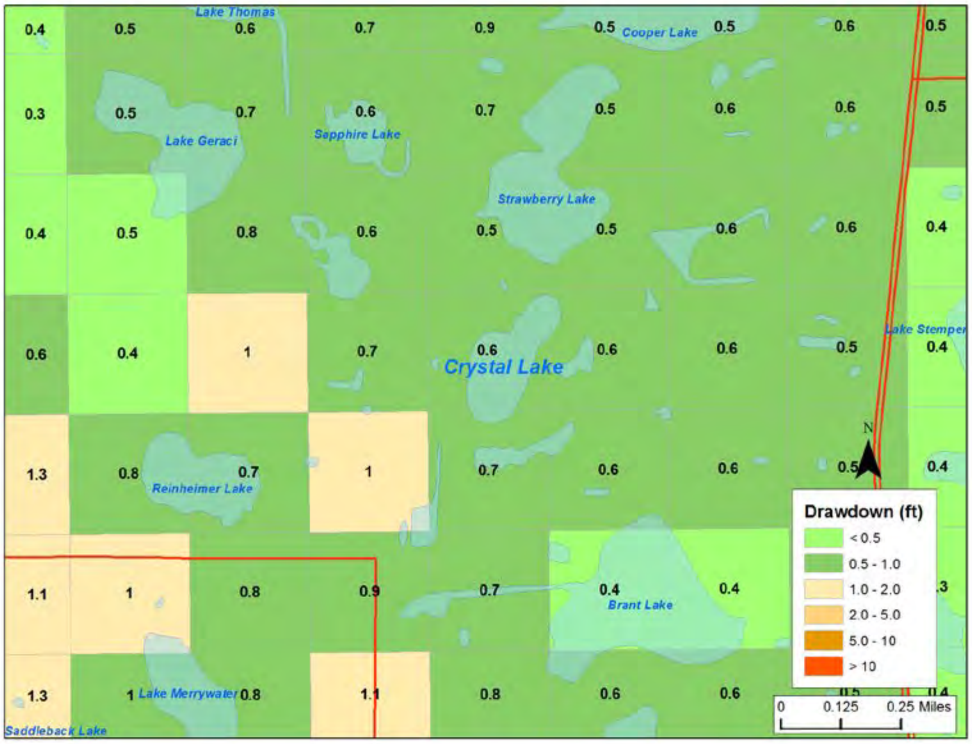

Figure 7. Predicted mean drawdown in the surficial aquifer due to TBW 90 mgd groundwater withdrawals.

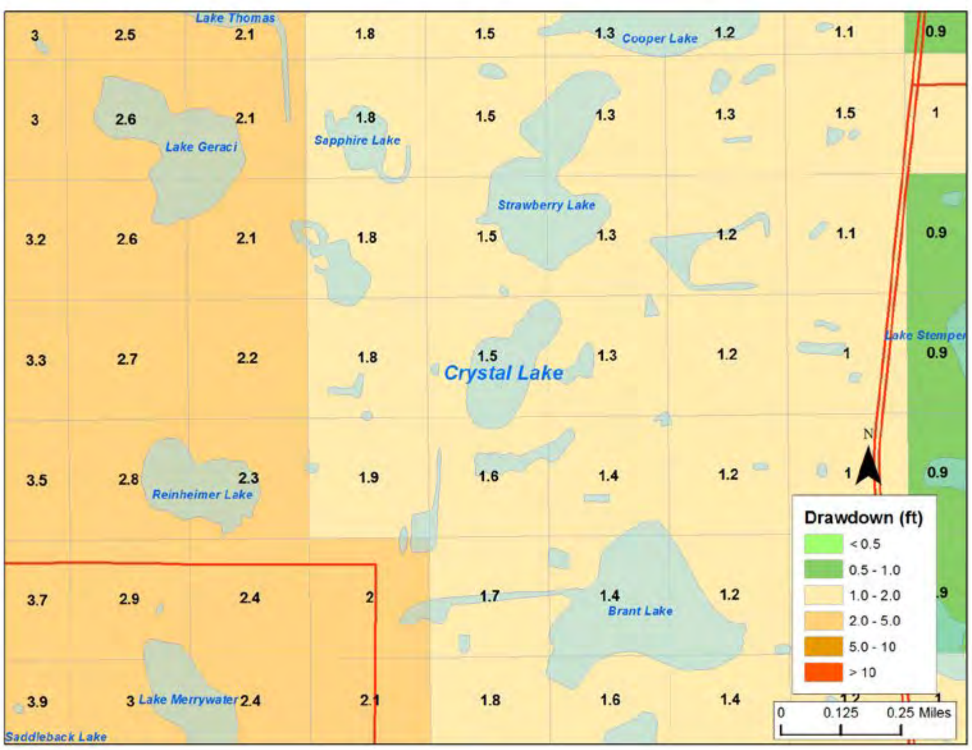

Figure 8. Predicted mean drawdown in the Upper Floridan aquifer due to TBW 90 mgd groundwater withdrawals.

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