Revised Minimum and Guidance Levels for Horse Lake in Hillsborough County, Florida

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Resource Evaluation Section
Water Resources Bureau
Southwest Florida Water Management District

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David Carr
Michael Hancock

Resource Evaluation Section
Water Resources Bureau
Southwest Florida Water Management District
2379 Broad Street
Brooksville, Florida 34604-6899

Cover: Aerial picture of Horse Lake December 1997, (Southwest Florida Water Management District files).

Contents

Introduction

Reevaluation of Minimum Flows and Levels

This report describes the development of revised minimum levels for Horse Lake in Hillsborough County, Florida. These revised levels were developed based on the reevaluation of minimum and guidance levels approved by the Southwest Florida Water Management District (District) Governing Board in December 2004 and subsequently adopted into rule in May 2005. The revised minimum and guidance levels represent necessary revisions to the currently adopted levels.

Horse Lake was selected for reevaluation based on development of modeling tools used to simulate natural water level fluctuations in lake basins that were not available when the currently adopted minimum levels for the lake were developed. Adopted levels for Horse Lake 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.

Minimum Flows and Levels Program Overview

Legal Directives

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

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

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

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

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

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

Programmatic Description and Major Assumptions

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

A substantial portion of the District's organizational resources has been dedicated to its MFLs Program, which logistically addresses six major tasks: 1) development and reassessment of methods for establishing MFLs; 2) adoption of MFLs for priority water bodies (including the prioritization of water bodies and facilitation of public and independent scientific review of revised 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 revised 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 a three fundamental assumptions. First, it is assumed that many water resource values and associated features are dependent upon and affected by long-term hydrology and/or changes in long-term hydrology. Second, it is assumed that relationships between some of these variables can be quantified and used to develop significant harm thresholds or criteria that are useful for establishing MFLs. Third, the approach assumes that alternative hydrologic regimes may exist that differ from non-withdrawal impacted conditions but are sufficient to protect water resources and the ecology of these resources from significant harm.

Support for these assumptions is provided by a large body of published scientific work addressing relationships between hydrology, ecology and human-use values associated with water resources (e.g., see reviews and syntheses by Postel and 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 revised 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 Rule (Chapter 40D-8, F.A.C.). The rule also provides for the establishment of Guidance Levels for lakes, which serve as advisory information for the District, lakeshore residents and local governments, or to aid in the management or control of adjustable water level structures.

Information regarding the development of adopted methods for establishing minimum and guidance lake levels is included in 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 recommended minimum levels. For Category 1 or 2 Lakes, a significant change standard, referred to as the Cypress Standard, is developed. For Category 3 lakes, six significant change standards 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 revised minimum levels for Horse Lake 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 identified in the state Water Resource Implementation Rule for consideration when establishing minimum and guidance levels and associated significant change standards and other information used by the District for consideration of the environmental values.

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

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

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 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 fringing cypress wetlands or with cypress wetlands less than 0.5 acres in size are classified as Category 3 Lakes.

According to (Chapter 40D-8.624, F.A.C.), Horse Lake meets the classification as a Category 3 lake, as it is not contiguous with any cypress-dominated wetlands. The standards associated with Category 3 lakes described below will be developed in a subsequent section of this report.

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 (Chapter 62-40.473, F.A.C.).

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 of >0.8, or from a value >0.8 to a value of <0.8.

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 (RLWR) Statistics.

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 RLWR statistics where Historic lake data are not available.

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 **Aesthetics Standard** is developed to protect aesthetic values associated with the inundation of lake basins. The standard is intended to protect aesthetic values associated with the median lake stage from diminishing beyond the values associated with the lake when it is staged at the Low Guidance Level. The Aesthetic Standard is established at the Low Guidance Level. Water levels equal or exceed the standard ninety percent of the time during the Historic period, based on the Historic, composite water level record.

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 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, and use of Historic lake stage data or region-specific RLWR statistics where Historic lake data are not available.

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 Other information taken into consideration to determine the elevation at which changes in lake stage would result in substantial changes in potential wetland area to **herbaceous wetland vegetation** 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. Using methods described in Caffrey (2006), mean secchi disk depth is used to calculate the maximum depth of colonization for aquatic plants. From this, the total acreage at each lake stage that is available for aquatic plant colonization is calculated.

A **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 un-impacted 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).

Minimum 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 revised levels, the levels are adopted by the District Governing Board into Chapter 40D-8, F.A.C. Code (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), may include the following (refer to Rule 40D-8.624, F.A.C.).

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

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

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

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

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

Development of Minimum and Guidance Levels for Horse Lake

Lake Setting and Description

Watershed

Horse Lake is in Northwest Hillsborough County (Section 26, Township 27 South, Range 17 East) and within the Brooker Creek Watershed (Figure 1 & Figure 2). Surface water inflow to Horse Lake from the lake's small (approximately 77 acres) drainage basin occurs as overland flow, and minor inflow systems such as small drainage swales. A culvert under Gunn Highway on the western shore of the lake serves as the single discharge (Figure 3). Water can then travel to Lake Raleigh via an excavated, unmaintained outlet ditch.

Site Specific Details

Horse Lake is located just north of the Cosme-Odessa Wellfield, a Tampa Bay Water public water supply production facility that has been in service since 1930, the oldest public supply wellfield in the District. Therefore, Horse Lake and other adjacent lakes have been subjected to the effects of groundwater withdrawals longer than nearly any other lakes in the District. Monthly withdrawals steadily climbed to as much as 21 million gallons per day (mgd) in 1962, but current withdrawal rates at the wellfield have typically averaged approximately 6 mgd on annual average.

Land Use Land Cover

An examination of the 1950 and 2011 Florida Land Use, Cover and Forms Classification System (FLUCCS) maps revealed that there has been considerable changes to the landscape in the vicinity during this period; specifically the dominant land forms. Land use in 1950 was primarily agriculture and upland forests (Figure 4). By 2011, much of the agriculture had been replaced by upland forest and urban land uses (Figure 5). Aerial photography chronicles landscape changes to the immediate lake basin from 1938 to 1968 (Figures 6 through 8).

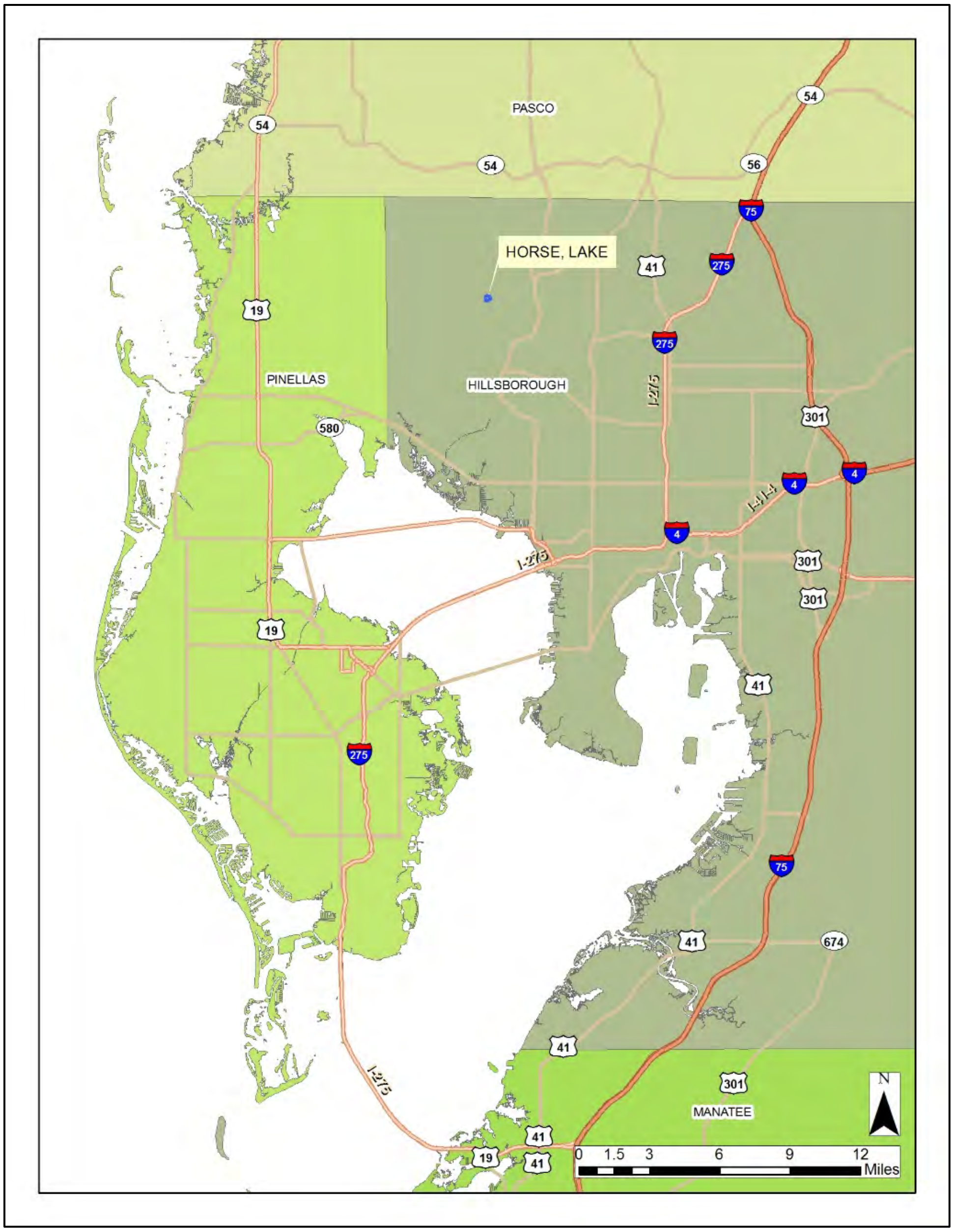

Figure 1. Location of Horse Lake in Hillsborough County, Florida.

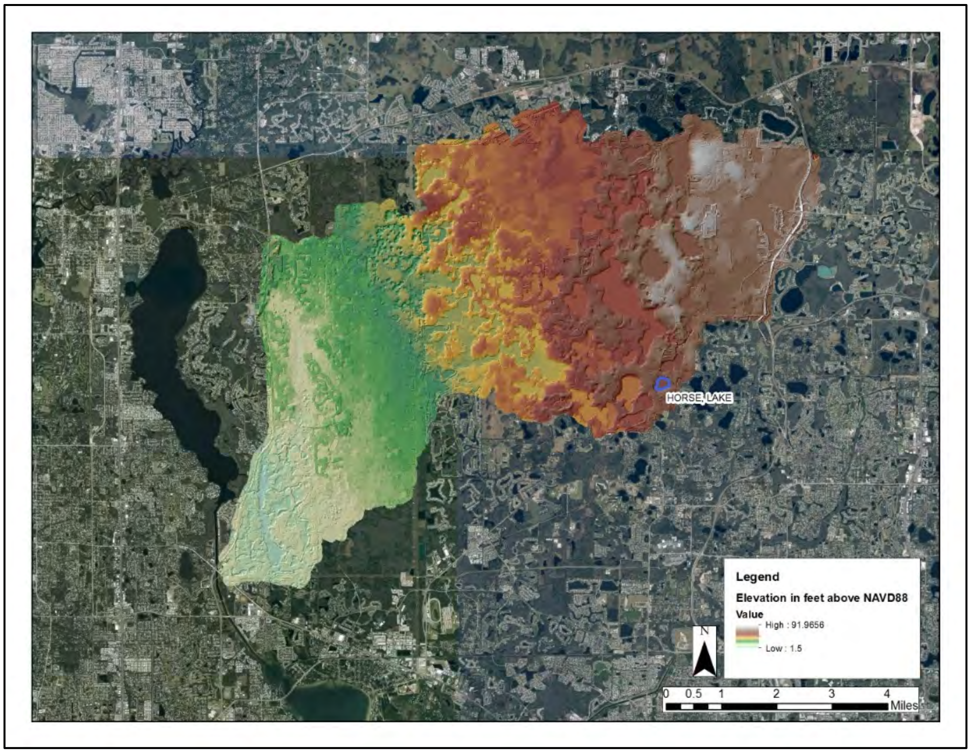

Figure 2. Brooker Creek Watershed Delineation and Topography.

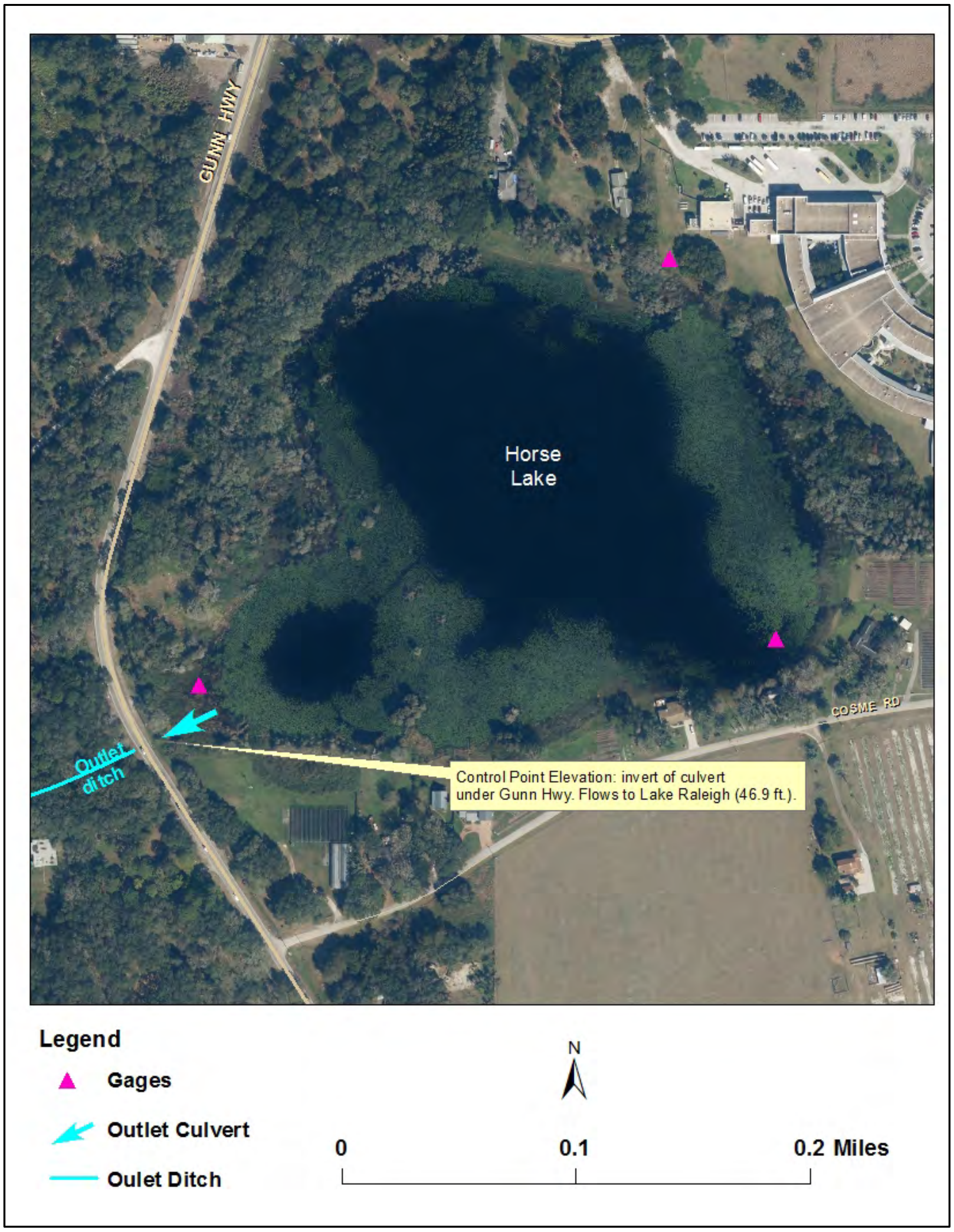

Figure 3. Lake Outlet Conveyance System and Water Level Gage Locations.

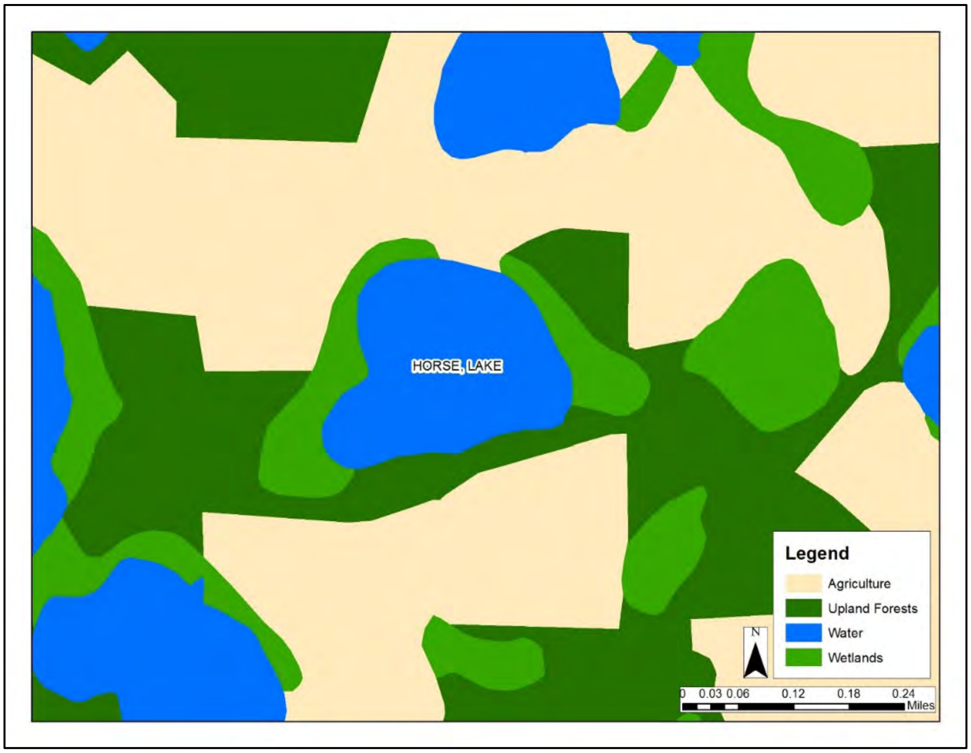

Figure 4. 1950 Land Use Land Cover Map of the Horse Lake Vicinity.

Figure 5. 2011 Land Use Land Cover Map of the Horse Lake Vicinity.

Figure 6. 1938 Aerial Photograph of Horse Lake.

Figure 7. 1957 Aerial Photograph of Horse Lake.

Figure 8. 1968 Aerial Photograph of Horse Lake.

Bathymetry Description and History

One foot interval bathymetric data gathered from recent field surveys resulted in lake-bottom contour lines from 24 ft. to 48 ft. (Figure 9). These data revealed that the lowest lake bottom contour (24 ft.) is located in a small area just southeast of the lake center. For visual purposes, a 48 ft. elevation contour line represents a high line that the lake rarely gets above based on the measured stage water level data. Additional morphometric or bathymetric information for the lake basin is discussed in the Methods, Results and Discussion section of this report.

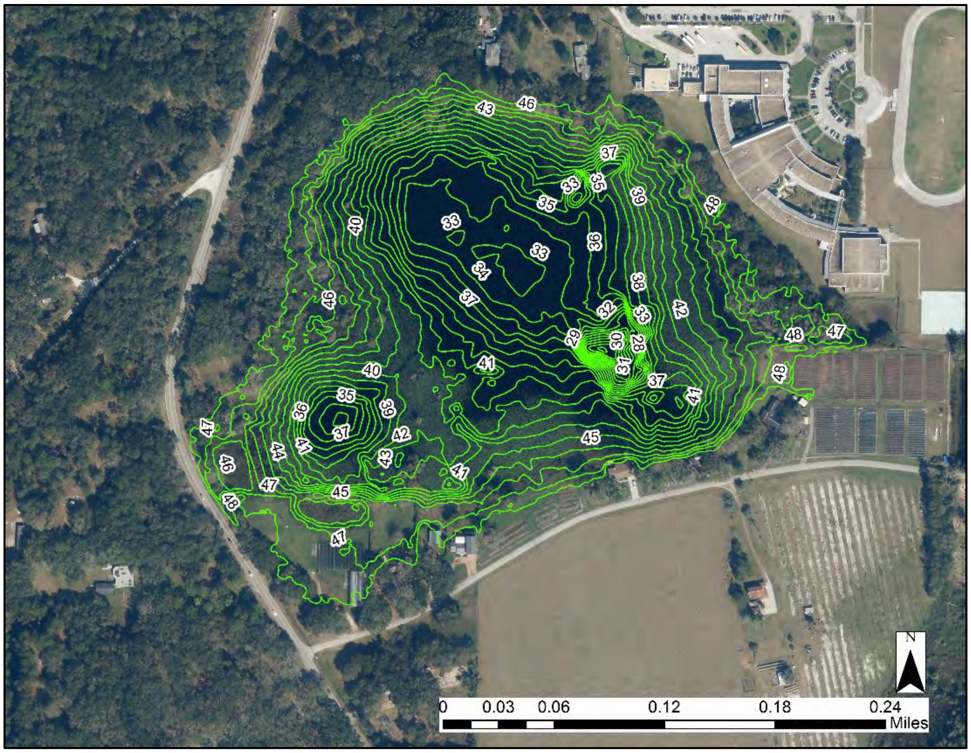

Figure 9. Horse Lake Contours on a 2014 Natural Aerial Photograph.

Water Level (Lake Stage) Record

Lake stage data, i.e., surface water elevations, were collected from three gages over its period of record. These water level data are available for Horse Lake from the District's Water Management Information System (SIDs 19866, 827842 and 815809) (Figures 10 and 11). The District continues to monitor the water levels on an hourly, real-time frequency. Horse Lake has one of the longest periods of record for water levels of any lakes in the District. Water level data collection began in mid-1930, although the frequency of data collection has been inconsistent over the years. The highest lake stage elevation on record (50.0 ft.) occurred August 1, 1959 during a period of record high water in the area leading up to Hurricane Donna. Water levels were nearly that high prior to that on September 1, 1933 and August 28, 1937. An aerial photograph that most closely exhibits these high water levels is one taken in 2015 (Figure 12). Though more than a foot lower than in 1959, similar seasonally high waters commonly occurred during the 1930s-1940s. The lowest lake stage elevation on record (36.33 ft.) occurred on June 14, 2002 during a drought that impacted Florida statewide. The aerial photograph available that exhibited low water levels was taken in the 1970s (Figure 13).

Figure 10. Horse Lake Gage SID 815809 on January 2014.

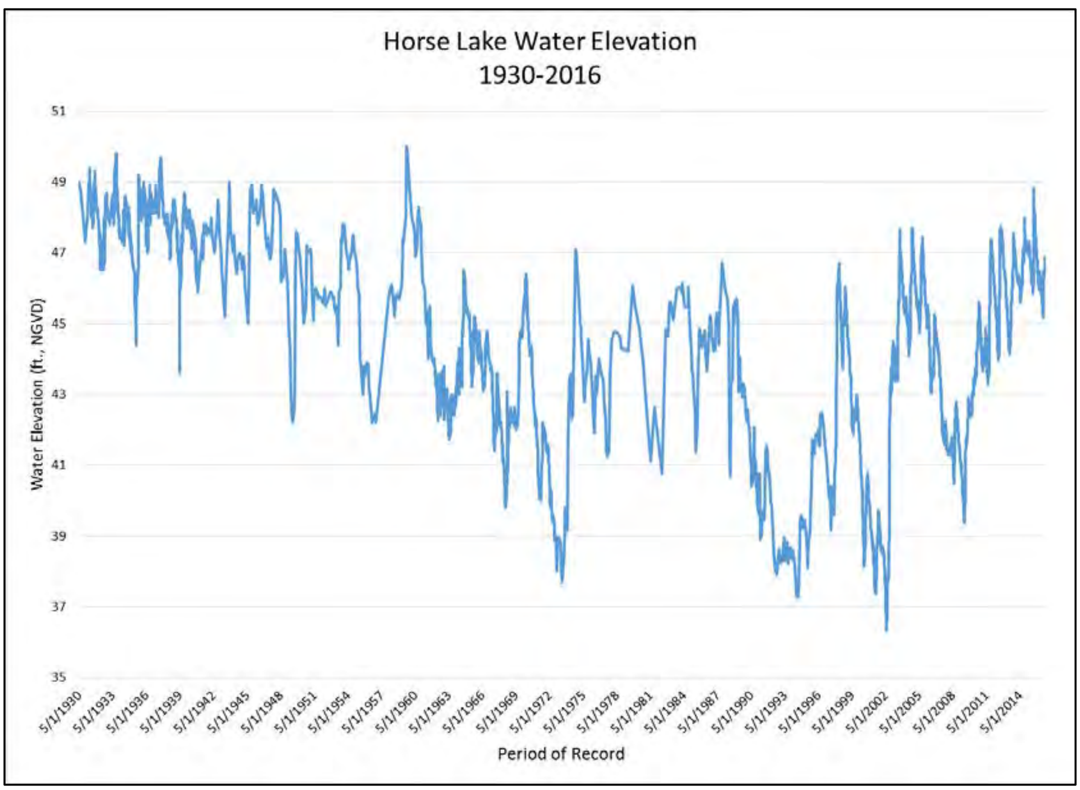

Figure 11. Horse Lake Period of Record Stage Data
(SIDs 19866, 827842 and 815809).

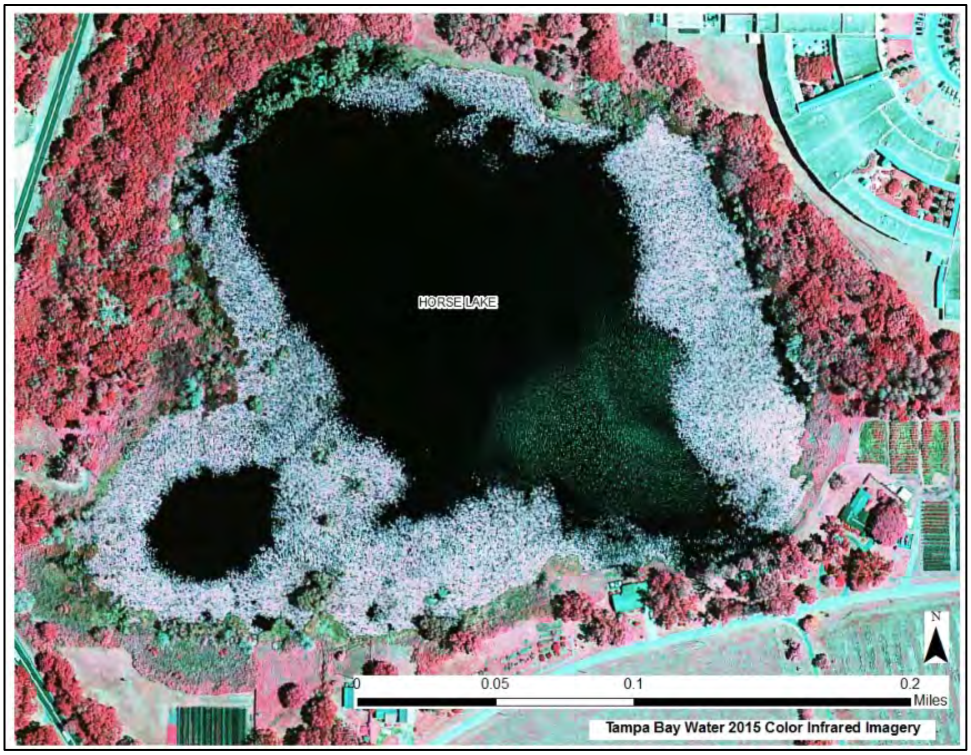

Figure 12. Wet Period (2015) Aerial Photograph of Horse Lake.

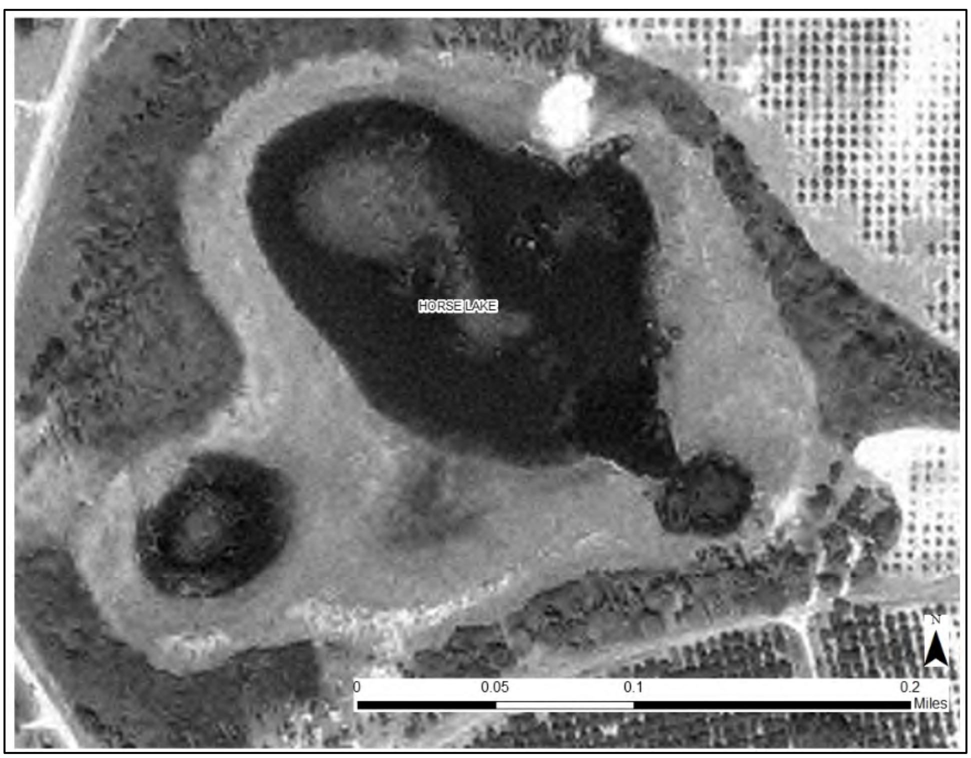

Figure 13. Dry period (1970s) Aerial Photograph of Horse Lake.

Historical and Current 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 previously approved Guidance and Minimum levels for Horse Lake (Table 2) which were subsequently adopted into Chapter 40D-8, Florida Administrative Code in May 2005 using the methodology for Category 3 Lakes described in SWFWMD (1999a and 1999b).

Table 2. Previously adopted Guidance and Minimum Levels for Horse Lake

Level	Elevation (ft., NGVD)
Ten Year Flood Guidance Level	48.9
High Guidance Level	46.9
High Minimum Level	45.8
Minimum Level	44.8
Low Guidance Level	44.8

Methods, Results and Discussion

The Minimum and Guidance Levels revised in this report were developed for Horse Lake using the methodology for Category 3 lakes described in Chapter 40D-8, F.A.C. Revised levels along with lake surface area for each level are listed in Table 3 along with other information used for development of the revised levels. 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 revised Minimum and Guidance Levels associated surface areas for Horse Lake.

Levels	Elevation in Feet NGVD 29	Lake Area (acres)
Lake Stage Percentiles		
Historic P10 (1946 to 2013)	47.4	35
Historic P50 (1946 to 2013)	44.7	26
Historic P90 (1946 to 2013)	42.5	21
Normal Pool and Control Point		
Normal Pool	50.4	NA
Control Point	46.9	33
Significant Change Standards		
Lake Mixing Standard	NA	NA
Dock-Use Standard	NA	NA
Basin Connectivity Standard	45.0	27
Species Richness Standard	43.0	22
Aesthetics Standard	42.5	21
Recreation/Ski Standard	42.2	20
Cypress Standard	48.6	44
Wetland Offset Elevation	43.9	24
Other		
Lowest Floor Slab Elevation	50.0	ND
Ground at Lowest Well	47.2	34
Minimum and Guidance Levels		
High Guidance Level	47.4	35
High Minimum Lake Level	44.9	26
Minimum Lake Level	43.9	24
Low Guidance Level	42.5	21

NA - not appropriate; ND – No Data available.

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 Horse Lake 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 Horse Lake. Light Detection and Ranging Data (LiDAR) was processed with LP360 for ArcGIS and merged with bathymetric data collected with both sonar and mechanical (manual) methods. 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 14).

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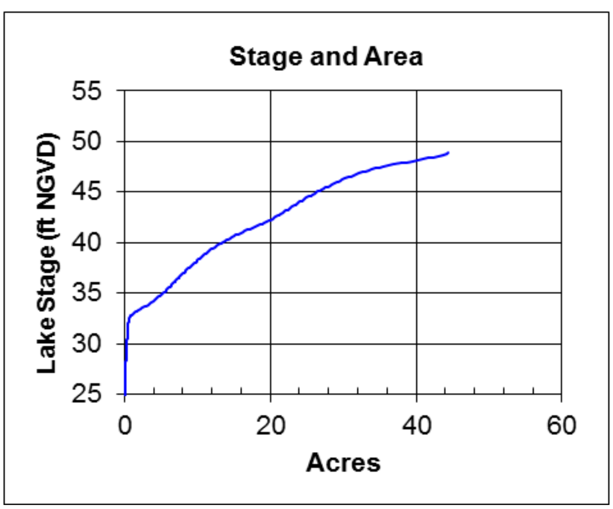

Figure 14. Lake Stage (ft.) to Surface Area (Acres).

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 (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). An evaluation of groundwater withdrawal impacts to Horse Lake is available in Appendix C.

The initial approach included creating developing a water budget model which incorporated the effects of precipitation, evaporation, overland flow, and groundwater interactions (Appendix A). Using the results of 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 Horse Lake and composite regional rainfall.

A combination of model data produced a hybrid model which resulted in a 68 year (1946-2013) 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 47.4 ft. The Historic P50, the elevation the lake water surface equaled or exceeded fifty percent of the time during the historic period, was 44.7 ft. The Historic P90, the lake water surface elevation equaled or exceeded ninety percent of the time during the historic period, was 42.5 ft. (Figure 15 and Table 3).

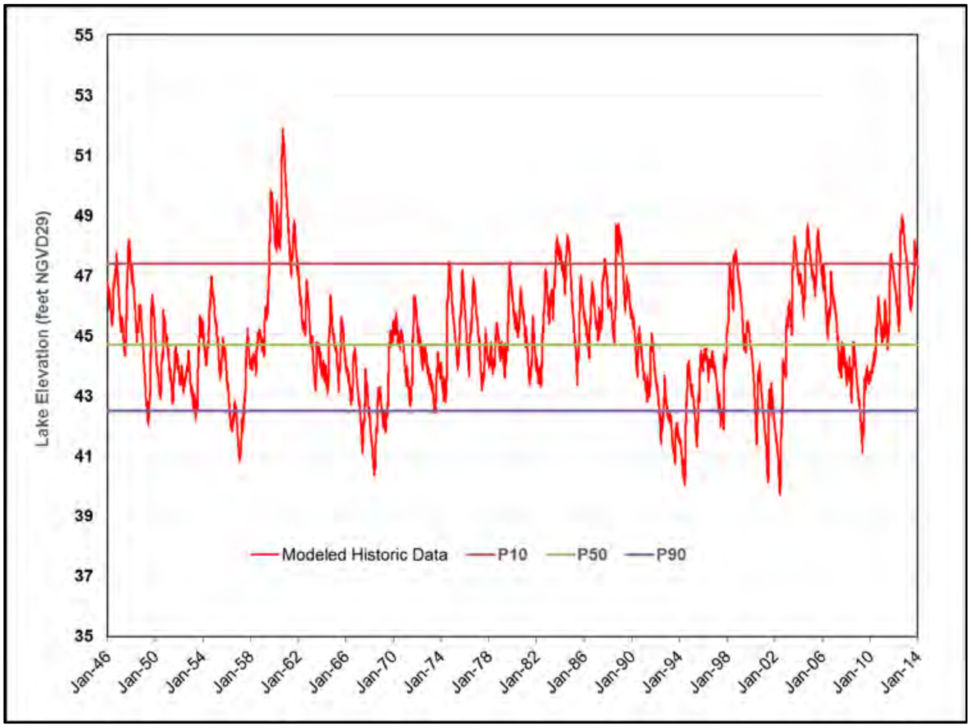

Figure 15. Historic Water Levels (hybrid) Used to Calculate Percentile Elevations Including P10, P50, and P90.

Historic Normal Pool Elevation and Additional Information

The Historic 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) on the trunks of cypress trees have been shown to be reliable biologic indicators of Historic Normal Pool (Carr, et al. 2006). Although Category 3 lake (e.g., Horse Lake) Minimum Lake Levels determination are not set using Normal Pool elevations, there are a limited number of cypress on the lake that exhibit inflection points. Therefore, cypress trees with inflection points were measured to document what Historic Normal Pool elevations were present on the lake in May 2016 (Table 4). Based on the survey of these biologic indicators, the Historic Normal Pool elevation was established at 50.41 ft.

Table 4. Summary statistics for 2016 hydrologic indicator measurements used for establishing Historic Normal Pool elevations for Horse Lake.

Summary Statistic	Number (N) or Elevation
N	5
Median	50.41
Maximum	50.86
Minimum	49.91
Range	0.95

Additional information to consider in establishing Minimum and Guidance Levels are the Control Point elevation (46.9 ft.) and the lowest building floor (slab) elevation (50.0 ft., 5.1 ft. higher than the revised HMLL). The ground elevation of the lowest well within the lake basin is an irrigation well at 47.2 ft. (2.3 ft. higher than the revised HMLL). The Control Point elevation is the elevation of the highest stable point along the outlet profile of a surface water conveyance system that can control the lake water level fluctuations at the high end. Based on survey data, it was determined that the highest spot in the outflow conveyance system is the invert of the culvert under Gunn Highway at the west side of the lake and serves as the control point at 46.9 ft.

Revised Guidance Levels

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 expected Historic P10 of the lake i.e., with the current structural alterations). The Historic P10 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 Horse Lake, the revised High Guidance Level was established at the Historic P10 elevation, 47.4 ft. The period of record stage data exceeded the High Guidance Level more often than not during 1930 – 1960 (with a peak level of 50.0 ft. in August 1959), and regularly during the summers 2003-2005 and 2011-2015. (Figure 11).

The Low Guidance Level 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, RLWR statistics (Ellison, 2002). RLWR statistics are used when adequate historic or current data are not available. These statistics represent differences between P10, P50 and P90 lake stage elevations for typical, regional lakes that exhibit little or no impacts associated with water withdrawals, i.e., reference lakes. RLWR statistics include the RLWR50, RLWR90 and RLWR5090, which are, respectively, median differences between P10 and P50, P50 and P90, and P10 and P90 lake stage percentiles for a set of reference lakes. Based on the availability of Historic data for Horse Lake, the revised Low Guidance Level was established at the Historic P90 elevation, 42.5 ft. Stage water level data shows that the drought in 2002 was the lowest in the period of record since 1930, at 36.33 ft. (Figure 11).

Significant Change Standards

Category 3 significant change standards including a Lake Mixing Standard, Dock-Use Standard, Basin Connectivity Standard, Species Richness Standard, Aesthetics Standard, and a Recreation/Ski Standard were established for Horse Lake, where appropriate. Each standard was previously defined in the Lake Classification section of this report. Each standard was evaluated for minimum levels development for Horse Lake and presented in Table 3.

- The **Lake Mixing Standard** was not established due to the dynamic ratio (basin slope) did not shift as the rule requires, indicating that potential changes in basin susceptibility to wind-induced sediment re-suspension would not be of concern for minimum levels development.
- There were no docks on the lake, therefore the **Dock-Use Standard** was not established.
- The **Basin Connectivity Standard** was established at 45.0 ft. The lake separates on occasion into two pools. The main pool of the lake and the round, likely sinkhole feature pool on the southwest side. This is visually revealed by the historical aerial photography (Figure 7 and 13) and Lake Bathymetry data (Figure 9) of the lake.
- The **Species Richness Standard** was established at 43.0 ft., based on a 15% reduction in lake surface area from that at the Historic P50 elevation.
- The **Aesthetic-Standard** for Horse Lake was established at the Low Guidance Level elevation of 42.5 ft.
- The **Recreation/Ski Standard** was calculated at 42.2 ft. based on a ski elevation of 35.0 ft. plus enough depth to allow skiing.
- The **Wetland Offset Elevation** was established at 43.9 ft., or 0.8 ft. below the historic P50 elevation.
- Review of changes in potential herbaceous wetland area associated with change in lake stage (Figure 16), and potential change in area available for aquatic macrophyte colonization (Figure 17) did not indicate that use of any of the identified standards would be inappropriate for minimum levels development.

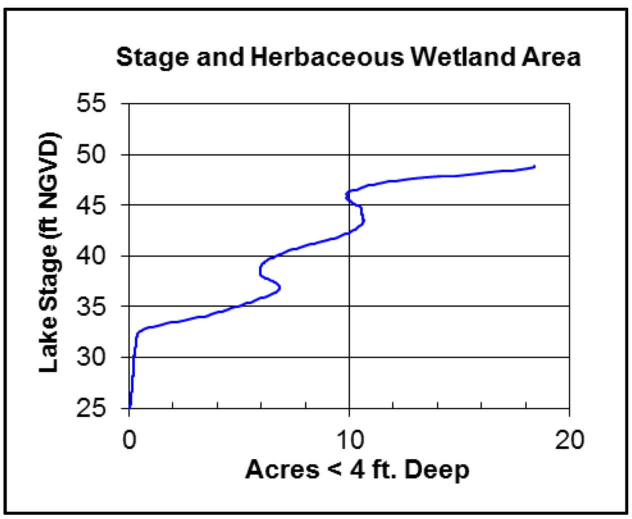

Figure 16. Lake Stage Compared to Available Herbaceous Wetland Area.

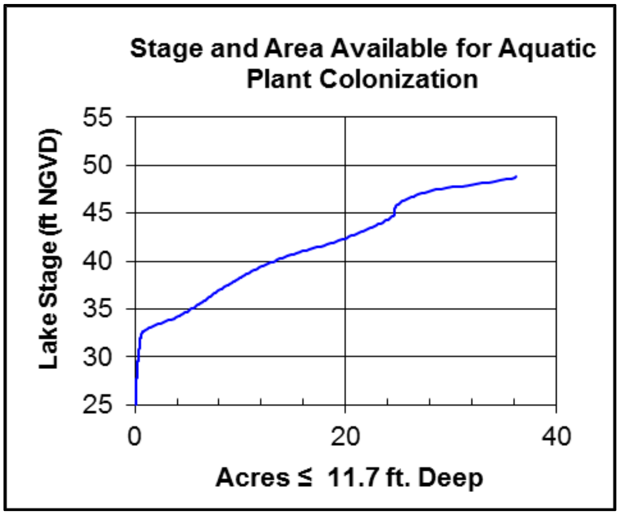

Figure 17. Lake Stage and Area Available for Aquatic Plant Colonization.

Revised Minimum Levels

The Minimum Lake Level is the elevation that a lake's water levels are required to equal or exceed fifty percent of the time on a long-term basis. For a Category 3 lake, the Minimum Lake Level is established at the elevation corresponding to the most conservative (i.e., the highest) standard that does not result in an elevation above the historic P50. In the case of Horse Lake, the Minimum Lake Level is based on the Wetland Offset at an elevation of 43.9 ft. (Table 3).

The High Minimum Lake Level is the elevation that a lake's water levels are required to equal or exceed ten percent of the time on a long-term basis. For a Category 3 lake, Chapter 40D-8.624, F.A.C. allows for the HMLL to be established using one of two methods. The High Minimum Lake Level is established at the elevation corresponding to the Minimum Lake Level plus the difference between the Historic P10 and the Historic P50 or alternatively, the revised HMLL is established at the elevation corresponding to the MLL plus the RLWR value. Based on the concerns for flooding on the lake discussed at the public workshop, the latter RLWR method was used, resulting in a revised HMLL of (44.9 ft. This elevation allows for potential relief from long-term flooding concerns, yet also allows for a relatively natural fluctuation of lakes levels.

Revised Minimum and Guidance levels for Horse Lake are plotted on the Historic water level record (Figure 18). To illustrate the approximate locations of the lake margin when water levels equal the revised minimum levels, revised levels are imposed onto a 2014 natural color photograph in Figures 19.

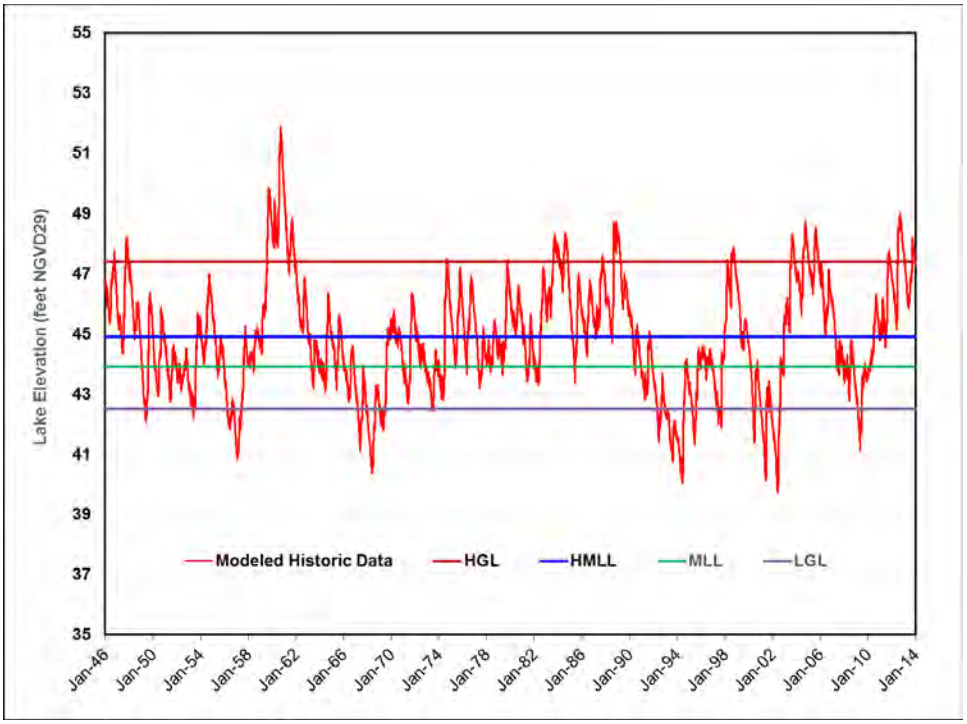

Figure 18. Historic water levels (hybrid) used to calculate the Revised Minimum and Guidance Levels. The revised levels include the High Guidance Levels (HGL), High Minimum Lake Levels (HMLL), Minimum Lake Levels (MLL), and Low Guidance Levels (LGL).

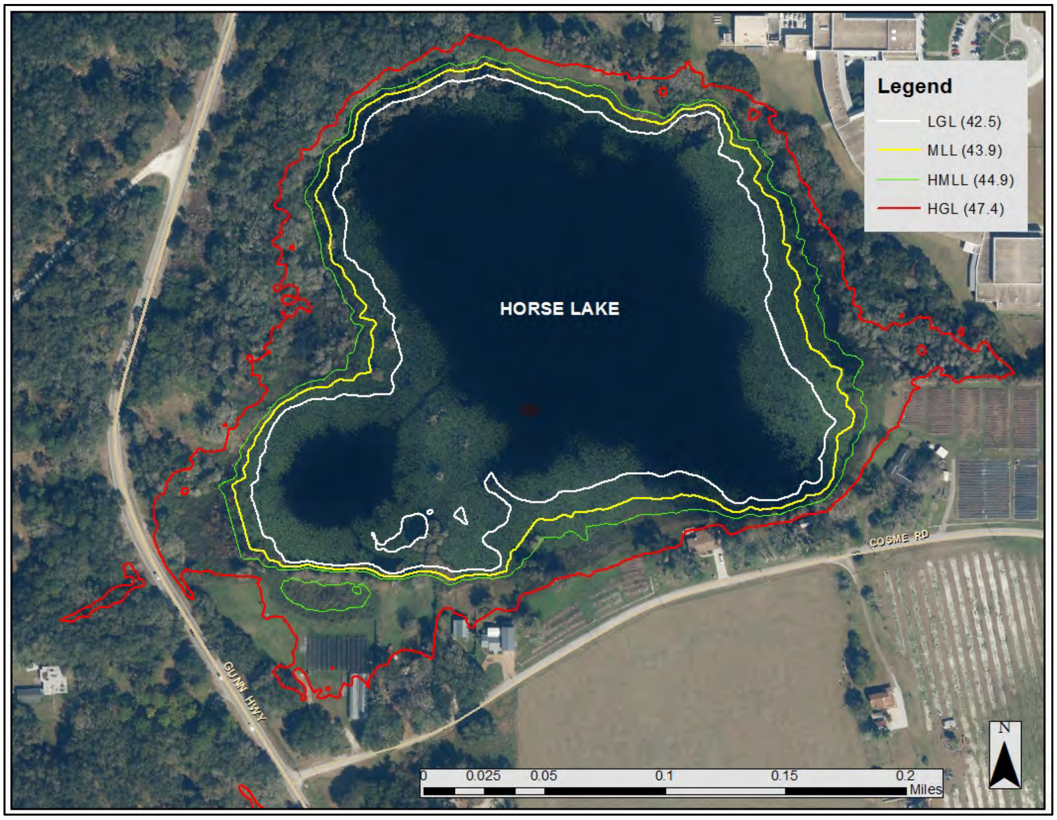

Figure 19. Horse Lake Minimum and Guidance Level Contour Lines Imposed Onto a 2014 Natural Color Aerial Photograph.

Many federal, state, and local agencies, such as the U.S. Army Corps of Engineers, the Federal Emergency Management Agency, United States Geological Survey, and Florida's water management districts are in the process of upgrading from the National Geodetic Vertical Datum (NGVD29) standard to the North American Vertical Datum (NAVD88) standard. For comparison purposes, the revised MFLs for Horse Lake are presented in both datum standards (Table 5). The datum shift was calculated based on third-order leveling ties from vertical survey control stations with known elevations above the North American Vertical Datum on 1988. The NGVD29 datum conversion to NAVD88 is -0.90 ft. to the current gage at Walker Middle School (SID 815809) installed January 30, 2014 and -0.83 for the previous gage (SID 19866).

Table 5. Revised Minimum and Guidance Levels for Horse Lake in NGVD29 and NAVD88.

Minimum and Guidance Levels	Elevation in Feet NGVD29	Elevation in Feet NAVD88
High Guidance Level	47.4	46.5
High Minimum Lake Level	44.9	44.0
Minimum Lake Level	43.9	43.0
Low Guidance Level	42.5	41.6

Consideration of Environmental Values

The revised minimum levels for Horse Lake 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. The Wetland Offset Elevation was used for developing revised Minimum Levels for Horse Lake based on its classification as a Category 3 lake. This standard is associated with protection of several environmental values identified in Rule 62-40.473, F.A.C., including: fish and wildlife habitats and the passage of fish, transfer of detrital material, aesthetic and scenic attributes, filtration and absorption of nutrients and other pollutants, and water quality (refer to Table 1).

The minimum levels revised is protective of three additional environmental values identified in Rule 62-40.473, F.A.C. Species Richness, and Aesthetics standards are lower than the revised Minimum Level. The Recreation/Ski was below the Historic P90 water level and deemed inappropriate. They are nevertheless, protective of the recreation in and on the water, fish and wildlife habitats and the passage of fish, transfer of detrital material, filtration and absorption of nutrients and other pollutants, and water quality.

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 that permitted withdrawals will not lead to violation of adopted minimum flows and levels.

Comparison of Revised and Currently Adopted Levels

The revised High Guidance Level is 0.5 ft. higher than the adopted level (Table 6). This difference is because historic water level modeling data was not available in 2005 when the adopted levels were established. Therefore, the adopted level was set on the control point elevation (culvert under Gunn Highway). The revised level is based on historic long-term water level data as estimated through the modeling effort.

The Low Guidance Level is 2.3 ft. lower than the adopted guidance level for Horse Lake, the revised High Minimum Lake Level is 0.9 ft. lower than the adopted High Minimum Lake Level, and the revised Minimum Lake Level is 0.9 ft. lower than the adopted Minimum Lake Level (Table 6). The revised level is based on historic long-term water level data as estimated through the modeling effort.

Table 6. Revised Minimum and Guidance Levels for Horse Lake compared to currently adopted Minimum and Guidance Levels.

Minimum and Guidance Levels	Revised Elevations (ft., NGVD)	Currently Adopted Elevation (ft., NGVD)
High Guidance Level	47.4	46.9
High Minimum Level	44.9	45.8
Minimum Level	43.9	44.8
Low Guidance Level	42.5	44.8

Minimum Levels Status Assessment

To assess if the revised Minimum and High Minimum Lake Levels are being met, observed stage data in Horse Lake 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 similar to recent conditions (referred to as the “Current” period). Current stage data observed on Horse Lake was determined to be from 1988 through 2015. The LOC model resulted in a 69-year long-term water level record (1946-2015).

For the status assessment, cumulative median (P50) and cumulative (P10) water surface elevations were compared to the revised Minimum Lake Level and High Minimum Lake Level to determine whether long-term water levels were above the revised levels. Results from these assessments indicate that Horse Lake water levels are currently below the revised Minimum Lake and above High Minimum Levels (see Appendix B).

The lake lies within the region of the District covered by an existing recovery strategy, the Comprehensive Environmental Resources Recovery Plan for the Northern Tampa Bay Water Use Caution (Rule 40D80-073, F.A.C.). The District plans to continue regular monitoring of water levels in Horse Lake and will also routinely evaluate the status of the lake’s water levels with respect to adopted minimum levels for the lake included in Chapter 40D-8, F.A.C.

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APPENDIX A

Technical Memorandum

June 7, 2016

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

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

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

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

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A. Introduction

In 2013, a water budget model was developed to assist the Southwest Florida Water Management District (District) in the establishment of minimum levels in Lakes Raleigh and Rogers, located in northwest Hillsborough County (Hancock and McBride, 2013). Horse Lake was included in that model since Horse Lake flows into Lake Raleigh. Horse Lake currently has adopted minimum levels which are scheduled to be re-assessed in FY 2016. Minimum levels were adopted on Lakes Raleigh and Rogers in 2013. This document will discuss the development and update of the Horse Lake models for development of Historic lake stage exceedance percentiles.

B. Background and Setting

Horse Lake is located in northwest Hillsborough County, along Gunn Highway in Odessa (Figure 1). Horse Lake lies across Gunn Highway from the Cosme-Odessa Wellfield, which is one of eleven regional water supply wellfields operated by Tampa Bay Water. The wellfield property is owned by the City of St. Petersburg, although the Hillsborough County Parks and Recreation Department maintains the wellfield land as a county park (Lake Rogers Park). Horse Lake's shoreline is approximately one-third private residences, one-third developed as a school, and one-third undeveloped.

Horse Lake is often described as being within the Brooker Creek or Rocky Creek watersheds, but the lake is relatively isolated. Surface water inflow to Horse Lake occurs as overland flow from the lake's small drainage basin, as well as flow through drainage swales and minor flow systems. Discharge from the lake can occur via a

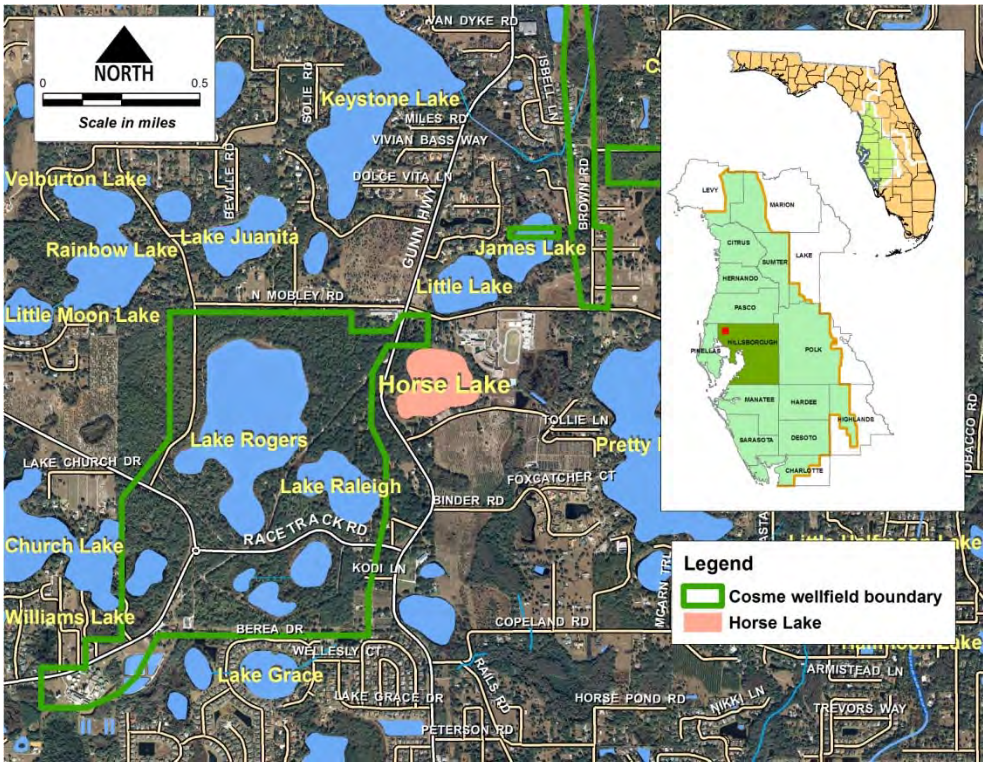

Figure 1. Location of Horse Lake in Hillsborough County, Florida.

culvert under Gunn Highway to an unmaintained ditch excavated from Gunn Highway to Lake Raleigh (Figure 2). Discharge from Lake Raleigh can occur to Lake Rogers via a low spot on a wellfield access road between the lakes, while discharge from Lake Rogers can occur through culverts under Race Track Road and Gunn Highway (Figure 2). Some discharge from both Lakes Horse and Raleigh has been documented in recent years, but there are no documented occurrences of discharge from Lake Rogers in over fifty years.

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

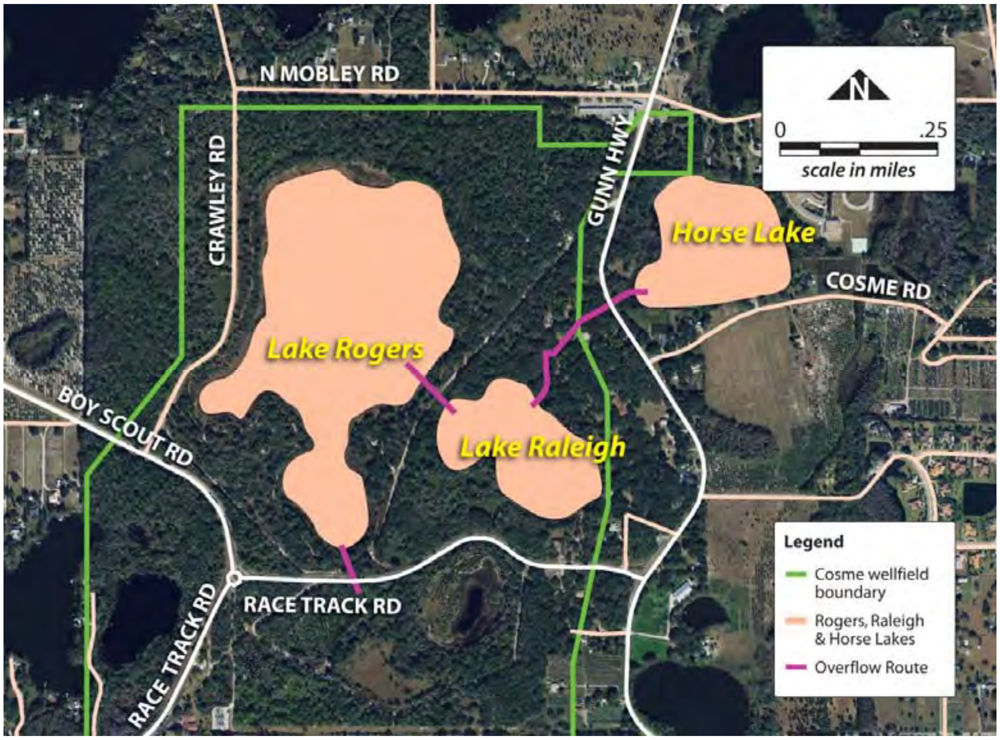

Figure 2. Flow between Lakes Horse, Raleigh, and Rogers.

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

Horse Lake has one of the longest periods of record for water levels of any lakes in the District. Water level data collection began in mid-1930, although the frequency of data collection has been inconsistent over the years (Figure 3). There are no lake water level data that predate wellfield withdrawals (which began in the 1930s), although withdrawal rates were likely less than 3 mgd at the time water level data collection

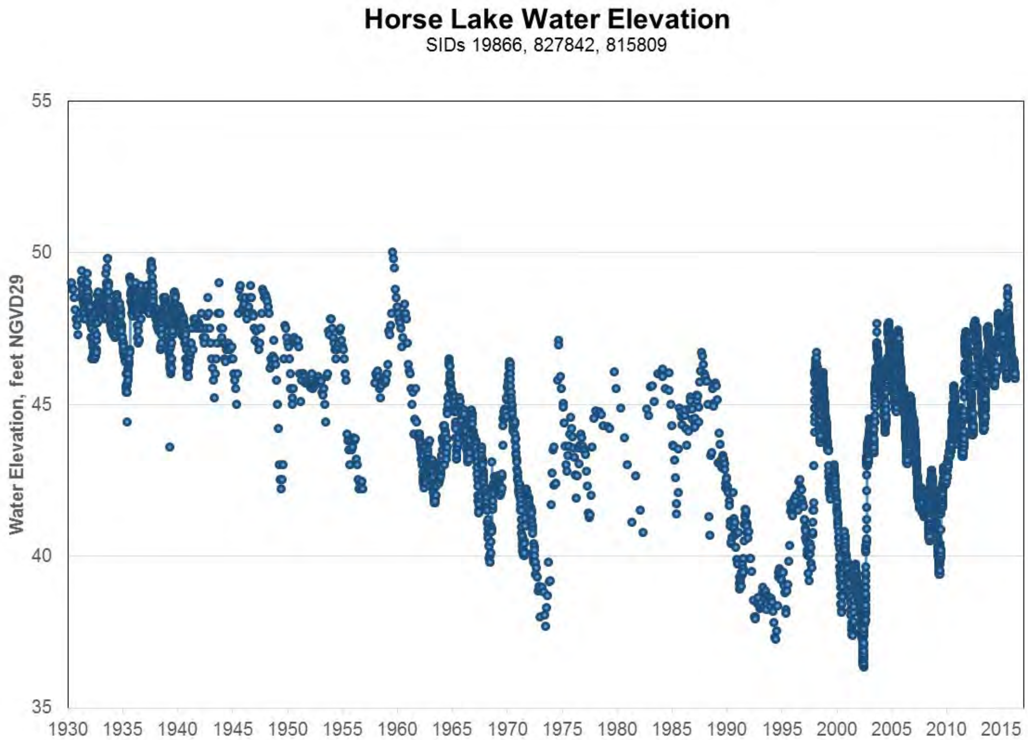

Figure 3. Horse Lake water levels.

began. Horse Lake water levels are represented by three gages over time, SID 19866 (1930-2012), SID 827842 (2012-2013), and SID 815809 (2013-current).

Water levels from two Upper Floridan aquifer monitor wells (Cosme 7 (SID 19539) and Cosme 3 (SID 19536)) exist for the same period of record as the lake stage data. About the time that data for the Cosme 7 well ended in the early 1970s (located between lakes Horse and Rogers), monitoring was initiated for the Cosme 3 well, located southwest of Lake Rogers (Figures 4 and 5). A third Upper Floridan aquifer monitor well, James 11 (SID 19597), is located northeast of Horse Lake, with a period of record beginning in 1965 (Figure 4 and 6).

Several surficial aquifer monitor wells exist in the area. Three wells were used for the Horse Lake water budget model: Horse Lake surficial, Cosme 20 surficial, and Lake Rogers surficial (all monitored by Tampa Bay Water) (Figure 4). The period of record of all three wells begins in the mid-1990s (Figure 7).

Land and Water Use

Horse Lake and other neighboring lakes are unique in that they are located in or adjacent to the Cosme-Odessa Wellfield, the oldest public supply wellfield in the District. Therefore, Horse and adjacent lakes have been subjected to the effects of groundwater withdrawals longer than any other lakes in the District. The wellfield consists of the

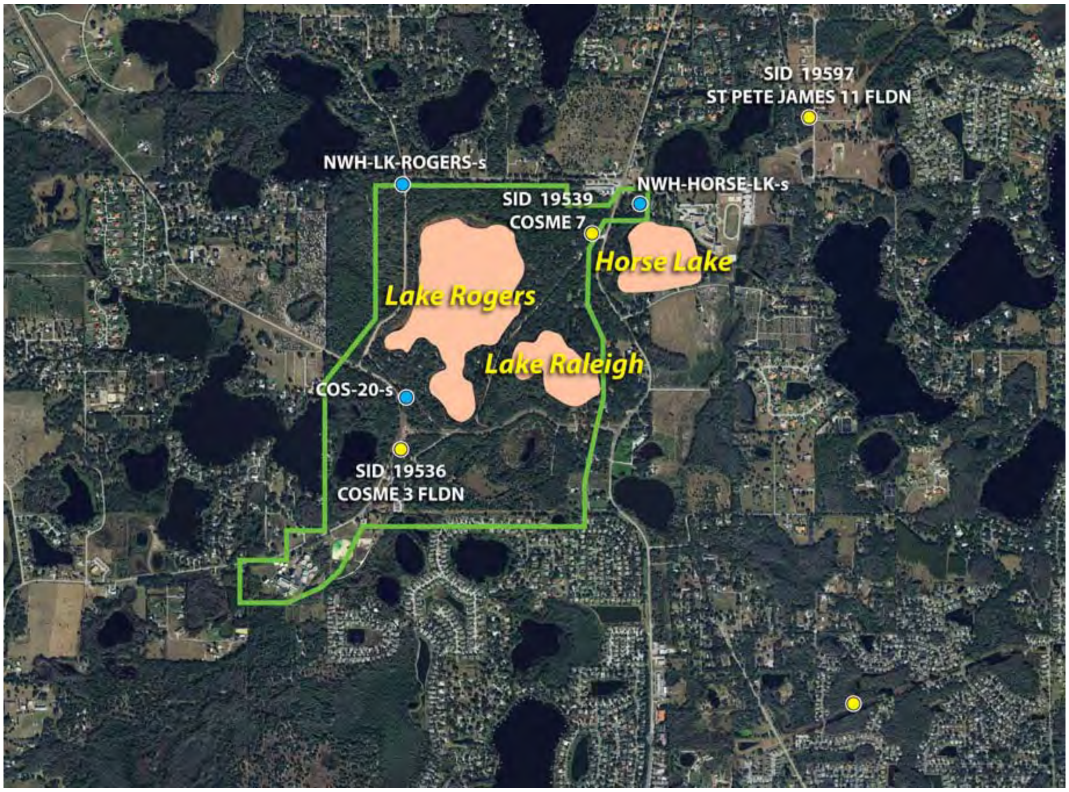

Figure 4. Location of monitor wells near Horse Lake.

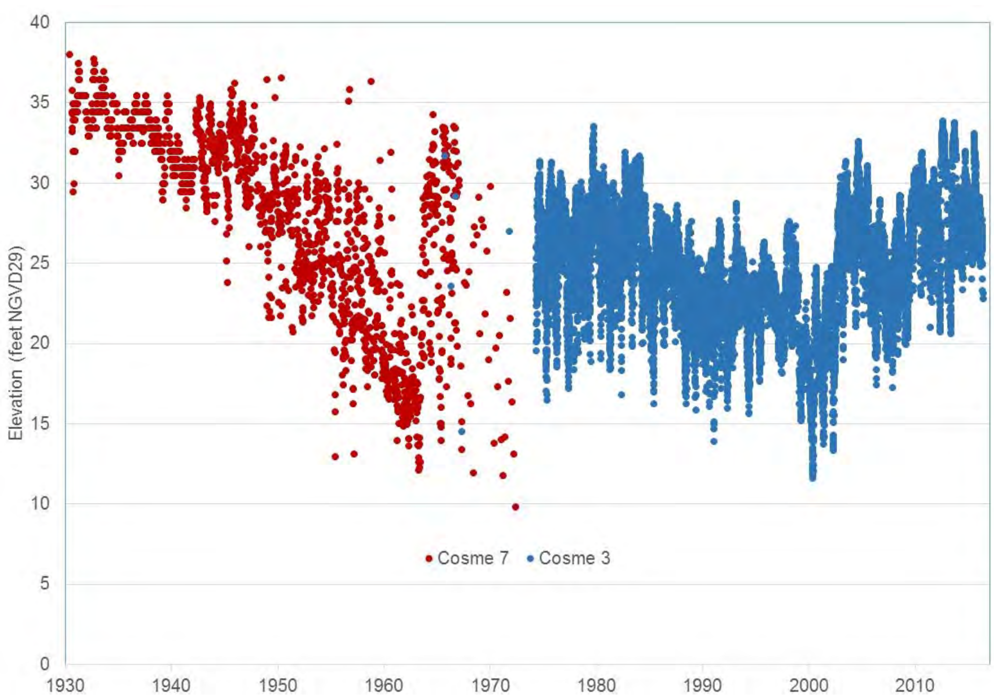

Figure 5. Water levels in Cosme 7 and Cosme 3 Floridan aquifer monitor wells.

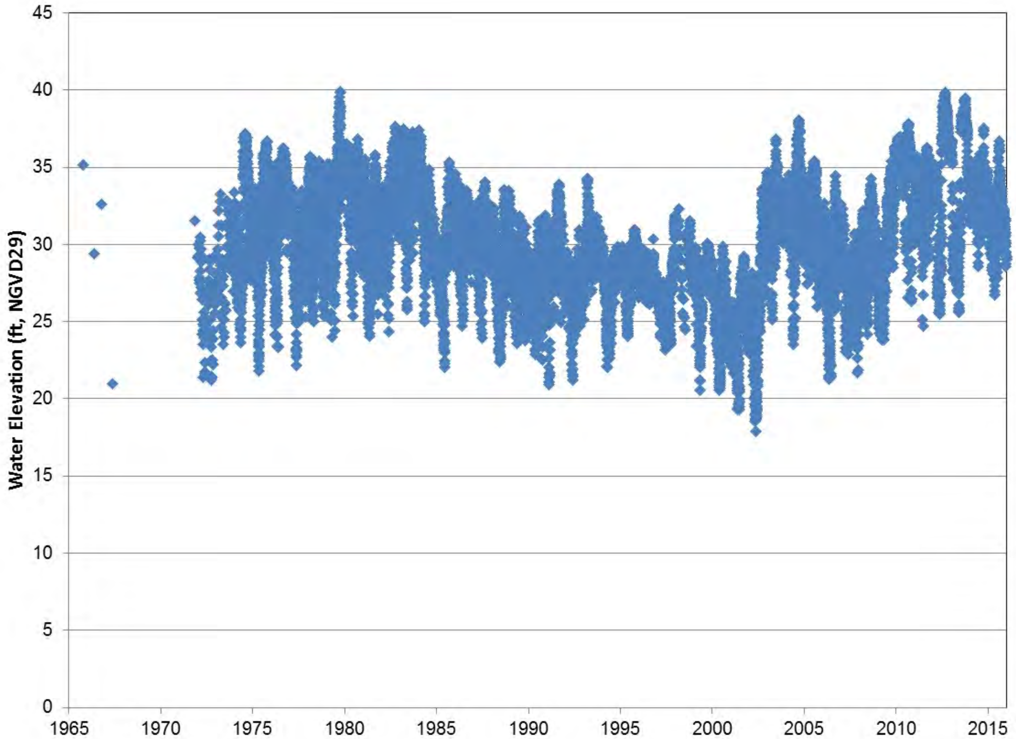

Figure 6. Water levels in James 11 Floridan aquifer monitor wells

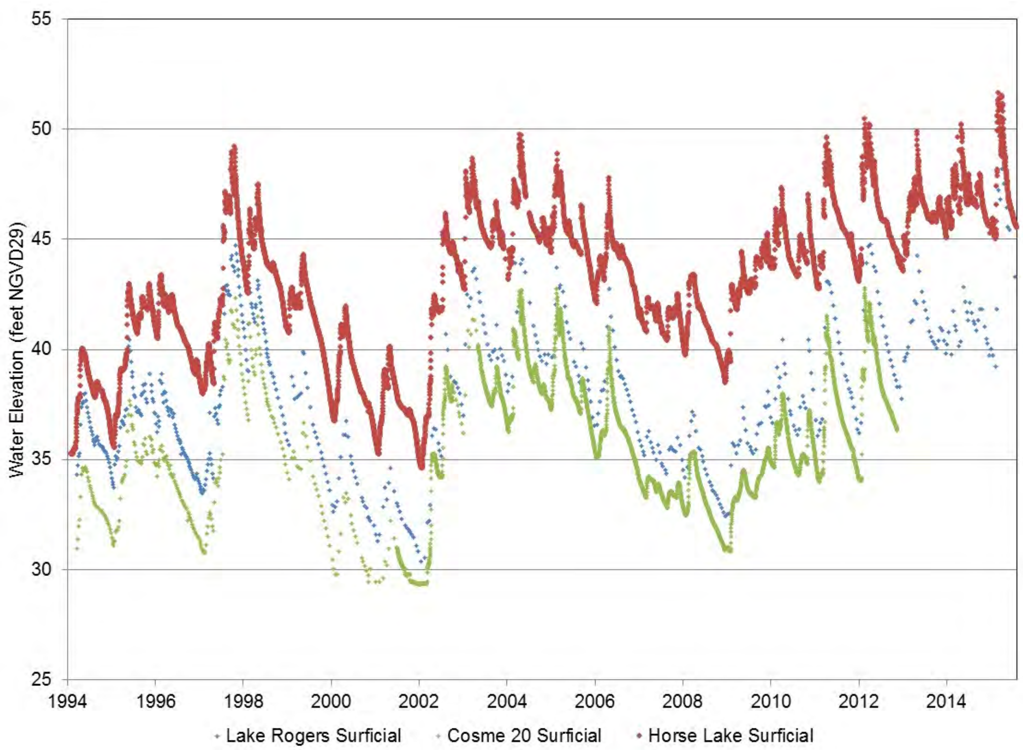

Figure 7. Water levels in Horse Lake, Cosme 20, and Lake Rogers surficial wells

original Cosme wellfield constructed in 1930 (on approximately 1.1 square miles of property), as well as a linear Odessa wellfield spanning approximately 2 miles to the north along Gunn Highway (Figure 8). The original wellfield began supplying water to the City of St. Petersburg in 1930, while withdrawals along the linear expansion began in the early 1950s. Monthly withdrawals steadily climbed to as much as 21 million gallons per day (mgd) in 1962 (Figure 9). By the 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 about 12 mgd on an annual average. Current withdrawal rates at the wellfield typically average approximately 6 mgd on annual average.

Water levels in Horse Lake have dropped significantly since groundwater withdrawals began at the wellfield (Figures 10 and 11). This drop in water levels despite cutbacks in wellfield withdrawals may suggest a structural change in the lake, including water control structures or structural changes in the physical characteristics of the lake itself.

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 stress can cause sediments in karst formations to unravel or can lower water levels that support overburden covering voids in the limestone aquifer. This can result in sinkholes that appear on the surface, or can result in changes that occur underground and cannot be seen at the surface. These changes, in turn, can result in pathways for water to connect lakes, wetlands, or the surficial aquifer in general, to the underlying Upper Floridan aquifer.

Sinclair (1982) discusses the observed formation of dozens of sinkholes following the initiation of groundwater withdrawals at the Section 21 wellfield (in northwest Hillsborough County, about 5 miles northeast of the Cosme-Odessa wellfield). Withdrawals at the Section 21 wellfield began in 1963. Sinkholes were documented as far as several miles away (many appearing in and around lakes and wetlands), and they continued to appear around the wellfield years later. Sinclair also mentions similar reports of sinkholes in and around the Cosme-Odessa wellfield, although because the area's land use was almost entirely agricultural at the time, little documented concern was expressed. One difference between the history of groundwater withdrawals at the Section 21 and Cosme-Odessa wellfields is that withdrawal rates at the Section 21 wellfield increased from zero to approximately 20 mgd in just two or three years, while withdrawal rates at the Cosme-Odessa wellfield took nearly 25 years to reach similar withdrawal rates. This may have caused karst changes to occur more slowly, or not to reach their peak rate of occurrence until withdrawal rates at the Cosme-Odessa wellfield

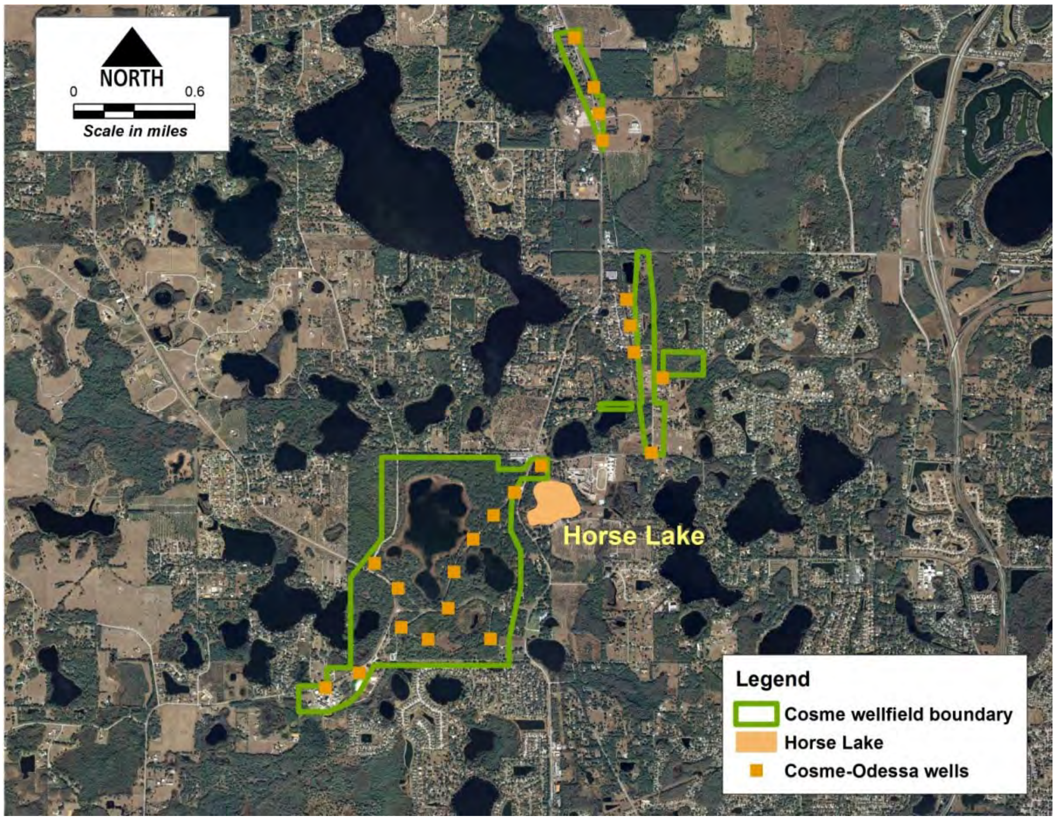

Figure 8. Horse Lake and the Cosme-Odessa Wellfield.

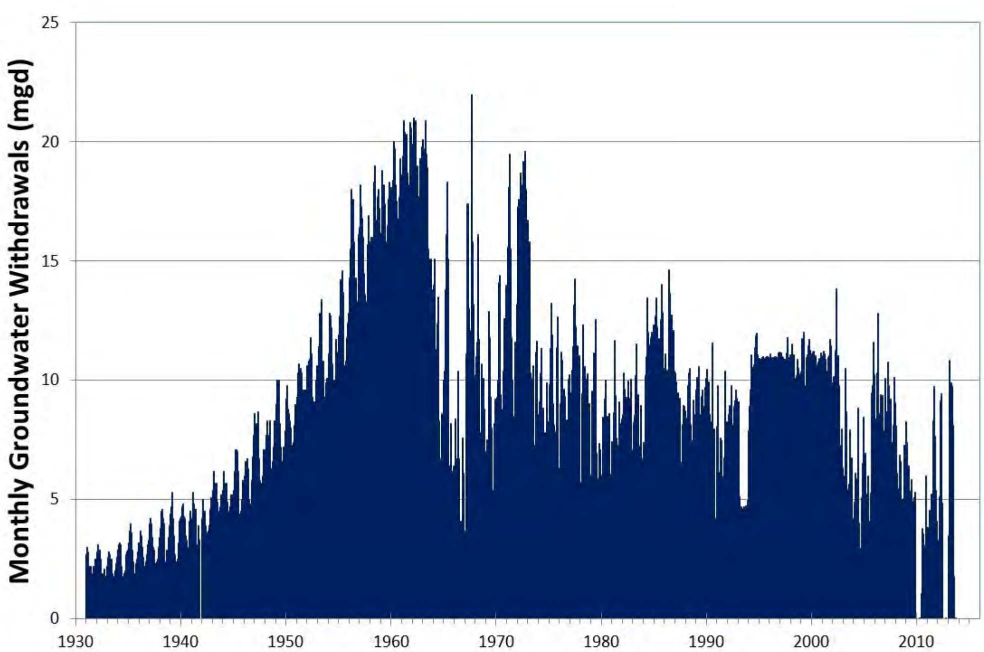

Figure 9. Cosme-Odessa Wellfield withdrawals

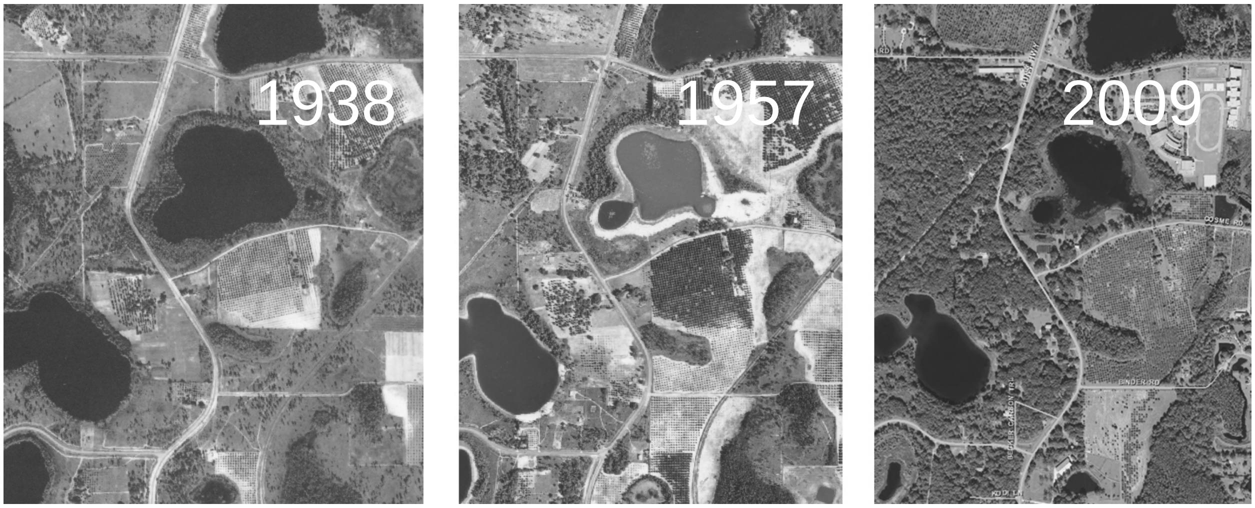

Figure 10. Water level changes in Horse Lake.

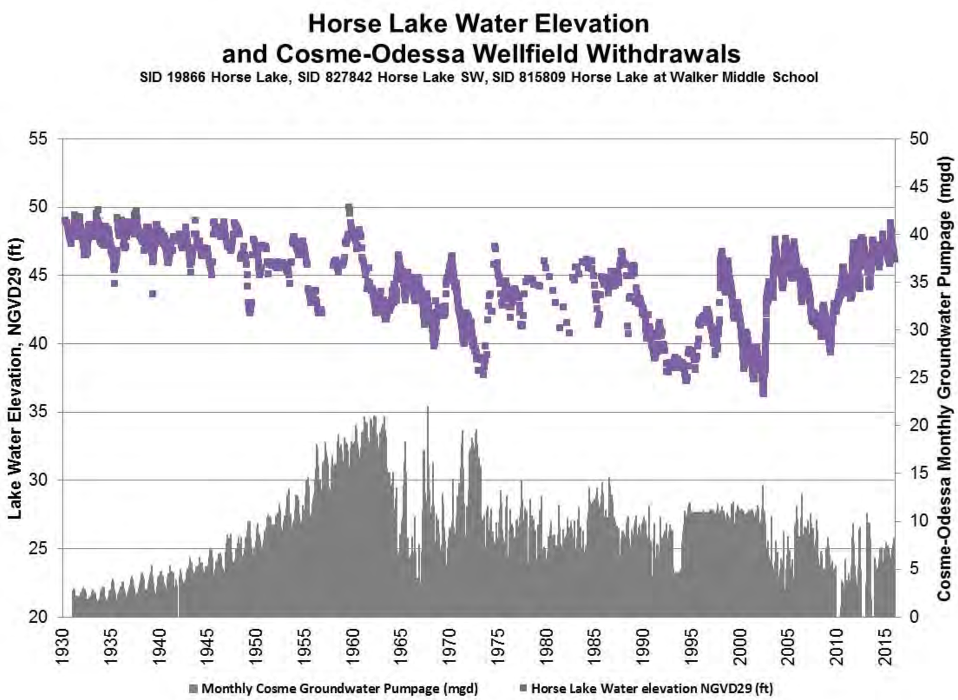

Figure 11. Water levels in Horse Lake and Cosme-Odessa Withdrawals

approached higher rates, coinciding with the 1950s to 1960s time period. A review of aerial photographs during periods when Horse Lake was low (Figure 10) shows the pattern of round sinkhole features that originally formed Horse and other nearby lakes. An enhancement of leakance properties of any one of these features or the creation of new karst connections could result in a change in the relationship between the lake and the underlying Upper Floridan aquifer.

Temporary Augmentation

During El Niño events in the winters of 1997/1998 and 2002/2003, high water flows from nearby Pretty Lake were transferred via pumps, temporary pipelines, and existing channels to Lakes Horse, Raleigh, and Rogers (Figure 12). Both of these transfers are

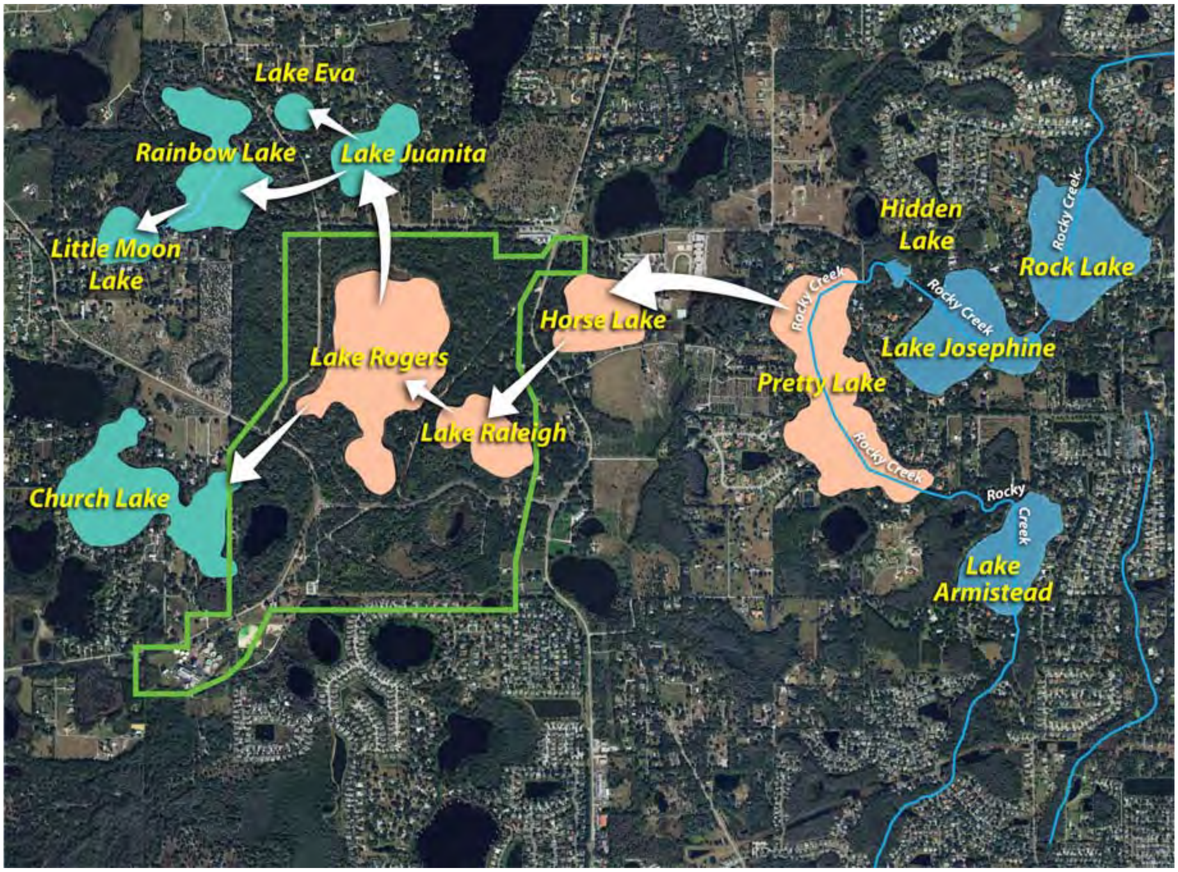

Figure 12. Temporary water transfers in 1997/1998 and 2002/2003

described in “Lake Pretty Water Transfer Project” (Southwest Florida Water Management District, 2003). Additional lakes received water pumped from Lake Rogers during the 2002/2003 temporary water transfer, including Lakes Juanita, Rainbow, Little Moon, Eva, and Church. During each transfer period (January 5, 1998 to April 2, 1998 and September 20, 2002 to May 9, 2003), high flows from Pretty Lake were transferred to Horse Lake. A pump at Horse Lake transferred water under Gunn Highway to the ditch that leads to Lake Raleigh. From Lake Raleigh, a third pump transferred water to Lake Rogers. Although augmentation quantities were not metered for each event, it is estimated that about 200 million gallons of water were transferred from Pretty Lake to the other lakes in the first event, and about 450 million gallons were transferred in the second event.

Water withdrawals upstream of an operable water conservation structure on Pretty Lake were strictly limited to a small percentage of the structure overflow, so no lowering of Pretty Lake below target water levels occurred due to the water transfers. Target levels in each receiving lake were used to determine when to stop inflows and begin transfers to other lakes down the augmentation chain. Because lake levels in some lakes augmented during the temporary projects were much lower prior to water transfers, and the size of each lake varies considerably, some lakes received significantly larger volumes of water than others. It is estimated that Lake Rogers received a much larger volume of water than the other lakes, since it is the largest of the receiving lakes, and initially was farthest below its target. It should be noted that significant rainfall during the pumping events also contributed to lake recovery and contributed to higher levels that lasted many months.

C. Purpose of Models

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

In the case of Horse Lake, the Cosme-Odessa Wellfield has affected lake water levels since before the beginning of data collection, so no Historic data exists for the lake. Therefore, the development of a water budget model coupled with a rainfall correlation model for the lake was considered essential for estimating long-term Historic percentiles, accounting for changes in the lake's drainage system, and simulating effects of changing groundwater withdrawal rates.

D. Water Budget Model Overview

The original water budget model used for Horse Lake, as well as Lakes Raleigh and Rogers, is described in detail in Hancock and McBride (2013), and is summarized below. Because discharge can occur from Horse Lake into Lake Raleigh, and then into Lake Rogers, the three lakes were modeled together. However, since each lake was modeled in a separate spreadsheet, and there is no significant channel flow into Horse Lake, the Horse Lake spreadsheet can be used as a separate model (referred to here as the Horse Lake water budget model).

The Horse Lake water budget model is a spreadsheet-based tool that 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 the lake that produced a unique lake stage for any total water volume within the control volume.

The hydrologic processes in the 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. The model is calibrated from 1988 to 2013, which provides the best balance of using available data for all parts of the water budget and the desire to have a long-term period. Because some techniques regularly used in developing District water budget models have changed and improved since the original Horse Lake water budget model was developed, the original Horse Lake model was updated as described below. Several of the model inputs are presented in Table 1.

Table 1. Model Inputs for the Horse Lake water budget model.

Input Variable	Input Value
Overland Flow Watershed Size (acres)	77.3
SCS CN of watershed	75
Percent Directly Connected	0
FL Monitor Well Used	James 11
Surf. Aq. Monitor Well(s) Used	Horse Lake Surf
Surf. Aq. Leakance Coefficient (ft/day/ft)	0.002
Fl. Aq. Leakance Coefficient (ft/day/ft)	0.0004
Outflow K	0.001
Outflow Invert (ft NGVD29)	46.9
Inflow K	N/A
Inflow Invert (ft NGVD29)	N/A

E. Water Budget Model Components

Lake Stage/Volume

Lake stage area and stage volume estimates were determined by building a terrain model of the lake and surrounding watersheds. Lake bottom elevations and land surface elevations were used to build the model with LP360 (by QCoherent) for ArcGIS, ESRI's ArcMap 10.2, 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. The lake stage and stage volume relationship from the original model was not changed.

Precipitation

Daily data from the ROMP TR 13-3 Race Track Road (E-101) and Cosme 18 rain gages were used to represent precipitation over the lake (Figure 13). The Lake Crescent gage, maintained by the District, and located approximately 3 miles to the north of the wellfield property, was used to fill in a few missing data points in the rainfall data set. This was the same precipitation used in the original Horse Lake water budget model.

Figure 13. Rain gages used in the Horse Lake water budget model.

Lake Evaporation

Lake evaporation was estimated through use of monthly energy budget evaporation data collected by the U.S. Geological Survey (USGS) at Lake Starr in Polk County (Swancar and others, 2000) (Figure 14). The data was collected from August of 1996 through July of 2011. Monthly Lake Starr evaporation data were used in the Horse Lake water budget model 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 (Figure 14), which concluded that the evaporation rates between the two lakes were similar (Swancar, 2011, personal communications). More details on the approach are described in Hancock and McBride (2013), from which no changes were made in this update.

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 CH2M HILL, 2003), and via directly connected impervious area calculations. An estimate of the lake's watershed (77.3 acres, Figure 15) was derived by work performed as part of an effort to model the Brooker Creek watershed for flood assessment purposes (PBSJ, 2006).

Inflow and Discharge Via Channels from Outside Watersheds

Inflow and outflow via channels from the watershed or to the watershed (hence referred to as "channel flow") are relatively small components of the water budget in Horse Lake, since water levels rarely reach elevations that allow inflow and outflow. Because the channel flow component is small, and detailed surveys and dimensions of structures and channels were not available, a simplified approach was used. To estimate flow out of each lake, the predicted elevation of the lake from the previous day is compared to the controlling elevation. If this value is a positive number, the difference is multiplied by the current area of the lake and an "outflow coefficient." The coefficient represents a measure of channel and structure efficiency, and produces a rough estimate of volume lost from the lake. This volume is then subtracted from the current estimate of volume.

Horse Lake has no significant channels draining into the lake, but does have a 24-inch culvert on the western side of the lake from which water can discharge. The culvert has a controlling elevation of 46.9 feet NGVD29. In the last several decades, there are few periods where the water levels in Horse Lake have reached the culvert elevation. The culvert passes below Gunn Highway, and empties into a poorly maintained ditch and

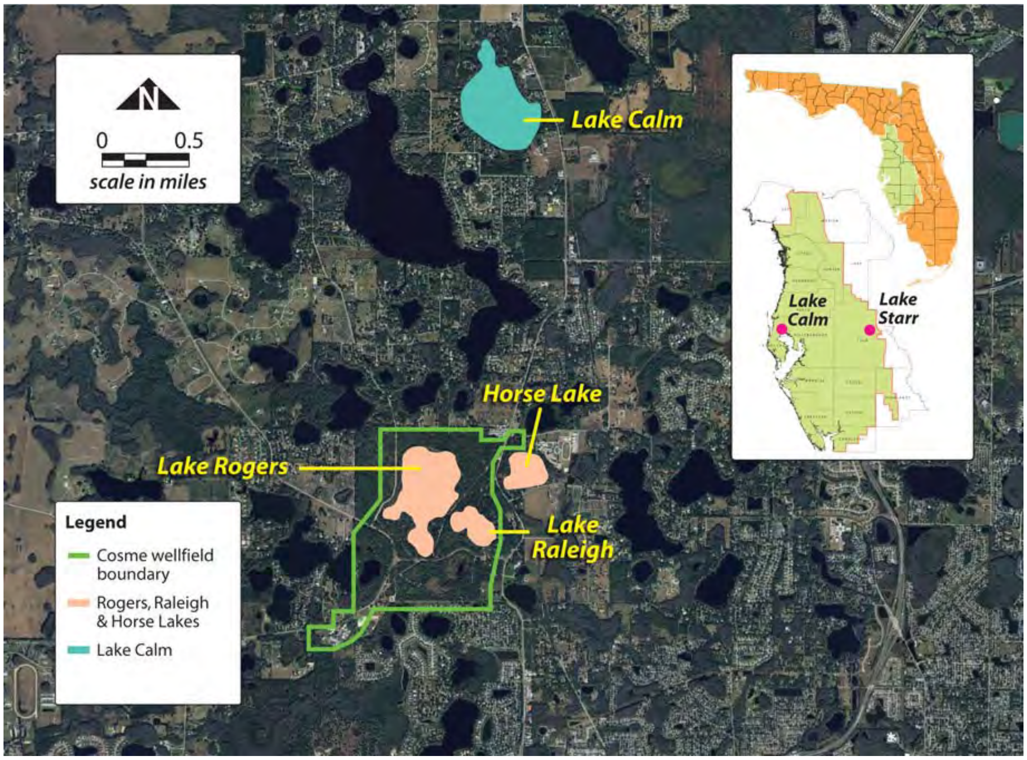

Figure 14. Location of Horse, Calm, and Starr Lakes (see map inset).

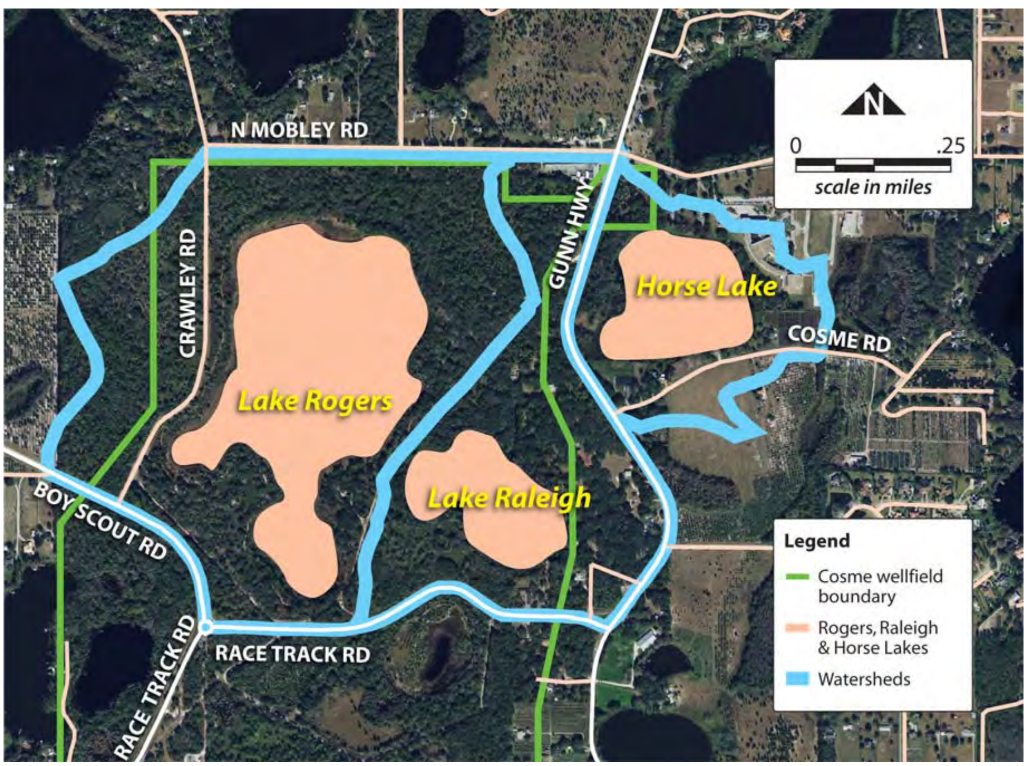

Figure 15. The watersheds of Horse Lake, Lake Raleigh, and Lake Rogers.

culvert system draining to Lake Raleigh. No changes were made in the outlet coefficient or control elevation from the original model.

Flow from and into the surficial aquifer and Upper Floridan aquifer

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

The James 11 Floridan aquifer monitoring well, located to the northeast of Horse Lake, was used to represent the Upper Floridan aquifer below Horse Lake. The monitoring well has a long period of record of daily data that extend well before the calibration period of the model. The Horse Lake surficial aquifer well, monitored by Tampa Bay Water, was used for the Horse Lake simulation due to its proximity to the lake. A simple approach was used to fill in missing data by using the last recorded data value until a new value was recorded. Because the period of record of the Horse Lake surficial aquifer well does not begin until January 1994, an average head difference between the well and the Horse Lake from 1994 through 2002 was used to infill the surficial aquifer water level data back to 1988.

F. Water Budget Model Approach

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

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

Attempts to determine a reasonably accurate time series of augmentation rates during the two water transfer events were not successful, so the augmentation quantities could not be included in the model. These rates were not metered, therefore, it was decided to remove the augmentation period from the calibration statistics. The effects of the augmentation events would be expected to affect lake levels during the period of augmentation, but also would be expected to affect lake levels for some period after the augmentation ceased. For purposes of calibration, the post-augmentation data was not used until the peak in the hydrograph partially caused by the augmentation reached a low and began to rise again by rainfall alone. For the first event, the period from

January 5, 1998 through December 31, 2000 was excluded, and for the second event, the period from October 15, 2002 to December 31, 2007 was excluded (see Figure 16). The second period was longer partially due to several wet summers in a row, including two hurricanes in 2004.

Figure 16 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 the modeled water budget components for the model calibration.

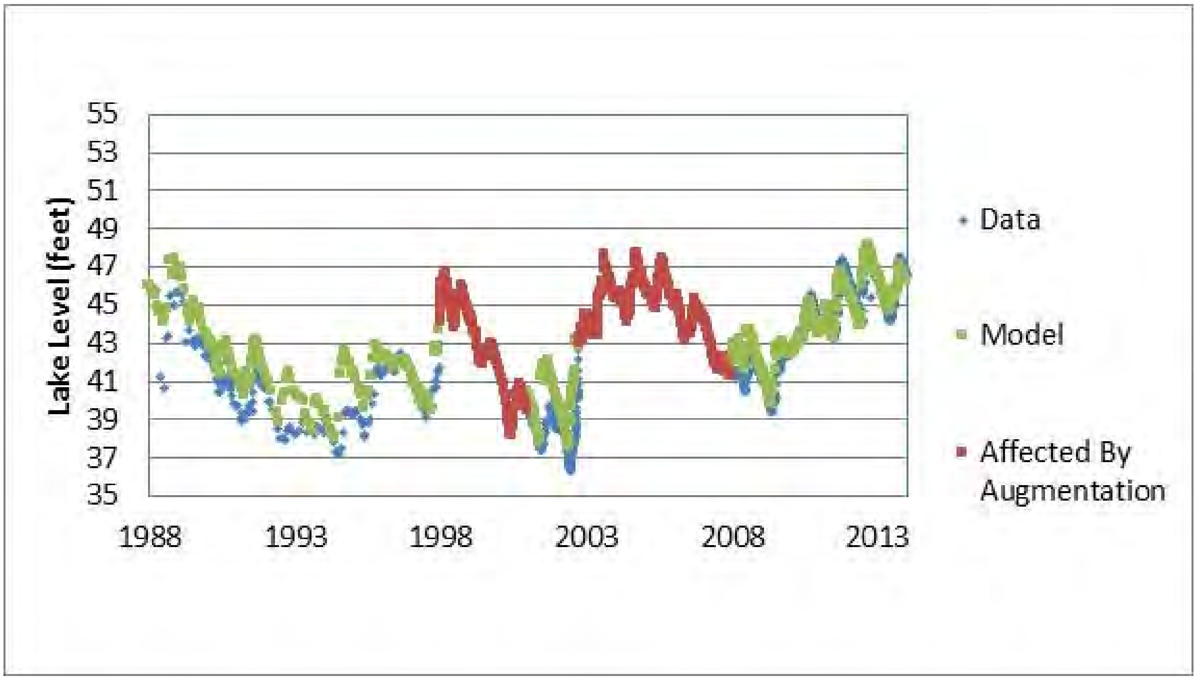

Figure 16. Modeled water levels predicted for Horse Lake in the calibrated water budget model (Model) and measured levels used for the model calibration (Data). Data affected by augmentation that were not used for model calibration are also shown.

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

	Horse Lake Data	Horse Lake Model
P10	46.8	46.6
P50	43.3	43.3
P90	38.6	40.2

Table 3. Horse Lake Model Water Budget (1988-2013)

Inflows	Rainfall	SURF GW Inflow	FL GW Inflow	Runoff	DCIA Runoff	Inflow via channel	Total
Inches/year	53.7	1.4	0.0	37.0	0.0	0.0	92.1
Percentage	58.3	1.6	0.0	40.1	0.0	0.0	100.0
Outflows	**Evaporation**	**SURF GW Outflow**	**FL GW Outflow**			**Outflow via channel**	**Total**
Inches/year	58.1	9.6	24.3			0.1	92.1
Percentage	63.1	10.4	26.4			0.1	100.0

G. Water Budget Model Calibration Discussion

Based on a visual inspection of Figure 16, the model appears to be reasonably well calibrated. There are a few periods when the peaks in the modeled hydrograph are higher or lower than the measured values, and these differences contributed to minor differences between the modeled and measured percentiles associated with higher and lower lake levels, i.e., the P10 and P90 percentiles. The augmentation probably had the least effect on Horse Lake (as compared to Lakes Raleigh and Rogers – see Hancock and McBride (2013)), since it was closest to its target levels prior to augmentation, and water was immediately pumped from the lake to the others once the Horse Lake target was reached. This also implies that the actual quantities diverted and left in the lake were small compared to the amount of rainfall that was received during the same period. Reduced precision in the higher and lower ranges of the stage-volume relationships for the lake may also have contributed to the percentile differences.

The effect of curve numbers may be somewhat important in the model results, particularly since there was a significant decrease in groundwater withdrawals from the Cosme-Odessa Wellfield (and other nearby wellfields) during the period of calibration. Sensitivity experimentation showed that water levels in the earlier periods of the calibration period matched better when a lower curve number was used (indicating a drier soils condition), while water levels in the later periods of the calibration period matched better when a higher curve number was used (indicating a wetter soils condition). This would be consistent with the effects of reducing groundwater withdrawals. As explained earlier, curve numbers representing an intermediate condition were used. Further sensitivity runs showed that the range of possible curve numbers had only a minor effect on the resulting percentiles.

A review of Table 2 shows that there are no differences in median percentile (P50), a 0.2 feet difference at the P10 percentile, and a 1.6 foot difference at the P90 percentile between the data and model for the lake. Attempts at better calibration of the P90 resulted in larger differences between the medians. Some of the differences at the lower percentiles may be due to less detail in the lower stage-volume relationships.

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

H. Water Budget Model Scenario

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

The Integrated Northern Tampa Bay (INTB) model (Geurink and Basso, 2013) is an integrated model developed for the northern Tampa Bay area. The INTB model has the ability to account for groundwater and surface-water, as well as the interaction between them. The domain of the INTB application includes the Cosme-Odessa Wellfield area, and represents the most current understanding of the hydrogeologic system in the area.

The INTB was used to determine the drawdown in the surficial aquifer and Upper Floridan aquifer in response to groundwater withdrawals in the area. 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 1988 through 2002, while the post-cutback period is 2003 through 2013. The model results allowed the drawdowns associated with all permitted withdrawals to be calculated before and after wellfield cutbacks, assuming changes in all other withdrawals are consistent 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 in the area of the wellfields. Groundwater withdrawal rates from the Cosme-Odessa Wellfield in each scenario were 11 mgd and 6.2 mgd, respectively.

Results from the INTB modeling scenarios showed that there is a fairly linear relationship between Upper Floridan aquifer drawdown and withdrawal rates at the wellfields. Because of the leaky nature of the confining unit in the area of Horse Lake, and because the water table in the model is not active, the relationship between groundwater withdrawals in the Upper Floridan and water levels in the surficial aquifer was also of interest. The same scenarios described above showed that one mgd of groundwater withdrawals resulted in approximately 0.2 feet of drawdown in the water table, which was also consistent throughout the area of the three lakes. 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 1988 to 2013 water budget model period, two periods of adjustment were used to reflect the cutbacks that took place at the Cosme-Odessa Wellfield. The adjustments to each Upper Floridan aquifer and surficial aquifer well are found in Table 4.

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

Well	Adjustment (feet) 1988 to July 2002	Adjustment (feet) August 2002 to 2013
Floridan aquifer	11.3	5.9
Surficial aquifer	1.8	0.9

Figure 17 presents measured water level data for the lake along with the model-simulated lake levels under Historic conditions, i.e., in the absence of groundwater withdrawals with structural alterations similar to current conditions. Table 5 presents the Historic Percentiles as estimated by the water budget model.

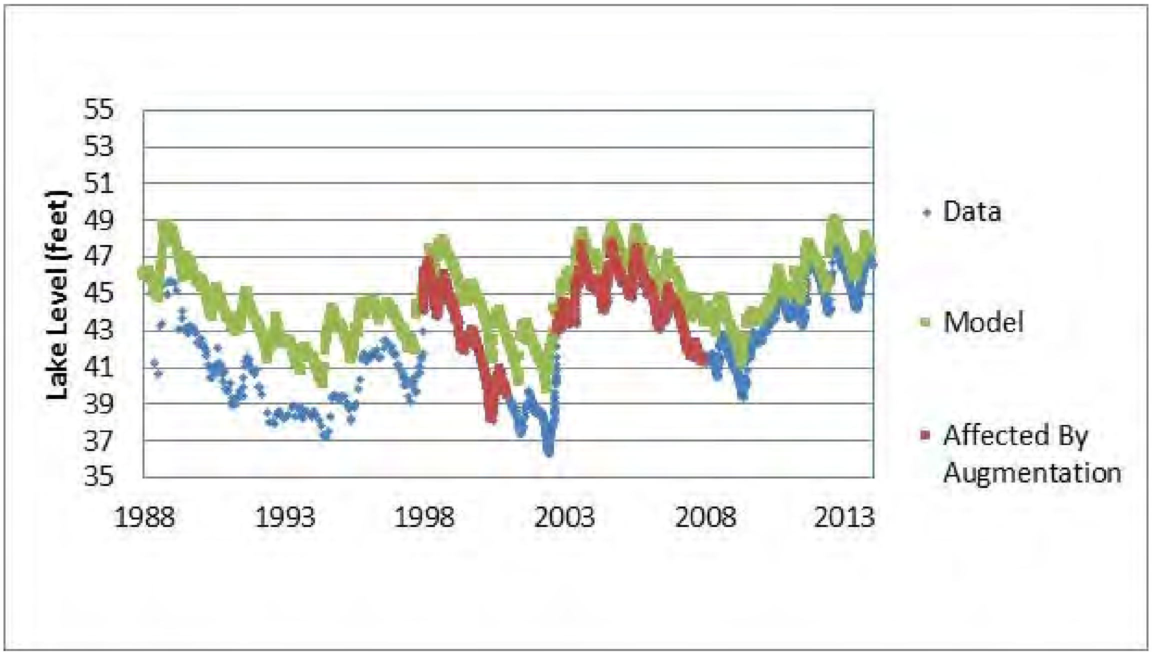

Figure 17. Measured lake levels (Data) and Historic water levels predicted with the calibrated Horse Lake water budget model (Model).

Table 5. Historic percentiles as estimated using the Horse Lake water budget model (all in feet NGVD29).

Percentile	Horse Lake
P10	47.5
P50	44.6
P90	41.9

The Historic normal pool was determined in the field for Horse Lake at 50.4 feet NGVD29. While the Historic normal pool and natural P10 in lakes and wetlands in the northern Tampa Bay area may differ by several tenths of a foot in many cases, the P10 of the model's estimates of Historic P10 for Horse Lake is 2.9 feet lower than the Historic normal pool elevation. Since the modeled P10 estimate is so much lower than the field determined Historic normal pool, it appears that the Historic normal pool water levels experienced prior to the wellfield establishment cannot be achieved again at the P10 frequency due to structural changes.

I. Rainfall Correlation Model

In an effort to extend the period of record of the water levels used to determine the Historic Percentiles to be used in the development of the Minimum Levels, a line of organic correlation (LOC) was performed using the results of the water budget model and long-term rainfall. The LOC is a linear fitting procedure that minimizes errors in both the x and y directions and defines the best-fit straight line as the line that minimizes the sum of the areas of right triangles formed by horizontal and vertical lines extending from observations to the fitted line (Helsel and Hirsch, 1997). 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 (1988-2013). Data from the “Cosme” rain gage, which was replaced by the Cosme 18 due to quality control issues, was used to extend the rain data back to 1945. Quality control issues at the Cosme gage reportedly occurred after 1995, and there is no evidence that there were quality control issues at the Cosme gage prior to that time. Finally, rainfall data from the St. Leo gage (Figure 18) were used to extend the data from 1945 back to 1930. Although the St. Leo gage is approximately 26 miles from Horse Lake, it is one of only a few rain gages in the vicinity with data preceding 1945, and in this case, is only used in the first few years of the correlation.

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

Rainfall was correlated to the water budget model results for the entire period used in the water budget model (1988-2013), and the results from 1946-2013 (68 years) were produced. For Horse Lake, the 4-year weighted model had the highest correlation coefficient, with an R^2 of 0.77. Previous correlations for lakes in the northern Tampa Bay area have consistently had best correlation coefficients in the 2 to 5 year range. The results are presented in Figure 19.

In an attempt to produce Historic percentiles that apply significant weight to the results of the water budget models, the rainfall LOC results for the period of the water budget model are replaced with the water budget model results. Therefore, the LOC rainfall model results are used for the period of 1946-1987, while the water budget results are used for the period of 1988-2013. These results are referred to as the “hybrid model.” The resulting Historic percentiles for the hybrid model are presented in Table 6. Note that the difference between the P10, P50, and P90 percentiles from the water budget model (Table 5) and those from the hybrid rainfall model (Table 6) for Horse Lake are 0.1, 0.1, and 0.6 feet, respectively. Therefore, there are small changes to the Historic percentiles between the two models.

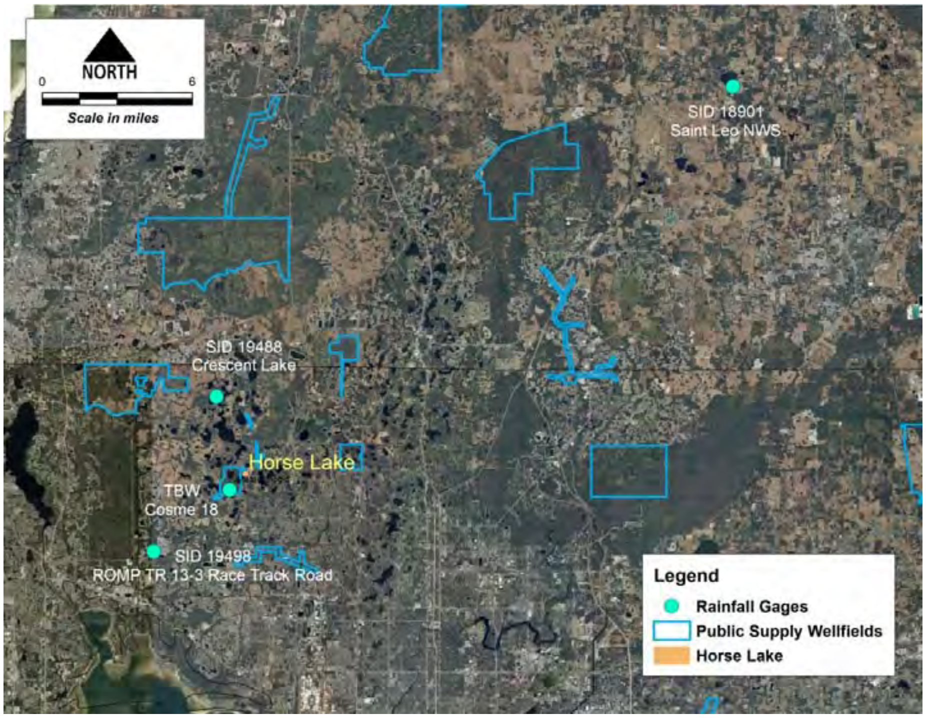

Figure 18. Location of rain stations used for the rainfall correlation model.

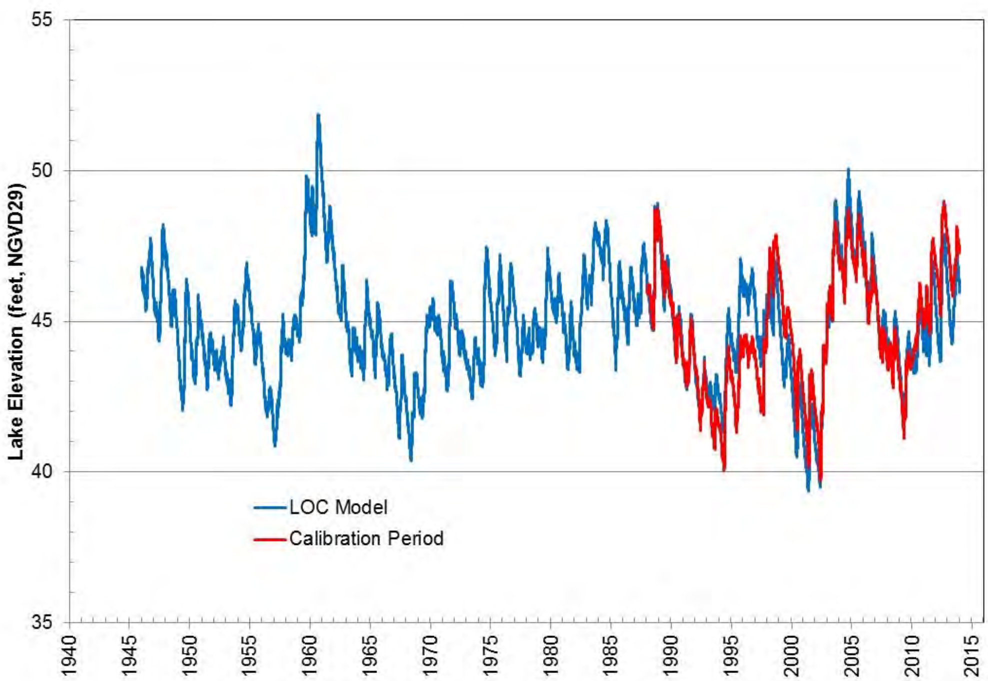

Figure 19. LOC model results for Horse Lake.

J. Conclusions

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

Table 6. Historic percentiles as estimated by the hybrid model from 1946 to 2013 (all in feet NGVD29).

Percentile	Horse Lake
P10	47.4
P50	44.7
P90	42.5

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APPENDIX B

Technical Memorandum

August 22, 2016

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

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

Subject: Horse Lake Initial Minimum Levels Status Assessment

A. Introduction

The Southwest Florida Water Management District (District) is reevaluating adopted minimum levels for Horse Lake and is proposing revised minimum levels for the lake, in accordance with Section 373.042 and 373.0421, Florida Statutes (F.S). Documentation regarding development of the revised minimum levels is provided by Hancock and McBride (2016) and Carr and others (2016).

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 Horse Lake 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 Horse Lake that are located in the area affected by the Consolidated Permit wellfields (i.e., the Central System Facilities) operated by Tampa Bay Water. This document provides information and analyses to be considered for evaluating the status (i.e., compliance) of the revised minimum levels proposed for Horse Lake and any recovery that may be necessary for the lake.

B. Background

Horse Lake is located in northwest Hillsborough County, along Gunn Highway in Odessa (Figure 1). Horse Lake lies across Gunn Highway from the Cosme-Odessa Wellfield, which is one of eleven regional water supply wellfields operated by Tampa Bay Water. The wellfield property is owned by the City of St. Petersburg, although the Hillsborough County Parks and Recreation Department maintains the wellfield land as a county park (Lake Rogers Park).

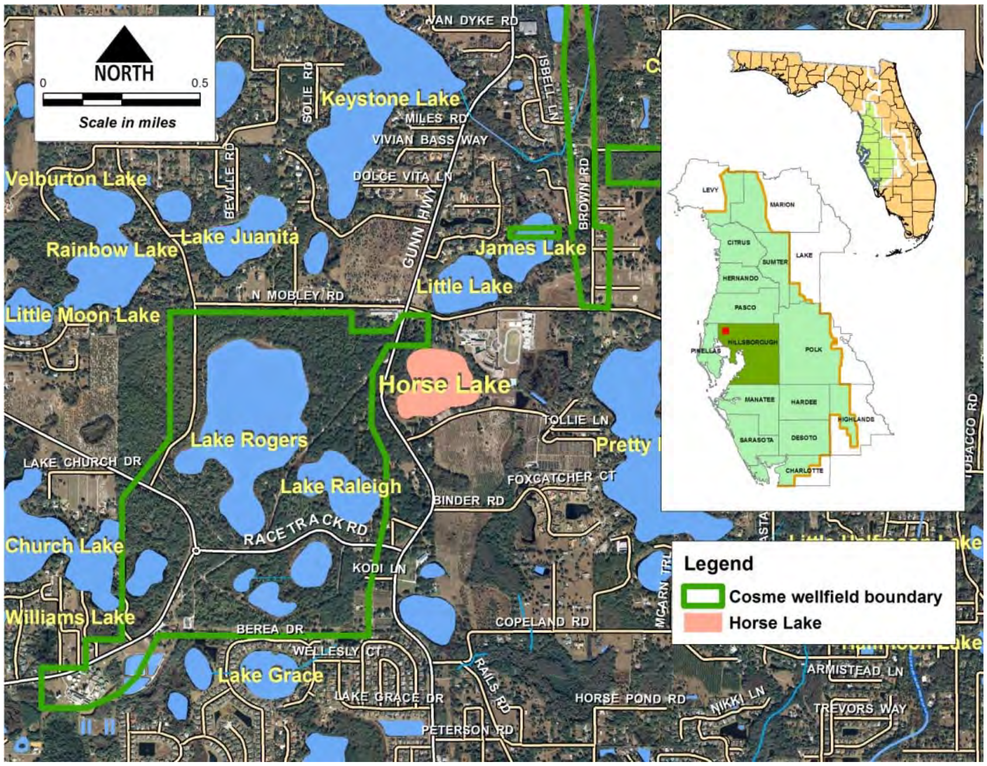

Figure 1. Location of Horse Lake in Hillsborough County, Florida.

Horse Lake's shoreline is approximately one-third private residences, one-third developed as a school, and one-third undeveloped. Horse Lake is often described as being within the Brooker Creek or Rocky Creek watersheds, but the lake is relatively isolated. Surface water inflow to Horse Lake occurs as overland flow from the lake's small drainage basin, as well as flow through drainage swales and minor flow systems. Discharge from the lake can occur via a culvert under Gunn Highway to an unmaintained ditch excavated from Gunn Highway to Lake Raleigh (Figure 2). Discharge from Lake Raleigh can occur to Lake Rogers via a low spot on a wellfield access road between the lakes, while discharge from Lake Rogers can occur through culverts under Race Track Road and Gunn Highway (Figure 2). Some discharge from both Lakes Horse and Raleigh has been documented in recent years, but there are no documented occurrences of discharge from Lake Rogers in over fifty years.

Horse Lake and other neighboring lakes are unique in that they are located in or adjacent to the Cosme-Odessa Wellfield, the oldest public supply wellfield in the District. Therefore, Horse and adjacent lakes have been subjected to the effects of groundwater withdrawals longer than any other lakes in the District. The wellfield consists of the original Cosme wellfield constructed in 1930 (on approximately 1.1 square miles of property), as well as a linear Odessa wellfield spanning approximately 2 miles to the north along Gunn Highway (Figure 3). The original wellfield began supplying water to the City of St. Petersburg in 1930, while withdrawals along the linear expansion began in the early 1950s. Monthly withdrawals steadily

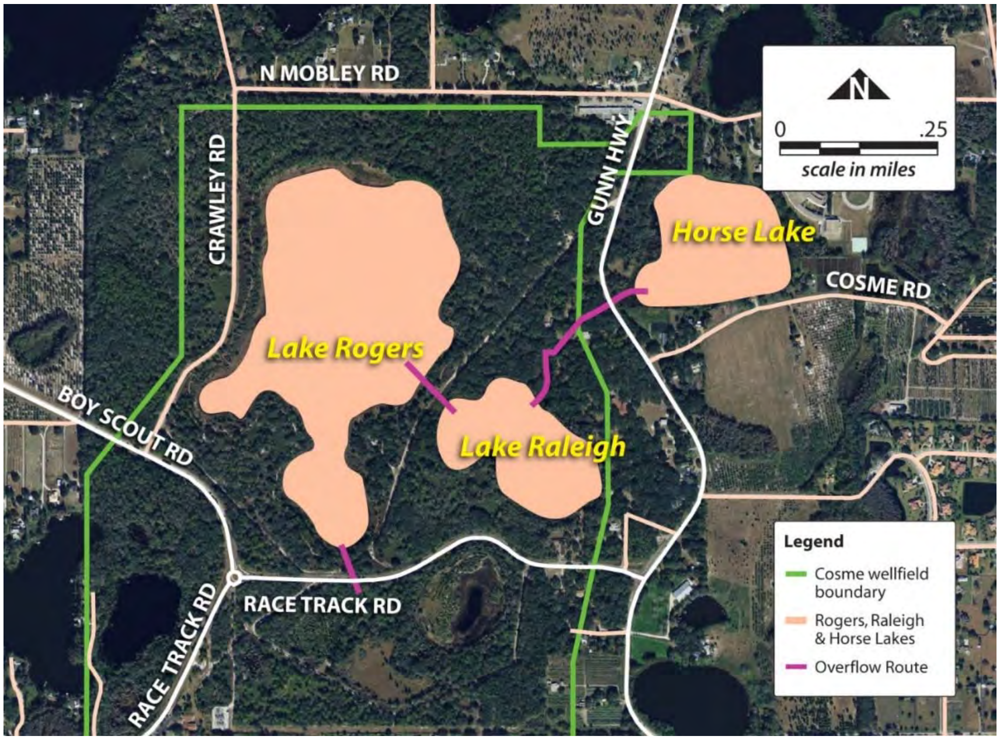

Figure 2. Flow between Lakes Horse, Raleigh, and Rogers.

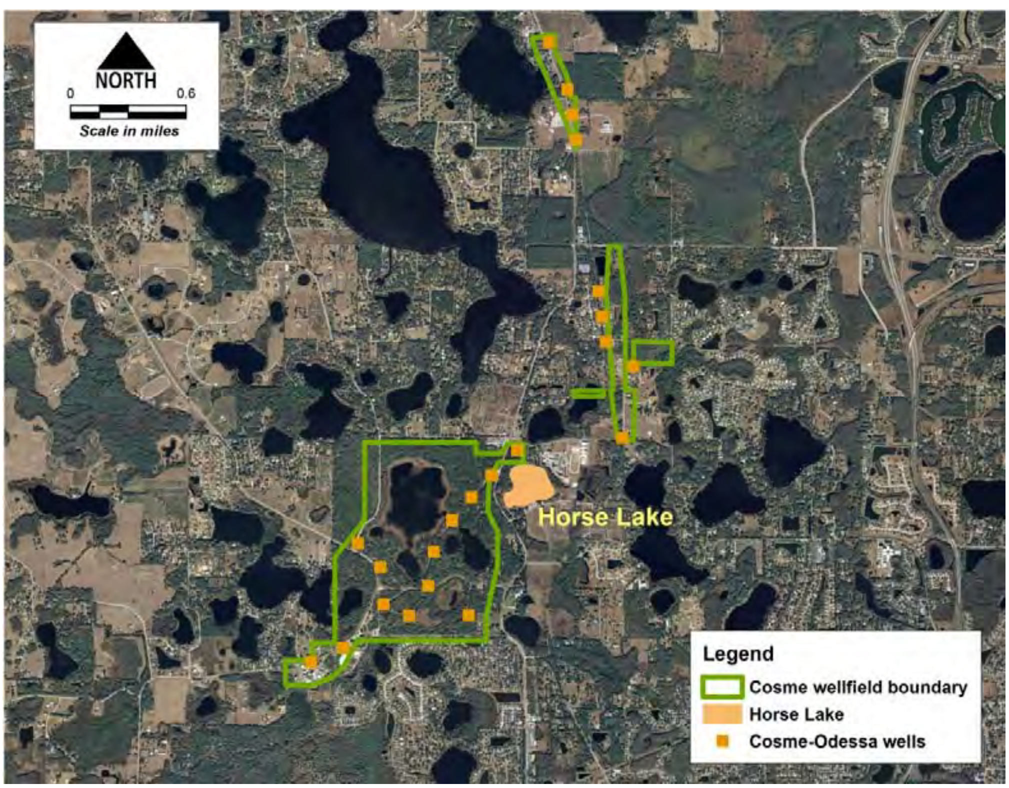

Figure 3. Horse Lake and the Cosme-Odessa Wellfield.

climbed to as much as 21 million gallons per day (mgd) in 1962 (Figure 4). By the 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 about 12 mgd on annual average. Withdrawal rates during the Current period at the wellfield typically average approximately 6 mgd on annual average.

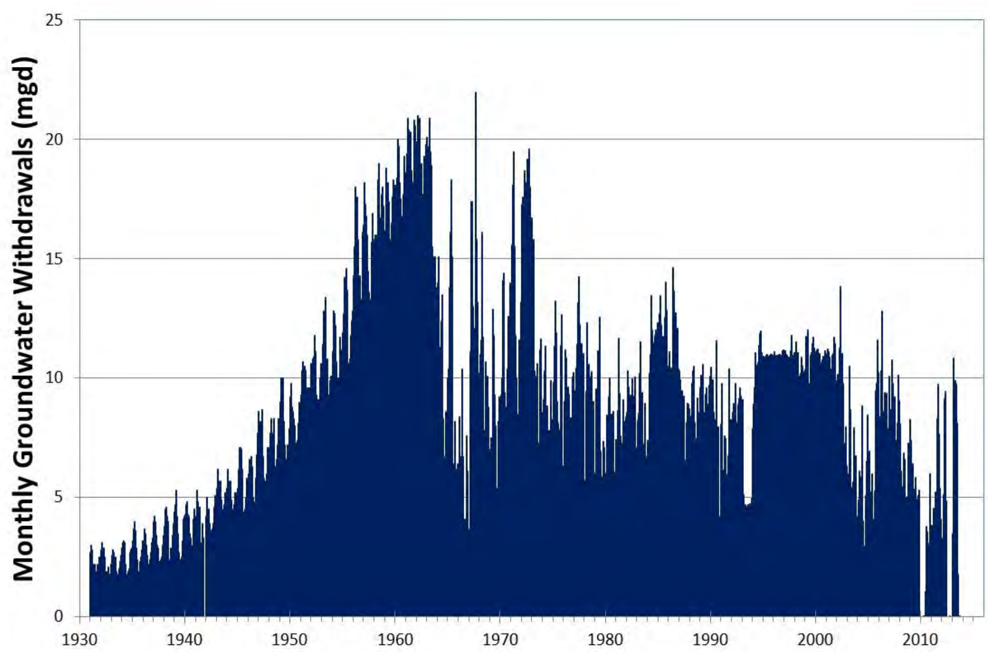

Figure 4. Cosme-Odessa Wellfield withdrawals

C. Revised Minimum Levels Proposed for Horse Lake

Revised minimum levels proposed for Horse Lake are presented in Table 1 and discussed in more detail by Carr and others (2016). Minimum levels represent long-term conditions that, if achieved, are expected to protect water resources and the ecology of the area from significant harm that may result from water withdrawals. The Minimum Lake Level is the elevation that a lake's water levels are required to equal or exceed fifty percent of the time on a long-term basis. The High Minimum Lake Level is the elevation that a lake's water levels are required to equal or exceed ten percent of the time on a long-term basis. The Minimum Lake Level therefore represents the required 50th percentile (P50) of long-term water levels, while the High Minimum Lake Level represents the required 10^{th} percentile (P10) of long-term water levels. To determine the status of minimum levels for Horse Lake or minimum flows and levels for any other water body, long-term data or model results must be used.

Table 1. Proposed Minimum Levels for Horse Lake.

Proposed Minimum Levels	**Elevation in Feet** NGVD 29
High Minimum Lake Level	44.9
Minimum Lake Level	43.9

D. Status Assessment

The lake status assessment approach involves using actual lake stage data for Horse Lake from August 2002 through 2015, which was determined to represent the "Current" period. The Current period represents a recent "Long-term" period when hydrologic stresses (including groundwater withdrawals) and structural alterations are reasonably stable. "Long-term" is defined as a period that has been subjected to the full range of rainfall variability that can be expected in the future. As demonstrated in Hancock and McBride (2016), groundwater withdrawals during this period were relatively consistent. To create a data set that can reasonably be considered to be "Long-term", a line of organic correlation (LOC) analysis 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 Horse Lake (Hancock and McBride, 2016). By using this technique, the limited years of Current lake level data can be projected back to create a simulated data set representing over 60 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 Horse Lake was used for the status assessment (Hancock and McBride, 2016). The best resulting correlation for the LOC model created with measured data was the 4-year weighted period, with a coefficient of determination of 0.65. A hybrid model was used for the final results, in which the model results from August 2002 through 2015 were replaced with actual lake data for that period, in order to produce the best possible long-term results. The resulting lake stage exceedance percentiles are presented in Table 2.

As an additional piece of information, Table 2 also presents the percentiles calculated directly from the measured lake level data for Horse Lake for the period from August 2002 through 2015. A limitation of these values is that the resulting lake stage exceedance percentiles are representative of rainfall conditions during only the past 13 years, rather than the longer-term rainfall conditions represented in the 1946 to 2015 LOC model simulation.

Table 2. Comparison of lake stage exceedance percentiles derived from the lake stage/LOC results, exceedance percentiles of the August 2002 to 2015 data, and the revised minimum levels proposed for Horse Lake.

Percentile	**Lake Stage/LOC Model Current Withdrawal Scenario Results** Elevation in feet NGVD 29	**August 2002 to 2015 Data** Elevation in feet NGVD 29	**Proposed Minimum Levels** Elevation in feet NGVD 29
P10	46.3	47.1	44.9
P50	43.6	44.9	43.9

A comparison of the LOC model with the revised minimum levels proposed for Horse Lake indicates that the Long-term P10 is 1.4 feet above the proposed High Minimum Lake Level, and the Long-term P50 0.3 feet lower than the proposed Minimum Lake Level. The P10 elevation derived directly from the August 2002 to 2015 lake data is 2.2 feet higher than the proposed High Minimum Lake Level, and the P50 elevation is 1.0 feet higher than the proposed Minimum Lake Level. Differences in rainfall between the shorter 2002 to 2015 period and the longer 1946 to 2015 period used for the LOC modeling analyses likely contribute to the differences between derived and measured lake stage exceedance percentiles.

Conclusions

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

Minimum flow and level status assessments are completed on an annual basis by the District and on a five-year basis as part of the regional water supply planning process. In addition, Horse Lake is included in the Comprehensive Environmental Resources Recovery Plan for the Northern Tampa Bay Water Use Caution Area (40D-80.073, F.A.C). Therefore, the status of Horse Lake will be reassessed by the District and Tampa Bay Water as part of this plan, and as part of Tampa Bay Water's Permit Recovery Assessment Plan (required by Chapter 40D-80, F.A.C. and the Consolidated Permit (No. 20011771.001)). Tampa Bay Water, in cooperation with the District, will assess the specific needs for recovery in Horse Lake and other water bodies affected by groundwater withdrawals from the Central System Facilities. By 2020, if not sooner, an alternative recovery project will be proposed if Horse Lake is found to not be meeting its adopted minimum levels. The draft results of the Permit Recovery Assessment Plan are due to the District by December 31, 2018.

E. References

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APPENDIX C

Draft Technical Memorandum

August 11, 2016

TO: David W. Carr, Staff Environmental Scientist, Resource Evaluation Section

FROM: Jason Patterson, Hydrogeologist, Resource Evaluation Section

Subject: Evaluation of Groundwater Withdrawal Impacts to Horse Lake

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1.0 Introduction

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

2.0 Hydrogeologic Setting

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

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

3.0 Evaluation of Groundwater Withdrawal Impacts to Horse Lake

A number of regional groundwater flow models have included the area around Horse Lake in northwest Hillsborough County. Ryder (1982) simulated the entire extent of the Southwest Florida Water Management District. In 1993, the District completed the Northern Tampa Bay groundwater flow model that covered a 2,000 square mile area of Hillsborough, Pinellas, Pasco, and Hernando Counties (SWFWMD, 1993). In 2002, the USGS simulated the entire Florida peninsula in their Mega Model of regional groundwater flow (Sepulveda, 2002). The most recent and advanced simulation of southern

Pasco County and the surrounding area is the Integrated Northern Tampa Bay (INTB) model (Geurink and Basso, 2012). The construction and calibration of this model was part of a cooperative effort between the SWFWMD and Tampa Bay Water (TBW), a regional water utility that operates 11 major

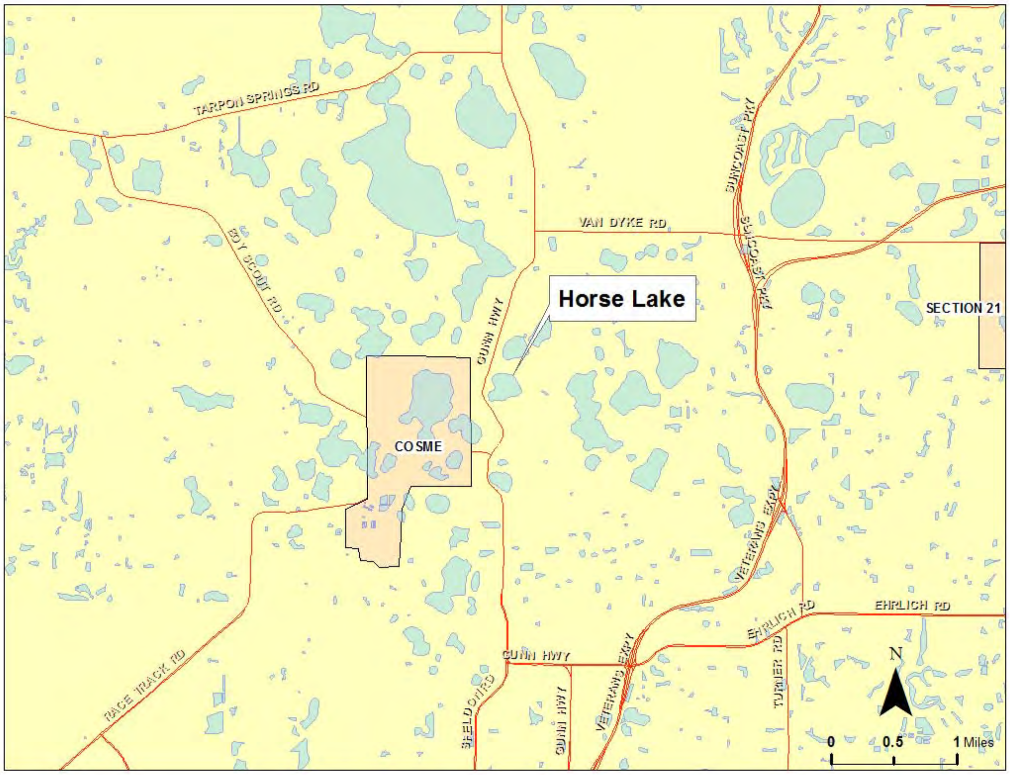

Figure 1. Location of Horse Lake.

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.

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

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

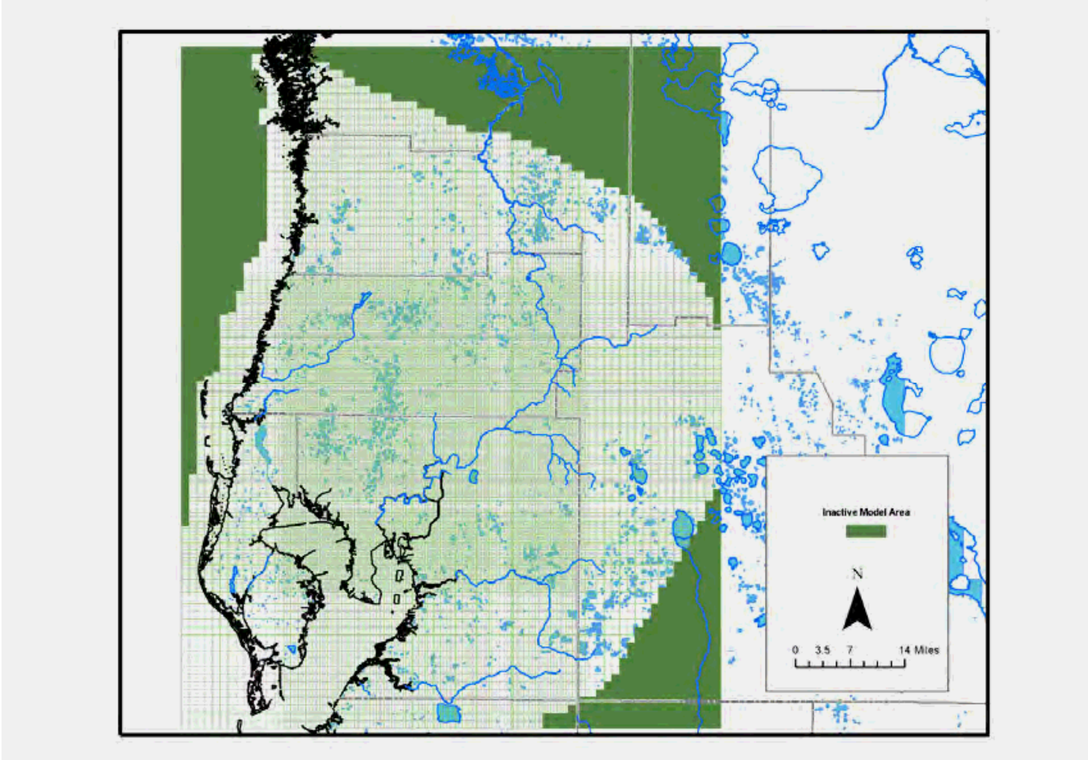

Figure 2. Groundwater grid used in the INTB model

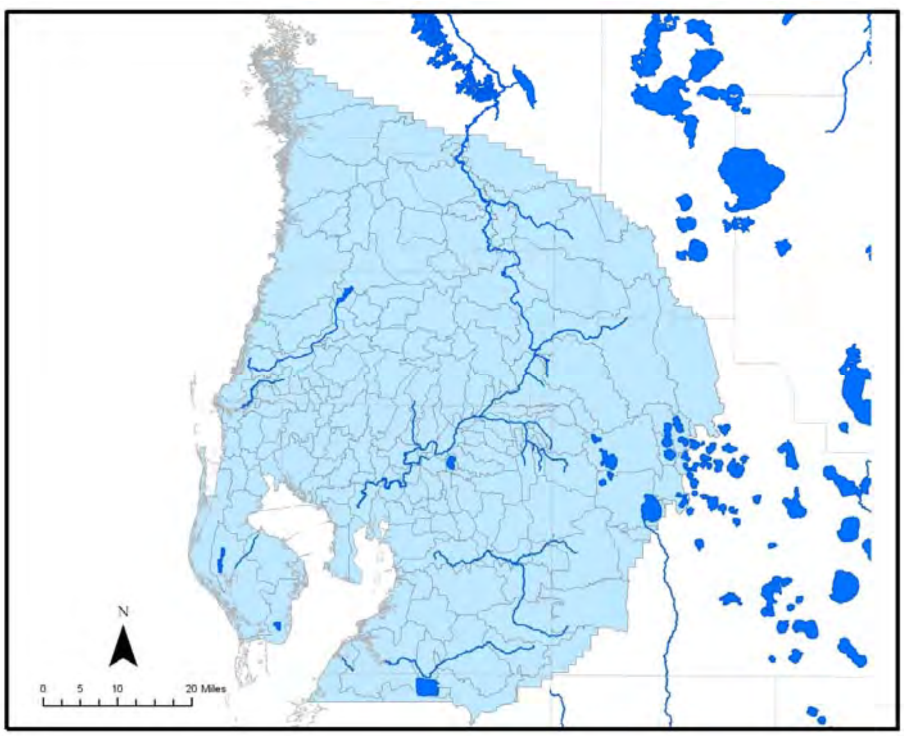

Figure 3. HSPF subbasins in the INTB model.

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

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

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

3.1 INTB Model Scenarios

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

Taking the difference in simulated heads from the 1989-2000 pumping to non-pumping runs, the average predicted drawdown in the surficial aquifer near Horse Lake was 1.8 ft and 11.3 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 Horse Lake was 0.9 ft and 5.9 ft in the Upper Floridan aquifer (Figure 7 and 8). Table 1 presents the predicted drawdown in the surficial aquifer based on the INTB model results.

Table 1. INTB model results for Horse Lake.

Lake Name	**Predicted Drawdown (ft) in the Surficial Aquifer due to 1989-2000 Withdrawals***	**Predicted Drawdown (ft) in the Surficial Aquifer with TBW Withdrawals reduced to 90 mgd***
Horse	1.8	0.9
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***
Horse	11.3	5.9

* Average drawdown from model cells intersecting lake

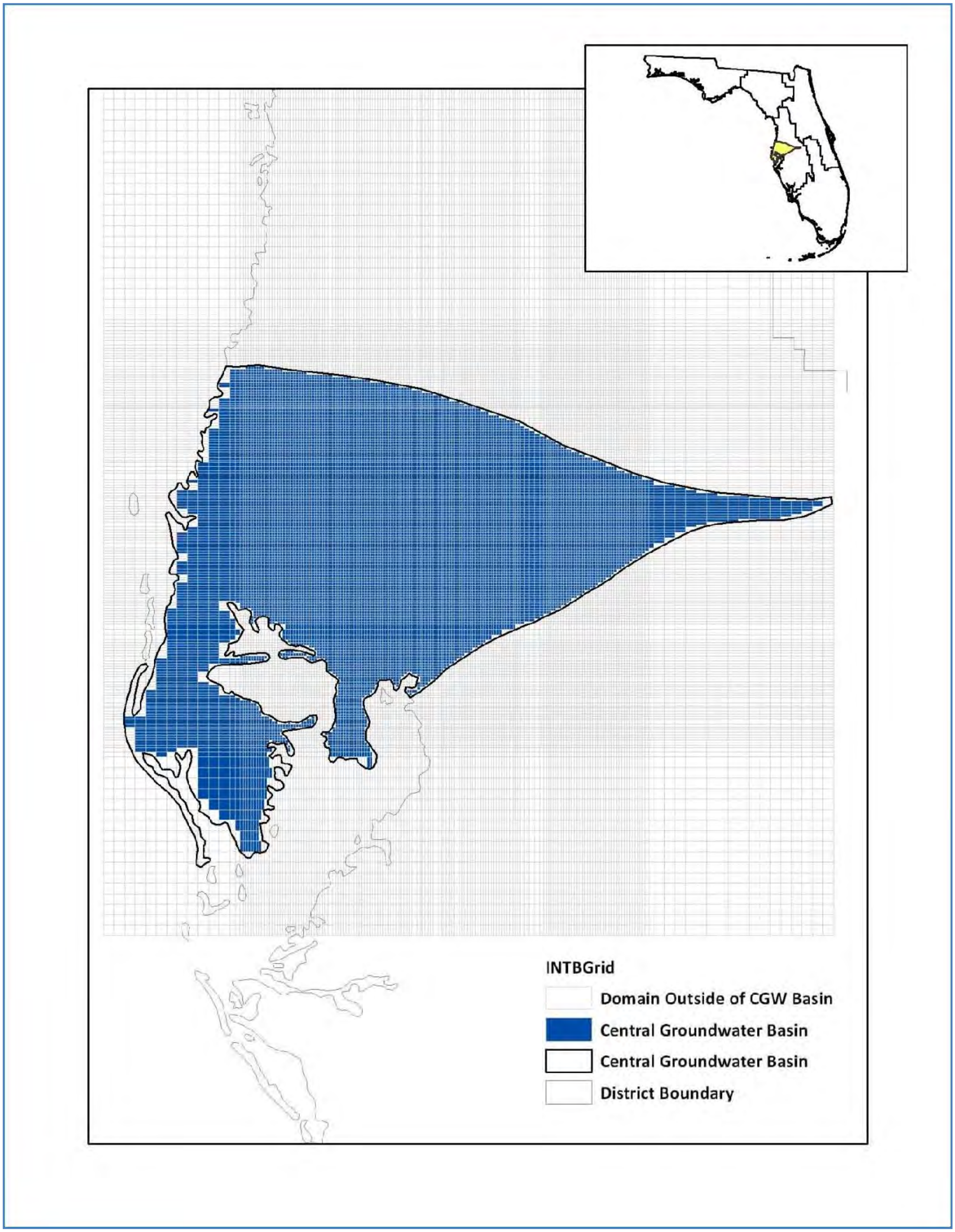

Figure 4. INTB scenarios where impacts to the hydrologic system were simulated due to groundwater withdrawals in the Central West-Central Florida Groundwater Basin.

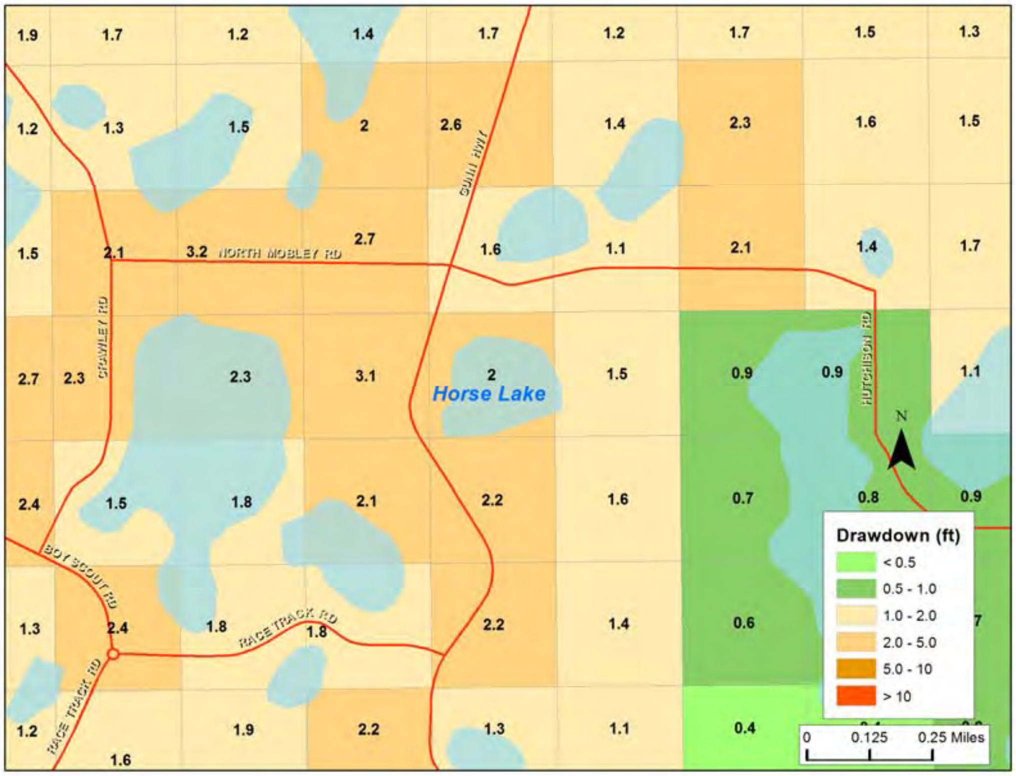

Figure 5. Predicted mean drawdown in the surficial aquifer due to 1989-2000 groundwater withdrawals.

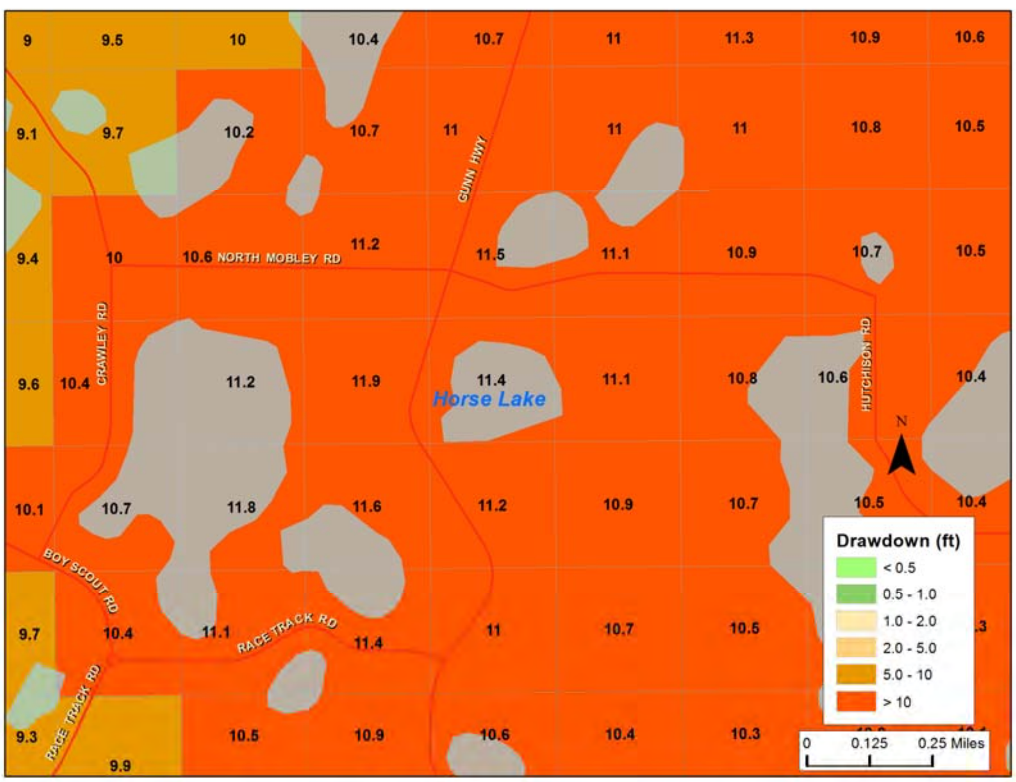

Figure 6. Predicted mean drawdown in the Upper Floridan aquifer due to 1989-2000 groundwater withdrawals.

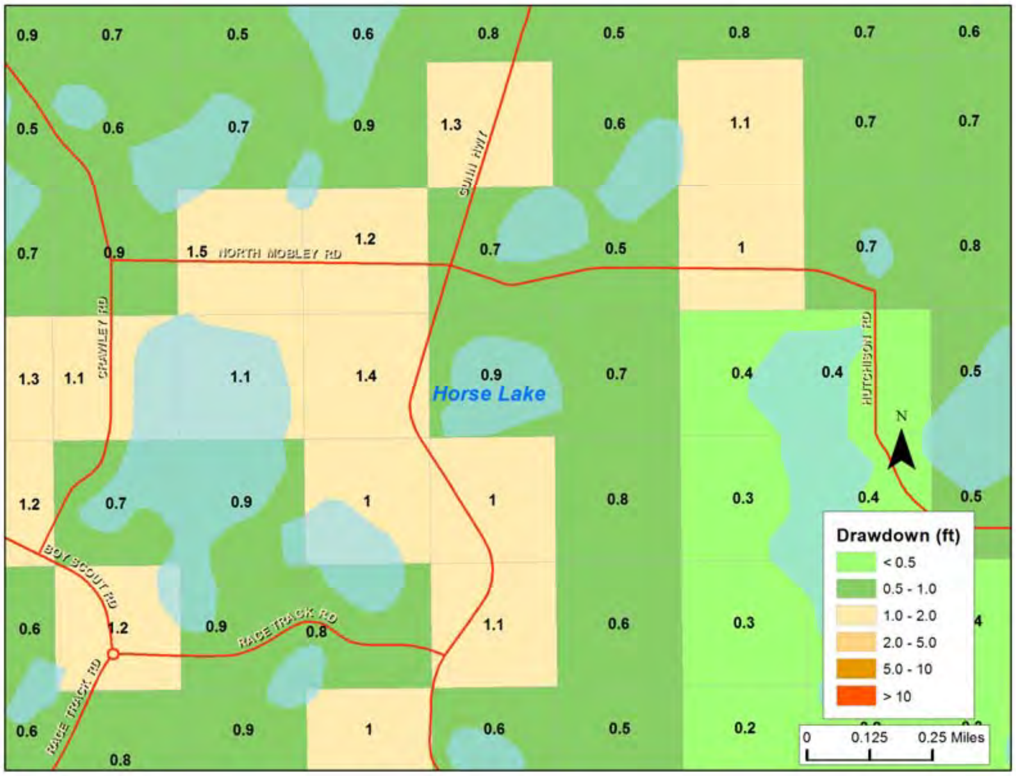

Figure 7. Predicted mean drawdown in the surficial aquifer due to TBW 90 mgd groundwater withdrawals.

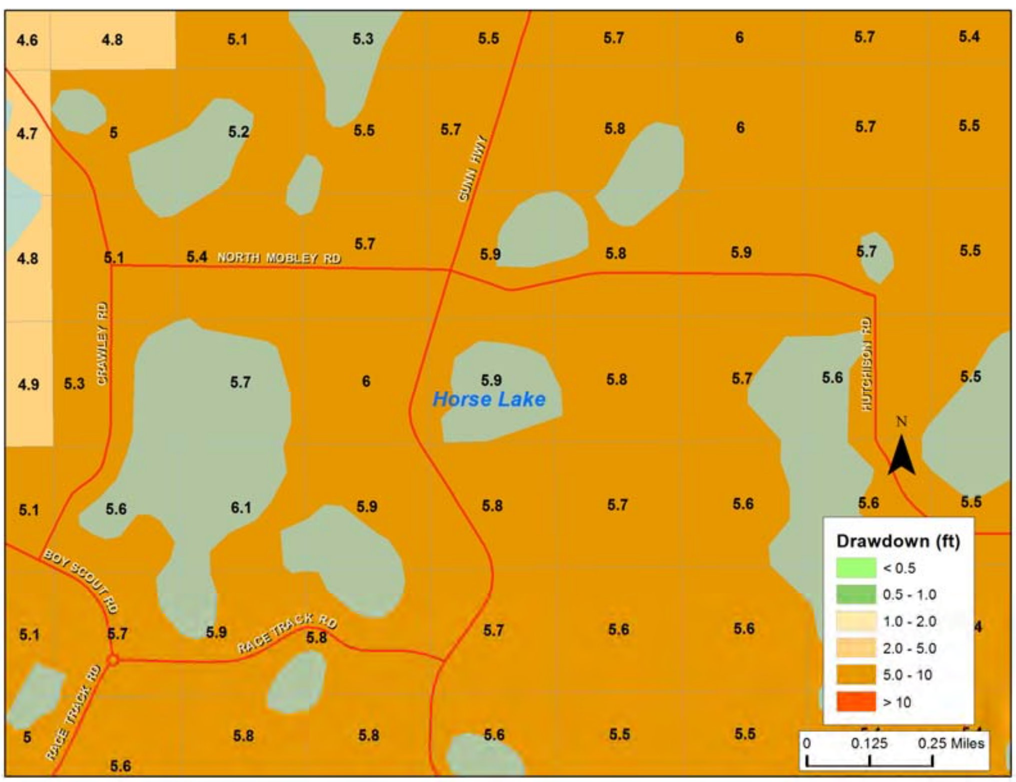

Figure 8. Predicted mean drawdown in the Upper Floridan aquifer due to TBW 90 mgd groundwater withdrawals.

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