Minimum and Guidance Levels for Starvation Lake in Hillsborough County, Florida

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Water Resources Bureau
Resource Evaluation Section

Southwest Florida Water Management District

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Cover: Sandhill cranes on a flooded road between Lake Starvation and Crum Lake; Gauge location on Starvation Lake, 10/17/2013.

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Introduction

Establishment of Minimum Flows and Guidance Levels for Starvation Lake

This report describes the development of minimum and guidance levels for Starvation Lake in Hillsborough County, Florida. The levels (Table 1) were developed using peer-reviewed methods for establishing lake levels within the Southwest Florida Water Management District (District) and are protective of all relevant environmental values identified for consideration in the Water Resource Implementation Rule when establishing minimum flows and levels (see Rule 62-40.473, Florida Administrative Code [F.A.C.]). Following a public input process, the minimum and guidance levels were approved by the District Governing Board on May 19, 2015, adopted into rule on September 1, 2015 and became effective on September 21, 2015. Rulemaking for these levels also included removal of previously adopted guidance levels for the lake from District rules.

Table 1. Minimum and Guidance Levels for Starvation Lake.

Minimum and Guidance Levels	Elevation in Feet NGVD 29	Elevation in Feet NAVD 88
High Guidance Level	53.5	52.65
High Minimum Lake Level	52.7	51.85
Minimum Lake Level	50.4	49.55
Low Guidance Level	49.7	48.85

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 for lakes, wetlands, rivers and aquifers. Section 373.042(1)(a), F.S., states that “[t]he minimum flow for a given watercourse shall be the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area." Section 373.042(1)(b), F.S., defines the minimum water level of an aquifer or surface water body as "…the level of groundwater in an aquifer and the level of surface water at which further withdrawals would be significantly harmful to the water resources of the area." Minimum flows and levels are established and used by the 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 minimum flows and levels 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 minimum flows and levels 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 setting identifying the need for establishment of minimum flows and levels.

The Florida Water Resource Implementation Rule, specifically Rule 62-40.473, F.A.C., provides additional guidance for the establishment of minimum flows and levels, 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 minimum flows and levels 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 minimum flows and levels 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 minimum flows and levels 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 minimum flows and levels for priority water bodies. The District implements established minimum flows and levels 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 Minimum Flow and Levels 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 Minimum Flows and Levels Program, which logistically addresses six major tasks: 1) development and reassessment of methods for establishing minimum flows and levels; 2) adoption of minimum flows and levels for priority water bodies (including the prioritization of water bodies and facilitation of public and independent scientific review of proposed minimum flows and levels and methods used for their development); 3) monitoring and compliance evaluations; 4) development and implementation of recovery strategies; 5) minimum flows and levels compliance reporting; and 6) ongoing support for minimum flow and level regulatory concerns and prevention strategies. Many of these tasks are discussed or addressed in this minimum levels report for Starvation Lake; additional information on all tasks associated with the District's Minimum Flows and Levels Program is summarized by Hancock *et al.* (2010).

The District's Minimum Flows and Levels Program is implemented based on a few 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. It is also 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 minimum flows and levels. Finally, the existence of long-term hydrologic regimes that may differ from non-withdrawal impacted conditions but are sufficient to meet flow or water level requirements associated with established minimum flows and levels and are therefore sufficient to prevent significant harm, is assumed.

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 body of knowledge has been used by the District and other water management districts within the state to identify significant harm thresholds or criteria supporting development of minimum flows and levels for hundreds of Florida 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 or hydrologic regime for a river or lake system that is not impacted or affected by groundwater or surface water withdrawals. A new hydrologic regime for the system would be associated with each increase in water use, from small, perhaps distant withdrawals that have no measurable effect on the historic regime to large, perhaps more proximal 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. The threshold regime, resulting primarily from water withdrawals, is expected to maintain the general hydropattern of the historic flow or water level regime, but with differences in the amplitude or duration of flows or levels may result in a general reduction of all or portions of the hydrologic regime. Identification of this threshold hydrologic regime based on use of appropriate significant harm thresholds or criteria is expected to allow for water withdrawals while protecting the water resources and ecology from significant harm. Thus, minimum flows and levels represent minimum acceptable rather than historic or potentially optimal hydrologic conditions.

Consideration of Changes and Structural Alterations and Environmental Values

When establishing minimum flows and levels, 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 minimum flows and levels 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 minimum flows and levels, 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 compliance status for water bodies with revised or established minimum flows and levels (*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 (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 recommend minimum levels. For Category 1 or 2 Lakes, a significant change standard, referred to as the Cypress Standard, is developed. For Category 3 lakes, six significant change standards, including a Basin Connectivity Standard, a Recreation/Ski Standard, an Aesthetics Standard, a Species Richness Standard, a Lake Mixing Standard and a Dock-Use Standard are typically developed. Other available information, including potential changes in the coverage of herbaceous wetland and submersed aquatic plants is also considered when establishing minimum levels for Category 3 Lakes. The standards and other available information are associated with the environmental values identified for consideration in Rule 62-40.473, F.A. C., when establishing minimum flows or levels (Table 2). Descriptions of the specific standards and other information evaluated to support development of minimum levels for Starvation Lake are provided in subsequent sections of this report.

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. (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.

In accordance with Chapter 40D-8, F.A.C., Minimum and Guidance Levels were developed for Starvation Lake (see Table 3), a Category 3 lake located in Northwest Hillsborough County, Florida. The levels were established using best available information, including field data that were obtained specifically for the purpose of minimum levels development. The data and analyses used for development of the revised levels are described in the remainder of this report

The District is in the process of converting from use of the NGVD29 datum to use of the North American Vertical Datum of 1988 (NAVD 88). While the NGVD29 datum is used for most elevation values included within this report, in some circumstances notations are made for elevation data that was collected or reported relative to mean sea level or relative to NAVD88 and converted to elevations relative to NGVD29. All datum conversions were derived using the Corpscon 6.0 software distributed by the United States Army Corps of Engineers.

Table 2. Environmental values identified in the state Water Resource Implementation Rule for consideration when establishing minimum flows and 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 Standard Basin Connectivity Standard Species Richness Standard Herbaceous Wetland Information Submersed Aquatic Macrophyte Information
Estuarine resources	NA[1]
Transfer of detrital material	Cypress Standard Wetland Offset 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	Lake Mixing Standard Cypress Standard Herbaceous Wetland Information Submersed Aquatic Macrophyte Information
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 Setting and Description

Starvation Lake (Figure 1) is located in northwest Hillsborough County, Florida (Section 21, Township 27 south, Range 18 east). The lake lies within the Section 21 Wellfield, which is one of eleven regional water supply wellfields operated by Tampa Bay Water under the Consolidated Permit. The property surrounding the lake is known as Lake Park, maintained by the Hillsborough County Parks and Recreation Department.

White (1970) classified the region of west-central Florida containing Starvation Lake as the Northern Gulf Coastal Lowlands physiographic region. The area surrounding the lake is also categorized as the Land-O-Lakes subdivision of the Tampa Plain in the Ocala Uplift Physiographic District (Brooks 1981). This area has numerous neutral to slightly alkaline, low to moderate nutrient, clear-water lakes (Griffith *et al.* 1997) in a region composed of a moderately thick plain of silty sand overlying limestone.

The drainage area for Starvation Lake is 0.7 square miles (Florida Board of Conservation 1969; Hancock and McBride 2014). Inlets to the lake include a culvert connected to a small cypress wetland northwest of the lake, and a ditch entering the lake from Lake Jackson to the west (Figure 2). A series of ditches, culverts, pipes and a wetland system connect Starvation Lake to Lakes Crum and Simmons. Water exits the lake system along the south shore of Lake Simmons through a forested wetland and off the southwest corner of Section 21 Wellfield.

Surface water flows from the Calusa Trace stormwater ponds to culverts under Van Dyke Road, where it enters the Section 21 property. Water then passes through a wetland forest and into Lake Jackson. Flow passes from Lake Jackson to Starvation Lake via a ditch once Lake Jackson reaches its control elevation (Figure 2). Minor flows may enter Lake Jackson via a culvert on Whirley Road originating from Van Dyke Estates (Figure 2 and 3). In 2001, the City of St. Petersburg was concerned that Starvation Lake water levels are strongly influenced by the development to the north and that the majority of the lake's inflow is not received until manmade retention basins in developments to the north reach storage capacity (Voakes 2001). In response to these concerns, the District took into account several factors. An inspection of historic aerials of the Starvation Lake area shows that many surface-water and land-use modifications have occurred in and around the lake basin from 1938 through current (Figure 4). Significant changes include: 1) the extension and paving of Dale Mabry Highway and Van Dyke Road in the 1950s, 2) the construction of the Interceptor Canal near the southern boundary of the wellfield property in 1961 (built to relieve flooding in the watersheds to the east of the wellfield), 3) the construction of ditches interconnecting the lakes on the wellfield in the early 1970s, and, 4) the development of subdivision to the north and west of the wellfield (late 1990s to

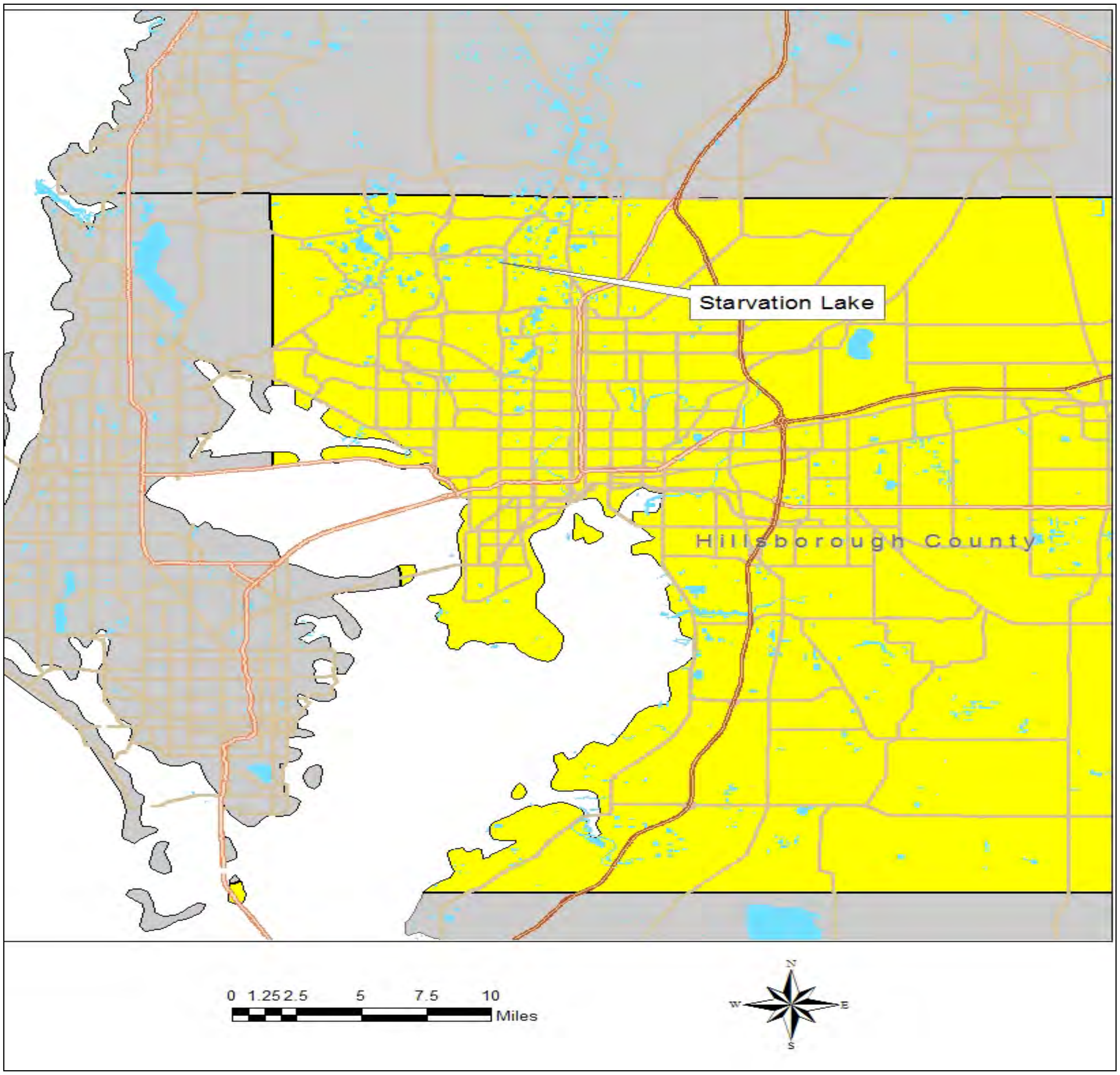

Figure 1. Location of Starvation Lake in Hillsborough County, Florida.

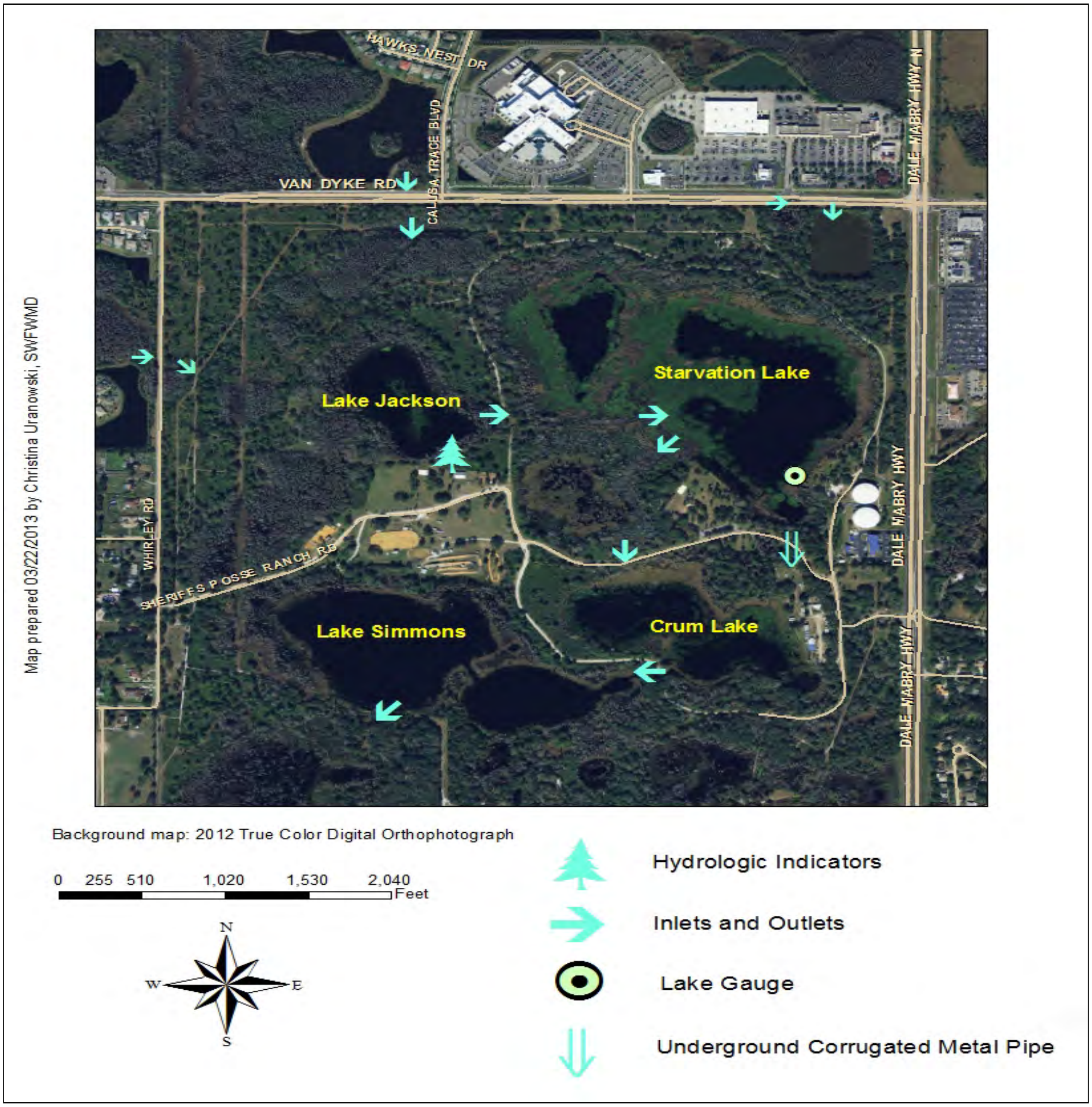

Figure 2. Starvation Lake level gauge, inlets, outlets and sites where hydrologic indicators were measured at within and around Section 21 Wellfield.

Figure 3. A representative road culvert at Whirley Road showing water entering Section 21.

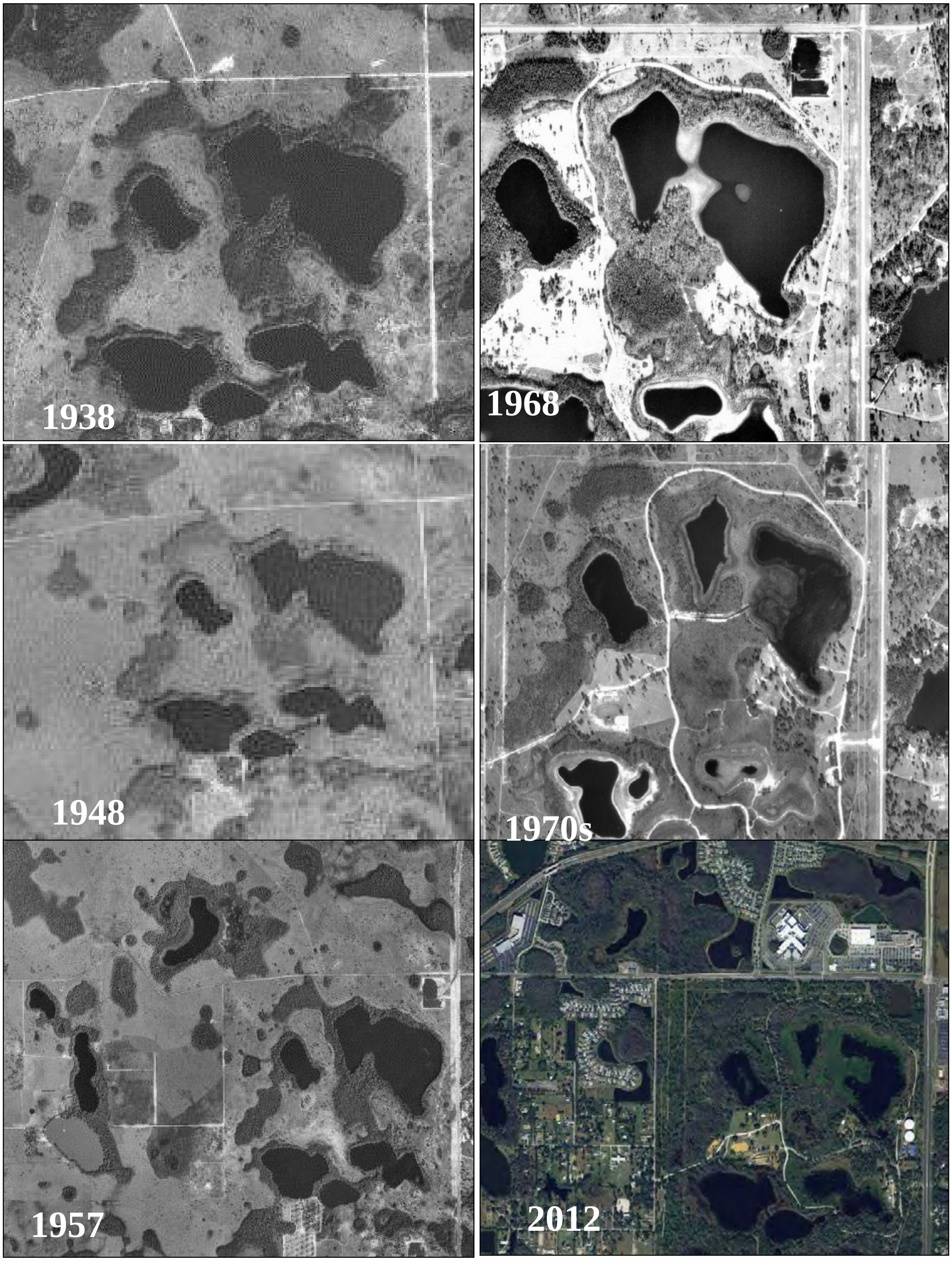

Figure 4. Selected historic aerial photographs (note differing scales) of the Lake Starvation area from 1938 through 2012.

2010s). Currently existing basin alterations are incorporated into the processes of a water budget model developed by the District for Starvation Lake. The model (discussed later in the report and documented in Appendix A) is inclusive of existing drainage features, and tracks inputs and outputs using a daily time-step from 1974 through 2011. The hydrologic processes of rainfall, evaporation, overland flow, engineered basin alterations of inflow and discharge via channels, and flow from and into surficial and Upper Floridan aquifers are included.

In addition to surface water inputs, anecdotal reports indicate that Starvation Lake was intermittently augmented with groundwater pumped from the Floridan aquifer prior to the 1980s (Hassell 1994).

Two long-term surficial aquifer District monitor wells exist within the wellfield, and both were used for Starvation Lake water budget analysis modeling: the St Pete Hillsborough 13 Shallow (SID 19553) and St Pete Jackson 26A Shallow (SID 19549) surficial aquifer monitor wells (Figure 5). Note that Figure 5 refers to SID 19553 St Pete Hillsborough 13 Shallow and SID 19551 St Pete Hillsborough 13 Deep as “Hillsboro” because that is the referenced name used in the District’s WMIS (Water Management Information System).

There are differences in confinement between the wells. A thicker confinement and a less variable water table are evident in the northwest portion of the wellfield when comparing the water levels for the two surficial wells (Figure 6). Communication between the sand surficial aquifer and the Floridan aquifer is high due to the extensive karst development as viewed by a rather deep penetration of the GPR signal (SDII 1995). There is a thin, discontinuous clay confining unit between the aquifers, breeched by many karst features resulting in moderate to high leakage in the Upper Floridan aquifer (Hancock and Basso 1996; and see Appendix A).

There are no surface-water withdrawals from Starvation Lake currently permitted by the District. However, Starvation Lake lies within Section 21 Wellfield, one of the oldest major permitted groundwater withdrawal wellfields in the District (see Appendix A). The locations of permitted groundwater withdrawals within 6 miles of the lake are shown in Figure 7. The maximum, average, and minimum withdrawals from 1992 through 2011 within a three-mile radius of the lake was 17.5, 8.9, and 0.40 mgd, respectively. Of those quantities, approximately 80 percent of the average withdrawals are derived from the wellfield (Figure 8). Water use within the first three miles peaked in 1999 and began decreasing in the mid-2000s due to the wellfield cutbacks.

Lake levels declined steadily from 1963 through early 1970’s when groundwater pumping reached nearly 15 million gallons per day (mgd), in 1964 (Figure 8). A precipitous drop in the lake levels occurred after 1967 through 1972 when withdrawal rates reached over 20 mgd. Wellfield withdrawals were reduced to approximately 10 mgd in 1973 after the South Pasco wellfield became operational (see Appendix A) and lake levels responded but the lake did not rebound to levels measured before wellfield withdrawals for the next 30 years.

Figure 5. Location of monitor wells near Starvation Lake within the Section 21 Wellfield.

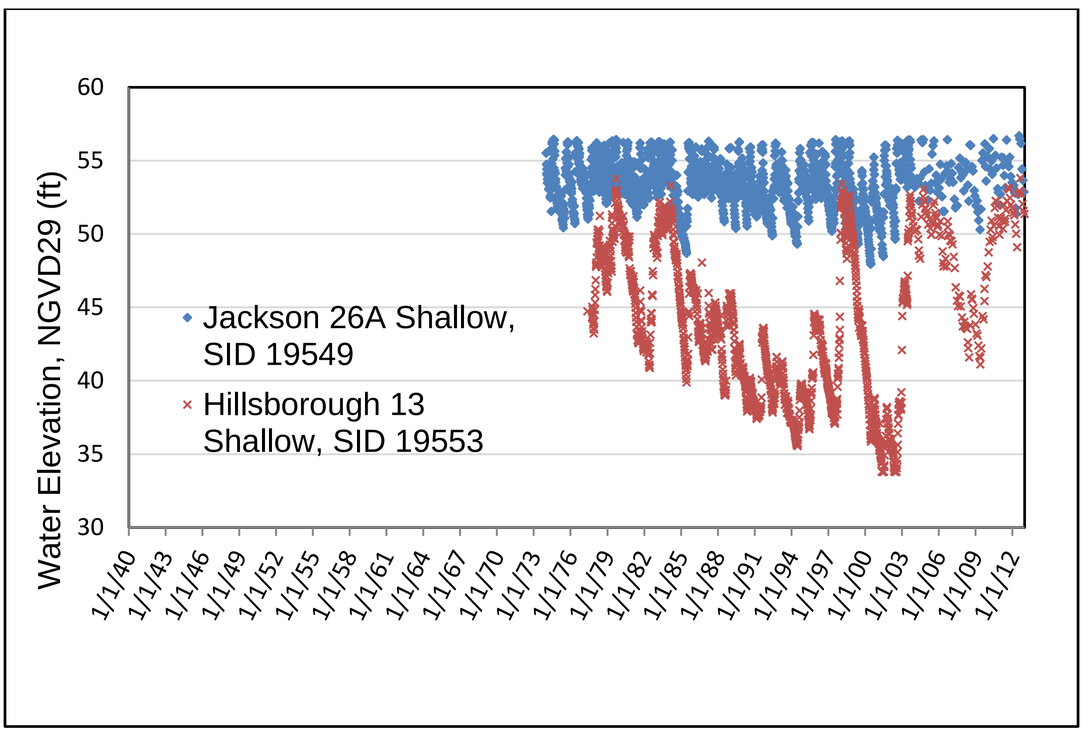

Figure 6. Water levels in Hillsborough 13 Shallow and the more confined and stable Jackson 26A Shallow surficial aquifer monitor wells at the Section 21 Wellfield.

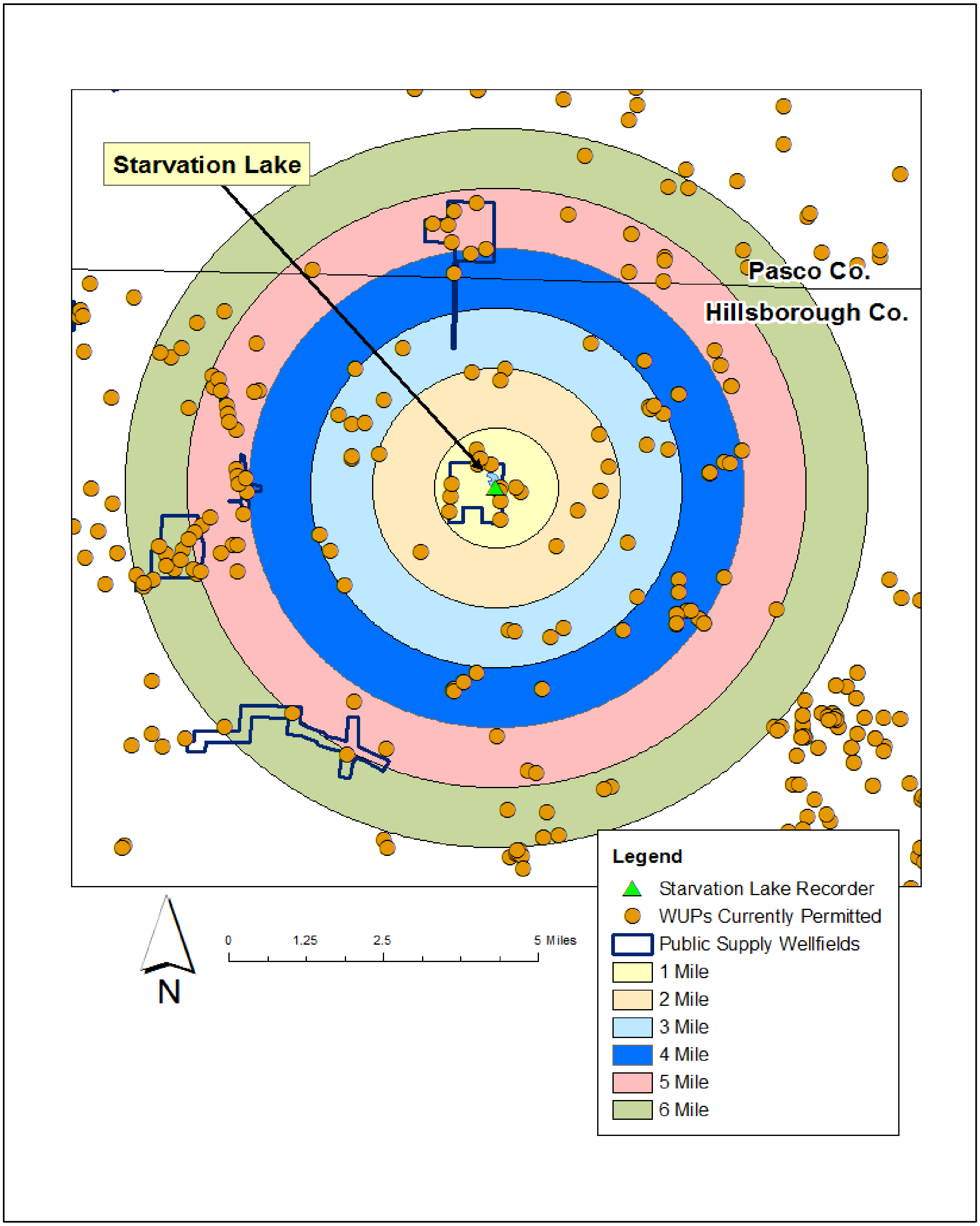

Figure 7. Groundwater withdrawals in 1 mile increments within a 6-mile radius of Starvation Lake.

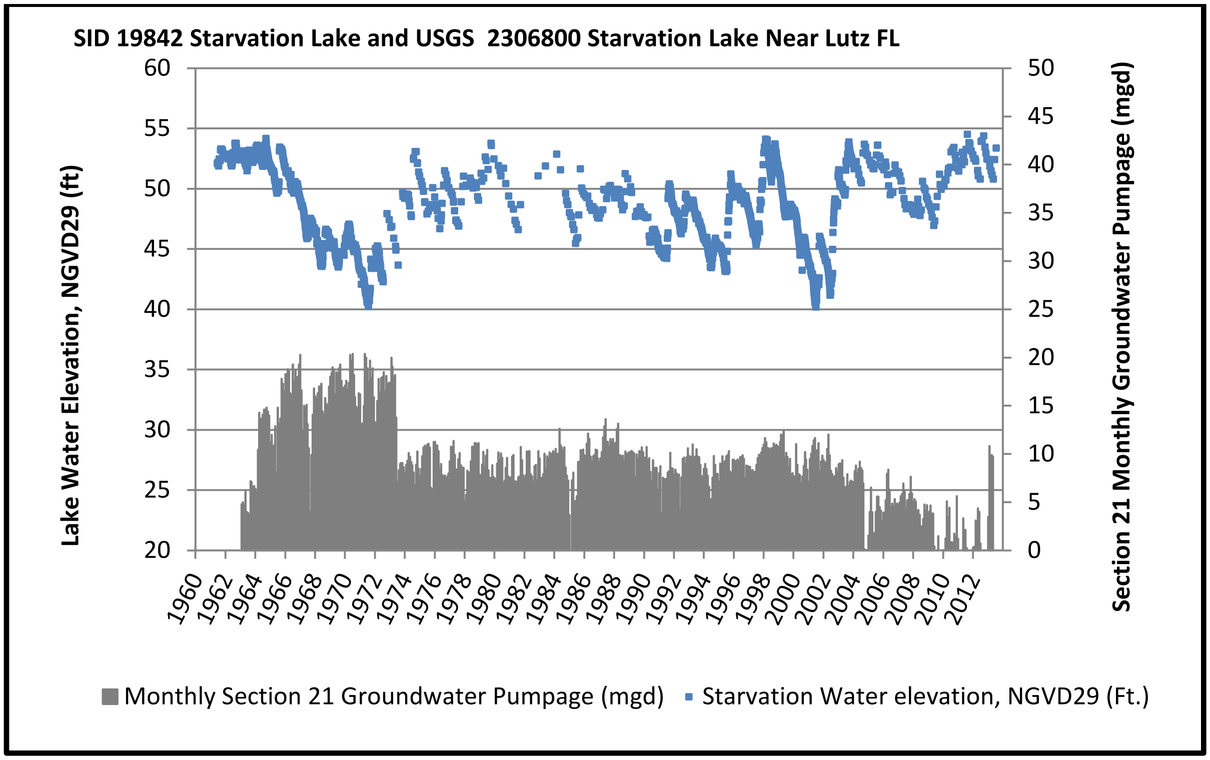

Figure 8. Starvation Lake long-term water level data and groundwater pumping in Section 21 Wellfield.

Since the wellfield withdrawal reductions in the mid-2000s, Starvation Lake occasionally floods over portions of Sheriff's Posse Ranch Road from the wetland that historically had a direct connection to Lake Crum (Figure 9), occurring when the water level reaches 52.8 feet. Flooding also occurs at this elevation on the southeastern side of the lake at the boat ramp (Figure 10).

A lake-depth (i.e., bathymetric) map developed using field survey data collected in August 2006, May 2008 and April 2010 and LiDAR data collected in 2007 is shown in Figure 11. Based on this map, the lake extends over 90.7 acres when the water surface elevation is 53.5 feet above NGVD29 and over 45 acres when the lake stage is 49.7 feet above NGVD29. The lake separates into two basins when the water surface elevation drops below about 46.5 to 48 feet above NGVD 29 (Figure 11). Both lobes of the lake have deep areas with depths of approximately 23 feet. The large lobe on the east side has deep areas at the southern and northern edges while the smaller west side lobe has a smaller southern deep spot.

Figure 9. Starvation Lake flooding over the west end of the paved road across from the BMX bicycle track taken October 17, 2013, gauge reading 53.5 feet above NGVD 29.

Figure 10. Starvation Lake flooding over the road at the boat ramp on July 22, 2003.

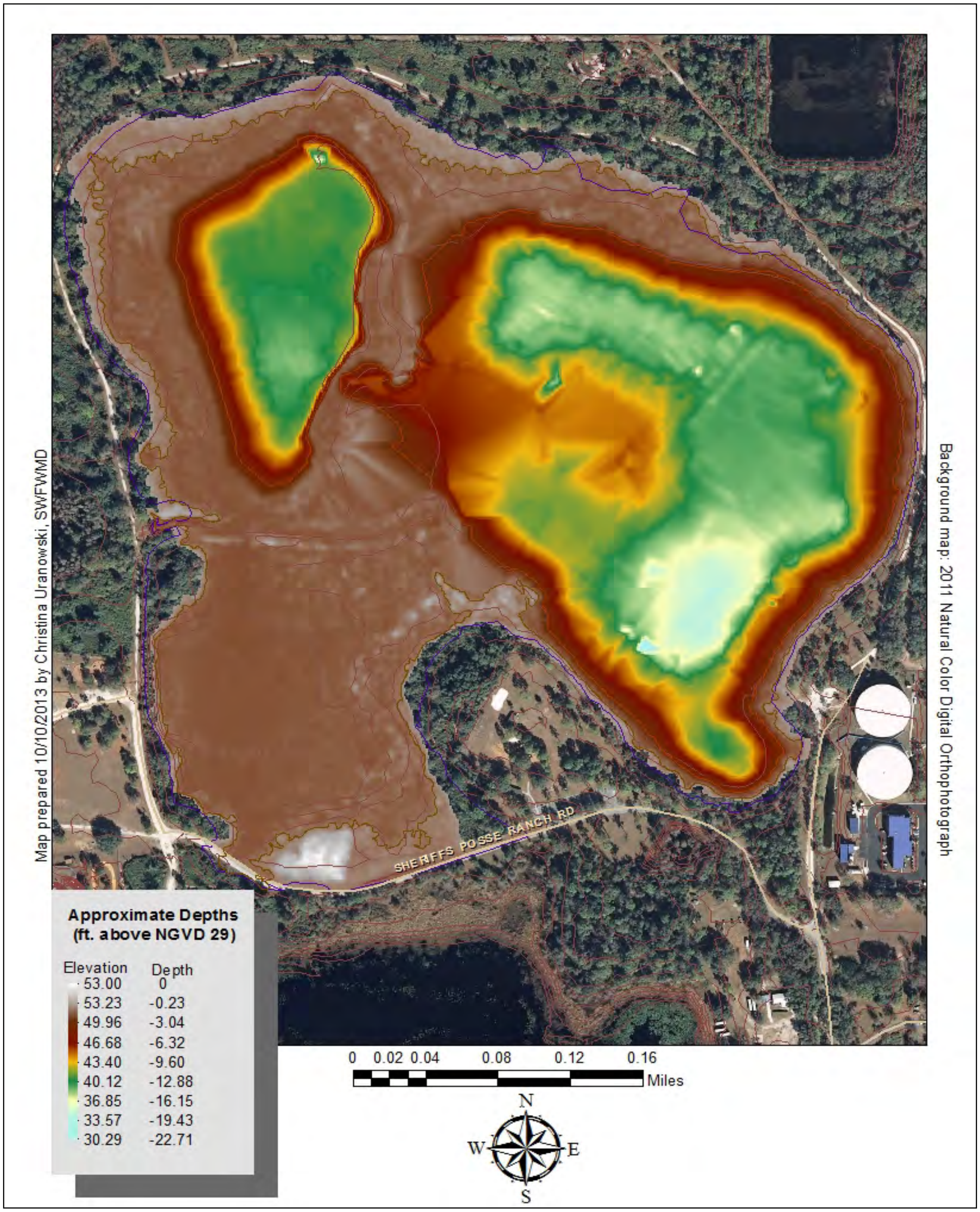

Figure 11. Approximate bottom elevations in ft. above NGVD 29 within the Starvation Lake basin. This triangular irregular network (TIN) map was hillshaded and colored by elevation to depict the elevational depth and was generated from 2007 LiDAR mass points and spot elevation data collected by District staff in 1999 and D.C. Johnson in 2010 using ArcMap 10 and QCoherent software LP360 for ArcGIS.

Previously Adopted Guidance Levels

The Southwest Florida Water Management 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 established.

In September 1980, the District adopted management levels, including minimum and flood levels for Starvation Lake and incorporated the levels into Chapter 40D-8, F.A.C. (Table 4). As part of the work leading to the adoption of management levels in 1980, a Maximum Desirable Level of 52.5 feet above NGVD 29 was also developed for the lake, but was not incorporated into Chapter 40D-8, F.A.C.

Based on changes to sections of the Florida Statutes that address minimum flows and levels in 1996 and 1997, and the development of new approaches for establishing minimum flows and levels, District Water Levels and Rates of Flow rules were modified in 2000. The modifications included incorporation of rule language addressing minimum flows and levels development and the renaming of established levels as Guidance Levels, as indicated for Starvation Lake in Table 4. Subsequent revisions to District rules incorporated additional rule language associated with developing minimum lake levels, and the Ten Year Flood Guidance Level for Starvation Lake and other lakes was removed from Chapter 40D-8, F.A.C. in 2007, when the Governing Board determined that flood-stage elevations should not be included in the District’s Water Levels and Rates of Flow rules. The intent of this latter action was not to discontinue development of regional and site-specific flood stage information, but rather to promote organizational efficiency by eliminating unnecessary rules. Flood stage levels for lakes will continue to be developed under the District's Watershed Management Program, but ten-year flood recurrence levels will not be incorporated into Chapter 40D-8, F.A.C.

Starting in 1989, the District began annually developing a list of stressed lakes to support District's consumptive water use permitting program. As described in the current Water Use Permit Information Manual Part B Basis of Review incorporated by reference into the District’s Consumptive Use of Water Rule (Chapter 40D-2, F.A.C.), "a stressed condition for a lake is defined to be chronic fluctuation below the normal range of lake level fluctuations.” Starvation Lake was classified as a stressed lake from 1991 through 2004.

The previously adopted Guidance and Maximum Levels were developed using methods that differ from the current District approach for establishing Minimum and Guidance Levels (Table 3). The levels are presented here for purposes of comparison, though, they do not necessarily correspond with the currently adopted levels that were developed using current methods.

Table 4. Previously adopted management/guidance Levels for Starvation Lake.

Previously Adopted Management Levels (as originally adopted)	Previously Adopted Guidance Levels[a]	Elevation (feet above NGVD 29)
Ten (10) Year Flood Warning Level	Ten Year Flood Guidance Level	55.55[b]
Minimum Flood Level	High Level	53.00
Minimum Low Management Level	Low Level	50.00
Minimum Extreme Low Management Level	Extreme Low Level	48.00

[a] Adopted management levels were renamed as Guidance Levels in District rules in 2000.
[b] Removed from District rules in 2007.

Methods, Results and Discussion

Summary Data Used in Development of Minimum and Guidance Levels

Minimum and Guidance Levels for Starvation Lake were developed using the methodology for Category 3 Lakes described in Rule 40D-8.624, F.A.C. The levels and additional information are listed in Table 5, along with lake surface areas for each level or feature/standard elevation. Detailed descriptions of the development and use of these data are provided in the subsequent sections of this report.

Lake Stage Data and Exceedance Percentiles

Lake stage data, *i.e.*, surface water elevations for Starvation Lake relative to NGVD 29 were obtained from the District's Water Management Information System (WMIS) data base (WMIS ID 19842). A fifty-two year record of lake stage data exists for Starvation Lake (WMIS SID 19842) from January 1961 through July 2013 (Figure 12, and Figure 2 for the location of the SWFWMD lake water level gage).

Water level data collection at Starvation Lake began in mid-1961, providing less than 2 years of pre-withdrawal data at the lake (Figure 12). The data collection frequency began as weekly until mid-1972, when after a gap of about 1.5 years, was reduced to monthly in January 1974 (Figure 12). Weekly data collection was resumed from 1990 to late-2003, and then returned to monthly data collection through the present. (see Appendix A).

Table 5. Minimum and Guidance Levels, lake stage exceedance percentiles, and control point elevations, significant change standards, and associated surface areas for Starvation Lake.

Level or Feature	Elevation (feet above NGVD)	Lake Area (acres)*
Lake Stage Percentiles		
Current P10 (2005 through 2011)	52.9	84.5
Current P50 (2005 through 2011)	50.4	47.2
Current P90 (2005 through 2011)	48.2	41.9
Historic P10 (Modeled 1974 through 2011)	53.5	90.7
Historic P50 (Modeled 1974 through 2011)	51.2	49.3
Historic P90 (Modeled 1974 through 2011)	49.7	45.5
Normal Pool, Control Point, Other		
Normal Pool	53.5	90.7
Low Floor Slab	56.3	NA
Low Other (boat ramp dirt road)	53.2	88.2
Low Other (top of paved boat ramp)	52.4	73.2
Low Road	52.8	82.8
Control Point	52.7	81
Minimum and Guidance Levels		
High Guidance Level	53.5	90.7
High Minimum Lake Level	52.7	81
Minimum Lake Level	50.4	47.2
Low Guidance Level	49.7	45.5
Significant Change Standards		
Species Richness Standard	48.4	42.3
Aesthetic Standard	49.7	45.5
Wetland Offset	50.4	47.2
Basin Connectivity Standard	52.5*	76.4
Dock-Use Standard	NA	NA
Recreation/Ski Standard	NA	NA
Lake Mixing Standard	NA	NA

NA = not available

* this standard is above the P50 elevation and was therefore not considered appropriate for minimum level development

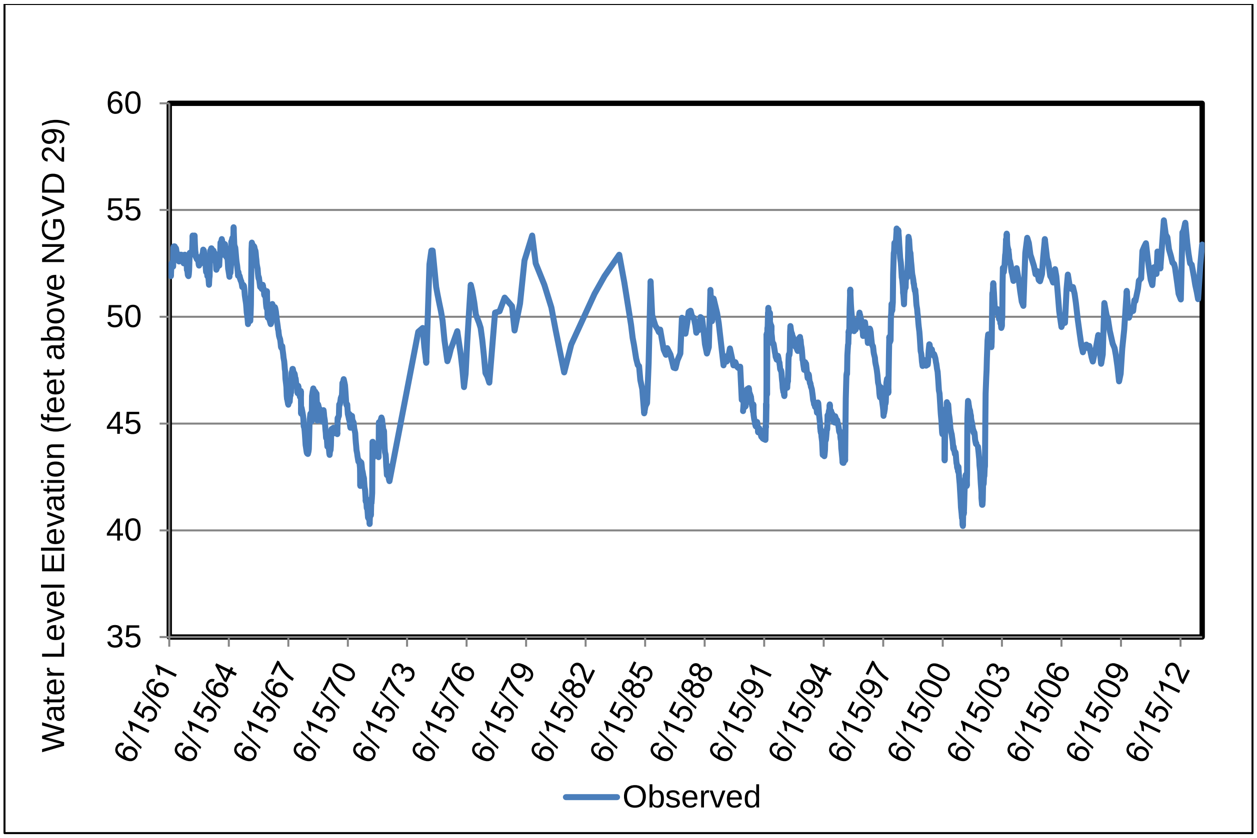

Figure 12. Weekly surface water elevations in feet above NGVD 29, from June 1961 through March 2013.

For the purpose of Minimum Levels determination, lake stage data are classified as "Historic" for periods when there were no measurable impacts due to water withdrawals, and impacts due to structural alterations were similar to existing conditions. As defined in Chapter 40D-8 F.A.C., "structural alteration" means man's physical alteration of the control point, or highest stable point along the outlet conveyance system of a lake, to the degree that water level fluctuations are affected. Lake stage data are classified as "Current" for periods when there were measurable, stable impacts due to water withdrawals, and impacts due to structural alterations were stable. Starvation Lake lies within the Section 21 wellfield that has been in production since early 1963. There are only about 20 months of data from the lake stage that exist prior to the commencement of the withdrawals from the Section 21 wellfield. But Cosme-Odessa wellfield, located less than 5 miles to the west of the lake, was withdrawing approximately 20 mgd during that period and may have affected levels at Starvation Lake. (see Appendix A).

“Current” values are represented from 2005 through 2011, a period of both stable structural alterations and groundwater withdrawals. Current values were calculated by adjusting the Surficial and Floridan aquifer levels in the water budget model to represent these post-cut back levels.

Because none of the field data is considered Historic, the development of a water budget model for this lake allowed for the estimation of long-term Historic percentiles (see

Appendix A). A spreadsheet-based water budget model that includes natural hydrologic processes and engineered alterations that act to control the water volume in the lake was chosen to model Starvation Lake. 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 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 1974 through 2011, which represents a period of time that is considered long-term for purposes of determining Historic percentiles (see Appendix A). The Historic P10, P50, and P90 developed from the modeled lake stage are 53.5, 51.2, and 49.7 feet above NGVD 29 (Figure 13).

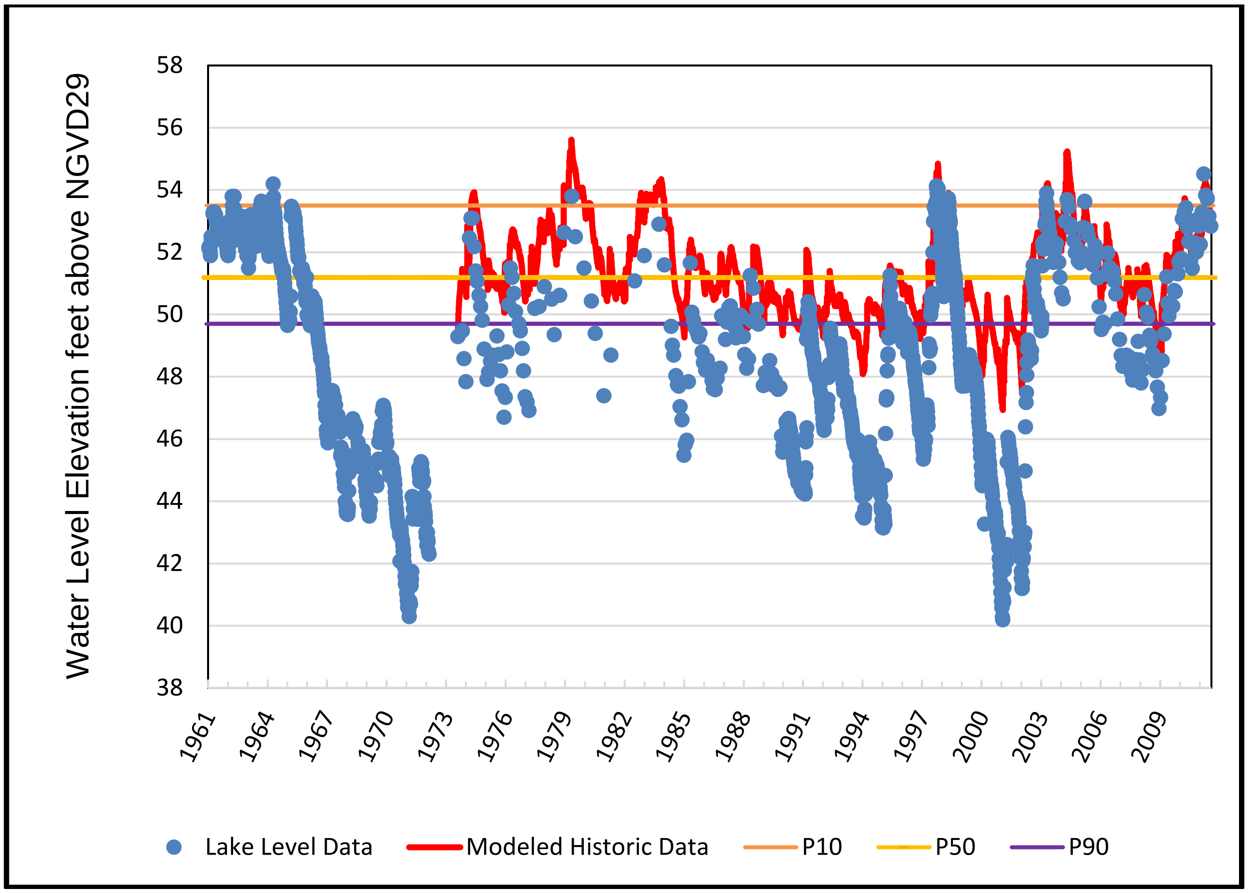

Figure 13. Modeled long term Historic lake stage (as monthly means, red line) and observed lake level data (in blue) with Historic P10 (53.5), Historic P50 (51.2) and Historic P90 (49.7) measured in elevation in feet above NGVD 29 for Starvation Lake.

Normal Pool, Control Point Elevation and Determination of Structural Alteration Status

The Normal Pool elevation, a reference elevation used for development of minimum lake and wetland levels, is established based on the elevation of Hydrologic Indicators of sustained inundation. Based on the elevations of *Taxodium ascendens* buttress inflection points, and the occurrence of saw palmetto (*Serenoa repens* along the lake shore measured in 1997, 1999 and confirmed in March 2013, the Normal Pool elevation was established at 53.5 feet above NGVD 29 (Figure 2, Table 6).

Starvation Lake is a Category 3 Lake, with a Normal Pool elevation above the control point, so the lake is considered to be Structurally Altered. The Control Point elevation is the elevation of the highest stable point along the outlet profile of a surface water conveyance system (e.g., weir, ditch, culvert, or pipe) that is the principal control of water level fluctuations in the lake. A Control Point may be established at the invert or crest elevation associated with a water control structure at a lake outlet, or at a high, stable point in a lake-outlet canal, ditch or wetland area. The invert or crest elevation is the lowest point on the portion of a water control structure that provides for conveyance of water across or through the structure. There are two outfall paths located on Starvation Lake.

Table 6. Elevation data used for establishing the Category 3 Lake Normal Pool Elevation for Starvation Lake in Hillsborough County, Florida. Data were collected by Jim Bays of CH2MHill in 1997 at Starvation Lake, and by District staff at Lake Jackson on August 12 1999 when the water level elevation was at 47.44 feet above NGVD 29 and reconfirmed by staff in March 2013.

Hydrologic Indicators	Elevation (feet above NGVD)
Base of saw palmetto at Starvation Lake (+0.25 feet)	53.8
Normal pool based on cypress buttress (Lake Jackson)	53.4
Normal pool based on cypress buttress (Lake Jackson)	53.4
Normal pool based on cypress buttress (Lake Jackson)	53.5
Normal pool based on cypress buttress (Lake Jackson)	53.6
Normal pool based on cypress buttress (Lake Jackson)	53.3
Normal pool based on cypress buttress (Lake Jackson)	53.7
N	**7**
Median	**53.5**
Mean	**53.5**
Standard Deviation	**0.17**

A discharge ditch system exists on the southeast shore of Starvation Lake, which passes under the main park road south of the lake via a culvert with an invert of 45.5 feet NGVD29. The ditch system flows to the south and eventually into Crum Lake, which discharges to Lake Simmons (Figure 2), which in turn discharges into a canal to the south of the park property. The high point in the ditch between Starvation Lake and Crum Lake was surveyed at 49.6 feet NGVD29. During very high stages in Starvation Lake, flow can occur over the park road to the west of the discharge ditch system, flowing into Crum Lake. A low point on the road in this area was surveyed at 52.8 feet NGVD29. A high point in the system to the south of Lake Simmons was surveyed at 52.7 feet NGVD29. Because the topography and bottom of the ditch system is so flat, water levels in the chain of lakes from Jackson to Simmons tend to equalize up to an elevation of 52.7 feet NGVD29, at which point flow out of the system occurs (Hancock and McBride 2014). Because water levels above 52.7 feet NGVD29 are historically rare, a dual system of outflow was used in the water budget model. Flow out of Starvation Lake begins at 49.6 feet NGVD29, but increases at 52.7 feet NGVD29. Because the secondary flow over the park road begins at approximately the same elevation as flow out of the park, the two flow paths can be considered as one (see Appendix A).

The low floor slab elevation, extent of structural alteration and the control point elevation were determined using available one-foot contour interval aerial and LiDAR maps and field survey data (Tables 5, 7).

Table 7. Summary of structural alteration and control point elevation information for Starvation Lake in Hillsborough County, Florida.

No.	Description	Elevation (feet above NGVD)
1	Invert at north end of 18" corrugated metal pipe running under paved park access road	43.0
2	Invert at south end of 18" corrugated metal pipe running under paved park access road	45.5
3	High spot in channel between Starvation Lake and Crum Lake	49.6
4	Invert at northeast end of 24" corrugated metal pipe running under unpaved park access road; invert at southwest end is 41.63 feet above NGVD.	42.0
5	Control point; vegetated natural ground	52.7
6	Low floor slab, barn east of Crum	56.3

Lake Classification

Lakes are classified as Category 1, 2 or 3 for the purpose of Minimum Levels development. Systems with fringing cypress wetlands greater than 0.5 acres in size where water levels regularly rise to an elevation expected to fully maintain the integrity of the wetlands, *i.e.,* the Historic P50 is not more than 1.8 feet below the Normal Pool elevation, are classified as Category 1 Lakes. Lakes with fringing cypress wetlands greater than 0.5 acres in size that have been structurally altered such that the Historic P50 is more than 1.8 feet below the Normal Pool elevation are classified as Category 2 Lakes. Lakes without fringing cypress wetlands or with less than 0.5 acres of fringing cypress wetlands are classified as Category 3 Lakes.

Starvation Lake is not contiguous with any cypress-dominated wetlands of 0.5 or more acres in size and is therefore classified as a Category 3 Lake for the purpose of minimum levels development. Aquatic macrophytes, including maidencane (*Panicum hemitomum*), cattail (*Typha* sp.), torpedograss (*Panicum repens*), spikerush (*Eleocharis baldwinii)*, southern naid (*Najas quadelupensis*) and spatterdock (*Nuphar luteum*) occur throughout the basin.

Guidance Levels

The **High Guidance Level** is provided as an advisory guideline for construction of lake-shore development, water dependent structures, and operation of water management structures. The High Guidance Level is the expected Historic P10 of the lake and is established using historic lake stage data if it is available, or is estimated using a hydrologic model. Based on the long-term Historic data developed by the water budget model for Starvation, the High Guidance Level was established at the Historic P10 elevation of **53.5 feet above NGVD 29** (Figures 13,14; Table 5).

The **Low Guidance Level** is provided as an advisory guideline for water dependent structures, information for lake shore residents, and operation of water management structures. The Low Guidance Level is the elevation that a lake's water levels are expected to equal or exceed ninety percent of the time (P90) on a long-term basis. The level is also established by using Historic lake stage data or estimated using a hydrologic model. Based on the long-term Historic data developed by the water budget model for Starvation Lake, the Low Guidance Level for Starvation Lake was established at the long term Historic P90 elevation, **49.7 feet above NGVD 29** (Figures 13,14; Table 5).

Significant Change Standards and Other Information for Consideration

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

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

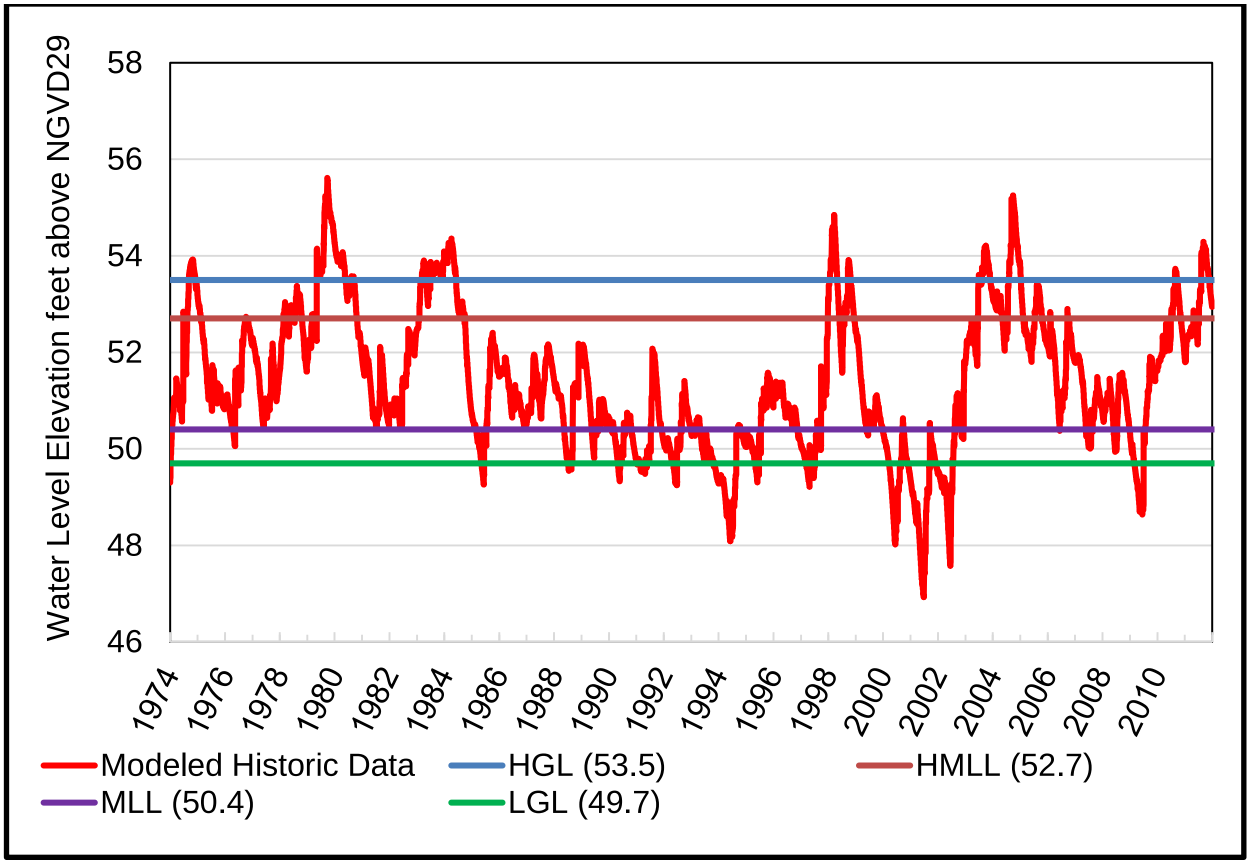

Figure 14. Modeled long term Historic lake stage (as monthly means, red line) and Minimum and Guidance elevation Levels for Starvation Lake in feet above NGVD 29. Established levels include the High Guidance Level (HGL), High Minimum Lake Level (HMLL), Minimum Lake Level (MLL), and Low Guidance Level (LGL).

The **Species Richness Standard** is developed to prevent a decline in the number of bird species that may be expected to occur at or utilize a lake. Based on an empirical relationship between lake surface area and the number of birds expected to occur at Florida lakes, the standard is established at the lowest elevation associated with less than a 15 percent reduction in lake surface area relative to lake area at the Historic P50 elevation (Figure 13, Table 5) for a plot of lake surface area versus lake stage). For Starvation Lake, the Species Richness Standard was established at **48.4 feet above NGVD 29**. The Species Richness Standard was equaled or exceeded eighty eight percent of the time, based on the modeled Historic water level record. The standard therefore corresponds to the Historic P88.

The **Aesthetics Standard** is developed to protect aesthetic values associated with the inundation of lake basins. The standard is intended to protect aesthetic values associated with the median lake stage from becoming degraded below the values associated with the lake when it is staged at the Low Guidance Level. The Aesthetic Standard is established at the Low Guidance Level, which for Starvation Lake is **49.7 feet above NGVD 29**. Because the Low Guidance Level was established at the Historic P90 elevation, water levels equaled or exceeded the Aesthetics Standard ninety percent of the time during the

Historic long term period (1974 through 2011, Table 5).

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 uses. The Basin Connectivity Standard is determined in areas of the lake that have potential surface water connectivity among sub-basins within the lake basin or between the lake, or other lakes. To determine this standard the critical high spot elevation is identified. Powerboats are not used on Starvation Lake therefore 1 foot and the difference between the P50 and the P90 are added to the critical high spot. A Basin Connectivity Standard was established at **52.5 feet above NGVD 29**, with a critical high-spot elevation of 50 feet above NGVD 29 was determined using LiDAR contours, spot elevations and aerial interpretations (Table 5). Given that the standard elevation is 1.3 feet higher than the Historic P50 elevation of 51.2 feet above NGVD 29, use of the standard for minimum level development was not considered appropriate.

Herbaceous Wetland Information is taken into consideration to determine the elevation at which change in lake stage would result in substantial change in potential wetland area within the lake basin (i.e., basin area with a water depth less than or equal to four feet). 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. Review of changes in potential herbaceous wetland area in relation to change in lake stage did not indicate that there would be a significant increase or decrease in the area of herbaceous wetland vegetation associated with use of the applicable significant change standards (Figure 15, Table 5). Because herbaceous wetlands are the dominant vegetation within the Starvation Lake basin, it was determined that an additional measure of wetland change should be considered for minimum levels development. Based on a review (Hancock 2006) of the development of minimum level methods for cypress-dominated wetlands, it was determined that up to an 0.8 foot decrease in the Historic P50 elevation would not likely be associated with significant changes in the herbaceous wetlands occurring within lake basins. A Wetland Offset elevation of **50.4 feet above NGVD 29** was therefore established for Starvation Lake by subtracting 0.8 feet from the Historic P50 elevation (Table 5). The standard elevation was equaled or exceeded 51 percent of the time, based on the Historic, composite water level record. The standard elevation therefore corresponds to the Historic P51. Review of changes in potential wetland area in relation to change in lake stage indicated there would not be a substantial increase or decrease in potential wetland area within the lake basin at the Wetland Offset Elevation (12 percent of the lake basin) relative to the potential wetland area at the Historic P50 elevation (17 percent of the lake basin).

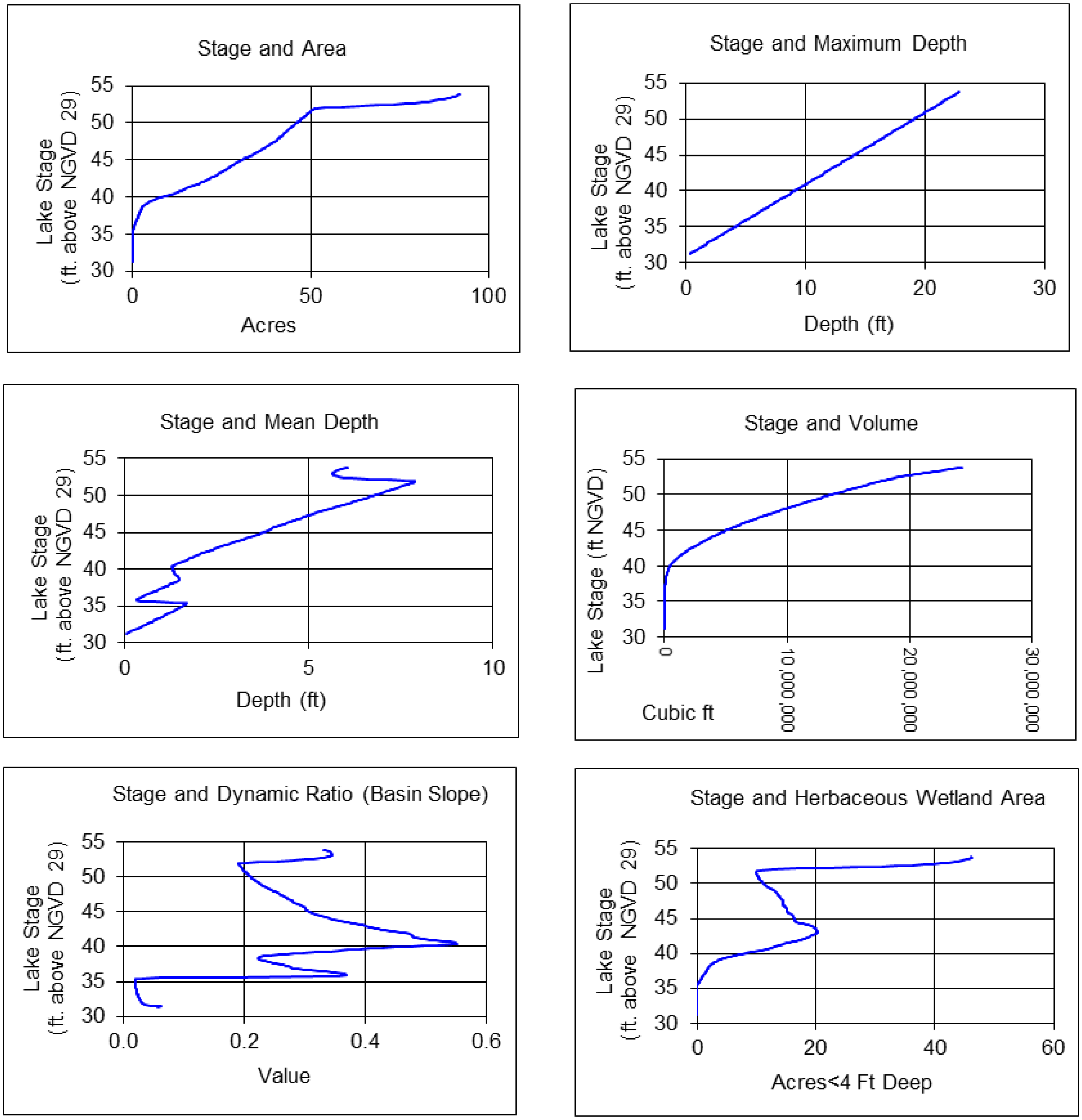

Figure 15. Stage, area and volume, mean and maximum depth, herbaceous wetland area, and dynamic ratio versus lake stage for Starvation Lake in Hillsborough County, Florida.

There are no docks within the basin and water skiing is not permitted, so development of **Dock-Use and Recreation/Ski Standards** was not appropriate. The **Lake Mixing Standard** is developed to prevent significant changes in patterns of wind-driven mixing of the lake water column and sediment re-suspension. The standard is established at the highest elevation at or below the Historic P50 elevation where the dynamic ratio (see Bachmann et al. 2000) shifts from a value of <0.8 to a value >0.8, or from a value >0.8 to a value <0.8. Because the dynamic ratio does not shift across the 0.8 threshold over the range of water levels that may be expected within the basin, a Lake Mixing Standard was not developed (Figure 15, Table 5).

Minimum Levels

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

The **Minimum Lake Level (MLL)** is the elevation that a lake's water levels are required to equal or exceed fifty percent of the time on a long-term basis. For Category 3 Lakes, the Minimum Lake Level is typically established at the elevation corresponding to the most conservative significant change standard, *i.*e.*,* the standard with the highest elevation, except where that elevation is above the Historic P50 elevation, in which case, the Minimum Lake Level is established at the Historic P50 elevation. Because all appropriate significant change standards were below the Historic P50 elevation, the Minimum Level for Starvation Lake was established at the Wetland Offset elevation of **50.4 feet above NGVD 29** (see Figure 14, Table 5).

The **High Minimum Lake Level (HMLL)** is the elevation that a lake's water levels are required to equal or exceed ten percent of the time on a long-term basis. For Category 3 lakes, the High Minimum Lake Level is developed using the Minimum Lake Level, Historic data or reference lake water regime statistics. If Historic Data are available, the High Minimum Lake Level is established at an elevation corresponding to the Minimum Lake Level plus the difference between the Historic P10 and Historic P50. If Historic data are not available, the High Minimum Lake Level is set at an elevation corresponding to the Minimum Lake Level plus the region-specific RLWR50 value. The High Minimum Lake Level was established at **52.7 feet above NGVD 29**, the Minimum Lake Level plus the difference between the Historic P10 (53.5 feet above NGVD 29) and Historic P50 (51.2 feet above NGVD 29) a difference of 2.3 feet (see Figure 14, Table 5).

The approximate locations of the lake margin when water levels equal the minimum levels are shown superimposed on aerial photographs from several years in Figures 16 through 18.

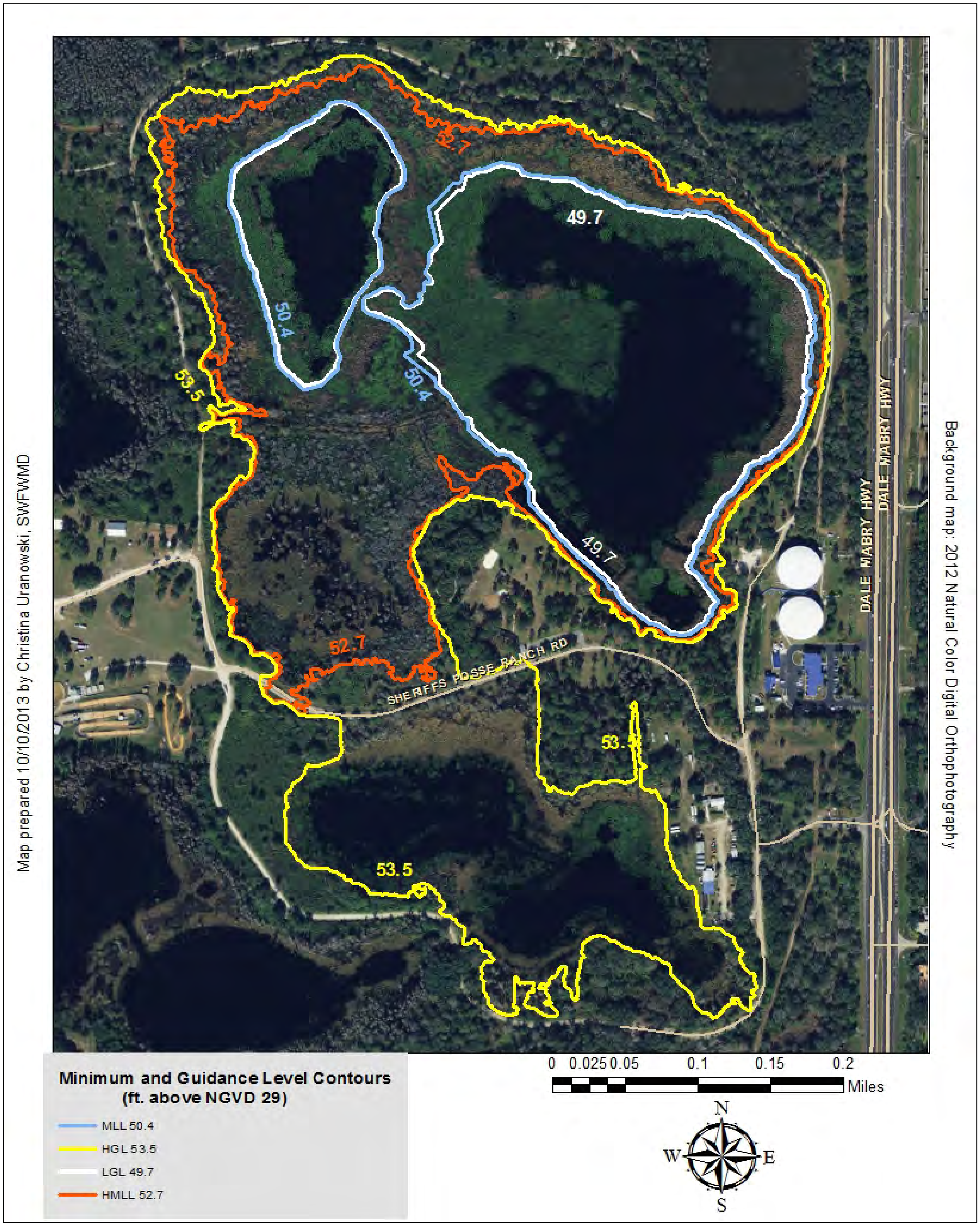

Figure 16. Starvation Lake contour map with Minimum and Guidance level contours in ft. above NGVD 29. Contours were prepared using a combination of LiDAR collected in 2007 and spot elevation data collected by D.C. Johnson in 2010 in ft. above NGVD 29 with background map in 2012 natural color aerial orthophotography.

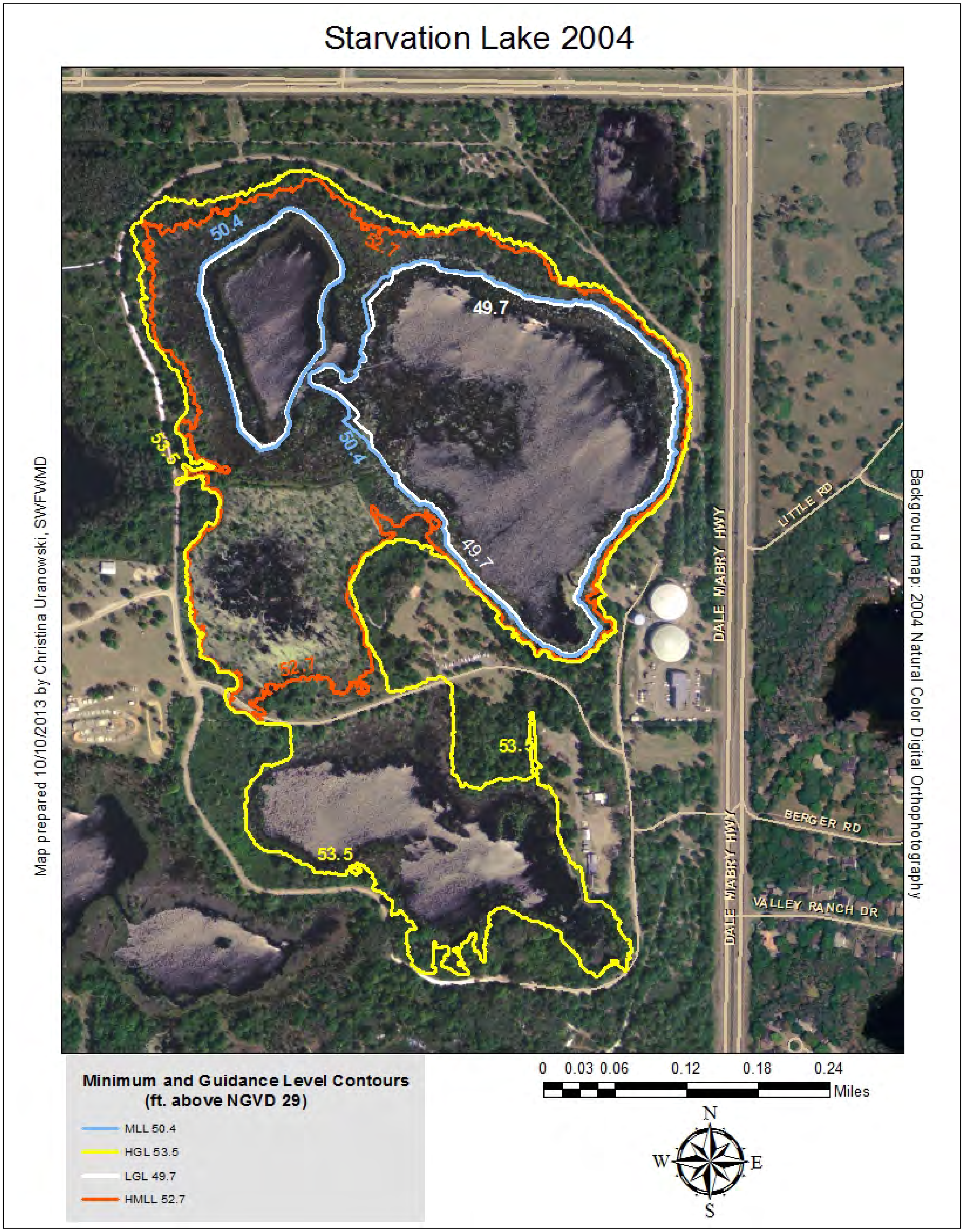

Figure 17. Starvation Lake contour map with Minimum and Guidance level contours in ft. above NGVD 29. Contours were prepared using a combination of LiDAR collected in 2007 and spot elevation data collected by D.C. Johnson in 2010 in ft. above NGVD 29 with background map in 2004 natural color aerial orthophotography.

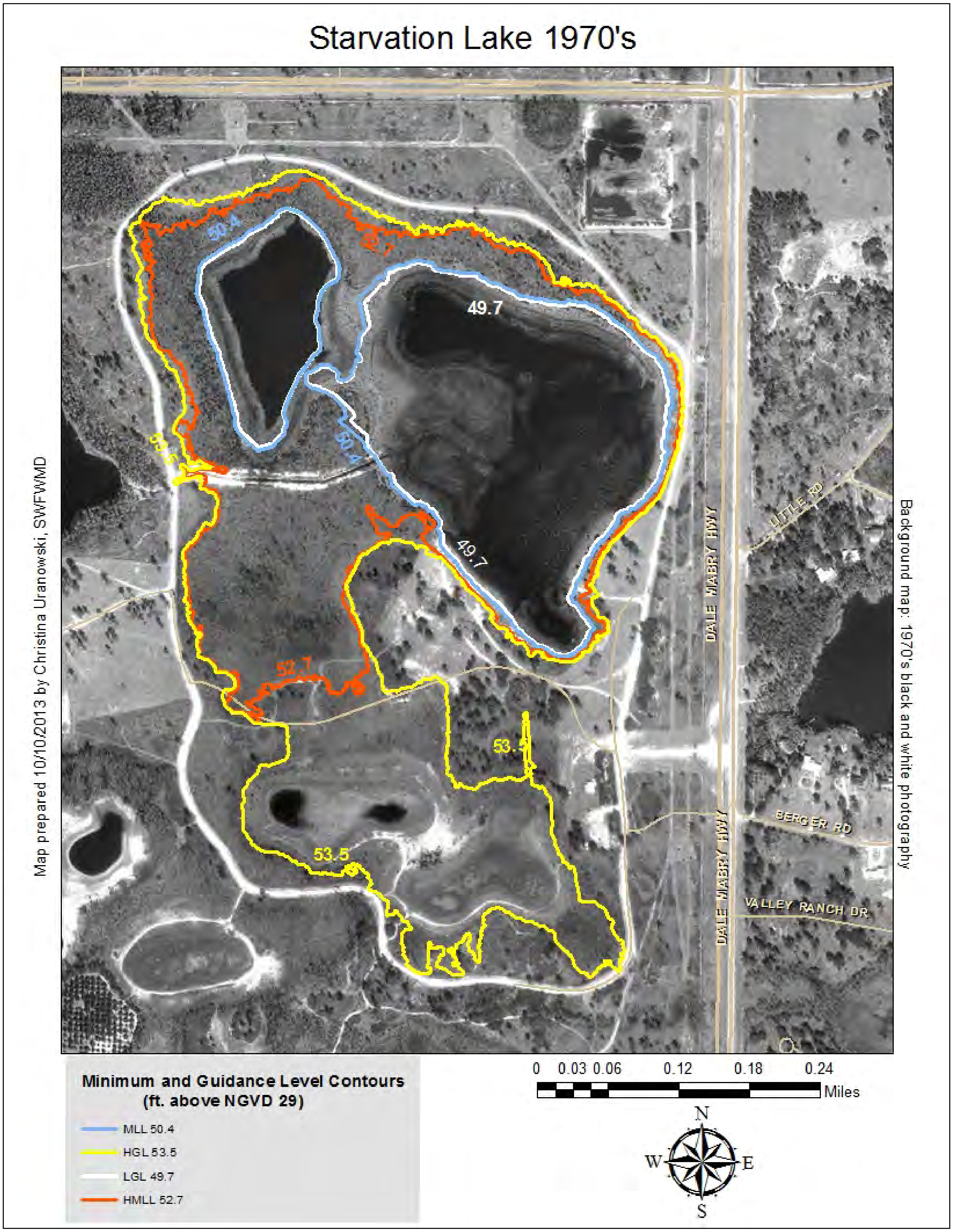

Figure 18. Starvation Lake contour map with Minimum and Guidance level contours in ft. above NGVD 29. Contours were prepared using a combination of LiDAR collected in 2007 and spot elevation data collected by D.C. Johnson in 2010 in ft. above NGVD 29 with background map in 1970 black and white aerial photography.

Consideration of Environmental Values

When developing minimum 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.

Four environmental values identified in Rule 62-40.473, F.A.C., are protected by the minimum levels for Starvation Lake .The environmental value, Aesthetics is associated with the Species Richness, Wetland Offset and Aesthetics standards developed for the lake, and each of these standards are associated with elevations lower than the High Guidance Level and the High Minimum Lake Level. Similarly, the environmental value, fish and wildlife habitats and the passage of fish, may be associated with Basin Connectivity Standard, which is also lower than the High Guidance Level and the High Minimum Lake Level. Basin connectivity, however, is not being considered for minimum level development because it is higher than the historic P50. The environmental value, maintenance of freshwater storage and supply is protected by the minimum levels based on the relatively modest potential changes in storage associated with the minimum flows hydrologic regime as compared to the non-withdrawal impacted historic condition. Maintenance of freshwater supply is also expected to be protected by the minimum levels based on inclusion of conditions in water use permits that stipulate that permitted withdrawals will not lead to violation of adopted minimum flows and levels.

Two environmental values identified in Rule 62-40.473, F.A.C., were not considered relevant to development of minimum levels for Starvation Lake. Estuarine resources were not considered relevant because the lake is only remotely connected to the estuarine resources associated with the downstream receiving waters of Tampa Bay, and water level fluctuations in the lake are expected to exert little effect on the ecological structure and functions of the bay. Sediment loads were similarly not considered relevant for minimum levels development for the lake, because the transport of sediments as bedload or suspended load is a phenomenon associated with flowing water systems.

Minimum Levels Status Assessment

The Minimum Lake Level and High Minimum Lake Level were evaluated for compliance through the water budget model (see Appendix A) that was used to develop the long-term Historic stage regime and percentiles. Based on the compliance information presented (see Appendix B), it is concluded that Starvation Lake is currently at or above its established minimum levels, although the long-term P50 is just at the Minimum Lake Level.

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

It is recommended that Tampa Bay Water continue to assess Starvation Lake as part of their Permit Recovery Assessment Plan, as required by Chapter 40D-80, F.A.C. and the Consolidated Permit 20011771.001 (see Appendix B).

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APPENDIX A

Technical Memorandum

August 13, 2014

TO: Christina Uranowski, Senior 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 S. McBride, P.G., Hydrogeologist, Water Resources Bureau

Subject: Starvation Lake Water Budget Model and Historic Percentile Estimation

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A. Introduction

A water budget model was developed to assist the Southwest Florida Water Management District (District) in the establishment of minimum levels for Starvation Lake in Hillsborough County. This document discusses the development of the Starvation Lake water budget model and use of the model for development of Historic lake stage exceedance percentiles.

B. Background and Setting

Lakes Starvation is located in northwest Hillsborough County, adjacent to the southwest corner of Dale Mabry Highway and Van Dyke Road in Lutz (Figure 1). The lake lies within the Section 21 Wellfield, which is one of eleven regional water supply wellfields operated by Tampa Bay Water as the Central System Facilities. The wellfield property is owned by the City of St. Petersburg, and the Hillsborough County Parks and Recreation Department maintains the wellfield land as a county park (Lake Park).

Starvation Lake lies within the Brushy Creek watershed. Brushy Creek is a tributary to Rocky Creek. Surface-water inflow from Lake Jackson to the west (Figure 2) occurs during high flow periods, although the topography is very flat, and flow can reverse when Starvation Lake reaches high stages. Discharge from Starvation Lake can occur via a culvert and ditch system, which flows through lakes Crum and Simmons to the south, and eventually out the southwest corner of the park property (Figure 2).

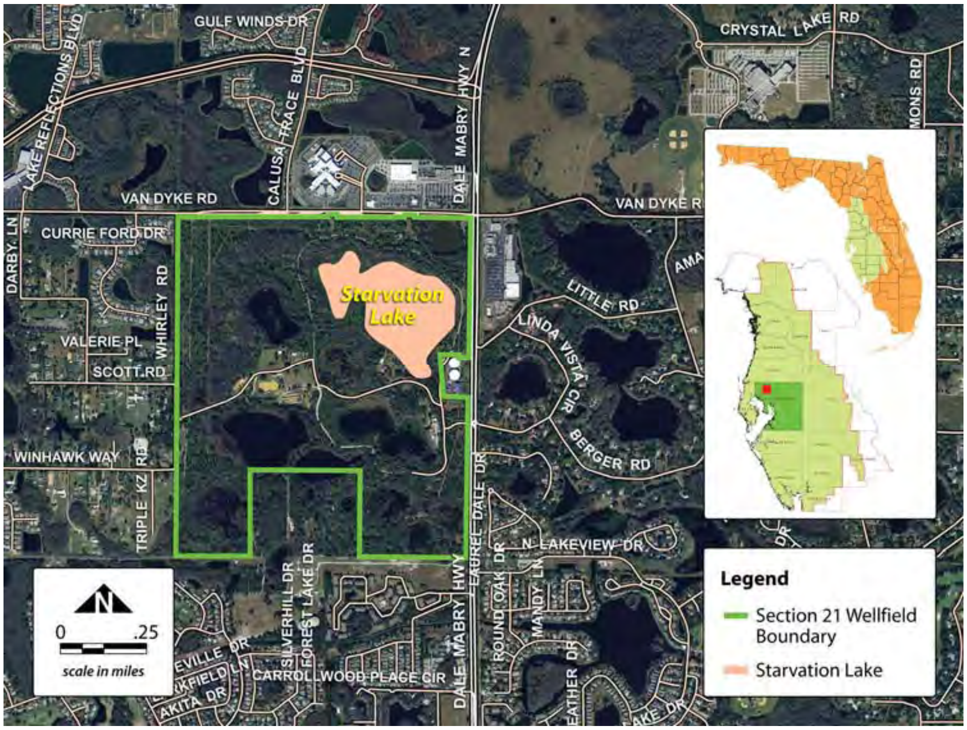

Figure 1. Location of Starvation Lake within the Section 21 Wellfield in Hillsborough County, Florida.

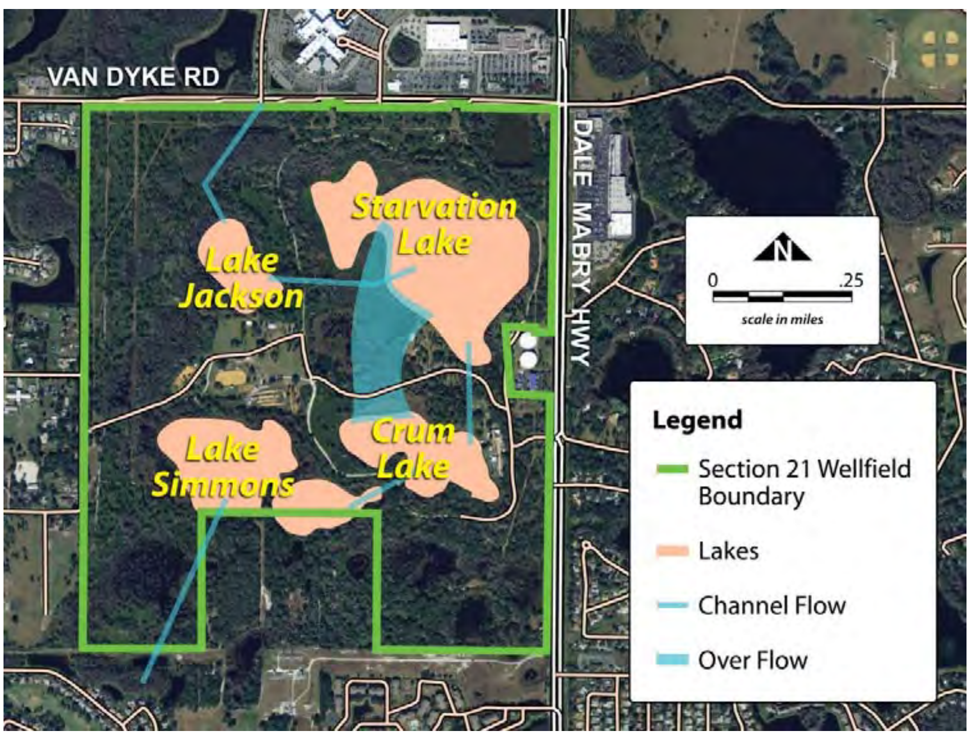

Figure 2. Major inlet and outlet flow paths between Lakes Jackson, Starvation, Crum, and Simmons.

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 conveyance systems.

The hydrogeology of the area includes a sand surficial aquifer; a discontinuous, intermediate clay confining unit; and the thick carbonate Upper Floridan aquifer. In general, the surficial aquifer in the study area is in good hydraulic connection with the underlying Upper Floridan aquifer because the clay confining unit is generally thin, discontinuous, and breeched by numerous karst features. The surficial aquifer is generally ten to thirty feet thick and overlies the limestone of the Upper Floridan aquifer that averages nearly one thousand feet thick in the area (Miller, 1986). In between these two aquifers is the Hawthorn Group clay that varies between a few feet to as much as 25 feet thick. Because the clay unit is breached by buried karst features and has previously been exposed to erosional processes, preferential pathways locally connect the overlying surficial aquifer to the Upper Floridan aquifer resulting in moderate-to-high leakage to the Upper Floridan aquifer (Hancock and Basso, 1996). Based on assessment of the conditions of the lakes on the park property, as well as data collection throughout the park, the northwest quarter of the park (area surrounding Lake Jackson) appears to be better confined than the rest of park (areas surrounding lakes Starvation, Crum, and Simmons.

Starvation Lake has been subjected to the effects of groundwater withdrawals for the approximate 50 years the Section 21 Wellfield has been in operation, and has potentially been affected by withdrawals at other regional wellfields where withdrawals were initiated as early as the 1930s. Withdrawals from 8 production wells located on the approximately one-square mile of land (2 currently inactive) comprising the Section 21 Wellfield began in 1963 (Figure 3).

Total withdrawals at the Section 21 Wellfield increased to nearly 15 million gallons per day (mgd) in 1964 and to over 20 mgd in 1967 (Figure 4). With the development of the South Pasco Wellfield in 1973, withdrawal rates at the Section 21 Wellfield were reduced to approximately 10 mgd. Withdrawal rates since 2005 have averaged a little over 3 mgd, with several extended periods when the Section 21 Wellfield was shut down completely.

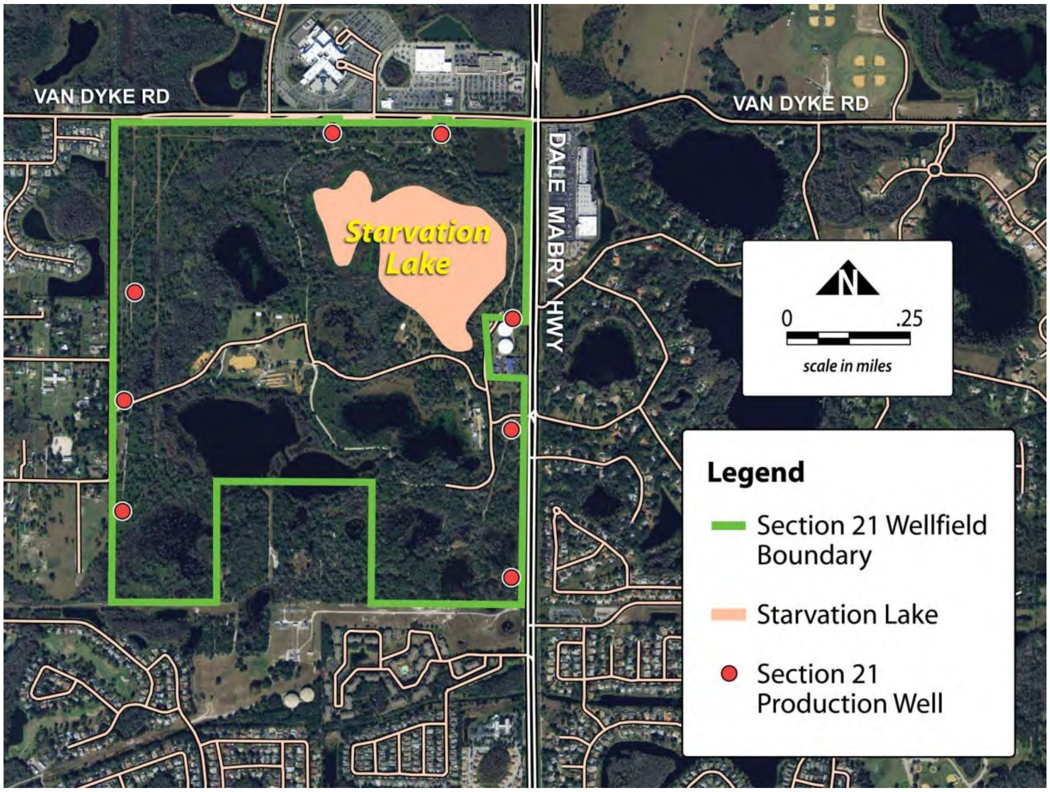

Figure 3. Section 21 Wellfield configuration.

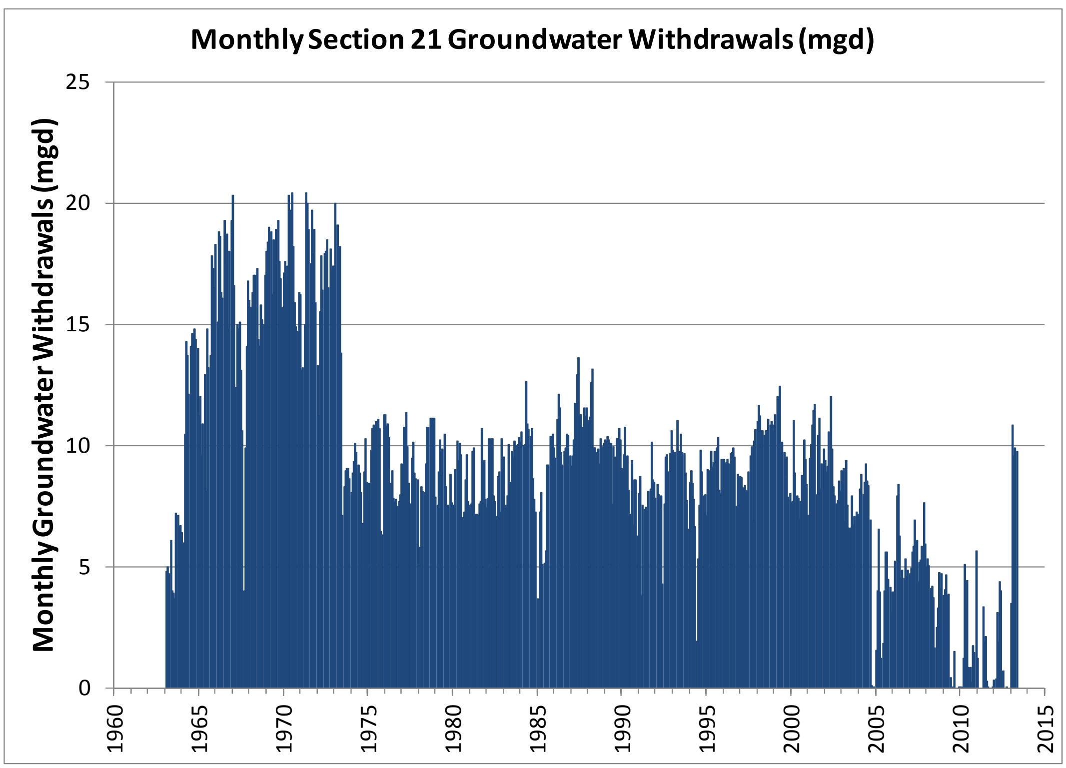

Figure 4. Section 21 Wellfield withdrawals.

Water level data collection at Starvation Lake began in mid-1961, providing less than 2 years of pre-withdrawal data for the lake. The initial weekly data collection frequency was continued until mid-1972, when after a gap of about 1.5 years, it was reduced to monthly in January 1974 (Figure 5). Weekly data collection was resumed from 1990 to late-2003 and followed by monthly data collection, which continues to the present time.

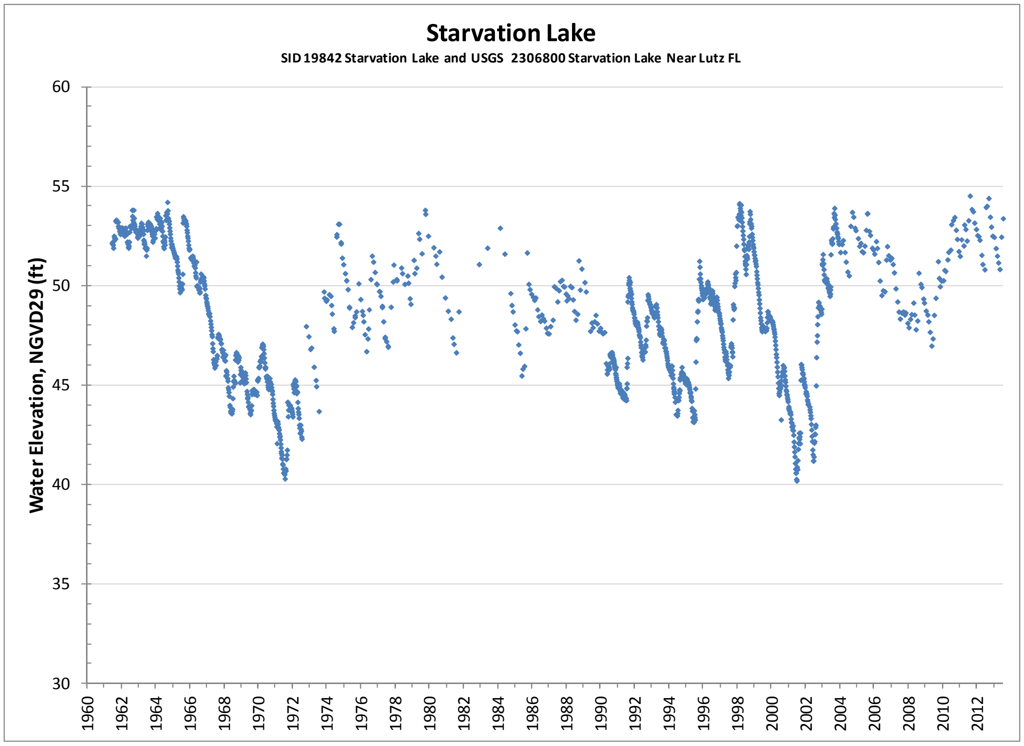

Figure 5. Starvation Lake water levels.

Two Upper Floridan aquifer monitor wells are located on the wellfield, and both were used for development of the Starvation Lake water budget model. Water levels from the Hillsborough 13 Upper Floridan aquifer monitor well have been collected since 1944, making it one of the longest term monitor wells in the District (Figure 6). The well is located approximately 1,600 feet to the south of Starvation Lake. The data collection frequency alternated from daily to monthly until approximately 1974, when daily data collection became consistent (Figure 7). The St. Petersburg 21-7 Upper Floridan aquifer monitor well is located approximately 250 feet to the northeast of Starvation Lake (Figure 6). Continuous data is available from this well back to 1974, with another year of monthly data preceding the continuous record (Figure 8).

Figure 6. Location of monitor wells near Starvation Lake.

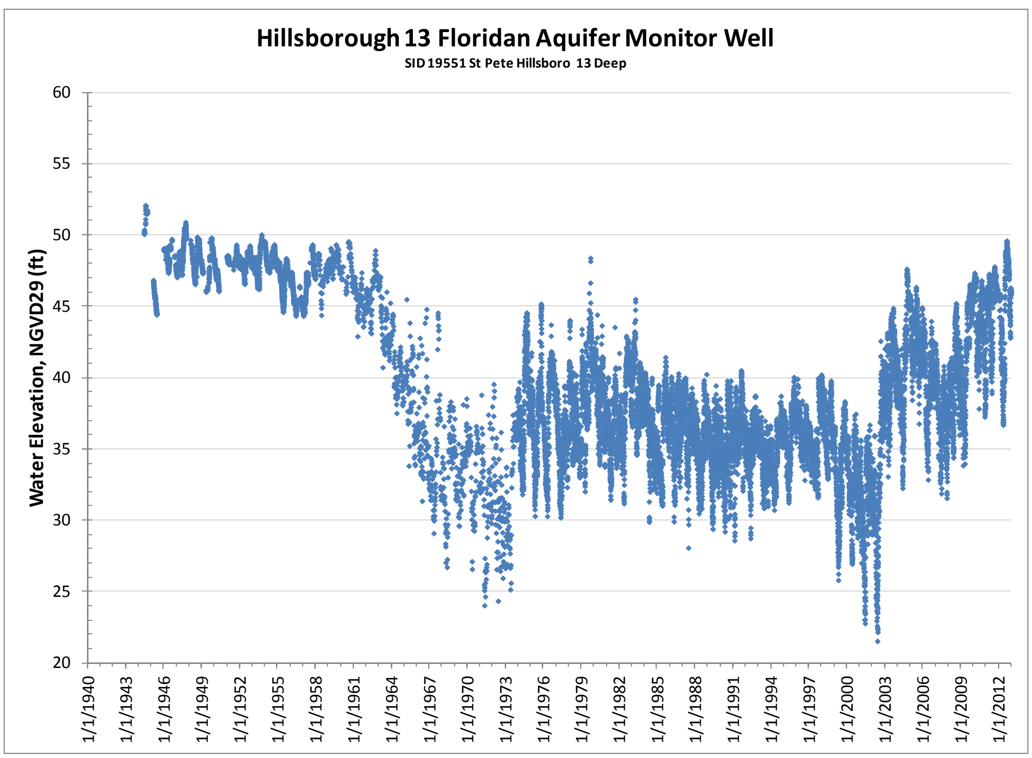

Figure 7. Water levels in Hillsborough 13 Floridan aquifer monitor well

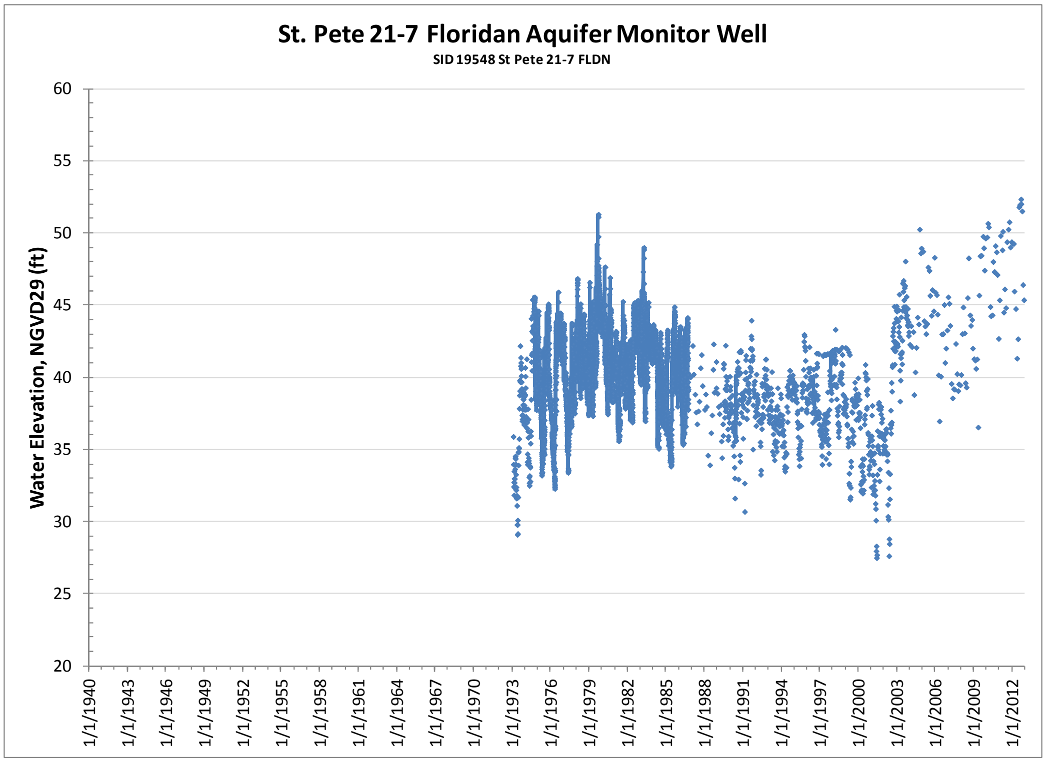

Figure 8. Water levels in the St. Pete 21-7 Floridan aquifer monitor well

Two long-term surficial aquifer monitor wells exist within the wellfield, and both were used for modeling Starvation Lake: the Hillsborough 13 Shallow and Jackson 26A Shallow surficial aquifer monitor wells (both monitored by the District). The Hillsborough 13 surficial aquifer monitor well is located adjacent to the Hillsborough 13 Floridan aquifer monitor well (Figure 6). The period of record of both surficial aquifer monitor wells begins in the mid-1970s (Figure 9). The difference in confinement between the northwest portion of the wellfield and the southwest portion of the wellfield is obvious when reviewing water level records for these two wells. The thicker confinement in the area surrounding the Jackson 26A well results in a water table with less variability and generally higher levels the Floridan aquifer water levels.

Water levels fluctuations in Starvation Lake have corresponded with variation in underlying Floridan aquifer water levels, which in turn have fluctuated with the groundwater withdrawals from the wellfield (Figures 9 and 11).

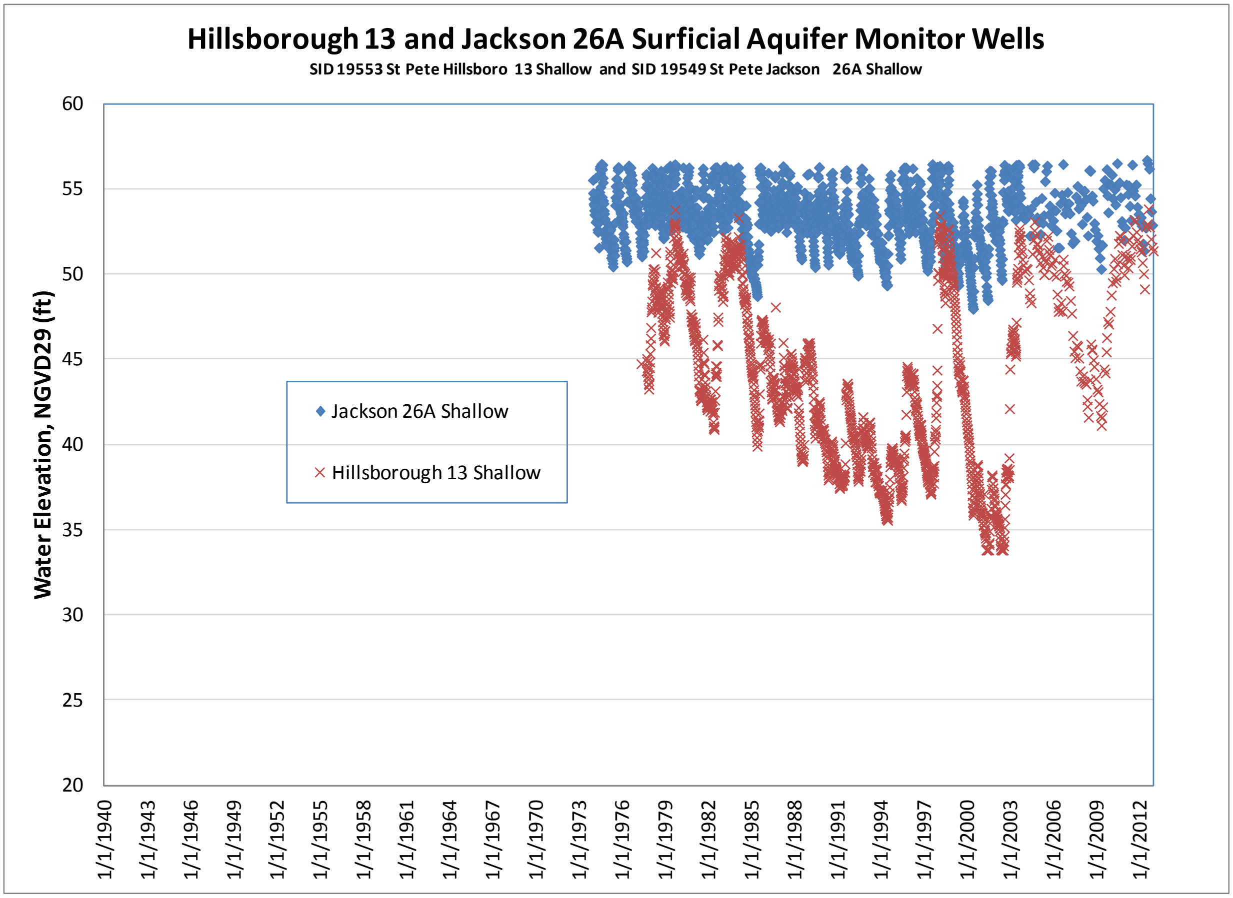

Figure 9. Water levels in Hillsborough 13 Shallow and Jackson 26A Shallow surficial wells.

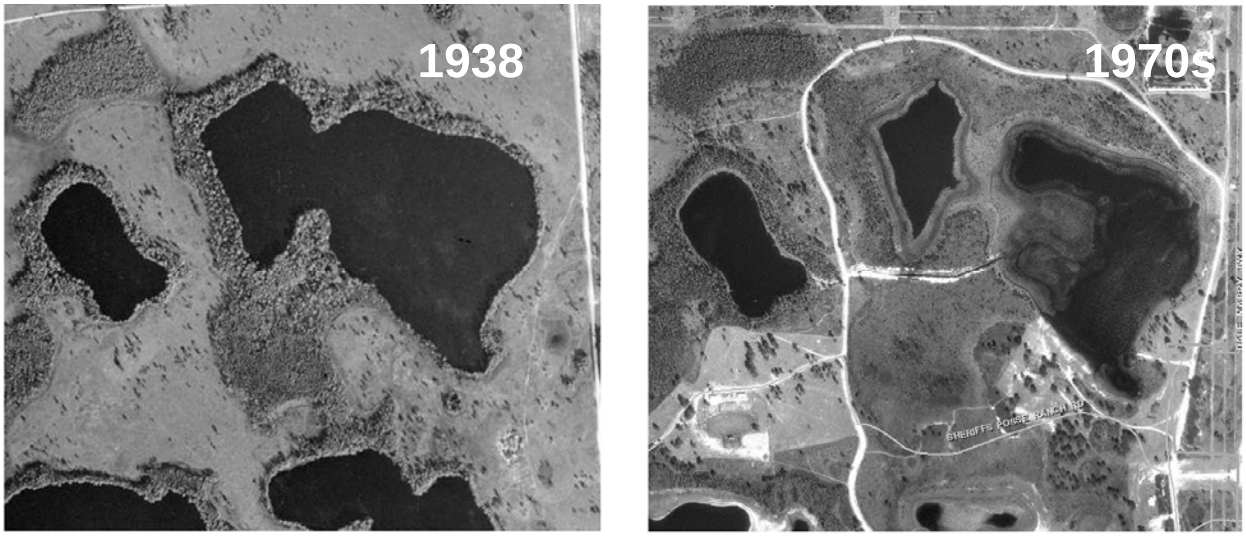

Figure 10. Water levels in Starvation Lake on two dates prior to and after initiation of groundwater withdrawals at the Section 21 Wellfield.

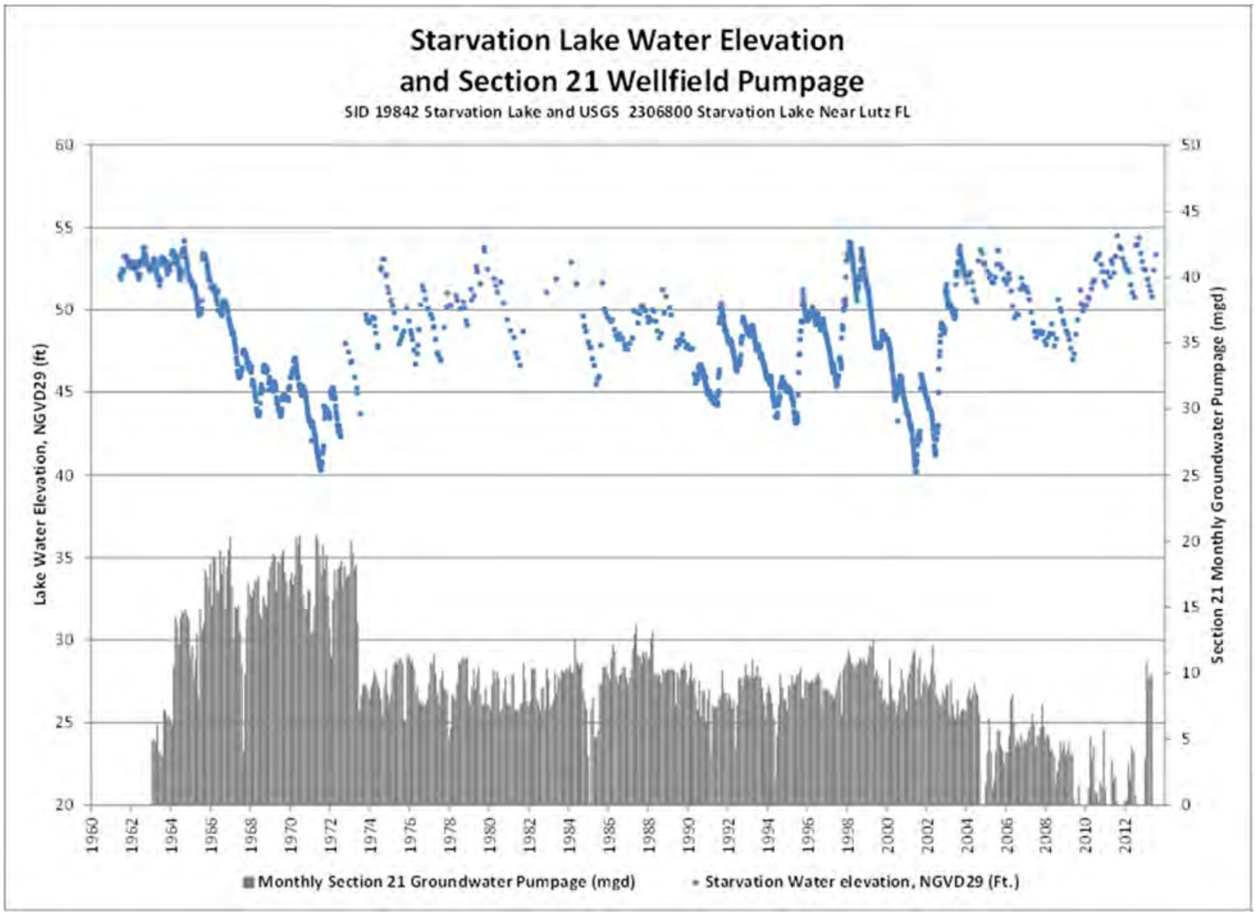

Figure 11. Water levels in Starvation Lake and withdrawals at the Section 21 Wellfield.

C. Model Purpose

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 percentile 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 Starvation Lake, the Section 21 Wellfield has affected lake water levels since early 1963, but only about 20 months of lake water level data are available for the period prior to initiation of groundwater withdrawals at the wellfield. Field indicators of historic normal pool (an elevation associated with hydrologic indicators representing approximate Historic P10 conditions) suggest that the limited water level records collected prior to initiation of the wellfield withdrawals are consistent with the historic indicators. However, the groundwater withdrawal rate at the Cosme-Odessa Wellfield, located less than 5 miles to the west of the Section 21 Wellfield, was approximately 20 mgd during the period of initial water level data collection at Starvation Lake. Starvation Lake levels represented by the early records may reflect or have integrated some degree of drawdown caused by Cosme-Odessa Wellfield and possibly other area withdrawals. Additionally, many land use changes have occurred and drainage features constructed in the area that may have also affected lake water levels to some degree. For the reasons noted here, no long-term Historic data exist for Starvation Lake. The development of a water budget model for the lake was therefore considered essential for estimating long-term Historic percentiles and simulating effects of changing groundwater withdrawal rates.

D. Model Overview

Since no long-term Historic data are available for Starvation Lake, a water budget approach was chosen to model lake water levels. The Starvation Lake model is a spreadsheet-based water budget tool that includes natural hydrologic processes and engineered alterations acting on the control volume of the lake. The control volume consists of the free water surface within the lake extending down to the elevation of the greatest lake depth. A stage-volume curve was derived for the lake that produced a unique lake stage for any total water volume within the control volume.

The hydrologic processes in the Starvation Lake model include:

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

The model uses a daily time-step, and tracks inputs, outputs, and lake volume to calculate a daily estimate of lake levels for the lake. The model is calibrated from 1974 through 2011, which provided a 38-year water level record considered long-term for purposes of determining Historic percentiles. This period also provides the best balance of using available data for all parts of the water budget and the desire to develop a long-term water level record.

E. Model Components

Lake Stage/Volume

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

Precipitation

After a review of several rain gages in the area of Starvation Lake, daily data from the Section 21 Lutz Wellfield and St. Pete Jackson 26A rain gages were used to represent precipitation over the watershed of the lake (Figure 12). Data maintained by the District were used, although Tampa Bay Water has also monitored these gages. The Section 21 gage is located immediately to the east of Starvation Lake, but was discontinued in 1998. The Jackson 26A gage, located to the west of Starvation Lake, near the Jackson 26A monitor well, began when the Section 21 gage was discontinued, and remains active currently. The Lake Crenshaw gage, located approximately one-half a mile to the north east of Starvation Lake (on private land) was used to in-fill the Jackson 26A data set during a few periods of missing data.

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 13). The data was collected from August 1996 through July 2011. Monthly Lake Starr evaporation data were used in the Starvation Lake model, when available, and monthly averages for the period of record were used for those months when Lake Starr evaporation data were not available.

Figure 12. Rain gages used in the Starvation Lake Model.

Figure 13. Location of Lakes Starvation, Calm and Starr (see inset map).

A recent study compared monthly energy budget evaporation data collected from both Lake Starr and Calm Lake (Swancar, 2011, personal communication). Calm Lake is located approximately 4.5 miles to the northwest of Starvation Lake (Figure 13). The assessment concluded that the evaporation rates between the two lakes were nearly identical, with small differences attributed to measurement error and monthly differences in latent heat associated with differences in lake depth.

Jacobs (2007) produced daily potential evapotranspiration (PET) estimates on a 2-square kilometer grid for the entire state of Florida. The estimates began in 1995, and are updated annually. These estimates, available from a website maintained by the USGS, were calculated through the use of solar radiation data measured by a Geostationary Operational Environmental Satellite (GOES). Because PET is equal to lake evaporation over open water areas, using the values derived from the grid nodes over the modeled lakes was considered. A decision was made to instead use the Lake Starr evaporation data since the GOES data nodes typically include both upland and lake estimates, with no clear way of subdividing the two. It was thought that using the daily PET estimates based on the GOES data would increase model error more than using the Lake Starr data directly.

Overland Flow

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

The modified SCS method was suggested for use in Florida by CH2M HILL (2003), and has been used in several other analyses. The modification adds a fourth category of antecedent moisture condition (AMC) to the original SCS method (SCS, 1972) to account for Florida’s frequent rainfall events.

The topography in the area of Starvation Lake is relatively flat, so determining watersheds based on relatively subtle divides can be challenging. Several slightly varying estimates of watershed boundaries have been performed in the past for different modeling efforts in the area. One of the most recent set of estimates was developed as part of an effort to model the Rocky Creek watershed for flood assessment purposes (Parsons, 2010). The watershed area values developed by

Parsons were adopted for the Starvation Lake model (Table 1) after an independent check confirming that they are reasonable for modeling purposes.

Starvation Lake has an immediate watershed from which it receives overland flow, and several other watersheds from which it can receive channel flow from Lake Jackson to the west (Figure 14). The entire area of the contributing watersheds is just under 450 acres (including the lake), while the area of the direct overland flow watershed is approximately 148 acres (including the lake).

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

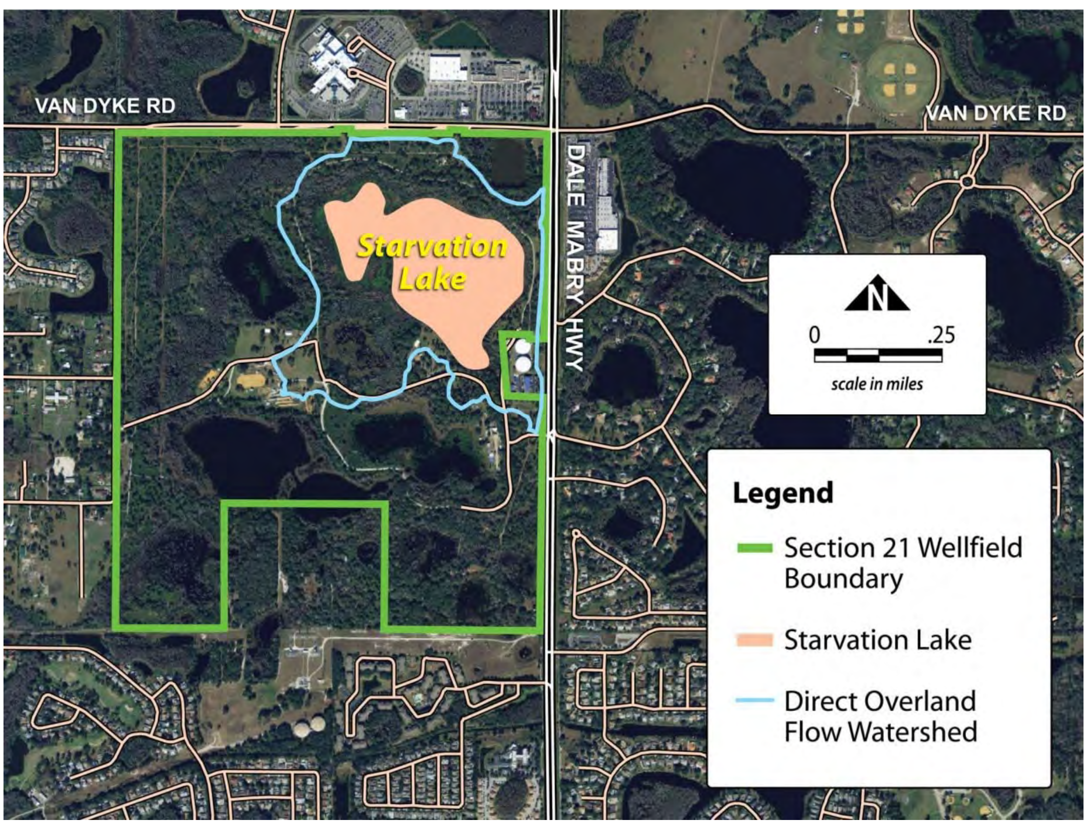

Figure 14. Direct overland flow portion of the Starvation Lake watershed.

The SCS CN and DCIA used for the direct overland flow portion of the watershed are listed in Table 1. Curve numbers were difficult to assess. Most of the soils in the area are B/D soils, which means that the characteristics of the soils are highly dependent on how well they are drained. A “D” soil will generally have a higher amount of runoff per quantity of rain than a “B” soil. Because of the proximity of the wellfield to the area being modeled, water levels have been historically lowered by the withdrawals, and soils in the area may have had lower runoff rates characteristic of “B” soils. Groundwater withdrawals during the period of model calibration were, however, significantly reduced relative to historic withdrawal rates, so the soils in the area may have begun to exhibit runoff properties more characteristic of “D” soils.

For purposes of this model, taking into account the range of conditions experienced, a compromise was used for the CN. The watershed contributing overland flow to Starvation Lake is mostly contained within the park, so very little impervious area exists. The DCIA of the watershed is essentially zero, and was modeled as such.

Table 1. Model inputs for the Starvation Lake model.

Input Variable	Value
Overland Flow Watershed Size (acres)	148
SCS CN of watershed	73
DCIA	0
Floridan Aquifer Monitor Well Used	Hillsborough 13 Floridan and 21-7
Surficial Aquifer Monitor Well(s) Used	Hillsborough 13 Surficial and Jackson 26A
Surficial Aquifer Leakance Coefficient (ft/day/ft)	0.01
Floridan Aquifer. Leakance Coefficient (ft/day/ft)	0.0005
Outflow One K	0.022
Outflow One Invert (ft NGVD29)	49.6
Outflow Two K	0.2
Outflow Two Invert (ft NGVD29)	52.77 ft
Inflow K	0.015
Inflow Invert (ft NGVD29)	49.7

Inflow and Discharge via Channels from Outside Watersheds

Inflow and outflow via channels from or to individual lake watersheds (i.e., “channel flow”) is an important component of the Starvation Lake water budget, although the gradients of the channels are relatively flat, and inflows to the lake likely occur only during high rainfall events.

To estimate flow out of Starvation Lake, the predicted elevation of the lake from the previous day is compared to the controlling elevation. Control elevations were determined based on professional surveying performed in the area. If the lake elevation is above the controlling elevation, the difference is multiplied by the current area of the lake and an "outflow coefficient." The coefficient represents a measure of channel and structure efficiency, and produces a rough estimate of volume lost from the lake. This volume is then subtracted from the current estimate of volume in the lake. To estimate flow into the lake, the same approach was applied. Daily lake stage information from Lake Jackson was included in the model, and the elevation of Lake Jackson each day was compared to the controlling elevation in the channel from Lake Jackson to Starvation Lake. If the Lake Jackson elevation is above the controlling elevation, the difference is multiplied by the current area of Starvation Lake and an outflow coefficient. The resulting volume is then added to the current estimate of volume in Starvation Lake.

A ditch system exists between Lake Jackson and Starvation Lake, and a similar ditch system exists from Starvation Lake to Crum Lake to the south. A high spot in the Lake Jackson channel was surveyed at 49.7 feet above the National Geodetic Vertical Datum of 1929 (NGVD29), which was used as the controlling elevation for Lake Jackson.

A discharge ditch system exists on the southeast shore of Starvation Lake, which passes under the main park road south of the lake via a culvert with an invert of 45.5 feet NGVD29. The ditch system flows to the south and eventually into Crum Lake, which discharges to Lake Simmons, which in turn discharges into a canal to the south of the park property. The high point in the ditch between Starvation Lake and Crum Lake was surveyed at 49.6 feet NGVD29. During very high stages in Starvation Lake, flow can occur over the park road to the west of the discharge ditch system, flowing into Crum Lake. A low point on the road in this area was surveyed at 52.8 feet NGVD29. A high point in the system to the south of Lake Simmons was surveyed at 52.7 feet NGVD29. Because the topography and bottom of the ditch system is so flat, water levels in the chain of lakes from Jackson to Simmons tend to equalize up to an elevation of 52.7 feet NGVD29, at which point flow out of the system occurs. Because water levels above 52.7 feet NGVD29 are historically rare, a dual system of outflow was used in the water budget model. Flow out of Starvation Lake begins at 49.6 feet NGVD29, but increases at 52.7 feet NGVD29. Because the secondary flow over the park road begins at approximately the same elevation as flow out of the park, the two flow paths can be considered as one. Therefore, two staged outflows with differing flow coefficients were used in the model (Table 1).

Flow from and into the surficial aquifer and Upper Floridan aquifer

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

The Hillsborough 13 Floridan aquifer monitoring well, located to the south of Starvation Lake, and the 21-7 Floridan aquifer monitor well, located just to the northeast of the lake, were used to represent the potentiometric surface of the Upper Floridan aquifer (Figures 6, 7, and 8). Both wells have long periods of record of daily data that extend well before the calibration period of the model. Because the 21-7 well is closer to Starvation Lake, a weighted approach using data from both wells was used based on distance from the lake. A two-thirds weight was applied to the 21-7 well, while a one-third weight was applied to the Hillsborough 13 well. Missing daily water level values were in-filled using the last previously recorded value for periods with missing data.

Similarly, a combination of two surficial aquifer monitoring wells was used to represent the water table in the surficial aquifer. The Hillsborough 13 surficial aquifer monitor well is located to the south of Starvations Lake (adjacent to the Hillsborough 13 Floridan well), while the Jackson 26A well is located to the west of the lake (Figures 6 and 9). Both wells are approximately the same distance from the lake, so a simple average of the levels from each well was used. Because the period of record of these wells does not begin until June 1977, an average head difference between the wells and the lakes was used to infill the surficial aquifer water level data back to 1974. Also, missing daily data were in-filled based on the approach used for the Upper Floridan aquifer monitoring wells.

F. Calibration Approach and Results

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

Measured data from the lake were used for comparison with modeled water levels. For the comparison, lake stage data collected on a weekly to monthly basis since June 1961 were in-filled to generate a record of daily values. The same approach that was used to fill-in well data was used for the measured lake stage data.

Figure 15 presents the calibration results of the model. Table 2 presents a comparison of the percentiles of the measured data versus the model results. Table 3 presents modeled water budget components for the model calibration.

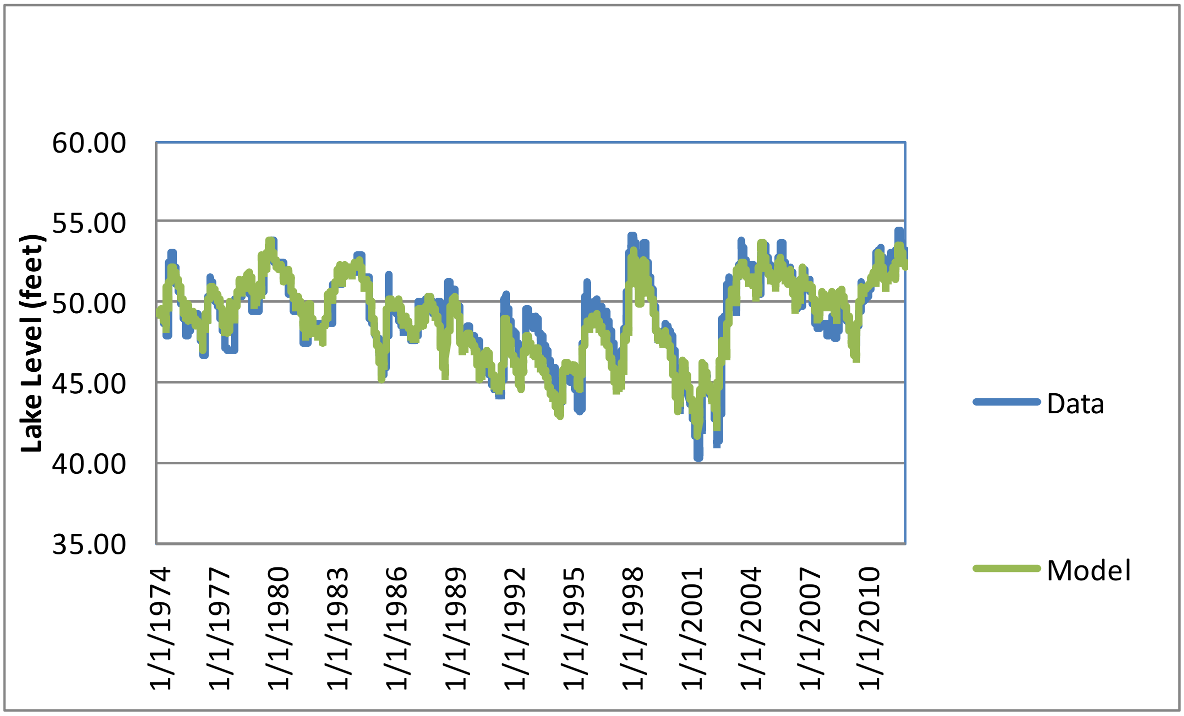

Figure 15. Modeled water levels predicted with the calibrated Starvation Lake water budget model and measured levels (Data) used for model calibration.

Table 2. Long-term percentiles of measured water level data compared to long-term calibration percentiles from the model (all in feet NGVD 29).

	Data	Model
P10	52.5	52.0
P50	49.3	49.3
P90	45.5	45.3

Table 3. Starvation Lake Water Budget (1974-2011).

Inflows	Rainfall	Surficial Aquifer Groundwater Inflow	Florida Aquifer GW Inflow	Runoff	DCIA Runoff	Inflow via channel	Total
Inches/year	50.8	14.0	0.0	25.1	0.0	75.7	165.6
Percentage	30.7	8.5	0.0	15.1	0.0	45.7	100.0

Outflows	Evaporation	Surficial Aquifer GroundwaterOutflow	Florida Aquifer Groundwater Outflow			Outflow via channel	Total
Inches/year	58.1	14.1	21.2			71.3	164.7
Percentage	35.3	8.5	12.9			43.3	100.0

G. Discussion

Based on visual inspection of Figure 15, the model appears to be reasonably well calibrated. There are a few periods when peaks in the modeled hydrograph are higher or lower than the measured values, and these differences contributed to minor differences between the modeled and measured percentiles associated with higher and lower lake levels, i.e., the P10 and P90 percentiles. Reduced precision in the higher and lower ranges of the stage-volume relationships for the lake may also have contributed to the percentile differences.

Choice of curve numbers may also have influenced model calibration and simulation results, particularly since there was a significant decrease in groundwater withdrawals from the Section 21 Wellfield and other nearby wellfields during the period of calibration. Sensitivity analysis indicated that water levels in the earlier portion of the calibration period matched better when a lower curve number was used (indicating a drier soils condition), while water levels in the later portion of the calibration period matched better when a higher curve number was used (indicating a wetter soils condition). These findings are consistent with the effects of reductions in groundwater withdrawals. However, as explained earlier, curve numbers representing an intermediate condition were used for model calibration. Additional sensitivity runs showed that the range of possible curve numbers had only a minor effect on the resulting percentiles.

The water budget component values used for 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 surrounding 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. Flow via the channels is significant, but net input to the lake over the time period of the model is only approximately six inches.

H. Determination of Historic Percentiles

Groundwater withdrawals are not directly included in the Starvation Lake model, but are indirectly represented by their effects on water levels in the Upper Floridan aquifer. Metered groundwater withdrawal rates from the Section 21 Wellfield are available for the model calibration period, so if a relationship between withdrawal rates and Upper Floridan aquifer potentiometric levels can be established, the effect of changes in groundwater withdrawals may 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 Section 21 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 1974 through 2004, while the post-cutback period is 2005 through 2011. 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 were 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 Section 21 Wellfield in each scenario were 8.9 mgd and 4.2 mgd, respectively.

Results from the INTB modeling scenarios showed that there is a fairly linear relationship between Upper Floridan aquifer drawdown and withdrawal rates at the Section 21 Wellfield, with one mgd of groundwater withdrawals resulting in approximately one foot of Upper Floridan aquifer drawdown. Because of the leaky nature of the confining unit in the area of Starvation 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 was also of interest. The same INTB modeling scenarios described above showed that for one mgd of groundwater withdrawals results in approximately 0.6 feet of drawdown in the water table (i.e. the surficial aquifer). 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 Starvation Lake water budget model were adjusted to represent zero withdrawals. For the 1974 through 2011 water budget model period, two adjustment periods were used to reflect the cutbacks that took place at the Section 21 Wellfield. Adjustments for each Upper Floridan aquifer and surficial aquifer well and the associated adjustment periods are listed in Table 4.

Table 4. Aquifer water level adjustments for the Starvation Lake Model to represent Historic percentiles

Well	**Adjustment (feet) 1974 through 2004**	**Adjustment (feet) 2005 through 2011**
Floridan aquifer	11.1	5.5
Surficial aquifer	5.2	2.4

Figure 16 presents measured water level data for the lake along with 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 based on the model output.

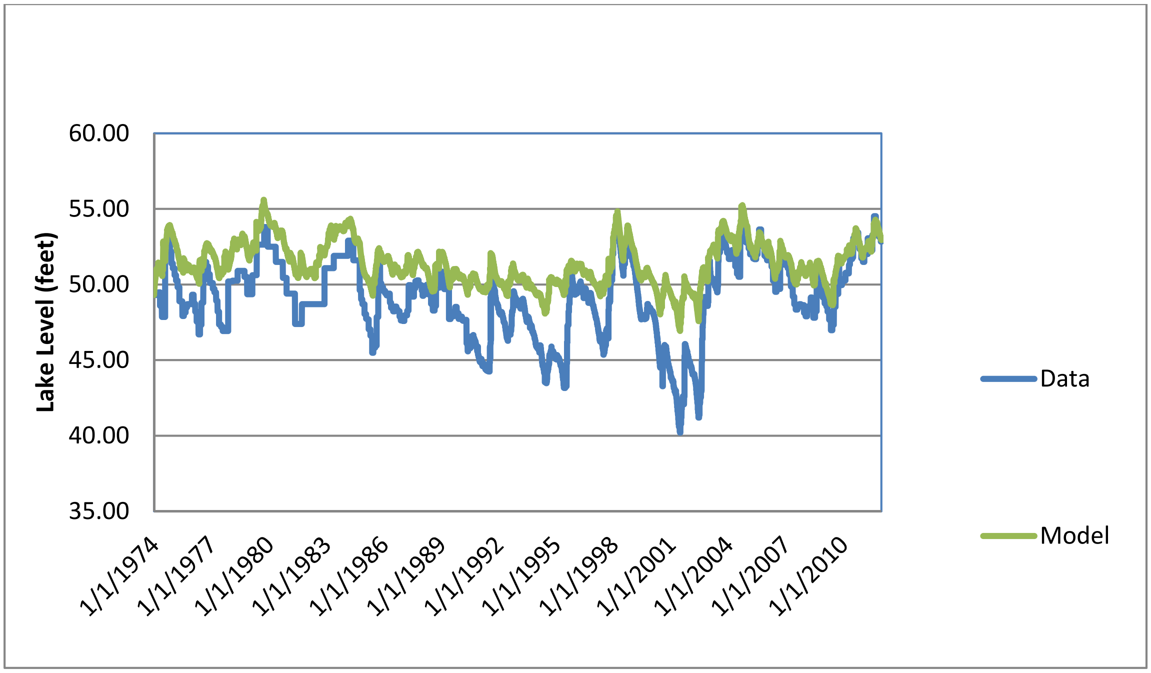

Figure 16. Measured lake levels (Data) and Historic water levels predicted with the calibrated Starvation Lake model (Model).

Table 5. Historic percentiles estimated using the Starvation Lake model (in feet NGVD 29).

Percentile	Elevation
P10	53.5
P50	51.2
P90	49.7

Historic normal pool elevations are established for lakes, ponds and wetlands to standardize measured water levels and facilitate comparison among wetlands and lakes. The Historic normal pool elevation is commonly used in the design of wetland storm water treatment systems (Southwest Florida Water Management District, 1988) and development of minimum levels (Chapter 40D-8, F.A.C.). This normal pool can be consistently identified in cypress swamps or cypress-fringed lakes based on similar vertical locations of several indicators of inundation (Hull, et al, 1989; Biological Research Associates, 1996). Historic normal pools have been used as an estimate of the Historic P10 in natural wetlands and lakes, based on observation of many control sites in the northern Tampa Bay area.

Historic normal pools were determined for Starvation Lake based on inflection points of remaining cypress trees. The historic normal pool for Starvation Lake was determined to be 53.5 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 model estimate of the Historic P10 for Starvation Lake is identical to the field determined Historic normal pool. Therefore, in this case, the natural water levels that occurred prior to development of the Section 21 Wellfield appear to be achievable, at least for the P10.

Conclusions

Based on the model results and the available data, the Starvation Lake model is a useful tool for assessing long-term percentiles in the lake. Based on the same information, lake stage exceedance percentiles developed through use of the model appear to be reasonable estimates for Historic conditions.

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APPENDIX B

Technical Memorandum

August 15, 2014

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

FROM: Michael C. Hancock, P.E., Senior Professional Engineer, Water Resources Bureau
Christina Uranowski, Senior Environmental Scientist, Water Resources Bureau

Subject: Starvation Lake Initial Compliance Assessment

A. Introduction

The Southwest Florida Water Management District (District) is proposing minimum levels for Starvation Lake, as required by Chapter 373.042, Florida Statutes (F.S.). The documentation on how the minimum levels for the lake were established is found in Hancock and McBride, 2014 and Uranowski, 2014.

Section 373.0421, F.S. requires that a recovery or prevention strategy be developed for all waterbodies that are found to be below their minimum flows or levels, or are projected to be within 20 years. In the case of Starvation 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 Starvation 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 minimum levels proposed for Starvation Lake and any recovery that may be necessary for the lake.

B. Background

The proposed minimum levels for Starvation Lake are presented in Table 1.

Table 1. Proposed Minimum Levels for Starvation Lake

Minimum Levels	**Elevation in Feet**
	NGVD 29
High Minimum Lake Level (P10)	52.7
Minimum Lake Level (P50)	50.4

Minimum levels are intended to represent long-term conditions under a variety of expected hydrological conditions. The Minimum Lake Level represents the 50th percentile (median) of long-term water levels, while the High Minimum Lake Level represents the 10^{th} percentile (as measured from the higher elevations of the water body) of long-term water levels. Therefore, to determine compliance with minimum levels, long-term data or model results must be used.

C. Assessment

The Starvation Lake water budget model (Hancock and McBride, 2014) was used to determine the long-term lake percentiles that would be expected if current withdrawal rates continued for a long period of time and structural alteration conditions were similar to those currently existing. The model was developed to determine the Historic percentiles of the lake, and is calibrated from 1974 through 2011.

The Section 21 Wellfield (in which Starvation Lake is located) has experienced two general withdrawal rates during the period of 1988 to 2011. From 2002 to 2005, a cutback in the withdrawal rates of most Tampa Bay Water wellfields occurred in response to the addition of several alternative water supply sources. Using the Integrated Northern Tampa Bay (INTB) model (Geurink and Basso, 2013), long-term drawdowns in the Upper Floridan aquifer and surficial aquifer were estimated for the period before and after the wellfield cutback. These drawdown estimates were then used to identify adjustments needed for the Upper Floridan and surficial aquifer representation in the Lake Starvation water budget model to represent different withdrawal rates. This approach is explained in more detail in Hancock and McBride (2014).

For this compliance assessment, Upper Floridan and surficial aquifer levels in the Starvation Lake water budget model were adjusted to represent average withdrawal rates since the 2005 cutbacks (referred to as “Current” conditions), and the model was run for the 1974 through 2011 period. Table 2 presents the resulting water level percentiles based on model output for the 37-year simulation period. Comparison of these results with the proposed minimum levels, which are also listed in Table 2, indicated that the modeled P10 based on long-term current conditions is higher than the proposed High Minimum Level, and the modeled P50 is equal to the proposed Minimum Level.

Table 2. Long-term “Current” percentiles for Starvation Lake as derived from the Starvation Lake water budget model.

Percentile	Current Conditions Simulation	Proposed MFLs
	Elevation in Feet NGVD 29	Elevation in Feet NGVD 29
P10	52.9	52.7
P50	50.4	50.4

Table 3 presents the percentiles of field-collected water level data from Starvation Lake from 1974 through 2011. The 2005 through 2011 percentiles are also shown since they represent a time period of lower withdrawal rates from the Section 21 Wellfield (and other Tampa Bay Water wellfields that may also affect the lake). There are two factors to note as these values are reviewed. First, during the period of approximately 1990 through 2004, water levels were typically collected several times a month, while monthly data collection was typical prior to 1990 and after 2004. Because of the larger number of data points during the period of 1990 through 2004, the medians are likely skewed towards the conditions during that period. Secondly, a comparison of the rainfall totals from 1974 through 2011 (50.9 inches per year, as used in the model) with rainfall from 2005 through 2011 (52.1 inches per year, as used in the model) shows rainfall in the shorter period averaged approximately 1.2 inches per year higher than that in the longer period.

Table 3. Field-collected water level percentiles for Starvation Lake

Percentile and Proposed Minimum Levels	Elevation in Feet NGVD 29
1974 through 2011 P10 field data	52.1
2005 through 2011 P10 field data	53.1
Proposed High Minimum Level	52.7
1974 through 2011 P50 field data	48.2
2005 through 2011 P50 field data	51.2
Proposed Minimum Level	50.4

Based on the information presented in this memorandum, including long-term percentiles simulated for recent withdrawal conditions and measured lake water levels, it is concluded that Starvation Lake is currently at or above its proposed minimum levels, although the long-term P50 is just at the proposed Minimum Lake Level.

D. Recovery/Prevention Recommendation

As outlined in the District's (2011) Regional Water Supply Plan, all minimum flow and level water bodies not in need of recovery are included in a three point prevention strategy that addresses: (1) monitoring water levels and flows for water resources/sites with established minimum flows and levels to evaluate the need for additional prevention strategies; (2) assessment of potential water supply/resource concerns as part of the regional water supply planning process; and (3) implementation of a water use permitting program that ensures water use does not cause established minimum flows and levels to not be met in the future.

Specifically for Starvation Lake, we also recommend that Tampa Bay Water continue to assess the lake as part of their Permit Recovery Assessment Plan, as required by the Comprehensive Environmental Resources Recovery Plan for the Northern Tampa bay Water Use Caution Area and the Hillsborough River Strategy (Rule 40D-80-073, F.A.C.), and the Consolidated Permit (Water Use Permit Number 20011771.001). As part of this plan, Tampa Bay Water, in cooperation with the District, will assess specific needs for restoration in this and other lakes affected by their groundwater withdrawals. At that time, if not sooner, alternative recovery projects will be proposed if the 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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