Technical Memorandum

November 16, 2020

TO: FILE

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                  Ron Basso, P.G., Chief Hydrogeologist, Water Resources Bureau
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Subject: **Reevaluation of Lakes Allen, Harvey and Virginia High Minimum Lake Levels**

A.   Background

Minimum levels for Lakes Allen, Harvey and Virginia in Hillsborough County were reevaluated in 2018 (Campbell et al., 2019). The three lakes share a control point elevation, are connected by dredged canals that allow their water levels to equalize, and accordingly have identical minimum levels (Ellison and Patterson, 2018b; Campbell et al., 2019). The wellfields nearest the lakes are South Pasco and Section 21 (Figure 1). A description of the lakes' hydrogeologic setting is available in Ellison and Patterson (2018b). Definitions of the terms Minimum Lake Level (MLL), High Minimum Lake Level (HMLL), P10, P50, Historic, Current, Normal Pool Elevation, Control Point Elevation, National Geodetic Vertical Datum of 1929 (NGVD29), Category 1 Lakes, and Structural Alterations are as in Campbell et al. (2019).

Rule 40D-8.624(8), Florida Administrative Code (F.A.C.), classifies a lake as Category 1 if it is fringed by ≥0.5 acres of cypress swamp and if its Historic P50 elevation is ≤1.8 feet below its Normal Pool Elevation. The MLL for a Category 1 lake is established at an elevation equal to Normal Pool less 1.8 feet, while the HMLL is established at an elevation equal to Normal Pool less 0.4 feet.

During the 2018 reevaluation of Lakes Allen, Harvey and Virginia, the Historic P10 and Historic P50 were, respectively, established at 62.3 and 61.3 feet NGVD29 based on water budget and statistical models (Ellison and Patterson, 2018b). The Normal Pool Elevation was established at 62.5 feet NGVD29 based on the median of data collected from the lakes in 2002 and 2003 (Campbell et al., 2019). Accordingly, Lakes Allen, Harvey and Virginia were classified as Category 1 Lakes, and their MLL and HMLL were set at 60.7 and 62.1 feet NGVD29, respectively. The Control Point Elevation for the lakes was established at 60.7 feet NGVD29 based on a structure connecting Lake Virginia to a wetland to its west.
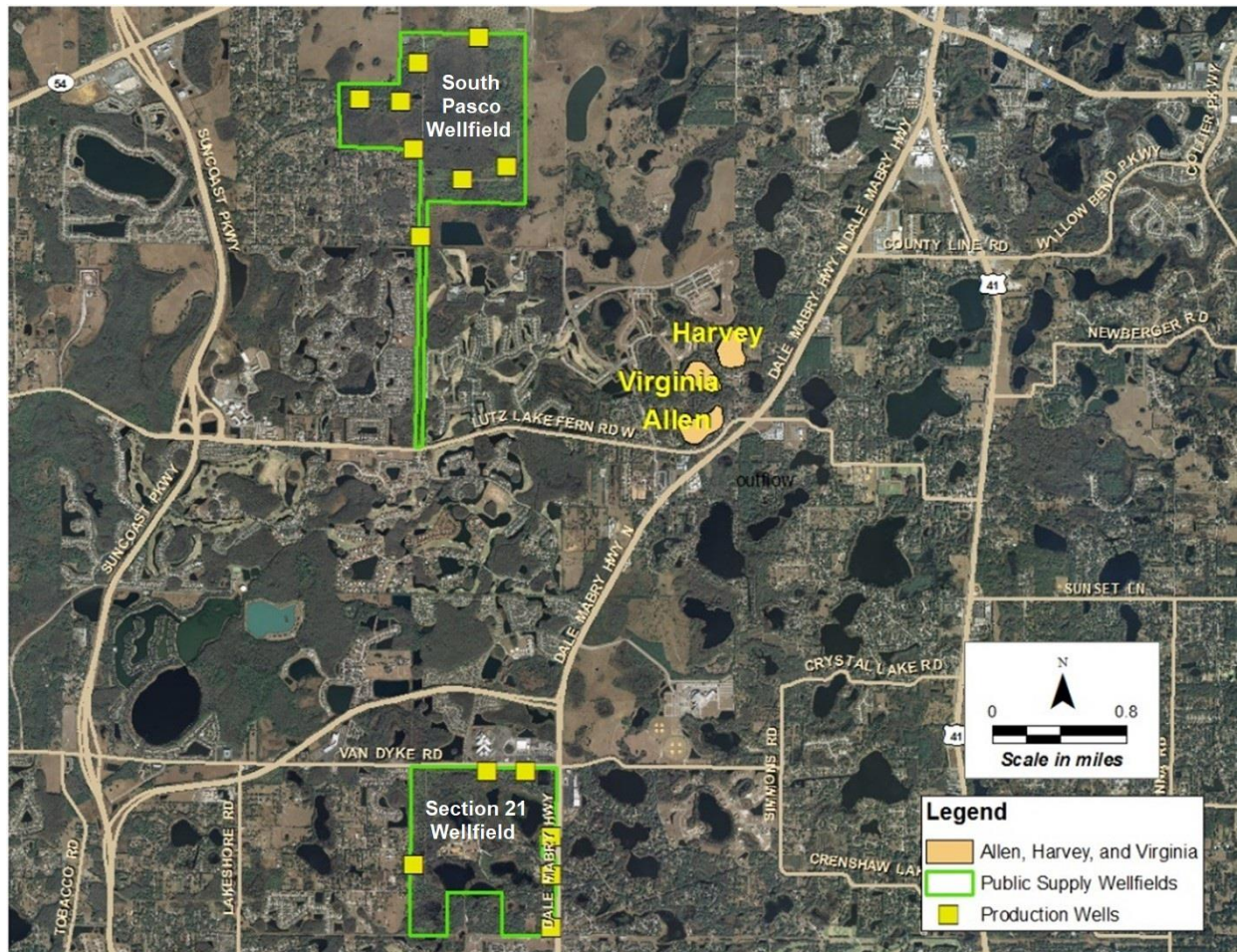
Figure 1. Location of Lakes Allen, Harvey and Virginia in Hillsborough County, Florida.

Based on long-term statistical modelling of Current water levels, Lakes Allen, Harvey and Virginia were deemed as meeting their MLL and HMLL at the time of the 2018 reevaluation (Ellison and Patterson, 2018a). During an updated annual status assessment, Basso et al. (2020) assessed the lakes' status using a weight-of-evidence approach. The report noted that since 2008, when withdrawals at the Tampa Bay Water central system wellfields were mandated to be at or below 90 million gallons per day, 1) nearby long-term monitor wells have shown surficial and upper Floridan aquifer groundwater levels near their 50- to 60-year maximum values, 2) wellfield withdrawals at South Pasco and Section 21 wellfields declined by 65 and 70 percent, respectively, and 3) the lakes' observed 2010-2019 P50 exceeded the MLL by 0.3 feet. However, the lakes' observed 2010-2019 P10 was 0.3 feet below their HMLL. Using the weight-of-evidence approach, Basso et al. (2020) concluded that this difference between the P10 and HMLL was unrelated to groundwater withdrawals, was potentially affected by uncertainty in the Normal Pool Elevation (associated with a relatively wide range of observed Normal Pool indicator elevations), and was likely reflective of structural alterations at the lakes, necessitating an additional reevaluation of the lakes' HMLL.

B.   Stage Data Record

As noted in Ellison and Patterson (2018b), the combined stage data record for the lakes begins in 1970 and continues to present, including variable data collection frequency and gaps throughout the period-of-record, with monthly data typically available for the most recent years (Figure 2). Due to having the fewest significant gaps and its agreement with Lakes Harvey ($R^2 = 0.96$; 79% of values within 0.1 feet) and Virginia ($R^2 = 0.96$; 86% of values within 0.1 feet) stages, the Lake Allen stage data, which begin in 1971, have typically been used for minimum level status assessments. In the following analyses, the Lake Allen stage data were considered representative of the three-lake system, with data used through 2019. Additionally, to avoid over-weighting periods of higher data collection during the calculation of percentiles, the data were aggregated to monthly means.

C.   Insensitivity of the P10 to Groundwater Withdrawals

To evaluate the relative insensitivity of Northern Tampa Bay (NTB) lakes' long-term P10s to changes in groundwater withdrawals at the population level, an analysis was conducted as part of the updated annual minimum flows and levels status assessment (Basso et al., 2020). Using a sample of 56 NTB lakes, the P10 did not significantly differ at the population level between a lower-pumping period (2010-2019) and a higher-pumping period (period-of-record). By comparison, the P50 showed significant differences, with clear increases in the lower-pumping period. This finding suggested that, at the
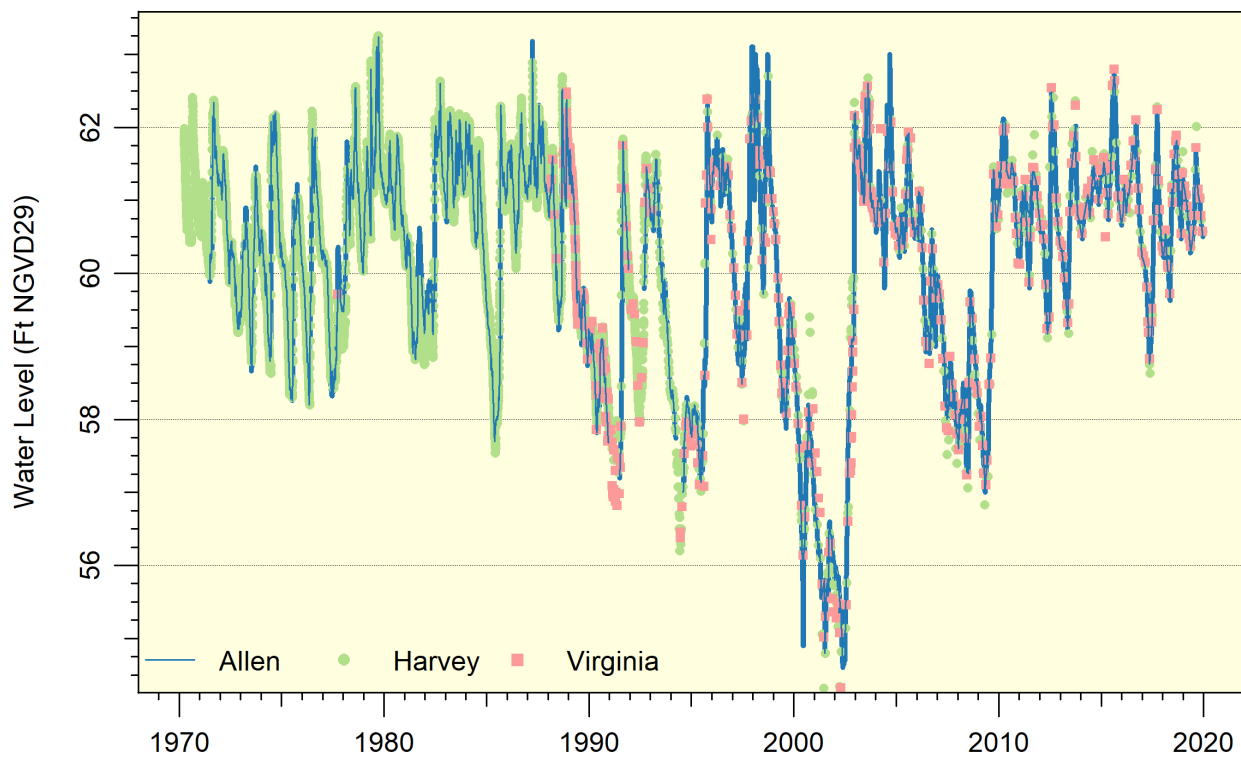

Figure 2. Hydrographs of Lakes Allen, Harvey and Virginia.

population level, long-term P10 elevations in NTB lakes are relatively insensitive to groundwater withdrawals, as the highest water levels in structurally altered lakes tend to be controlled more by structures and discrete rainfall events. However, since an individual lake system can have varying sensitivity to groundwater withdrawals based on its specific structural conditions and hydraulic connection to the upper Floridan aquifer, additional analyses were performed on Lakes Allen, Harvey and Virginia to assess the relationship of their P10 to groundwater withdrawals.

The analysis noted that at Lakes Allen, Harvey and Virginia, the P10 calculated using 1971-1980, 1981-1990, 1991-2000, 2001-2010, and 2011-2019 observed stage data showed only 0.2 feet of total variation (Basso et al., 2020). The fact that the P10 changed very little between these periods demonstrated the relative insensitivity of the lakes' long-term P10 to groundwater withdrawals, given significant changes (decreases) in groundwater withdrawals that began in the early 2000s (Figure 3). By comparison, the P50 varied by 1.3 feet, indicating the much greater sensitivity of the P50 to groundwater withdrawals. Therefore, it was concluded that groundwater withdrawals are unlikely to be responsible for causing the long-term observed P10 in Lakes Allen, Harvey and Virginia to remain below the HMLL of 62.1 feet NGVD29.

Using a rolling 10-year percentile from 1971-2019, the total variation is 0.4 feet for the P10 and 2.4 feet for the P50 at Lakes Allen, Harvey and Virginia (Figure 4). The 10-year P10 is only weakly correlated to the P50 ($R^2 = 0.17$), where the latter is highly sensitive to groundwater withdrawals for many NTB waterbodies (SWFWMD, 1999b). During the low rainfall, high pumping period of the early 2000s, the rolling 10-year P50 for Lakes Allen, Harvey and Virginia fell dramatically, while the P10 remained relatively stable (Figure 4). In fact, using a one-sided Wilcoxon signed-rank test, the mean of the rolling 10-year P10 was significantly higher during the 1980-1999 higher-pumping period compared to the 2010-2019 lower-pumping period ($p < 0.01$), although the magnitude of the difference was small (<0.1 feet) and this application violates the test's assumption of independence. The relatively small variations in the long-term P10 likely reflect rainfall conditions. These results support the conclusion that the long-term P10 of Lakes Allen, Harvey and Virginia is not significantly influenced by changes in groundwater withdrawals (Basso et al., 2020). Therefore, that the rolling 10-year P10 has remained below the HMLL throughout the period-of-record (Figure 4) indicates that the HMLL of 62.1 feet NGVD29 is not achievable and should be reevaluated.

D.   Uncertainty of the HMLL

In general, due to fewer available data, the extremes of any data distribution are associated with more uncertainty relative to the central tendency. By definition, the HMLL and P10 each represent a high-water level equaled or exceeded ten percent of the time. The percentile of the Normal Pool Elevation varies by system but also represents a high-
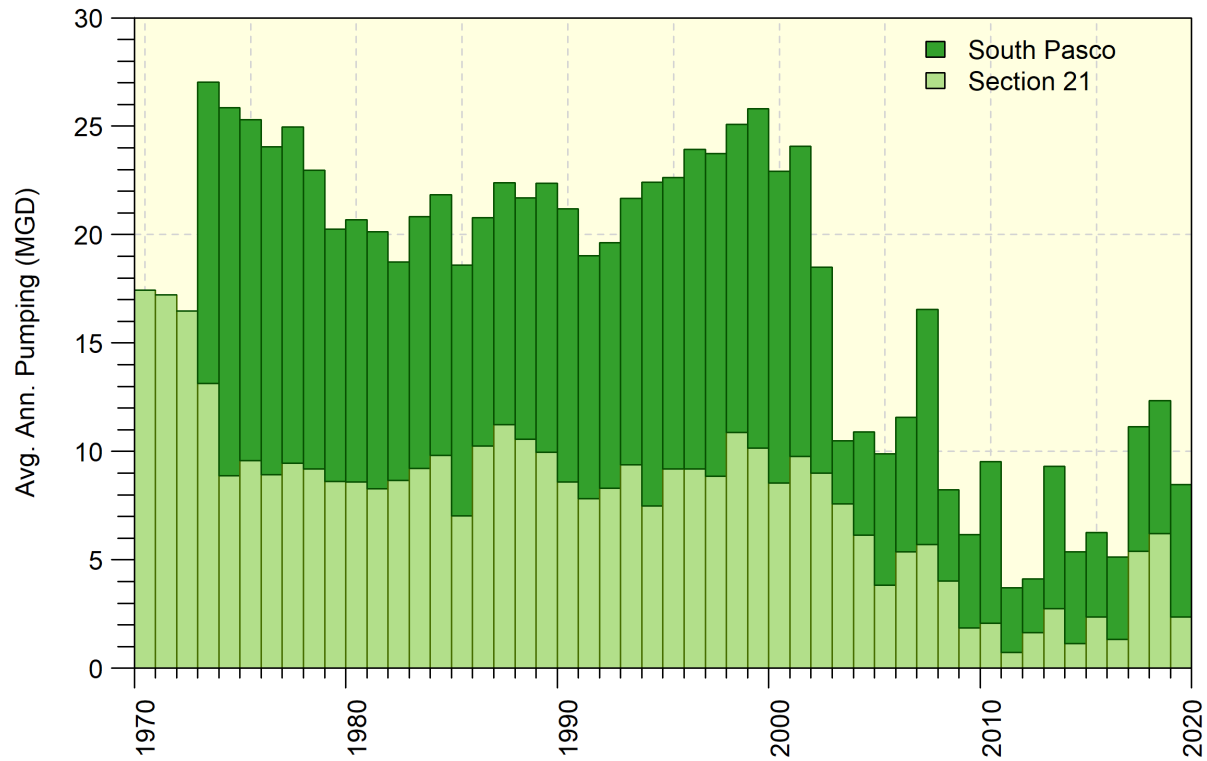
Figure 3. Average annual withdrawals at the South Pasco and Section 21 wellfields.
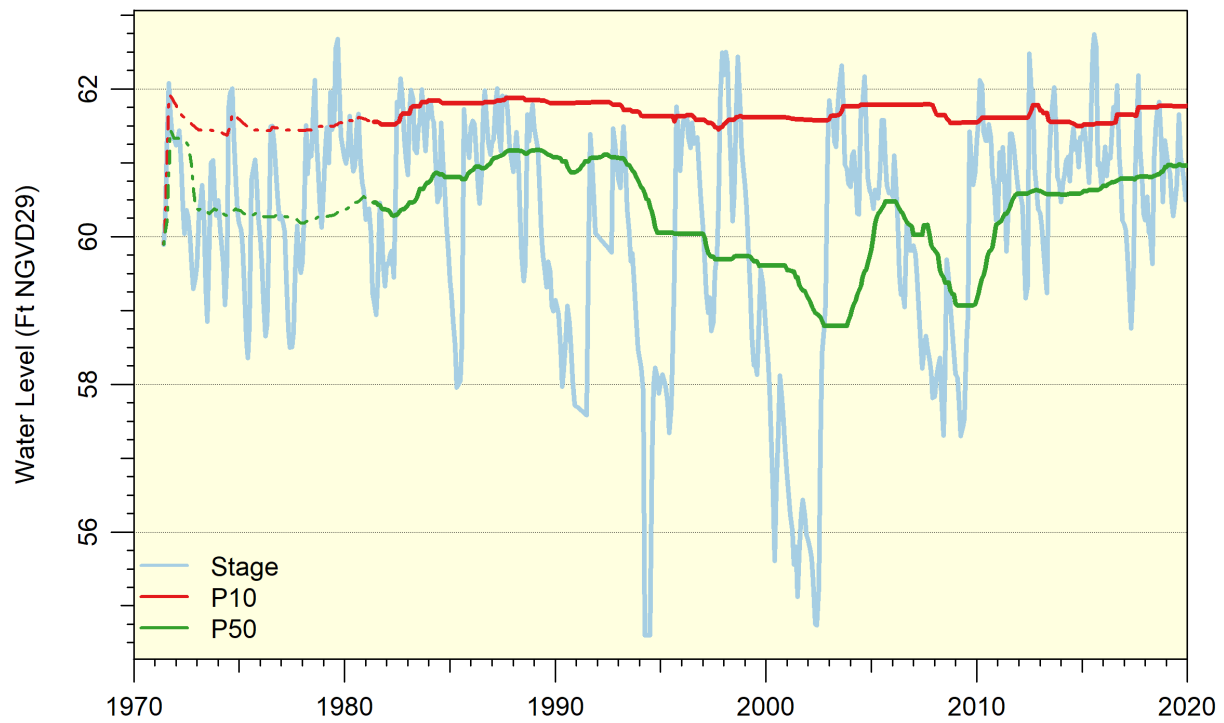

Figure 4. Rolling 10-year P10 and P50 for Lakes Allen, Harvey and Virginia.

water level; in cypress domes, on average, the Normal Pool Elevation is equaled or exceeded only about three percent of the time (P03) (Cameron et al., 2020). Based on 1971-2019 and 2010-2019 stage data for Lakes Allen, Harvey and Virginia, the Normal Pool Elevation corresponds to, respectively, the P02 and P01. Similarly, the Normal Pool Elevation was found to correspond with the P05 for Lakes Allen, Harvey and Virginia, based on a 1946-2016 Historic daily water level record developed using water budget and statistical models (Ellison and Patterson, 2018b).

Additionally, as a biological indicator, the Normal Pool Elevation reflects variation inherent to biological systems. District scientists assess numerous indicators and place the greatest confidence in the final Normal Pool Elevation when multiple elevation measurements show minimal variation. District staff typically consider it optimal if measured indicators have no more than 0.3 feet of variation, although 1.0 feet of variation is considered acceptable. At the time of the 2018 revaluation of Lakes Allen, Harvey and Virginia, District staff were unable to access appropriate Normal Pool indicators and so used data collected from the previous evaluation (Campbell et al., 2019). This data showed a mean and median elevation of 62.5 feet NGVD29, with a range of 4.0 feet, a standard deviation of 0.6 feet, and a standard error of the mean of 0.1 feet (SWFWMD, 2005a; SWFWMD, 2005b; SWFWMD, 2005c). Removing the minimum elevation and maximum elevation from the dataset, the range, standard deviation and standard error of the mean decrease to, respectively, 1.4, 0.3, and 0.05 feet, with the mean and median elevation unchanged. Thus, whether or not outliers are excluded, the variability and uncertainty in the Normal Pool indicators for Lakes Allen, Harvey and Virginia capture much of the 0.4 feet offset from Normal Pool used to establish the HMLL for Category 1 Lakes.

E.   Historic P10-P50 Difference

Based on modeled 1946-2016 Historic stage data, Ellison and Patterson (2018b) estimated that the Historic P10 is 1.0 feet above the Historic P50 for Lakes Allen, Harvey and Virginia. This value of 1.0 feet is similar to the observed difference of 0.8 feet between the P10 and P50 for the lakes using 2010-2019 stage data, during which time the lakes were determined to have minimal impacts due to groundwater withdrawals (see Basso et al., 2020). The 0.2 feet difference between the two approaches could result from model uncertainties, from comparing two different time periods, and from the usage of daily versus monthly data. Based on the average of these two values, the Historic P10-P50 fluctuation is estimated at 0.9 feet.

F.   Proposed HMLL

Although Rule 40D-8.624(8), F.A.C., describes a standard process for establishing MLL and HMLL for Category 1 Lakes, Rule 40D-8.624(9), F.A.C. provides that when a lake

has "unique factors," the MLL and HMLL can be adjusted appropriately. Additionally, in numerous instances, Rule 40D-8.624 calls for application of professional and scientific judgement in setting and assessing lake minimum levels. Unique factors at Lakes Allen, Harvey and Virginia include greater-than-typical uncertainty in the Normal Pool Elevation, plus a larger fluctuation (which could reflect one or both of structural alterations and natural variability) between the Normal Pool and Historic P10 elevations than the value prescribed in Rule 40D-8.624(8), F.A.C. Thus, strict application of Rule 40D-8.624(8), F.A.C., results in an HMLL higher than the lake can realistically achieve, even as data show the lakes' P10 has been stable for decades and is apparently not strongly influenced by groundwater withdrawals.

An adjustment to the HMLL for Lakes Allen, Harvey and Virginia is therefore appropriate. At this time, no revisions to the MLL are necessary, although future status assessments should consider the uncertainty present in the lakes' minimum levels.

As described above, the lakes' Historic P10-P50 fluctuation is estimated at 0.9 feet, which is the fluctuation expected to occur at the lake with current structural alterations but without groundwater withdrawal impacts. Therefore, it is proposed that the HMLL for Lakes Allen, Harvey and Virginia be set at the elevation equal to the existing MLL (60.7 feet NGVD29) plus the Historic P10-P50 fluctuation (0.9 feet), resulting in a proposed HMLL of 61.6 feet NGVD29 (Table 1). Establishing the HMLL at an elevation equal to the MLL plus the Historic P10-P50 fluctuation is also the approach that the District currently employs for Category 3 Lakes.

G.   Initial Status Assessment

Using the status assessment process described in Basso et al. (2020) for NTB lakes, to assess status for Lakes Allen, Harvey and Virginia, the P10 and P50 from 2010-2019 observed stage data are compared to, respectively, the proposed HMLL and the MLL (Table 1). Based on the 2010-2019 observed stage data, both the MLL and the proposed HMLL are considered met for Lakes Allen, Harvey and Virginia.

Table 1. Proposed minimum levels and initial status assessment for Lakes Allen, Harvey and Virginia.

Percentile	Proposed Minimum Levels (feet NGVD29)	Current Stage Data (2010-2019) (feet NGVD29)	Proposed Status (feet NGVD29)
P10	61.6	61.8	+0.2
P50	60.7	61.0	+0.3

H.   References

Basso, R., LeMond, L., Leeper, D., Cameron, C., Qi, J., and Weinstein, D. (2020). Northern Tampa Bay Lake and Wetland MFL Status Assessment (Draft Report). Southwest Florida Water Management District, Brooksville, FL.

Cameron, C. R., Hancock, M. C., Carr, D. W., Hurst, M. K., Campbell, D. E., Venning, T. J., Tara, P. D. and Holzwart, K. R. (2020). Hydroperiods of Cypress Domes in West-Central Florida, USA. *Wetlands*. https://doi.org/10.1007/s13157-020-01329-x

Campbell, D.E., Ellison, D., Patterson, J., and Sampson, J. (2019). Revised Minimum and Guidance Levels Based on Reevaluation of Levels Adopted for Lakes Allen, Virginia, and Harvey in Hillsborough County, Florida. Southwest Florida Water Management District, Brooksville, FL.   *(see Appendix 1)*

Ellison, D.L. and Patterson, J. (2018a). Technical Memorandum: Lakes Allen, Virginia and Harvey Initial Minimum Levels Status Assessment. Southwest Florida Water Management District, Brooksville, FL.   *(see Appendix 1)*

Ellison, D.L. and Patterson, J. (2018b). Technical Memorandum: Lakes Allen, Virginia and Harvey Water Budget Model, Rainfall Correlation Model, and Historic Percentile Estimations. Southwest Florida Water Management District, Brooksville, FL.
                                                                    (see Appendix 1)

Southwest Florida Water Management District (SWFWMD). (1999a). Northern Tampa Bay Minimum Flows and Levels: Whiter Papers Supporting the Establishment of Minimum Levels for Category 1 and 2 Lakes. Southwest Florida Water Management District, Brooksville, FL.

Southwest Florida Water Management District (SWFWMD). (1999b). Northern Tampa Bay Minimum Flows and Levels: Whiter Papers Supporting the Establishment of Minimum Levels in Palustrine Cypress Wetlands. Southwest Florida Water Management District, Brooksville, FL.

Southwest Florida Water Management District (SWFWMD). (2005a). Minimum and Guidance Levels for Lake Allen in Hillsborough County, Florida. Southwest Florida Water Management District, Brooksville, FL.

Southwest Florida Water Management District (SWFWMD). (2005b). Minimum and Guidance Levels for Lake Harvey in Hillsborough County, Florida. Southwest Florida Water Management District, Brooksville, FL.

Southwest Florida Water Management District (SWFWMD). (2005c). Minimum and Guidance Levels for Lake Virginia in Hillsborough County, Florida. Southwest Florida Water Management District, Brooksville, FL.

APPENDIX 1: Revised Minimum and Guidance Levels Based on Reevaluation of Adopted Levels for Lakes Allen, Virginia, and Harvey in Hillsborough County, Florida (Report Dated February 11, 2019)

Revised Minimum and Guidance Levels Based on Reevaluation of Levels Adopted for Lakes Allen, Virginia, and Harvey in Hillsborough County, Florida

February 11, 2019

Resource Evaluation Section
Water Resources Bureau

Southwest Florida
Water Management District

Revised Minimum and Guidance Levels Based on Reevaluation of Adopted Levels for Lakes Allen, Virginia, and Harvey in Hillsborough County, Florida

February 11, 2019

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Governing Board Approved: September 25, 2018
Effective in Rule 40D-8.624: February 11, 2019

Cover: 2017 Aerial Imagery of Lakes Harvey, Virginia, and Allen (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

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

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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

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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.

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

Introduction

Evaluation of Minimum Flows and Levels

This report describes the development of minimum levels and guidance levels for Lakes Allen, Virginia, and Harvey 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 November 2005 and subsequently adopted into District rules. The three lakes are connected by dredged canals which allow the lakes to equalize, and so they were evaluated together to determine one set of levels. Over the period of record that we have lake stage data for, Lakes Allen and Virginia are connected approximately 95% of the time, and are then connected with Lake Harvey, so that all three lakes are connected, approximately 70% of the time. The minimum and guidance levels represent necessary revisions to the previously adopted levels.

Lakes Allen, Virginia, and Harvey were 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 lakes were developed. Minimum levels for these lakes 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 September 25, 2018, the revised levels became effective on February 11, 2019.

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

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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 Lakes Allen, Virginia, and Harvey 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 Resources 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., Lakes Allen, Virginia, and Harvey meet the classification as Category 1 lakes. 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

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with the lake when it is staged at the Low Guidance Level. The Aesthetics Standard is established at the Low Guidance Level.

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

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

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

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

Lake Setting and Description

Lake Allen (Section 10, Township 27, Range 18; Section 3, Township 27, Range 18), Lake Virginia (Section 3, Township 27, Range 18), and Lake Harvey (Section 3, Township 27, Range 18; Section 2, Township 27, Range 18) are located in Hillsborough County, Florida (Figure 1) in the Anclote East and Northwest Five basins within the Southwest Florida Water Management District.

The lakes' watershed (Figure 2) has a drainage area of approximately 366 acres. Lake Allen has one inlet on the north shore of a channel coming from Lake Virginia, as well as a secondary inlet on the southeast shore delivering water from the Lake Thomas watershed (Figure 3). Lake Allen discharges at the northwest corner through a ditch and culvert to a wetland area (Figure 3). Lake Virginia receives water from Lake Harvey to the north, and discharges south to Lake Allen and west to the same wetland area that Lake Allen discharges to, through an operable structure maintained by Hillsborough County (Figure 3). Lake Harvey has inflows along the north and east shores, and discharges south to Lake Virginia (Figure 3). Above an elevation of 56.8 ft. NGVD Lake Allen is connected to Lake Virginia. Over our period of record for lake stage data, this occurs approximately 95% of the time. Above an elevation of 59.3 ft. NGVD Lakes Allen and Virginia are connected with lake Harvey, with all three lakes equalizing through their channels. Over our period of record for lake stage data, this occurs approximately 70% of the time. 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.
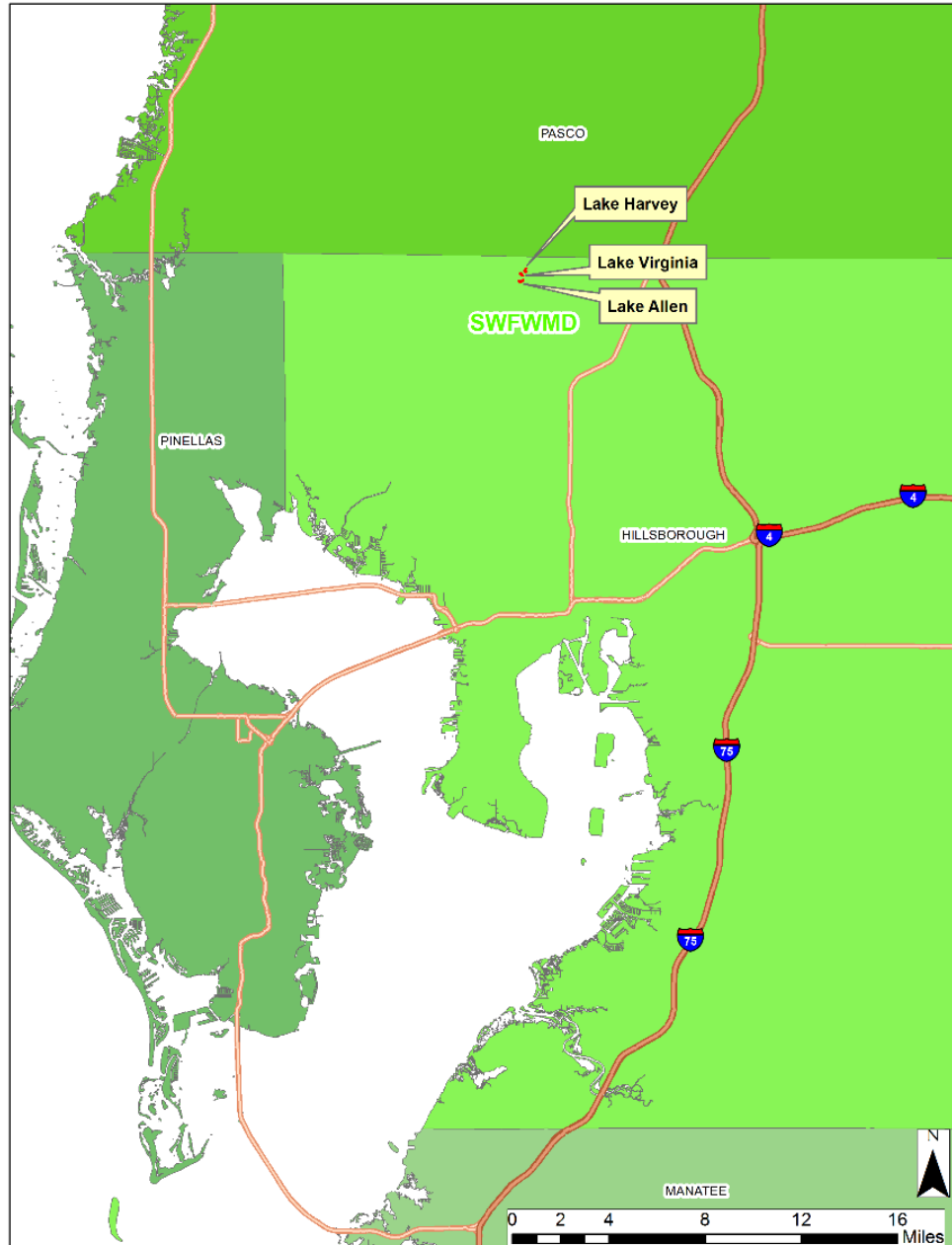
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Figure 1: Location of Lakes Allen, Virginia, and Harvey in Hillsborough County, Florida.
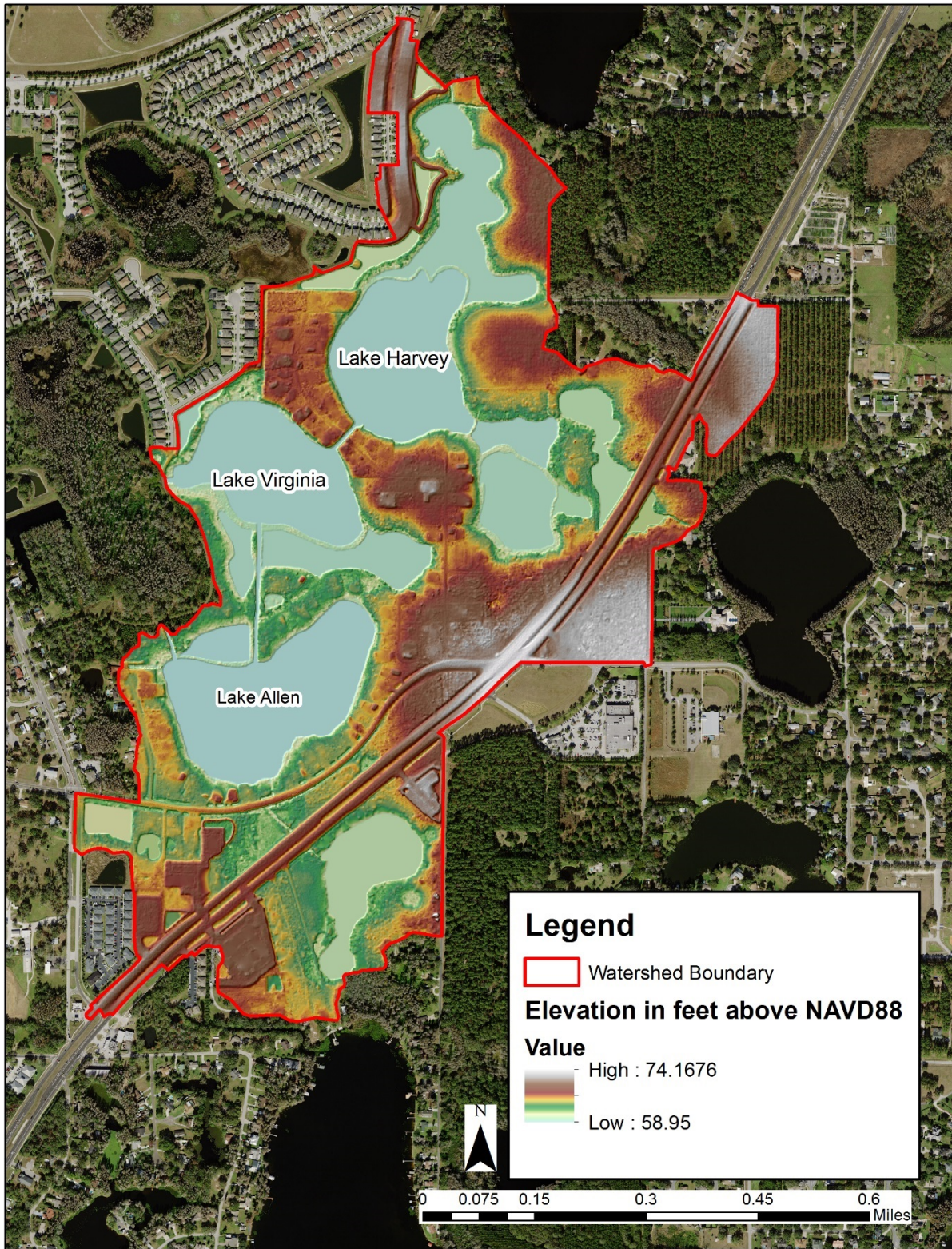
**Figure 2: Watershed Delineation and Topography.**

**Figure 3: Location of Conveyance Systems and District Gages.**

Land Use Land Cover

An examination of the 1950 and more current 1990 and 2011 Florida Land Use, Cover, and Forms Classification System (FLUCCS) maps revealed that there has been considerable change to the landscape in the vicinity of Lakes Allen, Virginia, and Harvey during this period (Figure 4 through Figure 6). In 1950 (Figure 4) most of the land surrounding the lakes was classified as either wetlands or agriculture. There was a small residential area along the southern shore of Lake Allen. By 1990 (Figure 5), much of the wetland area surrounding the lakes had been converted into urban and built-up residential area, with some increased rangeland and agriculture lands still present as you moved farther from the lakes. By 2011 (Figure 6) the majority of the land had been converted into urban and built-up areas with very little wetland or agriculture left, and a road had been built running along the eastern shores of the three lakes. Figure 7 through Figure 13 aerial photography chronicles landscape changes to the immediate lake basin from 1938 through 2017.
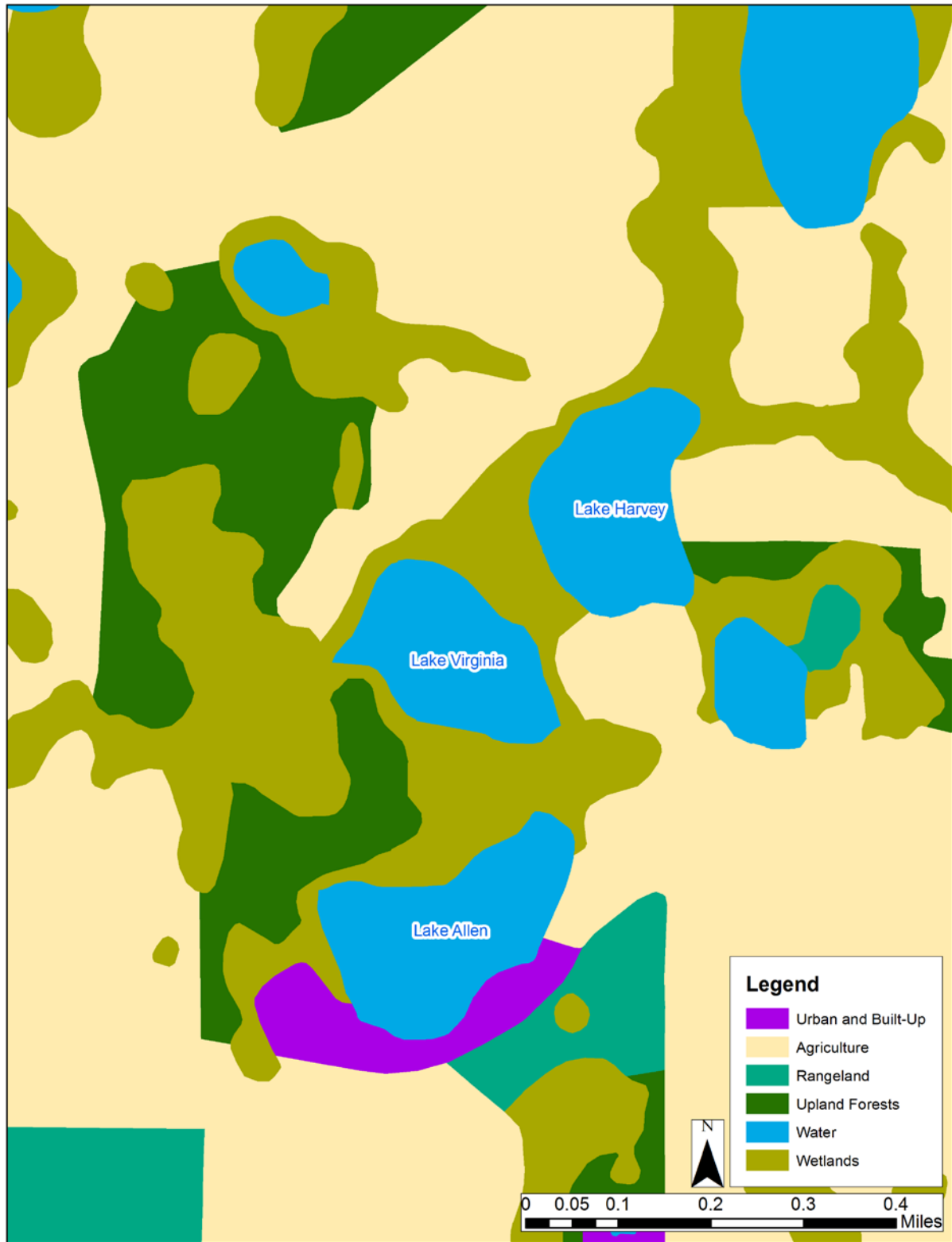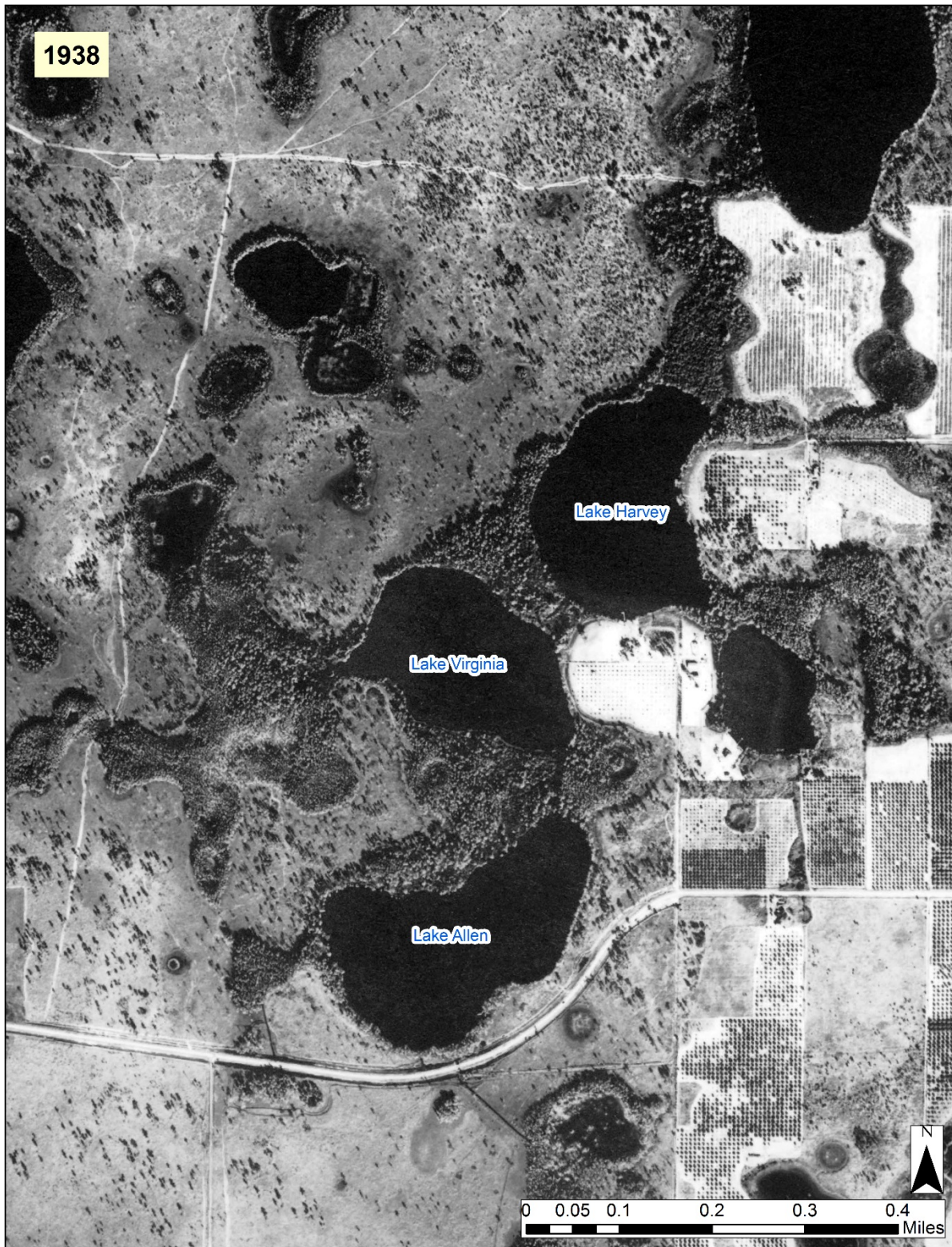
Figure 4: 1950 Land Use Land Cover Map of the Lakes Allen, Virginia, and Harvey Vicinity.

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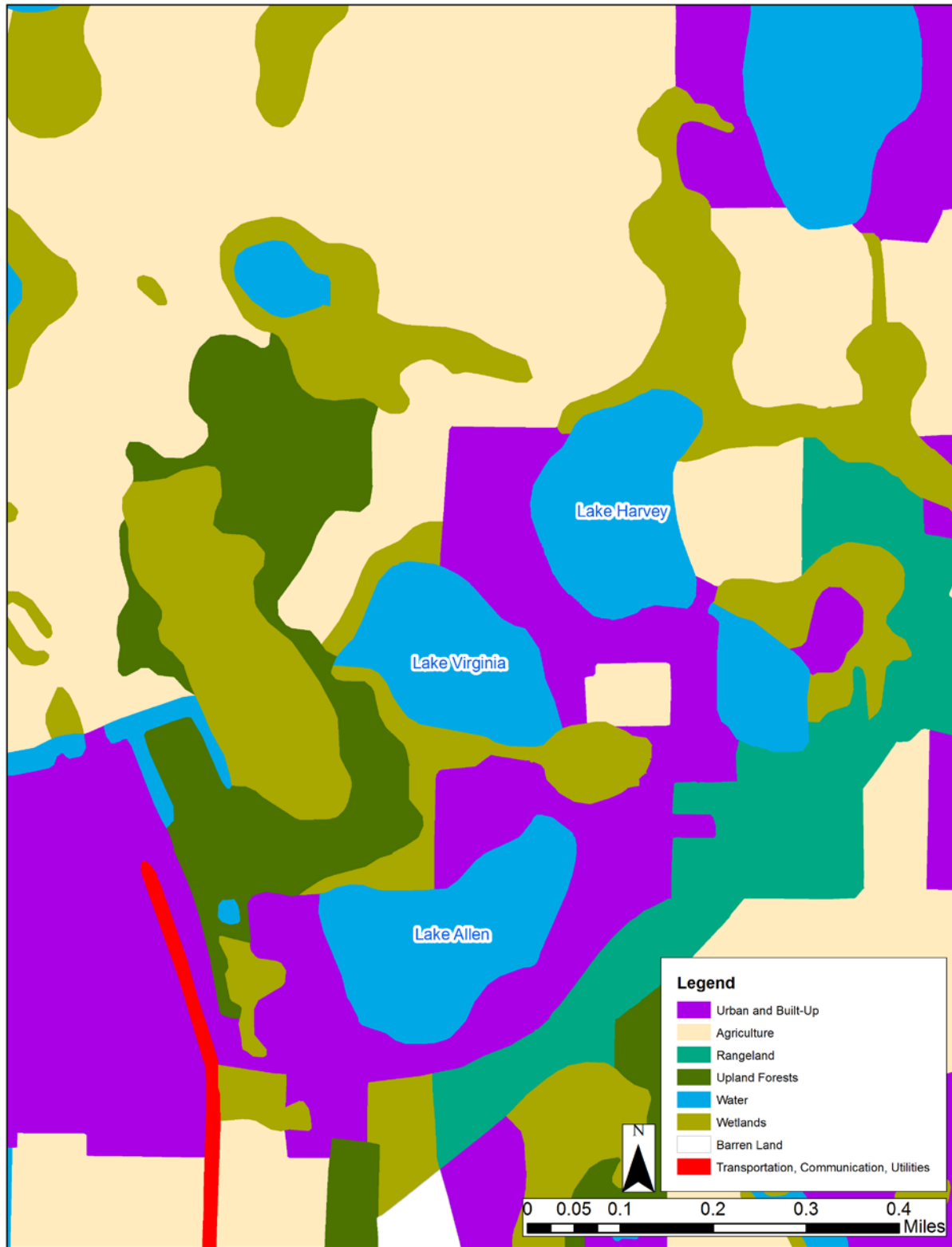
Figure 5: 1990 Land Use Land Cover Map of the Lakes Allen, Virginia, and Harvey Vicinity.

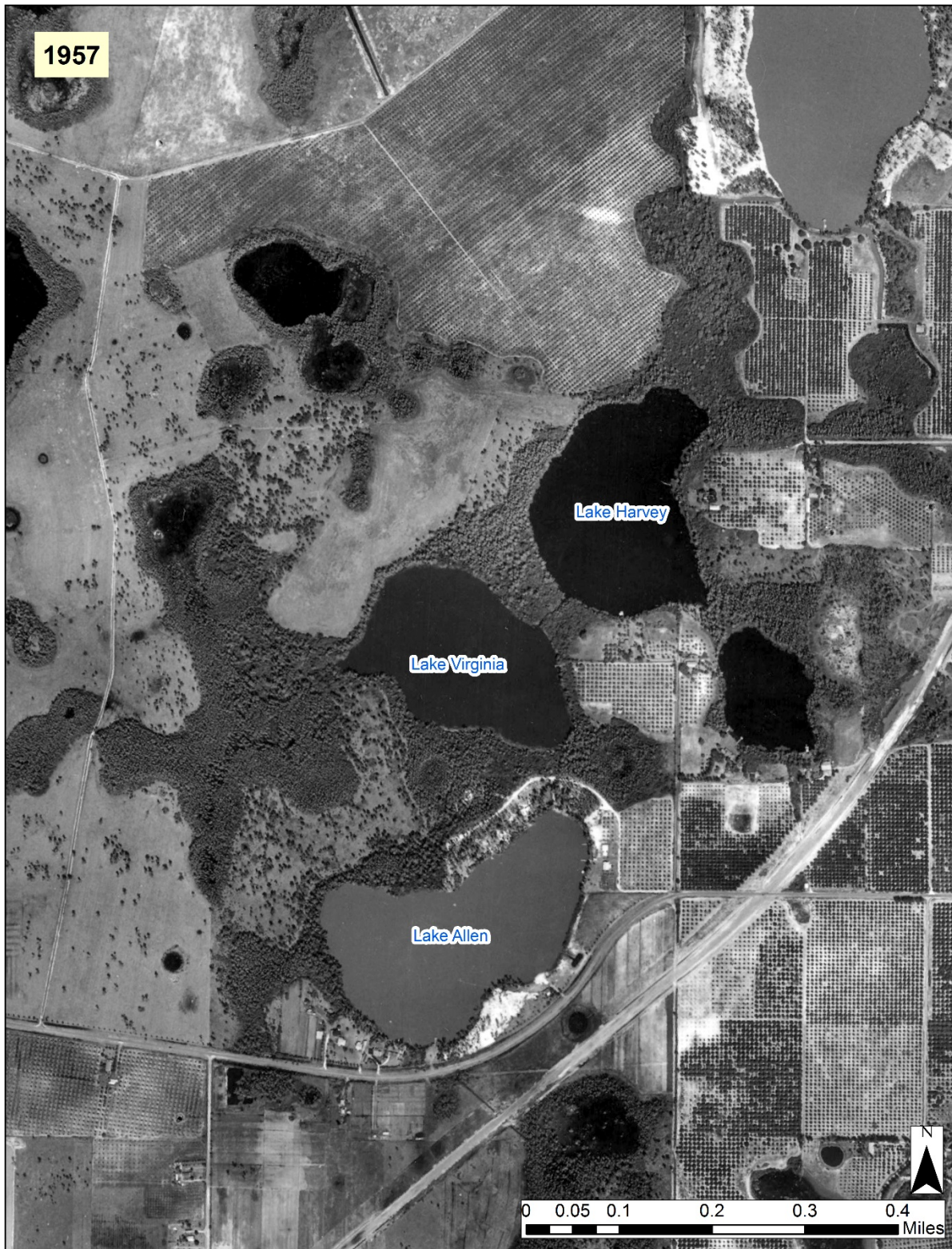**Figure 6: 2011 Land Use Land Cover Map of the Lakes Allen, Virginia, and Harvey Vicinity.**

Figure 7: 1938 Aerial Photograph of Lakes Allen, Virginia, and Harvey

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Figure 8: 1957 Aerial Photograph of Lakes Allen, Virginia, and Harvey

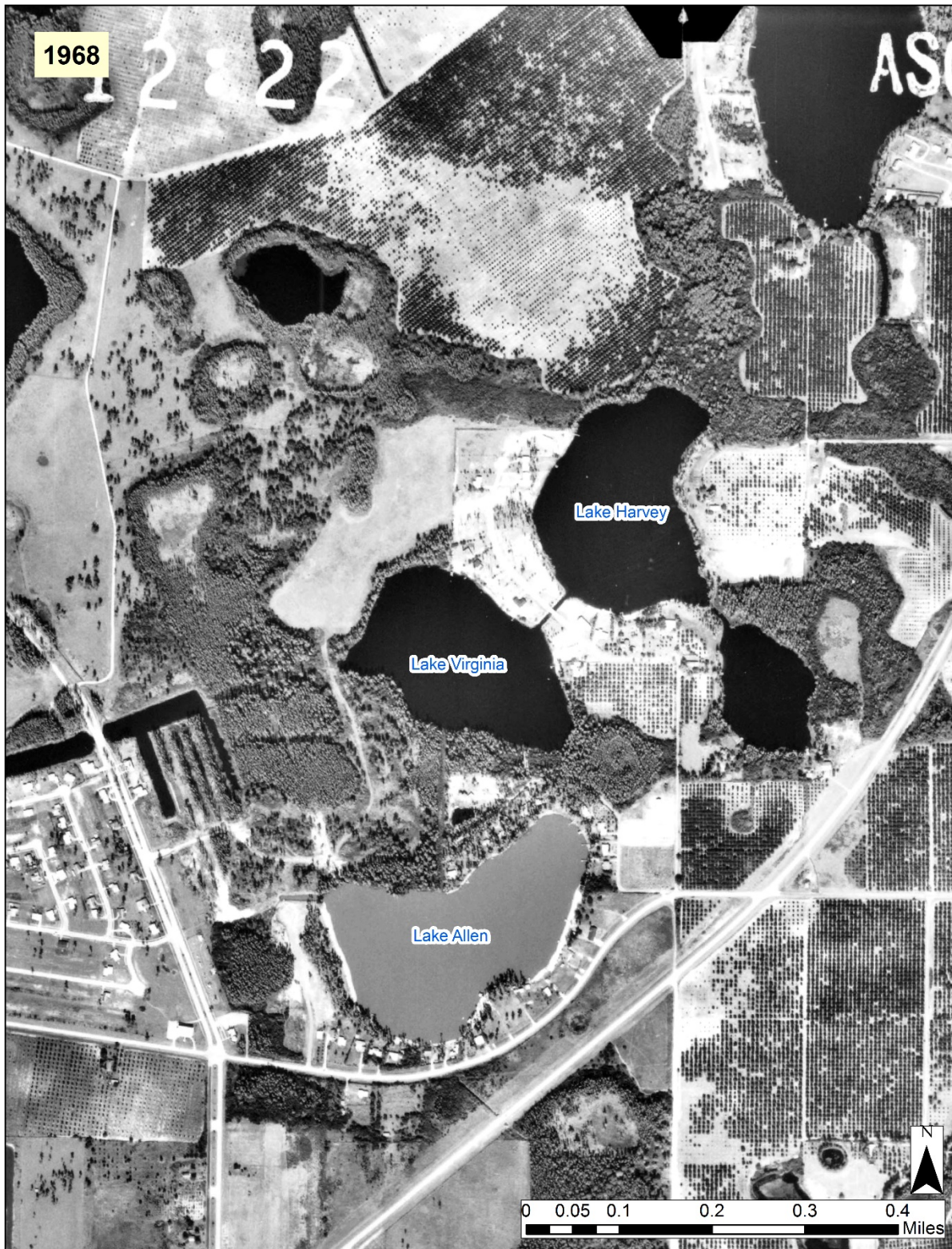**Figure 9: 1968 Aerial Photograph of Lakes Allen, Virginia, and Harvey**

Figure 10: 2004 Aerial Photograph of Lakes Allen, Virginia, and Harvey
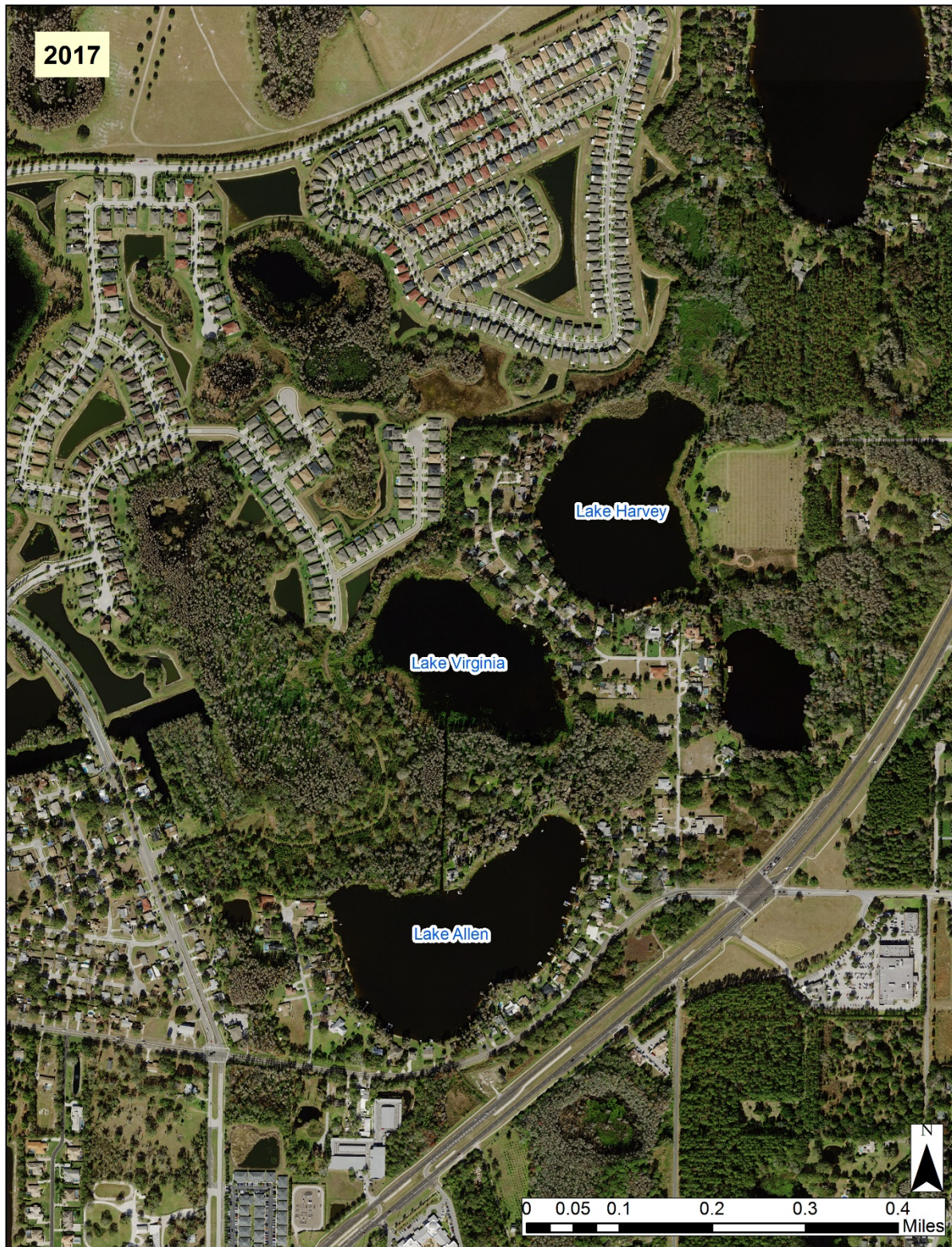
Figure 11: 2007 Aerial Photograph of Lakes Allen, Virginia, and Harvey

Figure 12: 2008 Aerial Photograph of Lakes Allen, Virginia, and Harvey

2017

Lake Harvey

Lake Virginia

Lake Allen

Figure 13: 2017 Aerial Photograph of Lakes Allen, Virginia, and Harvey

Bathymetry Description and History

Bathymetric data gathered from recent field surveys resulted in lake-bottom contour lines from 35 ft. to 63 ft., NGVD29 (Figure 14). These data revealed that the lowest lake bottom contour (35 ft. NGVD29) for Lake Allen, or the deepest part of the lake, is located off the western shore of the lake. The deepest part of Lake Virginia (43 ft.) is along the northeastern quarter of the lake, and the deepest part of Lake Harvey (39 ft.) is a hole on the western side of the lake. Additional morphometric or bathymetric information for the lake basin is discussed in the Methods, Results and Discussion section of this report.
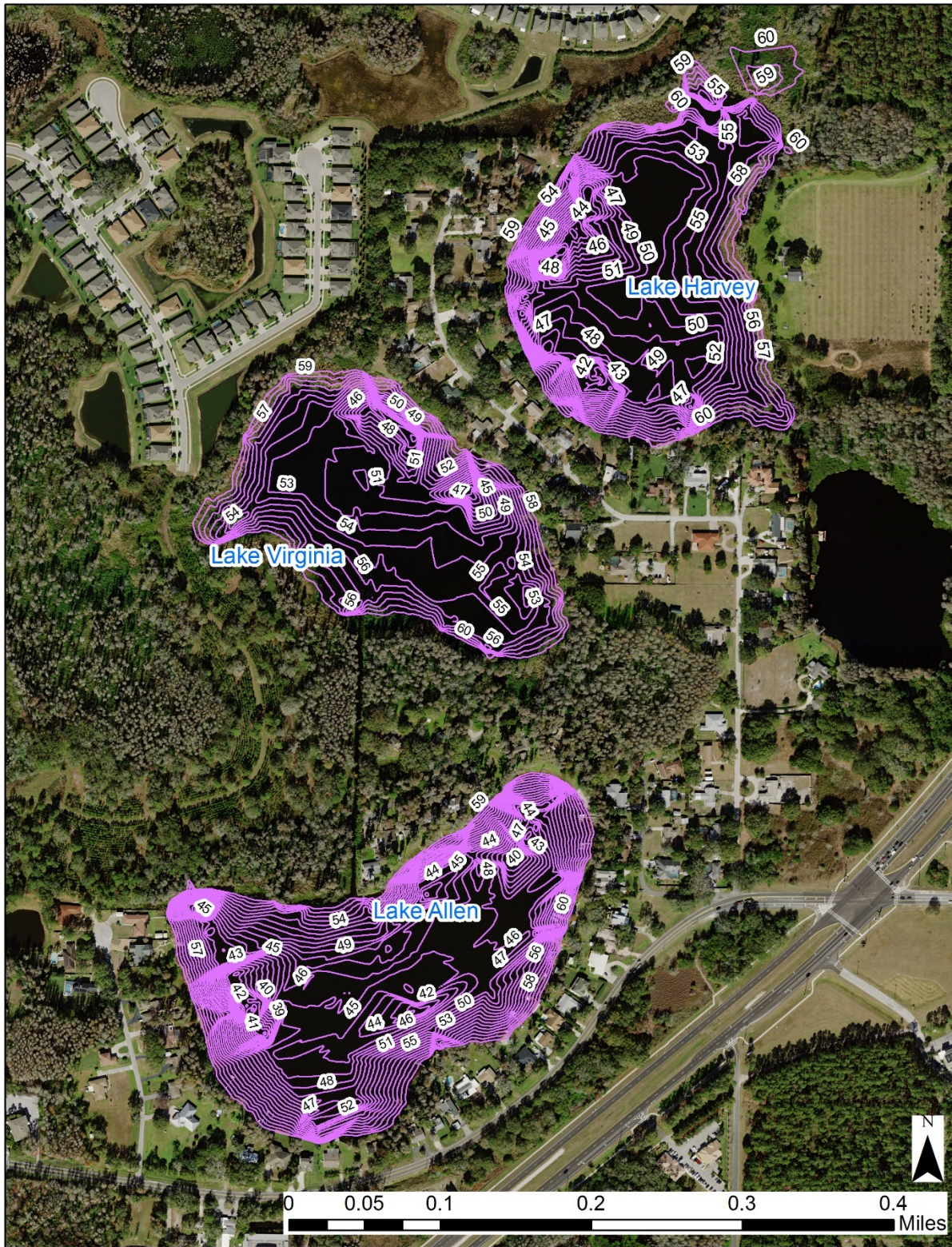
Figure 14: Lake Bottom Contours (ft., NGVD29) on a 2017 Natural Color Aerial Photograph

Water Level (Lake Stage) Record

Lake stage data, i.e.*,* surface water elevations, are available for Lake Allen (SID 19834 & 773919), Lake Virginia (SID 19814), and Lake Harvey (SID 19815) from the District's Water Management Information System (Figure 15). Data collection on Lake Allen began on June 29, 1971 from SID 19834. There were several brief lapses in data collection between January 1991 and August 1994, but otherwise continuous records are available. Data collection ceased from SID 19834 and began from SID 773919 on April 14, 2011. On December 28, 2015 the gauge was adjusted from NGVD29 to NAVD88, with a measured shift of -0.82 ft. Data collection began on Lake Virginia September 27, 1977, with only a few brief lapses in collection during its period of record. On March 25, 2015 the gauge on Lake Virginia was adjusted from NGVD29 to NAVD88, with a measured shift of -0.89 ft. Lake Harvey has the longest period of record, with data collection beginning on April 1, 1970 and continuing until present day. On July 21, 2015 the gauge on Lake Harvey was adjusted from NGVD29 to NAVD88, with a measured shift of -0.93 ft. Water elevations continue to be monitored at all three lakes on a monthly basis from SIDs 773919, 19814, and 19815 at the time of this report. The highest lake stage elevation on record was 63.9 ft. NGVD29 and occurred in December 1997. The lowest lake stage elevations on record occurred in May 2002 and were 54.6 ft. NGVD29 on Lake Allen, 53.3 ft. NGVD29 on Lake Virginia, and 53.9 ft. NGVD29 on Lake Harvey.
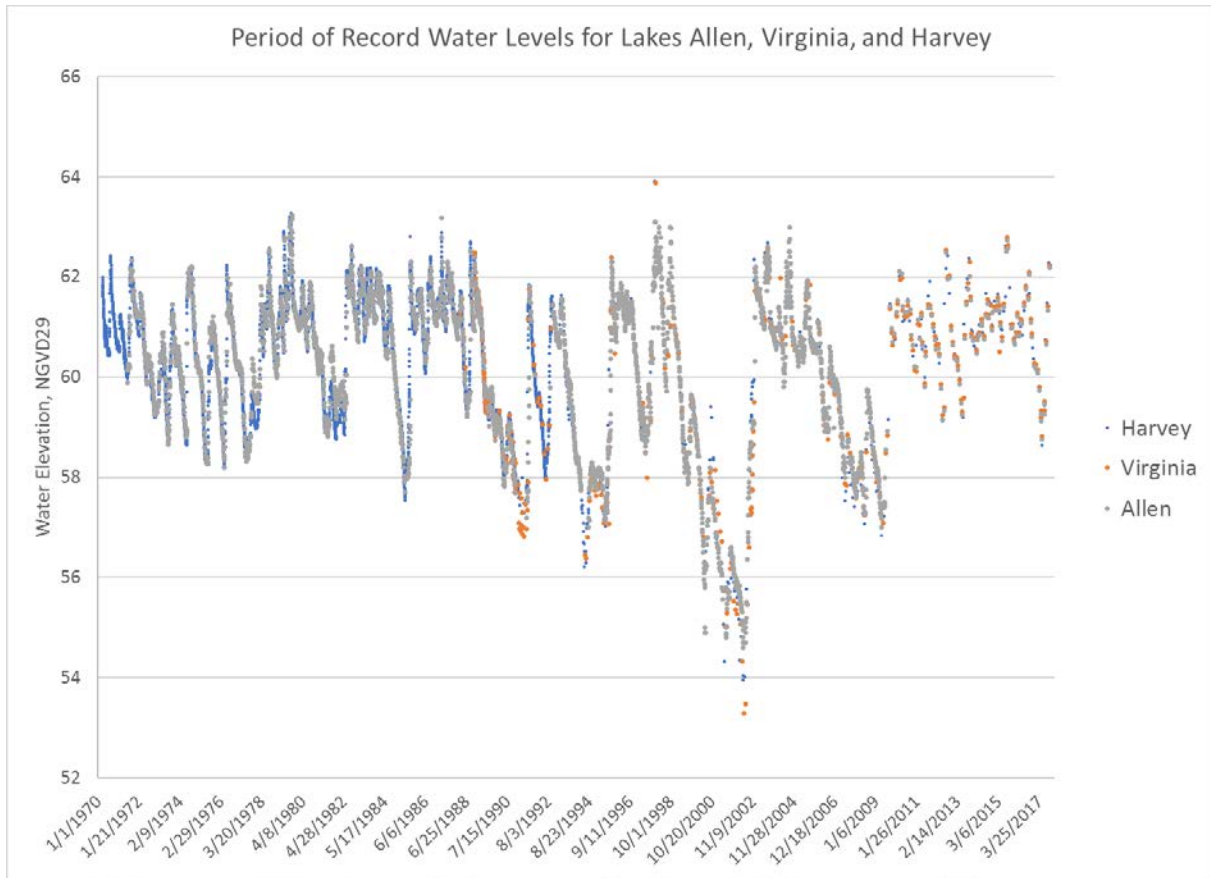
Figure 15: Lakes Allen, Virginia, and Harvey Period of Record Water Elevation Data (SID 19834 & 773919, SID 19814, and SID 19815, respectively)

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 Lakes Allen, Virginia, and Harvey (Table 2) in November 2005, 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 approved November 2005 for Lakes Allen, Virginia, and Harvey

Level	Elevation (ft., NGVD)
High Guidance Level	61.8
High Minimum Level	61.8
Minimum Level	60.7
Low Guidance Level	59.7

Methods, Results and Discussion

The Minimum and Guidance Levels in this report were developed for Lakes Allen, Virginia, and Harvey 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 Lakes Allen, Harvey, and Virginia.

| Levels	Elevation in Feet NGVD 29	Lake Area (acres)
Lake Stage Percentiles		
Historic P10 (1946 to 2013)	62.3	159
Historic P50 (1946 to 2013)	61.3	96
Historic P90 (1946 to 2013)	60.5	65
Normal Pool and Control Point		
Normal Pool	62.5	167
Control Point	60.7	67
Significant Change Standards*		
Recreation/Ski Standard	NA	NA
Dock-Use Standard	60.5	65
Wetland Offset Elevation	60.5	65
Aesthetics Standard	60.5	65
Species Richness Standard	61.1	82
Basin Connectivity Standard	62.1	150
Lake Mixing Standard	NA	NA
Minimum and Guidance Levels		
High Guidance Level	62.3	159
High Minimum Lake Level	62.1	150
Minimum Lake Level	60.7	67
Low Guidance Level	60.5	65

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

Two elevation data sets were used to develop the terrain model for Lakes Allen, Virginia, and Harvey. 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 16.
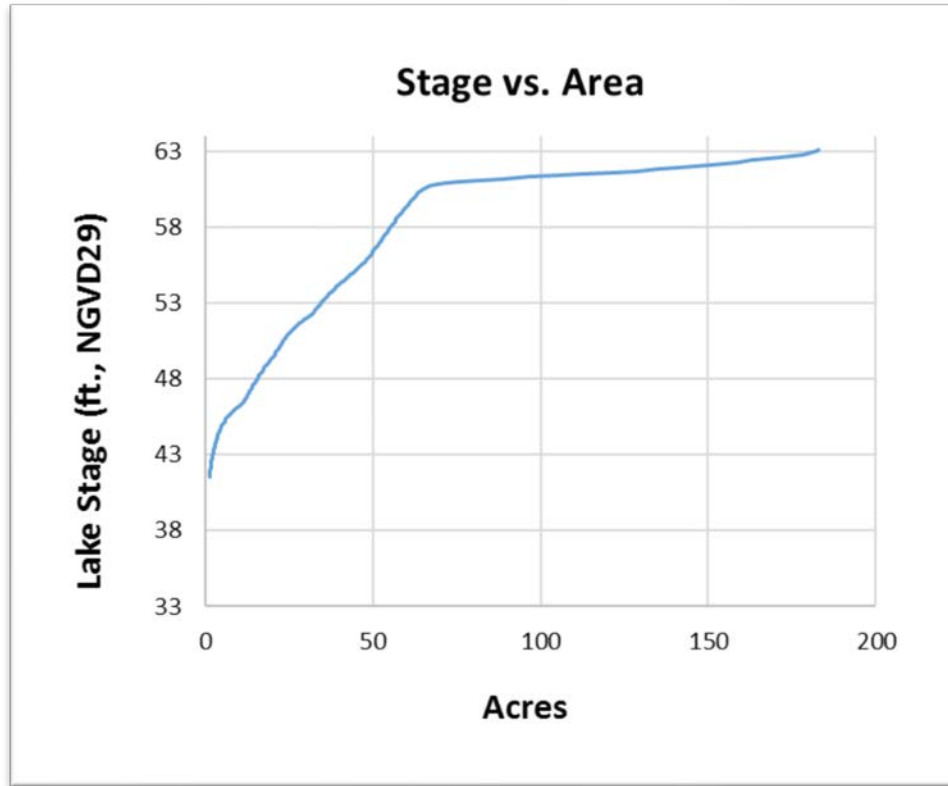
Figure 16: Lake Stage (Ft. NGVD29) to Surface Area (Acres) for Lakes Allen, Virginia, and Harvey.

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 Lakes Allen, Virginia, and Harvey and composite regional rainfall.

A combination of model data produced a hybrid model which resulted in a 70-year (1946-2016) Historic water level record. Based on this hybrid data, the Historic P10 elevation, i.e., the elevation of the lake water surface equaled or exceeded ten percent of the time, was 62.3 ft. The Historic P50, the elevation the lake water surface equaled or exceeded fifty percent of the time during the historic period, was 61.3 ft. The Historic P90, the lake water surface elevation equaled or exceeded ninety percent of the time during the historic period, was 60.5 ft. (Figure 17 and Table 3).
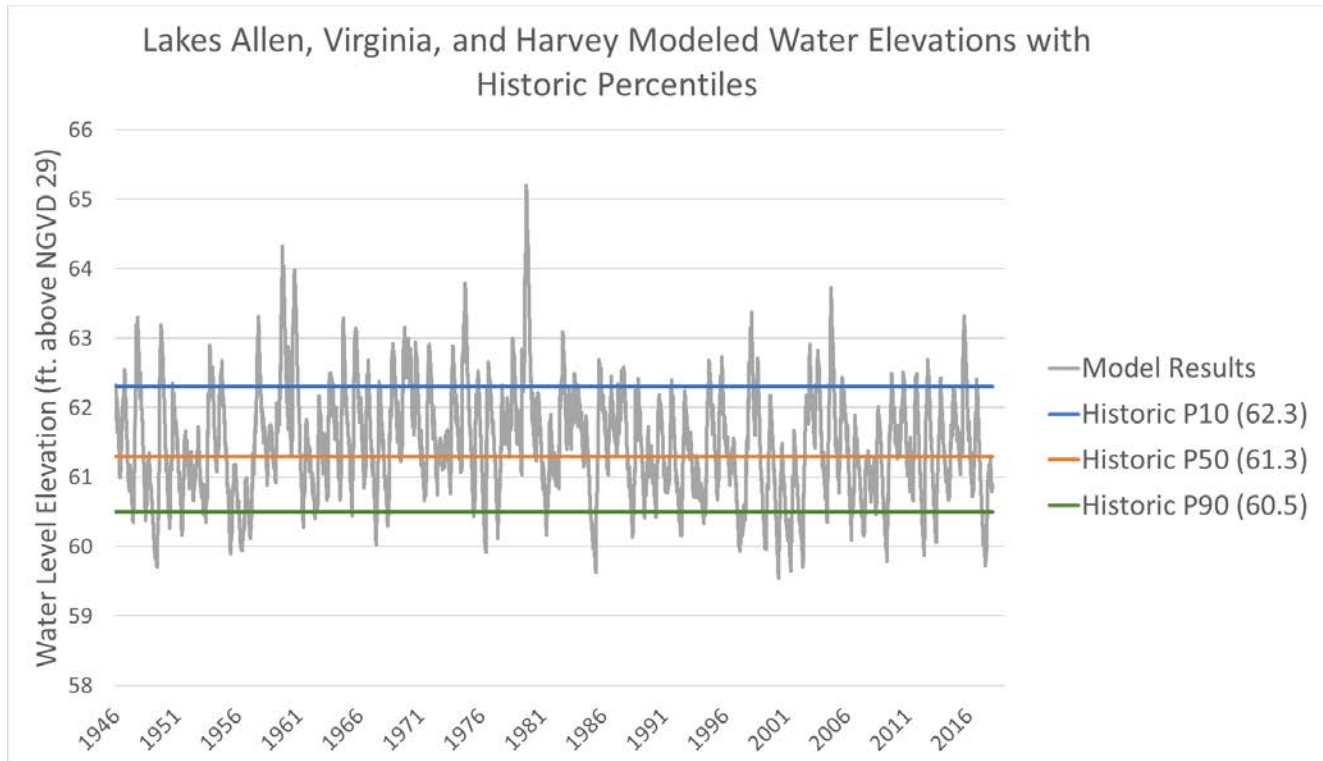
Figure 17: Historic Water Levels (hybrid) Used to Calculate Percentile Elevations Including P10, P50, and P90.

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). Based on elevations of buttress swelling on 30 trees collected from Lakes Allen, Virginia, and Harvey in 2002 and 2003 (Table 4), the Normal Pool elevation was established at the median normal pool of 62.5 ft. NGVD 1929. It was decided to use the same data collected from the previous evaluation for the current reevaluation because water levels at the time allowed data collectors to access more areas and collect more data, providing a more robust estimate of the Normal Pool. While there is seemingly a large range of the indicator elevations, which is generally not ideal, the majority of the indicators are within 1.5 ft. of each other, with just a few outliers (SWFWMD 2005).

Additional information to consider in establishing Minimum and Guidance Levels are the Control Point elevation and the lowest building floor (slab) or road 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 these lakes was determined at 60.7 ft., the elevation of a structure connecting

Lake Virginia to a wetland area to its west. The low road elevation, based on survey reports, was established at 62.3 ft. The lowest house floor was higher, at 63.6 ft.

Table 4: Summary statistics for hydrologic indicators used for establishing Normal Pool elevations for Lakes Allen, Harvey, and Virginia (feet NGVD29).

Summary Statistic	Number (N) or Elevation
N	30
Median	62.5
Mean	62.5
Minimum	60.2
Maximum	64.2

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 Lakes Allen, Virginia, and Harvey, the High Guidance Level was established at the Historic P10 elevation, 62.3 ft. Recorded data indicate that the highest level reached was in December 1997 at 63.9 ft.

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 Lakes Allen, Virginia, and Harvey, the Low Guidance Level was established at the Historic P90 elevation, 60.5 ft. The recorded period of record indicates the lowest lake level elevations were 54.6 ft. on Lake Allen, 53.3 ft. on Lake Virginia, and 53.9 ft. on Lake Harvey, all below the Low Guidance Level, in May 2002 (Figure 15). Some of the difference in the elevations between the lakes could be attributed to the gauge being read on different dates. The most recent record of the water level dropping below the Low Guidance Level was in January 2018 for Lakes Allen and Virginia, and December 2017 for Lake Harvey, with recorded levels of 60.2 ft., 60.3 ft., and 60.4 ft., respectively.

Significant Change Standards

For comparative purposes, Category 3 significant change standards were determined for Lakes Allen, Virginia, and Harvey 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 Lakes Allen, Virginia, and Harvey 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 on any of the three lakes. Thus, they were classified as non-ski lakes.

- The **Dock-Use Standard** was established at an elevation of 60.5 ft. based on the elevation of lake sediments at the end of 47 docks on the lakes, a 2-ft. clearance depth, and the difference between the Historic P50 and P90 of 0.8 ft.

- The **Wetland Offset Elevation** was established at 60.5 ft., or 0.8 ft. below the historic P50 elevation.

- The **Aesthetic Standard** was established at the Low Guidance Level elevation of 60.5 ft.

- The **Species Richness Standard** was established at 61.1 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 62.1 ft. based on a critical high spot elevation of 59.3 ft., the addition of two feet, plus the difference between the Historic P50 and P90 of 0.8 feet. This critical high spot is the elevation separating Lake Harvey from Lake Virginia.

- 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 18), and potential changes in area available for aquatic plant colonization (Figure 19) did not indicate that use of any of the identified standards would be inappropriate for minimum levels development. Figure 18 shows that as the lake stage increases, the acres available for herbaceous wetland area (acres < 4 ft.) also increase, up until around approximately 61 ft. NGVD29, where it then increased dramatically. Similarly, the area available for aquatic plant colonization (acres < 7.2 ft.) follows the same trend of increasing until a similar threshold point (Figure 19). The dramatic increase at around 61 ft. elevation is due to the watershed of the lakes increasing to include the surrounding wetland areas. The changes in the slope of the lines reflects the variation in lake bottom contours and the area which it contains.
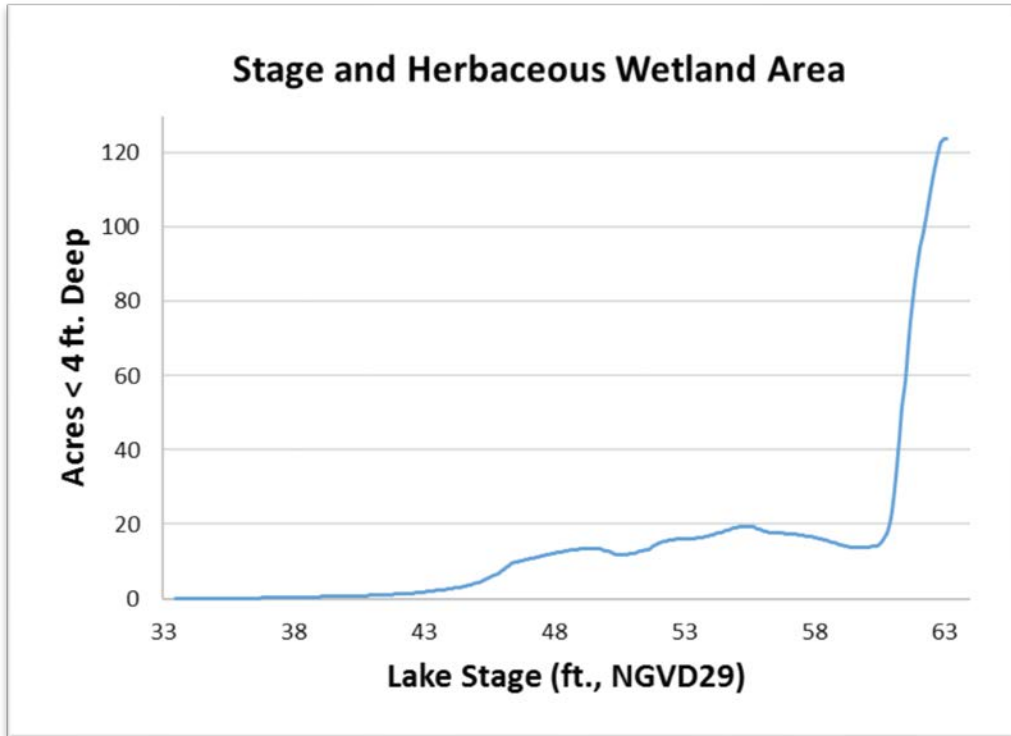
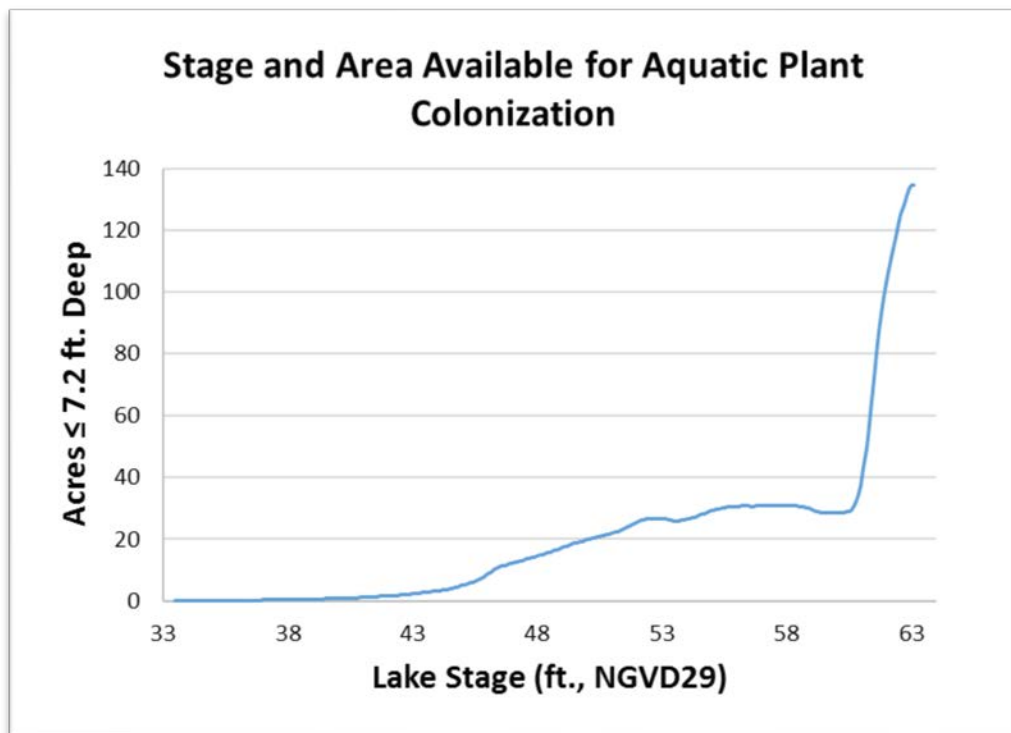**Figure 18: Lake Stage Compared to Available Herbaceous Wetland Area.**

Figure 19: Lake Stage and Area Available for Aquatic Plant Colonization.

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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. The MLL for Lakes Allen, Virginia, and Harvey is established at an elevation of 60.7 ft.

The High Minimum Lake Level (HMLL) is the elevation that a lake's water levels are ***required*** to equal or exceed ten percent of the time on a long-term basis. For a Category 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, resulting in a revised HMLL for Lakes Allen, Virginia, and Harvey of 62.1 ft. This elevation accounts for a natural fluctuation of lake levels.

Minimum and Guidance levels for Lakes Allen, Virginia, and Harvey are plotted on the recorded water level record in Figure 20. To illustrate the approximate locations of the lake margin when water levels equal the minimum levels, the levels are imposed on a 2017 natural color aerial photograph in Figure 21.
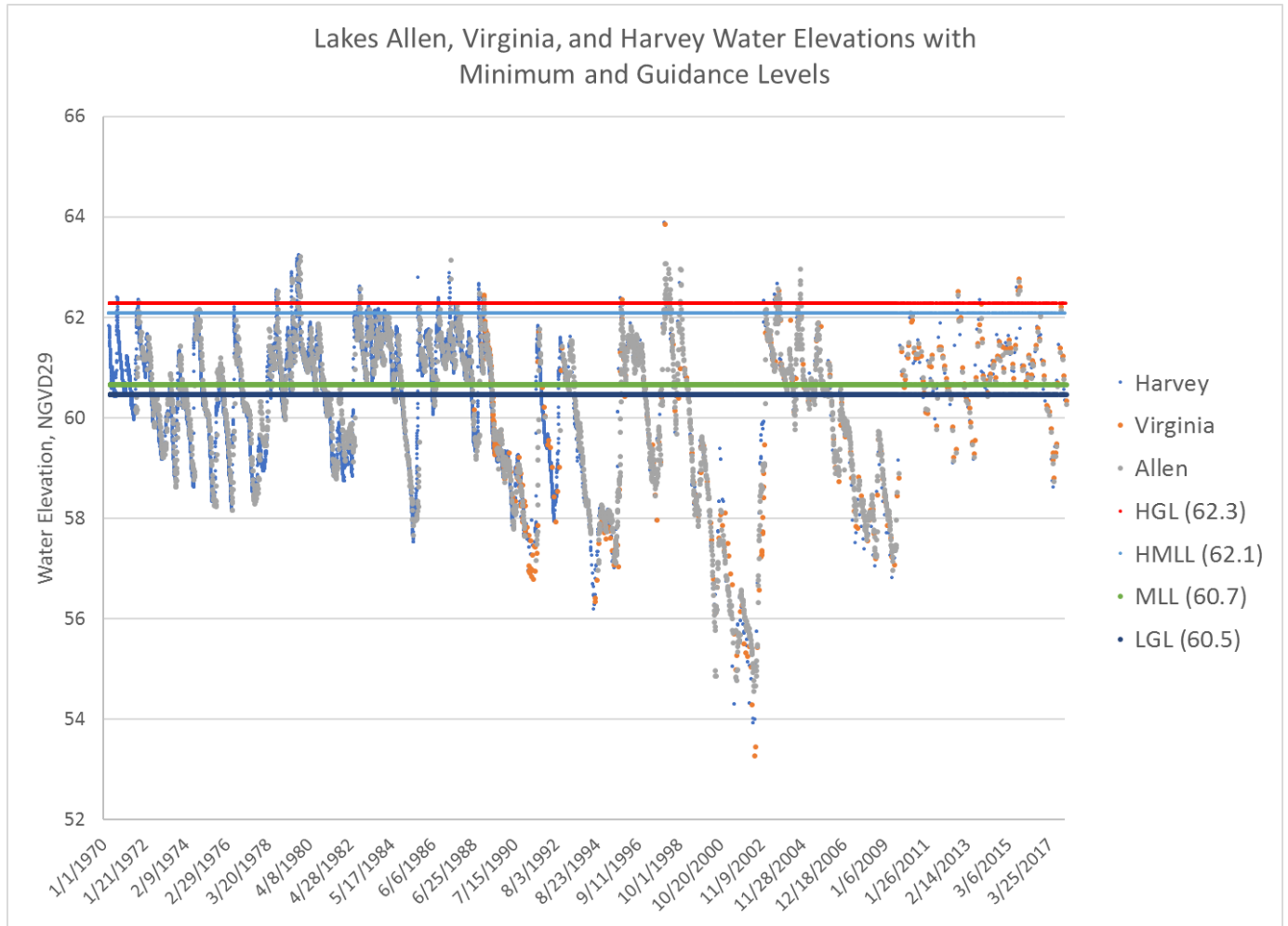
Figure 20: Recorded Water Level Elevations with Guidance and Minimum Lake Levels for Lakes Allen, Virginia, and Harvey.
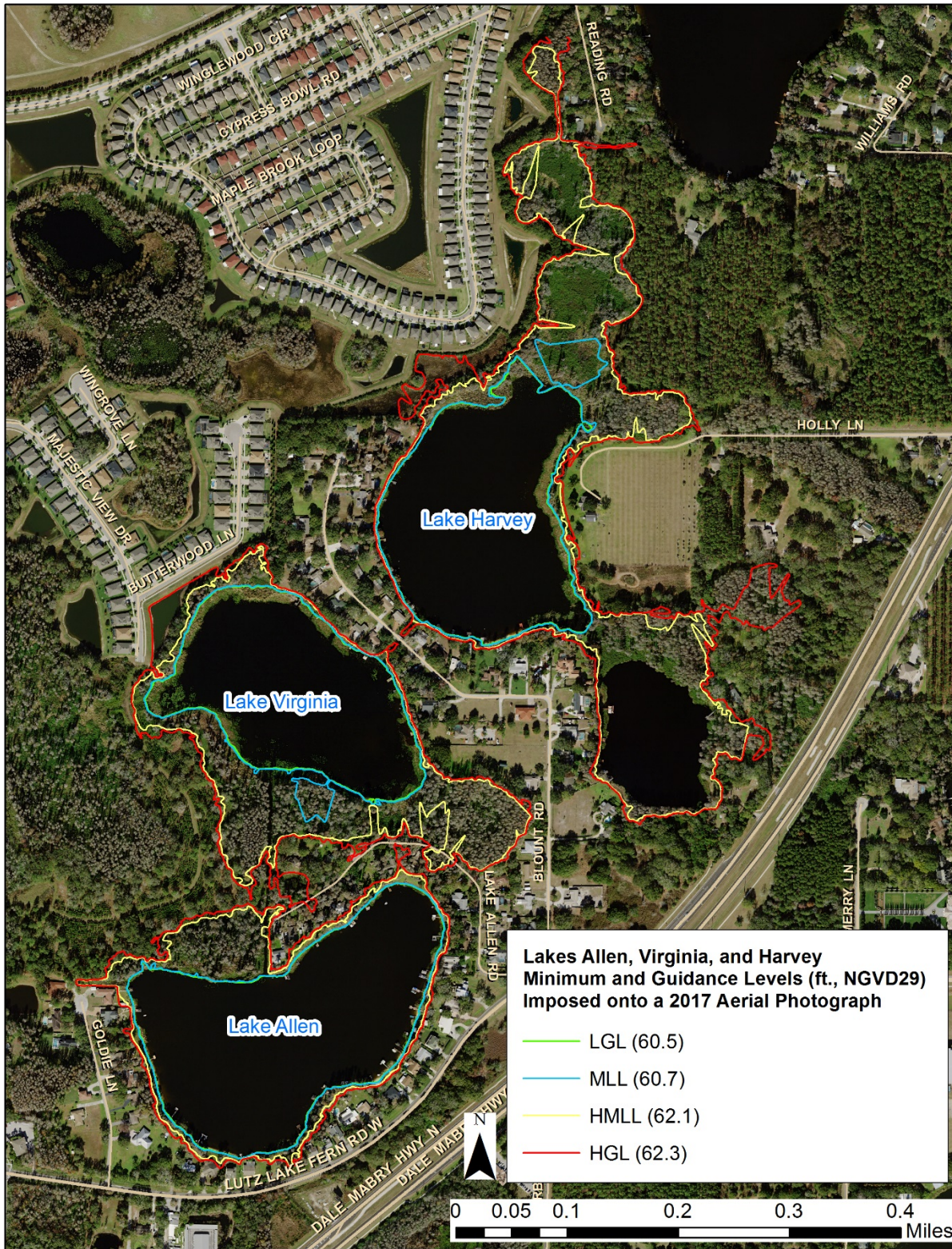
Figure 21: Lakes Allen, Virginia, and Harvey Minimum and Guidance Level Contour Lines Imposed onto a 2017 Natural Color Aerial Photograph.

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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 Lakes Allen, Virginia, and Harvey 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 used is -0.89 ft. for SID 19814 on Lake Virginia.

Table 5: Minimum and Guidance Levels for Lakes Allen, Virginia, and Harvey in NGVD29 and NAVD88.

Minimum and Guidance Levels	Elevation in Feet NGVD29	Elevation in Feet NAVD88
High Guidance Level	62.3	61.4
High Minimum Lake Level	62.1	61.2
Minimum Lake Level	60.7	59.8
Low Guidance Level	60.5	59.6

Consideration of Environmental Values

The minimum levels for Lake Allen 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 Lakes Allen, Virginia, and Harvey based on their classification as Category 1 lakes. 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 Lakes Allen, Virginia, and Harvey. Estuarine resources were not considered relevant because the lakes are not connected to an estuarine resource. Sediment loads were similarly not considered relevant for minimum levels development for the lakes, 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 High Guidance Level is 0.5 feet higher than the previously adopted High Guidance Level, while the Low Guidance Level is 0.8 feet higher 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 lakes, 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 High Minimum Lake Level for Lakes Allen, Virginia, and Harvey is 0.3 feet higher than the previously adopted High Minimum Lake Level. The Minimum Lake Level is not changed from the previously adopted Minimum Lake Level (Table 6). The difference in the High Minimum Lake Level is due to the differences in the modeling approach, as well as previously the HMLL was set at the HGL to account for possible flooding concerns, while this evaluation the HMLL was set at 0.4 ft below the Historic Normal Pool, based on Rule 40D-8.624. This elevation is still 0.2 ft below the low road elevation on Lake Allen Road, as well as 1.5 ft. below the lowest house floor slab.

The Minimum and Guidance Levels identified in this report replace the previously adopted levels for Lakes Allen, Virginia, and Harvey.

Table 6: Minimum and Guidance Levels for Lakes Allen, Harvey, and Virginia 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	62.3	61.8
High Minimum Lake Level	62.1	61.8
Minimum Lake Level	60.7	60.7
Low Guidance Level	60.5	59.7

Minimum Levels Status Assessment

To assess if the Minimum and High Minimum Lake Levels are being met, observed stage data on Lakes Allen, Virginia, and Harvey 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 the lakes were determined to be from 2010 through 2017. Using the Current stage data, the LOC model was created. The LOC model resulted in a 71-year long-term water level record (1946-2017).

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 Lakes Allen, Virginia, and Harvey water levels are above both the Minimum Lake Level and the High Minimum Lake Level (see Appendix B).

These lakes lie 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 on Lakes Allen, Virginia, and Harvey and will also routinely evaluate the status of the lakes' water levels with respect to adopted minimum levels for the lakes included in Chapter 40D-8, F.A.C.

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APPENDIX A

Technical Memorandum

June 21, 2018

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

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

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

Subject: Lakes Allen, Virginia and Harvey Water Budget Model, Rainfall Correlation Model, and Historic Percentile Estimations

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A.   Introduction

Water budget and rainfall correlation models were developed to assist the Southwest Florida Water Management District (District) in the reassessment of minimum levels for lakes Allen, Virginia and Harvey in northwest Hillsborough County. Allen, Virginia and Harvey currently have adopted minimum levels which are scheduled to be re-assessed in FY 2018. This document will discuss the development of the Allen, Virginia and Harvey lake model and use of the model for development of Historic lake stage exceedance percentiles.

B.   Background and Setting

Allen, Virginia and Harvey are in northwest Hillsborough County, northwest of the intersections between Lutz Lake Fern Road and Dale Mabry Highway (Figure 1). The lakes lie within the Upper Rocky Creek watershed that forms part of the larger Tampa Bay watershed (USGS HUC 03100206).

Browns Lake located north of Lake Harvey flows into Lake Harvey infrequently during extremely wet conditions when lake stage is greater than approximately 63 ft. NGVD29. The frequency of the connection is very limited, thus, the model developed didn't include inflow contributions from Browns Lake. Lake Harvey and Lake Virginia are connected when their stages are above 59.26 feet NGVD29. Virginia is connected to Allen when their stages are above 56.8 feet NGVD29 and all three lakes are connected above 59.26 feet NVGD29. The stages of the three lakes are the essentially the same

for much of the record (Figure 3). Flow exits Lake Virginia and Lake Allen at elevation 61.1 ft. NGVD29 (Figure 2).
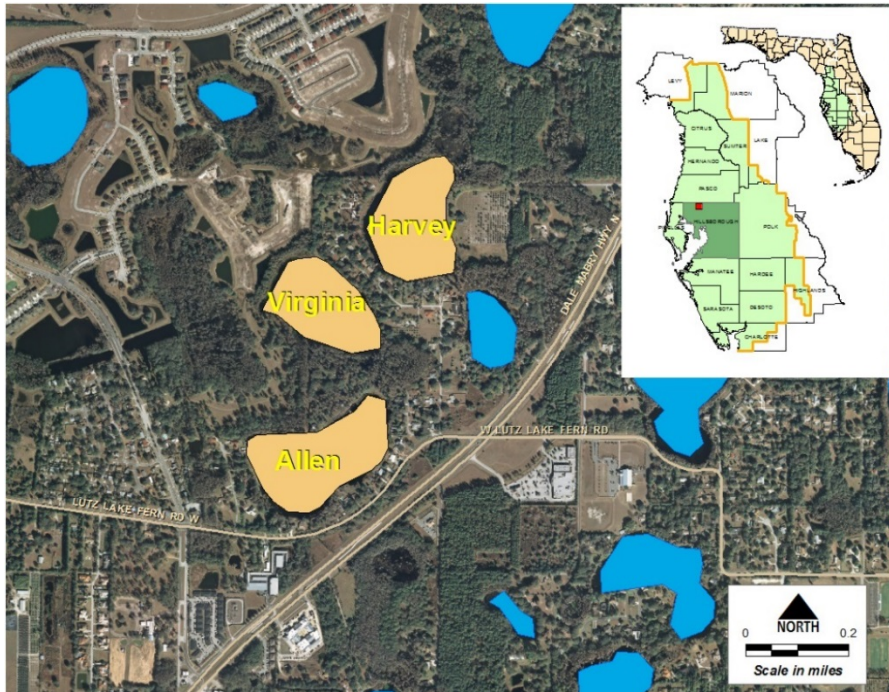

Figure 1. Location of Lakes Allen, Harvey, and Virginia in Hillsborough County, Florida
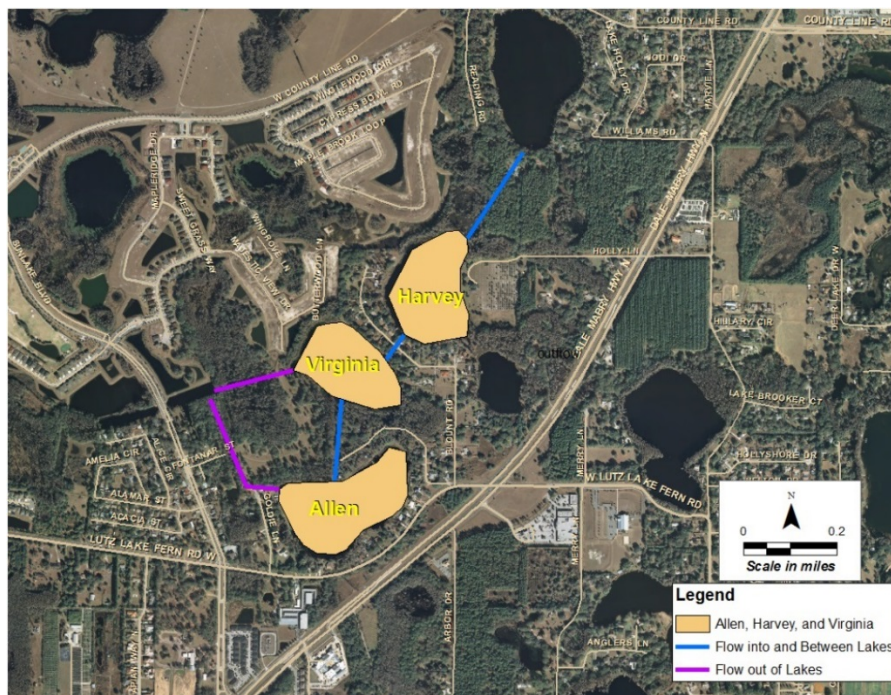

Figure 2. Inflow and outflow paths for Lakes Allen, Harvey, and Virginia

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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).

Data

The District began collecting water level data at Lake Allen in June 1971 (Figure 3) at a gage on its eastern shore (SID 19834). Data collection at this site, with various gaps, generally occurred once to twice weekly (with a large portion of December 9, 1991 to December 13, 1992 missing) until the site's discontinuation in April 2011. Data collection resumed at a new site (SID 773919) north of the original gage where monitoring has continued monthly through the present. The District began collecting water level data at Lake Harvey on April 1, 1970 (Figure 3) at a gage on its southern shore (SID 19815). Data collection at this site was daily up to October 1992, varied from daily, weekly and monthly up to December 2003; followed by monthly to present. The District began collecting water level data at Lake Virginia in September 1977 (Figure 3) at a gage on its eastern shore (SID 19814). A single reading was obtained in 1977 and after a long gap, readings started again in 1988 and varied in frequency from daily, weekly and monthly. A large gap occurred between January 1993 and June 1994. After this gap, the frequency of readings was generally weekly to monthly up the present. The average of the three lakes gages were used for the water budget model.
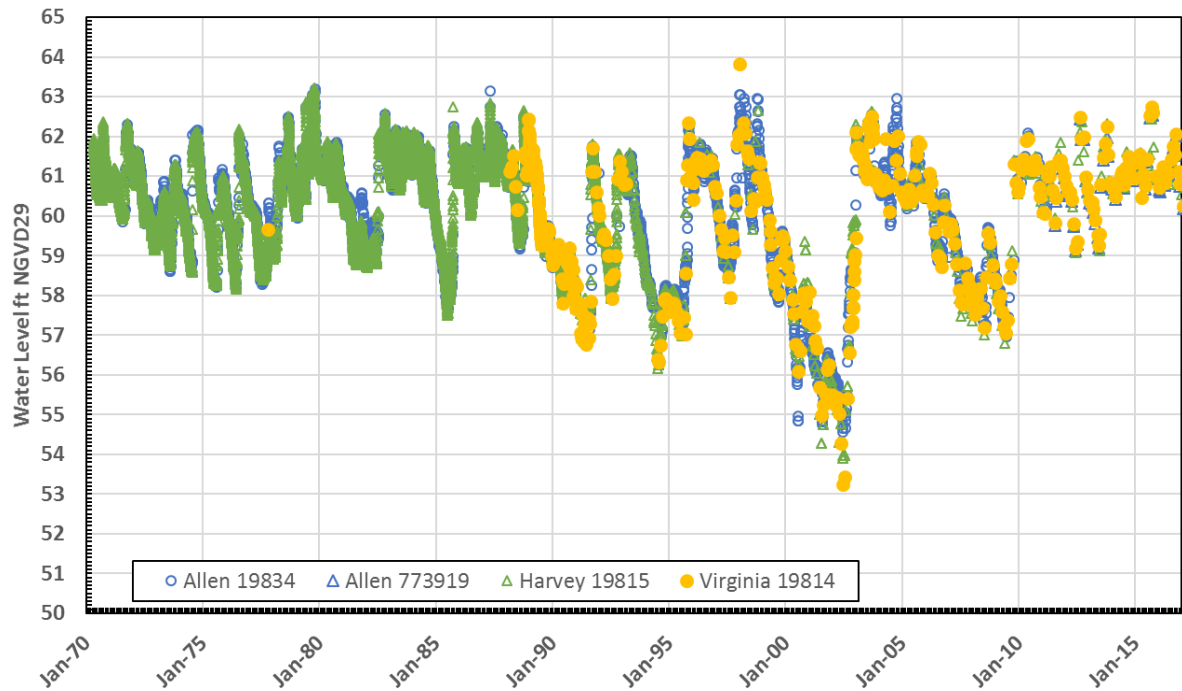
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Figure 3. Water levels at Lakes Allen (blue circle/triangle), Virginia (orange dot), and Harvey (green triangle) from January 1970 to December 2016.

The Lutz Park Upper Floridan (SID 19618) and Surficial (SID 19619) wells, located approximately 0.9 miles north of the lakes (Figures 4 and 5), are the closest wells to the lakes. Monthly observations for both wells occurred from 1989 to 2017. The Lutz Park Upper Floridan and surficial hydrographs were adjusted 4.8 and 3.7 feet lower in the model, respectively, to account for their location.
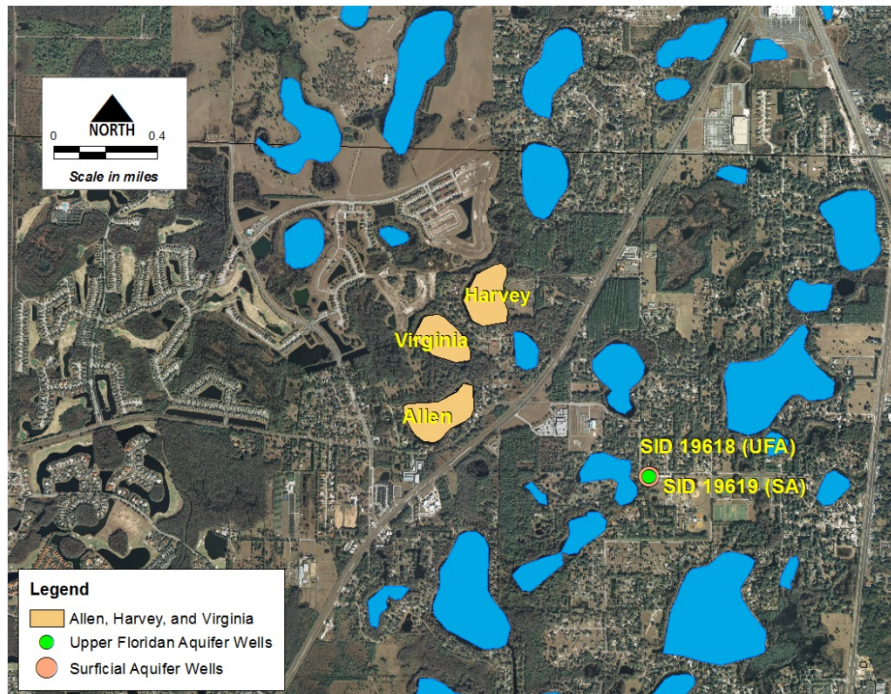
Figure 4. Location of monitor wells near lakes Allen, Harvey, and Virginia used for model inputs.
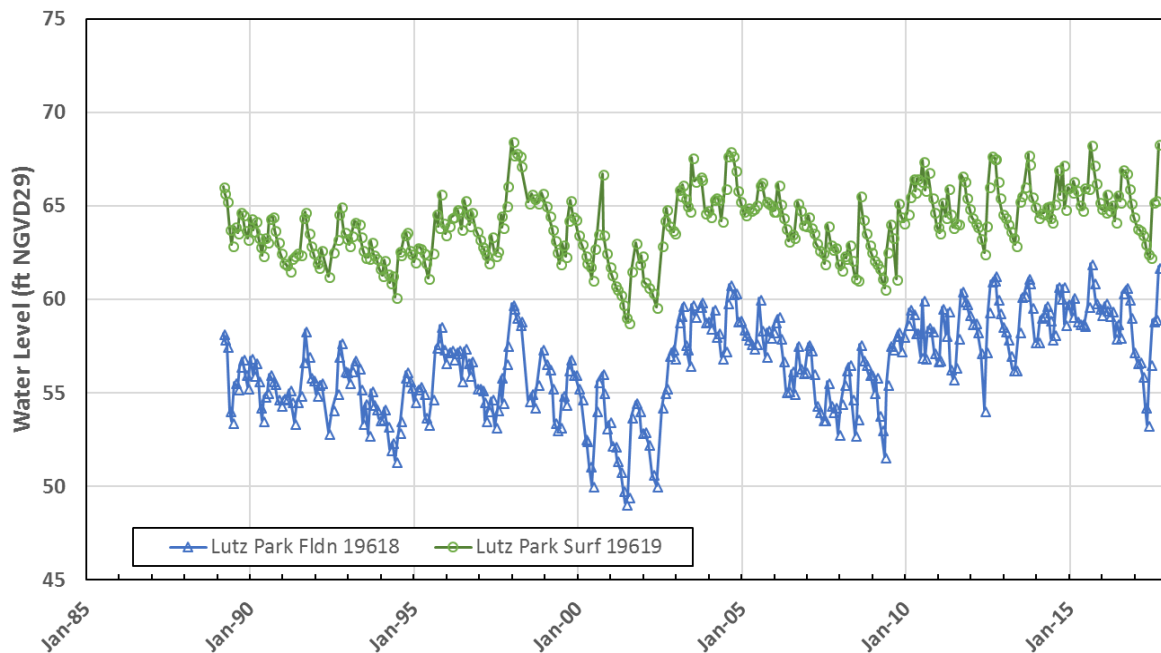

Figure 5. Water levels in the surficial and Floridan aquifer monitor wells.

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Land and Water Use

Lakes Allen, Virginia and Harvey are located approximately 1.5 miles southeast of the South Pasco Wellfield, and less than 2 miles northeast of the Section 21 wellfield, two of eleven regional water supply wellfields operated by Tampa Bay Water (Figure 6). Groundwater withdrawals began at the Section 21 Wellfield in 1963 and steadily climbed to approximately 20 mgd in 1967 (Figure 7). With the development of the South Pasco Wellfield in 1973, withdrawal rates at the Section 21 Wellfield were reduced to approximately 10 mgd, while withdrawal rates at the South Pasco Wellfield quickly rose to 16 to 20 mgd, for a combined withdrawal rate ranging from 20 to 30 mgd in the mid to late 1970s (Figure 4). Combined withdrawal rates since 2005 have ranged from zero to nearly 20 mgd, with several extended periods when one wellfield or the other was shut down completely.
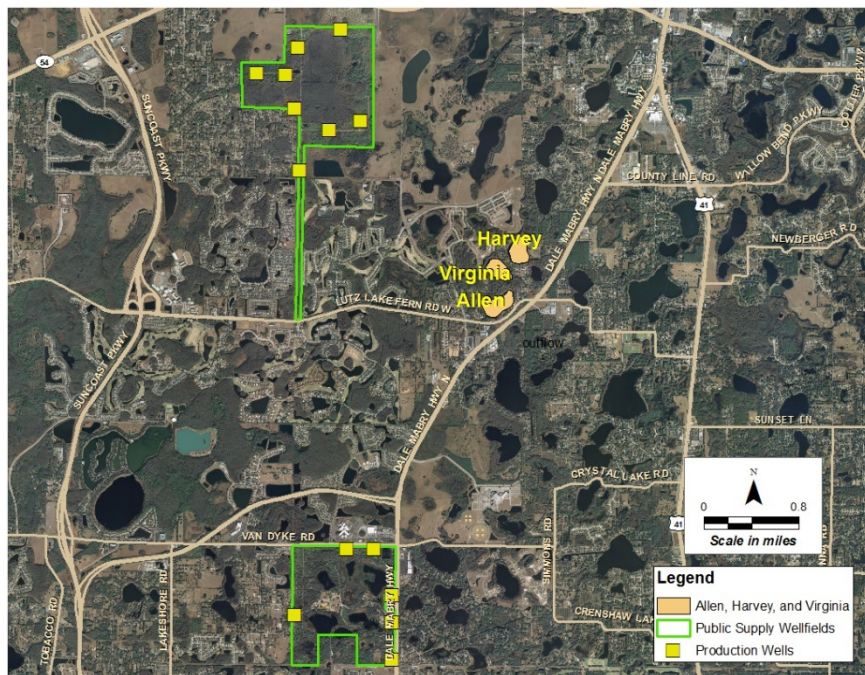

Figure 6. Lakes Allen, Harvey, and Virginia (center) between the Section 21 (to the south) and South Pasco (to the north) Wellfields.
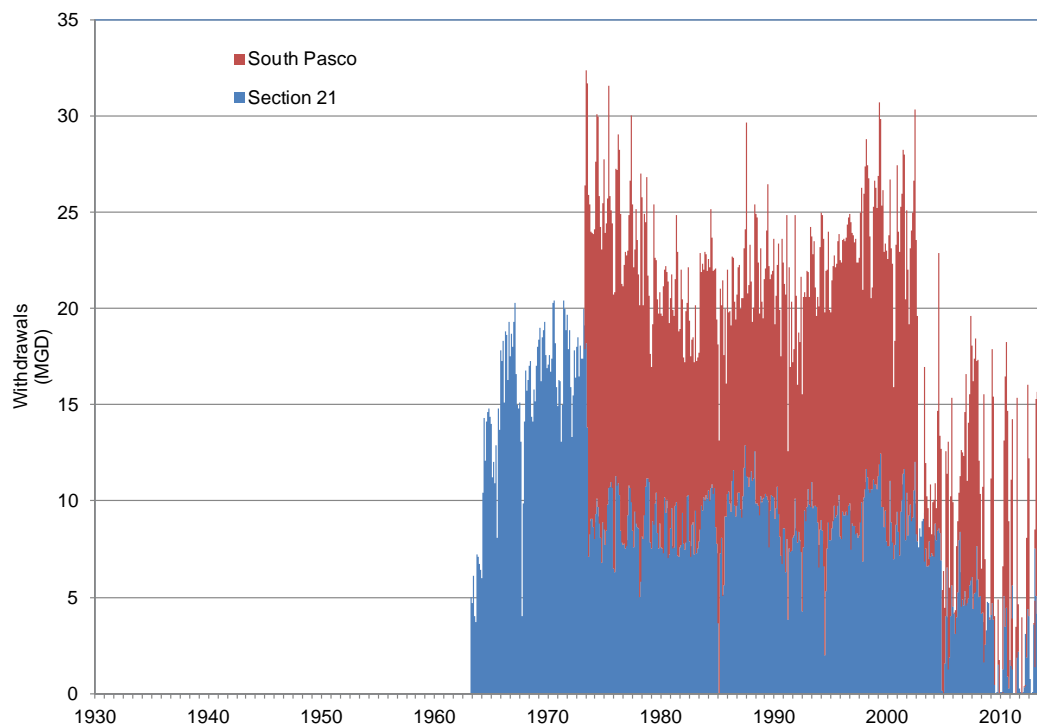
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Figure 7. Section 21 and South Pasco Wellfield withdrawals.

Water levels in several lakes in Section 21 and South Pasco wellfield areas have dropped significantly since public supply groundwater withdrawals began in the area (Hancock and Basso, 1996). Because water level data collection at Lake Allen, Virginia and Harvey did not begin in earnest until well after the beginning of withdrawals from the wellfields (Figures 5 and 6), 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 during that period could also account for some of the apparent recovery.

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 and others, 1965; Sinclair, 1973 Stewart and Hughes, 1974; Sinclair, 1982; Sinclair and others, 1985; Hancock and Basso, 1996; Metz and Sacks, 2002; and, Metz, 2011). Man-induced or natural hydrologic stressors can cause sediments in karst formations to unravel or can lower water levels that support overburden covering voids in the limestone aquifer.

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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 period. The Historic period is defined as a period 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 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 period does not exist, or if available Historic 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 Lakes Allen, Virginia and Harvey both the Section 21 and South Pasco wellfields have potentially affected water levels since they began operation in 1963 and 1973, respectively.   Stage data prior to the wellfields isn't available, thus, 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 water budget model for lakes Allen, Virginia and Harvey 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 the three lakes is calibrated from January 2010 through December 2016. This period begins after completion of a structural change to the outlets of Allen and Virginia in 2010.

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. Survey of the last high point in the channels connecting Allen, Virginia and Harvey indicates all three lakes are connected above 59.26 feet NGVD29.

Precipitation

After a review of several rain gages around the lakes, NEXRAD (Next Generation Weather Radar) derived rainfall data for the lake was used in the water budget model from 2010 through 2016 (Figure 8). The average of pixels 103644 and 103645 was used.
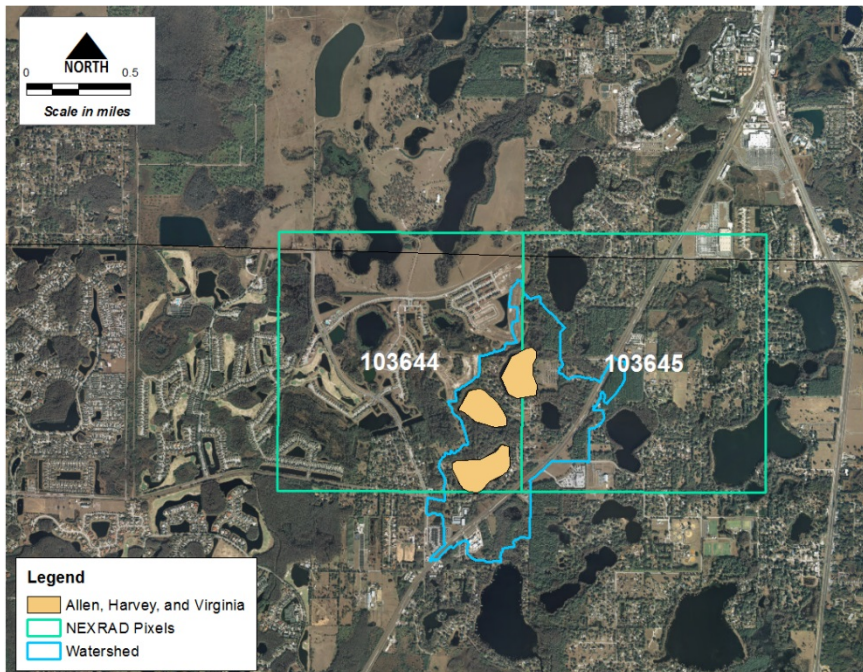
9

Figure 8. NEXRAD pixels used in the Lakes Allen, Harvey and Virginia water budget model.

Lake Evaporation

Lake evaporation was estimated through use of monthly energy budget evaporation data collected by the U.S. Geological Survey (USGS) at Lake Starr in Polk County (Swancar and others, 2000; Figure 9a). The data was collected from August of 1996 through July of 2011. Monthly Lake Starr evaporation data were used in the water budget model for lakes Allen, Virginia and Harvey when available, and monthly averages for the period of record were used for those months when Lake Starr evaporation data were not available.

A recent study compared monthly energy budget evaporation data collected from both Lake Starr and Calm Lake (Swancar, 2011, personal communications). 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 5.8 miles to the southwest of lakes Allen, Virginia and Harvey (Figure 9).

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 over open

water areas, using the values derived from the grid nodes over the modeled lake was considered. A decision was made to instead use the Lake Starr evaporation data since the GOES data nodes typically include both upland and lake estimates, with no clear way of subdividing the two. It was thought that using the daily PET estimates based on the GOES data would increase model error more than using the Lake Starr data directly.
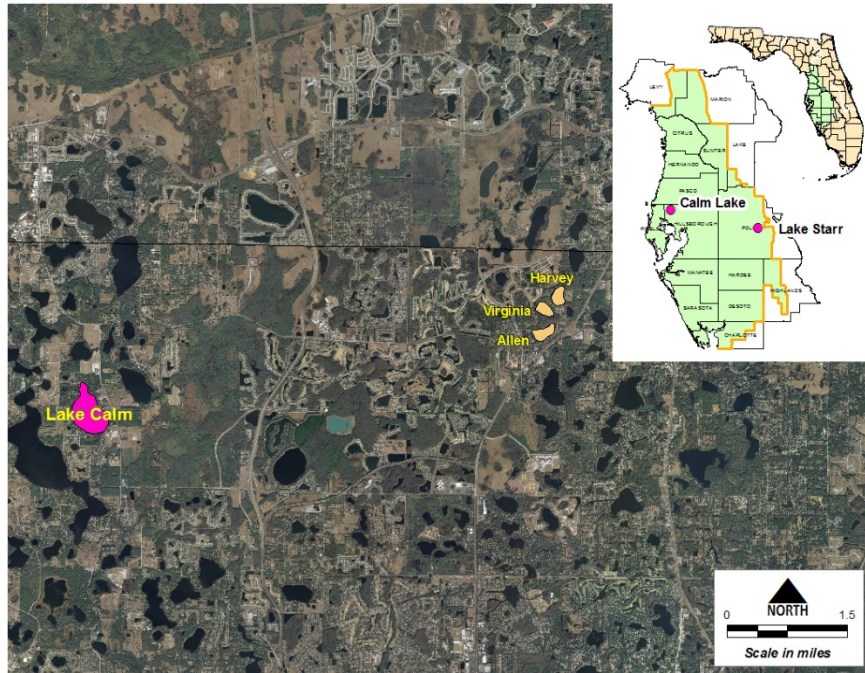

Figure 9. Location of Lakes Allen, Virginia and Harvey, Calm and (see map inset) Starr.

Overland Flow

The water budget model was set up to estimate overland flow via a modified version of the U.S. Department of Agriculture, Soil Conservation Service (SCS) Curve Number method (SCS, 1972), and via directly connected impervious area calculations. The free water area of 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.

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The topography around lakes Allen, Virginia and Harvey is relatively flat, so determining watersheds based on relatively subtle divides can be challenging. The watershed for lakes Allen, Virginia and Harvey as used in the model is shown in Figure 10. The entire area of the contributing watersheds is estimated to be approximately 366 acres (including the lakes).

The DCIA and SCS CN used for the direct overland flow portion of the watershed are listed in Table 1. Most of the soils in the area are A and A/D soils. A/D soils are highly dependent on how well they are drained. A "D" soil will generally have a higher amount of runoff per quantity of rain than 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 a higher frequency of 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 "A/D" soils. For purposes of this model, considering the range of conditions experienced, a CN (63) somewhere between the two conditions was used. The area of direct discharges to the lake (DCIA) of the watershed is approximately one acre.
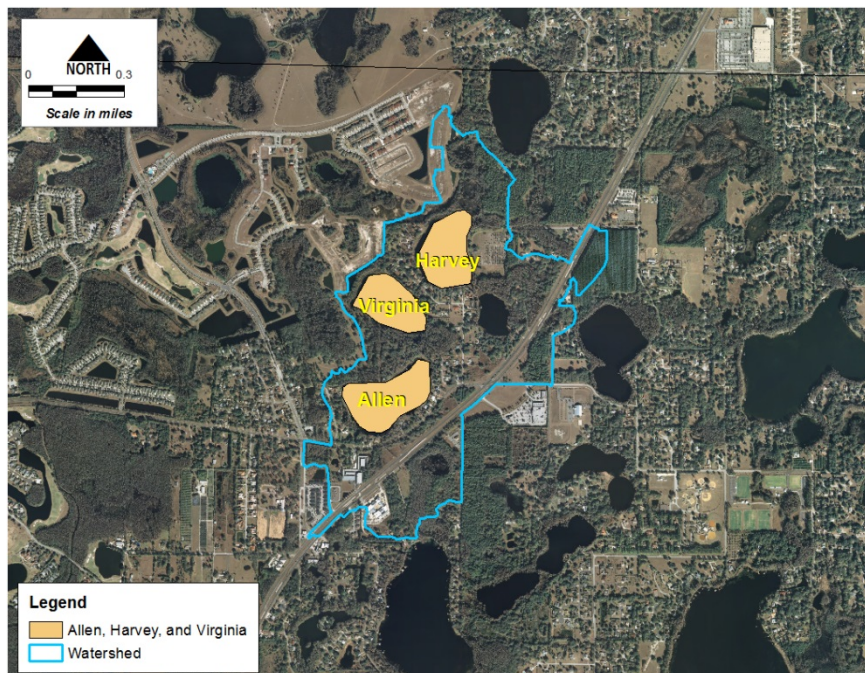

Figure 10. The watershed of Lakes Allen, Harvey, and Virginia as used in the model.

Inflow and Discharge via Channels from Outside Watersheds

Inflow and outflow via channels from or to the lake's watershed (i.e. "channel flow") is an important component of the water budget for lakes Allen, Virginia and Harvey, although

the gradients of the channels are relatively flat, and inflows to the lake only occur only during high rainfall events during extended wet periods.

During the calibration period of the water budget model, stages for all three lakes were similar and above high points in the three channels between the lakes. For modeling purpose, the lakes are connected and fluctuate as one. The high point between Harvey and Allen was surveyed at 59.26 feet NGVD, and 56.8 feet NGVD between Allen and Virginia. Outflow occurs from lakes Allen and Virginia on their west ends. The drop structure elevation was surveyed at 60.7 feet NGVD.

Infrequent inflow (Figure 3) occurs from Browns Lake to Lake Harvey during very wet conditions. Flow from Browns Lake passes through a wetland system and land elevations from LIDAR show a high point of 63 feet NGVD29. Finally, since lake Allen, Virginia and Harvey were modeled as a single unit (see "Lake Stage/Volume"), flows from the former to the latter for this model were not necessary.

Lakes Allen and Virginia discharge via a drop structure and culverts to a large wetland (Figure 3). To estimate flow out of the three lakes (considered one model), the predicted elevation of the lake from the previous day is compared to the controlling elevation. Control elevations were determined based on professional surveying performed in the area. If the lake elevation is above the controlling elevation, the difference is multiplied by the current area of the lake and an "outflow coefficient." The coefficient represents a measure of channel and structure efficiency and produces a rough estimate of volume lost from the lake. This volume is then subtracted from the current estimate of volume in the lake.

Flow from and into the surficial aquifer and Upper Floridan aquifer

Water exchange between the lake unit (Allen, Virginia and Harvey) 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.

Lutz Park (SID 19618) located approximately 0.9 miles southeast, is the closest Upper Floridan aquifer monitor to the three lakes (Figures 4 and 5). An inspection of May and September potentiometric surface maps from District archives over several years representing periods before and after wellfield cutbacks found water levels at this well location to be approximately 4 to 5 feet higher than the three lakes location. The hydrograph for the Upper Floridan aquifer was adjusted down 4.8 feet to represent the potentiometric surface at the lake. The land elevation at the Lutz Park Surficial monitoring well is approximately 4 feet higher than the lake unit area, and the water levels in the surficial well were adjusted down 3.7 feet. In both the Upper Floridan

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aquifer and surficial wells, missing data were infilled using linear interpolation, and the resulting well level time series was used to represent the water table at the lake daily from 2010 through 2016.

E.   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 lakes. Model calibration was therefore focused on matching long-term percentiles based on measured water levels, rather than short-term high and low levels. Model inputs are listed in Table 1.

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 11 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.

Table 1. Model inputs for lakes Allen, Virginia and Harvey water budget model.

Input Variable	Value
Overland Flow Watershed Size (acres)	366
SCS CN of watershed	63
Percent Directly Connected	0.003
FL Monitor Well(s) Used	Lutz Park Floridan (SID 19618)
Surf. Aq. Monitor Well(s) Used	Lutz Park Surficial (SID 19619)
Surf. Aq. Leakance Coefficient (ft/day/ft)	0.0001
Fl. Aq. Leakance Coefficient (ft/day/ft)	0.0006
Outflow K	0.0008
Outflow Invert (ft NGVD29)	60.7
Inflow K	N/A
Inflow Invert (ft NGVD29)	N/A

F.   Water Budget Model Calibration Discussion

Based on a visual inspection of 1, the model appears to be reasonably well calibrated. The mean and median differences of the residuals (observed less predicted values) are -0.03 feet each. A review of Table 2 shows no differences for the P10 and P50 percentiles between the data and model for the lake. The difference for the P90 is 0.1 ft (with the data being higher than the model).

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There are a few periods when the peaks in the modeled hydrograph are higher or lower than the measured values, and these differences contributed to minor differences between the modeled and measured percentiles associated with higher and lower lake levels, i.e., the P10 and P90 percentiles. Reduced precision in the higher and lower ranges of the stage-volume relationships for the lake likely contributed to percentile differences.

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.
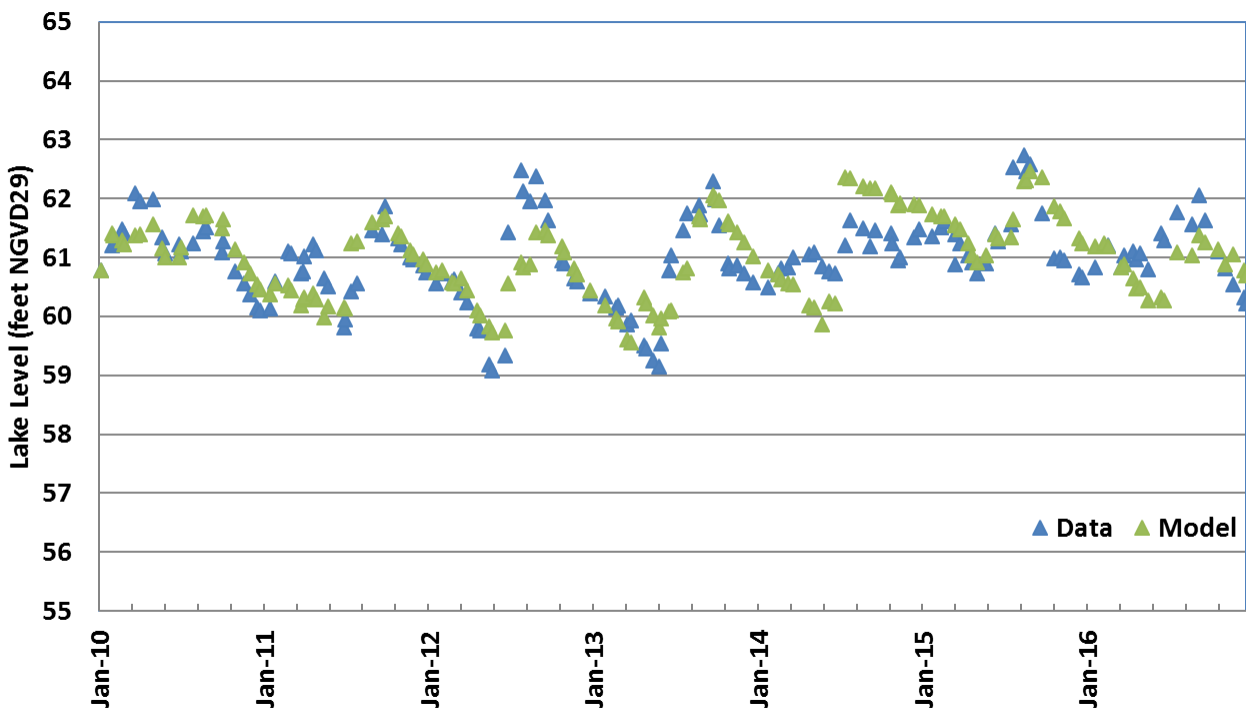

Figure 11. Modeled water levels predicted for the calibrated lake water budget model for Allen, Virginia and Harvey.

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

Percentile	Data	Model
P10	61.9	61.9
P50	61.0	61.0
P90	60.2	60.1

Table 3. Lakes Allen, Virginia and Harvey Water Budget (2010-2016)

Inflows	Rainfall	Surficial Aquifer Groundwater Inflow	Floridan Aquifer Groundwater Inflow	Runoff	DCIA Runoff	Inflow via channel	Total
Inches/year	55.1	0.1	0.0	22.2	0.5	0.0	78
Percentage	70.7	0.2	0.0	28.4	0.7	0.0	100

Outflows	Evaporation	Surficial Aquifer Groundwater Outflow	Floridan Aquifer Groundwater Outflow		Outflow via channel	Total
Inches/year	58.1	0.1	18.4		1.6	78.3
Percentage	74.2	0.2	23.5		2.1	100

G.   Water Budget Model Results

Groundwater withdrawals are not directly included in the lakes Allen, Virginia and Harvey water budget model, but are indirectly represented by their effects on water levels in the Upper Floridan aquifer. Metered groundwater withdrawal rates from the Section 21 and South Pasco Wellfields 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 lakes Allen, Virginia and Harvey area, and represents the most current understanding of the hydrogeologic system in the area.

The INTB was used to determine the drawdown in the surficial aquifer and Upper Floridan aquifer in response to groundwater withdrawals in the area. Drawdown in both aquifers was calculated for two withdrawal rates representing the effects of Tampa Bay

Water's regional wellfields before and after cutbacks from approximately 150 mgd to 90 mgd. The pre-cutback period in the model is from 1974 through 2004, while the post-cutback period is 2005 through 2017. 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 1996 to 2006 using a daily integration step. Drawdown values in feet were calculated by running the model with and without groundwater withdrawals and were calculated for each node in the model. The INTB model uses a one-quarter mile grid spacing around the wellfields. Average groundwater withdrawal rates for the period 2010 through 2016 from the Section 21 Wellfield and South Pasco Wellfield was 2 mgd and 4.5 mgd, respectively.

Results from the INTB modeling scenarios showed a near linear relationship between Upper Floridan aquifer drawdown and withdrawal rates at the wellfields. Because of the leaky nature of the confining unit around lakes Allen, Virginia and Harvey, and because the water table in the model is not active, the relationship between groundwater withdrawals in the Upper Floridan and water levels in the surficial aquifer was also of interest. Using the drawdowns determined through the INTB model, the Upper Floridan aquifer and surficial monitor well data in the model can be adjusted to reflect changes in groundwater withdrawals.

To estimate lake levels without the influence of groundwater withdrawals, the Upper Floridan aquifer and surficial aquifer wells in the water budget model were adjusted to represent zero withdrawals. For the 2010 through 2016 water budget model period. Adjustments to the Upper Floridan aquifer and surficial aquifer well are found in Table 4.

Table 4. Aquifer water level adjustments to the lakes Allen, Virginia and Harvey Model to represent Historic percentiles.

Well	Adjustment (feet) 2010 through 2016
Floridan aquifer	2.5
Surficial aquifer	0.6

Table 5. Water budget model period Historic percentiles for lakes Allen, Virginia and Harvey as estimated by the water budget model from 2010 to 2016 (in feet NGVD29).

Percentile	Elevation
P10	62.3
P50	61.4
P90	60.7

Figure 12 presents measured water level data for the lake along with the model-simulated lake levels in the lake under Historic conditions, i.e. in the absence of groundwater withdrawals with similar structural alterations to current conditions. Table 5 presents the Historic percentiles based on the model output.
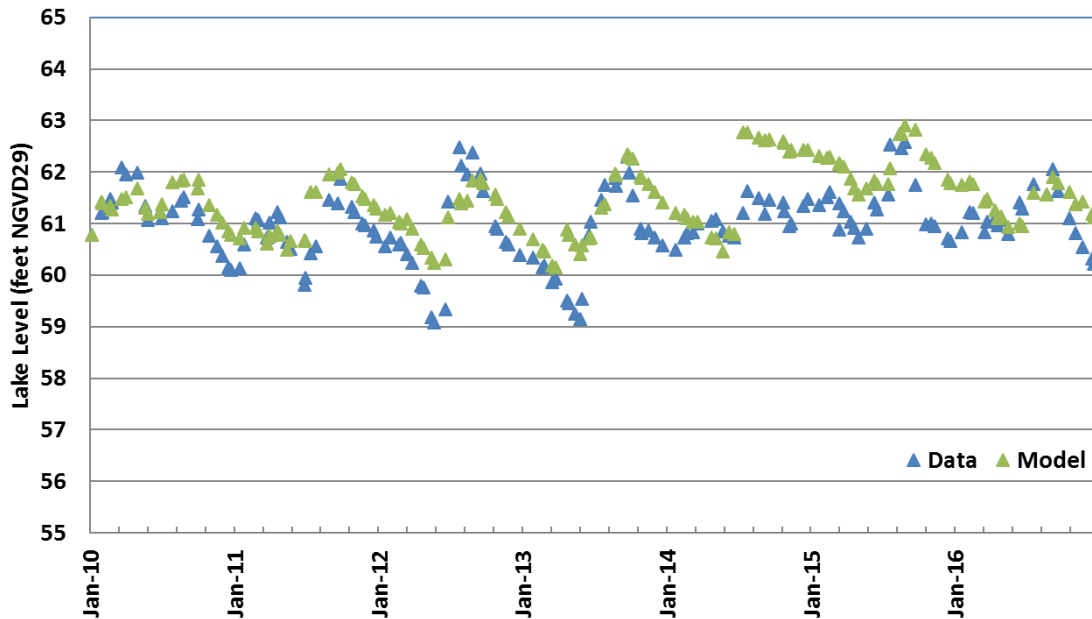

Figure 12. Measured lake levels (blue triangles) and Historic water levels (green triangles) predicted with the calibrated lakes model for Allen, Virginia and Harvey.

H.   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 (2010 through 2016). NEXRAD data was used back to 1995. Data from Tampa Bay Water's

Cosme rain gage (Figure 13); located on the Cosme Wellfield, approximately 7 miles from southwest lakes Allen, Virginia and Harvey), which was replaced by the Cosme 18 gage due to quality control issues, was used to extend the rain data back to 1974. The quality control issues at the gage reported occurred after 1995, and there is no evidence that there were quality control issues at the Cosme gage prior to that time. Data from the Lutz gage, located adjacent to Lake Harvey, is available in 1973 back to 1963. The Cosme gage was used again back to 1945. Finally, rainfall data from the St. Leo gage (Figure 13) were used to extend the data back to 1930. Although the St. Leo gage is approximately 22 miles northeast of lakes Allen, Virginia and Harvey, 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 for the entire period used in the water budget model (2010 through 2016), and results from 1946-2016 (71 years) were produced. For lakes Allen, Virginia and Harvey, the 1-year weighted model had the highest correlation coefficient, with an R^2 of 0.6, the results of which are presented in Figure 14. Previous correlations for lakes in the northern Tampa Bay area have consistently had best correlation coefficients in the 2 to 5-year range, which makes lakes Allen, Virginia and Harvey decay somewhat unusual.

To produce Historic percentiles that apply significant weight to the results of the water budget models, the rainfall LOC results for the period of the water budget model are replaced with the water budget model results. Therefore, the LOC rainfall model results are used for the period of 1946 through 2009, while the water budget results are used for the period of 2010 through 2017. These results are referred to as the "hybrid model." The resulting Historic percentiles for the hybrid model are presented in Table 6.

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

Historic normal pool was determined for lakes Allen, Virginia and Harvey based on inflection points of adjacent cypress trees. The Historic normal pool and natural P10 in lakes and wetlands in the northern Tampa Bay area are typically similar in many cases. The Historic normal pool for lakes Allen, Virginia and Harvey was found to be 62.3 feet NGVD29 as part of the lakes' re-evaluation, which equals the model's Historic P10.

Table 6. Historic percentiles for lake Allen, Virginia and Harvey as estimated by the hybrid model from 1946 to 2016 (feet NGVD29).

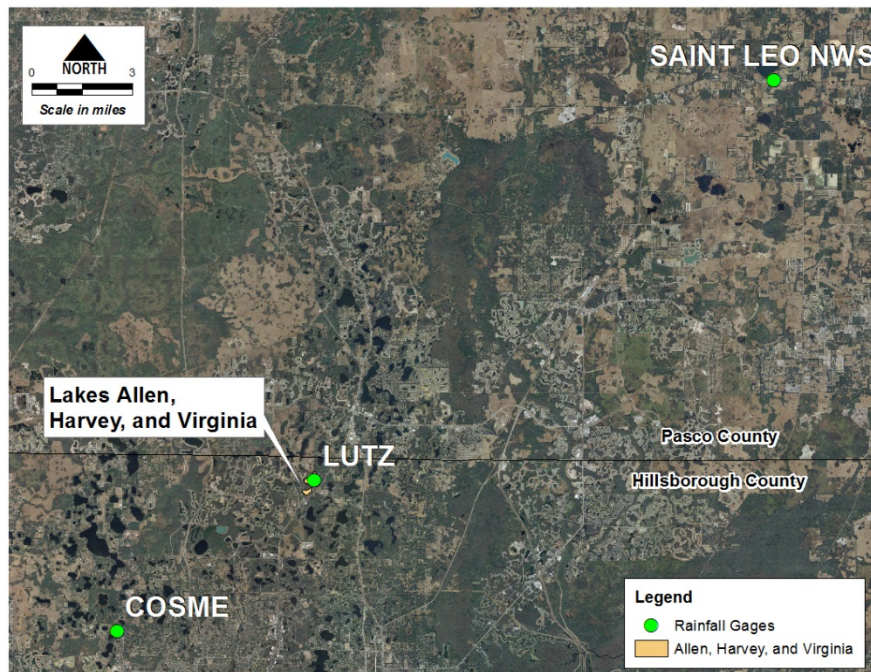| Percentile	Elevation
P10	62.3
P50	61.3
P90	60.5

Figure 13. Location of additional rain stations used for the rainfall correlation model.
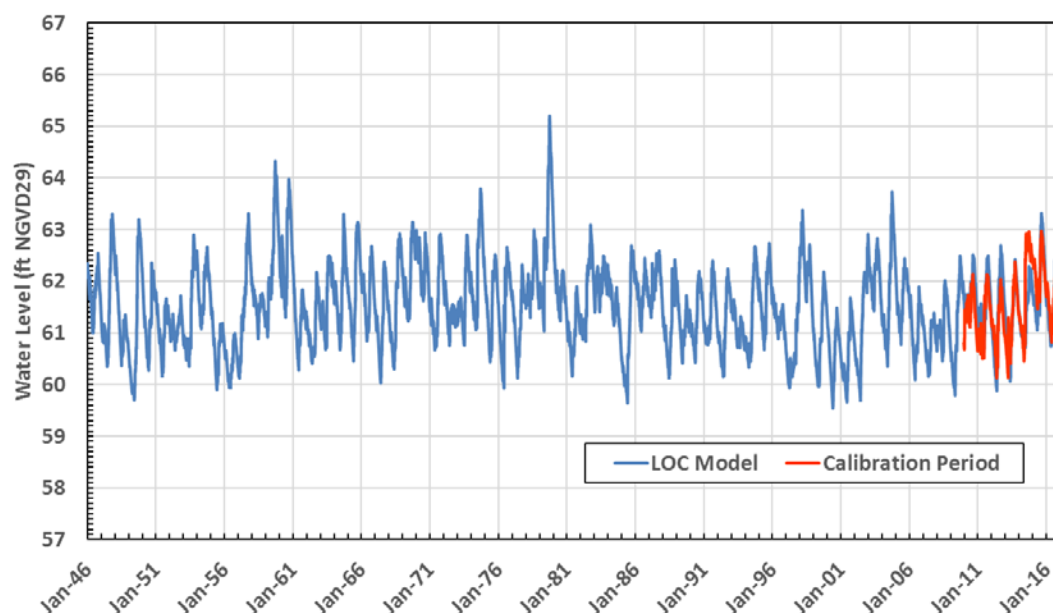
Figure 14. LOC model (blue) and water budget (red) results for lakes Allen, Virginia and Harvey.

I.   **Conclusions**

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

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APPENDIX B

Technical Memorandum

March 15, 2018

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

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

Subject: Lakes Allen, Virginia and Harvey Initial Minimum Levels Status Assessment

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A.   Introduction

The Southwest Florida Water Management District (District) is reevaluating adopted minimum levels for lakes Allen, Virginia and Harvey and is proposing revised minimum levels for the lakes, in accordance with Section 373.042 and 373.0421, Florida Statutes (F.S). Documentation regarding development of the revised minimum levels is provided by Ellison and Patterson (2018) and Campbell and others (2018).

Section 373.0421, F.S. requires that a recovery or prevention strategy be developed for all water bodies that are found to be below their minimum flows or levels, or are projected to fall below the minimum flows or levels within 20 years. In the case of lakes Allen, Virginia and Harvey 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 lakes Allen, Virginia and Harvey 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 lakes Allen, Virginia and Harvey and any recovery that may be necessary for the lake.

B.   Background

Allen, Virginia and Harvey are in northwest Hillsborough County, northwest of the intersections between Lutz Lake Fern Road and Dale Mabry Highway (Figure 1). The lakes lie within the Upper Rocky Creek watershed that forms part of the larger Tampa Bay watershed (USGS HUC 03100206).

Browns Lake located north of Lake Harvey flows into Lake Harvey infrequently during extremely wet conditions and lake stage is greater than approximately 63 ft. NGVD29. The frequency of the connection is very limited, thus, the model developed didn't include inflow contributions from Browns Lake. Lake Harvey and Lake Virginia are connected when their stages are above 59.26 feet NGVD29. Virginia is connected to Allen when their stages are above 56.8 feet NGVD29 and all three lakes are connected above 59.26 feet NVGD29. The stages of the three lakes are the essentially the same for much of the record. Flow exits Lake Virginia and Lake Allen at elevation 61.1 ft. NGVD29 (Figure 2).

Lakes Allen, Virginia and Harvey are located approximately 1.5 miles southeast of the South Pasco Wellfield, and less than 2 miles northeast of the Section 21 wellfield, two of eleven regional water supply wellfields operated by Tampa Bay Water (Figure 3). Groundwater withdrawals began at the Section 21 Wellfield in 1963 and steadily climbed to approximately 20 mgd in 1967 (Figure 4). With the development of the South Pasco Wellfield in 1973, withdrawal rates at the Section 21 Wellfield were reduced to approximately 10 mgd, while withdrawal rates at the South Pasco Wellfield quickly rose to 16 to 20 mgd, for a combined withdrawal rate ranging from 20 to 30 mgd in the mid to late 1970s (Figure 4). Combined withdrawal rates since 2005 have ranged from zero to nearly 20 mgd, with several extended periods when one wellfield or the other was shut down completely.

C.   Revised Minimum Levels Proposed for Lakes Allen, Virginia and Harvey

Revised minimum levels proposed for lakes Allen, Virginia and Harvey are presented in Table 1 and discussed in more detail by Campbell and others (2018). Minimum levels represent long-term conditions that, if achieved, are expected to protect water resources and the ecology of the area from significant harm that may result from water withdrawals. The Minimum Lake Level is the elevation that a lake's water levels are required to equal or exceed fifty percent of the time on a long-term basis. The High Minimum Lake Level is the elevation that a lake's water levels are required to equal or exceed ten percent of the time on a long-term basis. The Minimum Lake Level therefore represents the required 50th percentile (P50) of long-term water levels, while the High Minimum Lake Level represents the required 10th percentile (P10) of long-term water levels. To determine the status of lake minimum levels long-term data or model results must be used.

Table 1. Proposed Minimum Levels for Lakes Allen, Virginia and Harvey.

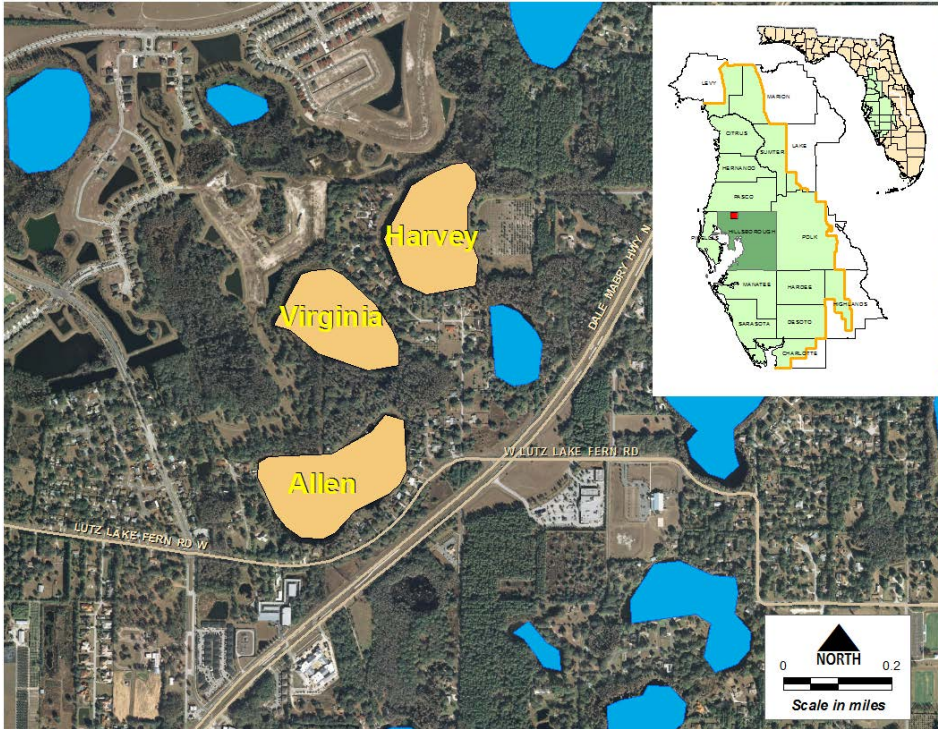| Proposed Minimum Levels	Elevation in Feet NGVD 29
High Minimum Lake Level	62.1
Minimum Lake Level	60.7

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Figure 1. Location of Lakes Allen, Harvey, and Virginia in Hillsborough County, Florida
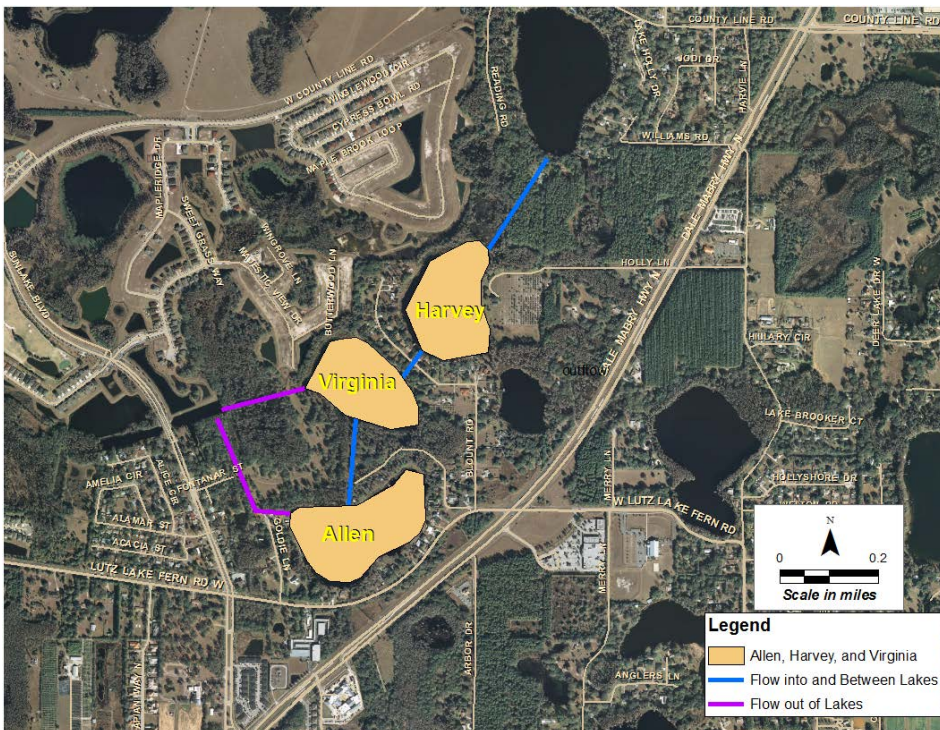

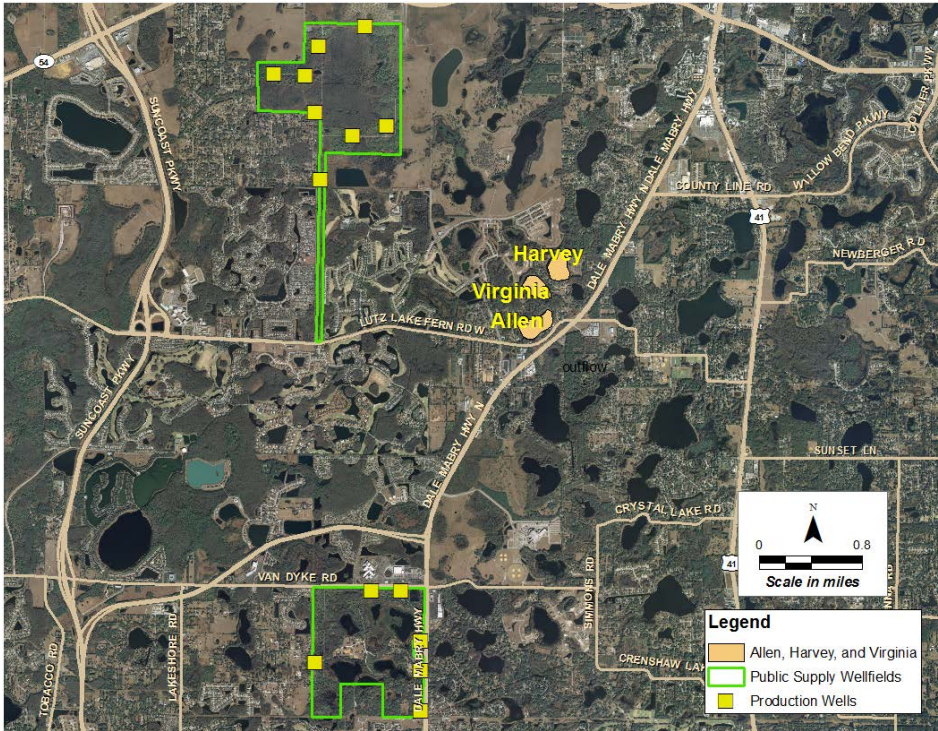Figure 2. Inflow and outflow paths for Lakes Allen, Harvey, and Virginia

Figure 3. Lakes Allen, Harvey, and Virginia (center) between the Section 21 to the south and South Pasco to the north
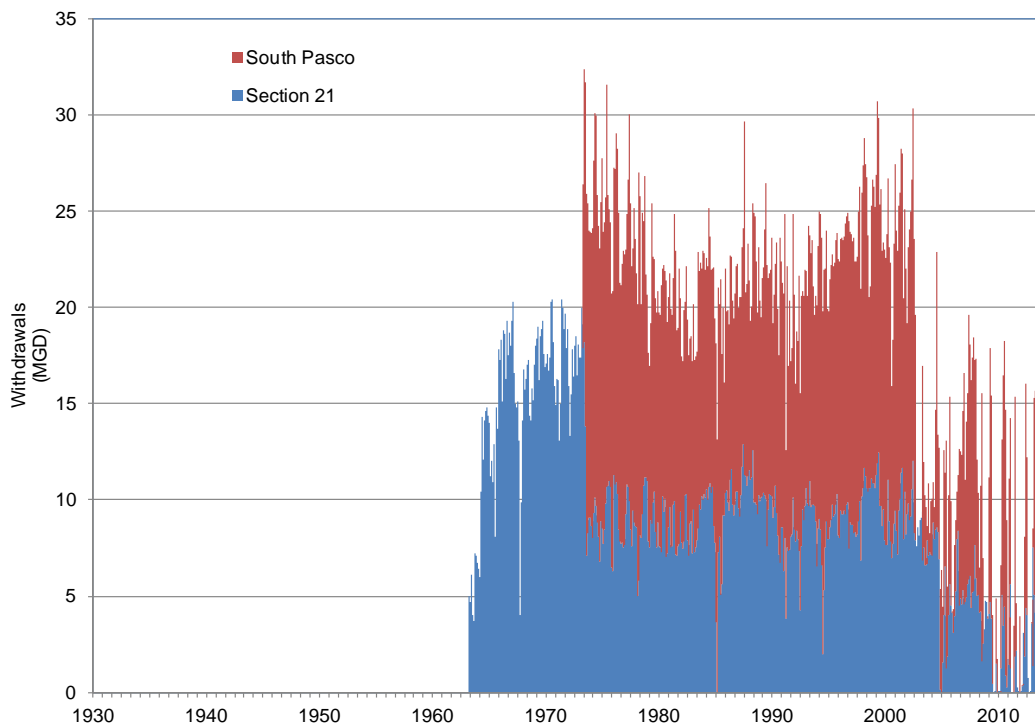

Figure 4. Stacked South Pasco and Section 21 Wellfield mean monthly withdrawals (mgd).

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D.   Status Assessment

The lake status assessment approach involves using actual lake stage data for lakes Allen, Virginia and Harvey from January 2010 through December 2017, which was determined to represent the "Current" period based on recent structural alterations to the Allen and Virginia. The Current period represents a recent period when hydrologic stresses (including groundwater withdrawals) and structural alterations are reasonably stable.

As demonstrated in Ellison and Patterson (2018), groundwater withdrawals during this period were relatively consistent. 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 lakes Allen, Virginia and Harvey (Ellison and Patterson, 2018). By using this technique, the limited years of Current lake level data can be projected back to create a simulated data set representing 72 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 lakes Allen, Virginia and Harvey was used for the status assessment (Ellison and Patterson, 2018). The best resulting correlation for the LOC model created with measured data (2010-2017) was the 1-year weighted period, with a coefficient of determination of 0.61. The resulting lake stage exceedance percentiles are presented in Table 2.

A comparison of the LOC model with the revised minimum levels proposed for lakes Allen, Virginia and Harvey indicates that the Long-term P10 is 0.1 feet above the proposed High Minimum Lake Level, and the Long-term P50 is 0.3 feet above the proposed Minimum Lake Level.

Table 2. Comparison of lake stage exceedance percentiles derived from the lake stage/LOC results and the revised minimum levels proposed for lakes Allen, Virginia and Harvey.

Percentile	Proposed Minimum Levels (feet NGVD29)	Long Term LOC Model Results (1946 to 2017) (feet NGVD29)
P10	62.1	62.2
P50	60.7	61.0

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Conclusions

Based on the information presented in this memorandum, it is concluded that for lakes Allen, Virginia and Harvey water levels are above both the revised Minimum and High Minimum Lake Levels 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, for lakes Allen, Virginia and Harvey are 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 for lakes Allen, Virginia and Harvey 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)).

E.   References

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

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APPENDIX C

Technical Memorandum

October 10, 2017

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

FROM: Jason Patterson, Hydrogeologist, Resource Evaluation Section

Subject: Evaluation of Groundwater Withdrawal Impacts to Lakes Allen, Virginia, and Harvey

1.0 Introduction

Lakes Allen, Harvey, and Virginia are 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 these lakes is not part of this report. This memorandum describes the hydrogeologic setting near the lake and includes the results of two numerical model scenarios of groundwater withdrawals in the area.

2.0 Hydrogeologic Setting

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

The base of the Upper Floridan aquifer generally occurs at the first, persistent sequence of evaporitic minerals such as gypsum or anhydrite that occur as nodules or discontinuous thin layers in the carbonate matrix. This low permeability unit is regionally extensive and is generally referred to as middle confining unit II. Underlying the middle confining unit II is the Lower Floridan aquifer (Miller, 1986).
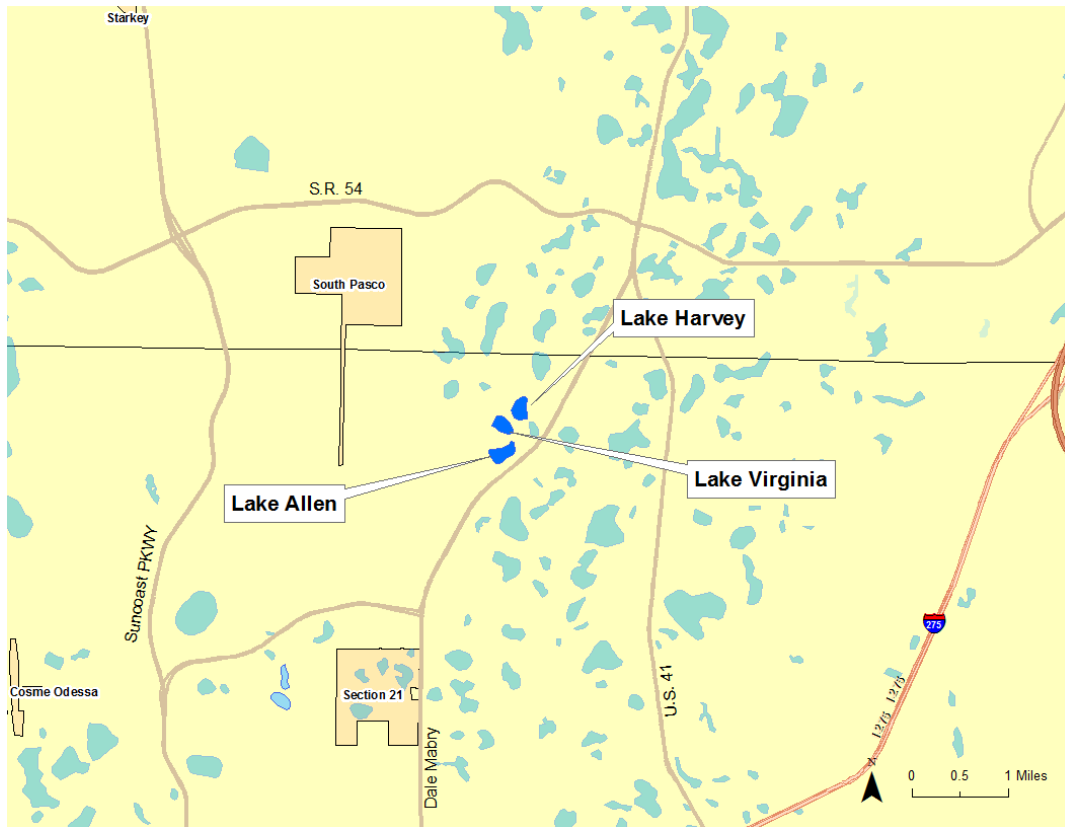
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Figure 1. Location of Lakes Allen, Harvey, and Virginia

3.0 Evaluation of Groundwater Withdrawal Impacts to Lakes Allen, Harvey and Virginia

Several regional groundwater flow models have included the area around Lakes Allen, Harvey, and Virginia 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.
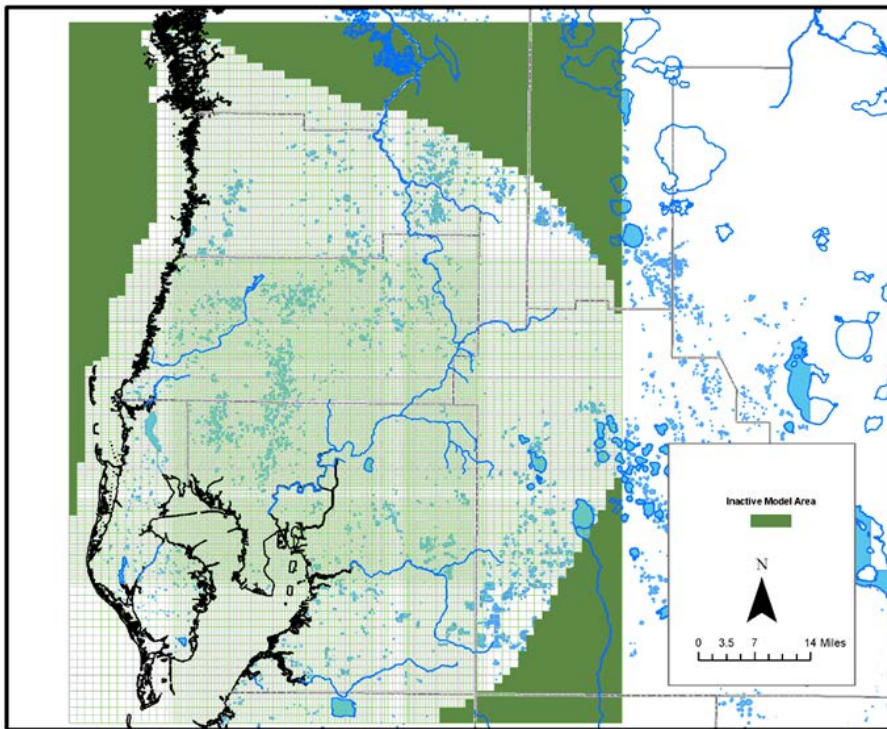
Figure 2. Groundwater grid used in the INTB model

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.
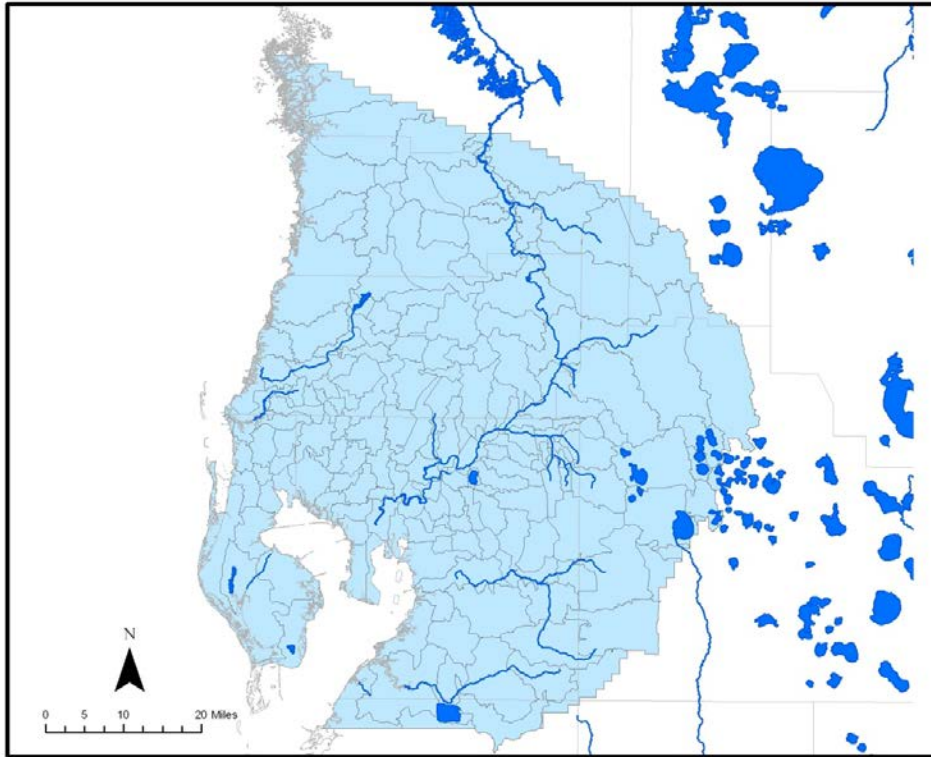
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Figure 3. HSPF subbasins in the INTB model

The INTB model is a regional simulation and has beenc 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).

3.1 INTB Model Scenarios

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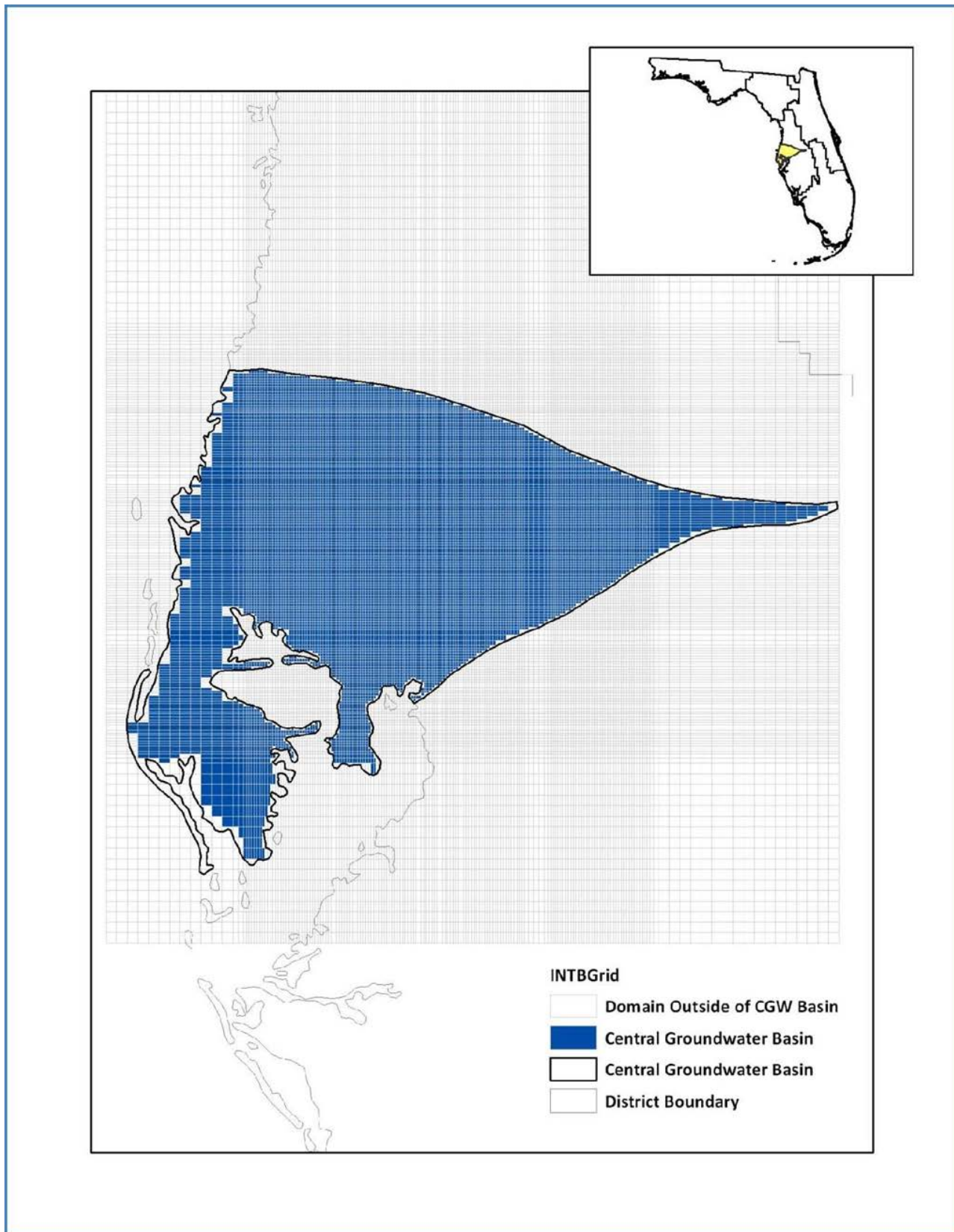
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Figure 4.   INTB scenarios where impacts to the hydrologic system were simulated due to groundwater withdrawals in the Central West-Central Florida Groundwater Basin

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Taking the difference in simulated heads from the 1989-2000 pumping to non-pumping runs, the average predicted drawdown in the surficial aquifer near Lakes Allen, Harvey, and Virginia was 1.8 ft, and 7.3 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 Lakes Allen, Harvey, and Virginia was 0.6 ft and 2.5 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.
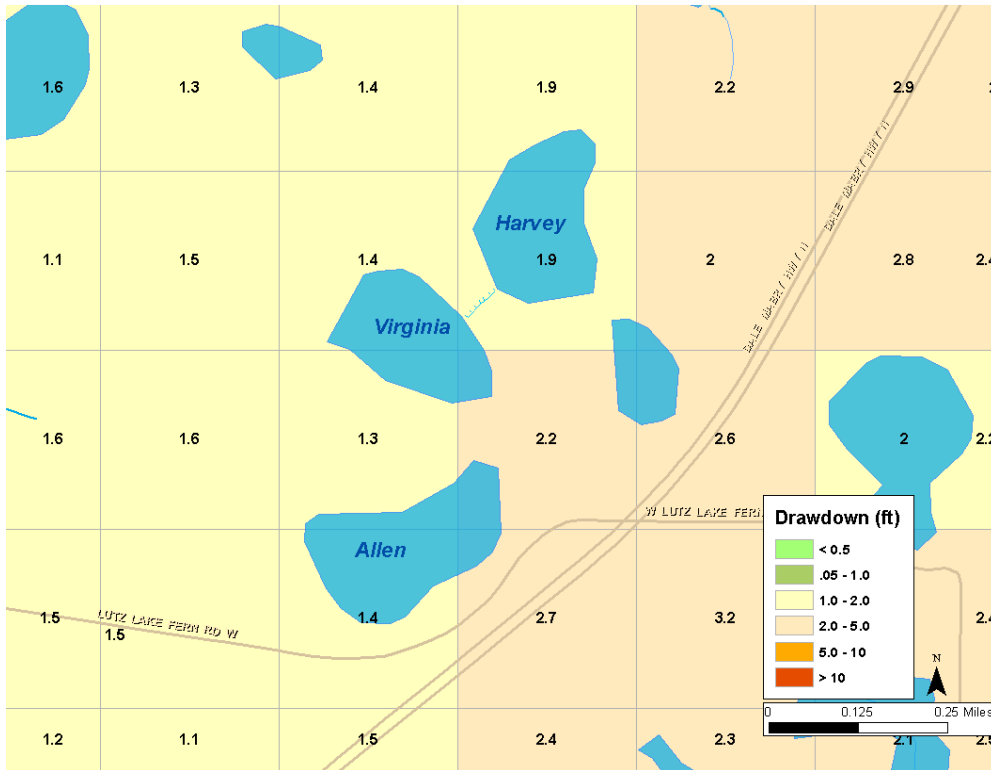

Figure 5. Predicted mean drawdown in the surficial aquifer due to 1989-2000 groundwater withdrawals
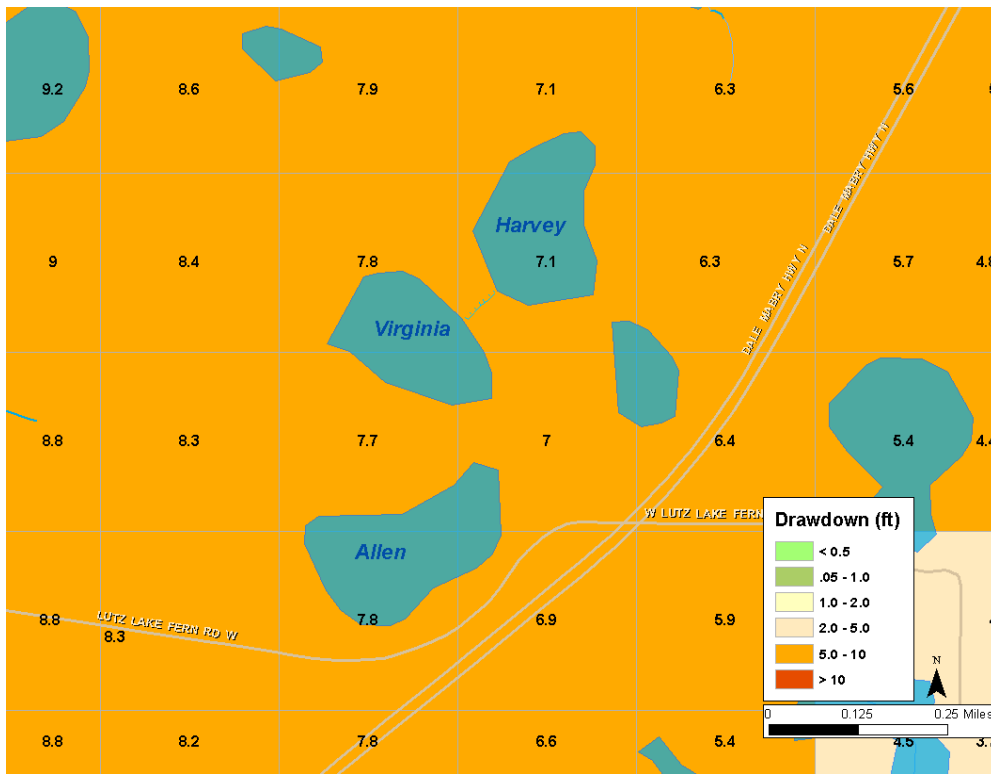
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Figure 6. Predicted mean drawdown in the Upper Floridan aquifer due to 1989-2000 groundwater withdrawals
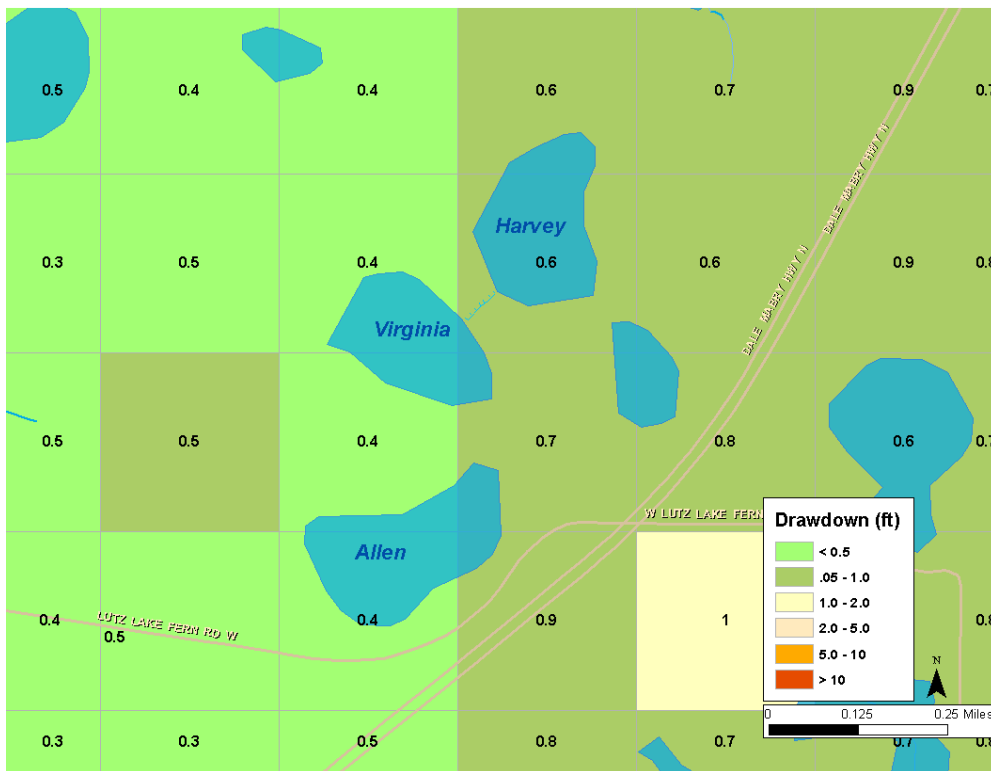

Figure 7. Predicted mean drawdown in the surficial aquifer due to TBW 90 mgd groundwater withdrawals
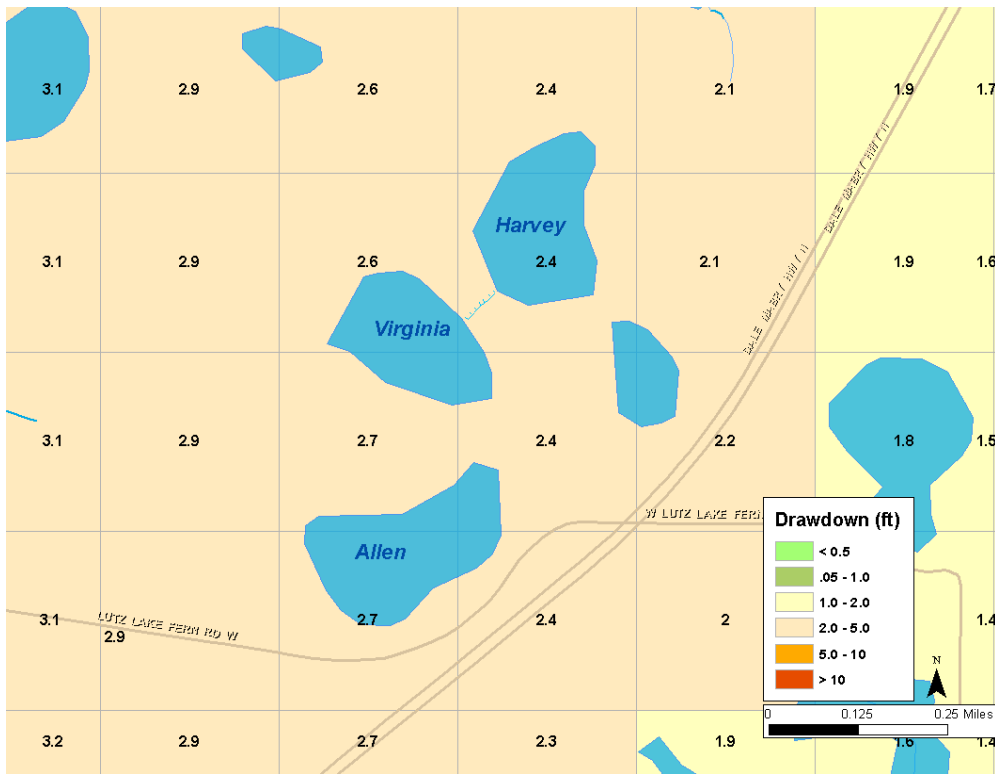
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Figure 8. Predicted mean drawdown in the Upper Floridan aquifer due to TBW 90 mgd groundwater withdrawals

Table 1. INTB model results for Lakes Allen, Harvey, and Virginia

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*
Allen, Harvey, Virginia	1.8	0.6
Lake Name	**Predicted Drawdown (ft) in the Upper Floridan Aquifer due to 1989-2000 Withdrawals***	**Predicted Drawdown (ft) in the Upper Floridan Aquifer with TBW Withdrawals reduced to 90 mgd***
Allen, Harvey, Virginia	7.3	2.5

* Average drawdown from model cells intersecting lake

8

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