Minimum and Guidance Levels for Lake Raleigh, Hillsborough County, Florida

October 1, 2013

Resource Evaluation Section
Water Resources Bureau

Southwest Florida
Water Management District

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Cover Page: 2012 aerial view Lake Raleigh (front) and Lake Rogers (background), Hillsborough County.

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Minimum and Guidance Levels for Lake Raleigh

Section 373.042, Florida Statutes (Fla. Stat.) directs the Department of Environmental Protection or the water management districts to establish minimum flows and levels for lakes, wetlands, rivers and aquifers. Section 373.042(1)(a), Fla. Stat., states that the minimum flow for a given watercourse "shall be the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area". Section 373.042(1)(b), Fla. Stat., defines the minimum level of an aquifer or surface water body as "the level of groundwater in the aquifer and the level of surface water at which further withdrawals would be significantly harmful to the water resources of the area". Minimum flows and levels are established and used by the Southwest Florida Water Management District (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.

Development of minimum flows and levels are key components in supporting resource protection, recovery and regulatory compliance by establishing standards below which significant harm will occur in specific water bodies. Section 373.0421, Fla. Stat., requires the development of a recovery or prevention strategy for water bodies if the " existing flow or level in a water body is below, or is projected to fall within 20 years below, the applicable minimum flow or level." Section 373.0421 (2), Fla. Stat., requires that recovery or prevention strategies be developed to: "(a) achieve recovery to the established minimum flow or level as soon as practicable; or (b) prevent the existing flow or level from falling below the established minimum flow or level." Periodic re-evaluation and, as necessary, revision of established minimum flows and levels are required by Section 373.0421(3), Fla. Stat.

Section 373.0421, Fla. Stat., requires that minimum flows and levels be established based upon the best available information with consideration 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 caveat that these considerations shall not allow significant harm caused by withdrawals. The Florida Water Resources Implementation Rule (Rule 62-40.473, Florida Administrative Code (Fla. Admin. Code), provides additional guidance for the establishment of minimum flows and levels, requiring that "consideration shall be given to the protection of water resources, natural seasonal fluctuations in water flows, and environmental values associated with coastal, estuarine, aquatic and wetland 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." The Water Resource Implementation Rule also indicates that "minimum flows and levels should be expressed as multiple flows or levels defining a minimum hydrologic regime, to the extent practical and necessary to establish the limit beyond which further withdrawals would be significantly harmful to the water resources or the ecology of the area".

The District has developed specific methodologies for establishing minimum flows or levels for lakes, wetlands, rivers and aquifers, subjected the methodologies to independent, scientific peer-review, and incorporated the methods into Chapter 40D-8, Fla. Admin. Code. For lakes, methodologies 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 without at least 0.5 acre of fringing cypress wetlands are classified as Category 3 Lakes. Rule 40D-8.624, Fla. Admin. Code, provides for the establishment of Guidance Levels, 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 provided in SWFWMD (1999 a, b), Leeper *et al.* (2001) and Leeper (2006). Peer-review findings regarding the lake level methods are available in Dierberg and Wagner (2001) and Wagner and Dierberg (2006).

Two Minimum Levels and two Guidance Levels have typically been established for lakes, and upon adoption by the District Governing Board, incorporated into Rule 40D-8.624, Fla. Admin. Code. The levels, which are expressed as elevations in feet above the National Geodetic Vertical Datum of 1929 (ft NGVD), are described below.

- The **High Guidance Level** 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 elevation that a lake's water levels are expected to equal or exceed ten 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** 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 **Low Guidance Level** 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.

In accordance with Chapter 40D-8, Fla. Admin. Code, Minimum and Guidance Levels were developed for Lake Raleigh (Table 1), a Category 3 lake located in Hillsborough County, Florida. The levels were established using best available information, including field data that were obtained specifically for the purpose of minimum levels development. The data and analyses used for development of the levels are described in the remainder of this report. Following a public input process, District staff recommended and the Governing Board approved incorporation of the proposed levels into District Rule, Chapter 40D-8, subsection 40D-8.624, Fla.Admin.Code., at their June 25, 2013 meeting. Public input included a public workshop held on May 29, 2013 in Odessa, Florida. Upon approval by the District Governing Board, staff prepared an amendment to subsection 40D-8.624, F.A.C. that establishes Minimum and Guidance levels for Lake Rogers based on current methodologies, replacing the previously proposed management levels proposed in 2003 (see Table 2). The rule amendment was submitted to the Joint Administrative Procedures Committee and notice was provided to the Governor's Office of Fiscal Accountability and Regulatory Reform (OFARR). The rule amendment and adoption of Minimum and Guidance levels (Table 1) became effective on September 3, 2013.

All elevation data values shown within this report on graphs, bathymetric maps, and within tables are expressed as elevations in feet above the National Geodetic Vertical Datum of 1929 (ft NGVD 29). In some reported circumstances data that was collected as North American Vertical Datum of 1988 (ft NAVD 88) was converted to ft NGVD 29. All datum conversions were derived using Corpscon 6.0, a software developed by the United States Army Corps of Engineers. In this report all references to elevations will be abbreviated as ft NGVD.

Table 1. Minimum and Guidance Levels for Lake Raleigh

Minimum and Guidance Levels	Elevation ft NGVD
High Guidance Level	41.9
High Minimum Lake Level	41.1
Minimum Lake Level	37.9
Low Guidance Level	36.4

Data and Analyses Supporting Development of Minimum and Guidance Levels for Lake Raleigh

Lake Setting and Description

Lake Raleigh is located in the Northwest Hillsborough Basin in Hillsborough County, Florida in Sections 26 and 27, Township 27S, Range 17E (Figure 1). 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. As part of the Florida Department of Environmental Protection's Lake Bioassessment/Regionalization Initiative, the area has been identified as the Keystone Lakes region, and described as an area of numerous slightly acidic, low nutrient, and mostly clear-water lakes (Griffith *et al.* 1997). A portion of the Lake Raleigh basin lies within the Cosme-Odessa wellfield, which is one of the major water supply wellfields operated by Tampa Bay Water. The Hillsborough County Parks and Recreation Department maintains a segment of the lake basin as a county park (Lake Rogers Park) on the north and west side of the lake; however there is no direct public access to the lake. There are several private residences located on the south and east side of the lake.

Lake Raleigh is considered an isolated lake during normal rainfall periods. During wet periods surface inflow occurs from Horse Lake through a small drainage ditch under Gunn Highway. Outflow occurs to Lake Raleigh after the lake reaches a control elevation of 44.0 ft NGVD (Figure 2). Natural outflow has not occurred since Hurricane Donna in the1960s.

Data used for production of the topographic map were obtained from Light Detection and Ranging Data (LiDAR) and from bathymetric data collected with both sonar and manual measurements. The bathymetric data was collected by a Florida licensed survey contractor of the District using hydrographic techniques outlined by Army Corp of Engineers, publication EM 1110-2-1003. The topographic map of the basin indicates Lake Raleigh is comprised of two oval shaped basins. Overall the lake is shallow with an average depth of 12.2 feet at a maximum lake stage (modeled peak stage) of 44.5 ft NGVD (Figure 3), but has two moderately deep pools with a maximum depth of 25 feet.

There are currently no surface water withdrawals from the lake permitted by the District. There are, however, several groundwater withdrawals in the region including those associated with the Cosme-Odessa wellfield. During the El Nino periods in 1997/1998 and 2002/2003, the lake was augmented with water pumped from Pretty Lake through Horse Lake to Lake Raleigh (Wylupek 2001, SWFWMD 2003) to test the feasibility of augmentation with surface water during wet periods.

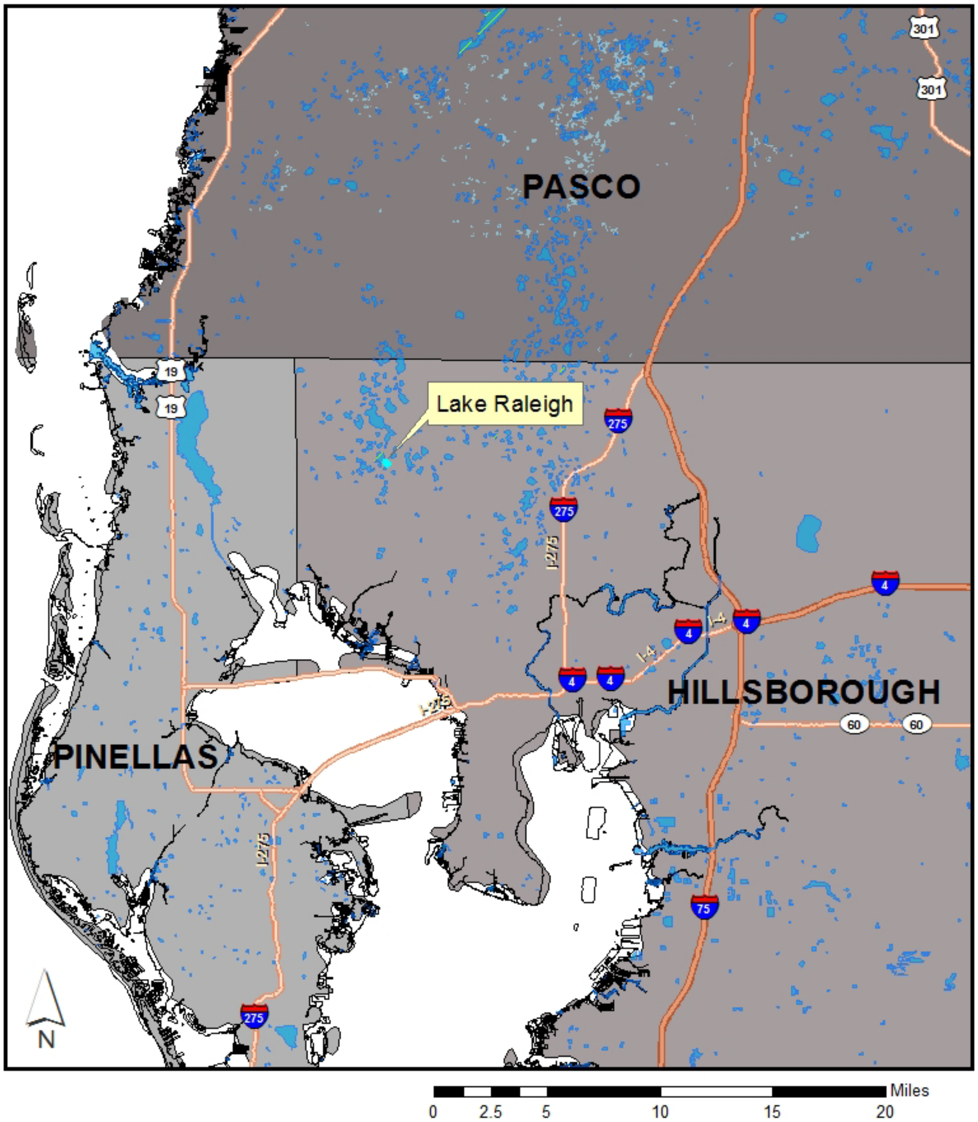


Figure 1. General location of Lake Raleigh in Hillsborough County, Florida.

Figure 2. Location of SWFWMD lake gage, inlets/outlets and sites where hydrologic indicators were measured for Lake Raleigh, Hillsborough County, Florida.

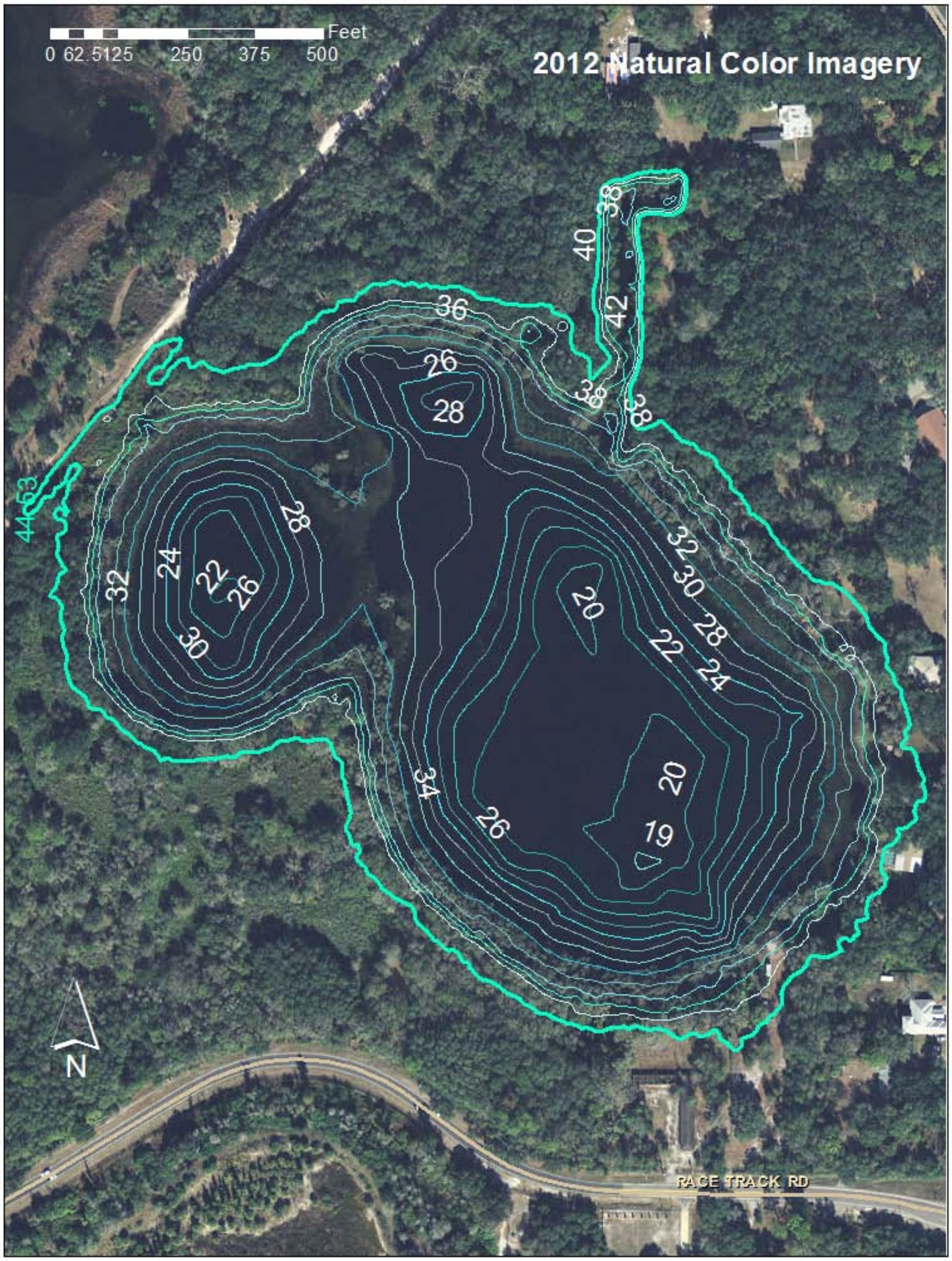


Figure 3. Two-foot elevation contours (as ft NGVD) within the Lake Raleigh basin. Contours were prepared using a combination of hydrographic survey (Peters 2012) and SWFWMD LiDAR land surface elevation data.

Control Point Elevation and Structural Alteration Status

Information about the control elevation and structural alteration status is used during the development of minimum levels. The control point elevation is the elevation of the highest stable point along the outlet profile of a surface water conveyance system (*e.g.,* weir, ditch, culvert, or pipe). Structural alteration status is determined by determining whether any man-made alterations exist that alter the lake's ability to reach its historical highs. In most cases structural alterations involve drainage features that were constructed to reduce potential flooding impacts to surrounding homes and development. The minimum level process must also consider the elevations of existing structures (including residential and commercial building) within the immediate lake basin and along connected surface water features, so that flooding concerns are factored into the minimum level process.

The control point was determined by reviewing surveyed elevation data, by reviewing LiDAR data, and through personal observations. The control point for Lake Raleigh is located between Lakes Raleigh and Rogers where natural overflow occurs during peak levels. The land between the two lakes was cleared in 1930s for the construction of the wellfield and service road. Water stages up to 44.0 ft NGVD before flow occurs across the service road. The outflow from Lake Raleigh appears to be overland flow with no defined conveyance channel. Outflow from the lake has not occurred since the Hurricane Donna period in 1960-1961, some 52 years ago. The maximum stage achieved in the past 52 years was approximately 43.7 ft NGVD during October 2012, and no flow was observed during this time period.

Based on the review of the elevation of the surveyed structural features and review of the digital elevation (DEM) of the lake watershed, Lake Raleigh was determined to be a closed basin lake with no significant surface water structural alterations. Although the lake is not considered to have undergone surface water alterations, subsequent sections in this report and that of the hydrologic modeling report (Hancock and McBride 2013) indicate that leakance properties of Lake Raleigh have likely changed. A change in leakance properties can be considered as a structural alteration.

Groundwater Withdrawals and Impact Assessment

An analysis of water use from 1992 to 2006 indicates there are significant withdrawals within the immediate vicinity of the Lake Raleigh (Figure 4) based on metered uses within the area. The cumulative average monthly water use between 1992 and 2006 within 1, 2, and 3 miles radius of the lake was 6.1 mgd, 8.3 mgd, and 10.4 mgd, respectively. The cumulative average monthly groundwater withdrawals extending out to 4, 5, and 6 mile radius is 16.8, 22.6, and 46.4 mgd, respectively. Modeled drawdowns predicted through the Integrated Northern Tampa Bay (INTB) model (Guerink and Basso, 2013) indicate that there is significant drawdown in both the water table and underlying Floridan aquifer near Lake Raleigh.

Lake Raleigh is located within the first established wellfield in the District, which started production in 1930. In the 1950s, the wellfield was expanded by installing additional production wells along Gunn Highway to the north of the original wellfield. The wellfield produced roughly 3 million gallons per day (mgd) in the early 1930's and steadily increased production to roughly 21 mgd by the early 1960s (Figure 5). Production of the wellfield decreased significantly starting around 1963 and then varied widely from 1963 to the mid-1970s between 4 mgd and 22 mgd. By the mid 1970s, the development of the Section 21 wellfield, also in Northwest Hillsborough County to the east of the Cosme-Odessa wellfield, allowed withdrawals at the Cosme-Odessa wellfield to be reduced to rates between 12 and 14 mgd. Current withdrawal rates at the wellfield have averaged approximately 6 mgd.

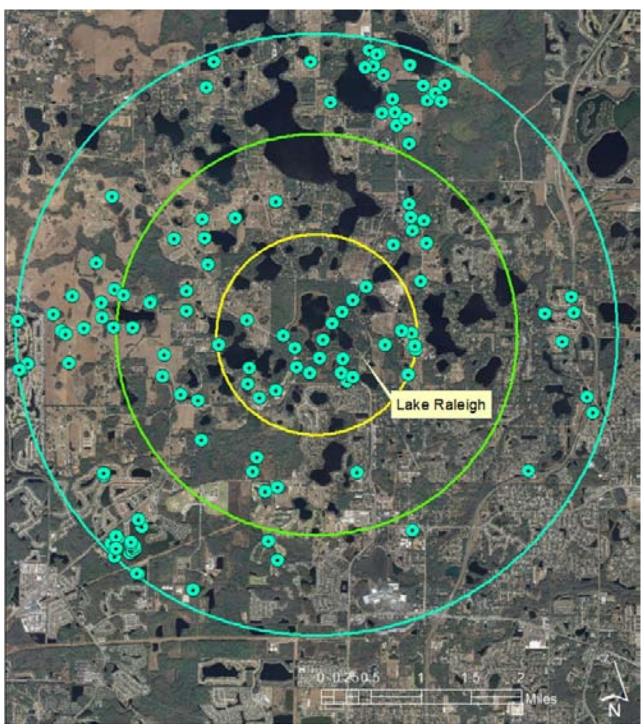


Figure 4. Permitted groundwater withdrawals within one, two, and three miles of Lake Raleigh, Hillsborough County.

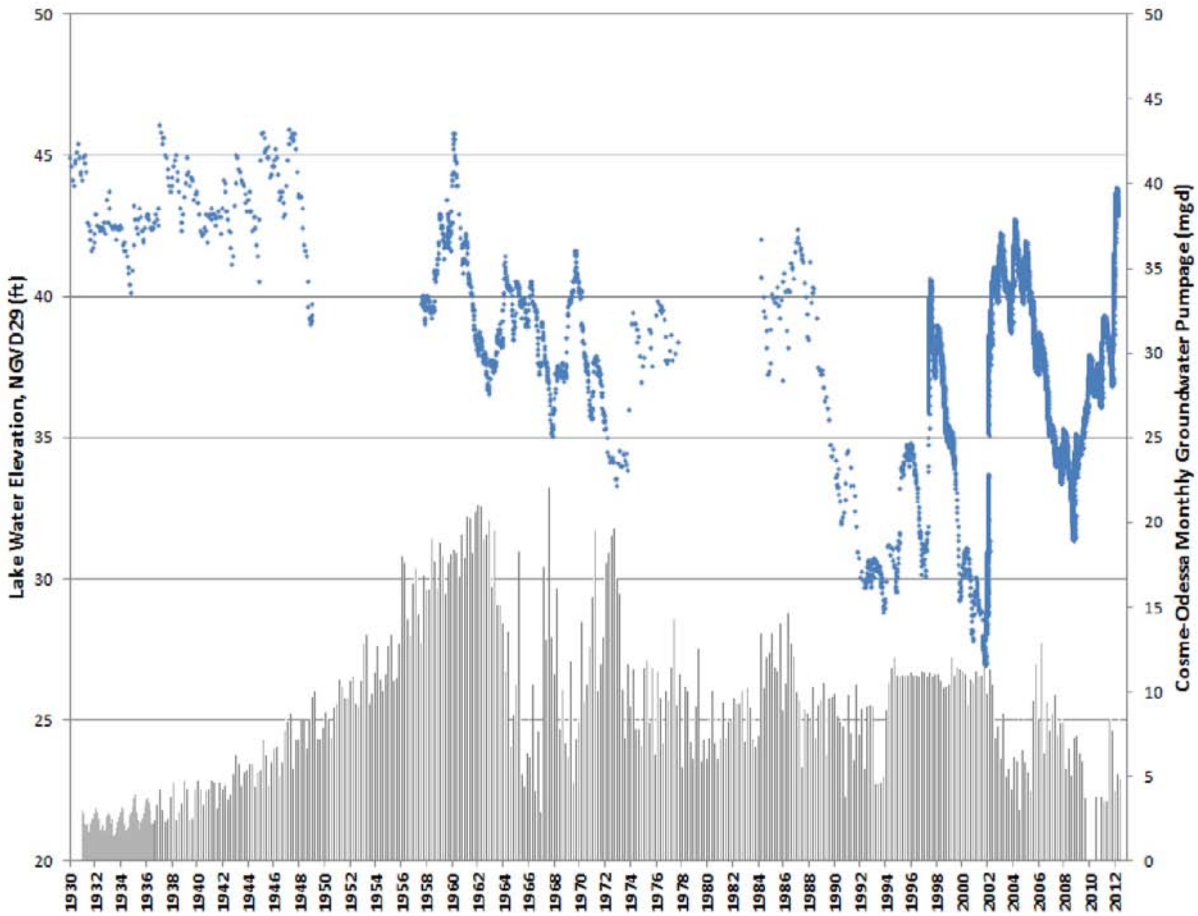


Figure 5. Daily surface water elevations (ft NGVD) through June 2012 for Lake Raleigh and monthly groundwater pumpage (mgd) withdrawal from the Cosme-Odessa wellfield from 1932 until 2012.

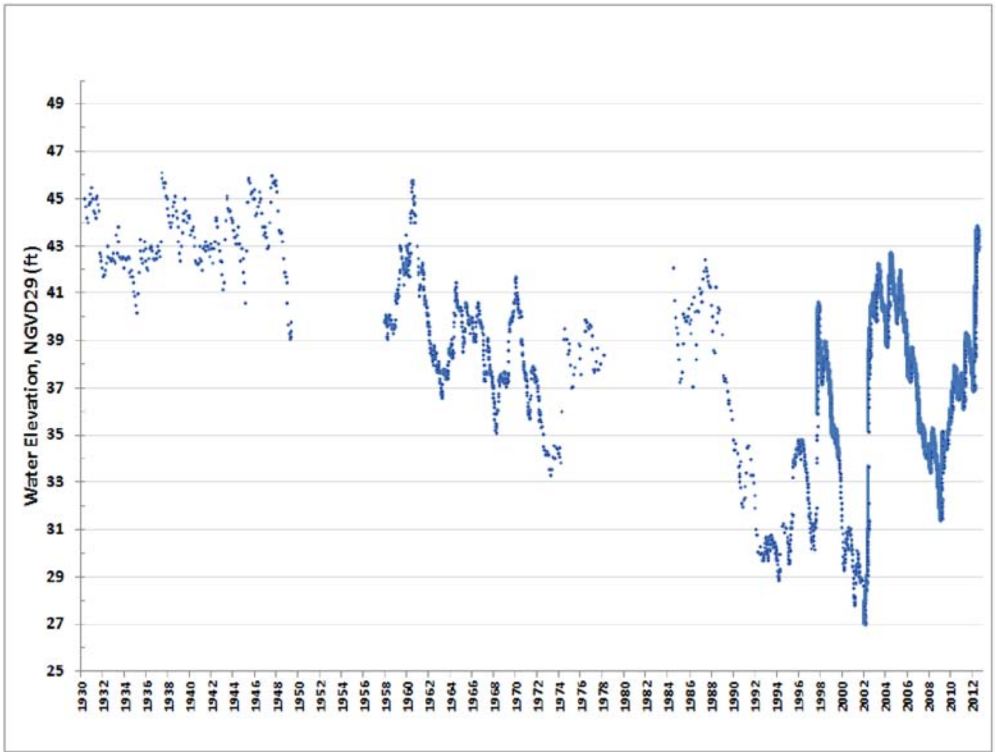
Lake Stage Data and Exceedance Percentiles

Lake stage data, *i.e.,* surface water elevations for Lake Raleigh relative to ft NGVD were obtained from the District's Water Management Information System (WMIS) database (see Figure 2 for the location of the SWFWMD lake water level gages, Site Identification Number 19861). There is an 80-year period of record (POR) for lake stage data on Lake Raleigh extending from May 1930 through present day. Although lake stage data is available starting in the 1930s, it's important to note that all lake stage data were collected after groundwater withdrawals from the Cosme-Odessa wellfield began. The lake stage data is depicted in the hydrograph shown in Figures 5 and 6.

The frequency of lake stage recordings varied through time from 1930 to 2002. Monthly measurements were completed from 1930 to 1956. Starting after 1956 data collection frequency varied from one to six times per month. The frequency of data collection increased to hourly in May of 2002 with the deployment of an automated stage recorder (Supervisory Control and Data Acquisition or SCADA system).

The highest surface water elevation recorded during the POR was 46.0 ft NGVD occurring on September 1, 1937. Similarly, a high stage at 45.8 ft NGVD was recorded in September 1960 after Hurricane Donna, with both Lakes Raleigh and Rogers reaching the same stage. The lowest surface water elevation of 26.98 ft NGVD observed on June 14, 2002 during a low rainfall period that affected many central Florida lakes. A long term decline is evident within the hydrograph over the 80 year period indicating both impacts from groundwater withdrawals and perhaps climate. The vertical fluctuation in lake stage is also greater within Lake Raleigh than most other lakes within the northwest Hillsborough County region. There is a 17 foot range between the highs and lows during the recent 50 year period which is indicative of withdrawal impacts.

The hydrograph illustrates two different stage regimes over the period of record with a shift downward occurring in the 1950s and 1960s. As a result of the regime shift, lake stage statistics calculated from the entire period of record are substantially higher than those calculated for periods after the shift. For example, the 50^{th} percentile or median of the lake stage from 1930-2012 (POR) was 39.6 ft NGVD versus 37.3 ft NGVD for 1966-2012 time period for a difference of 2.3 feet. The shift in the water regime is believed to be due to an increase in leakance properties within the lake basin as described in the summary of water budget model developed for Lake Raleigh (Hancock and McBride 2013). Based on a review of the lake hydrograph the change in leakance occurred sometime between the late 1950s to the mid 1960s. During this time period a significant increase and subsequent reduction in groundwater withdrawals from the Cosme-Odessa wellfield also took place as indicated within the plot of the withdrawals quantities (Figure 5). It is likely that the physical stress associated with increasing pumpage rates and additional surface storage at flood elevations (Hurricane Donna event) altered leakance properties between Lake Raleigh and the Upper Floridan aquifer, such as through sinkhole activity (Hancock and McBride, 2013). There are no known drainage alterations (no positive outfall) during this period that could be



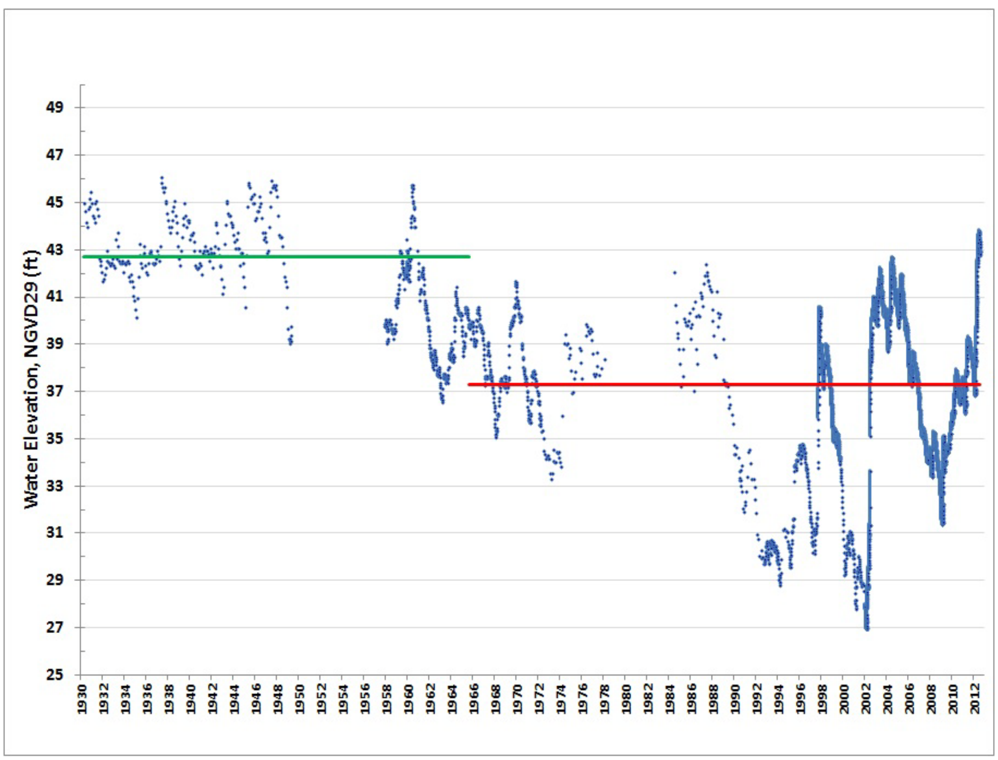


Figure 6. Top: Daily surface water elevations (ft NGVD) through June 2012 for Lake Raleigh; and Bottom: Daily surface water elevations with median lake stage for 1930 to 1965 (green line), and for 1966-2012 (red line). Data source was SWFWMD WMIS Site ID's 19861.

associated with the precipitous shift in lake stage. Due to the structural alteration associated with the change in leakance properties, Lake Raleigh can be considered a structurally altered lake, since these man-made alterations prevent the lake from reaching its historical highs and the lower stage regime has persisted through time to the present period.

Although the change in leakance properties likely occurred over a period of time, a specific year was selected to estimate a post-shift period for calculating stage statistics representative of post structural alterations. The post shift data statistics were also related to changes in the vegetation communities around the lake that have taken place over the past 46 to 55 years. Review of historical imagery and photographs taken at the lake and tree coring data were also evaluated for this time period.

The shift in the lake stage regime is apparent when comparing percentile statistics between approximate pre-shift (1930-1965) and post-shift periods (1966-2012). The median lake stage for the early period was 42.7 ft NGVD versus 37.3 ft NGVD for the later period (Table 2). Both medians are plotted in the bottom section of Figure 6 as horizontal lines. The P10 (90^{th} percentile) of the early data was 45.0 ft NGVD. This elevation is consistent with the Normal Pool elevation at 44.9 ft NGVD, measured by Leeper (2003). The P10 for the recent data was 40.6 ft NGVD. The P90 (10^{th} percentile) for each period was 39.3 ft NGVD and 30.6 ft NGVD respectively. The difference between the respective percentile elevations ranged between 4.4 and 8.7 feet (Table 2) with the greatest difference occurring at the P90 (bottom ten percent). For the time period of 1966 to 2012 a peak stage of 43.85 ft NGVD was recorded in October 11, 2012. The lowest surface water elevation of 26.98 ft NGVD was observed in June 14, 2002.

Table 2. Lake stage exceedance percentiles for the time period of 1930-1965 and 1966-2012 for Lake Raleigh, Hillsborough County.

Exceedance Percentiles	Observed Lake Stage (1930-1965)	Observed Lake Stage (1966-2012)	Difference
P10	45.0	40.6	4.4
P50	42.7	37.3	5.4
P90	39.3	30.6	8.7

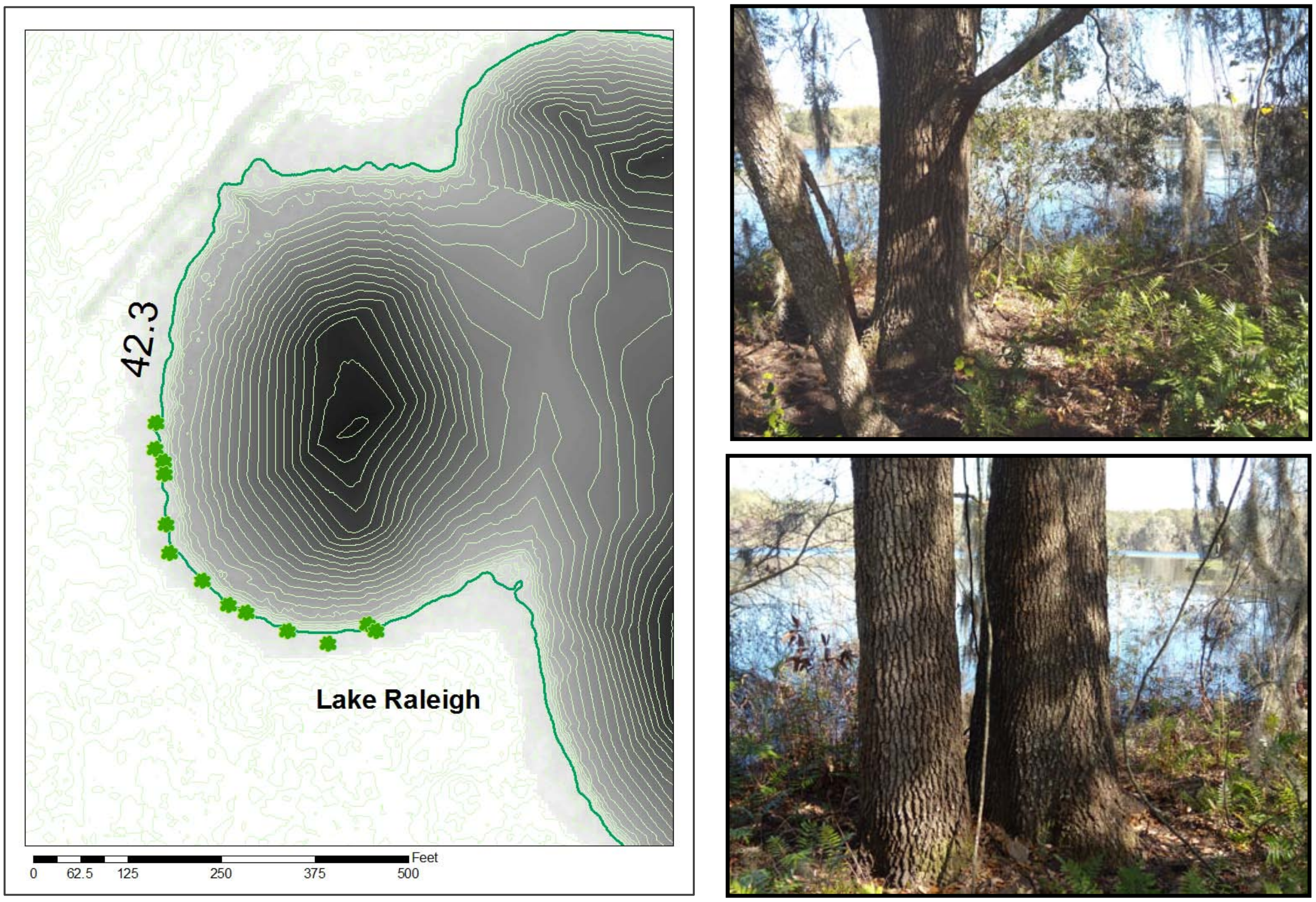


Figure 7. Left: location of lakeward line of mature oak trees and LiDAR derived elevation contour line at 42.3 ft NGVD, and Right: examples of large oaks plotted.

Lake Stage Decline and Vegetation Changes

The vegetation communities surrounding Lake Raleigh have been in transition over the past 46 to 55 years as a result of clear cutting activities in the 1950s and the onset of the lower lake stage regime in the 1950s to 1960s. Only six surviving cypress located on the east shoreline (with a median base elevation of 44.9 ft NGVD) serve as a record of the Normal Pool of the pre-shift period (Appendix A). With the exception of a few remaining cypress trees, the vegetation communities in place today no longer depict the historic lake stage regime that occurred prior to groundwater withdrawals in the region.

During the post shift time period, upland plant assemblages have encroached downward into the lake basin since the Normal Pool is no longer achieved. Normal Pool elevations are often correlated to the long term P10 elevation (upper ten percent of the stage data). The P10 determined for the post-shift data period is 4.4 ft lower than the P10 of the pre-shift period indicating that the stage duration and frequency of

Normal Pool elevation is no longer achieved (Table 2). Over time, the region below the Normal Pool elevation has transitioned into an assemblage of mature upland plants since the Normal Pool elevation has not been achieved. A thick canopy of trees comprising numerous laurel oaks, live oaks, and water oaks with estimated ages of 50 to 60 years are found down gradient of the Normal Pool elevation.

Vegetation surveys conducted in 2012 found biological indicators of a transitional normal pool associated with the lower lake stage representing the approximate post-shift P10 conditions or post-shift average high water mark. In the case of Lake Raleigh the transitional normal pool was established at the lower edge of mature oaks (50 to 60 years old). The lower edge of upland trees was found to occur at an approximate elevation of 42.3 ft NGVD for 13 trees measured in January 2013 along the northwest shoreline (Figure 7). A transitional Normal Pool was set at 42.3 ft NGVD based on the elevation of these large trees. The transition Normal Pool elevation is 2.6 feet lower than the Normal Pool established from six cypress trees measured in 2002 (Leeper 2003). The elevation of the transitional Normal Pool was included in the development of the levels to assess potential flooding impacts to the existing upland forest. The development of minimum levels for Lake Raleigh recognizes both the aesthetic value and habitat value of the upland assemblage. The transitional Normal Pool was developed to protect against prevent significant tree mortality and alteration of the park landscape by documenting the upland edge elevation.

Previously Proposed Guidance Levels and Minimum Levels

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

Based on work conducted in 2001-2003 (Leeper 2003), the District developed recommended lake management levels for Lake Raleigh (Table 3). The minimum levels were developed by applying standardized offsets developed from a lake stage regime evaluated for a group of reference lakes within the Northern Tampa Bay region (SWFWMD 1999). The median range between the P10 and P50, and P50 and P90 determined for the reference lake water regime (RLWR) was 1.0 ft and 2.1 ft, respectively. These ranges were subtracted from the Lake Raleigh Normal Pool to determine the Historic P50 and P90. The minimum low level was determined by applying the District's Category 3 lake change standards (Leeper 2006).

Both the minimum low level (42.78 ft NGVD) and high low level (43.78 ft NGVD) determined with this method were above the elevations of the upland forest. To mitigate for flooding concerns the levels were adjusted downward with the high minimum level proposed at 40.0 ft NGVD and a minimum level proposed at 39.0 ft

NGVD (determined by subtracting RLWR P10-P50 difference of 1.0 from the high minimum level 40.0 ft NGVD).

The methodology used to recommend minimum levels for Lake Raleigh in 2003 has been improved with current methods that include the development of a water budget model. The methodology applied in 2003 made the assumption that Lake Raleigh fluctuates similar to other regional lakes in the region and did not evaluate hydrologic functions specific to Lake Raleigh, such as a change in leakance properties. Minimum and Guidance Levels developed using current methods will replace the proposed 2003 minimum levels upon adoption by the District Governing Board into Chapter 40D-8, Fla. Admin. Code.

Table 3. Minimum Levels proposed in 2003 for Lake Raleigh, Hillsborough County, Florida (Leeper 2003).

Level	Elevation (feet above ft NGVD)
High Guidance Level	44.88
High Minimum Level	40.00
Minimum Lake Level	39.00
Low Guidance Level	42.78

Summary Data Used for Development of Minimum and Guidance Levels

Minimum and Guidance Levels for Lake Raleigh were developed using the methodology for Category 3 lakes described in Rule 40D-8.624, Fla. Admin. Code. For the purpose of Minimum Levels determination, lake stage data are classified 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. Lake stage data are classified as "Current" for periods when structural alterations and hydrologic stresses are stable. In the simplest of terms, the difference between Historic and Current data is that Historic data are from a period when influences of groundwater were absent or not measurable. Other factors including structural changes and long term climatic conditions are assumed to be the same as existing conditions.

Development of minimum levels for Lake Raleigh was uniquely challenging since all long term data (1930 to 2012) coincided with significant groundwater withdrawals. The downward shift in the long term stage data indicates unstable conditions and variations in hydrologic conditions that limit the use of the period of record for modeling hydrologic conditions.   A post-shift period (starting in approximately 1966) associated with change in leakance properties is presented in this report to represent the structurally altered stage regime associated with the change in leakance properties. The summary statistics for the post-shift regime were related to changes in the vegetation communities around the lake and used to describe hydrologic differences that have affected the surrounding vegetation and downward shift of upland plants.

Current Data

The Current data period selected for the development of the hydrologic model was from 2002 to present. This period was selected because it represents a period of stabilized stress associated with the onset of the wellfied pumping cutbacks (Figure 5). The pumpage reduction within the Cosme-Odessa wellfield was part of the Tampa Bay Water's regional cutbacks from 158 mgd to 90 mgd. Prior to 2002 the lake was subject to wider variations in stress due the severity of the 2001 drought and pre-cutback pumpage. Based on the lake stage hydrogaph (see Figure 5 and 6) the lake level began to recover and stabilize in late 2002 to 2003 as the lake began to recover from the record low levels experienced during the 2001 drought with conditions. Current data collected from January 2002 through December 2012 were used to calculate the Current P10, P50, and P90 (Table 4). The period used to develop the hydrologic model discussed below used a time period that included both pre-cutback and post-cutback conditions with wider ranging pumpage quantities.

Modeled Historic Data

The Historic time period is defined as a period of time when there is little to no groundwater withdrawal impact on the lake, and the lake's structural condition is similar as present day. The existence of data from a Historic time period is significant, since it provides the opportunity to establish strong predictive relationships between rainfall, groundwater withdrawals, and lake stage fluctuation that represent the lake's natural state in the absence of groundwater withdrawals. This relationship can then be used to calculate a long-term Historic P50 (or median), P10, and P90 for the lake. If data representative of a Historic time period does not exist, or available Historic time period data is considered too short to represent long-term conditions, then a model is developed to approximate long-term Historic time period data. In the case of Lake Raleigh, because the wellfield has affected water levels in the lakes since before the beginning of data collection, no Historic data exist for these lakes.   The development of a model for lakes without Historic data will allow an estimate of long-term Historic percentiles, and allow for simulations of the effects of changing groundwater withdrawal rates.

Since no Historic data of any length are available, a water budget approach was chosen to model Lake Raleigh (along with Horse Lake, which can drain to Lake Raleigh under high water level conditions). A separate technical memorandum was completed (Hancock and McBride 2013) to provide an overview of the water budget model. The spreadsheet-based water budget tool includes natural hydrologic processes and engineered alterations acting on the control volume of each 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 each lake that produced a unique lake stage for any total water volume within the control volume.

The hydrologic processes in the HRR model include:

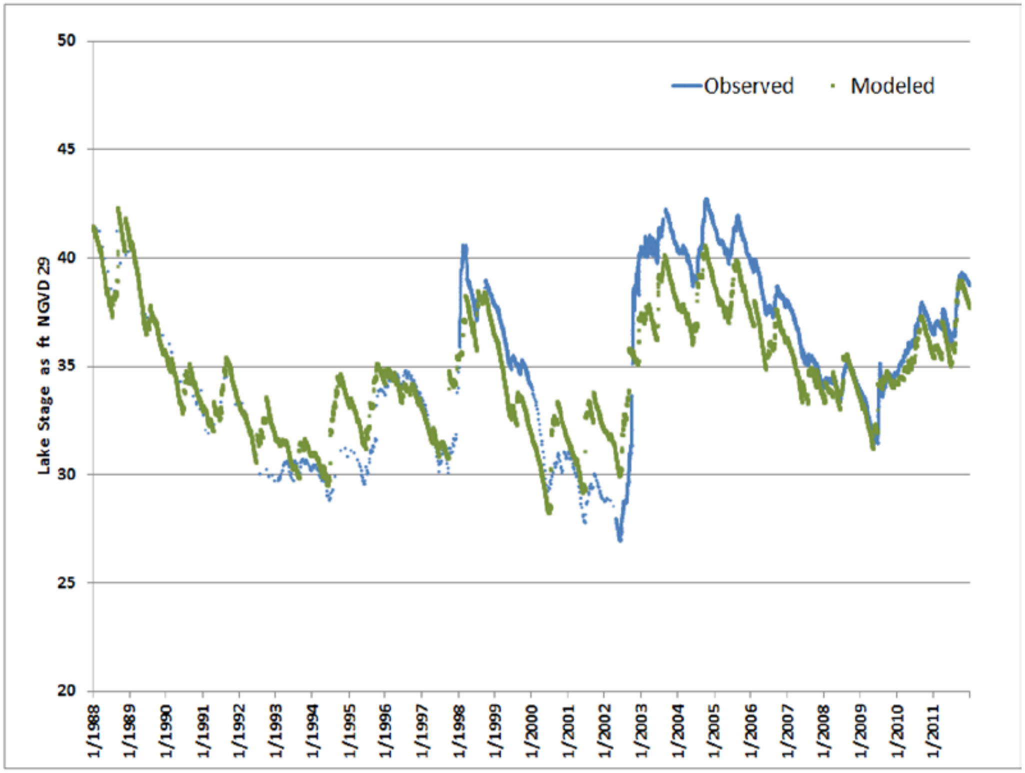
a. Rainfall and Evaporation
b. Overland flow
c. Inflow and Discharge via channels
d. Flow from and into the surficial aquifer
e. Flow from and into the Upper Floridan aquifer

The model uses a daily time-step, and tracks inputs, outputs, and lake volume to calculate a daily estimate of lake levels for each lake. The Lakes Horse/Raleigh/Rogers Water Budget Model (HRR) model was calibrated from 1988 to 2011, which provides a period of time that is considered long-term for purposes of determining Historic percentiles for Lake Raleigh. This period also provides the best balance of using available data for all parts of the water budget and the desire to have a long-term period. It's important to note that the calibration focused on matching the long-term percentiles of the lakes, rather than short-term highs and lows.

The model calibration results are shown in Figure 8 (see top), providing a comparison of the observed data from each lake to the modeled water levels. Since the model calibration period includes a time period that the lake was augmented, the augmentation period was excluded from the model calibration period (Hancock and McBride 2013). The excluded augmentation period is shown in the bottom half of Figure 8.

Following the completion of the model calibration, a Historic stage regime was modeled (Figure 9) by completing simulations of reduced groundwater withdrawal rates while also incorporating the change in leakance rates. The simulations used drawdowns determined through the Integrated Northern Tampa Bay (INTB) model (Geurink and Basso, 2013) and monitor well data from both the Upper Floridan aquifer and the surficial aquifer. The monitor well data in the model were adjusted to reflect changes in groundwater withdrawals. To estimate lake levels during Historic conditions (without the influence of groundwater withdrawals but allowing for structural alterations), the wells in the model were adjusted to represent zero withdrawals. For the 1988 to 2011 model period, two periods of adjustment were used to reflect the cutbacks that took place at the Cosme-Odessa wellfield.

The modeled Historic stage regime representing Historic conditions was used to calculate the Historic Percentiles. The Historic P10 elevation, the elevation the lake water surface equaled or exceeded ten percent of the time during the historic period, was 41.9 ft NGVD. The Historic P50 elevation, the elevation the lake water surface



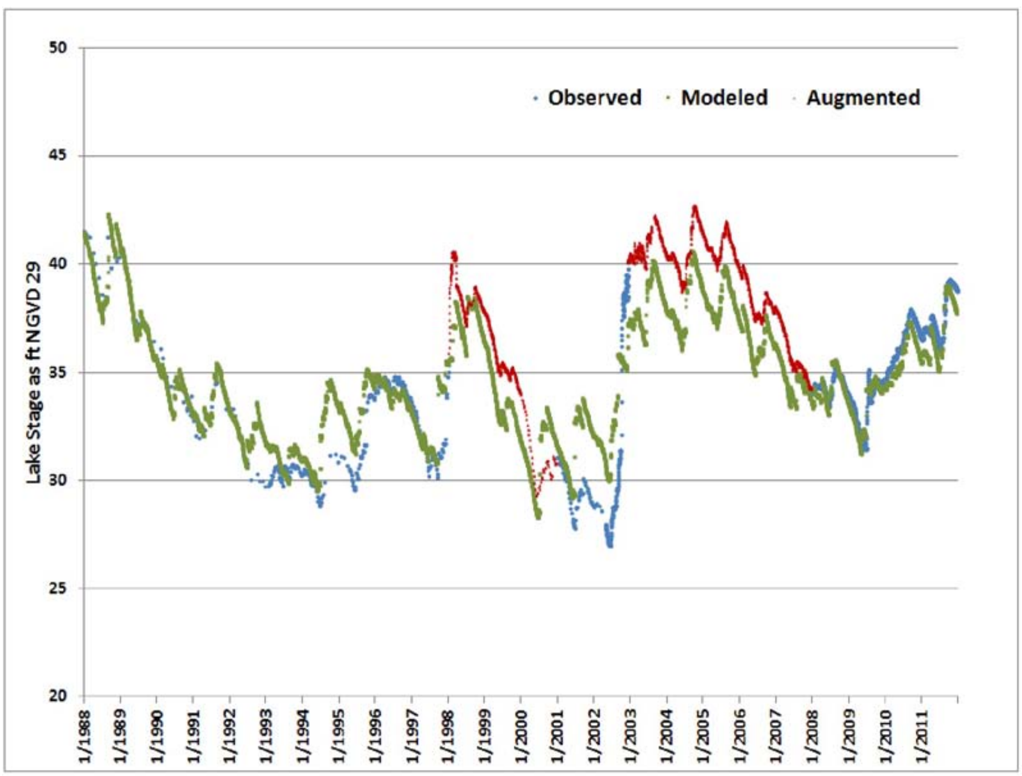


Figure 8: Top: Water budget model calibration results showing modeled (green) versus observed data (blue) and Bottom: data excluded (red) from model calibration during the augmentation period (Hancock and McBride 2013).

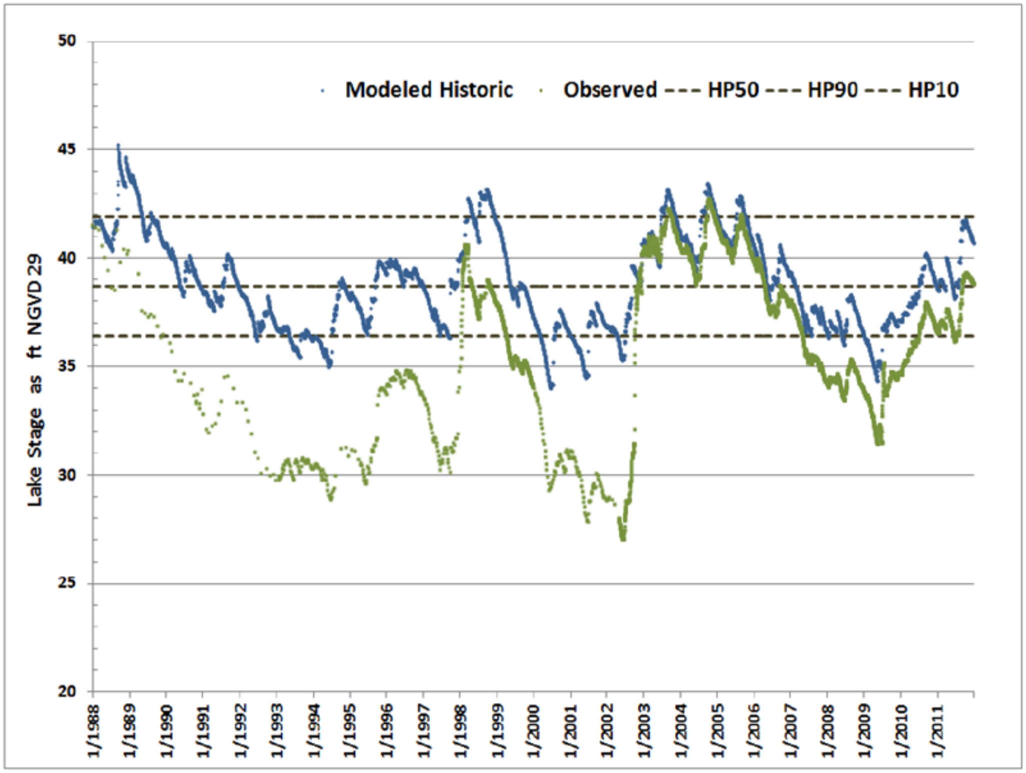


Figure 9. Top: Modeled Historic lake stage (as daily, see blue points) and observed lake stage shown with Historic percentiles (HP10, HP50, and HP90) as dashed lines.

equaled or exceeded fifty percent of the time during the historic period, was 38.7 ft NGVD. The Historic P90 elevation, the elevation the lake water surface equaled or exceeded 90 percent of the time during the historic period, was 36.4 ft NGVD. The Historic percentiles are plotted in Figure 9 and also listed within Table 4.

Guidance Levels

The High Guidance Level is provided as an advisory guideline for construction of lake-shore development, water dependent structures, and operation of water management structures. The High Guidance Level is the expected Historic P10 of the lake and is established using historic lake stage data if it is available, or is estimated using the Current P10, the control point, and the Normal Pool elevation. Based on the availability of the modeled Historic data record for Lake Raleigh, the High Guidance Level was established at 41.9 ft NGVD (Figure 10, Table 4).

Table 4. Minimum and Guidance Levels, lake stage exceedance percentiles, and control point elevations, significant change standards, and associated surface areas for Lake Raleigh.

Levels	Elevation in Feet ft NGVD	Lake Area (acres)
Lake Stage Percentiles		
POR 1930 to 2012 - P10	44.1	32.0
POR 1930 to 2012 - P50	39.6	26.0
POR 1930 to 2012 - P90	31.9	15.4
Post Shift 1966 to 2012 - P10	40.6	26.9
Post Shift 1966 to 2012 - P50	37.2	23.3
Post Shift 1966 to 2012 - P90	30.6	13.5
Current P10 (2002-2012)	41.6	27.9
Current P10 (2002-2012)	37.6	23.7
Current P10 (2002-2012)	33.6	18.1
Historic P10 (Modeled)	41.9	28.2
Historic P50 (Modeled)	38.7	25.1
Historic P90 (Modeled)	36.4	22.1
Normal Pool and Control Point		
Normal Pool	44.9	33.4
Transition Normal Pool (1966 to 2012)	42.3	28.6
Control Point	44.0	31.8
Significant Change Standards		
Wetland Offset Elevation	37.9	24.1
Basin Connectivity Standard	36.9	22.9
Aesthetics Standard	36.4	22.2
Species Richness Standard	35.8	21.4
Recreation/Ski Standard	n/a	n/a
Lake Mixing Standard	n/a	n/a
Minimum and Guidance Levels		
High Guidance Level	41.9	28.2
High Minimum Lake Level	41.1	27.4
Minimum Lake Level	37.9	24.1
Low Guidance Level	36.4	22.2

n/a – not applicable

The Low Guidance Level is provided as an advisory guideline for water dependent structures, information for lake shore residents, and operation of water management structures. The Low Guidance Level is the elevation that a lake's water levels are expected to equal or exceed ninety percent of the time (P90) on a long-term basis. The level is established using Historic or Current lake stage data, and in some cases, the Reference Lake Water Regime (RLWR) statistics. Based on the availability of the modeled Historic data set for Lake Raleigh, the Low Guidance Level for Lake Raleigh was established at 36.4 ft NGVD (Figure 10, Table 4).

Lake Classification

Lakes are classified as Category 1, 2, or 3 for the purpose of Minimum Levels development. Those with fringing cypress wetlands greater than 0.5 acres in size where water levels currently rise to an elevation expected to fully maintain the integrity of the wetlands (*i.e.*, the Historic P50 is equal to or higher than an elevation 1.8 feet below the Normal Pool elevation) are classified as Category 1 Lakes. Lakes with fringing cypress wetlands greater than 0.5 acres in size that have been structurally altered such that the Historic P50 elevation is more than 1.8 feet below the Normal Pool elevation are classified as Category 2 Lakes. Lakes without fringing cypress wetlands or with cypress wetlands less than 0.5 acres in size are classified as Category 3 Lakes. Lake Raleigh is not contiguous with any cypress-dominated wetlands of 0.5 or more acres in size and is therefore classified as a Category 3 Lake for the purpose of minimum levels development.

Significant Change Standards and Other Information for Consideration

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 Resources Implementation Rule (Rule 62-40.473, Fla. Admin. Code). Other information taken into consideration includes potential changes in the coverage of herbaceous wetland vegetation and aquatic plants.

Six significant change standards are developed for Category 3 Lakes, including a Dock-Use Standard, a Basin Connectivity Standard, a Recreation/Ski Standard, a Species Richness Standard, Aesthetics Standard, and a Lake Mixing Standard. A Wetland Offset Elevation is also developed and used along with the significant change standards to identify desired median lake stage elevations that if achieved, are intended to preserve various natural system and human-use lake values.

The Basin Connectivity Standard is developed to protect surface water connections between lake basins or among sub-basins within lake basins to allow for movement of aquatic biota, such as fish, and support recreational lake-use. The standard is based on the elevation of lake sediments at a critical high-spot between lake basins or lake, clearance values for movement of aquatic biota or powerboats and other watercraft, and use of Historic lake stage data or region-specific reference lake water regime statistics. A review of historical aerial imagery for years 1938 and 1968 indicates that Lake Raleigh remained as one continuous lake basin. The lake separates into two pools during extended low periods after 1966, such as observed in the 1994 aerial imagery. The Basin Connectivity Standard was established at 36.9 ft, based on one foot for movement of biota and clearance of non-gasoline powered boats in the lake, a critical high-spot elevation of 33.6 ft (Figure 11), plus the difference between the Historic P50 and P90 (2.3 feet). The Species Richness Standard was equaled or exceeded 79.4 percent of the time, based on the modeled Historic water level record. The standard elevation therefore corresponds to the Historic P79.4.

The Aesthetics Standard is developed to protect aesthetic values associated with the inundation of lake basins. The standard is intended to protect aesthetic values associated with the median lake stage from becoming degraded below the values associated with the lake when it is staged at the Low Guidance Level. The Aesthetic Standard was established at the Low Guidance Level, which for Lake Raleigh is 36.4 ft NGVD. Because the Low Guidance Level was established at the Historic P90 elevation, water levels equaled or exceeded the Aesthetics Standard ninety percent of the time during the Historic Modeled period.

The Species Richness Standard is developed to prevent a decline in the number of bird species that may be expected to occur at or utilize a lake. Based on an empirical relationship between lake surface area and the number of birds expected to occur at Florida lakes (Emery and Martin 2009), the standard is established at the lowest elevation associated with less than a 15 percent reduction in lake surface area relative to the lake area at the Historic P50 elevation (see Figure 12) for a plot of lake surface area versus lake stage. For Lake Raleigh, the Species Richness Standard was established at 35.8 ft NGVD. The Species Richness Standard was equaled or exceeded 94.6 percent of the time, based on the modeled Historic water level record. The standard elevation therefore corresponds to the Historic P94.6.

The Lake Mixing Standard is developed to prevent significant changes in patterns of wind-driven mixing of the lake water column and sediment resuspension. 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. A shift in the dynamic ratio indicates the elevation at which the lake depth and bottom slope becomes susceptible to resuspension of bottom sediments. Review of the dynamic ratio for lake stages bounded by the High and Low Guidance Levels did not indicate that potential changes in basin susceptibility to wind-induced sediment resuspension would be of concern for minimum levels development (Figure 12).

The Dock-Use Standard is developed to provide for sufficient water depth at the end of existing docks to permit mooring of boats and prevent adverse impacts to bottom-dwelling plants and animals caused by boat operation. The standard is based on the elevation of lake sediments at the end of existing docks, a clearance value for boat mooring, and use of Historic lake stage data or region-specific reference lake water regime statistics. The Recreation/Ski Standard is developed to identify the lowest elevation within the lake basin that will contain an area suitable for safe water skiing. The standard is based on the lowest elevation (the Ski Elevation) within the basin that can contain a five-foot deep ski corridor delineated as a circular area with a radius of 418 ft, or a rectangular ski area 200 ft in width and 2,000 ft in length, and use of Historic lake stage data or region-specific reference lake water regime statistics. No docks are located in the lake basin, so a Dock-Use Standard was not developed. Similarly, a Recreation/Ski Standard was not developed, based on area and depth restrictions imposed upon skiing activity within the basin.

Because the Lake Raleigh basin contains significant herbaceous wetlands, it was determined that an additional measure of wetland change should be considered for minimum levels development. Based on a review (Hancock 2006) of the development of minimum level methods for cypress-dominated wetlands, it was determined that up to an 0.8 foot decrease (or Wetland Offset) in the Historic P50 elevation would not likely be associated with significant changes in the herbaceous wetlands occurring within lake basins. A Wetland Offset elevation of 37.9 ft NGVD was therefore established for Lake Raleigh by subtracting 0.8 feet from the Historic P50 elevation. The standard was equaled or exceeded 62.7 percent of the time, based on the modeled Historic data, therefore corresponds to the Historic P62.7.

Information on herbaceous wetlands is taken into consideration when determining the elevation at which changes in lake stage would result in substantial changes in potential wetland area within the lake basin (*i.e.*, basin area with a water depth of four or less feet). Similarly, changes in lake stage associated with changes in lake area available for colonization by rooted submersed or floating-leaved macrophytes are also evaluated, based on water transparency values (*i.e.*, basin area with a water depth of 12.9 feet or less feet). Review of changes in area available for submersed aquatic plant colonization in relation to change in lake stage indicated that there only be a moderate increase in potential wetland area relative to the wetland area of the Historic P50 for the Connectivity standard. A substantial increase in emergent vegetation relative to the wetland area of the Historic P50 would occur at the elevation of both the Aesthetics Standard and the Species Richness Standard (Figure 13). Based on the stage area of the lake, the open water area (area with depth greater than 4 feet) would decrease 19 and 23 percent relative to the area at the Historic P50, at the elevation of the Aesthetics and Species Richness Standards, respectively (Figure 14). The reduction in open water relative to the area at the modeled peak stage (44.5 ft NGVD) of the lake at the Aesthetics and Connectivity standard is significant at 40.3 and 43.5 percent.

Review of changes in potential herbaceous wetland area or area available for submersed aquatic plant colonization in relation to change in lake stage indicated only a small increase in potential wetland area within the lake basin at the Wetland Offset elevation relative to the potential wetland area at the Historic P50 elevation. Based on the area of the lake with depth less than 4 feet, a 2 percent increase in emergent aquatic vegetation is estimated to take place at the wetland offset (37.9 ft NGVD) relative to the area of emergent vegetation at the a Historic P50 (38.9 ft NGVD). Additionally, the open water portion of the lake would decrease by approximately 5.6 percent relative to the open water at the Historic P50. The Wetland Offset would provide for basin connectivity (1ft over saddle, Figure 11) and the associated movement of aquatic fauna between the pools within the lake) for approximately 99 percent of the time based on the Historic regime and 97 percent of the time based on the Wetland Offset stage regime. The lake surface area at the Wetland Offset standard is about 82% of that associated with lake area at the transitional Normal Pool (42.3 ft NGVD) and 74% of the lake area at the modeled Historic peak stage elevation of 44.5 ft NGVD.

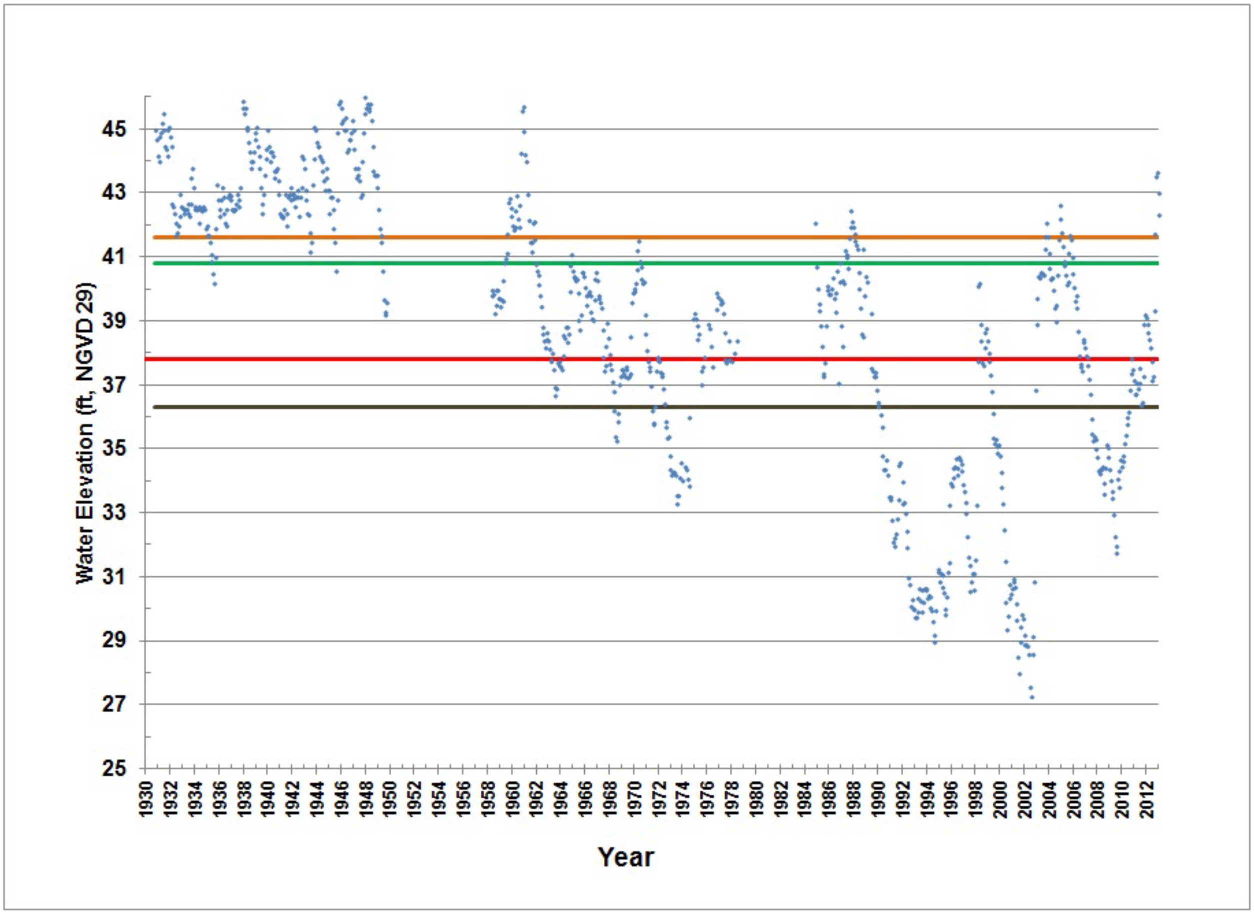


Figure 10. Mean monthly POR lake stage for Lake Raleigh; and Minimum and Guidance Levels for Lake Raleigh (as ft NGVD). Adopted Levels included the High Guidance Level (orange), High Minimum Lake Level (green), Minimum Lake Level (red), and the Low Guidance Level (black).

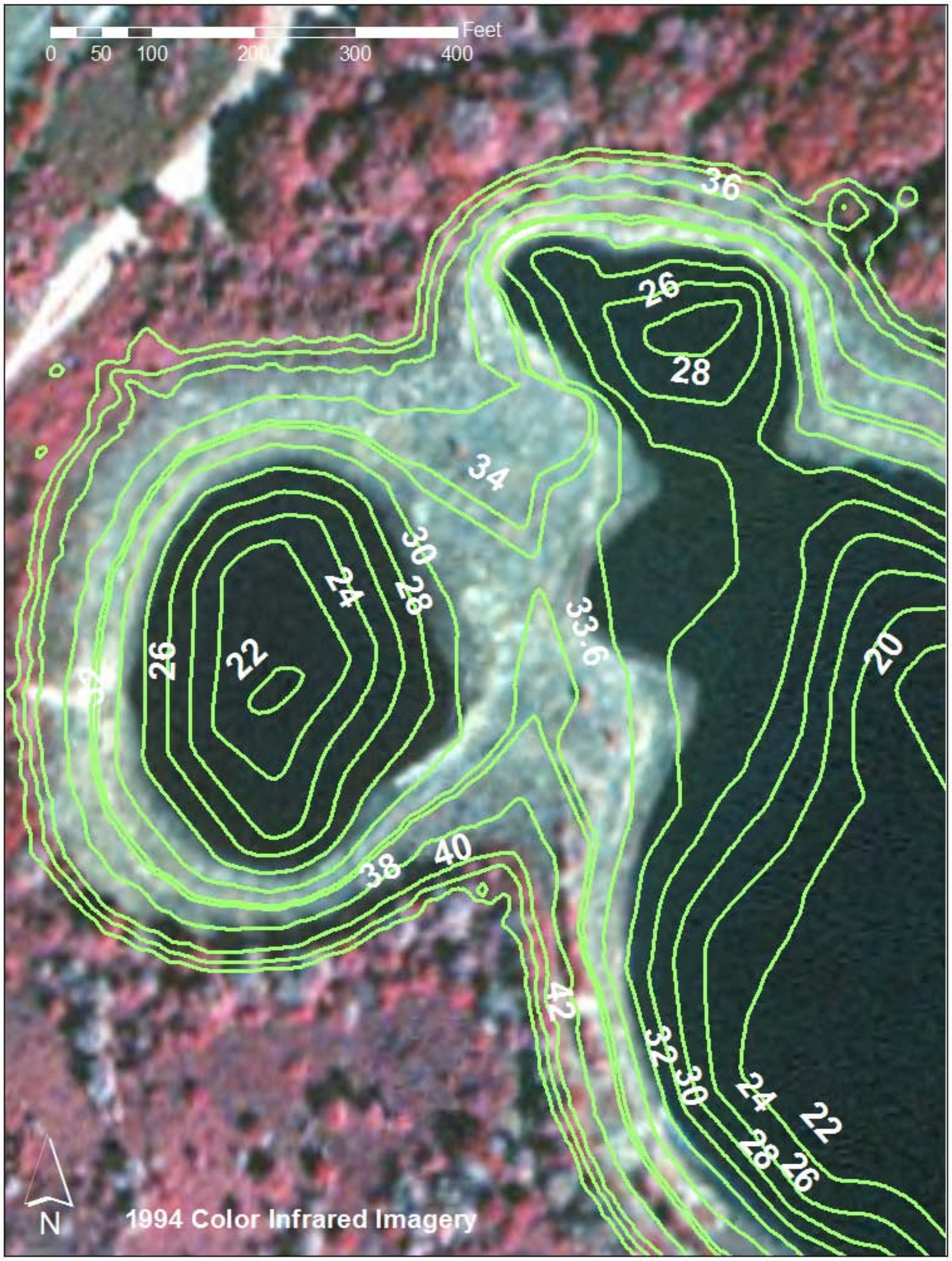


Figure 11. Elevated region in Lake Raleigh where separation of pools occurs, showing 33.6 ft NGVD as the saddle elevation used to develop connectivity standard for Lake Raleigh, Hillsborough County.

Minimum Levels

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

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 Category 3 Lakes, the Minimum Lake Level is typically established at the elevation corresponding to the most conservative appropriate significant change standard, *i.e*., the standard with the highest elevation, except where that elevation is above the Historic P50 elevation, in which case, the Minimum Lake Level is established at the Historic P50 elevation. The Minimum Lake Level was established at the Wetland Offset elevation, 37.9 ft NGVD, the most conservative standard below the Historic P50 (Figure 10). The Minimum Lake Level was equaled or exceeded 62.7 percent of the time, based on the Historic regime and corresponds to the Historic P62.7. This level is expected to afford protection to the natural system and human-use values associated with the identified significant change standards and also provide protection for wetlands occurring within the basin.

A review of the stage area and estimated area of emergent zone versus pelagic zones indicates that the targeted Minimium Lake Level provides acceptable changes to both habitat types (Figure 14). A 30% reduction (8 of 27 acres) in open water area is expected to occur from a modeled peak stage elevation of 44.5 ft NGVD to the elevation of the Minimum Level; whereas, a 10% decrease (0.5 of 5.9 acres) is expected to occur in emergent vegetation (Figure 14).

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 Category 3 lakes, the High Minimum Lake Level is developed using the Minimum Lake Level, Historic data or reference lake water regime statistics. If Historic Data are available, the High Minimum Lake Level is established at an elevation corresponding to the Minimum Lake Level plus the difference between the Historic P10 and Historic P50. If Historic data are not available, the High Minimum Lake Level is set at an elevation corresponding to the Minimum Lake Level plus the region-specific RLWR50. Based on the availability of modeled Historic data for Lake Raleigh, the High Minimum Lake Level was established at 41.1 ft NGVD (Figure 10), by adding the difference between the Historic P50 and Historic P10 (3.2 feet) to the Minimum Lake Level. The High Minimum

Lake Level at 41.1 ft NGVD was equaled or exceeded 18.5 percent of the time, modeled Historic water level record, and corresponds to the Historic P18.5.

The final step in the development of minimum levels is to evaluate the levels for potential flooding of both man-made and natural lake attributes. Adjusting the minimum levels and high minimum levels downward is sometimes required to protect the function and use of the existing attributes from potential flooding. The elevations of the residential dwellings on Lake Raleigh and the elevations of the mature upland plant assemblages were considered (Table 1 and 2, Appendix A).

Staging of the lake at minimum level established at the Wetland Offset (Figures 15 and 16) would not be expected to flood any of the residential dwelling, natural features, or upland forest within the immediate lake basin. A High Minimum Lake Level was established at 41.1 ft above ft NGVD, an elevation corresponding to the Minimum Lake Level plus the difference between the HP10 and HP50. The High Minimum Lake Level is approximately 5.9 ft below the low floor slab and 4.5 ft below the lowest residential structure. The High Minimum Lake Level is approximately 1.7 ft below the low spot in the park access road located between Lake Raleigh and Lake Raleigh (42.8 ft NGVD), so no flooding concerns are anticipated for this feature. The High Minimum Level is 1.2 ft below the scattered large live oak and laurel oaks (see Figure 7). Mortality of the large oak trees is not expected at the High Minimum Level.

Achievement of the minimum levels would result in inundation of the upland forest edge approximately 3 percent of the time, based on the modeled Wetland Offset lake stage regime. This frequency of inundation is not expected to cause tree mortality, but would be beneficial for providing natural control of further encroachment of shrubby upland plants including several invasive species found on the park property.

Compliance Evaluation

Minimum levels are intended to represent long-term conditions under a variety of expected hydrological conditions. The Minimum Lake Level represents the 50th percentile (median) of long-term water levels, while the High Minimum Lake Level represents the top percent of the lake stage data (90^{th} percentile) of long-term water levels. Therefore, to determine compliance, long-term data or model results should be used. Specific details of the process for determining compliance for Lake Raleigh are summarized in a separate technical memorandum completed by Hancock (2013).

The Lakes Horse/Raleigh/Rogers Water Budget Model (HRR) used to develop the Historic percentiles was also used for the compliance assessment. Upper Floridan and surficial aquifer levels in the HRR model were adjusted to represent the current withdrawal rates in the area, and the model was run for the 1988 to 2011 period. Based on the information presented in the technical memorandum, it is concluded that Lake Raleigh is not currently meeting the minimum levels (Hancock et al 2013) and recovery alternatives be needed to achieve the target MFL regime. Additional details regarding the recovery alternatives are provided by in compliance technical memorandum (Hancock et al 2013).

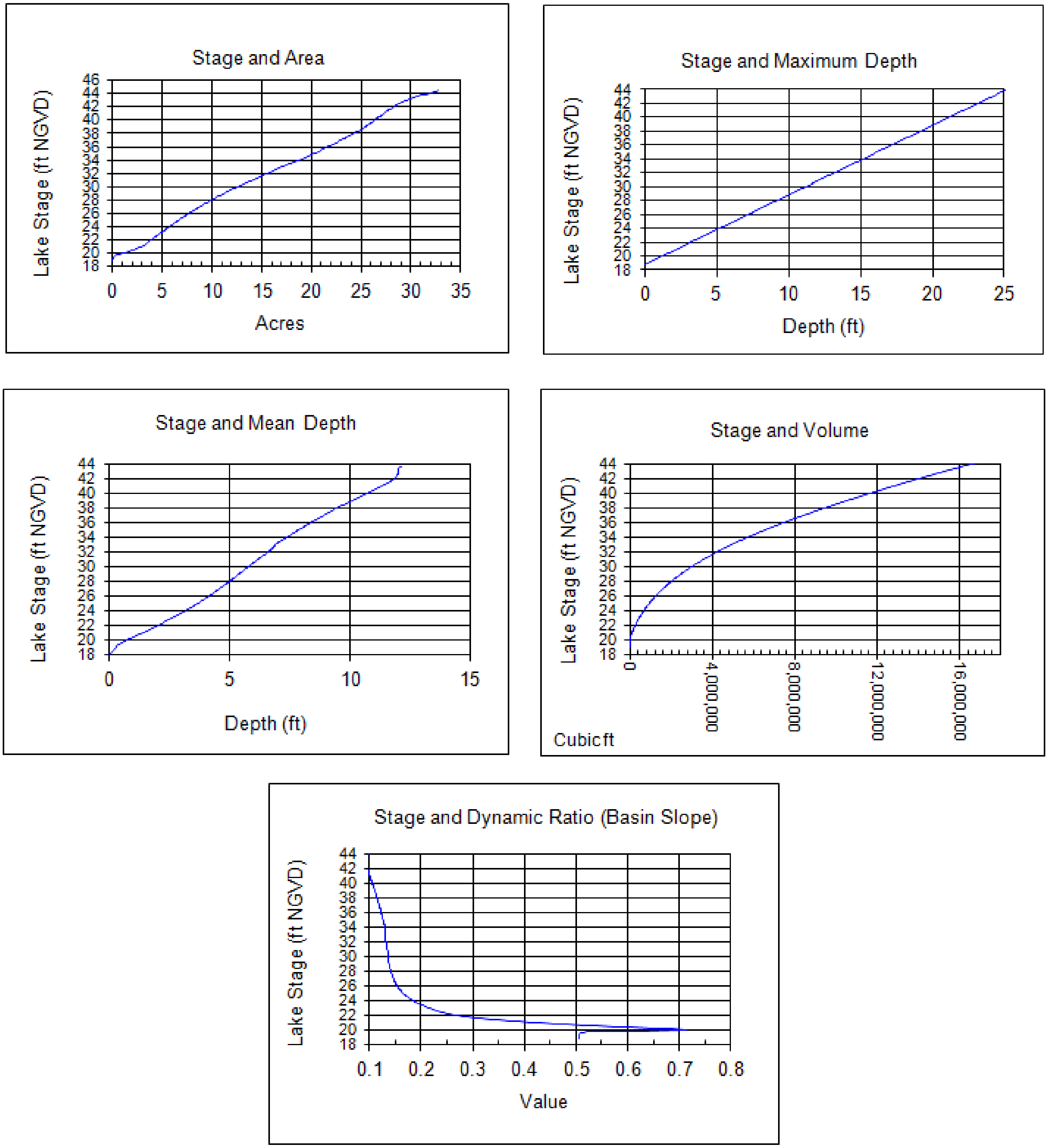
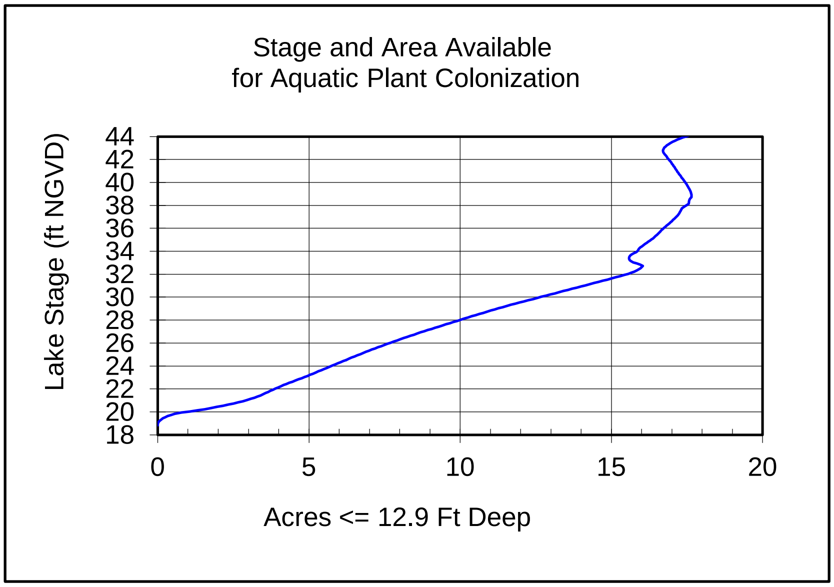


Figure 12. Surface area, maximum depth, mean depth, volume, dynamic ratio (basin slope) in feet above ft NGVD for Lake Raleigh.



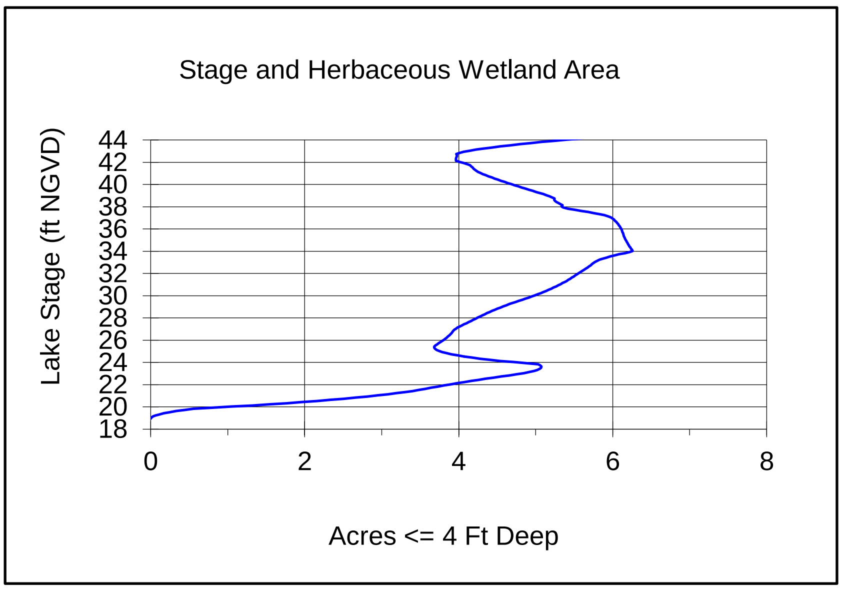


Figure 13. Potential area available for submersed macrophyte colonization (top) and estimated area of herbaceous wetland (emergent vegetation) area (bottom) in Lake Raleigh as a function of lake stage (water surface elevation).

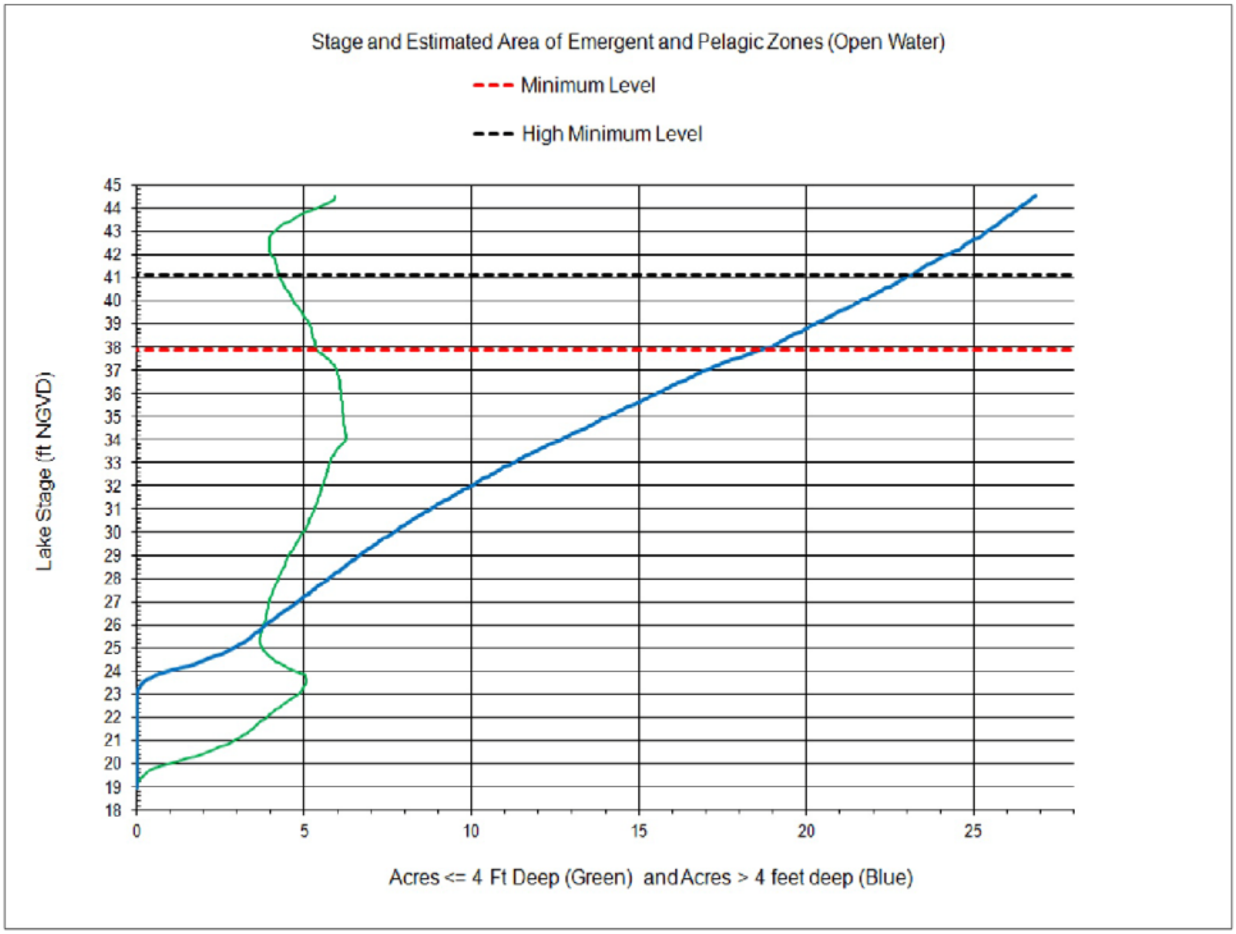


Figure 14. Estimated area of herbaceous wetland (emergent zone) and open water as a function of lake in Lake Raleigh with horizontal lines depicting the minimum level and high minimum level.

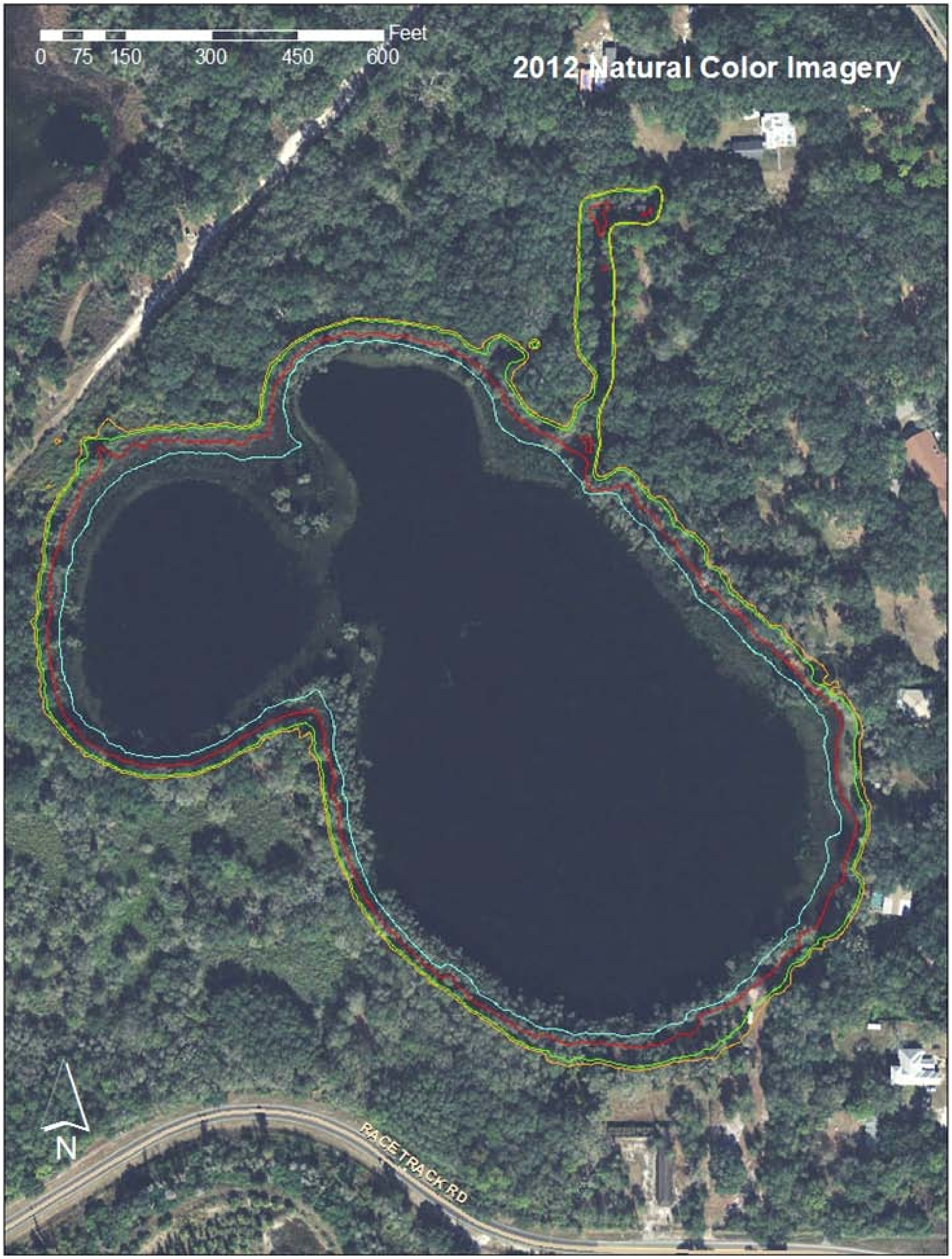


Figure 15. 2012 aerial view of Lake Raleigh with contour lines representing the High Guidance Level (41.9 ft NGVD), High Minimum Lake Level (41.1 ft NGVD), Minimum Lake Level (37.9 ft NGVD), and Low Guidance Level (36.4).

Figure 16**.** 1994 aerial view of Lake Raleigh with contour lines representing the High Guidance Level (41.9 ft NGVD), High Minimum Lake Level (41.1 ft NGVD), Minimum Lake Level (37.9 ft NGVD), and Low Guidance Level (36.4 ft NGVD).

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Appendix A

Summary of elevation data measured in the Lake Raleigh basin

Table 1. Elevation data of roads and structures

Description	**Elevation (feet as ft NGVD)**
Low road (low spot in dirt road used for park maintenace) *	42.8
Low Other (low floor slab in the Lake Raleigh basin) *	47.07
Low Other (pool deck in Lake Raleigh basin) *	45.58
Low spot between lakes Rogers and Raleigh	44.0

*** -** Source of elevation is SWFWMD 2002.

Table 2. Supplemental elevation data used for establishing the Category 3 Lake Normal Pool elevation for the Lake Raleigh. Data were collected in the Lake Raleigh basin on June 1, 1998; the lake water level was 38.10 ft above ft NGVD**.**

Hydrologic Indicator	**Elevation (feet above ft NGVD)**
Cypress (*Taxodium* sp.) normal pool	44.86
Cypress (*Taxodium* sp.) normal pool	45.00
Cypress (*Taxodium* sp.) normal pool	44.90
Cypress (*Taxodium* sp.) normal pool	44.77
Cypress (*Taxodium* sp.) normal pool	45.14
Cypress (*Taxodium* sp.) normal pool	44.84
N	6
Mean	44.92
Standard Deviation	0.13
Median	44.88