Revised Minimum and Guidance Levels Based on Reevaluation of Levels Adopted for Lake Charles in Hillsborough County, Florida

June 10, 2020

Resource Evaluation Section
Water Resources Bureau
Southwest Florida Water Management District

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Cover: 2017 Aerial Imagery of Lake Charles (Southwest Florida Water Management District).

Contents

Definitions

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

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

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

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

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

Introduction

Reevaluation of Minimum Flows and Levels

This report describes the development of minimum levels and guidance levels for Lake Charles in Hillsborough County, Florida. These levels were developed based on the reevaluation of minimum and guidance levels approved by the Southwest Florida Water Management District (District) Governing Board in August 2004 and subsequently adopted into District rules. The minimum and guidance levels represent necessary revisions to the previously adopted levels.

Lake Charles was selected for reevaluation based on development of modeling tools used to simulate natural water level fluctuations in lake basins that were not available when the previously adopted minimum levels for the lake were developed. Adopted levels for Lake Charles were also reevaluated to support ongoing District assessment of minimum flows and levels and the need for additional recovery in the Northern Tampa Bay Water Use Caution Area (NTB WUCA), a region of the District where recovery strategies are being implemented to support recovery to minimum flow and level thresholds.

Following Governing Board approval on December 10, 2019, the levels became effective on May 27, 2020.

Minimum Flows and Levels Program Overview

Legal Directives

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

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

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

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

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

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

Programmatic Description and Major Assumptions

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

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

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

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

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

Consideration of Changes and Structural Alterations and Environmental Values

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

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

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

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

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

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

Categorical significant change standards and other available information are developed to identify criteria that are sensitive to long-term changes in hydrology and can be used for establishing minimum levels. For all lake categories, the most sensitive, appropriate criterion or criteria are used to develop minimum levels. For Category 1 or 2 Lakes, a significant change standard, referred to as the Cypress Standard, is developed. The Cypress Standard is 1.8 feet below the normal pool elevation. For Category 3 lakes, six significant change standards are typically developed. Other available information, including potential changes in the coverage of herbaceous wetland and submersed aquatic plants, is also considered when establishing minimum levels for Category 3 Lakes. The standards and other available information are associated with the environmental values identified for consideration in Rule 62-40.473, F.A.C., when establishing MFLs (Table 1). The specific standards and other information evaluated to support development of minimum levels for Lake Charles are provided in subsequent sections of this report. More general information on the standards and other information used for consideration when developing minimum lake levels is available in the documents identified in the preceding sub-section of this report.

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

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

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

Lake Classification

Lakes are classified as Category 1, 2, or 3 for Minimum Levels development. According to Rule 40D-8.624, F.A.C., Lake Charles meets the classification as a Category 1 lake, with more than 0.5 acre of fringing cypress wetlands. The standards associated with Category 3 lakes described below will also be developed in a subsequent section of this report. Although the change standards are not used to establish Minimum Levels for a Category 1 or 2 Lake, they are developed and provided for comparison purposes.

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

The Recreation/Ski Standard is developed to identify the lowest elevation within the lake basin that will contain an area suitable for safe water skiing. The standard is based on the lowest elevation within the basin that can contain a 5-foot deep ski corridor delineated as a circular area with a radius of 418 feet, or a rectangular ski corridor 200 feet in width and 2,000 feet in length (the Ski Elevation), and use of Historic lake stage data or region-specific Reference Lake Water Regime statistics where Historic lake data are not available.

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

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

The Aesthetics Standard is developed to protect aesthetic values associated with the inundation of lake basins. The standard is intended to protect aesthetic values associated with the median lake stage from diminishing beyond the values associated with the lake when it is staged at the Low Guidance Level. The Aesthetics Standard is established at the Low Guidance Level.

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

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

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

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

Minimum and Guidance Levels

Two Minimum Levels and two Guidance Levels are typically established for lakes. Upon completion of a public input/review process and, if necessary completion of an independent scientific review, either of which may result in modification of the proposed levels, the levels are then adopted by the District Governing Board into Chapter 40D-8, F.A.C. (see Hancock *et al.* 2010 for more information on the adoption process). The levels, which are expressed as elevations in feet above the National Geodetic Vertical Datum of 1929 (NGVD29), include the following (refer to Rule 40D-8.624, F.A.C.):

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

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

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

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

The District is in the process of converting from use of the NGVD29 datum to use of the North American Vertical Datum of 1988 (NAVD 88). While the NGVD29 datum is used for most elevation values included within this report, in some circumstances, notations are made for elevation data that was collected or reported relative to mean sea level or relative to NAVD88 and converted to elevations relative to NGVD29.

Development of Minimum and Guidance Levels for Lake Charles

Lake Setting and Description

Lake Charles (Figure 1) is located in Hillsborough County, Florida (Section 23, Township 27 South, Range 18 East) in the Brushy Creek Watershed within the larger, Tampa Bay and Coastal Areas primary basin in the Southwest Florida Water Management District.

The lake's immediate watershed (Figure 2) has a drainage area of approximately 48 acres. The lake has no inlet currently but a structure did exist at one time along the eastern portion of the lake which allowed inflow from Brant Lake to the northeast during high water events (Figure 3). Currently, if the lake is staged higher than 56.5 ft. above NGVD, overland flow may spill along an easement on the northwest side of the lake, and if the lake is staged higher than 57.0 ft above NGVD, overland flow will spill from the site of the former structure on the northeast side of the lake to a culvert system draining under Lake Charles Circle to an adjacent wetland (Figure 3).

There are currently no surface water withdrawals from the lake permitted by the District. There are, however, several permitted groundwater withdrawals in the lake vicinity. The lake has been augmented since 1968 and the augmentation is currently permitted (Water Use Permit No. 4549.004) through July 29, 2020.

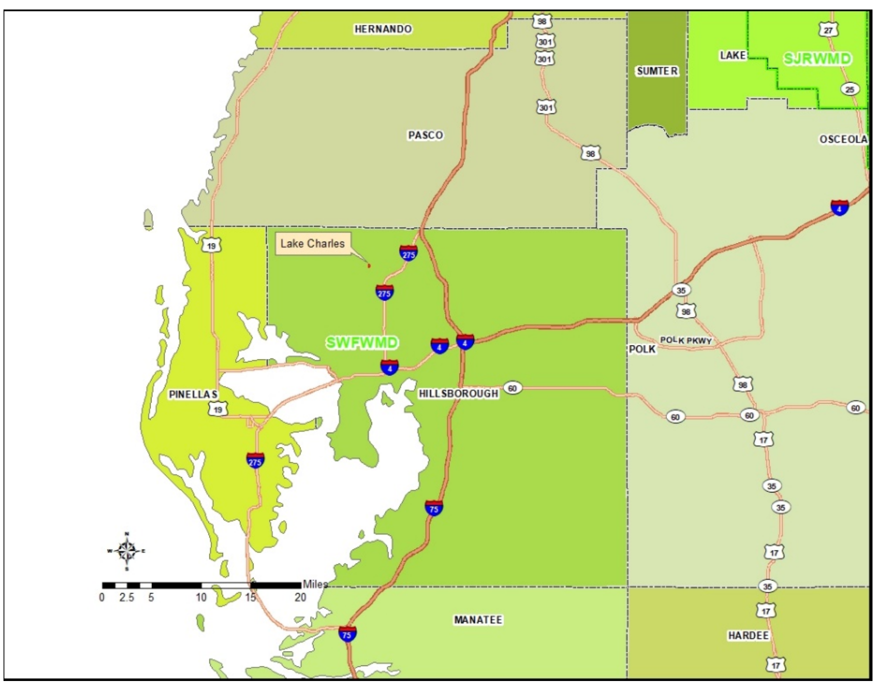

Figure 1: Location of Lake Charles in Hillsborough County, Florida.

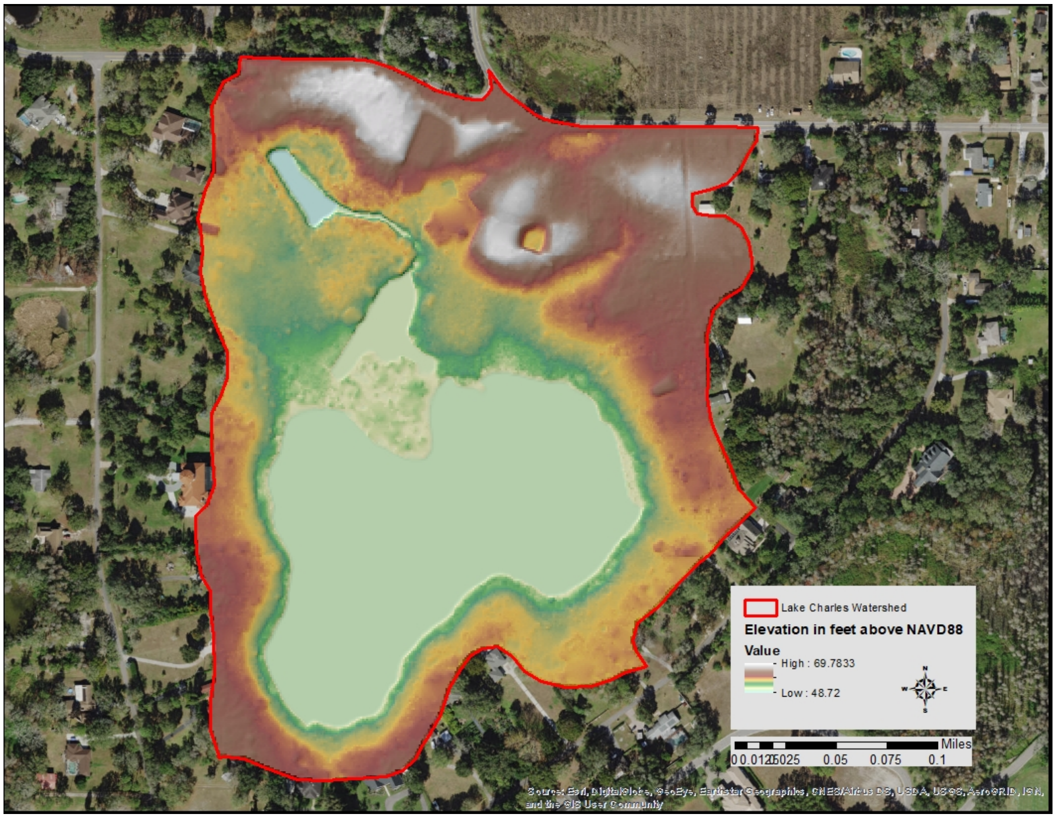

Figure 2: Watershed Delineation and Topography.

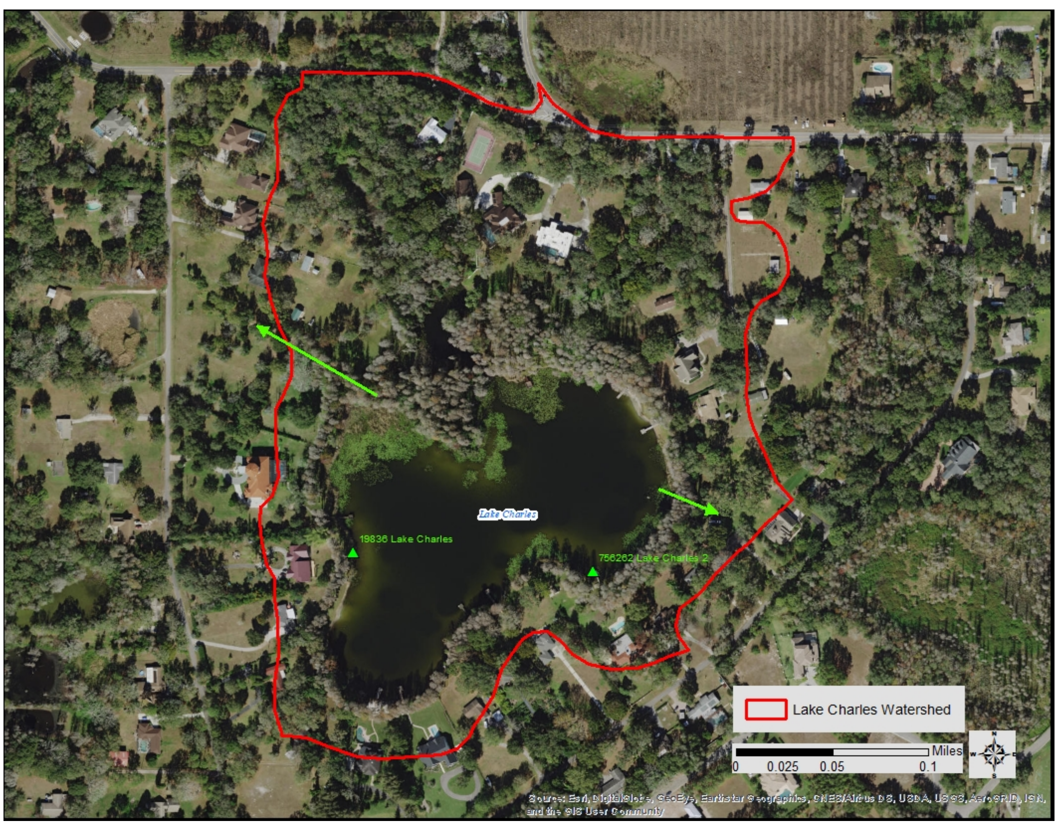

Figure 3: Location of Conveyance Systems and District Gages.

Land Use Land Cover

An examination of the 1950, 1990, and more current 2011 Florida Land Use, Cover, and Forms Classification System (FLUCCS) maps revealed that there has been some change to the landscape (specifically the dominant land forms) in the vicinity during this period (Figure 4, 5, and 6). In 1950 (Figure 4) much of the land surrounding Lake Charles was classified as either pine flatwoods, crop and pastureland; row crops, or cypress. By 1990 (Figure 5) most of the pine flatwoods had been replaced by residential with some large areas of pine flatwoods remaining to the south and some crop and pastureland to the north. By 2011 (Figure 6), more of the pine flatwoods to the south and west of the lake had been replaced with residential as well as more of the crop and pastureland to the northwest of the lake. Figure 7 through Figure 12 aerial photography chronicles landscape changes to the immediate lake basin from 1938 through 2017.

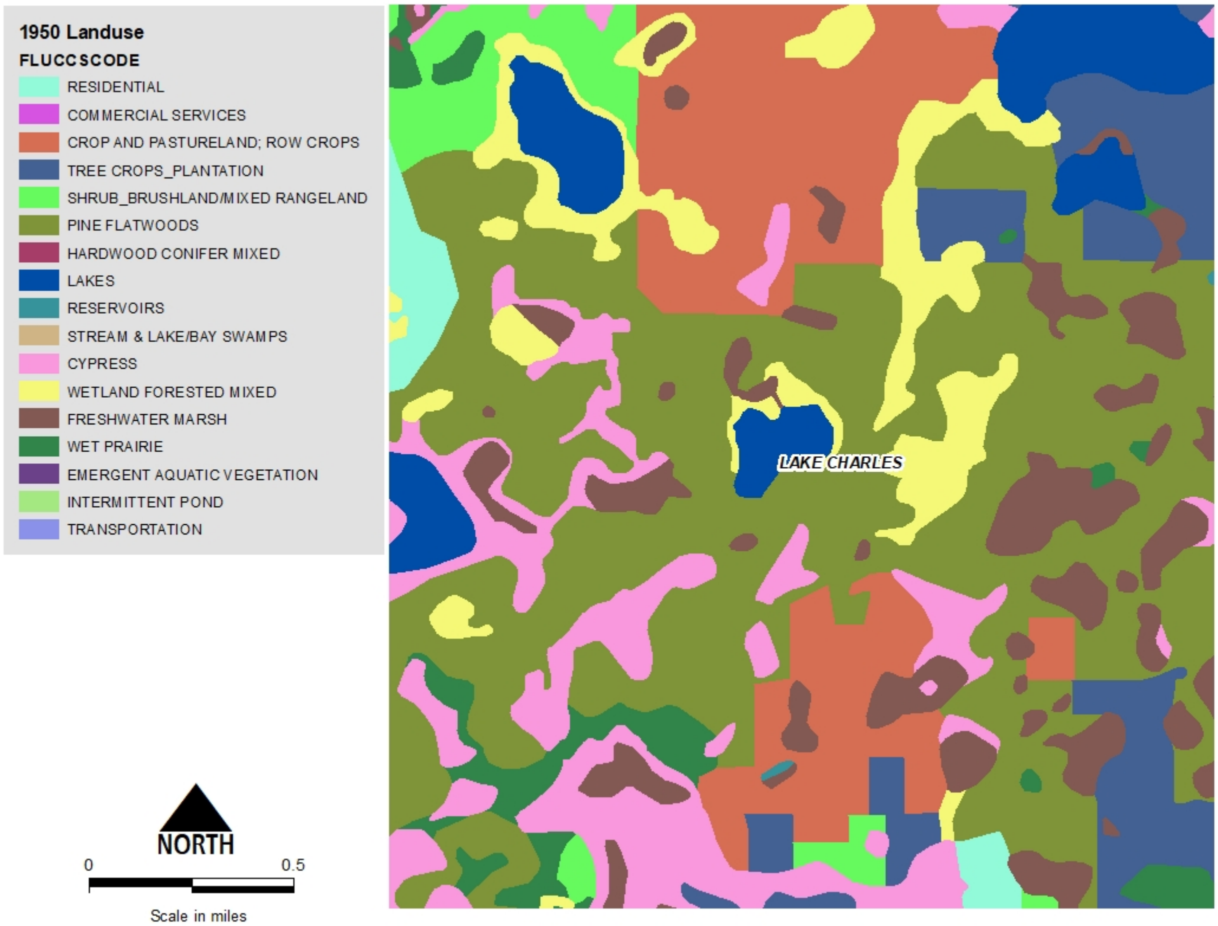

Figure 4: 1950 Land Use Land Cover Map of the Lake Charles Vicinity.

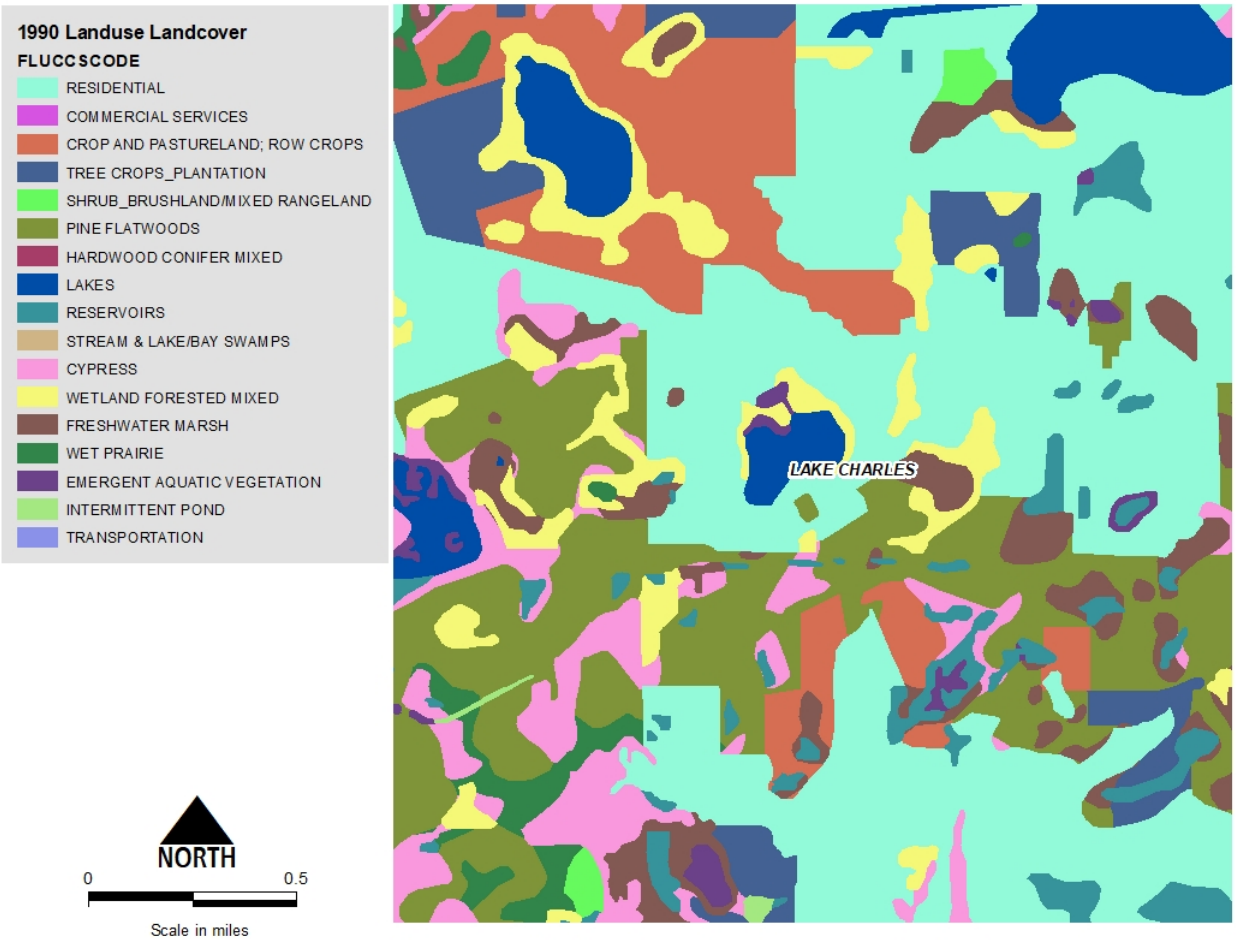

Figure 5: 1990 Land Use Land Cover Map of the Lake Charles Vicinity.

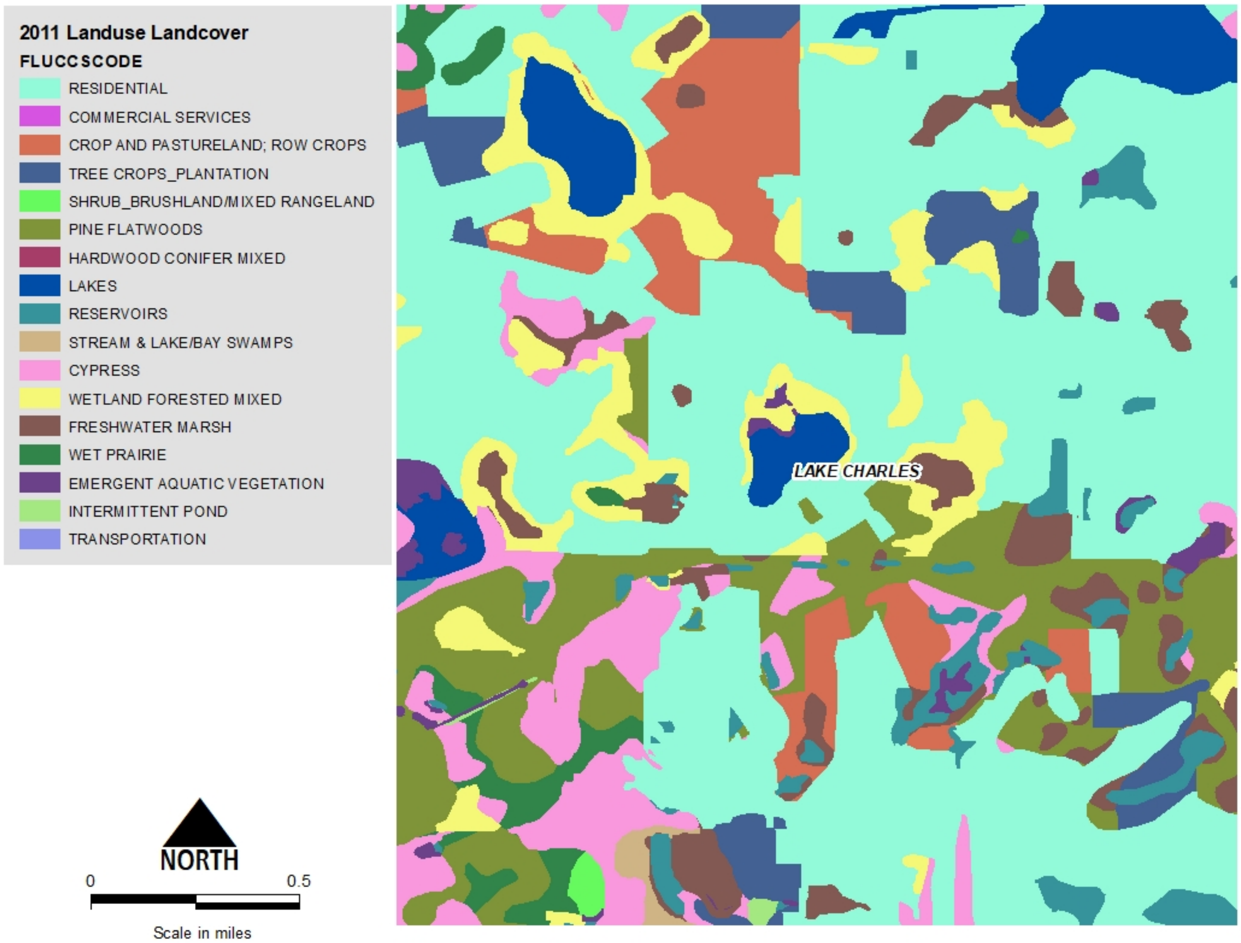

Figure 6: 2011 Land Use Land Cover Map of the Lake Charles Vicinity.

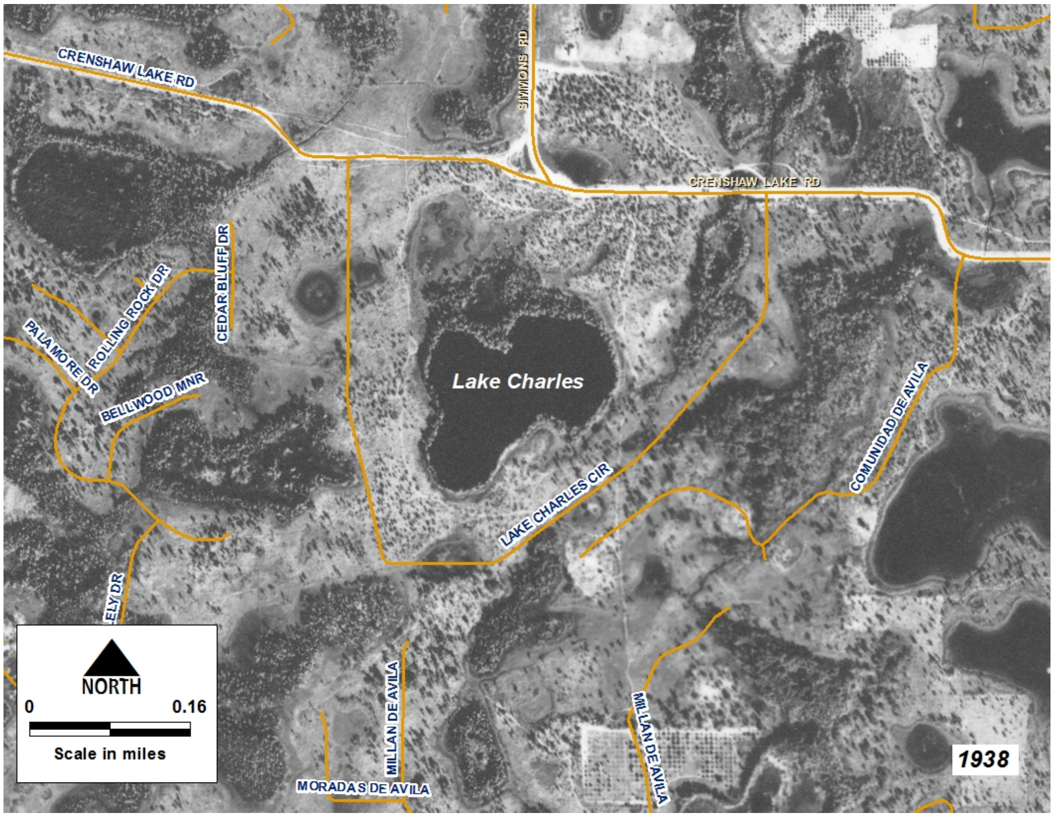

Figure 7: 1938 Aerial Photograph of Lake Charles

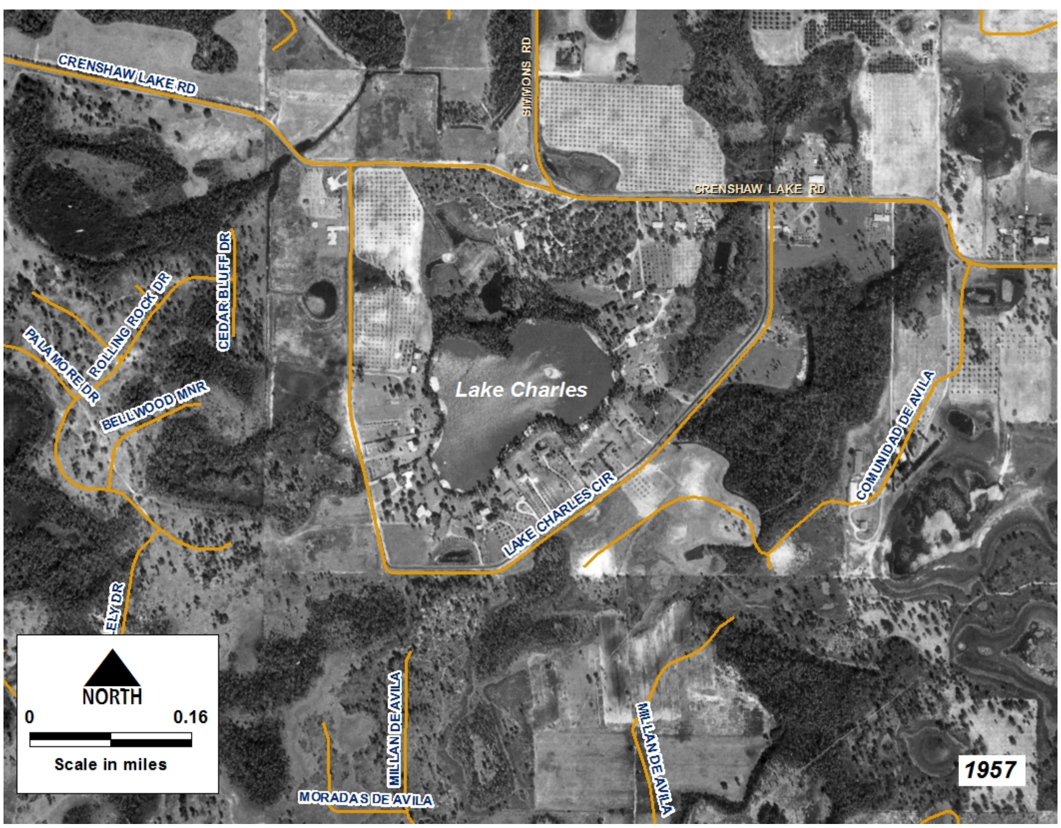

Figure 8: 1957 Aerial Photograph of Lake Charles

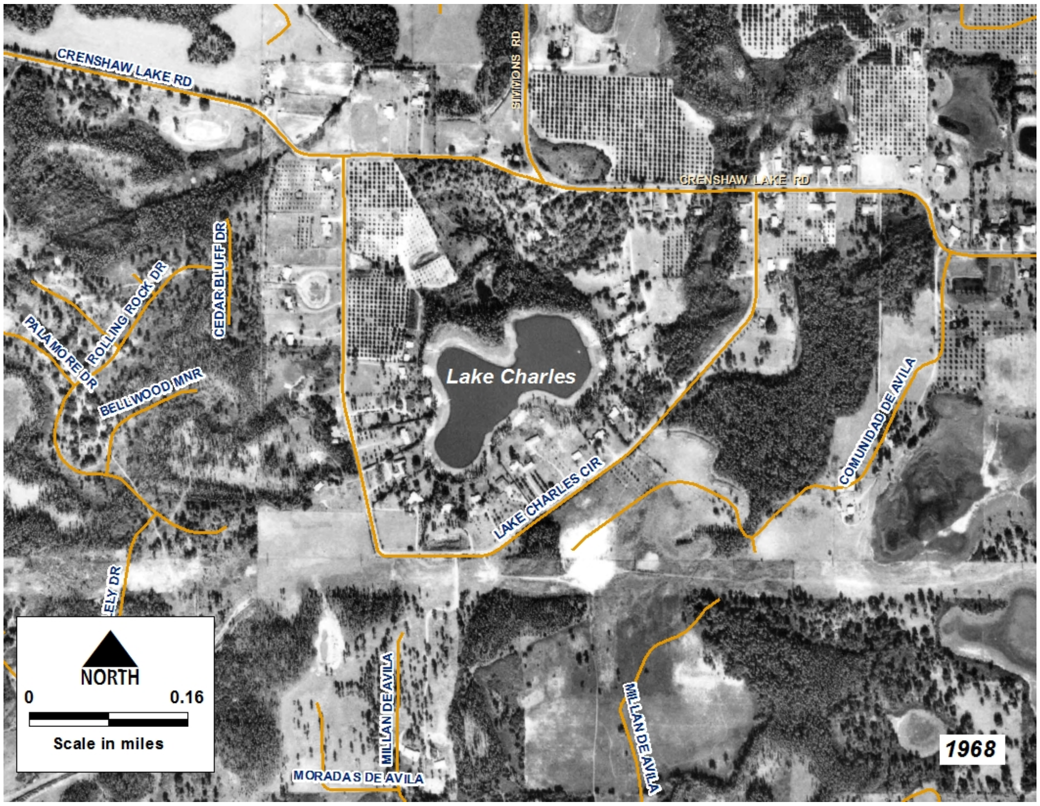

Figure 9: 1968 Aerial Photograph of Lake Charles

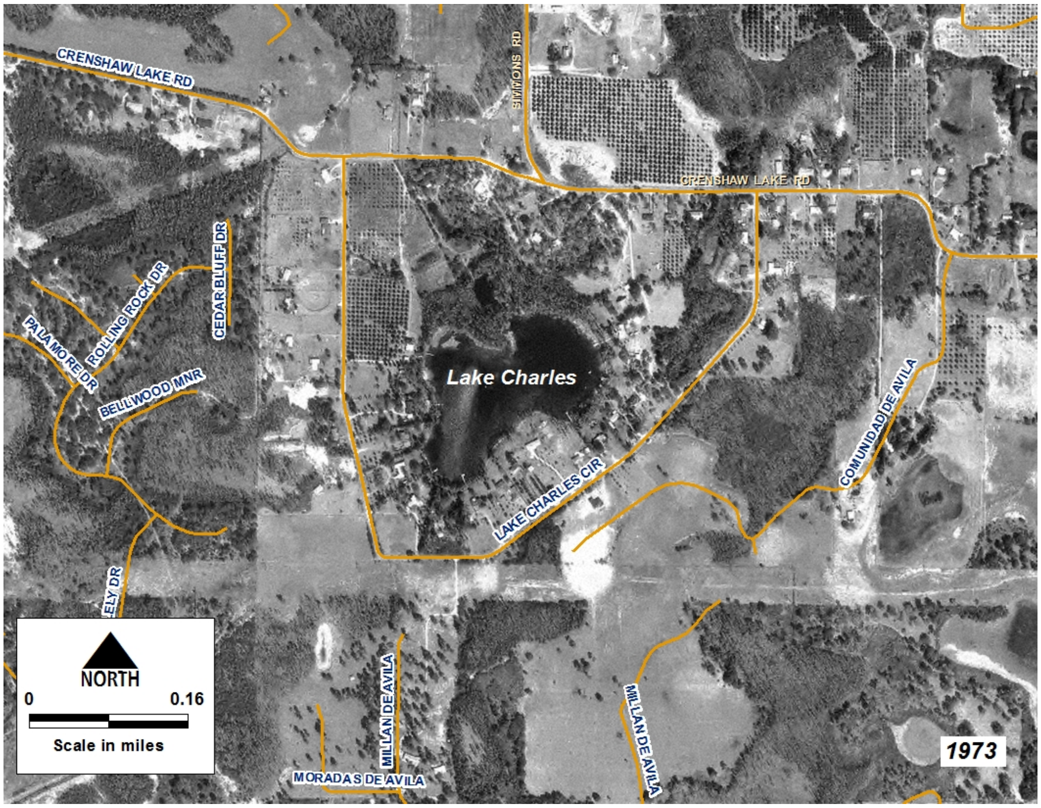

Figure 10: 1973 Aerial Photograph of Lake Charles

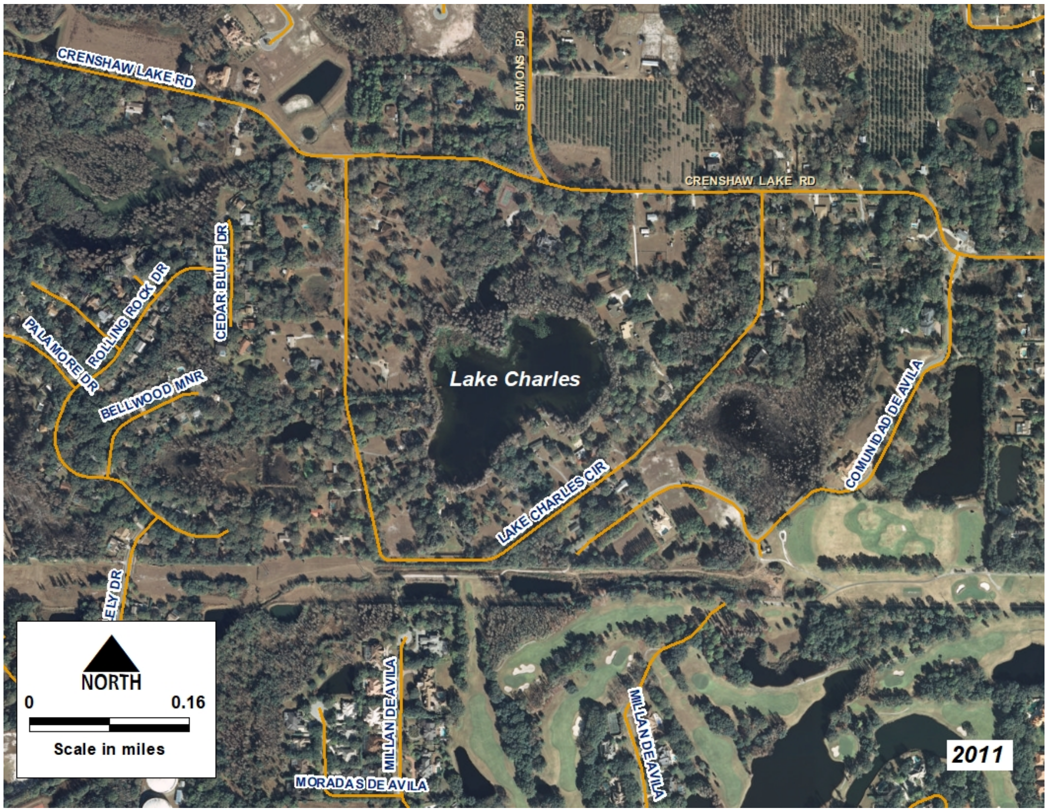

Figure 11: 2011 Aerial Photograph of Lake Charles

Figure 12: 2017 Aerial Photograph of Lake Charles

Bathymetry Description and History

One-foot interval bathymetric data gathered from recent field surveys resulted in lake-bottom contour lines from 39.0 ft. to 53.0 ft., NGVD29 (Figure 13). These data revealed that the lowest lake bottom contour (39.0 ft. NGVD29), or the deepest part of the lake, is located in the northeast quarter of the lake. Additional morphometric or bathymetric information for the lake basin is discussed in the Methods, Results and Discussion section of this report.

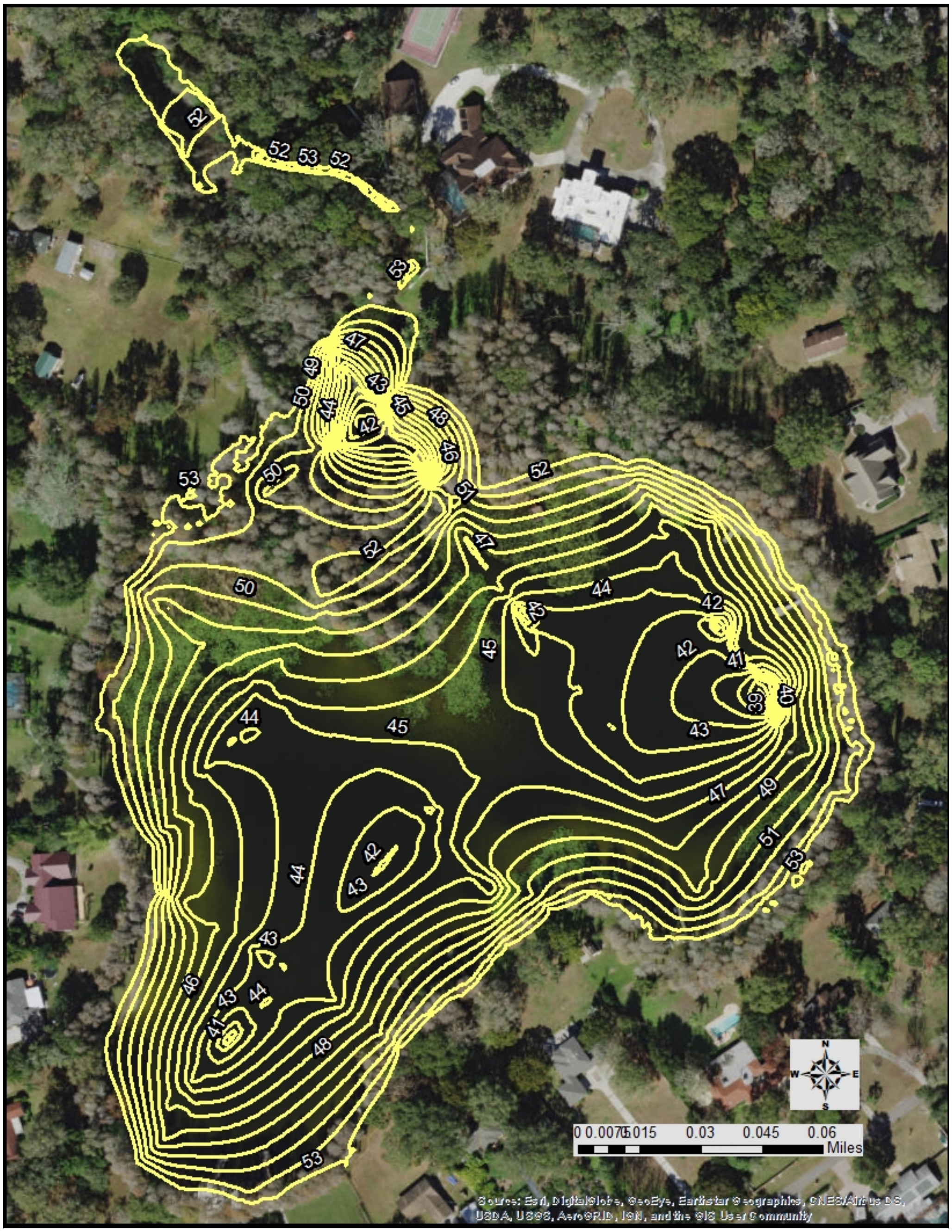

Figure 13: Lake Bottom Contours (ft., NGVD29) on a 2017 Natural Color Aerial Photograph

Water Level (Lake Stage) Record

Lake stage data, i.e., surface water elevations, are available for Lake Charles from the District's Water Management Information System (SID 19836 & 756262) (Figure 14). Data collection began on June 24, 1971 from SID 19836. There was a brief lapse in data collection between January and March 2010, but monitoring began again from SID 756262 on April 21, 2010. Water elevations continue to be monitored on a monthly basis from SID 756262 at the time of this report. On September 15, 2009 the gauge (SID 19836) was adjusted from NGVD29 to NAVD88, using a VERTCON shift of -0.83 ft. On April 21, 2010 staff gauge (SID 756262) was installed to replace SID 19836 due to a loss of access to SID 19836. On May 7, 2015 SID 756262 was adjusted from NGVD29 to NAVD88 using a measured datum shift of -0.94. The highest lake stage elevation on record was 56.93 ft. and occurred on September 28, 1979. The lowest lake stage elevation on record was 47.00 ft. and occurred on February 22, 1985.

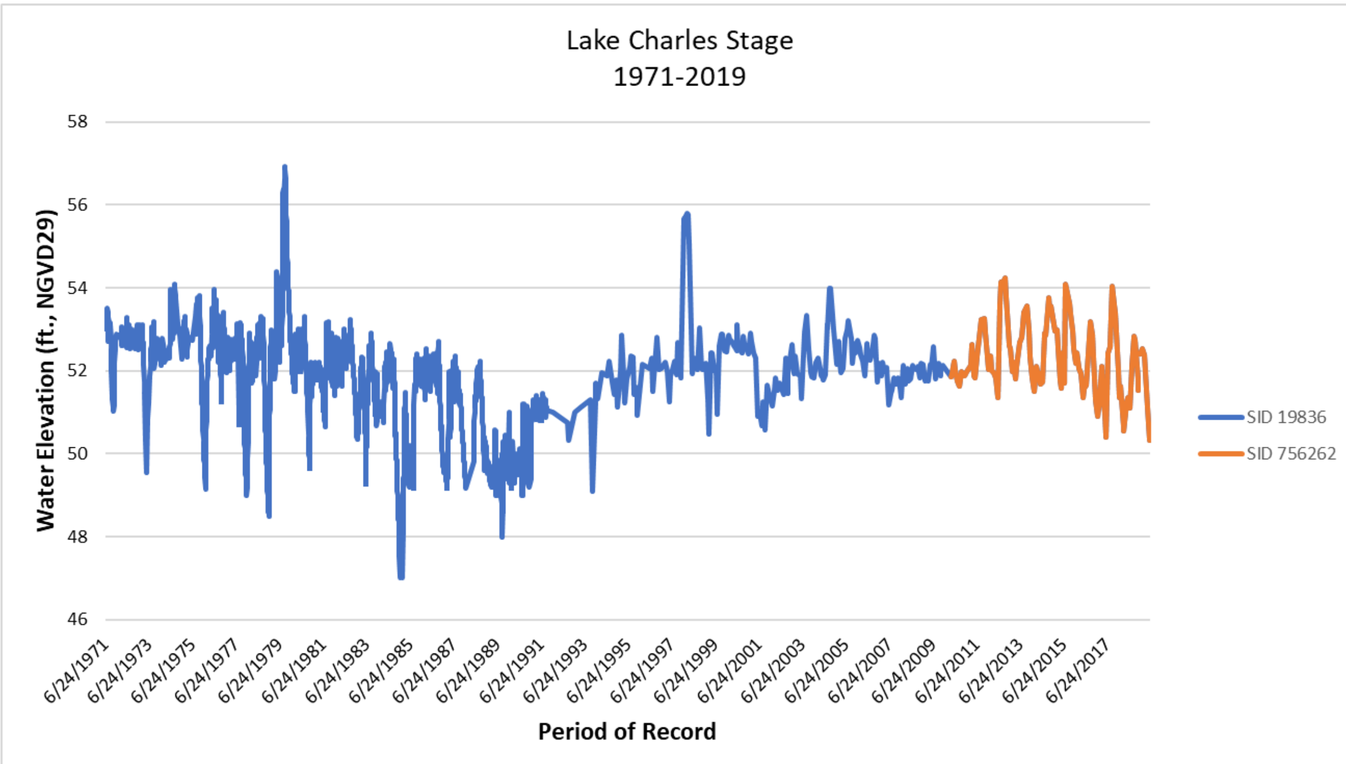

Figure 14: Lake Charles Period of Record Water Elevation Data (SID 19836 & 756262)

Historic Management Levels

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

The District Governing Board first approved Guidance and Minimum Levels for Lake Charles (**Table 2**) in August 2004, which were subsequently adopted into Chapter 40D-8, Florida Administrative Code using the methodology for Category 1 Lakes described in SWFWMD (1999a and 1999b).

Table 2: Minimum and Guidance Levels adopted August 1, 2004 for Lake Charles

Level	Elevation (ft., NGVD)
High Guidance Level	54.2
High Minimum Level	53.8
Minimum Level	52.4
Low Guidance Level	52.1

Methods, Results and Discussion

The Minimum and Guidance Levels in this report were developed for Lake Charles using the methodology for Category 1 lakes described in Chapter 40D-8, F.A.C. Levels, Standards, and other information used for development of the levels, are listed in Table 3, along with lake surface area for each level. Detailed descriptions of the development and use of these data are provided in subsequent sections of this report.

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

Levels	**Elevation in Feet NGVD 29**	**Lake Area (acres)**
Lake Stage Percentiles		
Historic P10 (1946 to 2019)	53.7	16.9
Historic P50 (1946 to 2019)	52.0	14.3
Historic P90 (1946 to 2019)	50.5	12.0
Normal Pool and Control Point		
Normal Pool	Not Determined	NA
Control Point	56.5	25.3
Significant Change Standards*		
Recreation/Ski Standard	NA	NA
Dock-Use Standard	51.7	13.8
Wetland Offset Elevation	51.2	13.0
Aesthetics Standard	50.5	12.0
Species Richness Standard	50.6	12.2
Basin Connectivity Standard	46.7	6.9
Lake Mixing Standard	NA	NA
Minimum and Guidance Levels		
High Guidance Level	53.7	16.9
High Minimum Lake Level	53.3	16.3
Minimum Lake Level	51.9	14.1
Low Guidance Level	50.5	12.0

NA - not appropriate

* Used for comparison purposes only

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

Stage-area-volume relationships were determined for Lake Charles by building and processing a digital elevation model (DEM) of the lake basin and surrounding watershed. Elevations of the lake bottom and land surface elevations were used to build the model through a series of analyses using LP360 (by QCoherent) for ArcGIS, ESRI® ArcMap 10.6 software, the 3D Analyst ArcMap Extension, Python, and XTools Pro. The overall process involves merging the terrain morphology of the lake drainage basin with the lake basin morphology to develop one continuous 3D digital elevation model. The 3D digital elevation model is then used to calculate area of the lake and the associated volume of the lake at different elevations, starting at the largest size of the lake at its peak or flood stage, and working downward to the base elevation (deepest pools in the lake).

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

The DEM created from the combined elevation data sets was used to develop topographic contours of the lake basin and to create a triangulated irregular network (TIN). The TIN was used to calculate the stage areas and volumes using a Python script file to iteratively run the Surface Volume tool in the Functional Surface toolset of the ESRI® 3D Analyst toolbox at one-tenth of a foot elevation change increments. Selected stage-area-volume results are presented in Figure 15.

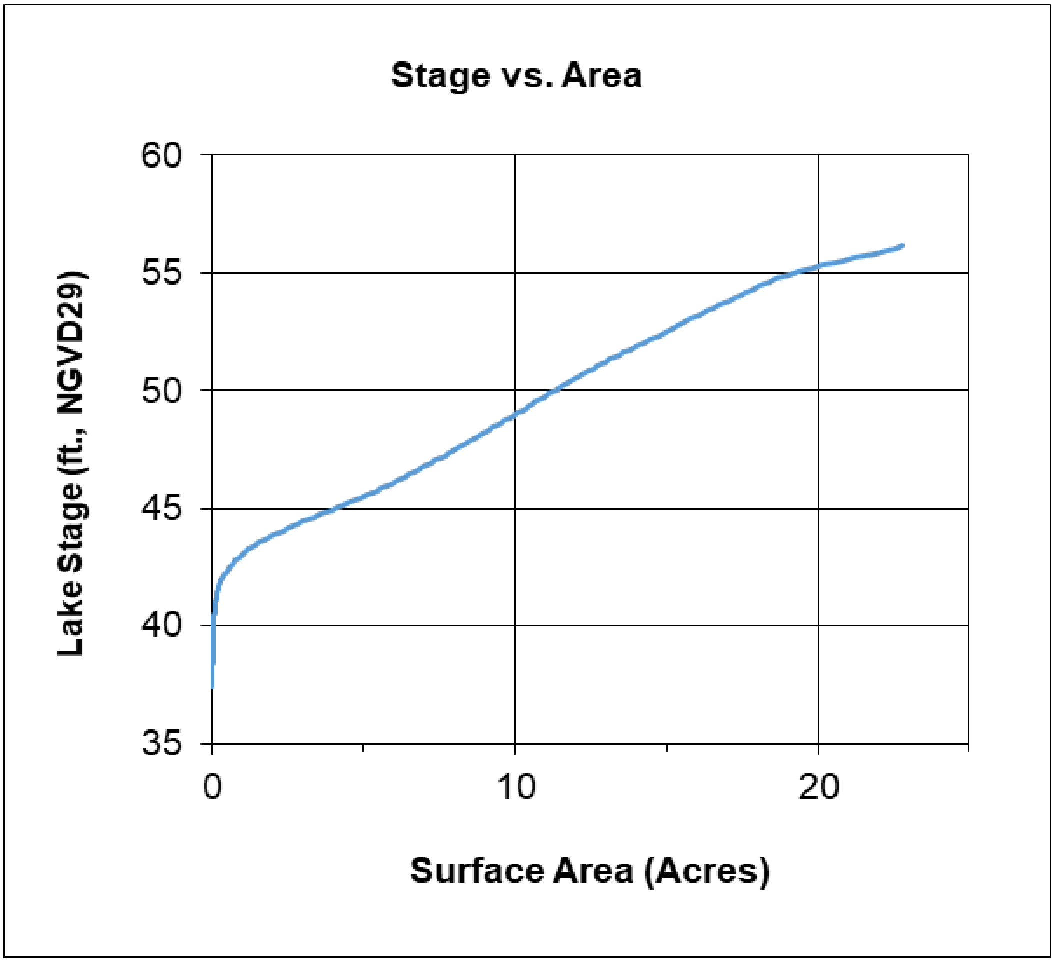

Figure 15: Lake Stage (Ft. NGVD29) to Surface Area (Acres) for Lake Charles.

Development of Exceedance Percentiles

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

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

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

A combination of model data produced a hybrid model which resulted in a 73-year (1946-2019) Historic water level record. Based on this hybrid data, the Historic P10 elevation, i.e., the elevation of the lake water surface equaled or exceeded ten percent of the time, was 53.7 ft. The Historic P50, the elevation the lake water surface equaled or exceeded fifty percent of the time during the historic period, was 52.0 ft. The Historic P90, the lake water surface elevation equaled or exceeded ninety percent of the time during the historic period, was 50.5 ft. (Figure 16 and Table 3).

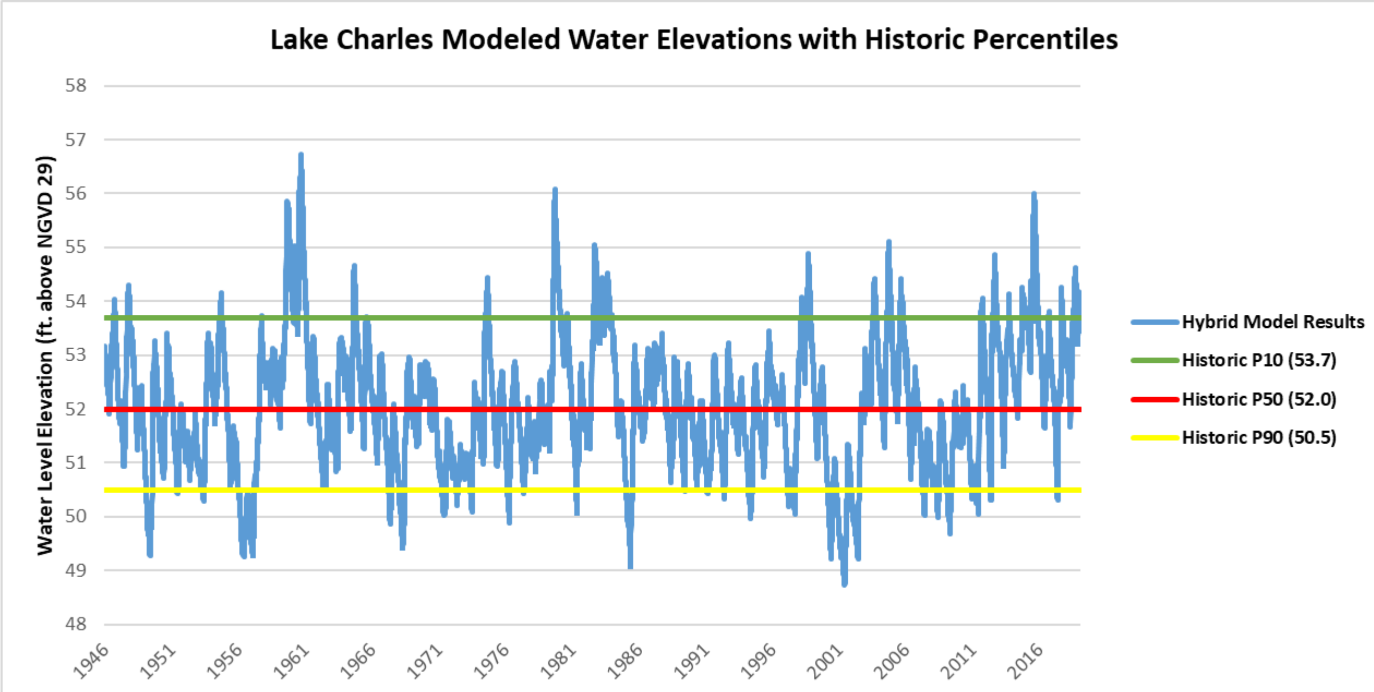

Figure 16: Historic Water Levels (hybrid) Used to Calculate Percentile Elevations Including P10, P50, and P90.

Normal Pool Elevation and Additional Information

The Normal Pool elevation, a reference elevation used for development of minimum lake and wetland levels, is established based on the elevation of hydrologic indicators of sustained inundation. The inflection points (buttress swelling) and moss collars on the trunks of cypress trees have been shown to be reliable biologic indicators of hydrologic Normal Pool (Carr et al. 2006). Four separate field visits in July and October of 2018 and again in June of 2019 resulted in a total of twenty-one measurements of cypress buttress swelling (Table 4). Based on the survey of these biologic indicators, it was determined that the quality of some of the indicators along with the large range in elevations were not appropriate for setting a normal pool elevation.

Additional information to consider in establishing Minimum and Guidance Levels are the Control Point elevation and the lowest building floor (slab) elevation within the lake basin (determined by field survey data). The Control Point elevation is the elevation of the highest stable point along the outlet profile of a surface water conveyance system that can principally control the lake water level fluctuations at the high end. The Control Point for Lake Charles was determined at 56.5 ft., the elevation of a natural high area along the northeast portion of the lake near the fringing cypress wetland. The low floor slab elevation, based on survey reports, was established at 57.4 ft.

Table 4: Summary statistics for hydrologic indicators measured for Normal Pool elevations for Lake Charles (feet NGVD29).

Summary Statistic	Number (N) or Elevation
N	21
Median	53.1
Mean	54.3
Minimum	52.6
Maximum	56.5

Guidance Levels
The High Guidance Level (HGL) is provided as an advisory guideline for construction of lakeshore development, water dependent structures, and operation of water management structures. The High Guidance Level is the expected Historic P10 of the lake and is established using Historic data if it is available, or is estimated using the Current P10, the Control Point elevation and the Normal Pool elevation. Based on the availability of Historic data developed for Lake Charles, the High Guidance Level was established at the Historic P10 elevation, 53.7 ft., NGVD29. Recorded data indicate that the highest levels reached were in late August and September of 1979 with a peak of 56.93 ft., NGVD29 in September 1979.

The Low Guidance Level (LGL) is provided as an advisory guideline for water dependent structures, and as information for lakeshore residents and operation of water management structures. The Low Guidance Level is the elevation that a lake's water levels are expected to equal or exceed ninety percent of the time on a long-term basis. The level is established using Historic or Current lake stage data and, in some cases, Reference Lake Water Regime (RLWR) statistics. Based on the availability of Historic data for Lake Charles, the Low Guidance Level was established at the Historic P90 elevation, 50.5 ft. The recorded period of record indicates the lowest lake level elevation was 47.0 ft., NGVD29, below the Low Guidance Level, in January and February 1985 (Figure 18). The most recent record of the water level dropping below the Low Guidance Level was in June 2019, with a recorded level of 50.3 ft.

Significant Change Standards

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

- The **Recreation/Ski Standard** was not established since a circular ski corridor with a radius of 418 feet or a rectangular corridor 200 x 2,000 feet was not possible. Thus, Lake Charles is classified as a Non-Ski lake.
- The **Dock-Use Standard** was established at an elevation of 51.7 ft. based on the elevation of lake sediments at the end of 10 docks on the lake, a 2-ft. clearance depth, and the difference between the Historic P50 and P90 of 1.5 ft.
- The **Wetland Offset Elevation** was established at 51.2 ft., or 0.8 ft. below the historic P50 elevation.
- The **Aesthetic Standard** was established at the Low Guidance Level elevation of 50.5 ft.
- The **Species Richness Standard** was established at 50.6 ft., based on a 15% reduction in lake surface area from that at the Historic P50 elevation.
- The **Basin Connectivity Standard** was established at an elevation of 46.7 ft. based on a critical high spot elevation of 44.2 ft, the addition of 1 foot, plus the difference between the Historic P50 and P90 of 1.5 ft. This critical high spot is the elevation separating the north and south “pools” of Lake Charles.
- The **Lake Mixing Standard** was not established, as the dynamic ratio does not reach a value of 0.8 (see Bachmann et al. 2000).

Review of changes in potential herbaceous wetland area associated with change in lake stage (Figure 17) did not indicate that use of any of the identified standards would be inappropriate for minimum levels development. Figure 17 shows that as the lake stage increases, the acres available for herbaceous wetland area (acres < 4 ft.) also increase, up until around 47.5 ft. NGVD. The acres available for herbaceous wetlands then decrease as the lake becomes deeper and then increases again as the main pool of the lake connects with the northern pool associated with the fringing cypress wetland on that portion of the lake. The changes in the slope of the line reflects the variation in lake bottom contours and the area which it contains.

Potential change in area available for aquatic plant colonization was not calculated due to insufficient Secchi data available for Lake Charles.

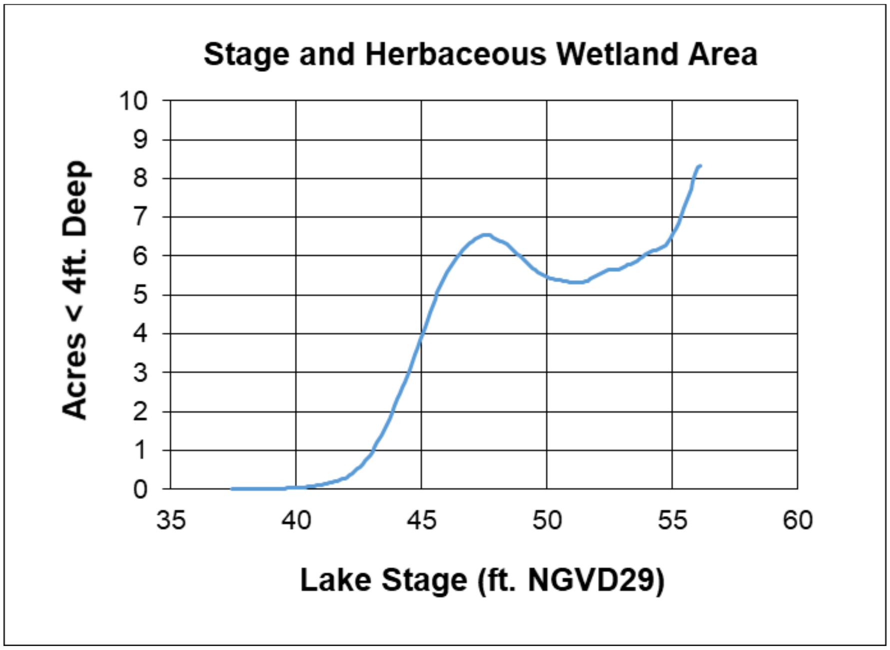

Figure 17: Lake Stage Compared to Available Herbaceous Wetland Area.

Minimum Levels

The Minimum Lake Level (MLL) is the elevation that a lake's water levels are ***required*** to equal or exceed fifty percent of the time on a long-term basis. For a Category 1 lake, Rule 40D-8.624, F.A.C. requires the Minimum Lake Level to be established at the elevation of the Historic Normal Pool minus 1.8 feet. Due to the fact that no reliable Historic Normal Pool elevation could be established using field methods, the MLL was set using the Historic P10 value minus 1.8 feet.

The High Minimum Lake Level (HMLL) is the elevation that a lake's water levels are ***required*** to equal or exceed ten percent of the time on a long-term basis. For a Category 1 lake, Rule 40D-8.624, F.A.C. requires the HMLL to be established at the elevation of the Historic Normal Pool minus 0.4 feet. Since no Historic Normal Pool elevation could be determined for Lake Charles, the HMLL was set using the Historic P10 value minus 0.4 feet.

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

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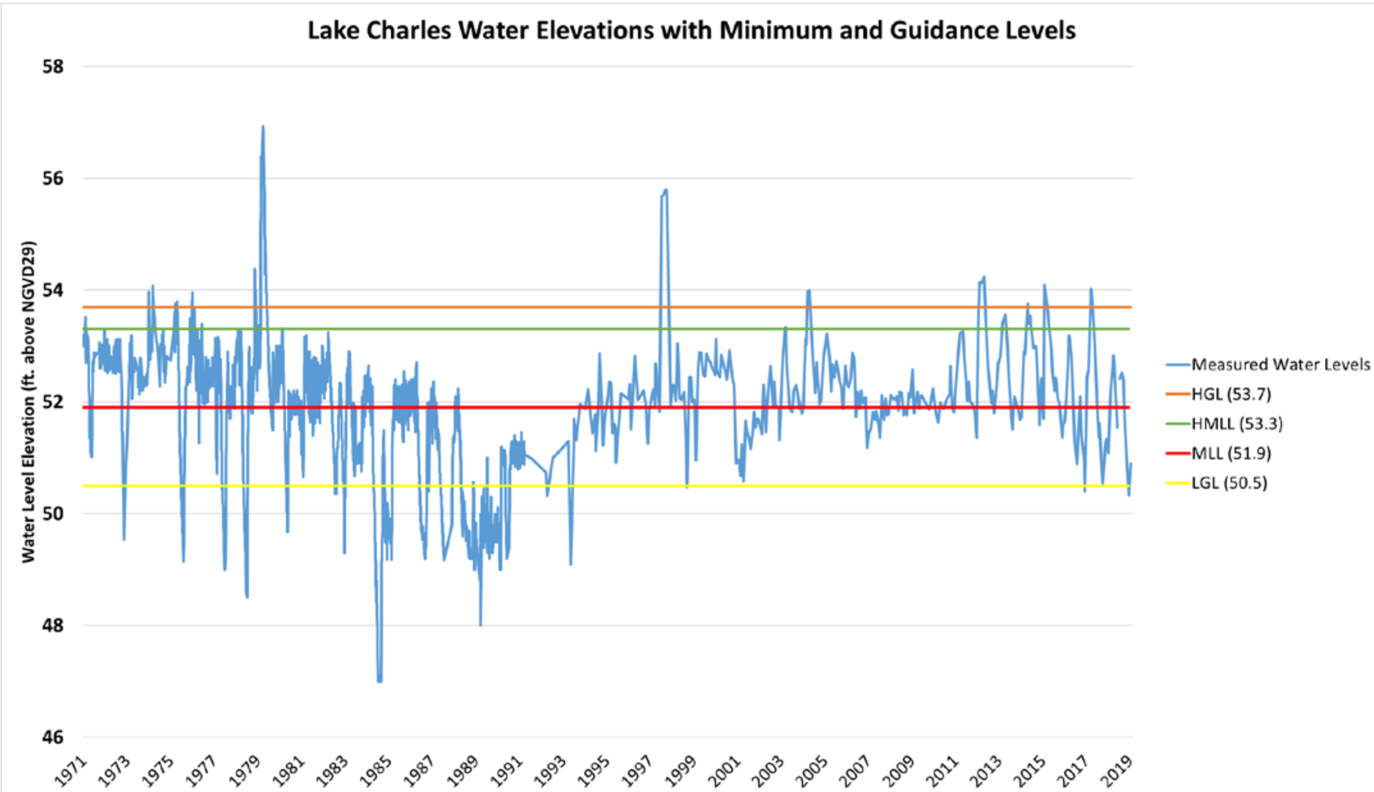

Figure 18: Recorded Water Level Elevations with Guidance and Minimum Lake Levels for Lake Charles.

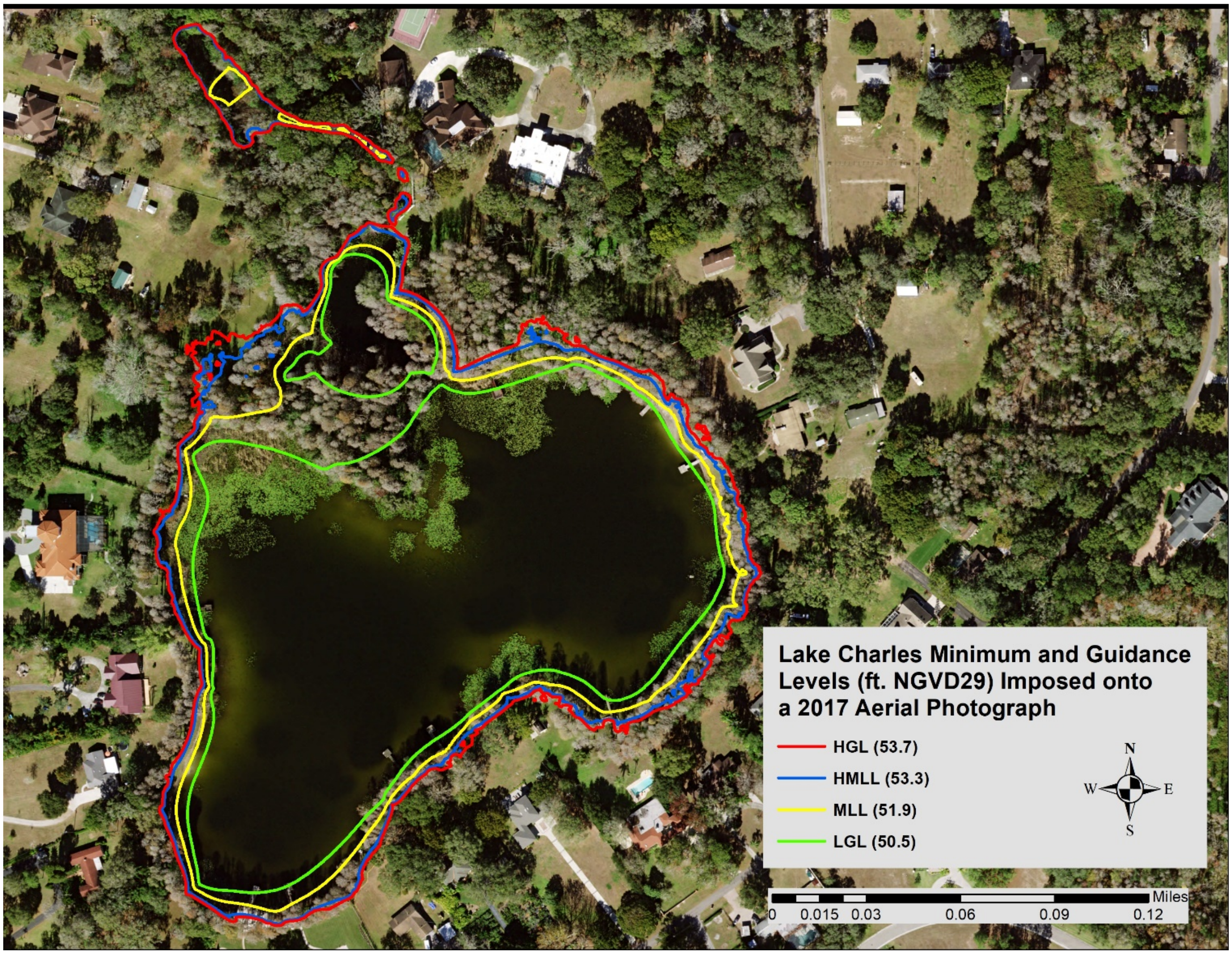

Figure 19: Lake Charles Minimum and Guidance Level Contour Lines Imposed onto a 2017 Natural Color Aerial Photograph.

Many federal, state, and local agencies, such as the U.S. Army Corps of Engineers, the Federal Emergency Management Agency, United States Geological Survey, and Florida's water management districts are in the process of upgrading from the National Geodetic Vertical Datum (NGVD29) standard to the North American Vertical Datum (NAVD88) standard. For comparison purposes, the MFLs for Lake Charles are presented in both datum standards (Table 5). The datum shift was calculated based on third-order leveling ties from vertical survey control stations with known elevations above the North American Vertical Datum on 1988. The NGVD29 datum conversion to NAVD88 is -0.94 ft. for SID 756262 on Lake Charles.

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

Minimum and Guidance Levels	Elevation in Feet NGVD29	Elevation in Feet NAVD88
High Guidance Level	53.7	52.8
High Minimum Lake Level	53.3	52.4
Minimum Lake Level	51.9	51.0
Low Guidance Level	50.5	49.6

Consideration of Environmental Values

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

A Cypress Standard (1.8 ft. below the historic normal pool elevation) was identified to support development of minimum levels for Lake Charles based on its classification as a Category 1 lake. The standard is associated with protection of several environmental values identified in the Water Resource Implementation 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 (Table 1). Given this information, the levels are as protective of all relevant environmental values as they can be.

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

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

Comparison of Revised and Previously Adopted Levels

The revised High Guidance Level is 0.5 feet lower than the previously adopted High Guidance Level, while the revised Low Guidance Level is 1.6 feet lower than the previously adopted Low Guidance Level (Table 6). These differences are associated with application of a new modeling approach for characterization of Historic water level fluctuations within the lake, i.e., water level fluctuations that would be expected in the absence of water withdrawal impacts given existing structural conditions, and additional data since the last evaluation.

The revised High Minimum Lake Level for Lake Charles is 0.5 feet lower from the previously adopted High Minimum Lake Level. The revised Minimum Lake Level is 0.5 feet lower than the previously adopted Minimum Lake Level (Table 6). These differences are due to the same factors discussed above for the changes in the Guidance Levels.

The Minimum and Guidance Levels identified in this report replace the previously adopted levels for Lake Charles.

Table 6: Revised Minimum and Guidance Levels for Lake Charles compared to previously adopted Minimum and Guidance Levels.

Minimum and Guidance Levels	Elevations (in Feet NGVD29)	Previously Adopted Elevations (in Feet NGVD29)
High Guidance Level	53.7	54.2
High Minimum Lake Level	53.3	53.8
Minimum Lake Level	51.9	52.4
Low Guidance Level	50.5	52.1

Minimum Levels Status Assessment

To assess if the Minimum and High Minimum Lake Levels are being met, observed stage data in Lake Charles were used to create a long-term record using a Line of Organic Correlation (LOC) model, similar to what was developed for establishing the Minimum Levels (Appendix A). For the status assessment, the lake stage data used to create the LOC must be from a period representing a time when groundwater withdrawals and structural alterations are reasonably stable, and represent current conditions, referred to as the "Current" period. Current stage data observed on Lake Charles were determined to be from 2010 through 2019. Using the Current stage data, the LOC model was created. The LOC model resulted in a 73-year long-term water level record (1946-2019).

For the status assessment, cumulative median (P50) and cumulative P10 water elevations were compared to the Minimum Lake Level and High Minimum Lake Level, respectively, to determine if long-term water levels were above these levels. Results from these assessments indicate that Lake Charles water levels are above the Minimum Lake Level and below the High Minimum Lake Level (see Appendix B). This discrepancy is most likely explained by the augmentation of the lake which is consistent with the Minimum Lake Level.

The lake lies within the region of the District covered by an existing recovery strategy for the Northern Tampa Bay Water Use Caution Area (Rule 40D-80.073, F.A.C.).The District plans to continue regular monitoring of water levels in Lake Charles and will also routinely evaluate the status of the lake's water levels with respect to adopted minimum levels for the lake included in Chapter 40D-8, F.A.C.

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APPENDIX A

Technical Memorandum

October 29, 2019

TO: T.J. Venning, Staff Environmental Scientist, Water Resources Bureau

THROUGH: Tamera McBride, P.G, Manager, Resource Evaluation, Water Resources Bureau

FROM: Cortney Cameron, G.I.T., Hydrogeologist, Water Resources Bureau
Don Ellison, P.G., Senior Hydrogeologist, Water Resources Bureau

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

A. Introduction

Water budget and rainfall correlation models were developed to assist the Southwest Florida Water Management District (District) in the reassessment of minimum levels for Lake Charles in northwest Hillsborough County. Lake Charles currently has adopted minimum levels which are scheduled to be re-assessed in FY 2019. This document will discuss the development of the Lake Charles models and use of the models for development of Historic lake stage exceedance percentiles.

B. Background and Setting

Lake Charles is located in northwest Hillsborough County, inscribed by Lake Charles Circle to the south and Crenshaw Lake Road to the north (Figure 1). The lake lies within Brushy Creek watershed, which forms part of the larger Tampa Bay watershed (USGS HUC 03100206), where Brushy Creek is a tributary to Rocky Creek. Lake Charles has no significant inflow other than overland flow. The topography is very flat, however, and flows are often negligible. In the 1990s, Lake Charles was structurally disconnected from the flowpath between Brant Lake to its northeast and Lake Heather to its southwest and is currently considered a closed basin lake (Figure 2).

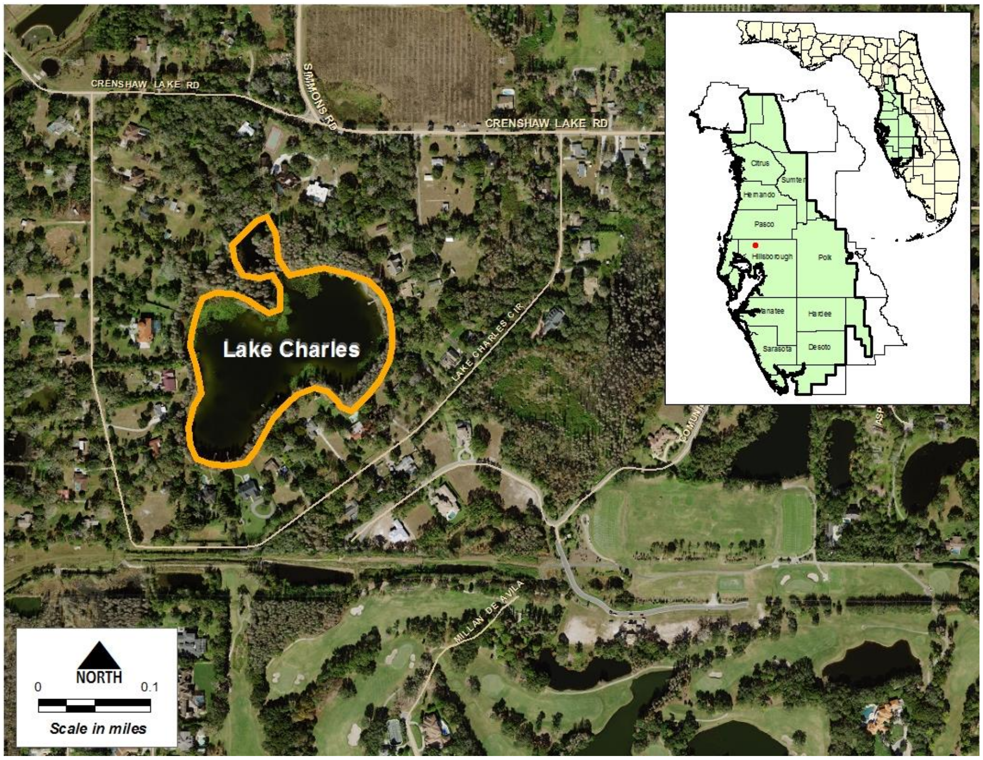

Figure 1. Location of Lake Charles in Hillsborough County, Florida.

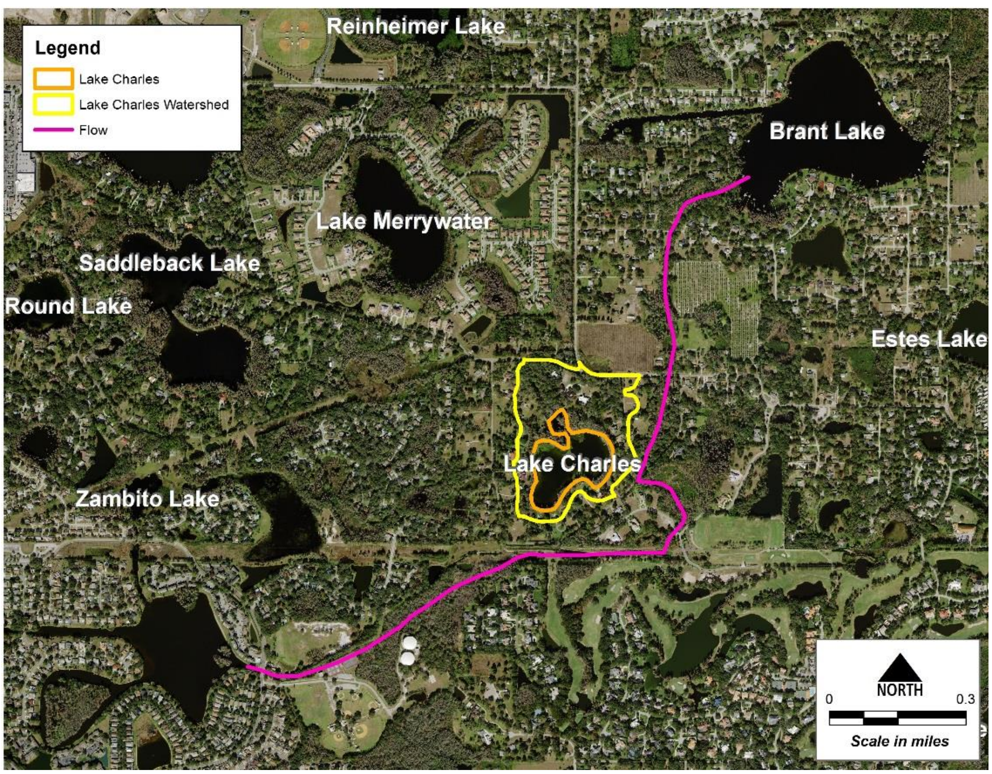

Figure 2. Approximate flow conveyance path (pink line) from Brant Lake (top right) to Lake Heather (bottom left) in the vicinity of Lake Charles (center-right; orange outline).

Physiography and Hydrogeology

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 into the lake is a combination of overland flow and flow through drainage swales and minor conveyance systems.

The hydrogeology of the area includes a sand surficial aquifer; 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).

Stewart and Hughes (1974) report that the typical thickness of surficial sediments in Lake Charles is on the order of 25 feet but thins to 12 feet in the deepest parts of the lake. Calculating that maintenance of stages at Lake Charles required twice to thrice the augmentation rate (per acre of lake surface) of the nearby Round and Saddleback Lakes, the same study concluded that Lake Charles had a stronger hydraulic connection with the Upper Floridan aquifer.

Data

Water level data for Lake Charles begin in June 1971 (Figure 3), initially collected by the United States Geological Survey via a staff gage located near the lake’s western shore. The District assumed data collection in 1983. After loss of access to the original staff gage, a new gage was installed near the lake’s southeastern shore in 2010. Generally, data collection occurred once or twice weekly from 1971 to 1975, every one to three days from 1976 to 1991, bimonthly to quarterly in 1992 and 1993, and once monthly thereafter, with several gaps and variations.

The Upper Floridan aquifer monitor well nearest Lake Charles is the ROMP 65 FMW-5 Fldn (SID 19586), while the surficial aquifer monitor well nearest Lake Charles is the EC222718W2 Surf (SID 639072) (Figure 4 and Figure 5). These monitor wells and their data collection frequency are further discussed in "Flow from and into the surficial aquifer and Upper Floridan aquifer" under Section E of this Appendix.

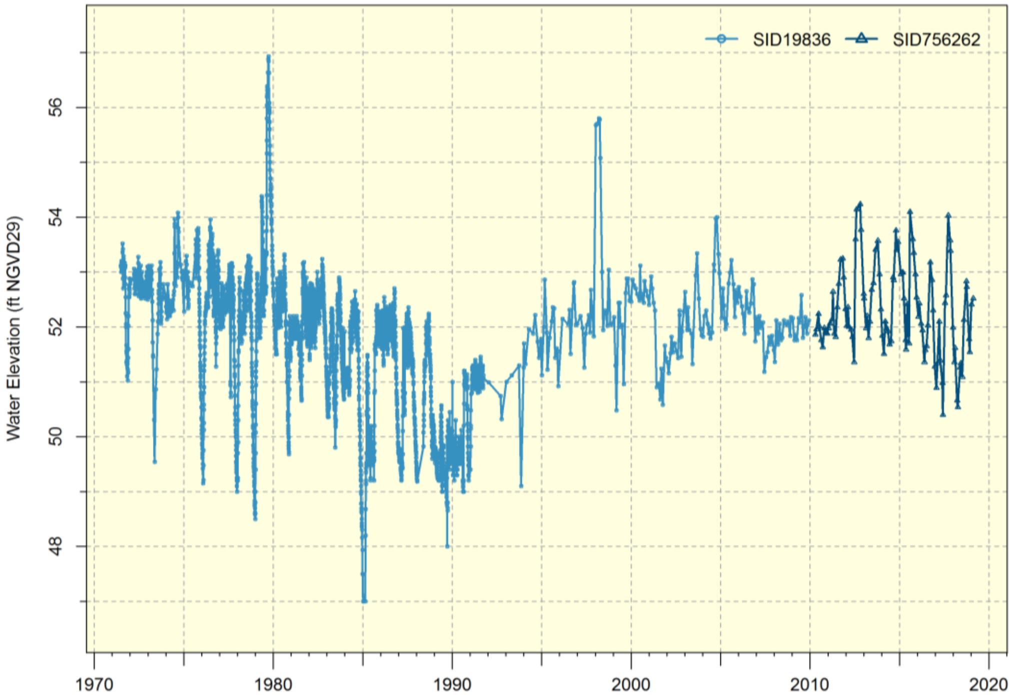

Figure 3. Lake Charles water levels from June 1971 to February 2019.

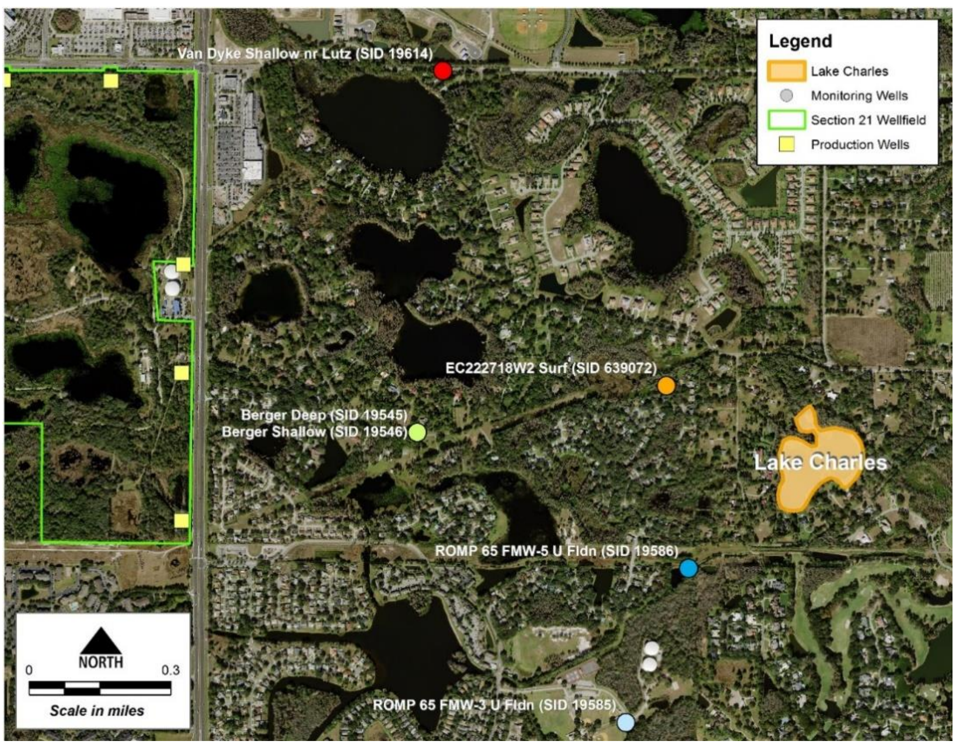

Figure 4. Location of monitor wells near Lake Charles considered for model use. Note that the colors of the well locations correspond to those of the lines in Figure 5.

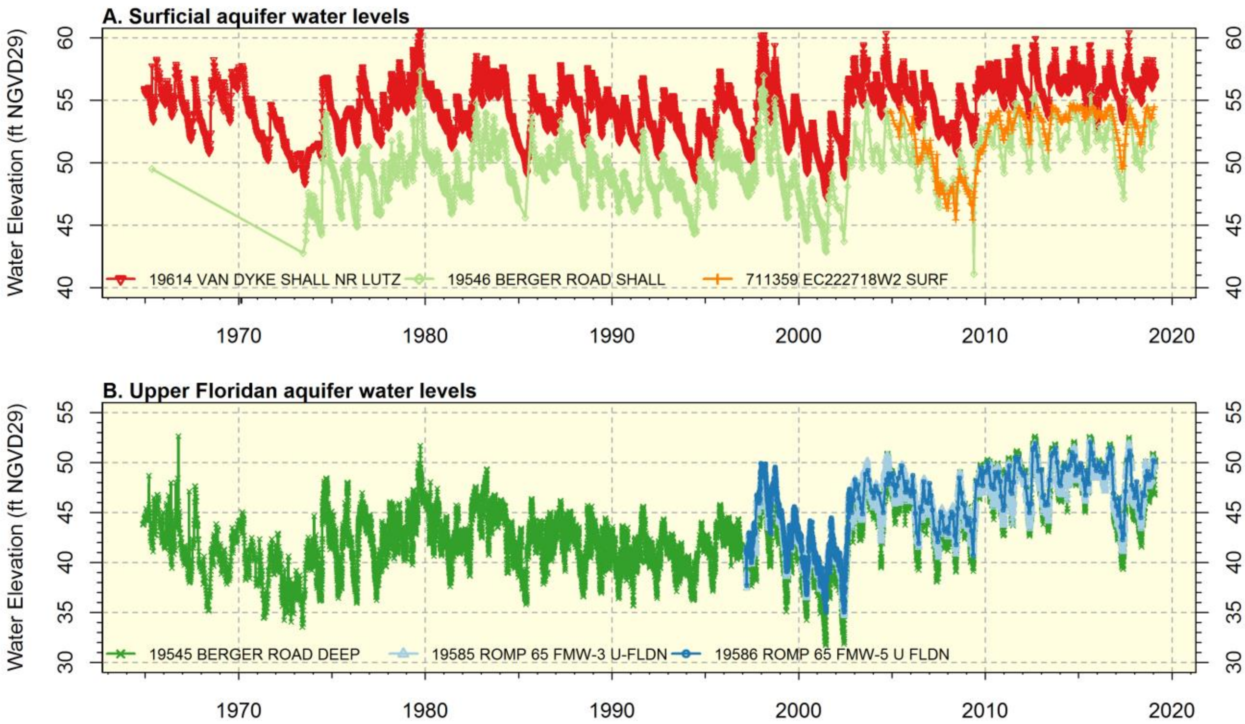

Figure 5. Water levels in A. surficial and B. Upper Floridan aquifer monitor wells near Lake Charles. Note that the colors of the lines correspond to those of the well locations in Figure 5.

Land and Water Use

Lake Charles is located approximately 1.5 miles east of the Section 21 wellfield, one of ten regional water supply wellfields operated by Tampa Bay Water (Figure 6). Groundwater withdrawals began at the Section 21 wellfield in 1963, reaching 15 million gallons a day (mgd) the following year, 20 mgd by 1967, and then in 1973 fell to approximately 10 mgd and again in 2005 to 3 mgd, with several extended periods since where the wellfield has shut down completely.

Water levels in several lakes in the Section 21 area dropped significantly after public supply groundwater withdrawals began in the area (Hancock and Basso, 1996). However, Lake Charles water level data collection did not begin until well after the beginning of withdrawals from the wellfields (Figure 3 and Figure 7), so the correlation between groundwater withdrawals and lake levels is not easily seen in the early data. Lake recovery during the period of recent reductions in groundwater withdrawals can be seen in Figure 3, but above average rainfall combined could also account for some of the apparent recovery.

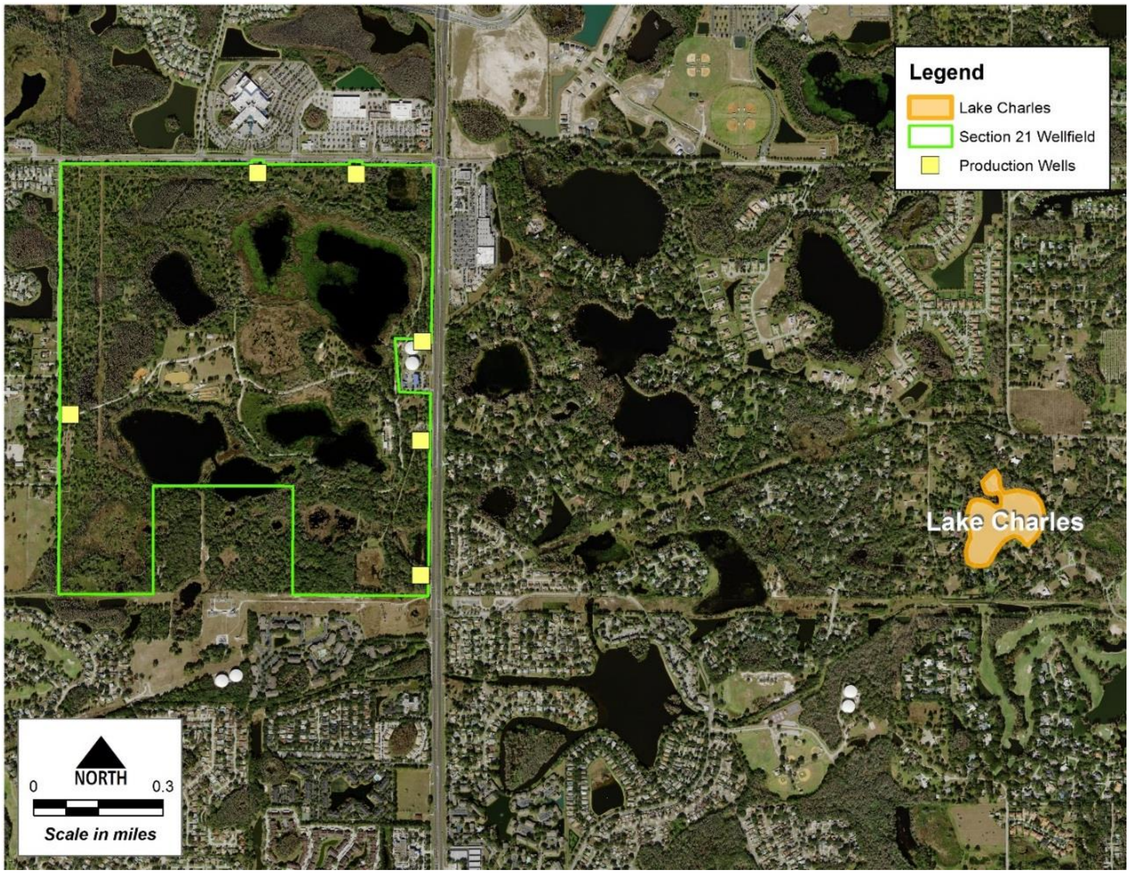

Figure 6. Lake Charles and the Section 21 wellfield.

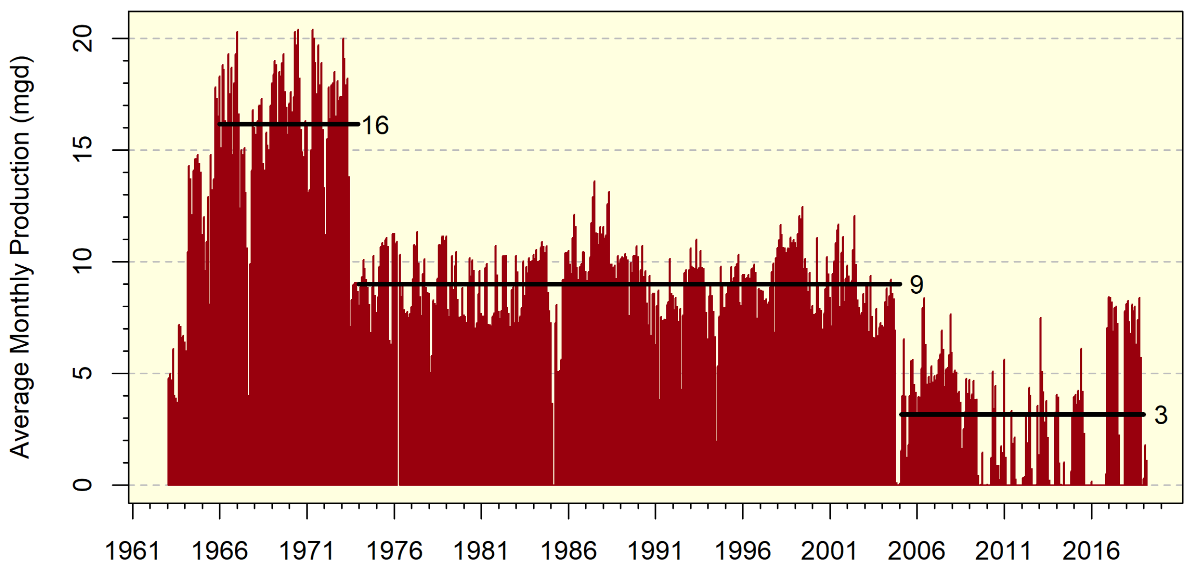

Figure 7. Average monthly withdrawals at the Section 21 wellfield. Horizontal black lines indicate the average production of the time period spanned by the line.

Comparing the 1948, 1967, 1970s, 1984, 1994, 2006, 2010, and 2017 aerial and satellite imageries of Lake Charles, lake bottom was extensively exposed along Lake Charles shores in 1967 (Figure 8). Depending on exactly when the 1967 image was taken, the exposed lake bottom may be due to a combination of low rainfall and groundwater withdrawals from the wellfields.

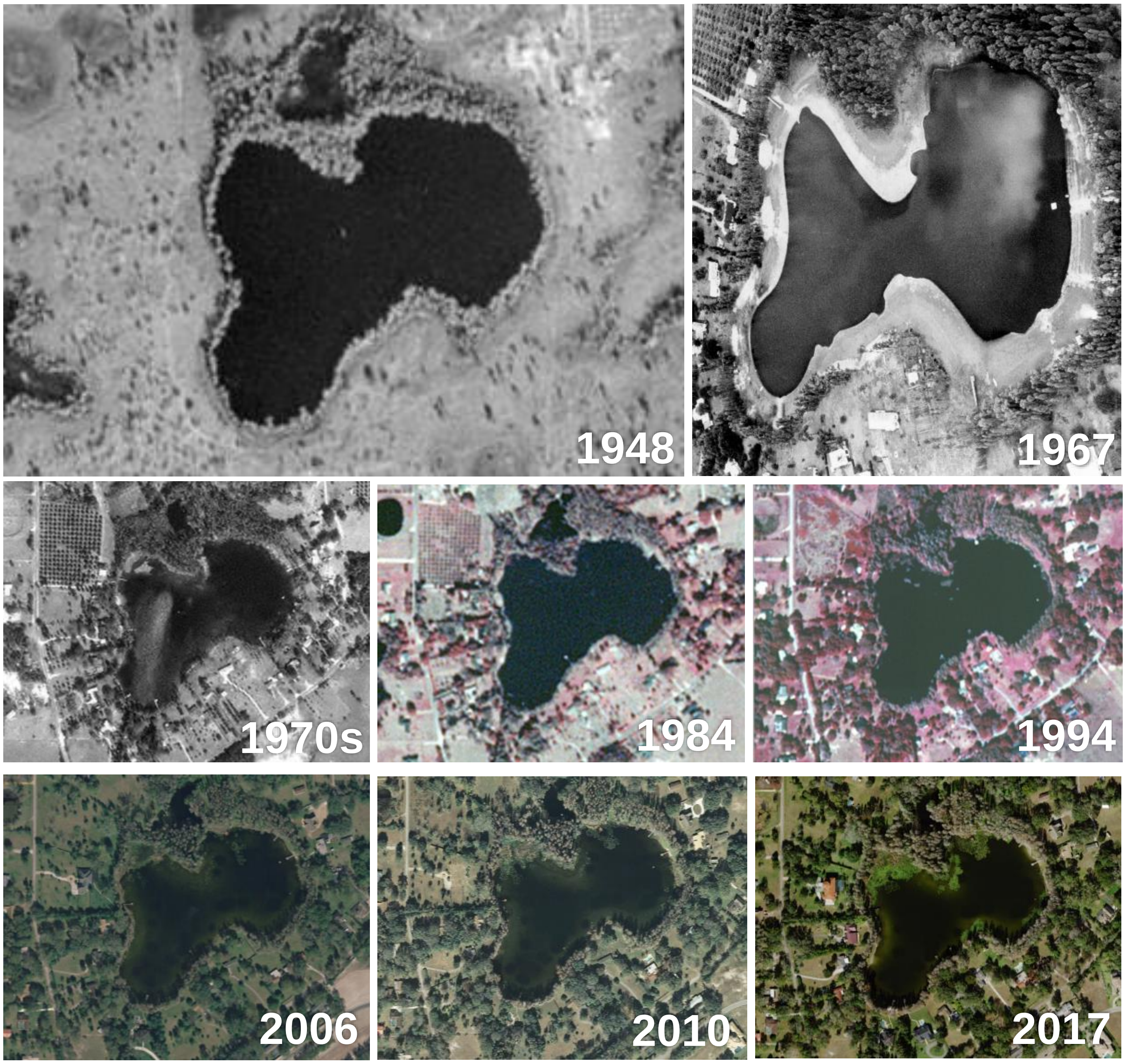

Figure 8. Water level changes in Lake Charles through time. Exposed lake bottom along the lake perimeter is evident in the photograph from 1967. Augmentation began in 1968.

The relationship between sinkhole formation or karst activity and hydrologic stress in the northwest Hillsborough County area has been well established and thoroughly discussed (Bredehoeft et al., 1965; Sinclair, 1973 Stewart and Hughes, 1974; Sinclair, 1982; Sinclair et al., 1985; Hancock and Basso, 1996; Metz and Sacks, 2002; Metz, 2011). Anthropogenic or natural hydrologic stress can cause sediments in karst formations to unravel or can lower water levels that support overburden covering voids in the limestone aquifer. This can result in sinkholes that appear on the surface, or can result in changes that occur underground and cannot be seen at the surface. These changes, in turn, can result in pathways for water to connect lakes, wetlands, or the surficial aquifer in general, to the underlying Upper Floridan aquifer. It is thus possible that a change in leakance properties between Lake Charles and the Upper Floridan aquifer (possibly due to karst activity beneath or surrounding the lakes) has occurred.

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 long-term Historic lake stage exceedance percentiles such as the P10, P50, and P90, which are, respectively, the water levels equaled or exceeded ten, fifty, and ninety percent of the time. If data representative of a Historic time period 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 Lake Charles, the Section 21 wellfield has potentially affected water levels since it began operation in 1963. Empirical data are not available to evaluate the potential impacts of the early groundwater withdrawals near the wellfields. Other groundwater withdrawals (including other wellfields) could also affect levels, but the effect of such withdrawals would be smaller and less consistent. 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 any changes in the lake’s drainage system, and simulating effects of changing groundwater withdrawal rates.

D. Water Budget Model Overview

The Lake Charles 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 the lake. The water budget model for Lake Charles is calibrated from April 2010 through February 2019. 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. Temporally limiting data were augmentation, surficial aquifer water levels, and structural changes. Model inputs are summarized in Table 1.

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

Input Variable	Value
Overland Flow Watershed Size (acres)	48.4
SCS CN of watershed	73
Percent Directly Connected	0
Fl. Aq. Monitor Well(s) Used	ROMP 65 FMW-5 Fldn
Surf. Aq. Monitor Well(s) Used	EC2227 18W2 Surf
Fl. Aq. Leakance Coefficient (ft/day/ft)	0.0034
Surf. Aq. Leakance Coefficient (ft/day/ft)	0.002
Outflow K*	0.005
Outflow Invert (ft NGVD29)*	56.5
Inflow K	N/A
Inflow Invert (ft NGVD29)	N/A

* Channel outflow never occurred during the model period.

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 10.4.1, 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 all available rain data in the area of Lake Charles during the water budget model period, a combination of the St Pete Jackson 26A rain gage (SID 19550; approximately 2.2 miles west-northwest of Lake Charles) was selected for use in the water budget model, with minor contribution the Lake Hanna rain gage (SID 18593; approximately 2.7 miles northeast of Lake Charles) and NEXRAD data. Both rain gages are operated by the District, while NEXRAD (Next Generation Weather Radar) is a network of 160 high-resolution Doppler weather radars controlled by the National Weather Service, Air Force Weather Agency, and Federal Aviation Administration. The goal was to use the closest available data to the lake, as long as the data appeared to be high quality (Figure 9).

Lake Evaporation

From August 1996 to July of 2011, lake evaporation at Lake Starr in Polk County was estimated through the use of monthly energy budget evaporation data collected by the U.S. Geological Survey (Swancar et al., 2000; Swancarr, 2015). These data were used to develop an average evaporation rate for each month of the calendar year, then this was used estimate daily evaporation at Lake Charles.

A recent study compared monthly energy budget evaporation data collected from both Lake Starr and Calm Lake (Swancar, 2015). The assessment concluded that the evaporation rates between the two lakes were nearly identical, with small differences attributed to measurement error and monthly differences in latent heat associated with differences in lake depth. Calm Lake is located approximately 6.4 miles (center-to-center) to the west-northwest of Lake Charles (Figure 10).

Jacobs (2007) produced daily potential evapotranspiration (PET) estimates on a 2-square kilometer grid for the entire state of Florida. The estimates begin in 1995, and are updated annually. These estimates, available from a website maintained by the USGS, were calculated using solar radiation data measured by a Geostationary Operational Environmental Satellite (GOES). Because PET is equal to lake evaporation

Figure 9. Rain gages and NEXRAD pixel used in the Lake Charles water budget model.

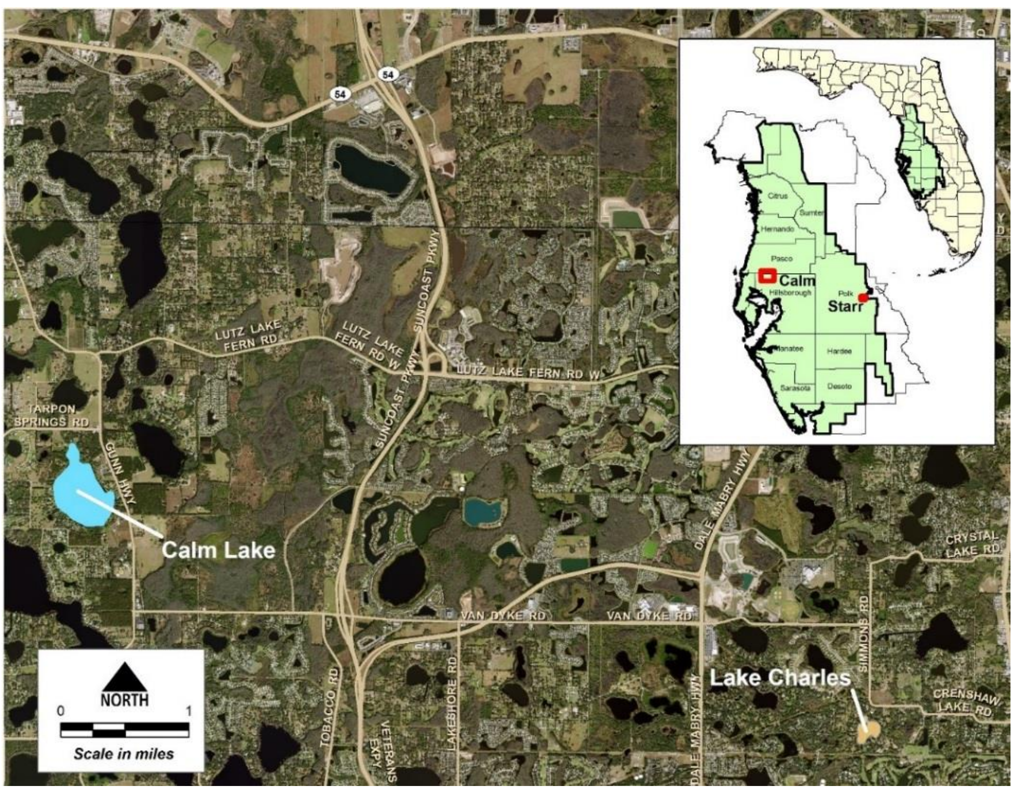

Figure 10. Location of Lakes Calm, Charles and Starr (see map inset).

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.

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) was 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 considers 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 around Lake Charles is relatively flat, so determining watersheds based on relatively subtle divides can be challenging. Several slightly varying estimates of watershed boundaries have been performed in the past for different modeling efforts in the area. The most recent set of estimates was developed as part of an effort to model the five main watersheds in northwest Hillsborough County for flood assessment purposes (CH2M HILL Engineers, 2016). The watershed area values developed by CH2M HILL were adopted for the Lake Charles model (Table 1) after an independent check confirming that they are reasonable for modeling purposes.

Lake Charles's watershed as used in the model is shown in Figure 11. The entire area of the contributing watersheds is estimated to be approximately 48.4 acres (including the lake).

The DCIA and SCS CN used for the direct overland flow portion of the watershed are listed in Table 1. Curve numbers are difficult to assess. Most of the soils in the area are A/D soils, which 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 "A" soil. Because of the proximity of the wellfields to the area being modeled, water levels have been historically lowered by the withdrawals, and soils in the area may have had lower runoff rates (characteristic of “A” soils). Groundwater withdrawals during the period of model 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. Basinger, Holopaw, and Samsula depressional soils comprise the majority of the watershed, with some Myakka and Zolfo fine sands, all A/D.

For purposes of this model, considering the range of conditions experienced, a CN was used somewhere between the two conditions. No direct discharges to the lake were identified, so the DCIA of the watershed is zero.

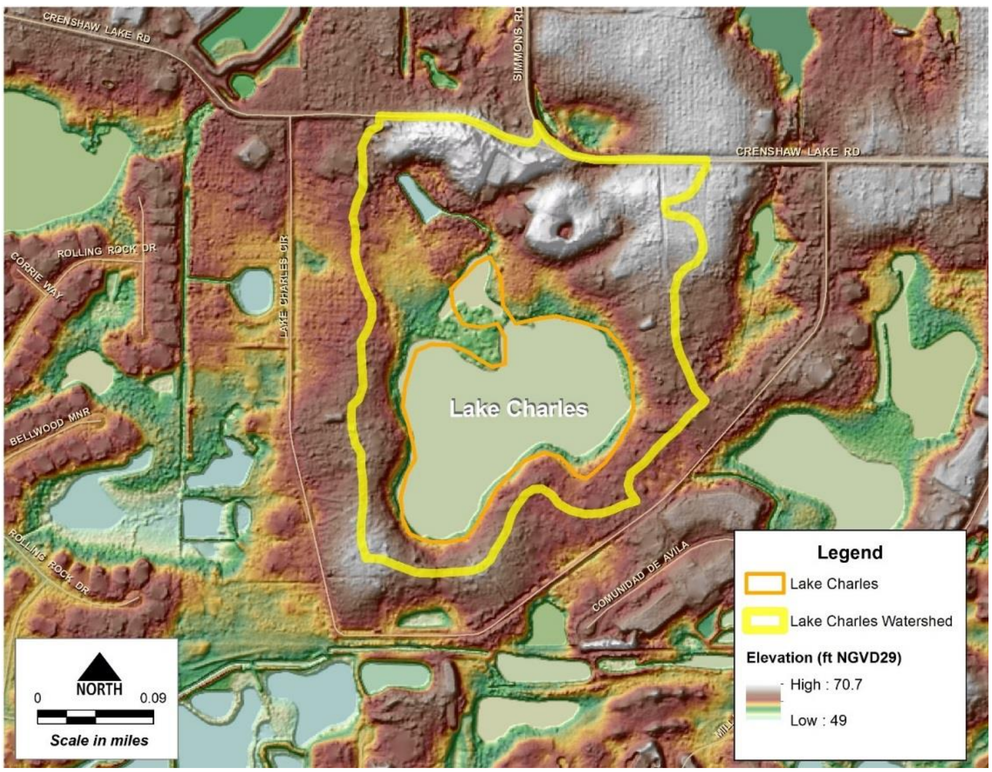

Figure 11. Watershed of Lake Charles as used in the water budget model.

Augmentation withdrawn from the Upper Floridan aquifer

Augmentation at Lake Charles began in 1968 via an 8-inch well drilled 485 feet into the Upper Floridan aquifer (Stewart and Hughes, 1974). By December 1971, total augmentation to the lake had reached 410 million gallons of water, representing an average augmentation rate of 0.3 mgd over that period (Stewart and Hughes, 1974).

Augmentation continues into the present under Water Use Permit (WUP) 4549, which currently (Revision 4) permits up to an average of 290,000 gallons per day (peak usage of 652,000 gallons per day) to be withdrawn from the well. Augmentation is authorized only when water levels at Lake Charles fall either 1) below the Extreme Low Management Level (ELML) of 50.0 ft NGVD29, or 2) if Lake Charles has fallen to the ELML at any point in the previous four years, below the Low Management Level of 52.0 ft NGVD29. According to the most recent permit application, the well has a capacity of 120 gallons per minute (gpm) and is equipped with an hourly flow meter that can be used to calculate withdrawal quantities as the well capacity multiplied by time operated.

As as condition of the permit, the permittee must report aggregate monthly groundwater withdrawals to the District. While augmentation began in 1968, augmentation data is only available beginning April 1980 (Figure 12). According to this data, augmentation has been trending downward over time. From 1980 to 1989, reported monthly augmentation averaged approximately 0.19 mgd; from 1990 to 1999, 0.06 mgd; from 2000 to 2009, 0.03 mgd; and from 2010 to 2017, under 0.01 mgd. However, average monthly augmentation has been reported as high as 0.86 mgd.

The early augmentation data may include various gaps and variable quality, potentially corresponding to changes in the reporting party as well as possible undocumented changes in the flow meter device or in pump capacity. Augmentation data was manually compared with permitee meter reading reports but did not reconcile all apparent discrepancies between augmentation data and lake response. Namely, for some months with zero augmentation reported, notable divergence occurs between groundwater levels and lake water levels during low rainfall periods, whereby the lake displays a relatively flat hydrograph while groundwater and rainfall levels drop (Figure 12). Additionally, delinquent notices frequently coincide with periods of suspect data. Finally, flow meter or pump capacity changes may have occurred without sufficient documentation, with possible implications for data quality. For example, in a letter from a resident dated 1989, the pump capacity was reported as 453 gpm, versus 120 gpm in the most recent permit application and 500 gpm reported in Stewart and Hughes (1974), while a letter dated 1990 noted that a lightning strike had disabled the pump for months.

Augmentation data following the most recent permit renewal in 2010 appear of reasonable quality. For these reasons, while a water budget model period starting in 1997 (based on the availability of Upper Floridan water level measurements) was evaluated, due to uncertainty in earlier augmentation data, the water budget model calibration period was limited to a timeframe where augmentation was minimal starting in 2010 (due to unavailable lake stage data during the first three months of 2010, the model starts in April 2010). At the time of writing, the last meter reading reported was for June 2017; for the purposes of the model, augmentation has been assumed to be zero since, which seems reasonable based on relatively high rainfall since then (Figure 12).

To generate a daily time series from the reported monthly totals, each monthly total was assumed to be uniformly distributed across each day of the month (Figure 12). 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. Along with structural changes to the lake over time (see “Inflow and Discharge via Channel”), this made augmentation the temporally limiting data for the model.

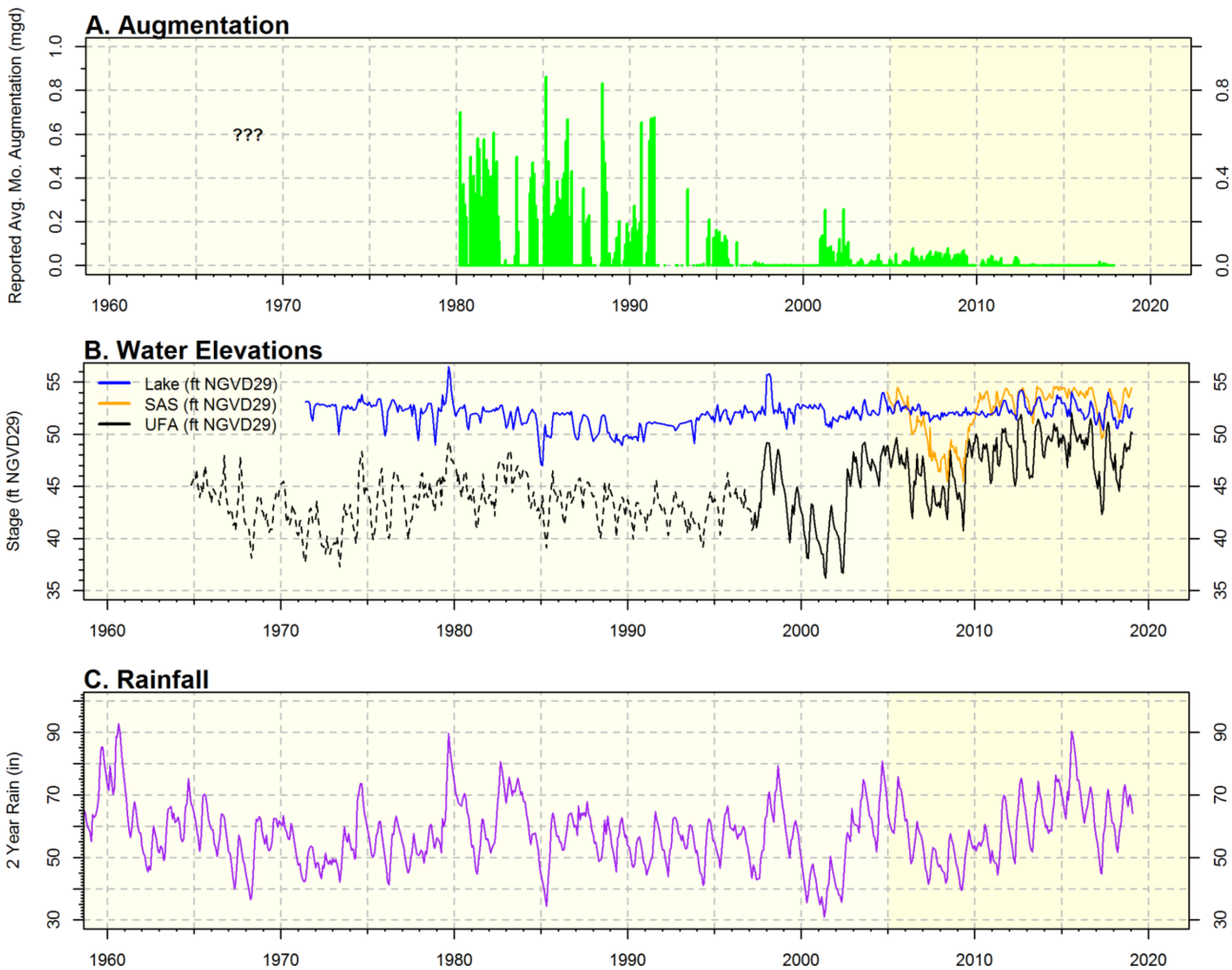

Figure 12. A. Reported average monthly augmentation (mgd) at Lake Charles. Augmentation started in 1968 at undocumented rates, as augmentation data begins in 1980. B. Water level elevations (feet NGVD29) for Lake Charles (blue line), the surficial aquifer (orange line), and Upper Floridan aquifer (black line, dashed where estimated using Berger Deep [SID 19545]). C. Rainfall (inches), two-year inverse linear decay sum.

<u>Inflow and Discharge via Channels from Outside Watersheds</u>

Inflow and outflow via channels to or from the lake's watershed (i.e. "channel flow") is a important component of the water budget for many lakes in northwestern Hillsborough County, although the gradients of the channels are typically relatively flat, with inflows often occuring only under high rainfall events. In the case of Lake Charles, the lake is currently considered to have a closed basin, with neither regular channel inflow nor outflow.

Structural controls on Lake Charles have varied throughout time, including undocumented modifications made by lakefront residents. As explained in Munson and Leeper (2004), "Surface inflow to the lake historically occurred from a ditch that conveyed water from Lake Brant to areas south of Lake Charles. Inflow to Lake Charles from the canal occurred as overland flow or discharge through a culvert/water control structure. The structure, which was installed in 1966, was designed to prevent inflow of water from the open ditch system and also serve as an outlet for the lake. In the 1990s, the open ditch in the vicinity of Lake Charles was converted to a closed-culvert conveyance system, and the water control structure/culvert system was removed from the shoreline of Lake Charles."

Most recently, in 2017, Hillsborough County completed structural modifications near Lake Charles under Environmental Resource Permit (ERP) 42833. In its permit application, the County stated that, "This project proposes to install multiple pipes within private properties and Lake Charles Circle to alleviate flooding upstream. A property owner filled in an existing swale (without a valid ERP) and installed a 24 inch CMP pipe. This pipe has insufficient capacity to convey the upstream drainage. These proposed pipes are designed to closely match the swale's conveyance capacity." A wetland located to the east-northeast of Lake Charles receives flow from Brant Lake to its north; the new pipe system directs flow from that wetland to the south under Lake Charles Circle (bypassing Lake Charles) for eventual conveyance to Brushy Creek to the southwest.

Based on LiDAR elevation data, outflow from Lake Charles could occur under current structural conditions at an elevation range of approximately 56.5 to 57 feet NGVD29 (Figure 11). The period-of-record maximum stage value for Lake Charles is 56.93 feet NGVD29, which occurred in September 1979 (Figure 3); the lake has since never surpassed even 56 feet NGVD29. Thus, Lake Charles remains essentially a closed basin lake.

To estimate flow out of Lake Charles, the predicted elevation of the lake from the previous day is compared to the controlling elevation. 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. However, channel outflow never occurred in the time period of the water budget model.

Flow from and into the surficial aquifer and Upper Floridan aquifer

Water exchange between Lake Charles and 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.

Upper Floridan aquifer. The Upper Floridan aquifer monitor well nearest Lake Charles is the ROMP 65 FMW-5 Fldn (SID 19586)—located approximately 1,200 feet from the shore of Lake Charles's southwestern apex (1,900 feet from the centroid)—for which data begins in March 1997 (Figure 4 and Figure 5). Through 2002, data collection occurred almost daily, with several gaps and variations, then monthly beginning 2003. An inspection of multiple May and September potentiometric surface maps from District archives over several years representing periods before and after wellfield cutbacks found both the ROMP 65 FMW-5 Fldn well and Lake Charles to be consistently located within the same potentiometric contour, suggesting that no adjustment of the water levels at the well was required to represent the potentiometric surface at the lake.

Surficial aquifer. The surficial aquifer monitor well nearest Lake Charles is the EC2227 18W2 Surf (SID 639072)—located approximately 1,500 feet from the northwestern shore of Lake Charles (1,900 feet from the centroid)—for which data begins in December 2004 (Figure 4 and Figure 5). Throughout the period of record, data collection has typically occurred twice monthly, with several gaps and variations. Surficial aquifer elevation estimates at previous lakes have been obtained by adjusting the nearest surficial aquifer well according to topographic elevation differences between the well and the lake. The land surface elevation at this well is generally comparable to those around Lake Charles, suggesting that no adjustment was required to represent the elevation of the surficial aquifer under Lake Charles. Gaps or missing data were bilinearly interpolated.

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 13 presents the calibration results for 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.

G. Water Budget Model Calibration Discussion

Based on a visual inspection of Figure 13, the model appears to be reasonably well calibrated. The mean and median differences of the residuals (observed less predicted values) are 0.17 and 0.05 feet, respectively.

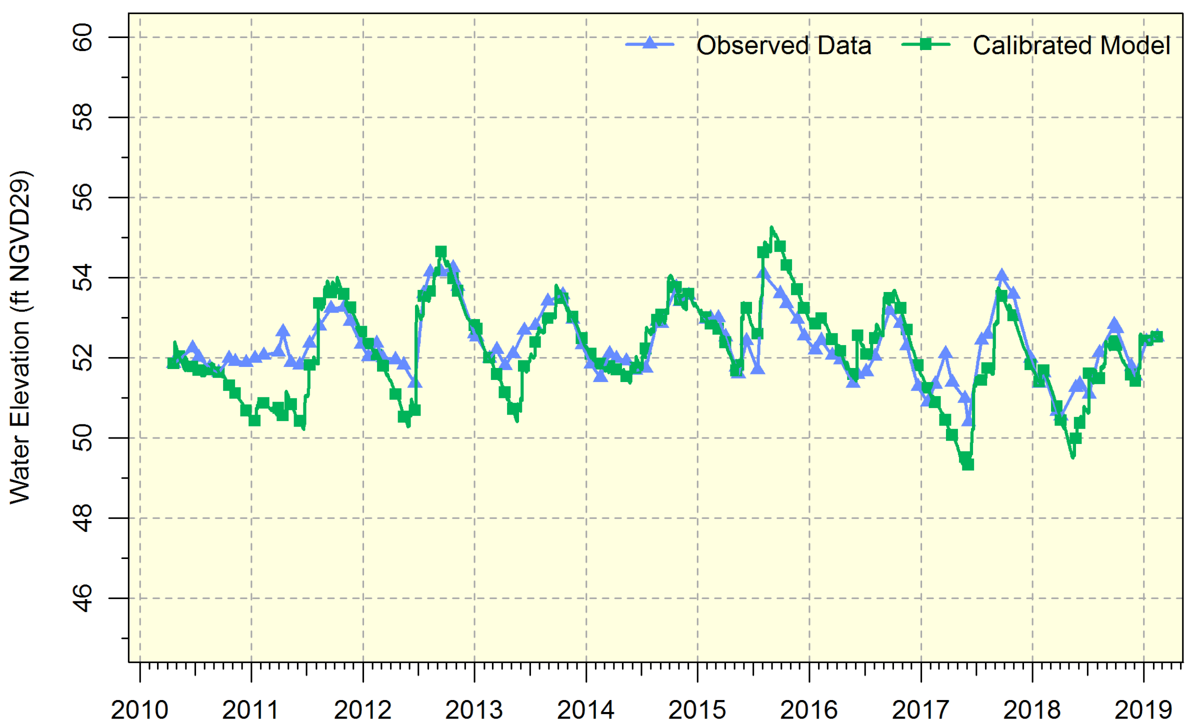

Figure 13. Modeled water levels predicted for the calibrated Lake Charles water budget model (Model; green squares) and measured levels used for the model calibration (Data; blue triangles).

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

	Data	**Model**
P10	53.6	53.6
P50	52.1	52.1
P90	51.4	50.6

A review of Table 2 shows that the P50 and P10 percentiles between the lake data and model are the same (within 0.1 feet), while the model P90 is 0.8 feet lower. There are 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. The minimum and maximum differences are -1.18 and 2.08 feet, respectively. The high bias of the model during mid-2015 to mid-2016 could be related to surface withdrawals that occurred at Lake Charles during that time period; according to a letter from a resident dated September 2015, "the county [was then] pumping water out of the lake" in response to flooding that occurred during portions of 2015. Reduced precision in the higher and lower ranges of the stage-volume relationships for the lake may also have contributed to the percentile differences. Finally, augmentation that occurred during lower stages may not be captured by the data, accounting for at least some of the mismatch at the P90, but this was determined to have minimal impact on the calibration and final Historic percentiles.

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 represent low runoff rates.

Table 3. Lake Charles Water Budget (April 2010 – February 2019).

Inflows	Rainfall	Surficial Aquifer Groundwater Inflow	Floridan Aquifer Groundwater Inflow	Runoff	DCIA Runoff	Augmen-tation	Total
Inches/year	61.5	11.3	0.0	32.4	0.0	8.3	113.6
Percentage	54.2	10.0	0.0	28.5	0.0	7.3	100.0
Outflows	**Evaporation**	**Surficial Aquifer Groundwater Outflow**	**Floridan Aquifer Groundwater Outflow**			**Outflow via channel**	**Total**
Inches/year	58.4	0.1	54.4			0.0	113.0
Percentage	51.7	0.1	48.2			0.0	100.0

For comparison, a simple water budget for Lake Charles for the month of May 1971, Stewart and Hughes (1974) found 0.64 mgd inflow from augmentation, 0.08 mgd inflow from the surficial aquifer, 0.05 mgd outflow to net evaporation, and 0.52 mgd outflow to the Upper Floridan aquifer.

H. Historic Water Budget Model Results

Groundwater withdrawals are not directly included in the Lake Charles water budget model, but are indirectly represented by their effects on water levels in the Upper Floridan aquifer. Metered groundwater withdrawal rates from Section 21 wellfield are available throughout the period of the calibrated model, so if a relationship between withdrawal rates and Upper Floridan aquifer potentiometric levels can be established, the effect of changes in groundwater withdrawals can be estimated by adjusting Upper Floridan aquifer levels in the model.

The Integrated Northern Tampa Bay (INTB) model (Geurink and Basso, 2013) is an integrated model developed for the northern Tampa Bay area. The INTB model can account for groundwater and surface-water, as well as the interaction between them. The domain of the INTB application includes the Lake Charles 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. Only the post-cutback period, which begins in 2005, is represented in the water budget model. 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 for the modeled period.

The INTB model was run for each withdrawal scenario from 1989 to 2006 using a daily integration step (Appendix C). 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 around the wellfields. Groundwater withdrawal rates from 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 (e.g. Figure 14). Because of the leaky nature of the confining unit around Lake Charles, and because the water table in the water budget 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 water budget model can be adjusted to reflect changes in groundwater withdrawals.

The local hydrogeology, observed lake responses to wellfield initiation, and proximity of Lake Charles to the Section 21 wellfield suggest that this wellfield exerts the largest influence on Lake Charles with respect to drawdowns. Therefore, using the existing INTB model runs (Appendix C), linear models were developed to associate withdrawal rates at the Section 21 wellfield with drawdowns predicted in the upper Floridan and surficial aquifers (Figure 14). The resulting linear models (Figure 14) were used with actual average monthly pumping at the Section 21 wellfield (Figure 15 and Figure 16) to estimate monthly drawdowns, which were then disaggregated into a daily time series assuming a uniform distribution (Figure 16). This approach allows for consideration of the variations in withdrawal rates, and therefore drawdowns, that have occurred throughout time.

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. Additionally, the effects of augmentation were removed by setting all augmentation quantities to zero.

Figure 17 presents measured water level data for the lake along with the model-simulated lake levels in the lake under Historic conditions, i.e. with structural alterations similar to current conditions and in the absence of groundwater withdrawals and augmentation. Table 4 presents the Historic percentiles based on the model output. Compared to the calibrated water budget, the Historic percentiles are 0.4 feet higher for the P10 for the P90, and 0.7 feet higher for the P90.

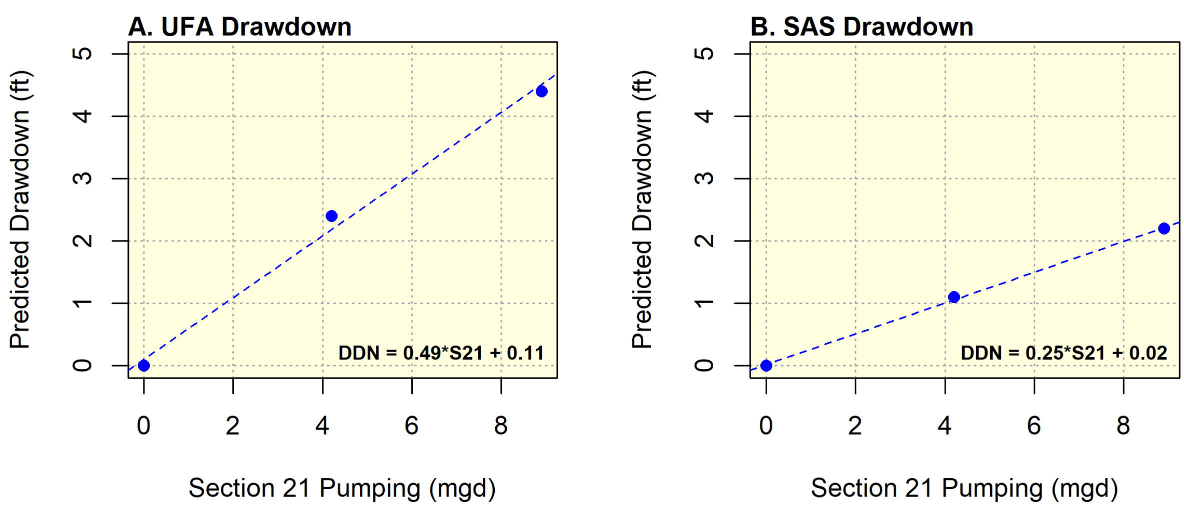

Figure 14. Relationship between average monthly pumping at the Section 21 wellfield (mgd) and long-term average drawdown predicted by the INTB for the A. the upper Floridan aquifer and B. the surficial aquifer system at Lake Charles.

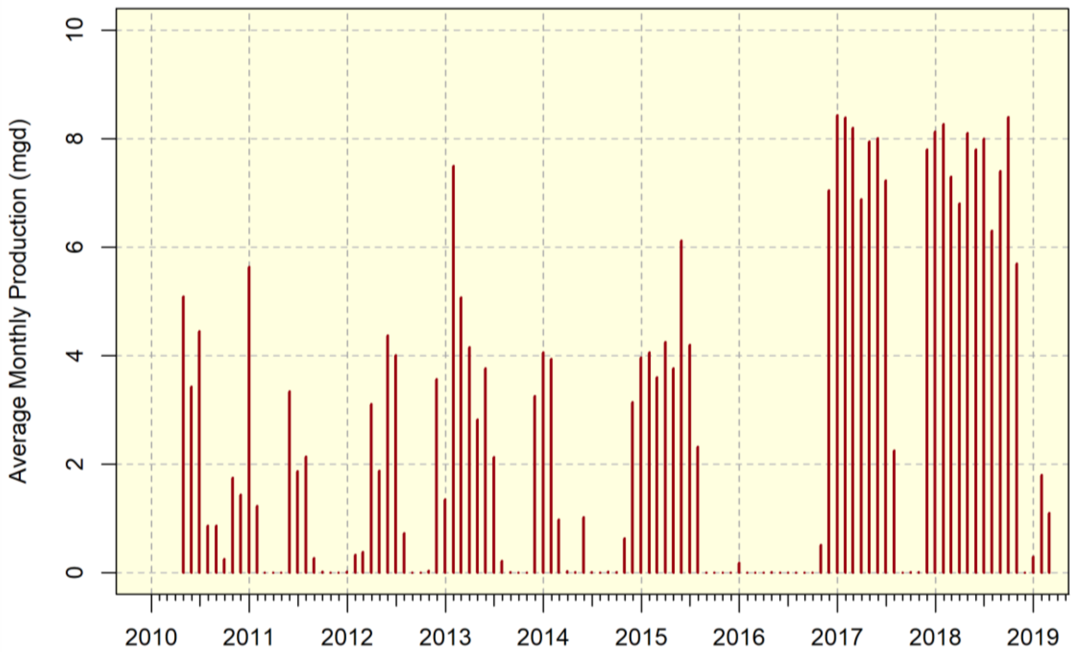

Figure 15. Average monthly pumping at the Section 21 wellfield.

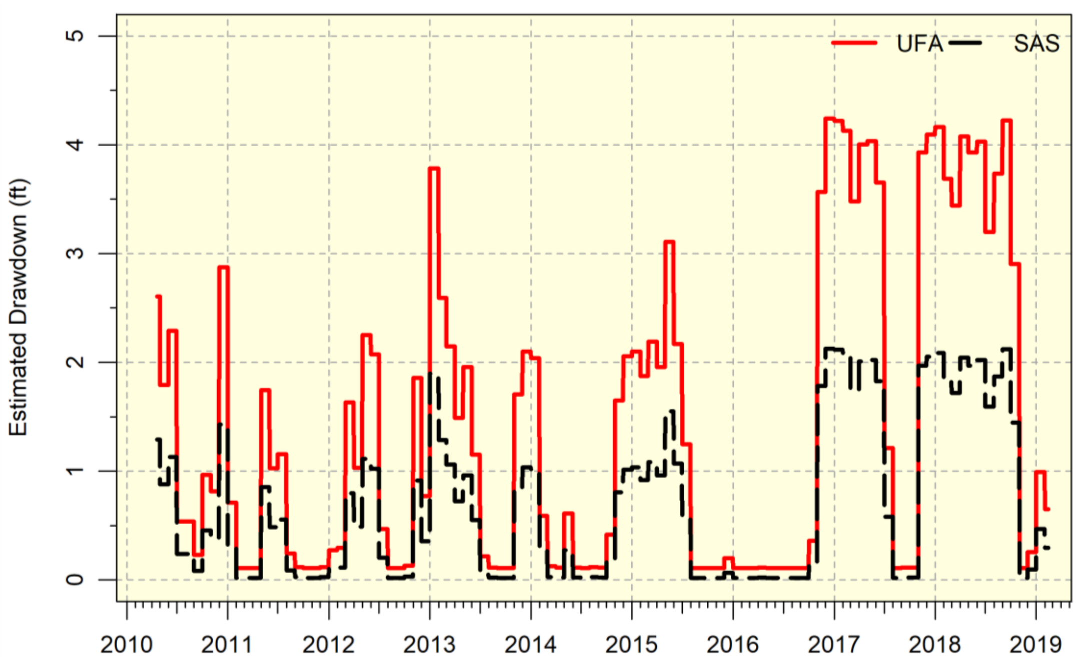

Figure 16. Estimated drawdown at Lake Charles in the upper Floridan (solid red line) and surficial (dashed black line) aquifers.

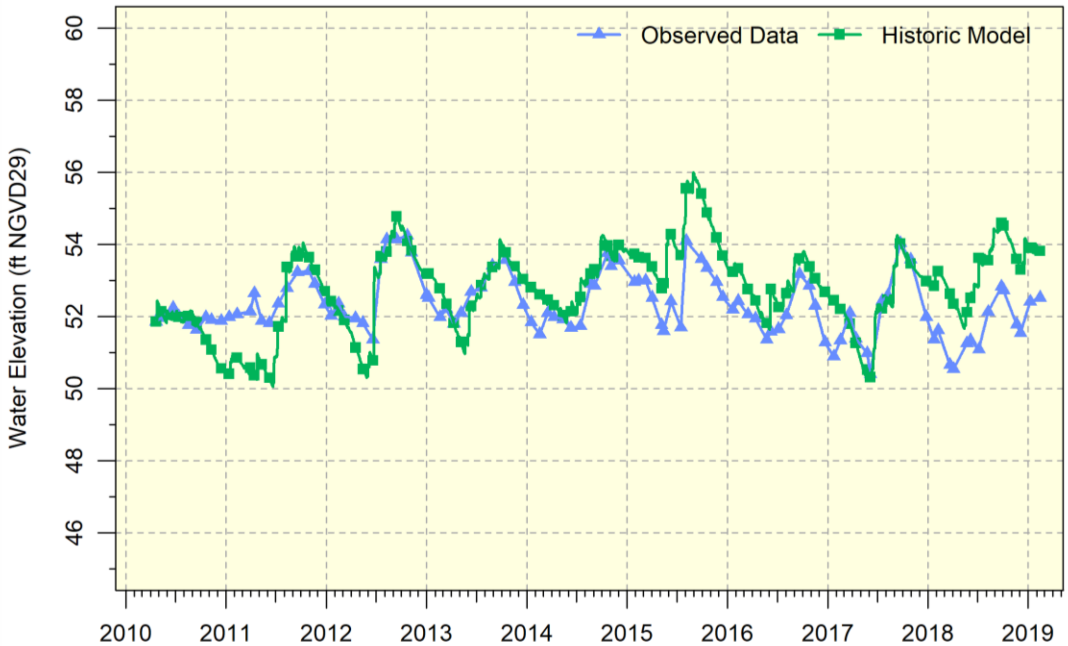

Figure 17. Measured lake levels (Data; blue triangles) and Historic water levels (Model; green squares) predicted using the calibrated Lake Charles model adjusted for drawdown and augmentation.

Table 4. Historic percentiles (in feet NGVD29) estimated using the Lake Charles water budget model (April 2010 to February 2019).

Percentile	Elevation
P10	54.0
P50	52.8
P90	51.0

I. Rainfall Correlation Model

A line of organic correlation (LOC) was performed using the results of the water budget model and long-term rainfall to extend the data set used to determine the Historic percentiles. These Historic percentiles are considered in development of the Minimum Levels. 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 (April 2010 - February 2019; Figure 9). NEXRAD data was used to extend the rainfall time series back to 1995 (Figure 9), followed by the Whalen rain gage through 1975 (SID 19492; approximately 0.5 miles east-northeast of Lake Charles), the Crenshaw Lake rain gage through 1972 (SID 20005; approximately 1.1 miles west-northwest of Lake Charles), the Section 21 Lutz Wellfield rain gage (SID 19491; approximately 1.4 miles west-northwest of Lake Charles) through 1965, and the Lutz rain gage (SID 19629; approximately 3.2 miles north of Lake Charles) through 1963 (Figure 18). Tampa Bay Water's Cosme rain gage, located in the Cosme-Odessa Wellfield approximately 6.8 miles west-southwest of Lake Charles, was used to extend the rain data back to 1945. Finally, the St. Leo National Weather Service gage (SID 18901) was used to extend the data back to 1930 (Figure 18). Although the St. Leo gage is approximately 20.2 miles northeast of Lake Charles Lake (Figure 18), 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, the results are compared, and the correlation with the highest correlation coefficient (R^2) is chosen as the best model.

Rainfall was correlated to the water budget model results from April 2010 to February 2019 (Figure 19). The resulting stage-rainfall relationship was used with rainfall to produce daily lake water elevations from January 1946 to February 2019 (73.2 years). For Lake Charles, the 2-year weighted model had the highest correlation coefficient, with an R^2 of 0.88. 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 19, which displays the lake's predicted behavior in the absence of both withdrawals and augmentation.

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 January 1946 through April 2010, while the water budget results are used for the period of April 2010 through February 2019. These results are referred to as the "hybrid model." The resulting Historic percentiles for the hybrid model are presented in Table 5. Note that the P10, P50, and P90 percentiles for the Historic water budget model (Table 4) differ from those of the Historic hybrid rainfall model (Table 5) for Lake Charles by 0.3, 0.8, and 0.5 feet, respectively.

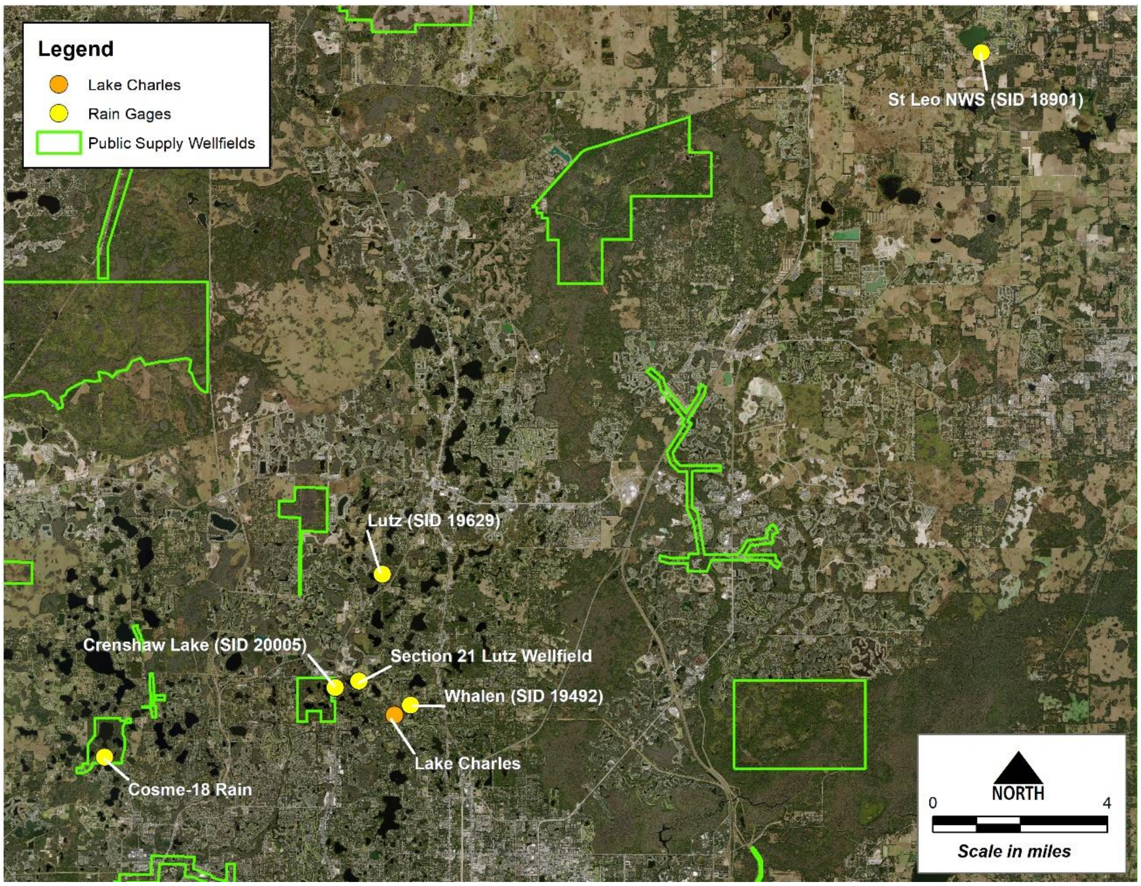

Figure 18. Location of rain stations used for the rainfall correlation model.

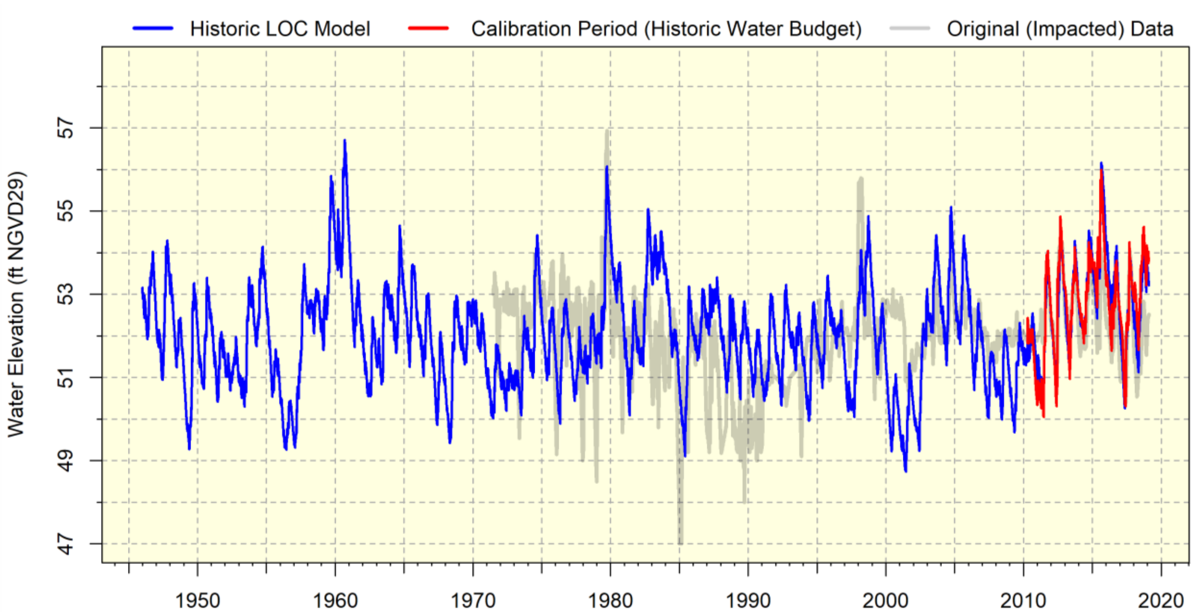

Figure 19. Historic LOC model (blue line) and water budget (red line) results for Lake Charles.

Table 5. Historic percentiles as estimated by the hybrid model from January 1946 to February 2019 (feet NGVD29).

Percentile	Lake Charles
P10	53.7
P50	52.0
P90	50.5

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.

While the Historic normal pool elevation was most recently determined to be 53.1 feet NGVD29 for Lake Charles based on inflection points of adjacent cypress trees, marked variability in these measurements at Lake Charles limited the usability of this hydrologic indicator for the lake (Venning et al., 2019). Even so, the Historic normal pool and Historic P10 in lakes and wetlands in the northern Tampa Bay area has differed by several tenths of a foot in many cases. In the case of Lake Charles, the hybrid rainfall model's estimate of the Historic P10 (53.7 feet NGVD29) is 0.6 feet higher than the most recently field determined Historic normal pool (53.1 feet NGVD29) and 0.5 feet lower than the previously determined Historic normal pool (54.2 feet NGVD29; Munson and Leeper, 2004).

J. Conclusions

Based on the model results and the available data, the Lake Charles 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

October 29, 2019

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

FROM: Cortney Cameron, G.I.T., Staff Hydrogeologist, Water Resources Bureau
Don Ellison, P.G., Senior Hydrogeologist, Water Resources Bureau

Subject: Lake Charles Initial Minimum Levels Status Assessment

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A. Introduction

The Southwest Florida Water Management District (District) is reevaluating adopted minimum levels for Lake Charles and is proposing revised minimum levels for the lake, in accordance with Section 373.042 and 373.0421, Florida Statutes (F.S). Documentation regarding development of the revised minimum levels is provided by Cameron and Ellison (2019) and Venning and others (2019).

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 Lake Charles and other waterbodies 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 Lake Charles that are 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 Lake Charles and any recovery that may be necessary for the lake.

B. Background

Lake Charles is located in northwest Hillsborough County, inscribed by Lake Charles Circle to the south and Crenshaw Lake Road to the north (Figure 1). The lake lies within Brushy Creek watershed that forms part of the larger Tampa Bay watershed (USGS HUC 03100206), where Brushy Creek is a tributary to Rocky Creek. Lake Charles has no significant inflow other than overland flow. The topography is very flat, however, and flows are often negligible. In the

1990s, Lake Charles was structurally disconnected from the flowpath between Brant Lake to its northeast and Lake Heather to its southwest and is currently considered a closed basin lake (Figure 2).

Lake Charles is located approximately 1.5 miles east of the Section 21 wellfield, one of ten regional water supply wellfields operated by Tampa Bay Water (Figure 3). Groundwater withdrawals began at the Section 21 wellfield in 1963, reaching 15 million gallons a day (mgd) the following year, 20 mgd by 1967, and then in 1973 fell to approximately 10 mgd and again in 2005 to 3 mgd, with several extended periods since where the wellfield has shut down completely (Figure 4).

Augmentation at Lake Charles began in 1968 via a well drilled into the Upper Floridan aquifer. Augmentation continues into the present under Water Use Permit (WUP) 4549, which currently (Revision 4) permits up to an average of 290,000 gallons per day (peak usage of 652,000 gallons per day) to be withdrawn for augmentation. As a condition of the permit, the permittee must report aggregate monthly groundwater withdrawals to the District. According to this data, which is available starting April 1980, from 1980 to 1989, monthly augmentation averaged approximately 0.19 mgd; from 1990 to 1999, 0.06 mgd; from 2000 to 2009, 0.03 mgd; and from 2010 to 2017, under 0.01 mgd. However, average monthly augmentation has been reported as high as 0.86 mgd.

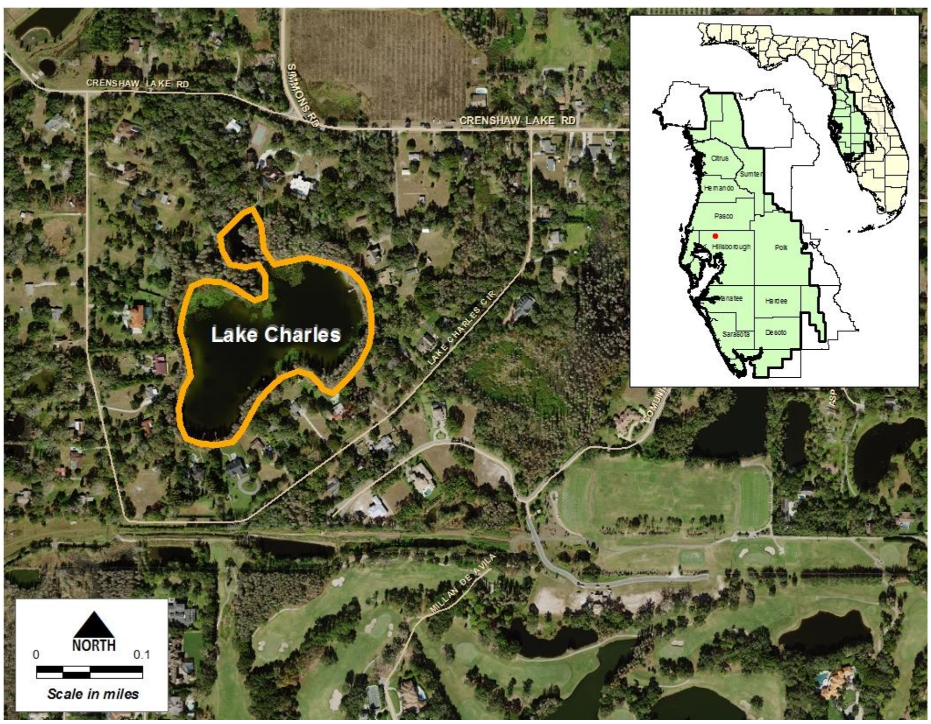

Figure 1. Location of Lake Charles in Hillsborough County, Florida.

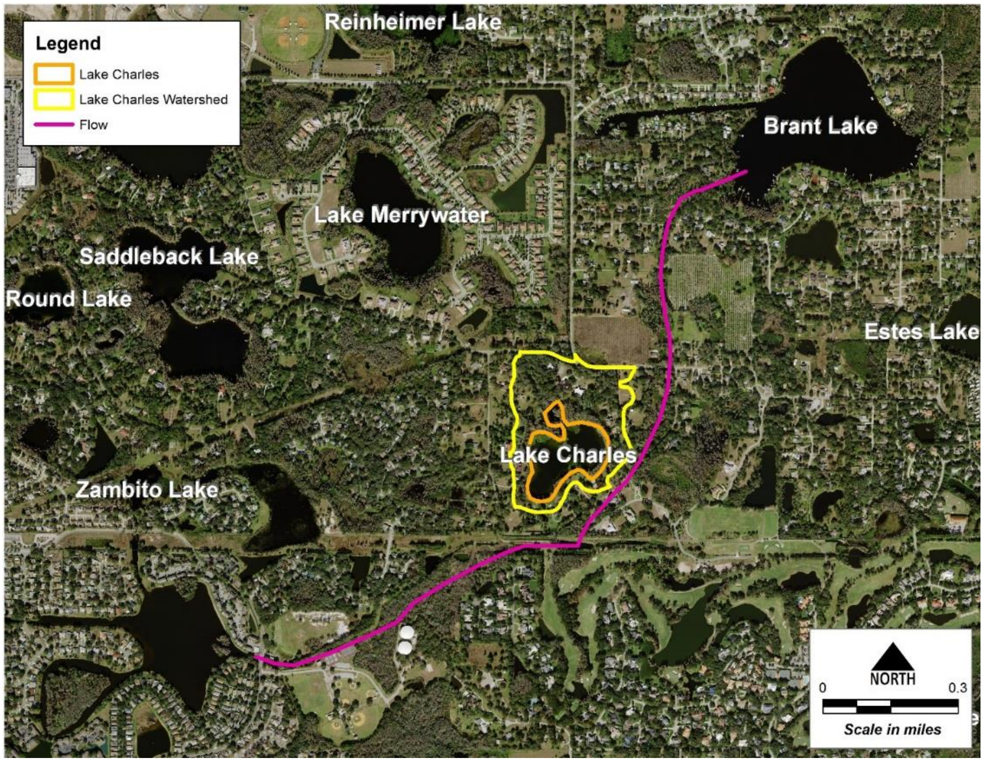

Figure 2. Approximate flow conveyance path (pink line) from Brant Lake (top right) to Lake Heather (bottom left) in the vicinity of Lake Charles (center-right; orange outline).

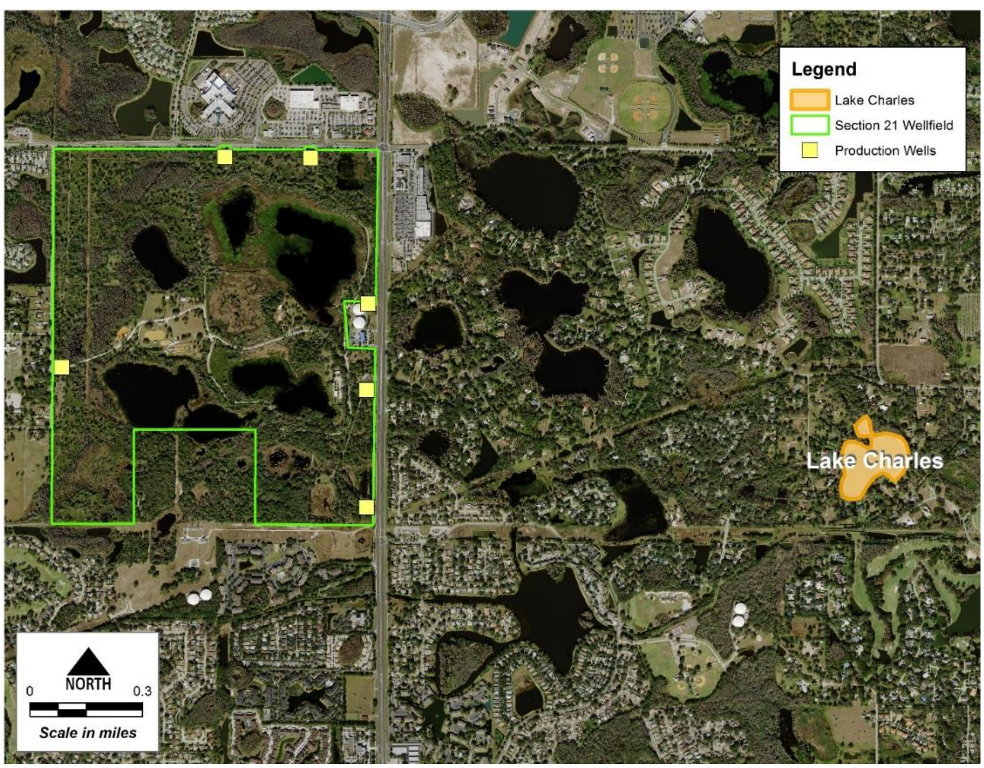

Figure 3. Lake Charles and the Section 21 wellfield.

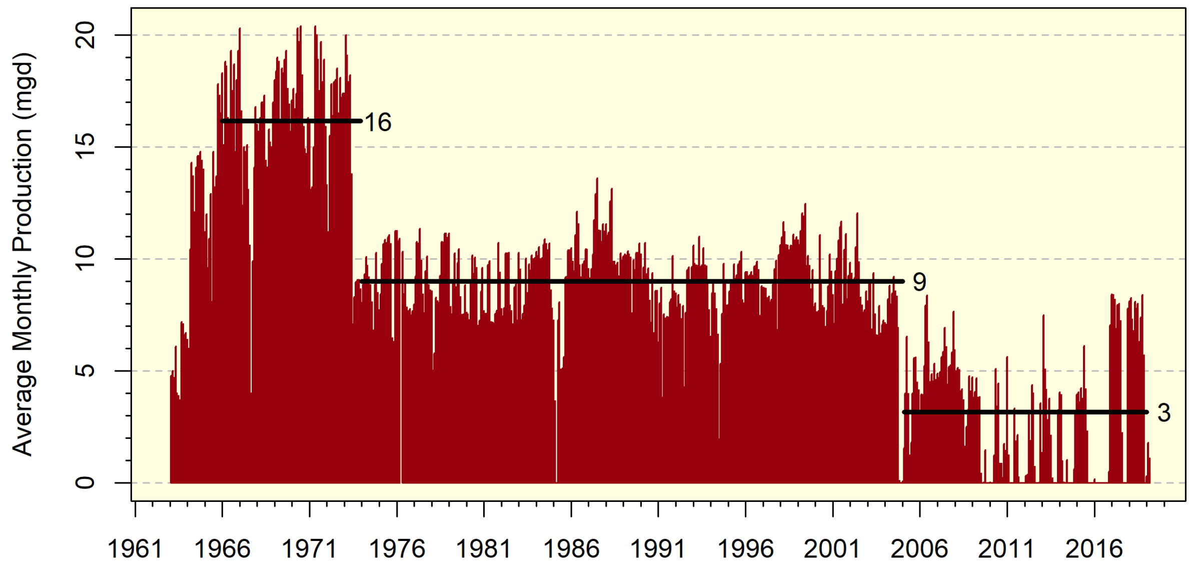

Figure 4. Average monthly withdrawals at the Section 21 wellfield. Horizontal black lines indicate the average production of the time period spanned by the line.

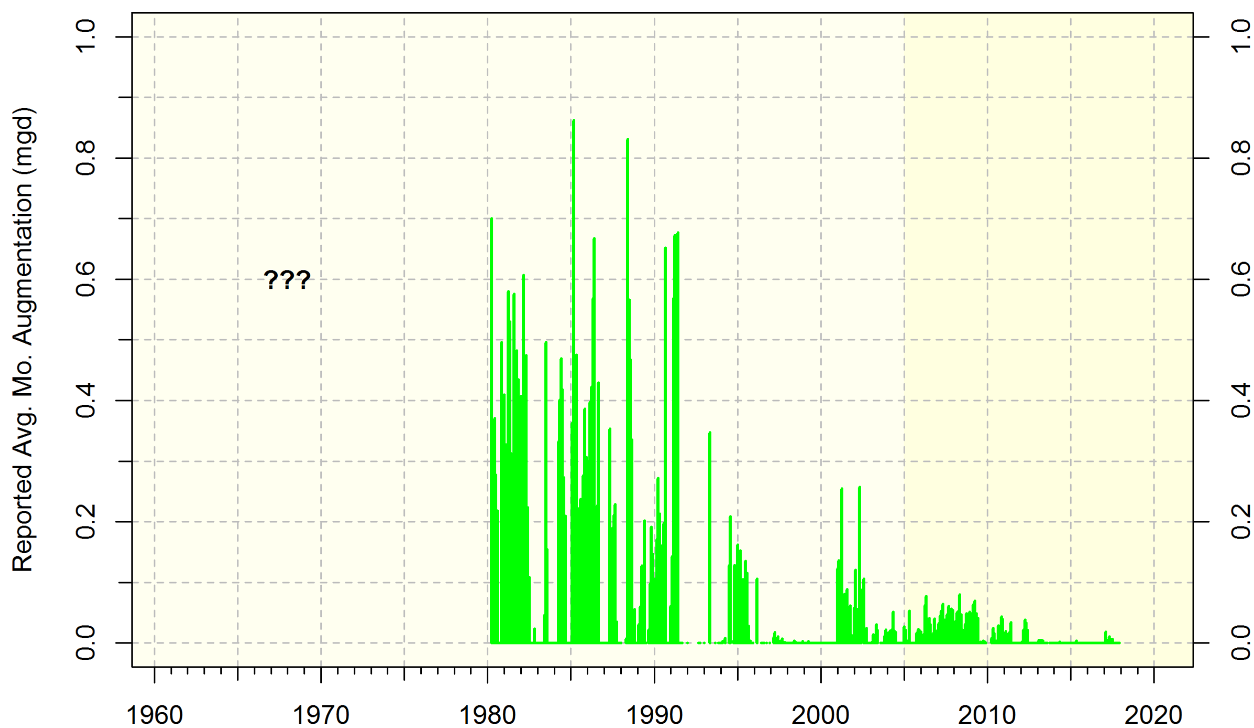

Figure 5. Reported average monthly augmentation (mgd) at Lake Charles. Augmentation started in 1968 at undocumented rates, as augmentation data begins in 1980.

C. Revised Minimum Levels Proposed for Lake Charles

Revised minimum levels proposed for Lake Charles are presented in Table 1 and discussed in more detail by Venning and others (2019). Minimum levels represent long-term conditions that, if achieved, are expected to protect water resources and the ecology of the area from significant harm that may result from water withdrawals. The Minimum Lake Level is the elevation that a lake's water levels are required to equal or exceed fifty percent of the time on a long-term basis. The High Minimum Lake Level is the elevation that a lake's water levels are required to equal or exceed ten percent of the time on a long-term basis. The Minimum Lake Level therefore represents the required 50th percentile (P50) of long-term water levels, while the High Minimum Lake Level represents the required 10^{th} percentile (P10) of long-term water levels. To determine the status of minimum levels for Lake Charles or minimum flows and levels for any other water body, long-term data or model results must be used.

Table 1. Proposed Minimum Levels for Lake Charles.

Proposed Minimum Levels	**Elevation in Feet** NGVD 29
High Minimum Lake Level	53.3
Minimum Lake Level	51.9

D. Status Assessment

The lake status assessment approach involves using actual lake stage data for Lake Charles from January 2010 through February 2019, which was determined to represent the "Current" period based on consistent augmentation rates and the commencement of cutbacks at the neighboring Section 21 wellfield (Figures 4 and 5). As demonstrated in Cameron and Ellison (2019), groundwater withdrawals and augmentation during this period were relatively consistent. The Current period represents a recent "Long-term" period when hydrologic stresses (including groundwater withdrawals) and structural alterations are reasonably stable. "Long-term" is defined as a period that has been subjected to the full range of rainfall variability that can be expected in the future. As stage data are not available during the first three months of 2010, April 2010 is used as the start of the Current period in the following analyses.

To create a data set that can reasonably be considered "Long-term," a regression analysis using the line of organic correlation (LOC) method was performed on the lake level data from the Current period. The LOC is a linear fitting procedure that minimizes errors in both the *x* and *y* directions and defines the best-fit straight line as the line that minimizes the sum of the areas of right triangles formed by horizontal and vertical lines extending from observations to the fitted line (Helsel and Hirsch, 2002). The LOC is preferable for this application since it produces a result that best retains the variance (and therefore best retains the "character") of the original data. This technique was used to develop the minimum levels for Lake Charles (Cameron and Ellison, 2019). By using this technique, the limited years of Current lake level data can be projected back to create a simulated data set representing over 70 years of lake levels, based on the current relationship between lake water levels and actual rainfall.

The same rainfall data set used for setting the minimum levels for Lake Charles was used for the status assessment (Cameron and Ellison, 2019). The best resulting correlation for the LOC model created with measured data (April 2010 to February 2019) was the 1-year weighted period, with a coefficient of determination of 0.58. The results are presented in Figure 6, which displays the lake's predicted behavior under Current withdrawal and augmentation conditions.

As an additional piece of information, Table 2 also presents the percentiles calculated directly from the measured lake level data for Lake Charles for the period from April 2010 through February 2019. A limitation of these values is that the resulting lake stage exceedance percentiles are representative of rainfall conditions during only the past 10 years, rather than the longer-term rainfall conditions represented in the January 1946 to February 2019 LOC model simulation.

A comparison of the LOC model with the revised minimum levels proposed for Lake Charles indicates that the Long-term P10 is 0.2 feet below the proposed High Minimum Lake Level, and the Long-term P50 is 0.1 feet above the proposed Minimum Lake Level. The P10 elevation derived directly from the April 2010 to February 2019 measured lake data is 0.2 feet above the proposed High Minimum Lake Level, and the P50 elevation is 0.2 feet above the proposed Minimum Lake Level. Differences in rainfall between the shorter April 2010 to February 2019 period and the longer 1946 to February 2019 period used for the LOC modeling analyses likely contribute to the differences between derived and measured lake stage exceedance percentiles. Additionally, differences between actual withdrawal and augmentation rates and those used in the models may have contributed to some of the differences in the percentiles.

E. Conclusions

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

Minimum flow and level status assessments are completed on an annual basis by the District and on a five-year basis as part of the regional water supply planning process. In addition, Lake Charles 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 status of Lake Charles 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 Lake Charles 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 Lake Charles is found to not be meeting its adopted minimum levels. The draft results of the Permit Recovery Assessment Plan were due and received by the District by December 31, 2018.

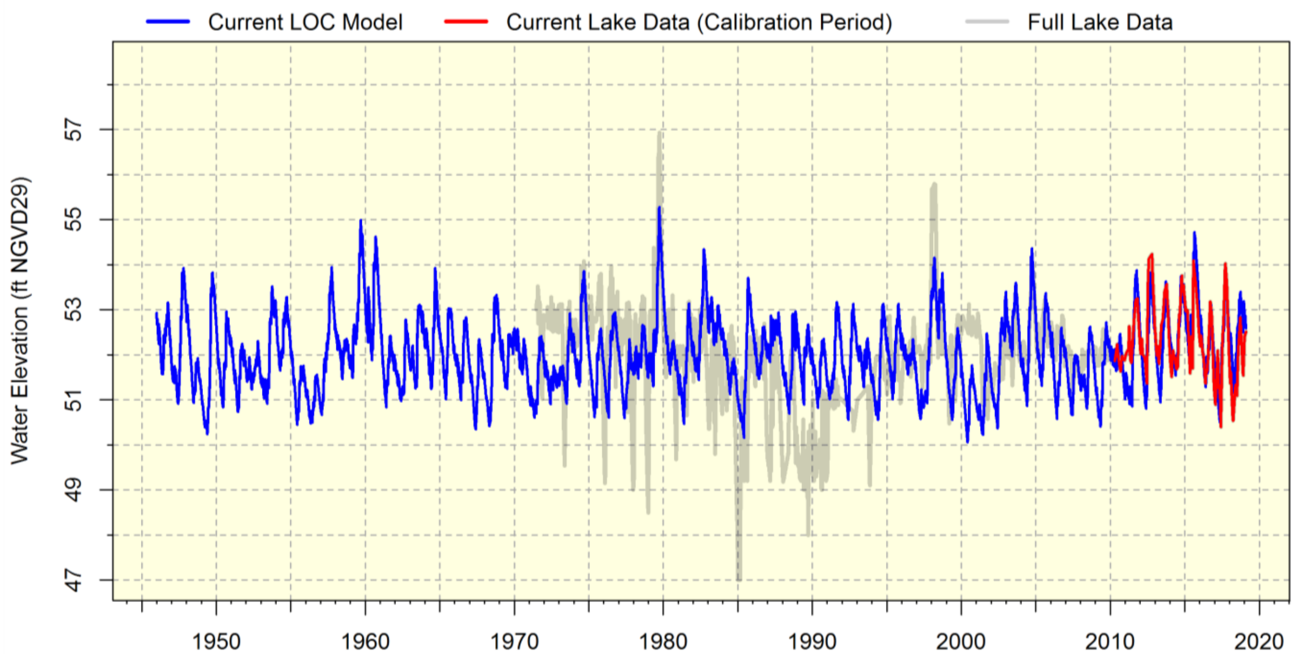

Figure 6. Current LOC model results (blue line) and observed data (red line) for Lake Charles.

Table 2. Comparison of lake stage exceedance percentiles derived from the lake stage/LOC results, exceedance percentiles of the April 2010 to February 2019 data, and the revised minimum levels proposed for Lake Charles. All elevations in feet NGVD 29.

Percentile	Proposed Minimum Levels	Long Term LOC Model Results (1946 to 2019*)†	Measured Lake Levels for Current Period (2010 to 2019*)	LOC Model Results – Percentage of Time At or Above Level (1946 to 2019*)†
P10	53.3	53.1	53.5	7%
P50	51.9	52.0	52.1	53%

* February 2019

† LOC model based on Current Period extended using rainfall for January 1946 to February 2019.

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APPENDIX C

Technical Memorandum

October 29, 2019

TO: T.J. Venning, Staff Environmental Scientist, Water Resources Bureau
Cortney Cameron, G.I.T., Staff Hydrogeologist, Water Resources Bureau

FROM: Cortney Cameron, G.I.T., Staff Hydrogeologist, Water Resources Bureau

Subject: Evaluation of Groundwater Withdrawal Impacts to Lake Charles

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A. Introduction

Lake Charles 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 Lake Charles 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, which are used to estimate drawdown time series used in the Lake Charles water budget model (Appendix A, Section H).

B. 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. Underlying the middle confining unit II is the Lower Floridan aquifer (Miller, 1986).

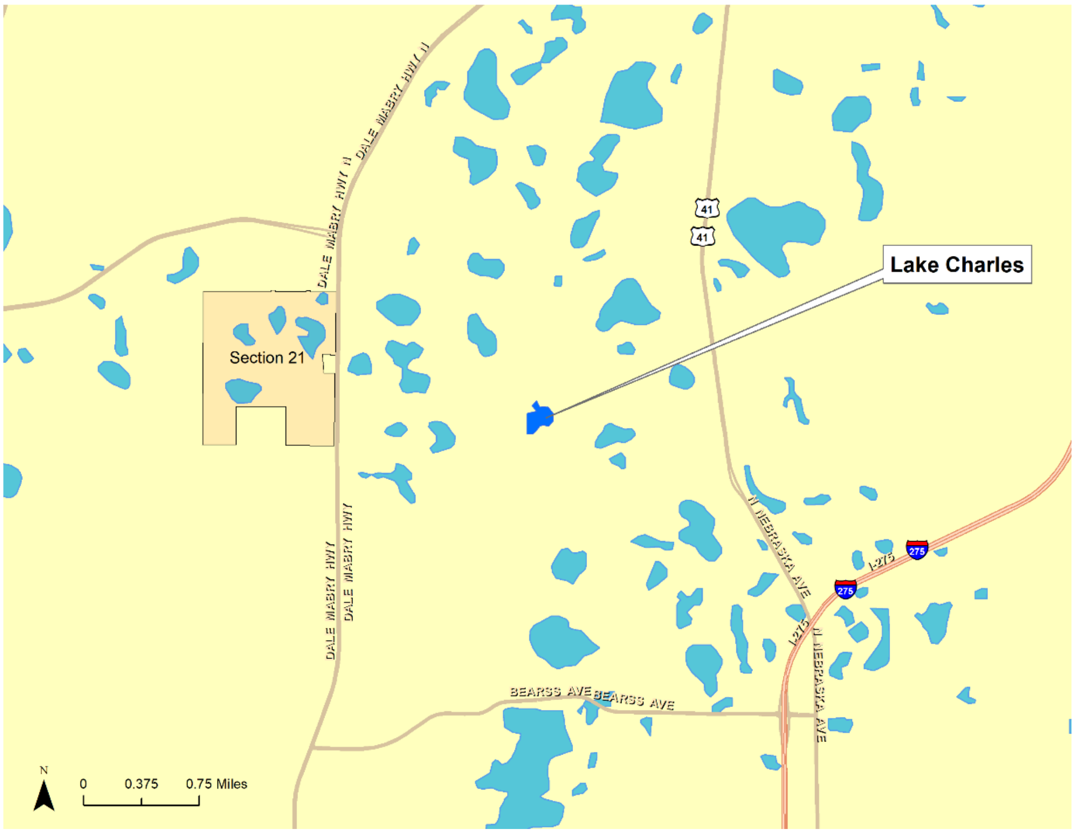

Figure 1. Location of Lake Charles.

C. Evaluation of Groundwater Withdrawal Impacts to Lake Charles

Several regional groundwater flow models have included the area around Lake Charles 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).

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.

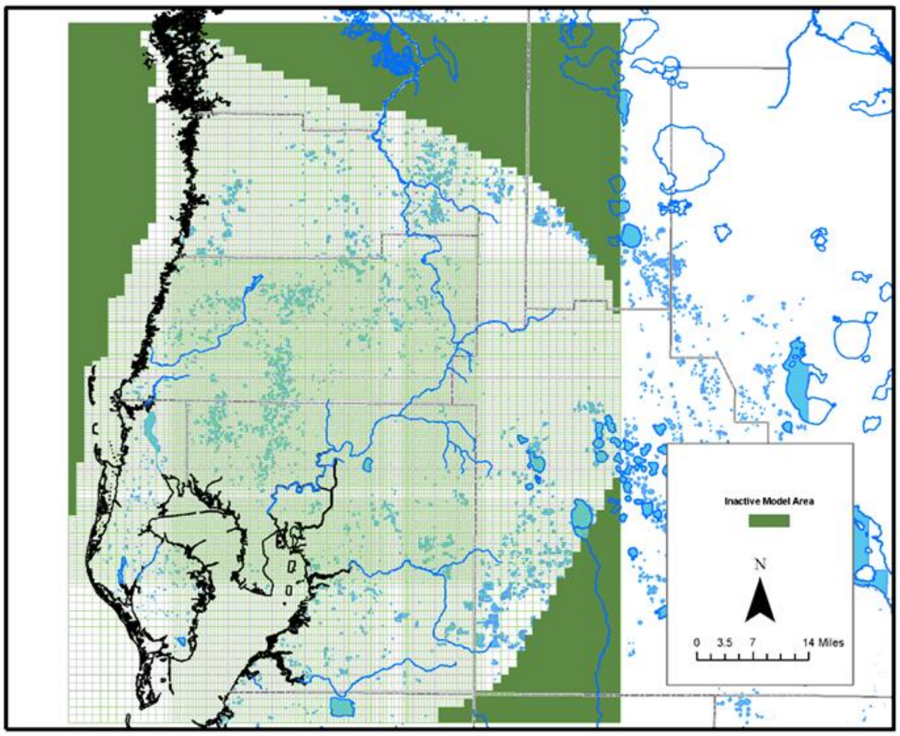

Figure 2. Groundwater grid used in the INTB model.

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 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.

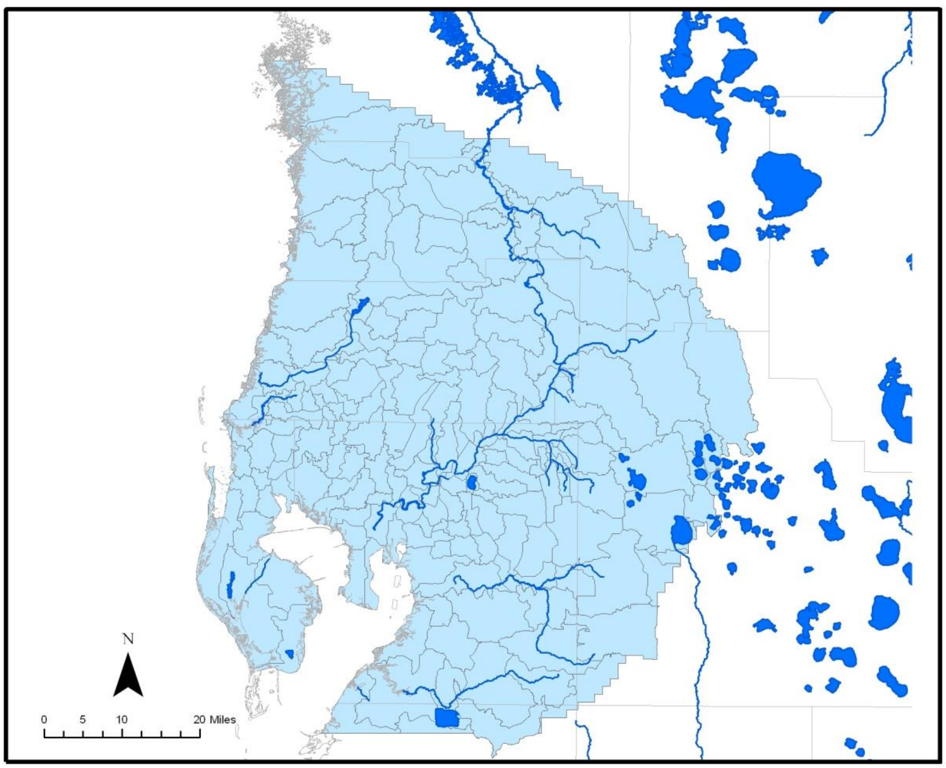

Figure 3. HSPF subbasins in the INTB model.

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 was also 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).

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 Lake Charles was 2.4 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 Lake Charles was 1.1 ft and 2.2 ft in the Upper Floridan aquifer (Figure 6 and 7). Table 1 presents the predicted drawdown in the surficial and the Upper Floridan aquifer based on the INTB model results.

Table 1. INTB model results for Lake Charles.

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***
Charles	2.2	1.1
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***
Charles	4.4	2.4

* Average drawdown from model cells intersecting lake

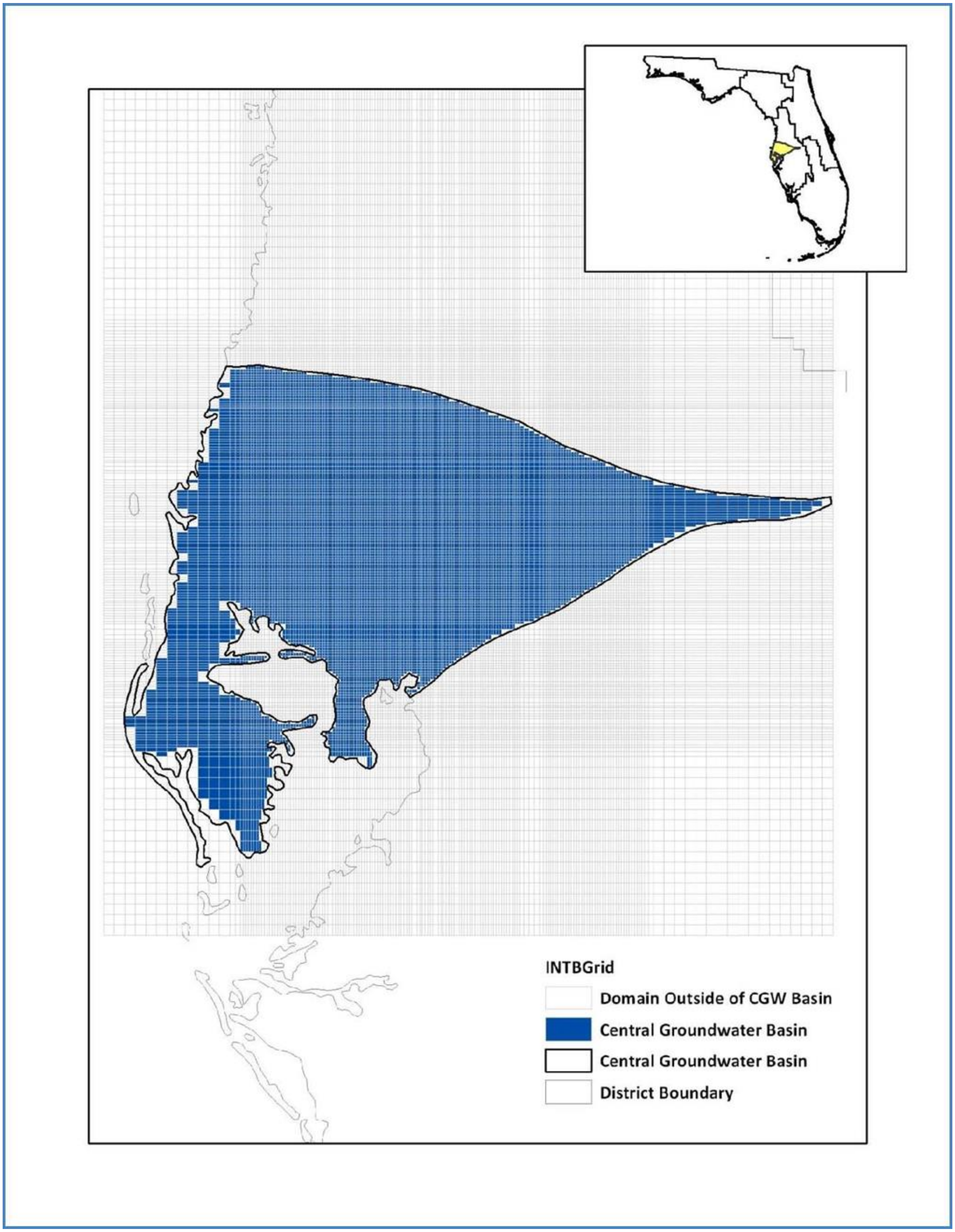

Figure 4. INTB scenarios where impacts to the hydrologic system were simulated due to groundwater withdrawals in the Central West-Central Florida Groundwater Basin.

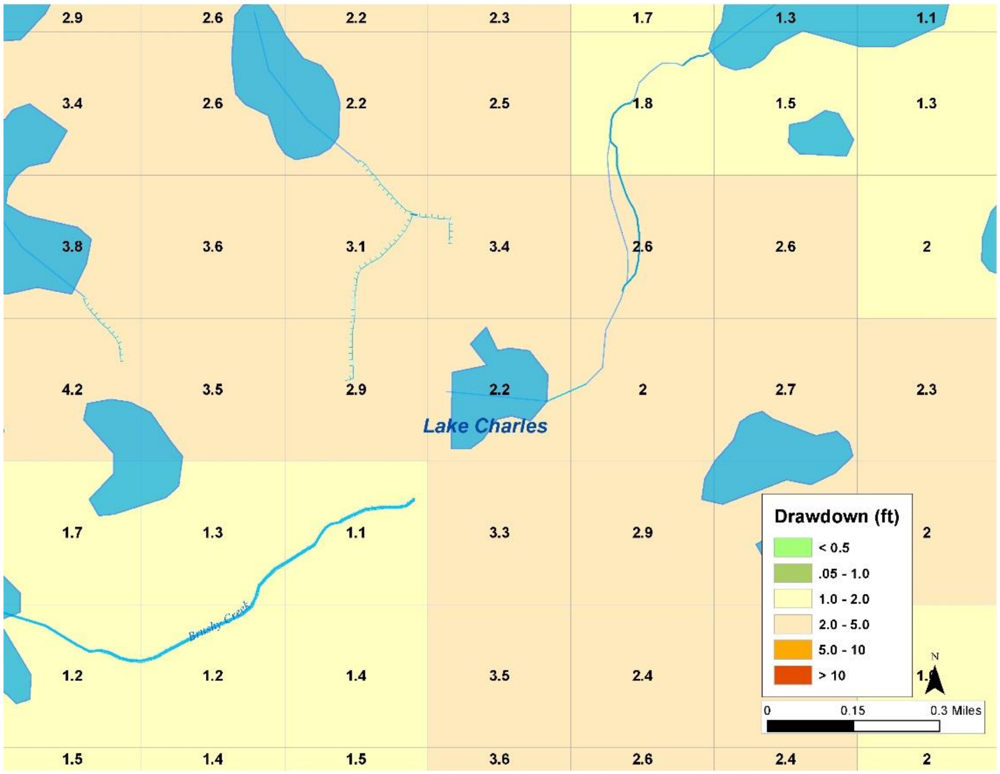

Figure 5. Predicted mean drawdown in the surficial aquifer due to 1989-2000 groundwater withdrawals.

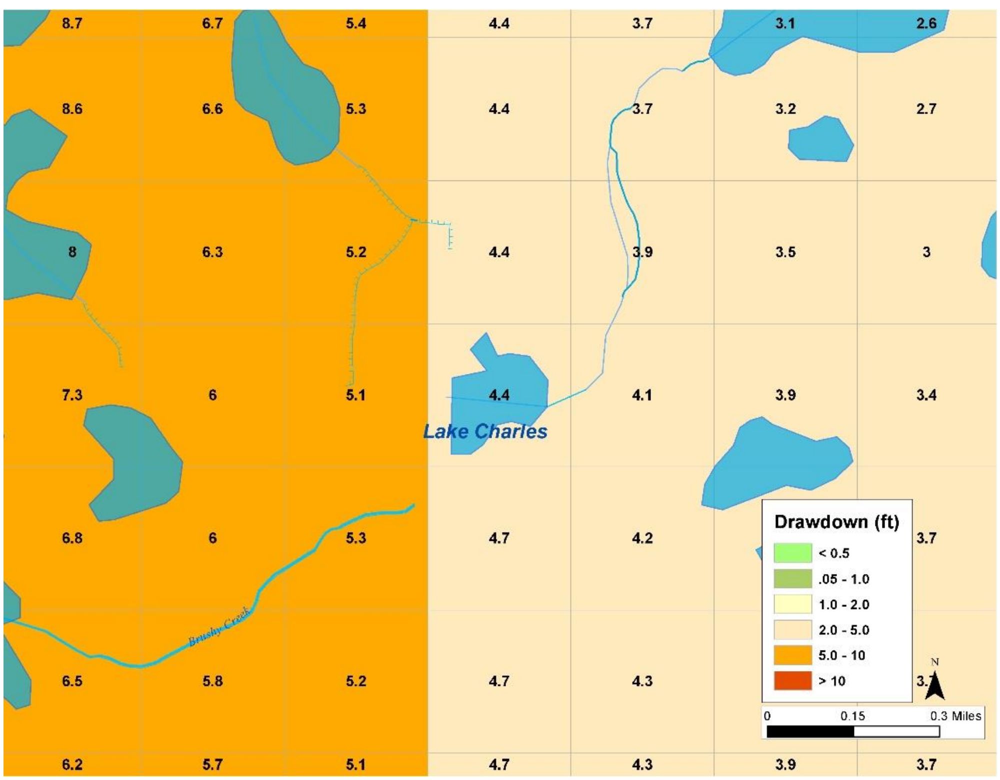

Figure 6. Predicted mean drawdown in the Upper Floridan aquifer due to 1989-2000 groundwater withdrawals.

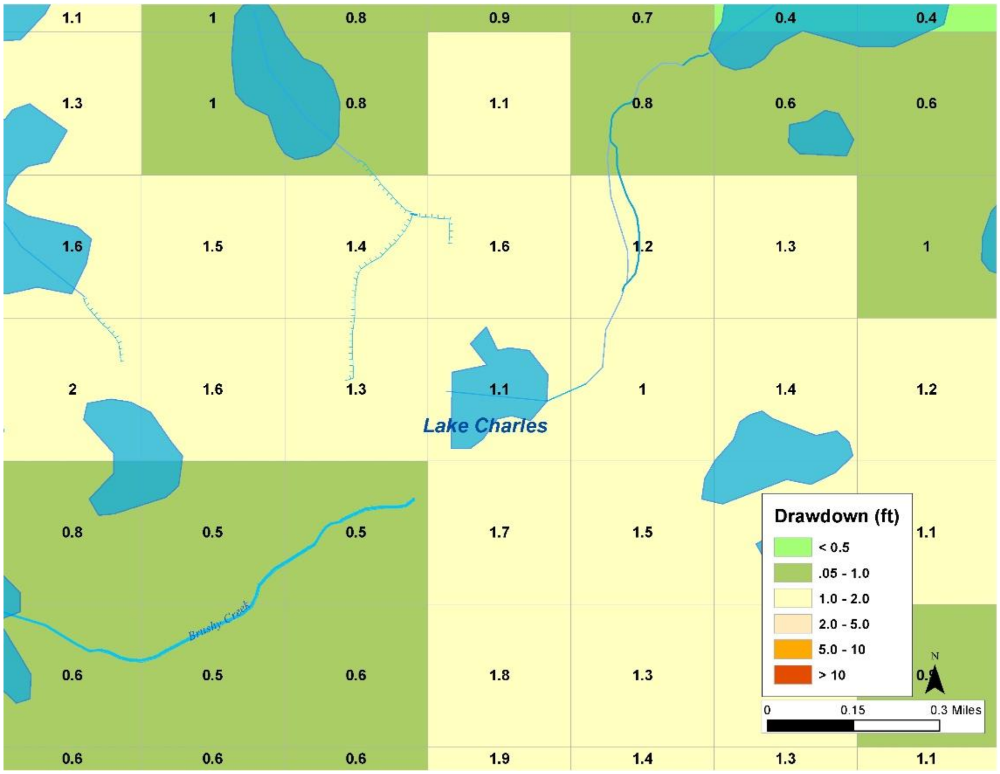

Figure 7. Predicted mean drawdown in the surficial aquifer due to TBW 90 mgd groundwater withdrawals.

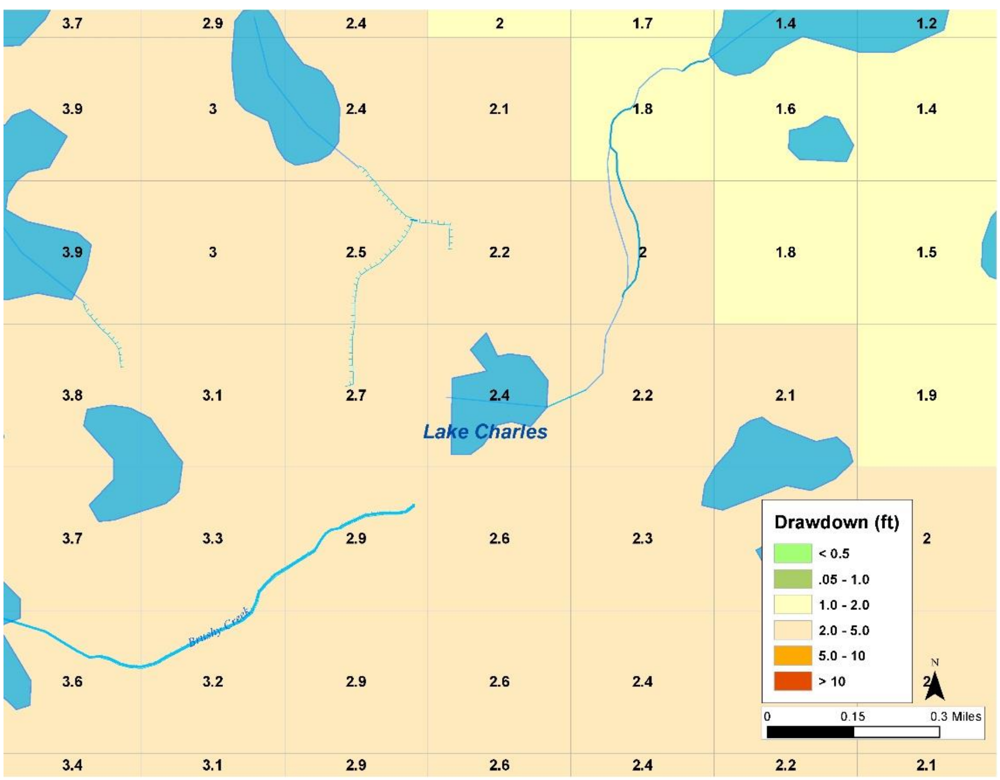

Figure 8. Predicted mean drawdown in the Upper Floridan aquifer due to TBW 90 mgd groundwater withdrawals.

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