Revised Minimum and Guidance Levels for Lake Starr, in Polk County, Florida

May 18, 2017

Resource Evaluation Section
Water Resources Bureau

Southwest Florida
Water Management District

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Introduction

Reevaluation of Minimum Flows and Levels

This report describes the development of revised minimum and guidance levels for Lake Starr in Polk County, Florida. These revised 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 December 2015 and became effective on February 12, 2017. Rulemaking for these levels also included removal of previously adopted guidance levels for the lake from District rules.

Table 1. Revised Minimum and Guidance Levels for Lake Starr

Minimum and Guidance Levels	Elevation in Feet NGVD29	Elevation in Feet NAVD88
High Guidance Level	107.2	106.3
High Minimum Lake Level	106.4	105.5
Minimum Lake Level	103.2	102.3
Low Guidance Level	101.4	100.5

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

Minimum Flows and Levels Program Overview

Legal Directives

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

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

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

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

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

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

Programmatic Description and Major Assumptions

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

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

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

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

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

Consideration of Changes and Structural Alterations and Environmental Values

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

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

- adjust measured flow or water level historical records to account for existing changes/alterations;
- model or simulate flow or water level records that reflect long-term conditions that would be expected based on existing changes/alterations and in the absence of measurable withdrawal impacts;
- develop or identify significant harm standards, thresholds and other criteria;
- aid in the characterization or classification of lake types or classes based on the changes/alterations;

- evaluate the status of water bodies with proposed or established MFLs (i.e., determine whether the flow and/or water level are below, or are projected to fall below the applicable minimum flow or level); and
- support development of lake guidance levels (described in the following paragraph).

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

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

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

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

Table 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, 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

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

Vertical Datum of 1929 (NGVD29), may include the following (refer to Rule 40D-8.624, F.A.C.).

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

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

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

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

The District is in the process of converting from use of the NGVD29 datum to use of the North American Vertical Datum of 1988 (NAVD 88). 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. All elevation values presented in this report are reported in the NGVD29 datum.

Lake Classification

Lakes are classified as Category 1, 2 or 3 for Minimum Levels development based on the presence or absence of fringing cypress wetlands greater than 0.5 acres in size. Lake Starr does not have fringing cypress wetlands of any size and is therefore classified as a Category 3 Lake. The significant change standards for Category 3 lakes include a Lake Mixing Standard, a Dock-Use Standard, a Basin Connectivity Standard, a Species Richness Standard, an Herbaceous Wetland Standard, a Submerged Aquatic Macrophyte Standard, an Aesthetics Standard, and a Recreation/Ski Standard.

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

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

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

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

Herbaceous Wetland Information is taken into consideration to determine the elevation at which changes in lake stage would result in substantial changes in potential wetland area within the lake basin (i.e., basin area with a water depth of four or less feet). Similarly, changes in lake stage associated with changes in lake area available for colonization by rooted submersed or floating-leaved macrophytes are also evaluated, based on water transparency values.

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

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

Lake Setting and Description

Location

Lake Starr is in the Peace River Basin in Polk County, Florida (latitude 27 5 7 25, longitude 81 35 15) (Figure 1). The lake resides near the southeast border of the city of Lake Wales. The city of Lake Wales has a 2014 U.S. census estimated population of 15,140.

Physiology and Hydrology

Land form physiology or morphology of the nature or structure of the underlying geology in the region is primarily upland sand and deeper karst limestone. White (1970) classified the area of west-central Florida containing Lake Starr as the Lake Wales Ridge physiographic region. Brooks (1981) further described physiographic divisions and associated natural vegetation. The area surrounding the lake was characterized as the Iron Mountains unit of the Lake Wales Ridge subdivision, Central Lake District and was described as very high residual sand hills and relic beach ridges with native vegetation generally being longleaf pine-turkey oak woodlands.

As part of the Florida Department of Environmental Protection's Lake Bioassessment/Regionalization Initiative, the area has been identified as the Northern Lake Wales Ridge region and described as a narrow ridge of well-drained, sandy soils, 100-300 feet in elevation that forms the topographic crest of central Florida. The lakes are mostly alkaline, low to moderate nutrient, clear-water lakes (Griffith *et al.* 1997).

The hydrogeology of the region includes three distinct aquifer systems: a surficial aquifer, an intermediate confining unit or intermediate aquifer system (IAS), and an Upper (UFAS) and Lower Floridan aquifer system (LFAS) (Spechler and Kroening, 2007 and Copeland, et. al). The surficial aquifer consists of sandy soils, is an unconfined layer generally tens of feet or less thick, and is rainfall driven. Water levels vary seasonally 1ft. – 5ft. within the surficial aquifer and regional horizontal conductivity ranges from 0.3 to 55 ft. per day (SWFWMD, 2000). The IAS has similar thickness and is part of the Hawthorn Group Stratigraphic Unit with a mosaic of sand, silt, clay, limestone and dolomite (O'Reilly et al., 2002). The IAS functions as an aquitard constraining movement of rainfall supplied groundwater in the surficial aquifer to the FAS (Scott et al, 2001). The UFAS consists of Ocala Limestone, and the Avon Park Formation (dolomite and dolomitic limestone); both characterized by cavernous porosity and solution cavities. The LFAS consists of the Avon Park, Oldsmar, and Cedar Keys Formations (limestone and dolomite), and characterized by abundant fractures. Public water supply withdrawals water from the LFAS.

Figure 1. Lake Starr Location Map.

Bathymetry and Basin/Watershed Description and History

The 1952 United States Geological Survey 1:24,000 Lake Wales quadrangle map indicates an elevation of 108 ft. for Lake Starr. The “Gazetteer of Florida Lakes” (Florida Board of Conservation 1969, Shafer *et al.* 1986) lists the lake area at 147 acres at this elevation. One foot interval bathymetric data gathered from recent field surveys resulted in lake-bottom contour lines (Figure 3). At the ten-year flood guidance levels established in 2007 (105.8 feet, Table 4), the lake surface area is 138 acres based on recent stage volume data calculated in support of minimum levels development. These data revealed that the lowest lake bottom contour (76 ft.) located in the southeastern area of the lake is the deepest area at nearly 32 ft. deep. Additional morphometric or bathymetric information for the lake basin is discussed in the Methods, Results and Discussion section of this report and is also available from Florida Lakewatch.

Lake Starr is located in the 314-square mile Kissimmee River – Above Lake Hatchineha Watershed. There are no surface inflows to the lake, other than that from a few stormwater systems scattered throughout the basin. The lake has no surface water outflow conveyance system and is considered a closed basin. Lake Starr is however identified as a surficial groundwater flow-through lake (Swancar et. al, 2000) and like other lakes in the region, lake surface water interacts with groundwater inflow and outflow. There is no public access to the lake.

The Lake Starr basin/watershed land use has changed considerably from its pre-development times. Native vegetation historically included various species of trees including of *Pinus* (*palustris, elliottii, and clausa*), and Quercus (*laevis, marilandica, stellata, chapmanii and virginiana*), with understories of *Serenoa repens, Ilex glabra, Myrica cerifera, Aristida stricta, and Sorghastrum secundum*. This native vegetation is typical of the Tavares, Candler, Smyrna, Sparr and Pomello soils present in the lake basin (Ford et, al. 1990). Post-development land use changes include drainage modifications, agricultural activities, including citrus production and livestock grazing or pastureland use, and residential/urban development. Agricultural activities and constructed roads and more recently residential development are evident in the immediate lake basin in aerial photographs from the 1970s through recent times (Figures 3 through 5).

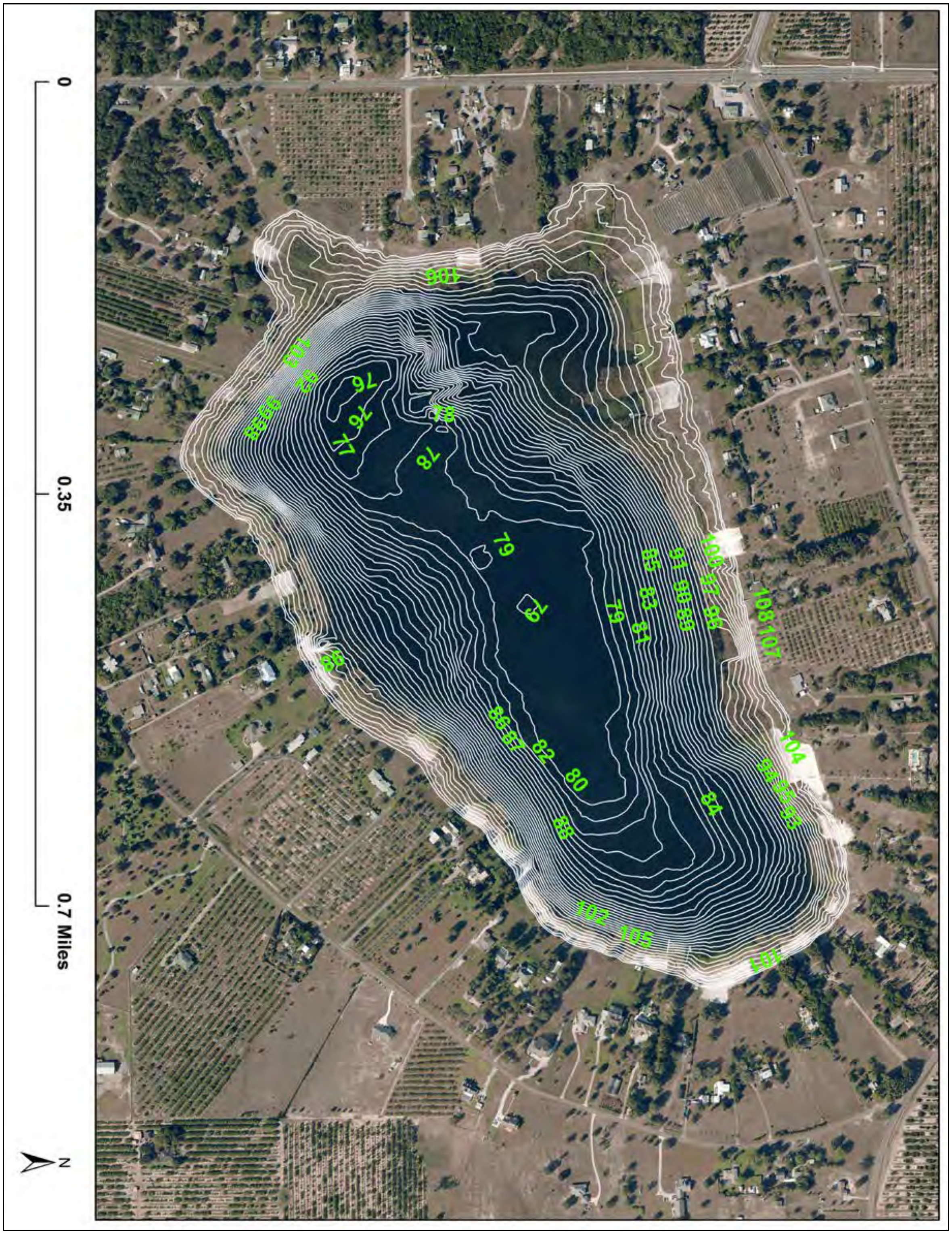


Figure 2. Lake Bottom Contours on a 2014 Natural Aerial Photograph.

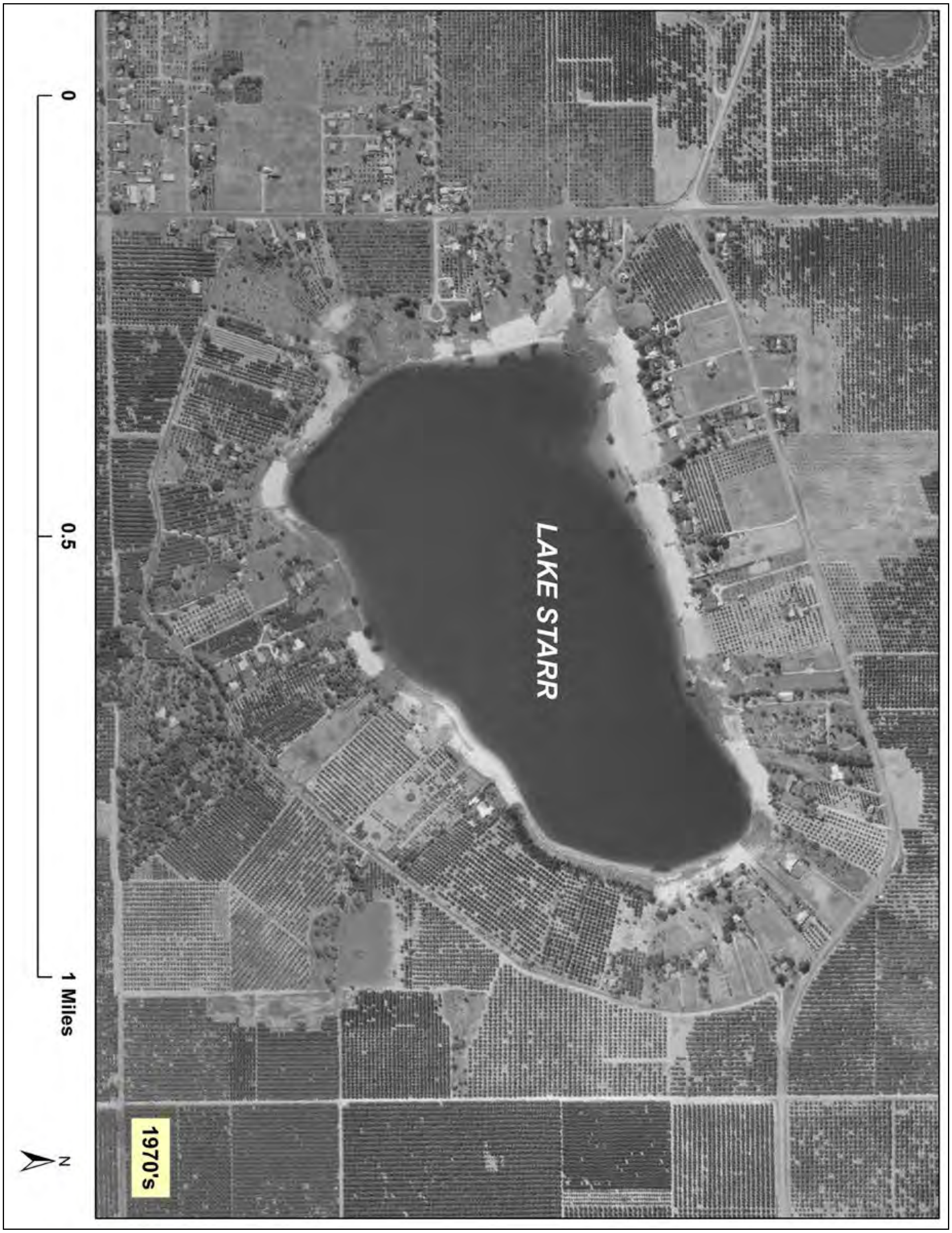


Figure 3. 1970's Aerial Photograph of Lake Starr

Figure 4. 2006 Aerial Photograph of Lake Starr

Figure 5. 2010 Aerial Photograph of Lake Starr

Based on review the Florida Land Use, Cover and Forms Classification System (FLUCCS) 2011 map maintained by the District Mapping and GIS Section, the land area in near Lake Starr is nearly half residential/open rural and half citrus (Figure 6). Similar 1990 data showed citrus held nearly three-quarters of the same area (data not shown). There is one wetland associated with the lake. A small three-acre freshwater marsh resides on the southwest shore.

Hydrology and MFLs Development

Water Level (Lake Stage) Record

Lake stage data, i.e., surface water elevations collected are available for Lake Starr from the District Water Management Information System (SID 25282) for the period from February 28, 1983 through the present time (Figures 7 and 8).

The District continues to monitor the water levels monthly and has done since January 1984. Concurrently, the USGS has recorded daily lake stage data beginning in September 1995. The highest lake stage elevation on record was 109.8 ft. and occurred in December 2005 in part in response to three hurricanes that made landfall (Dennis, Katrina, and Wilma). The lowest lake stage elevation on record was 96.2 ft. and occurred on July 5, 2001 following a 1999-2001 period of extended drought.

Evaluation of Withdrawal Impacts

There are numerous permitted groundwater withdrawals in the area that may affect Lake Starr water levels (Figure 9). An analysis of water use based on metered and estimated quantities for all water users in the area indicates that mean monthly water use within 1, 2, and 3 miles of Lake Starr was 1, 4.8 and 9.1 mgd, respectively, for the 20-year period from 1992 through 2011 (Figure 10). Mean monthly water use within 5, 10 and 20 miles of the lake for the same period increased to 17.9, 62.4 and 139.3 mgd, respectively.

Historical Management Levels and Current Minimum and Guidance Levels Development

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

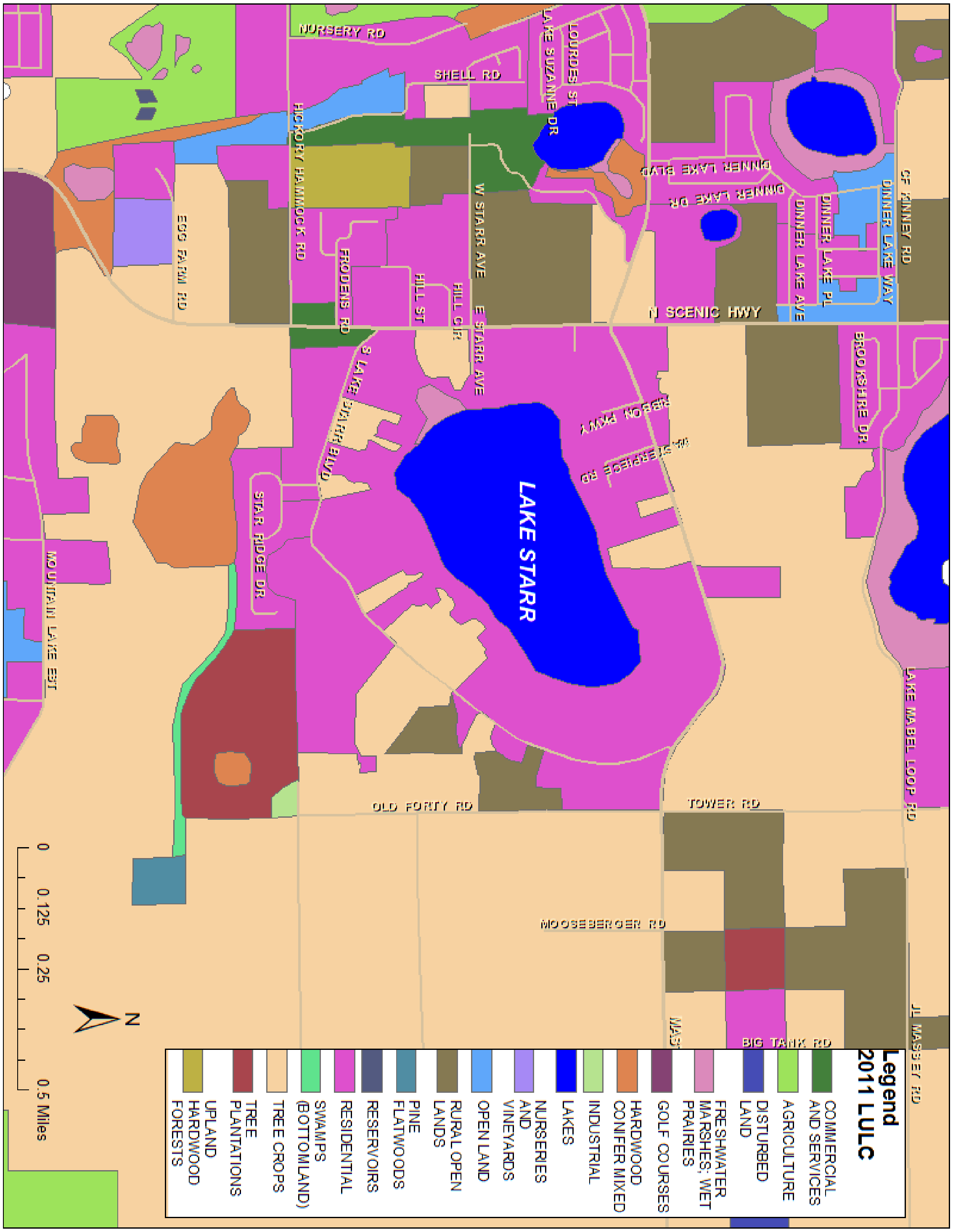


Figure 6. Land Use Land Cover Map of the Lake Starr Vicinity.

Figure 7. Location of the District Gage.

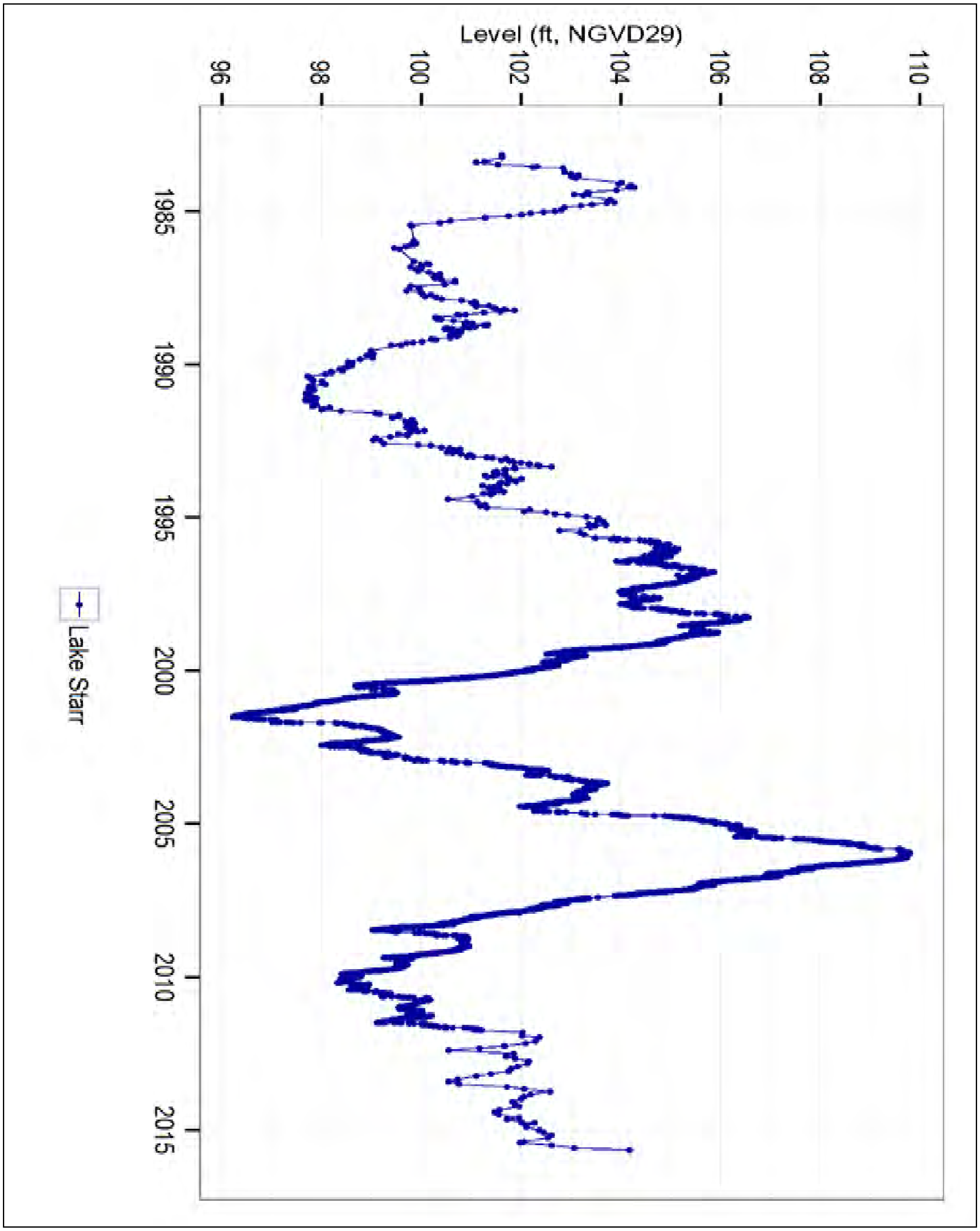
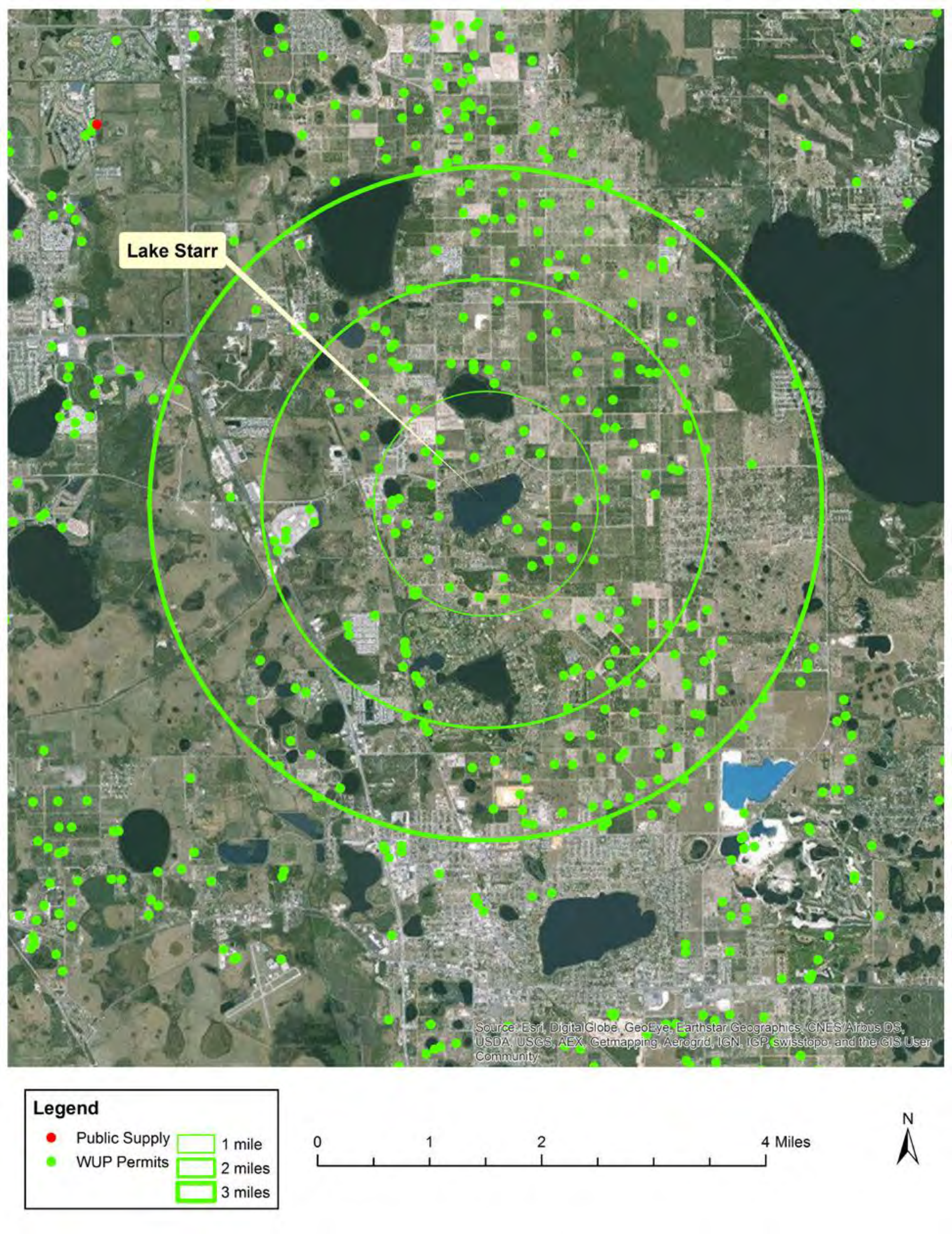


Figure 8. Lake Starr Period of Record Stage Data (WMIS SID 25282).



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 9. Permitted Groundwater Withdrawals Within a 1, 2, and 3 Mile Radius of Lake Starr.

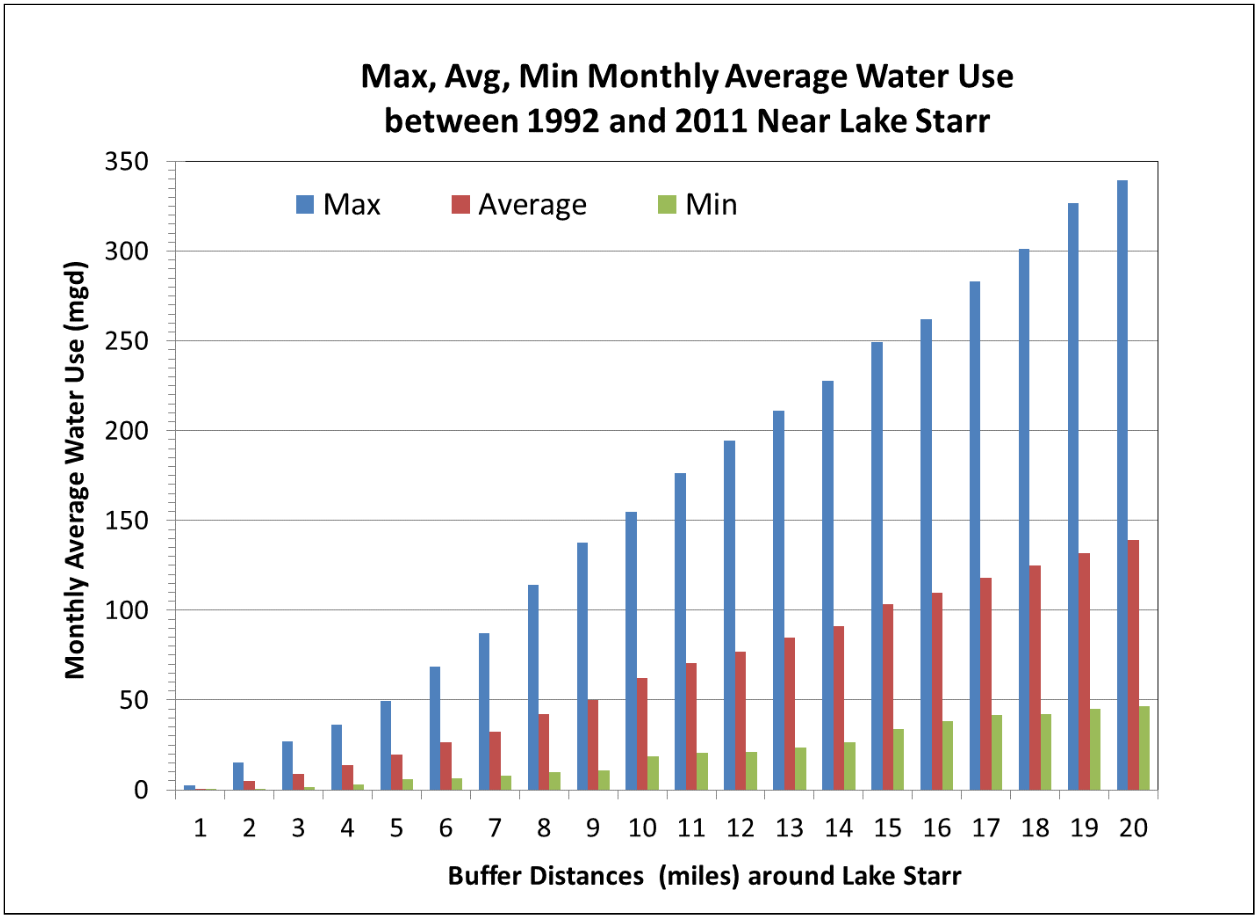


Figure 10. Monthly Average Water Use Within twenty miles of Lake Starr.

Based on work conducted in 1970s (see SWFWMD 1996), the District Governing Board adopted management levels (currently referred to as Guidance Levels) into Chapter 40D-8, Florida Administrative Code for Lake Starr in 1989 (Table 3). These previously adopted management levels for Lake Starr were approved for replacement by Minimum and Guidance Levels in October 2007 using the methodology for Category 3 Lakes described in Leeper *et al.* (2001), in accordance with modifications outlined by Dierberg and Wagner (2001). The previously adopted Minimum and Guidance Levels, along with area values for each water level are listed in Table 4.

Table 3. Previously adopted guidance levels (January 1989) and associated surface areas for Lake Starr, Polk County, Florida.

Level	Elevation (ft., NGVD)	Total Lake Area (acres)
Ten Year Flood Guidance Level	115.5	160
High Level	113.0	154
Low Level	110.0	148
Extreme Low Level	108.0	144

Table 4. Previously adopted minimum levels, guidance levels (board approved October 2007) and associated surface areas for Lake Starr, Polk County, Florida.

Level	Elevation (ft., NGVD)	Lake Area (acres)
High Guidance Level	105.8	138
High Minimum Lake Level	105.0	134
Minimum Lake Level	102.1	120
Low Guidance Level	100.7	113

NA = not available

Methods, Results and Discussion

Summary of Data and Analyses Supporting Development of the Revised Minimum and Guidance Levels

Revised Minimum and Guidance Levels were developed for Lake Starr using the methodology for Category 3 lakes described in Chapter 40D-8, F.A.C. Revised levels along with lake surface area for each level are listed in Table 5 along with other information used for development of the revised levels. Detailed descriptions of the development and use of these data are provided in subsequent sections of this report.

Table 5. Elevation data and associated area values used for establishing minimum levels for Lake Starr, Polk County, Florida.

Levels	Elevation (ft. NGVD)	Lake Area (acres)
Lake Stage Exceedance Percentiles		
Historic P10	107.2	141.2
Historic P50	104.0	123.9
Historic P90	101.4	110.2
Normal Pool and Control Point		
Normal Pool	NA	NA
Control Point	NA	NA
Low Floor Slab	120.4	173.1
Significant Change Standards		
Dock-Use Standard	107.7	142.7
Wetland Offset	103.2	119.3
Species Richness Standard	102.4	114.6
Aesthetic Standard	101.4	110.2
Recreation/Ski Standard	88.6	62.5
Mixing Standard	79.8	27.7
Basin Connectivity Standard	NA	NA
Cypress Standard	NA	NA
Revised Minimum and Guidance Levels		
High Guidance Level	107.2	141.2
High Minimum Lake Level	106.4	138.6
Minimum Lake Level	103.2	119.3
Low Guidance Level	101.4	110.2

Bathymetry

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

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

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

The DEM created from the combined elevation data sets was used to develop topographic contours of the lake basin and to create a triangulated irregular network (TIN). The TIN was used to calculate the stage areas and volumes using a Python script file to iteratively run the Surface Volume tool in the Functional Surface toolset of the ESRI® 3D Analyst toolbox at one-tenth of a foot elevation change increments (selected stage-area-volume results are presented in Figure 11).

Classification of Lake Stage Data and Development of Exceedance Percentiles

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

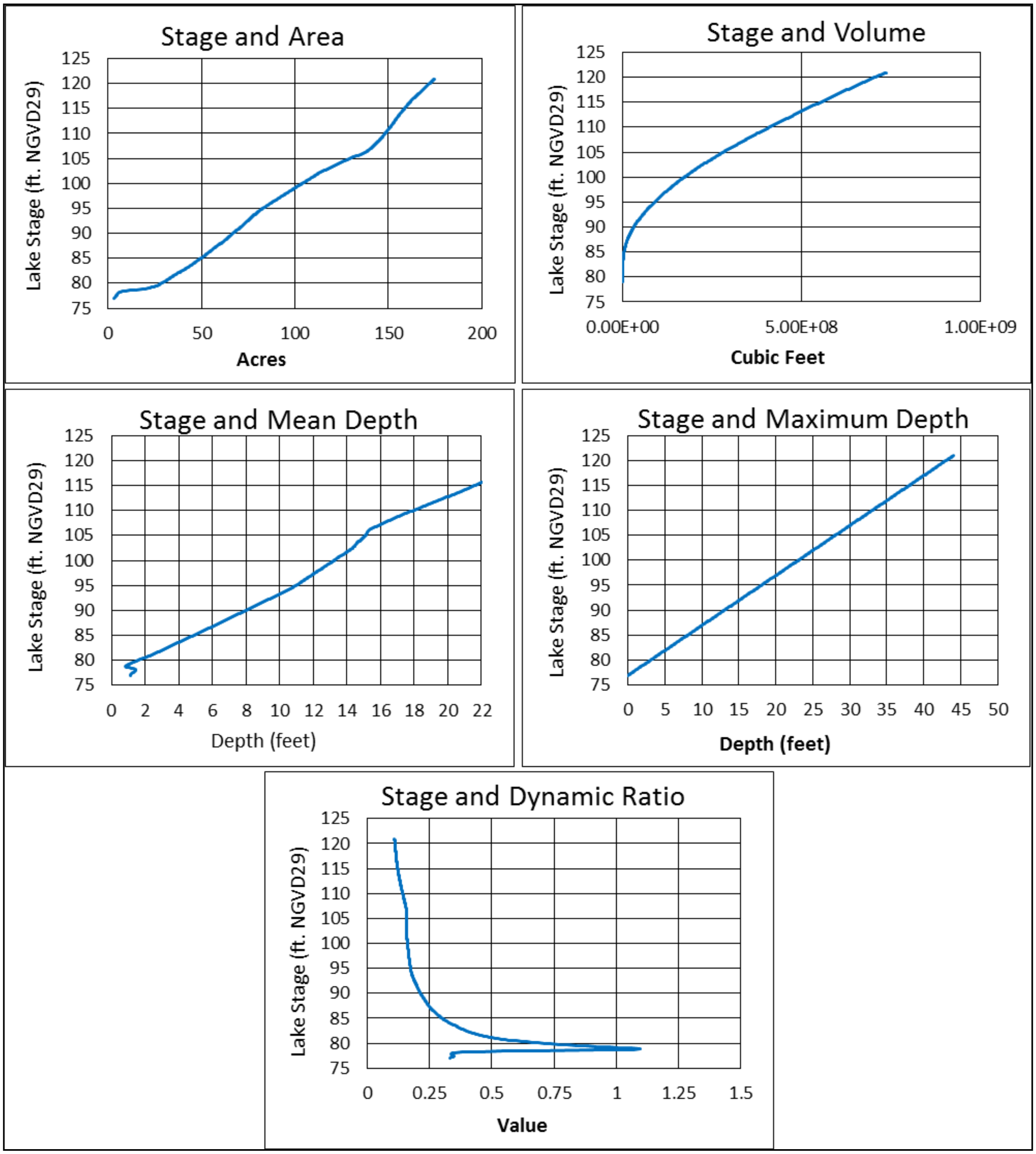


Figure 11. Surface area, volume, mean depth, maximum depth and dynamic ratio (basin slope) as a function of lake stage.

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

The approach included creating a water budget model which incorporated the effects of precipitation, evaporation, overland flow, and groundwater interactions (Appendix A). Using the results of water budget model, regression modeling for lake stage predictions was conducted using a linear line of organic correlation statistical model (LOC) (see Helsel and Hirsch 1992). The procedure was used to derive the relationship between daily water surface elevations for Lake Starr and composite regional rainfall.
A combination of model data produced a hybrid model which resulted in a 69 year (1946-2014) Historic water level record. Based on this hybrid data, the Historic P10 elevation, i.e., the elevation of the lake water surface equaled or exceeded ten percent of the time, was 107.2 ft. The Historic P50, the elevation the lake water surface equaled or exceeded fifty percent of the time during the historic period, was 104.0 ft. The Historic P90, the lake water surface elevation equaled or exceeded ninety percent of the time during the historic period, was 101.4 ft. (Table 5; Table 7 in Appendix A).

Revised Guidance Levels

The High Guidance Level is provided as an advisory guideline for construction of lakeshore development, water dependent structures, and operation of water management structures. The High Guidance Level is the expected Historic P10 of the lake, and is established using Historic data if it is available, or is estimated using the Current P10, the Control Point elevation and the Normal Pool elevation. Based on the availability of Historic data developed for Lake Starr, the revised High Guidance Level was established at the Historic P10 elevation, 107.2 ft. The High Guidance Level has been exceeded a few times in the Historic data. For example, the water level peaked at 111 ft. in response to a large magnitude flood in 1960 associated with Hurricane Donna (Figure 13). Based on the recent gaging record for the lake, the water level exceeded the High Guidance Level once when the level peaked at 109.8 ft. following the 2005 hurricane season (Figure 8).

The Low Guidance Level is provided as an advisory guideline for water dependent structures, and as information for lakeshore residents and operation of water management structures. The Low Guidance Level is the elevation that a lake's water levels are expected to equal or exceed ninety percent of the time on a long-term basis. The level is established using Historic or Current lake stage data and, in some cases, reference lake water regime statistics. Reference lake water regime statistics are used when adequate Historic or current data are not available. These statistics represent differences between P10, P50 and P90 lake stage elevations for typical, regional lakes that exhibit little or no impacts associated with water withdrawals, i.e., reference lakes. Reference lake water regime statistics include the RLWR50, RLWR90 and RLWR5090, which are, respectively, median differences between P10 and P50, P50 and P90, and P10 and P90 lake stage percentiles for a set of reference lakes. Based on the availability of Historic data for Lake Starr, the revised Low Guidance Level was established at the Historic P90 elevation, 101.4 ft.

Significant Change Standards and Other Information for Consideration

The stage-volume relationship developed and Category 3 significant change standards were established for Lake Starr including a Lake Mixing Standard, a Dock-Use Standard, a Basin Connectivity Standard, a Species Richness Standard, an Herbaceous Wetland Standard, a Submerged Aquatic Macrophyte Standard, an Aesthetics Standard, and a Recreation/Ski Standard. Each were evaluated for minimum levels development for Lake Starr and presented in Table 5.

The Mixing Standard was established at 79.8 ft., an elevation well below the Current P90 and Low Guidance Level elevations, indicating that potential changes in basin susceptibility to wind-induced sediment re-suspension would not be of concern for minimum levels development. The Dock-Use Standard was established at 107.7 ft., based on 90 percent of the dock-end sediment elevations (103.1 ft.), developed from measurement of 9 docks (Table 6). Historical aerial photography and Lake Bathymetry reveal that the lake is one continuous basin, therefore, the Basin Connectivity Standard was not considered. The Species Richness Standard was established at 102.4 ft., based on a 15% reduction in lake surface area from that at the Historic P50 elevation. Review of changes in potential herbaceous wetland area associated with change in lake stage, and potential change in area available for aquatic macrophyte colonization did not indicate that use of any of the identified standards would be inappropriate for minimum levels development (Figure 12). An Aesthetic-Standard for Lake Starr was established at the Low Guidance Level elevation of 101.4 ft. The Recreation/Ski Standard was calculated at 88.6 ft. based on a critical ski elevation of 81 ft., the standard was considered not applicable to the MFLs because it was considerably below the Historic P90 water level.

Table 6. Summary statistics and elevations associated with docks in Lake Starr based on measurements made by District staff in September 2015. Exceedance percentiles (P10, P50, and P90) represent elevations exceeded by 10, 50 and 90 percent of the docks.

Summery Statistics	Statistics Value (N) or Elevation (feet) of Sediments at Waterward End of Docks	Statistics Value (N) or Elevation (feet) of Dock Platforms
N (number of docks)	9	9
10th Percentile (P90)	96.5	103.4
Median or 50th Percentile	100.8	107.9
90th Percentile (P10)	103.1	110.0
Maximum	103.2	111.7
Minimum	94.6	103.3

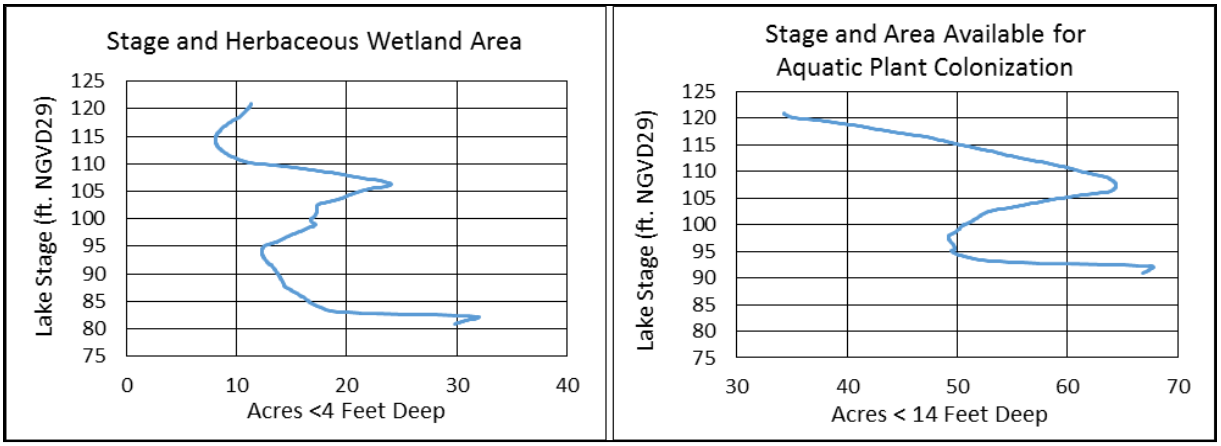


Figure 12. Potential herbaceous wetland area and area available for macrophyte colonization in Lake Starr as a function of lake stage.

Additional information to consider in establishing Minimum and Guidance Levels are the Control Point elevation and the lowest building floor (slab) elevation within the lake basin (determined by field survey data). The Control Point elevation is the elevation of the highest stable point along the outlet profile of a surface water conveyance system that can principally control the lake water level fluctuations. There is no Control Point elevation for Lake Starr and is designated as a closed basin. The low floor slab elevation was determined by field survey as 120.4 ft. (13.2 ft. higher than the HGL) and was not considered in establishing the Minimum and Guidance Levels. Water levels in the period of record stage data never reached the low floor slab elevation.

Revised Minimum Levels

The Minimum Lake Level is the elevation that a lake's water levels are required to equal or exceed fifty percent of the time on a long-term basis. For a Category 3 lake, the Minimum Lake Level is established at the most conservative significant change standard. In the case of Lake Starr, the revised minimum level is established by Wetland Offset at 103.2 ft. Recent lake stage has been near or above the Minimum Lake Level. Water level read on October 27, 2015 was 105.25; 2 ft. higher than the revised minimum level.

The High Minimum Lake Level is the elevation that a lake's water levels are required to equal or exceed ten percent of the time on a long-term basis. For Lake Starr, a Category 3 lake with Historic data, the High Minimum Lake Level is established at the Minimum Lake Level elevation plus the difference between the Historic P10 and the Historic P50. Therefore, the revised High Minimum Lake Level for Lake Starr is established at 106.4 ft.

Revised Minimum and Guidance levels for Lake Starr are plotted in Figure 13 along with the Historic water level record. The approximate locations of the lake margin when water levels equal the revised minimum levels are shown on a 2014 natural color photograph in Figure 14.

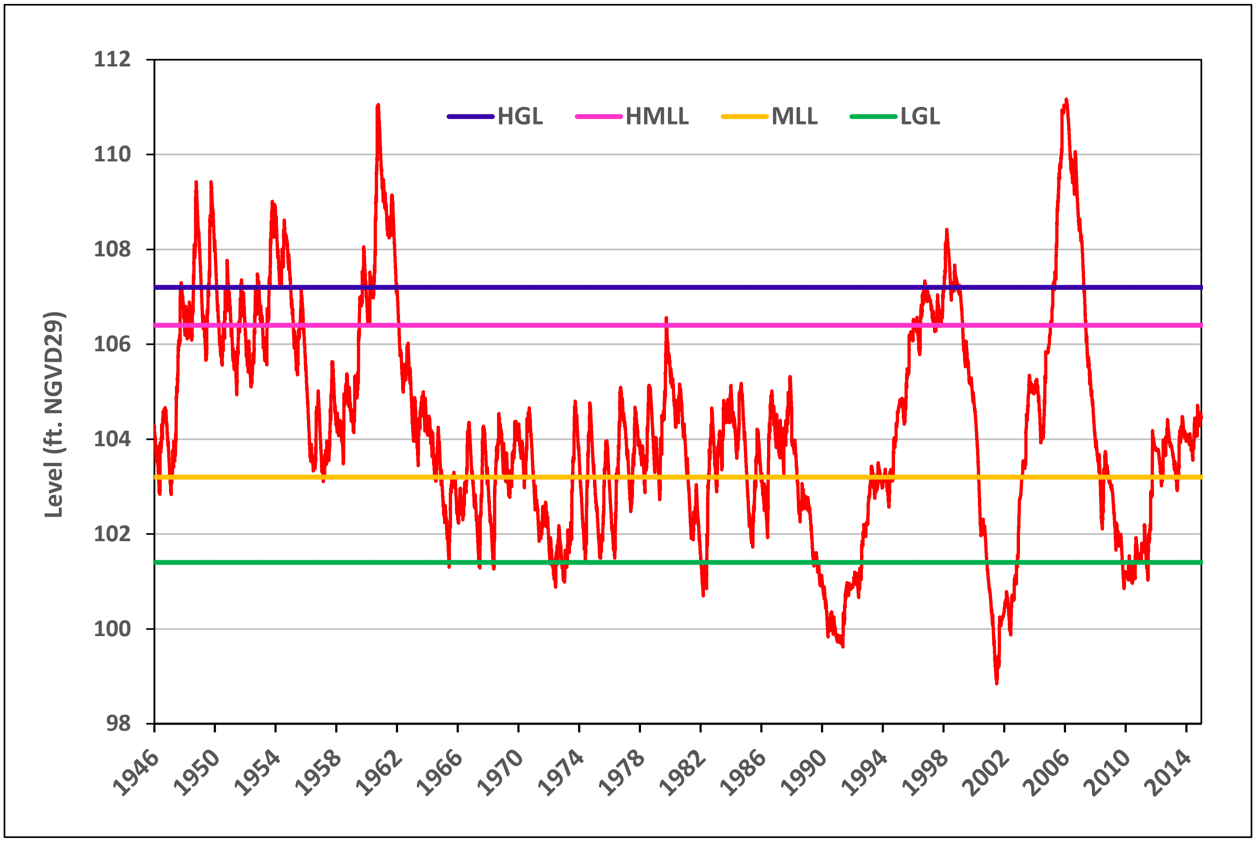


Figure 13. Historic water levels (hybrid) used to calculate the Revised Minimum and Guidance Levels. The revised levels include the High Guidance Levels (HGL), High Minimum Lake Levels (HMLL), Minimum Lake Levels (MLL), and Low Guidance Levels (LGL).

Many federal, state, and local agencies, such as the U.S. Army Corps of Engineers, the Federal Emergency Management Agency, United States Geological Survey, and Florida's water management districts are in the process of upgrading from the National Geodetic Vertical Datum (NGVD29) standard to the North American Vertical Datum (NAVD88) standard. For comparison purposes, the revised MFLs for Lake Starr are presented in both datum standards (Table 1). The datum shift was calculated based on third-order leveling ties from vertical survey control stations with known elevations above the North American Vertical Datum on 1988. The NGVD29 datum was converted to NAVD88 using the Corpscon conversion of 0.95 ft.

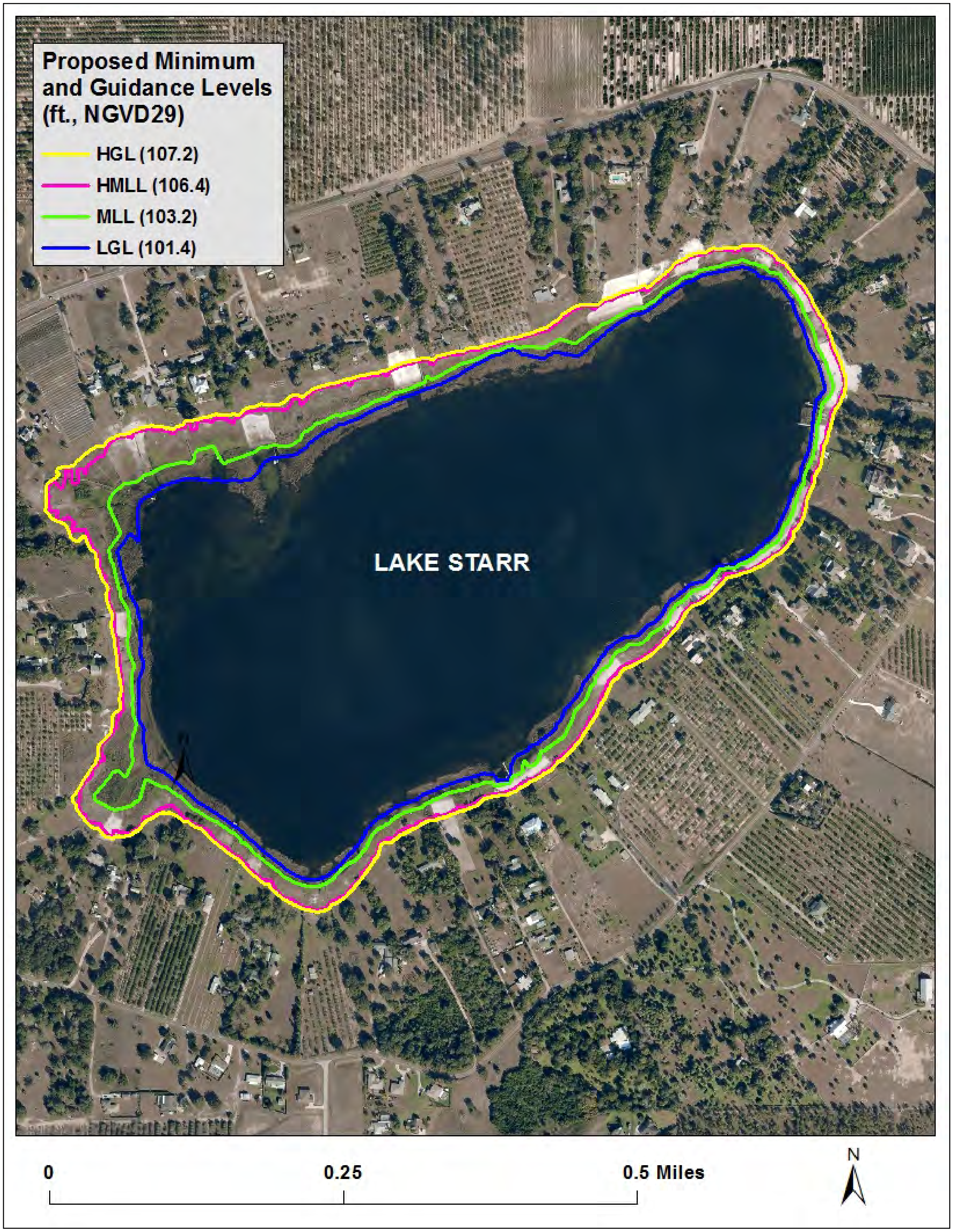


Figure 14. Lake Starr Minimum and Guidance Level Contour Lines Imposed Onto a 2014 Natural Color Aerial Photograph.

Consideration of Environmental Values

The revised minimum levels for Lake Starr are protective of relevant environmental values identified for consideration in the Water Resource Implementation Rule when establishing minimum flows and levels (see Rule 62-40.473, F.A.C.). As presented above when developing minimum lake levels, the District evaluates categorical significant change standards and other available information to identify criteria that are sensitive to long-term changes in hydrology and represent significant harm thresholds. Wetland Offset Standard was used for developing revised Minimum Levels for Lake Starr based on its classification as a Category 3 lake. This standard is associated with protection of several environmental values identified in Rule 62-40.473, F.A.C., including: fish and wildlife habitats and the passage of fish, transfer of detrital material, aesthetic and scenic attributes, filtration and absorption of nutrients and other pollutants, and water quality (refer to Table 2).

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

Two environmental value values identified in Rule 62-40.473, F.A.C., were not considered relevant to development of revised minimum levels for Lake Starr. Estuarine resources were not considered relevant because the lake is not connected to an estuary. 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.

The environmental value, maintenance of freshwater storage and supply is protected by the revised minimum levels based on the relatively modest potential changes in storage associated with the MFLs hydrologic regime as compared to the non-withdrawal impacted historic condition. Maintenance of freshwater supply is also expected to be protected by the revised minimum levels based on inclusion of conditions in water use permits that stipulate that permitted withdrawals will not lead to violation of adopted MFLs.

Comparison of Revised and Previously Adopted Levels

The revised High Guidance Level and Low Guidance Level for Lake Starr are respectively, 1.4 ft. and 0.7 ft. higher than the previously adopted guidance levels. These differences are associated with application of a new modeling approach for characterization of Historic water level fluctuations within the lake, i.e., water level fluctuations that would be expected in the absence of water withdrawal impacts given existing structural conditions.

The revised High Minimum Lake Level for Lake Starr is 1.4 ft. higher than the previously adopted High Minimum Lake Level. The revised Minimum Lake Level is 1.1 ft. higher than the previously adopted Minimum Lake Level. These differences are primarily due to the differences in the water level data used in Minimum and Guidance Level development.

These revised levels were adopted by the Governing Board on January 24, 2017 and replaced previously adopted levels.

Minimum Levels Status Assessment

To assess whether the revised Minimum Lake Level is being met, observed stage data in Lake Starr were used to create a long-term record using a modified version of the LOC model developed for predicting long-term lake levels (Appendix A). For the status assessment, the “current” lake stage data used to create the LOC must be from a period representing a time when groundwater withdrawals and structural alterations are reasonably stable. Current stage data observed on Lake Starr was determined to be from 1992 through 2014. Using the current stage data, the LOC model was created. Utilizing rainfall data in the LOC model resulted in a 68-year long-term water level record (1946-2014).

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

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

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APPENDIX A

Draft Technical Memorandum

November 30, 2015

TO: David Carr, Staff Environmental Scientist, Water Resources Bureau
THROUGH: Jerry L. Mallams, P.G., Manager, Water Resources Bureau
FROM: Nathan T. Johnson, P.E., Groundwater Engineer, Water Resources Bureau
Mark D. Barcelo, P.E. Chief Professional Engineer, Water Resources Bureau

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

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Introduction

Water budget and rainfall correlation models were developed to assist the Southwest Florida Water Management District (District) in the reassessment of minimum levels for Lake Starr in east-central Polk County in 2015. Lake Starr currently has adopted minimum levels that are scheduled to be re-assessed in fiscal year 2015. This document will discuss the development of the Lake Starr models and use of these models for development of Historic lake stage exceedance percentiles.

Background and Setting

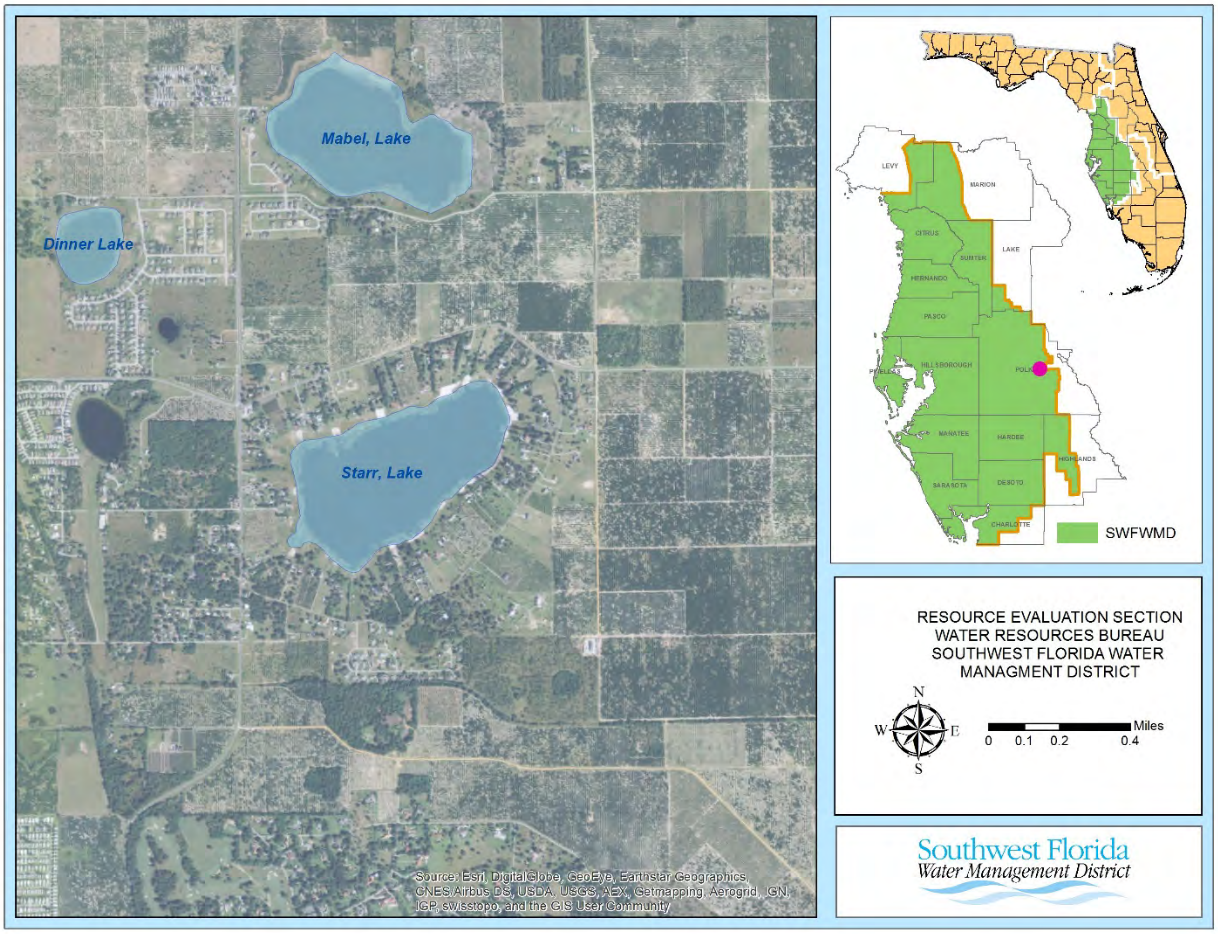
Lake Starr is located in east-central Polk County, Florida (sections 14 and 23, Township 29 South, Range 27 East) in the Peace River Basin of the Southwest Florida Water Management District (Figure 1). It resides in central Florida on the Northern Lake Wales Ridge in mostly well-drained sandy soils. Low nutrients and alkaline pH levels generally result in a clear lake classification. Overland runoff into Lake Starr originates from the residential and citrus agricultural area adjacent to the lake. Residential development surrounds the periphery of Lake Starr and citrus groves covers much of the surrounding area. Lake Starr is considered a closed basin lake and has no outlet conveyance system to control surface water elevations. There are no permitted surface water withdrawals from the lake and no public access to the lake. A topographic map indicates that the lake extends over 143 acres at an elevation of 108 feet above NGVD 29 (107.10 feet above NAVD88).

Hydrogeology

The hydrogeology of the area includes a sand surficial aquifer; an intermediate clay confining/aquifer unit perforated by karst features (sinkholes); and the thick carbonate

Upper Floridan aquifer (Spechler and Kroening 2007; New 1981; Decker 1987). Sinkholes are numerous along the ridges in Polk County and range in size from small depressions to large lakes. Sinkholes provide more direct connection for water from the surficial aquifer to recharge the underlying Upper Floridan aquifer. Lateral movement of water through the surficial aquifer is generally confined to individual lake basins, but there are exceptions. The surficial aquifer is recharged by area rainfall; however, much of the rain that falls drains into lakes or is lost to evapotranspiration. Other sources of recharge that are applied to land include wastewater, reclaimed water, septic effluent, and irrigation of agricultural land or landscape areas (Spechler and Kroening 2007). In elevated areas, such as the Lake Wales Ridge, the water table generally is a subdued reflection of land surface topography (Yobbi 1996). The intermediate aquifer layer that consists mostly of interbedded clay, silt, phosphate, and sand is present at Lake Starr and serves as a confining layer except where breached by sinkholes. The geology illustrated in the ROMP #57X wellsite is described in a District report (Henderson 1986). This site is approximately 4.25 miles southwest of Lake Starr at Hillcrest Elementary School. The surficial aquifer at this site coincides with undifferentiated, unconsolidated quartz sand and clayey quartz sand deposits present from land surface datum (LSD) to 192 feet below LSD. The surficial aquifer generally exhibited moderate to high porosity and permeability. The water table at this site was found to be 101 feet below LSD.

Lake Starr is classified as a seepage lake created through sinkhole activity and is highly connected to the underlying aquifer (Swancar et al. 2000). The hydrogeology of in the vicinity of Lake Starr is characterized by complex unique interactions with the underlying aquifer dividing the lake into two sides, the northeast and southwest sides. The northwest side of the lake has a continuous intermediate confining unit creating relatively isotropic lateral flow to the lake from the surficial aquifer. At the lake and to the southwest side, the confining unit develops breaches allowing more groundwater exchange with the UFA creating downward flow in addition to lateral flow. Surficial groundwater flows from the northeast side of the lake and exits to the southwest. Recharge to the UFA is a function of the intermediate confining unit integrity and the differential head between the UFA and lake stage.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 1: Location and imagery, Lake Starr in Polk County, FL

Data

Water level data collection at Lake Starr (SID 25282) began in February 1983 with discrete manual measurements on the west side of the lake (Figure 2). Data collection frequency was approximately monthly through September 1995 when a continuous data recorder was installed. Continuous recordings were gathered for 16 years until September of 2011 when the continuous data recorder was removed and only discrete monthly manual measurements continued to be collected (Figure 3). The minimum and maximum recorded values are 96.23 and 109.8 ft. NGVD29 respectively with a range of 13.57 feet of fluctuation over the period of record available. Discrete measurements were imputed using linear interpolation to create a daily time series of lake water levels for use in water budget and rainfall regression models (Figure 4). Lake Starr filled had an average value of 101.57 ft. NGVD29 over the period 1988-2014.

The Hart Floridan well (SID 25252) is the closest Upper Floridan aquifer monitor well the longest record in the vicinity of Lake Starr, and was used to represent the potentiometric surface at the lake. The Hart well located southwest of the lake and approximately 425 ft. from the southwest perimeter (Figure 2). The well has discrete measurements starting in

1996 and ending in 2011 with a total of 155 level measurements recorded (Figure 3). The minimum and maximum recorded values are 88.21 and 102.13 ft. NGVD29 respectively with a range of 13.92 feet of fluctuation over the period of record available. Several adjustments to the data collected from the Hart Well were made for purposes of the model. First, because regular data collection did not begin until October 1996, and the starting year for the water budget model is 1988, a correlation between Hart Well and ROMP 57X, the next closest Upper Floridan aquifer monitor well with characteristics similar to Hart Well was performed to estimate water levels in Hart before data collection began at that well. ROMP 57X Upper Floridan aquifer monitor well (SID 25354) has regular daily data collection beginning in November 1987. There were, for some periods, multi-month gaps in the ROMP 57X Upper Floridan aquifer monitor well data. Secondly, because the frequency of data collection at ROMP 57X has been regularly daily since data collection began in November 1987, the transformed data from ROMP 57X can also be used to impute or in other words infill data at Hart Well when data collection there was monthly, or when data is missing from the Hart Well records. One noticeable gap in water level data for the Hart Well that was imputed using ROMP 57X exists between September 1998 and October 2001. When data does not exist at either well, linear interpolation is implemented (Figure 4). The imputed Hart well had a median of 93.08 ft. NGVD29 over period 1988-2014.

Two surficial wells were used in the analysis that had the longest period of record and characterized their respective side of the lake. The southeast side well Lake Starr STUSE (SID 25283) is 750 feet from the perimeter of the lake (Figure 2) with a period of record from January 2003 through November 2010. A well to the northwest of Lake Starr named Lake Starr WTS-1 (SID 25267) is 1,400 feet from the perimeter of the lake with a period of record from October 2002 through July 2011. Both wells have discrete manual measurements over their respective periods of record and were limited in span of record (Figure 3). Accordingly, both wells were imputed and interpolated using linear regression with Lake Starr water level elevations to create a complete daily record over 1988-2014 (Figure 4).

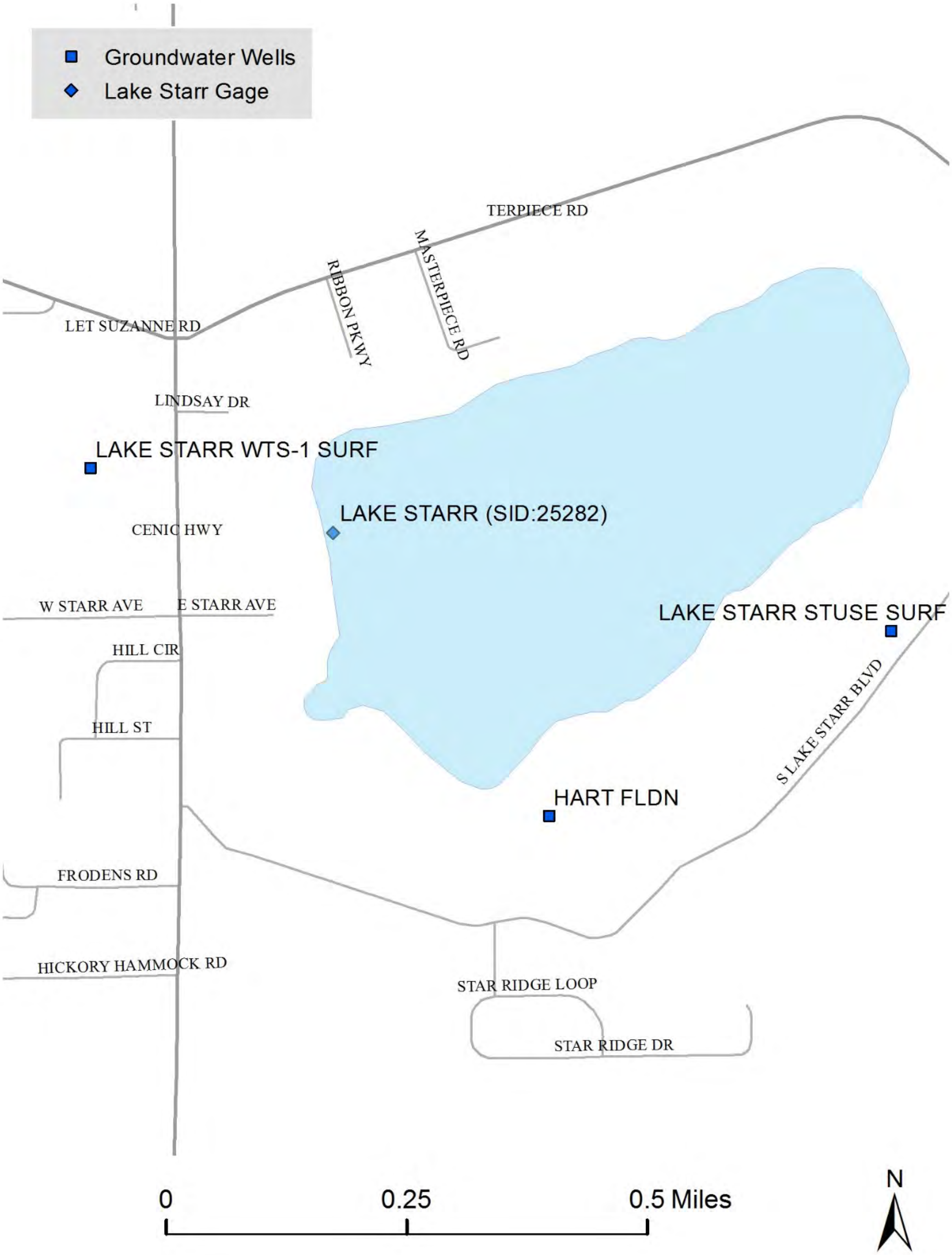


Figure 2: Map of selected water level stations with roads.

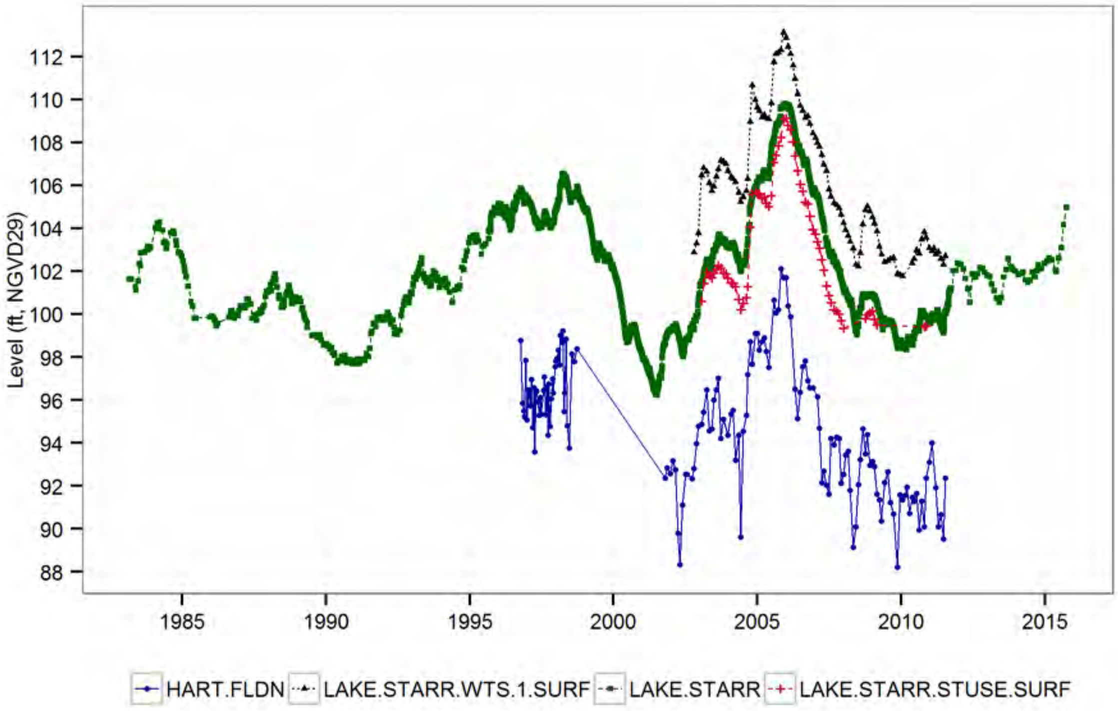


Figure 3: Original groundwater and surface water levels, Lake Starr.

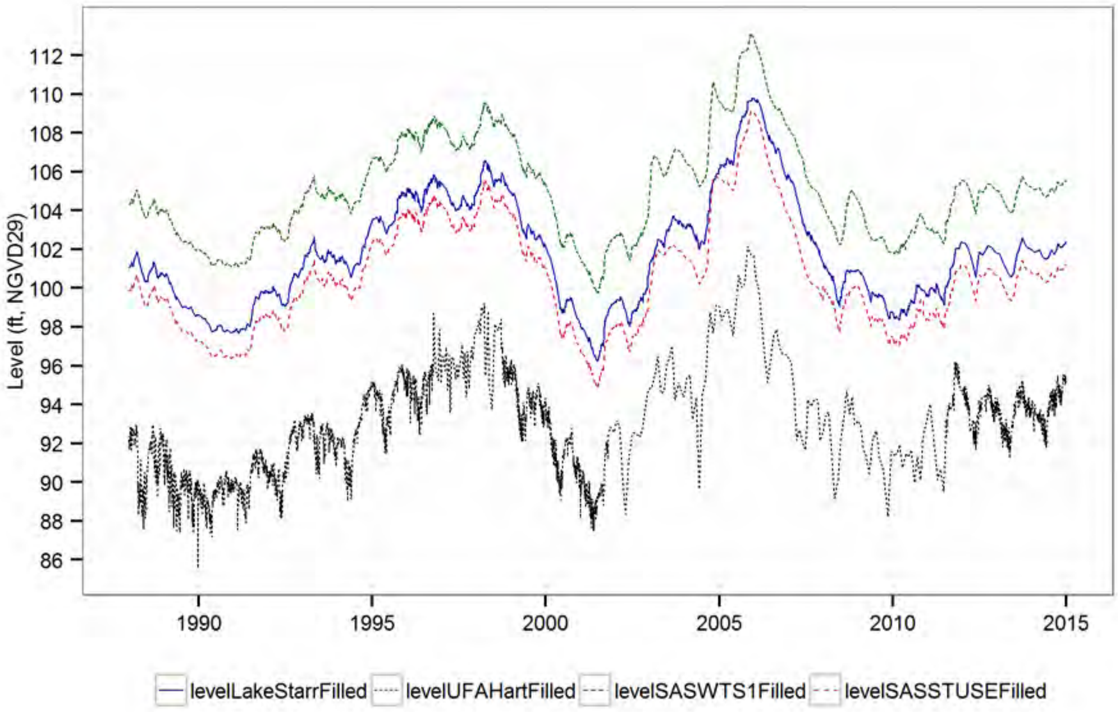


Figure 4: Imputed/Filled groundwater and surface water levels, Lake Starr (1988-2014).

Land and Water Use

Figure 5 presents total estimated and measured groundwater withdrawals in Polk County since the 1930s (updated from Southwest Florida Water Management District, 2006). Significant groundwater withdrawals began in the area throughout the 1940s and 1950s, and peaked in late 1960s and early 1970s. Throughout Polk County irrigation of citrus groves became more prevalent in the 1960s when it was determined that it could greatly improve crop yield. Water use by the phosphate industry, centered in an area southwest of Lake Starr, began to increase significantly throughout the late 1960s and 1970s. Additionally, sand mining east of Lakeland has expanded over time. Groundwater withdrawals in Polk County have been relatively stable since the early to mid-1990s, although this period includes both extreme dry (2000) and wet (2004/2005) conditions. Since 1994, estimated groundwater withdrawals in Polk County averaged about 218 mgd and ranged from 172 mgd in 2011 to 274 mgd in 2000.

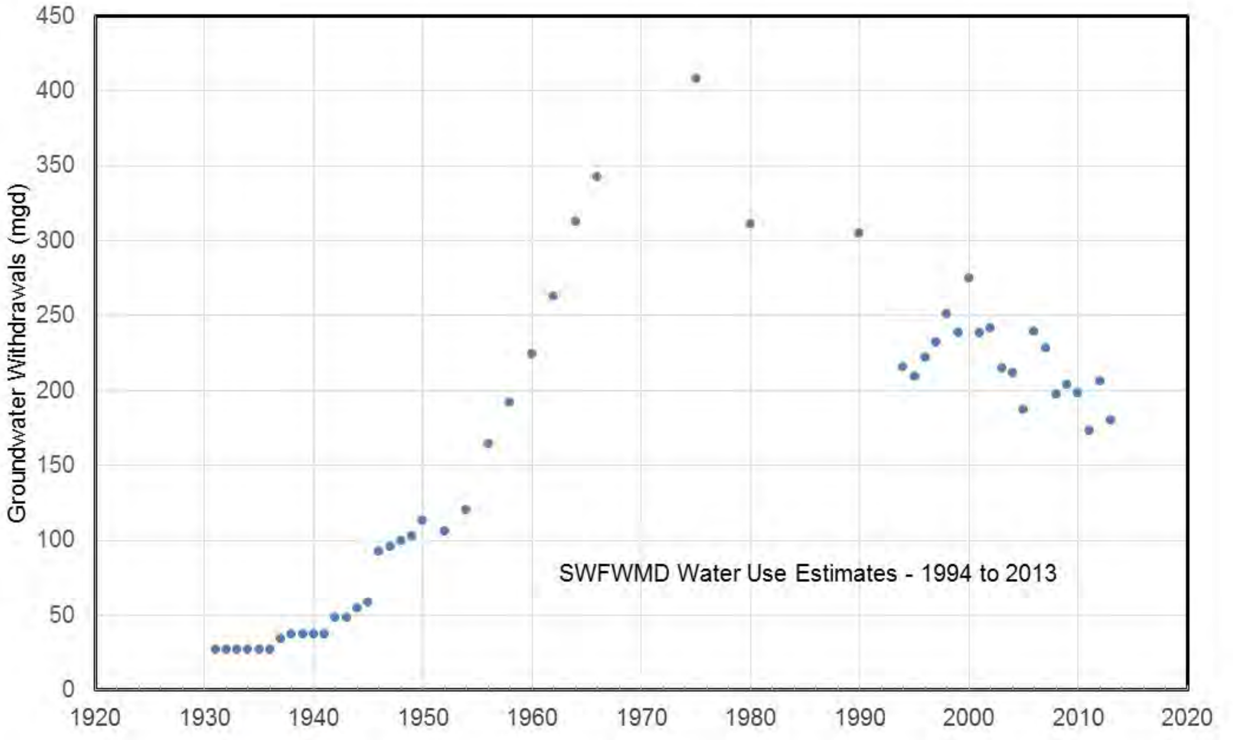


Figure 5: Groundwater withdrawal estimates for Polk County (1930-2013).

Much of the land use surrounding Lake Starr has remained the same since 1941 and 1958 and consists of citrus groves, undeveloped land, and some residential development (Figure 6 and 7). Much of the water use has remained agricultural with small residential lots surrounding the lake (Figure 8 and Table 1). The estimated total groundwater use average from 2008 to 2012 within one mile of the lake is approximately 1 million gallons per day (mgd), of which approximately 90 percent is agricultural and the remaining 10 percent is recreation. Within 5 miles of the lake, the estimated total groundwater use average from 2008 to 2012 is approximately 18 mgd, of which 65 percent is agricultural use and 20 percent is public supply. The remaining water use is commercial/industrial (7%), recreation (7%) and less than 1% of mining/dewatering.

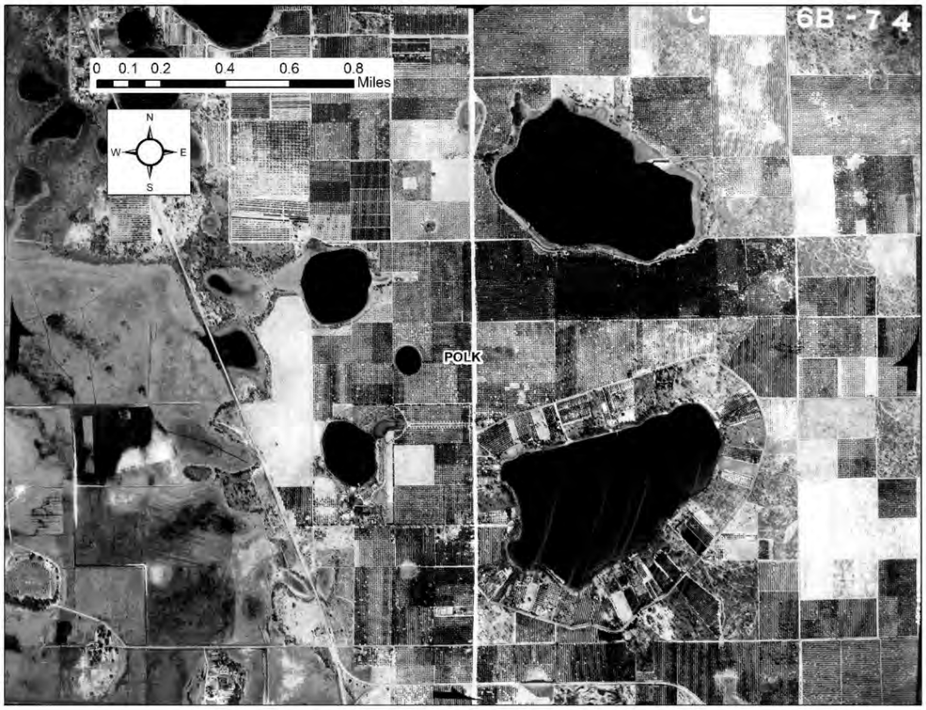


Figure 6: Historical imagery of Lake Starr - March 03, 1941.

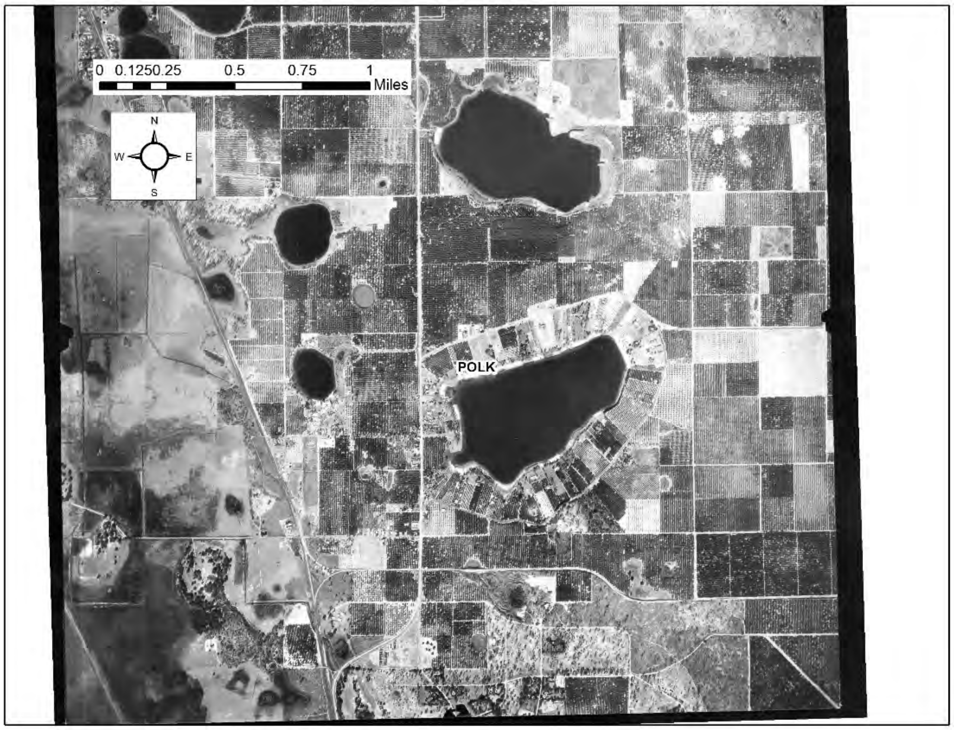


Figure 7: Historical imagery of Lake Starr - January 27, 1958.

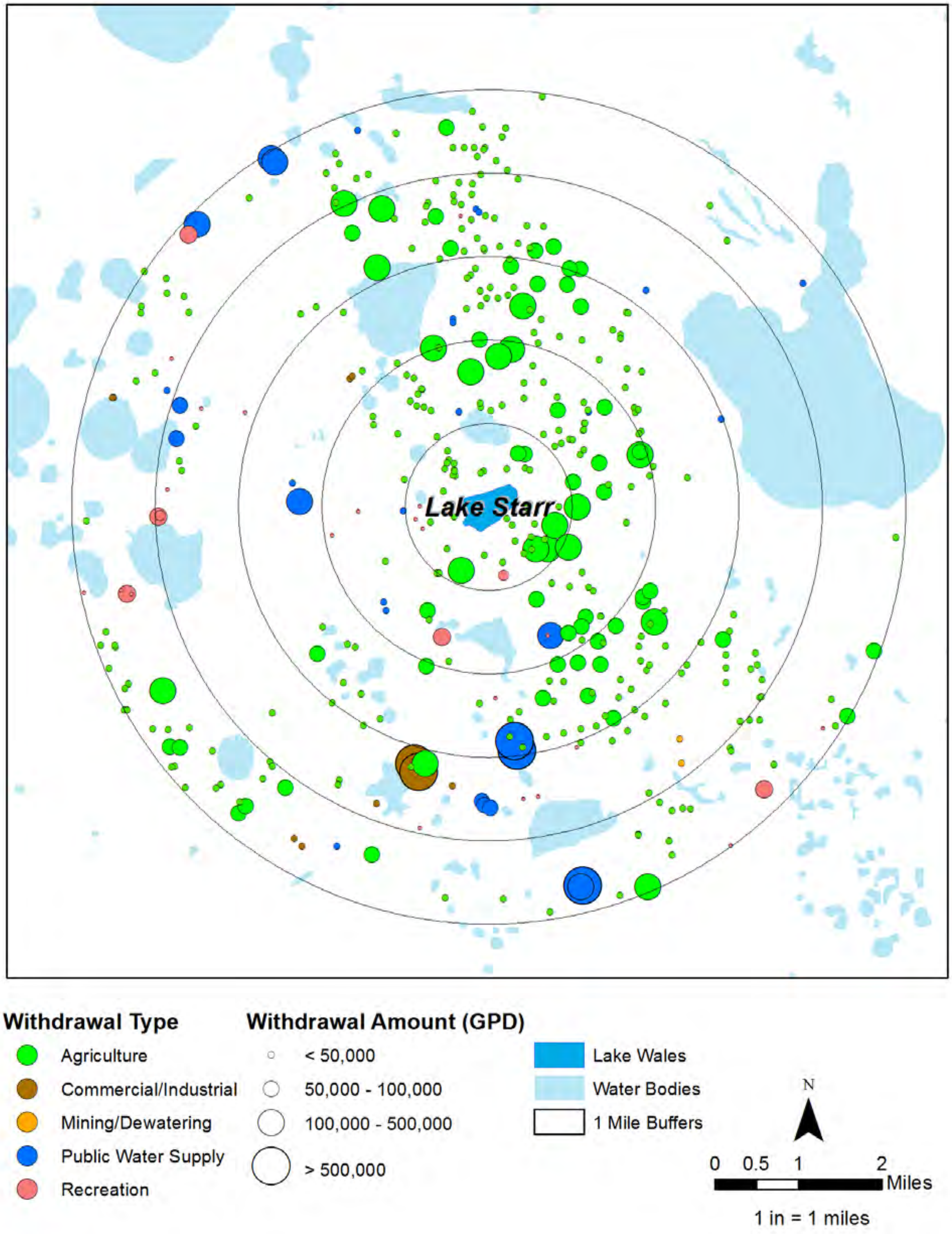


Figure 8: Water withdrawal estimates for 2011.

Table 1: Water use estimates for 2011.

Water Use Within 1 Mile of Lake Starr (GPD)			
Use Type	**SW**	**GW**	**Total**
Agriculture		866,115	866,115
Commercial/Industrial			-
Mining/Dewatering			-
Public Supply			-
Recreation	2,478	110,624	113,102
Total		976,739	979,217

Water Use Within 5 Miles of Lake Starr (GPD)			
Use Type	**SW**	**GW**	**Total**
Agriculture	26,392	11,565,876	11,592,267
Commercial/Industrial	237	1,259,634	1,259,871
Mining/Dewatering	6,282	222	6,504
Public Supply		3,779,478	3,779,478
Recreation	90,865	1,190,132	1,280,996
Total	123,775	17,795,341	17,919,116

Methods

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 a long-term Historic lake exceedance percentiles such as the P10, P50, and P90, which are, respectively, the water levels equaled or exceeded ten, fifty, and ninety percent of the time, respectively. If data that represents a Historic time period does not exist, or available Historic time period data is considered too short to represent long-term conditions, then a combination of a water budget model and a rainfall correlation model is developed to approximate long-term Historic data.

In the case of Lake Starr, withdrawals throughout the area have potentially affected water levels in the lake since the early 1940s. No data from Lake Starr exist prior to the initiation of groundwater withdrawals. Therefore, the development of the East Central Florida Transient Groundwater Flow Model (ECFT), water budget model, and rainfall regression model of the lake was considered essential for estimating long-term Historic percentiles, accounting for changes in the lake's drainage system, and simulating effects of changing groundwater withdrawal rates.

ECFT Model

Determining the amount of Upper Florida Aquifer drawdown that has occurred due to groundwater withdrawals involved the use of a regional groundwater model and analysis of water level data. The East-Central Florida Transient (ECFT) groundwater model (Sepulveda, et al., 2012 and CFWI, 2014) was used to quantify changes in water levels in response to changes in groundwater withdrawals. This was accomplished using a series of model runs whereby recent withdrawals and irrigation amounts were reduced by 25 percent, 50 percent, and 75 percent. This approach enabled the model to be used within the range of withdrawals that were used during the calibration phase. For the reassessment of minimum levels, the reduced pumping scenarios used a Reference Condition as a basis for comparing model reduction scenarios. The Reference Condition was based on the amount of groundwater withdrawals needed to meet the demands for water that existed as of 2005. Pumping amounts for each year and month of the 12 year transient model run were varied according to rainfall that occurred during each month.

Water Budget Model

Water budget model development is a primary method for understanding interactions between lake levels and the remaining parts of hydrologic cycle under various climatic conditions. Residence times of water in a seepage lake such as Lake Starr is normally measured in years therefore a water budget model of the lake should be calibrated over several successive years to ensure correct hydrologic processes. The Lake Starr water budget model is a spreadsheet-based tool that includes natural hydrologic processes and engineered alterations acting on the control volume of the lake. The control volume consists of the free water surface within the lake extending down to the elevation of the greatest lake depth. The water budget is developed at a daily scale to ensure that short-term and long-term processes are accurately modeled in the inflows and outflows to the lake. 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 water budget model however will not account for intraannual variations in pumping since pumping is estimated annually and would account for only small variations of lake level in this region. Once the drawdown in the UFA at Lake Starr was estimated using the ECFT model and analysis of long-term water level trends, it was as input into the water budget model. The effect on Lake Starr levels from drawdown can be estimated by adjusting Upper Floridan aquifer levels in a water budget model corresponding to the drawdown amounts.

Prior studies have constructed water budget models for lakes in this region (Swancar et al. 2000; Sacks et al. 1998; Swancar and Lee 2003; Clark et al. 1963; Watson et al. 2001). Many of the water budget models were calibrated over a limited number of years at larger time scales. In an effort to create consistent MFL water budget models, the District considered the previous developed models for the conceptual framework and parameter estimation.

The hydrologic processes and data in the water budget model include:

- Lake Stage/Volume
- Rainfall
- Evapotranspiration
- Overland flow
- Inflow and discharge via channels
- Flow from and into the surficial aquifer
- Flow from and into the Upper Floridan aquifer

The water budget model uses a daily time-step, and tracks inputs, outputs, and lake volume to calculate a daily estimate of lake levels. The water budget model for Lake Starr is calibrated from 1988 to 2014. This period provides the best budget of using available data for all parts of the water budget and the desire to develop a long-term water level record. A summary of model parameters is provided in Table 2.

Table 2: Summary of water budget parameters

Variable	**Value**
Overland Flow Watershed Size (acres)	342
SCS CN for watershed	40
Directly Connected Impervious Surface (DCIA)	3 percent
UFA Monitor Well	Hart Floridan well (SID 25252)
Northwest Surficial Aquifer Monitor Well	Lake Starr WTS-1 (SID 25267)
Southeast Surficial Aquifer Monitor Well	Lake Starr STUSE (SID 25283)
Lake Gage	Lake Starr (SID 25282)
UFA Leakance Coefficient (ft./day/ft.)	0.0008
Northwest Surf. Aq. Conductance (ft./day/ft.)	0.0045
Southeast Surf. Aq. Conductance (ft./day/ft.)	0.0052
Outflow K	N/A
Outflow Invert (ft. NGVD 29)	N/A
Inflow K	N/A
Inflow Invert (ft. NGVD 29)	N/A

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. The overall process involves merging the terrain morphology of the lake drainage basin with the underlying lake basin morphology to develop one continuous three-dimensional (3D) digital elevation model (Figure 9). The 3D digital elevation model was then used to calculate area of the lake and the associated volume of the lake at different elevations, starting at the extent of the lake at its flood stage and working downward to the lowest elevation within the basin. The minimum elevation is located in the southeast corner of the lake at 73.65 ft. The lake is characterized by steep sides and raises quickly at the perimeter.

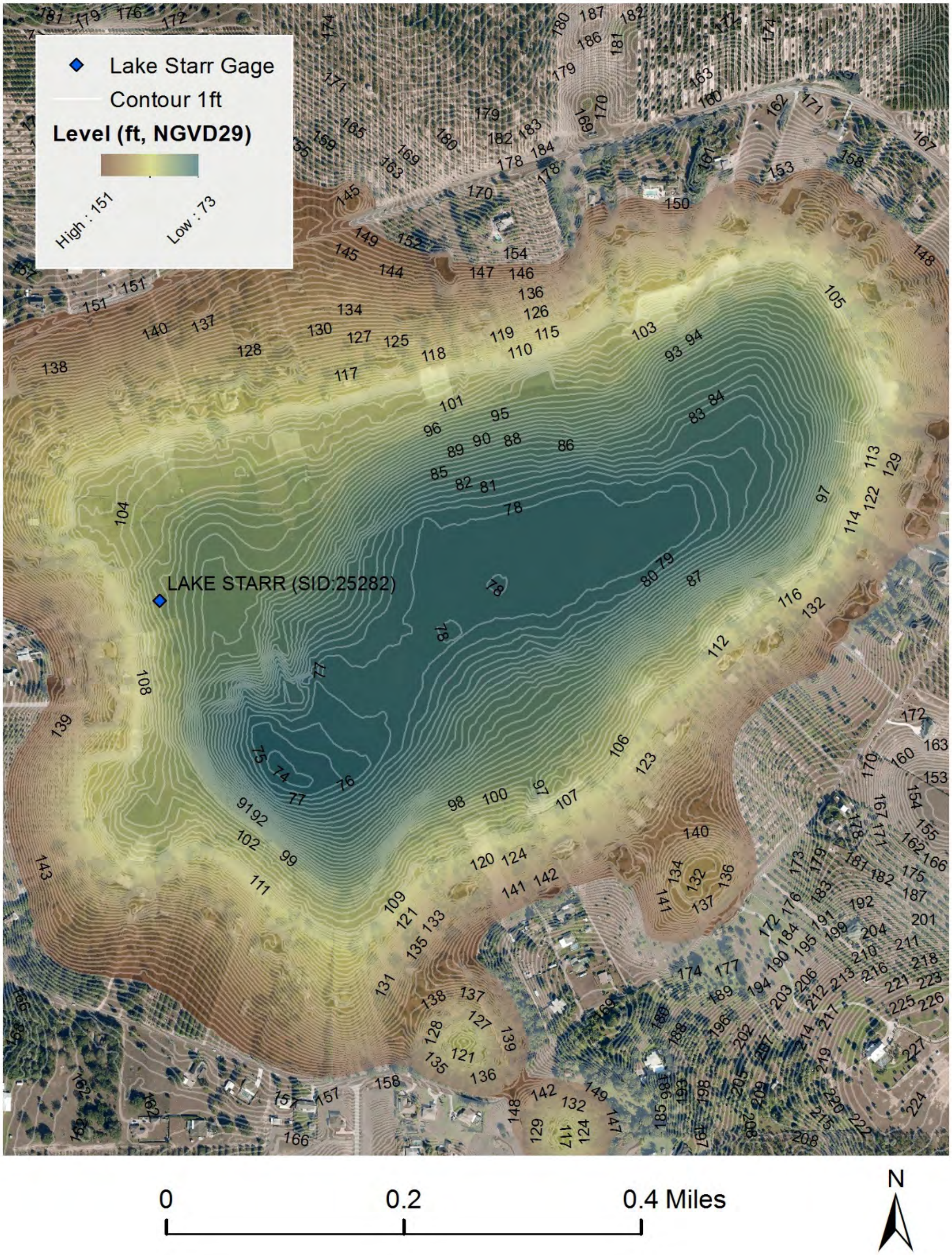


Figure 9: One-foot contours and bathymetric surface for Lake Starr (ft., NGVD29)

Rainfall

After a review of several rain gages in the area of Lake Starr, a composite of several stations was constructed given each stations' respective limited data availability, proximity to water body, and accuracy. The objective was to use the nearest high quality available data adjacent to the lake as well as minimize the number of stations used. Using fewer stations minimizes the effects of biases. The rainfall stations data used in the analysis are shown visually through time in Figure 10 and the spatial location in Figure 11. The Mountain Lake rainfall gage (SID 25147), located about 1.3 miles from Lake Starr, was used primarily and provides most of the record from 1946-2014. Other stations including ROMP 58 J H Wilson Elementary (SID 25146) and Lake Alfred Experimental Station (SID 17616) were used to fill in rainfall data where Mountain Lake rainfall gage data was not available. Another gage that had a long term record in the vicinity of Lake Starr was the National Weather Service gage near Bartow (SID 25164), with available data from 1892 to current. This gage is located about 7.5 miles to the southwest of Lake Starr. It was used primarily for quality assurance for the Mountain Lake rainfall gage.

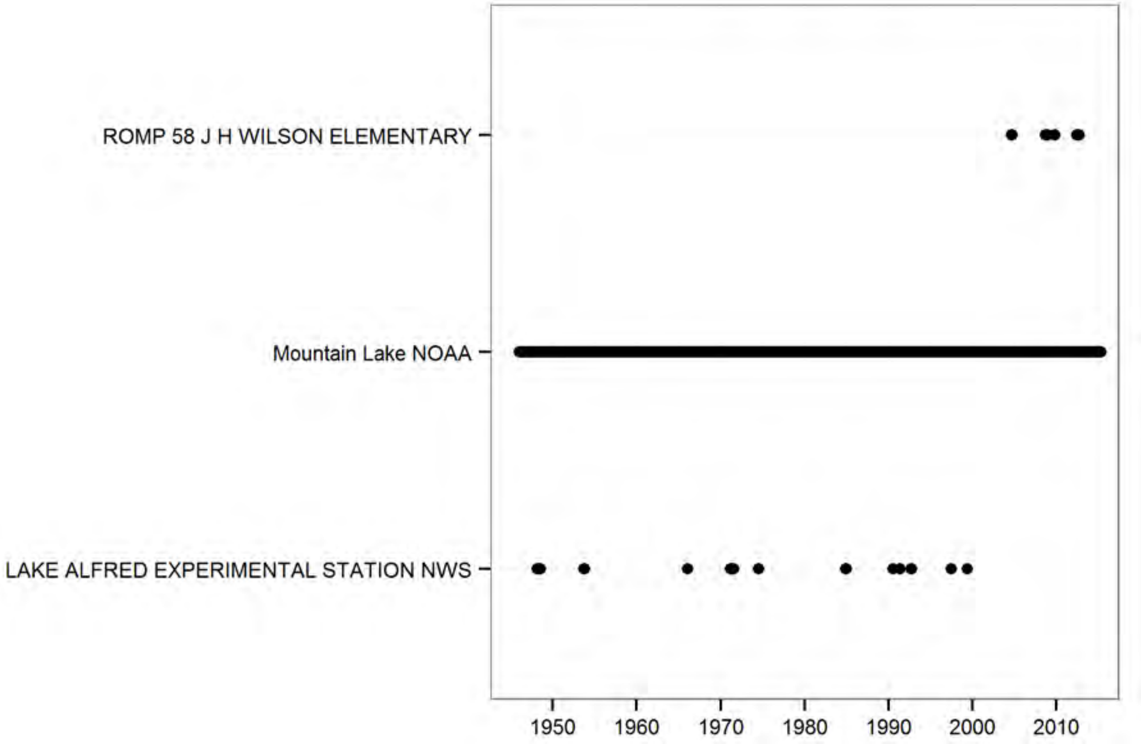


Figure 10: Station source for composite rainfall data.

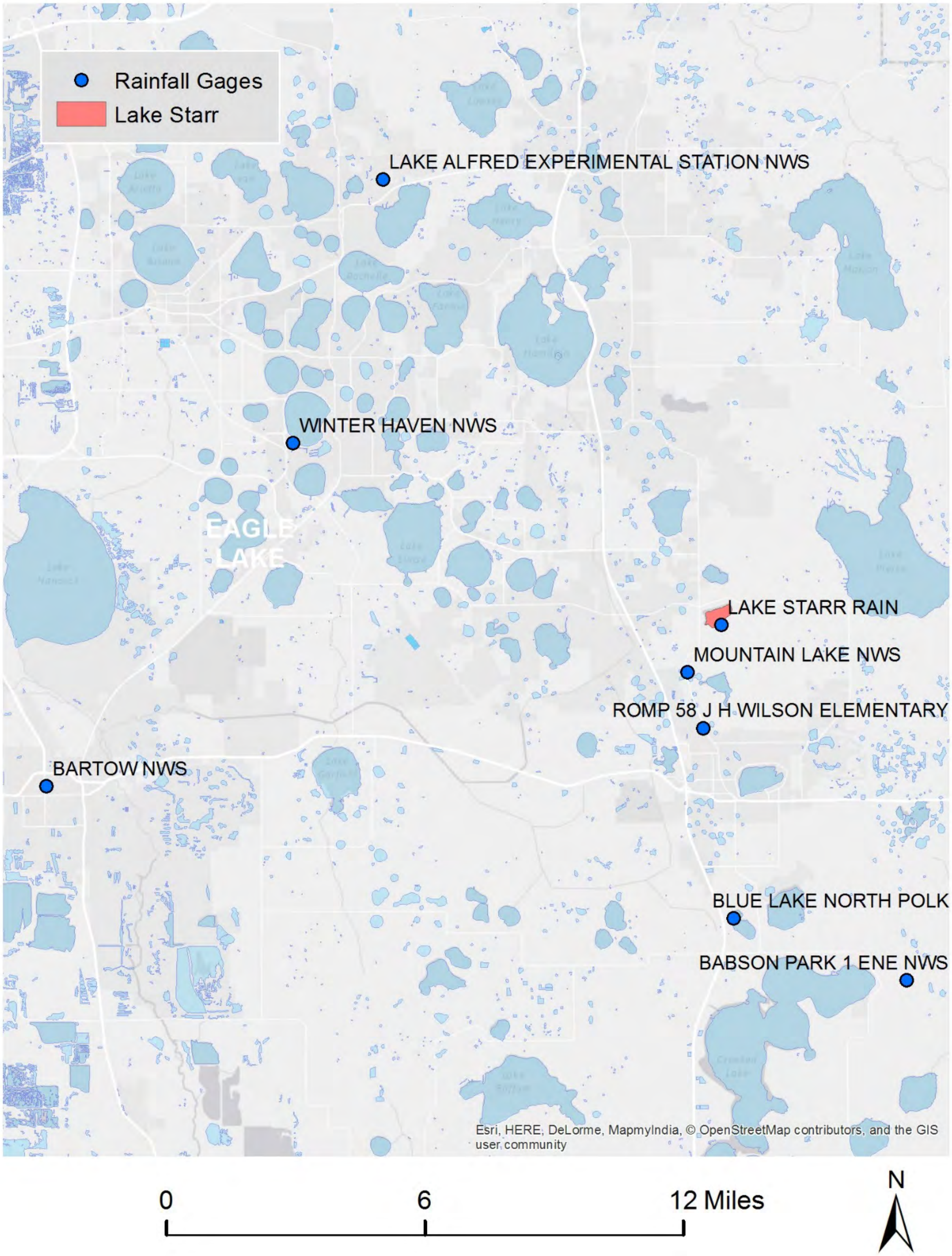


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Figure 11: Map of stations available for composite rainfall data compilation.

Lake Evaporation

Lake evaporation was estimated through use of monthly energy budget data collected by the U.S. Geological Survey (USGS) at Lake Starr in Polk County (Swancar, Lee, and O'Hare 2000). The data was collected from August of 1996 through July of 2011. Monthly Lake Starr evaporation data were used in the water budget model when available, and monthly averages for the period of record were used for those months in the model when Lake Starr evaporation data were not available. 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 lake was considered. A decision was made to use measured ET data since it most accurately represents the actual ET in the watershed.

Overland Flow

The water budget model was constructed 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) is 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.

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 Peace Creek for the Watershed Management Program (ADA Engineering 2012 and Atkins 2013). These watershed area values were adopted for the Lake Starr model after an independent check confirming that they are reasonable for modeling purposes. Lake Starr has no significant inflow from other lakes, so the entire watershed is as shown in Figure 12, which consists of 455 acres (including the lake).

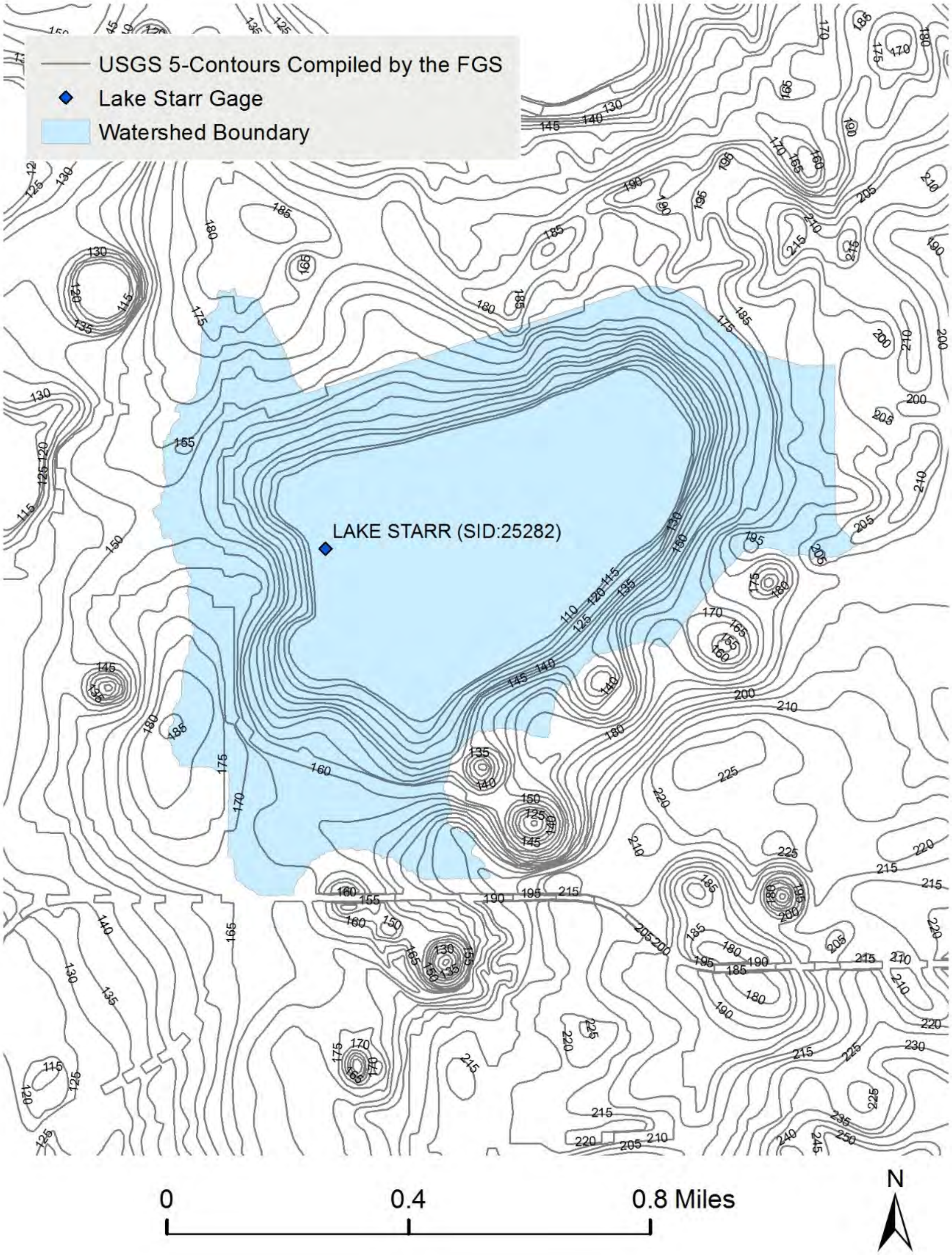

Figure 12: USGS 5 feet contours and Lake Starr watershed.

The DCIA and SCS CNs used for the direct overland flow portion of the watershed are listed in Table 2. The soils in the area of the lake are mostly A soils, with A/D soils along the edge of the lake (Figure 13). Land use in the watershed is mostly low to medium density residential, with some areas of agriculture (Figure 14). A curve number of 40 was used in the model to reflect the hydrologic soil group and land use.

Figure 13: Soil survey geographic database provided by NRCS, Lake Starr (NRCS).

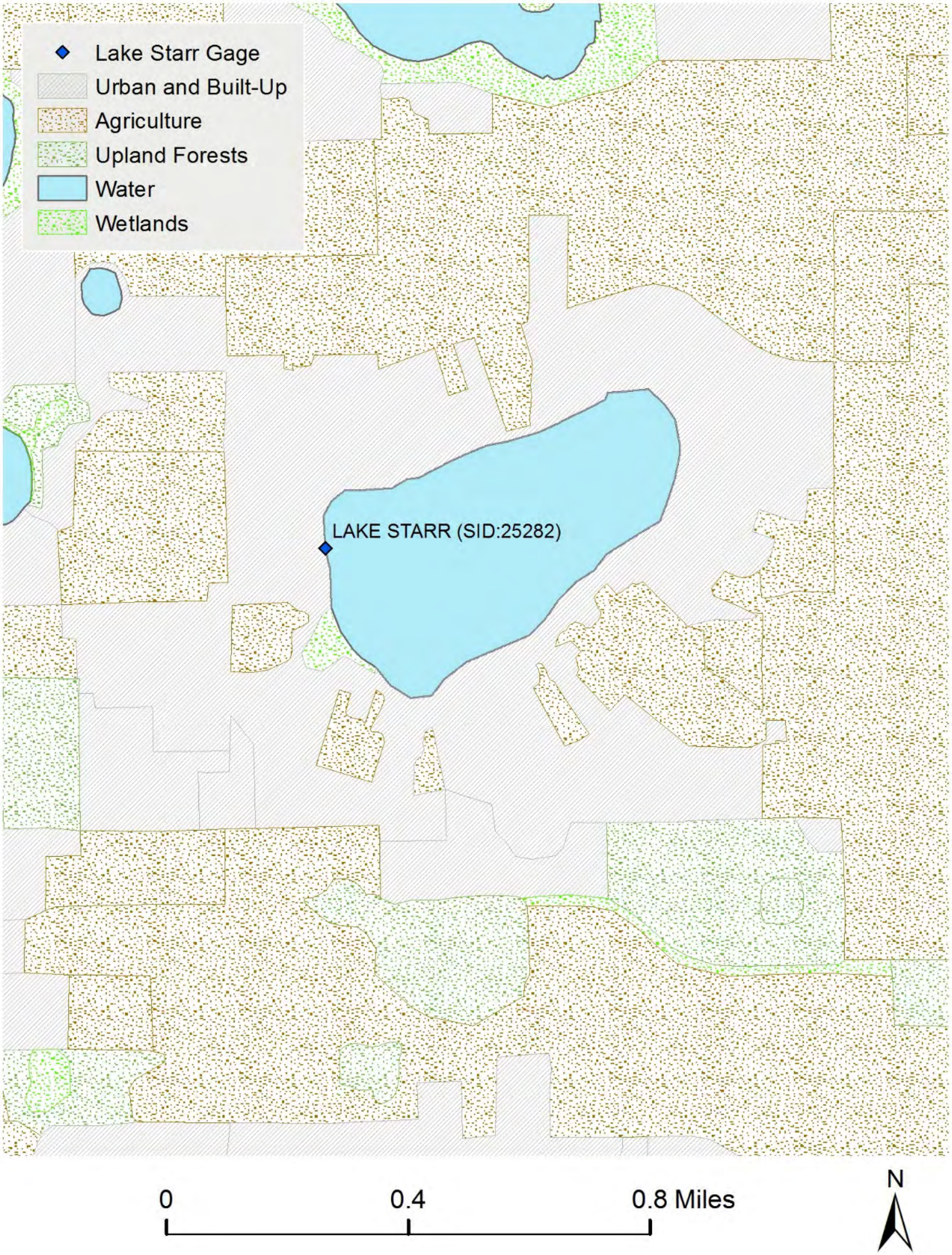

Figure 14: Land use map from 2011 for Lake Starr (compiled by SWFWMD)

Flow from and into the surficial aquifer

The water budget model was developed using two surficial wells, one at the northwest side of the lake and one at the southeast. This assumption maintained the observed water table to open surface gradient so as to not introduce artificially high fluxes into the lake from the water table. The conductance term used for Lake Starr WTS-1 was 0.0045 d^{-1} since most water comes from the surficial from the northwest side of the lake as is corroborated by (Swancar and Lee 2003). The conductance term used for Lake Starr STUSE on the southeast side was calibrated to 0.0052 d^{-1}.

Flow from and into the Upper Floridan aquifer

Water exchange between Lake Starr and the underlying Upper Floridan aquifer is estimated using a leakance coefficient and differential head between the lake and the aquifer level. In order to calculate the differential head, the potentiometric surface at the centroid of the lake was estimated. The UFA surface drops an estimated 8 feet from the northwest side to the southeast side of the lake. To account for the steep slope in the potentiometric surface, the Hart well levels were increased by 4 feet to represent the lake centroid. The leakance coefficient for the lake to the UFA was calibrated to 0.0008 day-1 which corroborates other studies (Swancar and Lee 2003).

Rainfall Correlation Model

To determine the Historic unimpacted percentiles over a long-term period in the development of the Minimum Levels, a line of organic correlation (LOC) model was developed using the results of the water budget model and long-term rainfall. The LOC is a linear fitting procedure that minimizes errors in both the x and y directions and defines the best-fit straight line as the line that minimizes the sum of the areas of right triangles formed by horizontal and vertical lines extending from observations to the fitted line (Helsel and Hirsch 2002). LOC is preferable for this application since it produces a result that best retains the variance (and therefore best retains the “character”) of the original data. In this application, the simulated lake water levels representing Historic conditions were correlated with long-term rainfall. For the correlation, additional representative rainfall records were added to the rainfall records used in the water budget model (1992-2014). Rainfall and estimated rainfall data from the Mountain Lake NWS gage were used to extend data from the calibration period back to January 1930. Rainfall is correlated to lake water level data by applying a linear inverse weighted sum to the rainfall. The weighted sum gives higher weight to more recent rainfall and less weight to rainfall in the past. In this application, weighted sums varying from 6 months to 10 years are separately used, and the results are compared, with the correlation with the highest correlation coefficient (R^2) chosen as the best model. Rainfall was correlated to the water budget model results for the entire period used in the water budget model (1992-2013), and the results from 1946-2014 (69 years) were produced.

Results

Several of the hydrologic technical methods were used and consolidated to determine the MFL for Lake Starr. These methods include the ECFT Groundwater model, water budget model, and the rainfall regression model. The ECFT model was used in the process to estimate UFA drawdown for input to the water budget model. The water budget model was used to build a conceptual framework for Lake Starr using the available data and physical processes that represent movement of water to and from the lake. Finally, the rainfall regression model was used to extend the results of the water budget model over a long-term period to estimate Historic water level percentiles for Lake Starr.

ECFT Groundwater Model

During evaluation of the reduced pumping scenarios, it was decided that an evaluation of long-term changes in water levels was needed to verify model results. For use in the evaluation of Lake Starr, long-term water levels in the ROMP 57X Upper Floridan aquifer well were extended back to the 1940s and 1950s time period using water levels from the Coley Deep well (SID 25339), located near the City of Frostproof; the ROMP 60 Upper Floridan aquifer abandoned (SID 17974) and replacement (SID 77757) wells located near the City of Mulberry; and the Claude Hardin Upper Floridan aquifer well (SID 17966), located near the City of Mulberry. This was done using water level data averaged over different periods, for example annual and monthly, and single months such as September, May and December. For each regression analysis, the regression parameters were determined using data for the period 1988 to 2014, which is the time frame for which data is available for the ROMP 57X Upper Floridan aquifer well. These parameters were then used to estimate water levels for the period available for the respective independent well levels (Coley Deep and ROMP 60 Upper Floridan aquifer). For the regression analyses, estimates of long-term changes in groundwater levels ranged from about 3.5 feet to 6.8 feet. It was then determined that model drawdown amounts using the ECFT model would be modified and that a recovery level of 3.5 feet in Upper Floridan Aquifer levels would be used for the analysis. With respect to the surficial aquifer, the relationship between the leakance coefficient and the ratio of surficial aquifer to Upper Floridan aquifer drawdowns established for previous modeling efforts was used. From the water budget model, the leakance coefficient was 0.0008 feet/day/feet which resulted in a ratio of surficial to Upper Floridan drawdown of 0.5. The resulting recovery in the surficial aquifer was then estimated as the product of this ratio and the estimated Upper Floridan aquifer recovery amount (3.5 feet) or 1.8 feet.

Water Budget

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

Calibration

The Lake Starr water budget was calibrated over the period 1988-2014. The calibration process adjusted the leakance coefficients and conductance terms between the lake and aquifers as well as the overland flow SCS curve number with parameters found in Table 2. Once these values were calibrated, the water budget model was compared to observed Lake Starr elevations (Figure 15). The model performed well as described by goodness of fit coefficient of determination R^2= 0.96. In addition, the goodness of fit based on percentiles are recorded in Table 3. The difference between the P50 for Lake Starr filled data and water budget were was 0.1 ft. indicating the model was calibrated well at median levels. The high P10 had a difference of 0.2 ft. indicating that the high levels were calibrated within a tenth foot. The P90 was calibrated within 0.1 ft. indicating that the fit was good for lower levels. This minor difference could be attributed to inaccuracies in rainfall estimates caused by the distance between rainfall gages and the lake in addition to non-linear characteristics of leakance during wet and dry periods. Even though data gaps as well as uncertainties in the values of model parameters have caused some differences between the model and observed data, the model is reasonably well calibrated and can be used to estimate the long term historic percentiles.

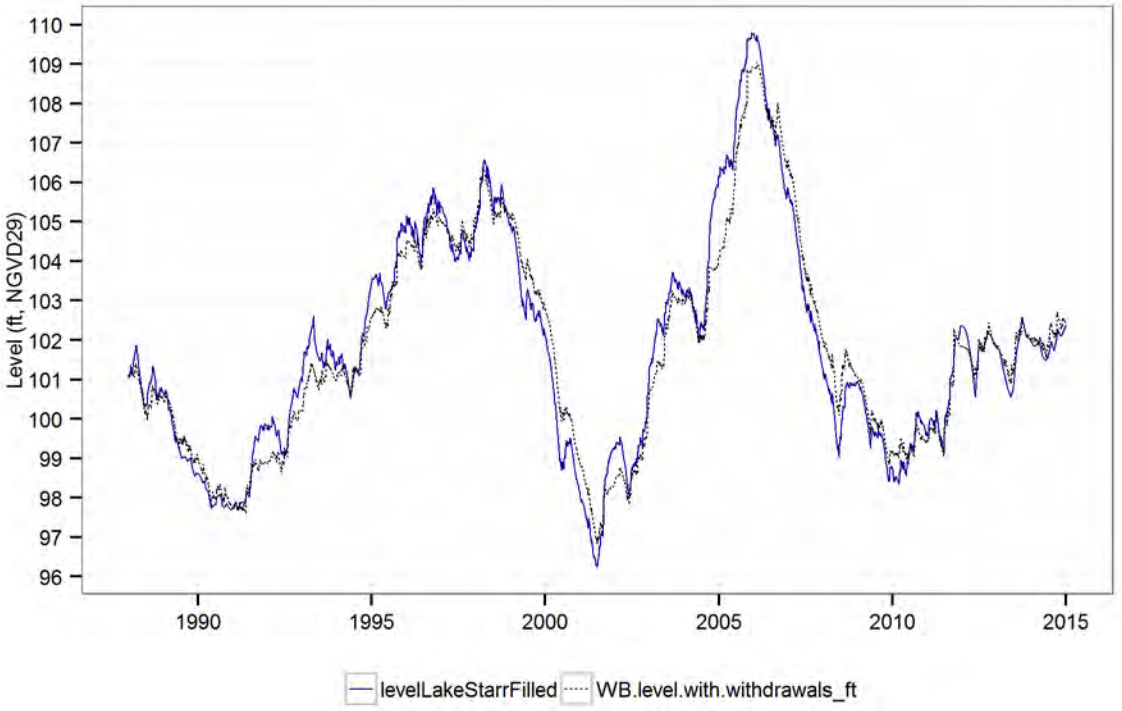

Figure 15: Lake Starr compared to water budget calibration levels (1988-2014).

Table 3: Percentile differences for water budget calibration and Lake Starr levels (1988-2014).

Percentile	Lake Starr (ft.)	Water Budget Model Calib (ft.)	Difference Calib (ft.)
P10	106.4	106.2	0.2
P50	102.4	102.5	-0.1
P90	98.7	98.7	0.0

Prediction

Once the water budget model was calibrated, the drawdown in the UFA was applied. Figure 16 presents the results of the predicted water budget model for Lake Starr with the effects of groundwater withdrawals. The results of drawdown in Lake Starr due to withdrawals are listed in Table 4 and ranged from 1.8 ft. at the P10 to 2.0 ft. at the P90. Overall the effects of withdrawals at the P50 were 2.2 feet. The shift in the P50 was the greatest indicating that the median levels were more influenced by pumping than both the dryer and wetter periods.

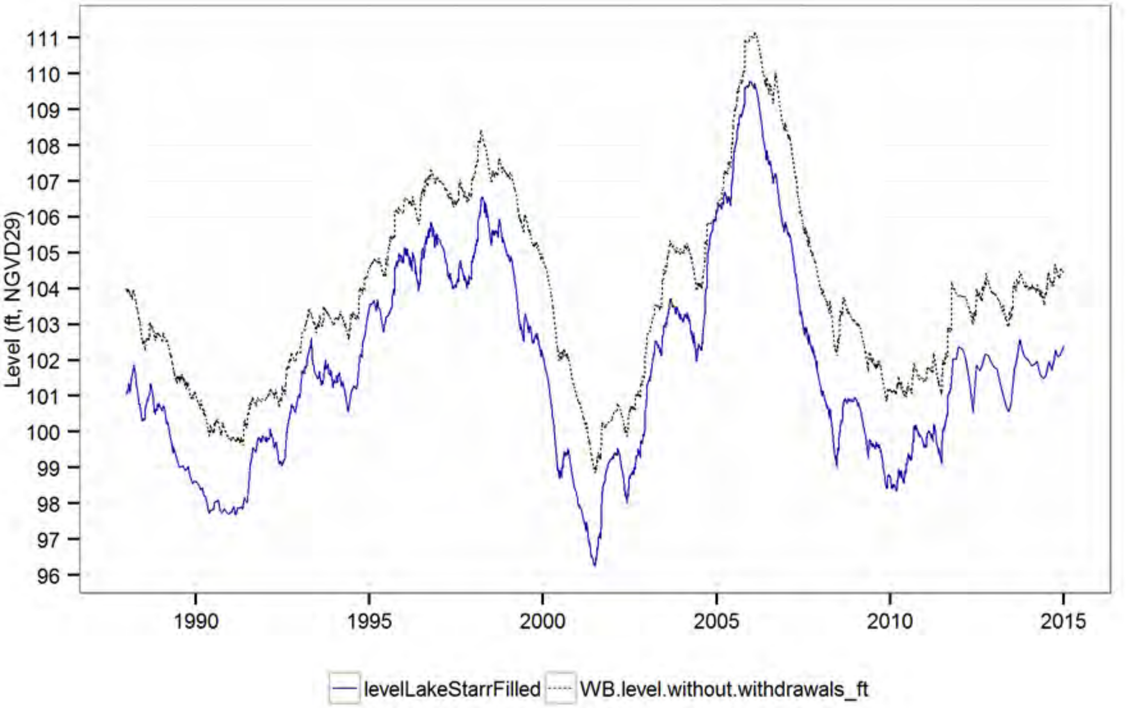

Figure 16: Lake Starr compared to water budget predicted results (1988-2014).

Table 4: Percentile differences for water budget prediction and Lake Starr levels (1988-2014).

Percentile	Lake Starr (ft.)	Water Budget Model Pred (ft.)	Difference Pred (ft.)
P10	106.4	108.2	-1.8
P50	102.4	104.6	-2.2
P90	98.7	100.7	-2.0

A summary of the water budget predictive results input and output variables is listed in Table 5. Composite rainfall was converted from in/day into ft.^{3}/day for the water budget model and has a maximum of 6 in/day or more than 3 million ft.^{3}/day on 10/24/2005 recorded at the Mountain Lake NWS station. Evapotranspiration data was collected at Lake Starr over the period 1998-2012. Evapotranspiration data was used in the water budget model for the period of record available. Monthly averages were used for the remainder of the record. The monthly averages range from an estimated 0.006 ft./day in January and the winter months to 0.018 ft./day in August and remains high during summer months. The two methods can be visually compared in Figure 17 to illustrate the range of ET difference.

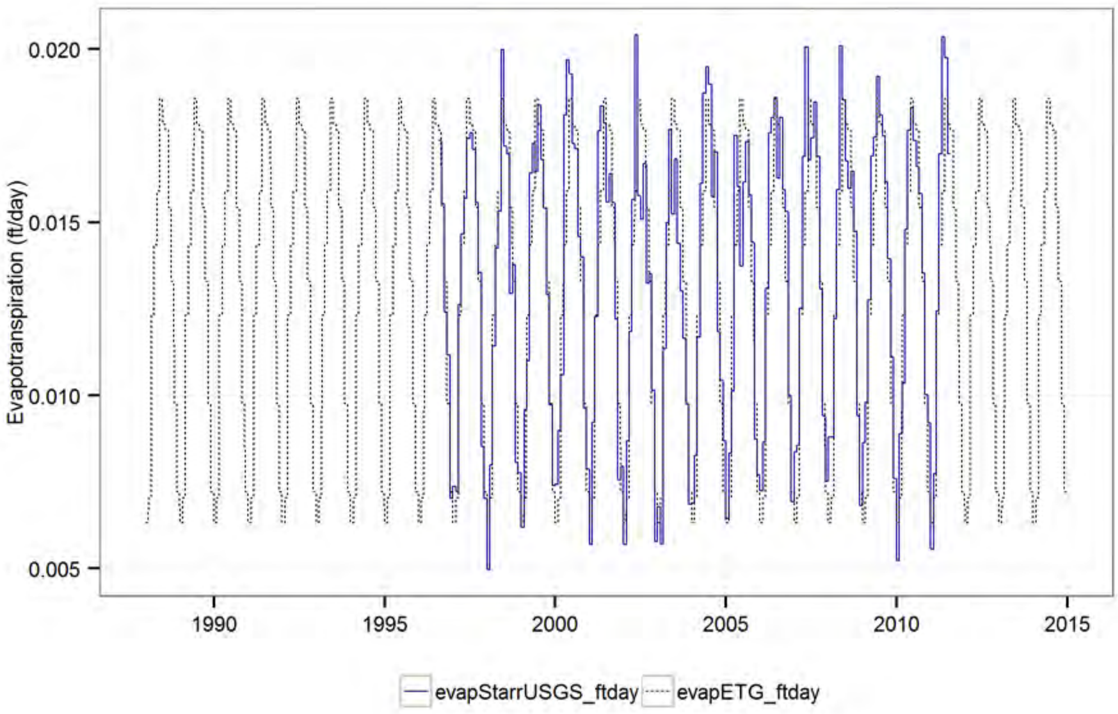

Figure 17: Evapotranspiration data from USGS and average monthly (ETG).

Leakage from the lake to the UFA is a function of the head difference between the lake and the underlying UFA. Leakage is estimated by a leakance coefficient to determine the interaction between the underlying aquifer and the lake. Figure 18 illustrates the variation of leakage over the model period with a maximum of 38,104 ft.^{3}/day and minimum of 3,591 ft.^{3}/day. The surficial flux to the lake is estimated by the conductance term and the head difference between the surficial and lake. Most of the surficial flux emanates from the northwest with a maximum of 87,636 ft.^{3}/day (Figure 19).

Table 5: Summary table of water budget variables for prediction

	Mean	Std Dev	Min	P90	P50	P10	Max	Obs
levelLakeStarrOrig	102.5	3.2	96.2	98.7	102.4	106.4	109.8	6048
levelLakeStarrFilled	101.8	2.8	96.2	98.5	101.6	105.6	109.8	9862
levelUFAHart	94.8	3.0	88.2	91.3	94.8	98.7	102.1	155
levelUFAHartFilled	93.3	2.8	85.5	89.8	93.1	96.8	102.1	9862
levelUFAHartFilled4Feet	97.3	2.8	89.5	93.8	97.1	100.8	106.1	9862
levelUFAHartECFT	100.8	2.6	92.6	97.3	100.7	104.1	108.7	9862
levelSASWTS1Orig	106.1	3.1	101.8	102.6	105.7	110.7	113.1	101
levelSASWTS1Filled	105.0	2.7	99.7	101.9	104.8	108.6	113.1	9862
levelSASSTUSEOrig	103.2	2.9	99.4	99.9	102.1	107.5	109.1	68
levelSASSTUSEFilled	100.6	2.8	94.9	97.3	100.3	104.5	109.1	9862
rainFinal_inday	0.14	0.40	0.00	0.00	0.00	0.41	6.00	9862
rainMtnLk_inday	0.12	0.35	0.00	0.00	0.00	0.35	5.80	9973
rainFinal_ftday	0.01	0.03	0.00	0.00	0.00	0.03	0.50	9862
evapStarrUSGS_ftday	0.01	0.00	0.00	0.01	0.01	0.02	0.02	5478
evapETG_ftday	0.01	0.00	0.01	0.01	0.01	0.02	0.02	9862
lakeArea_acres	122.3	13.2	99.0	106.2	120.5	140.9	150.7	9862
lakeArea_ft2	5,328,582	574,298	4,314,176	4,628,236	5,248,844	6,139,178	6,564,064	9862
watershedArea_ft2	14,174,141	486,735	13,264,419	13,505,803	14,210,216	14,866,687	15,093,114	9862
rain_ft3day	64,113	188,139	0.0	0.0	0.0	192,582	3,259,754	9861
evap_ft3day	73,431	24,418	30,355	38,043	77,696	103,278	119,005	9861
inflowSASWTS1_ft3day	36,317	9,513	13,416	25,127	35,720	46,311	87,636	9861
inflowSASSTUSE_ft3day	19,453	10,873	-25,985	7,773	19,317	31,747	51,661	9861
headDif_ft	-3.0	1.4	-8.0	-4.8	-2.9	-1.2	0.8	9861
leakage_ft3day	-13,069	6,774	-38,104	-21,764	-12,487	-5,032	3,591	9861
runoffSCS_ft3day	2,106	41,528	0.0	0.0	0.0	0.0	2,265,819	9862
DCIA_ft3day	5,082	14,806	0.0	0.0	0.0	15,441	226,135	9861
WB.level.with.withdrawals_ft	103.8	2.6	98.8	100.6	103.5	107.2	111.2	9862
WB.level.without.withdrawals_ft	101.8	2.6	96.8	98.6	101.4	105.2	109.1	9862

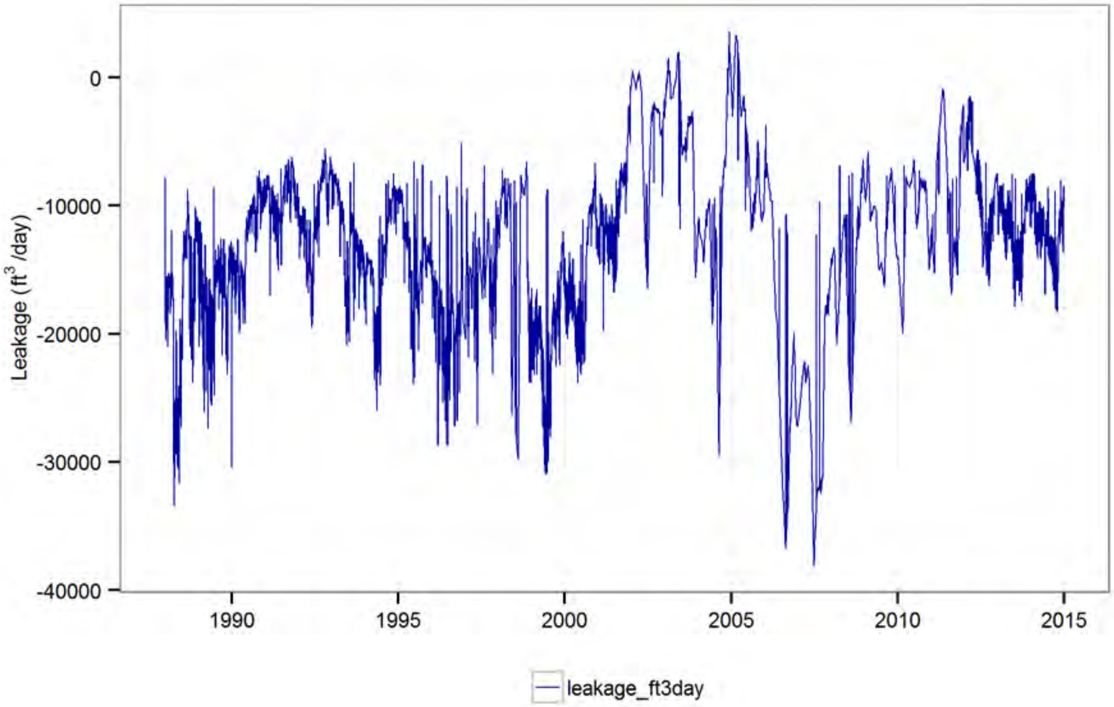

Figure 18: Leakage ft3/day to UFA from Lake Starr.

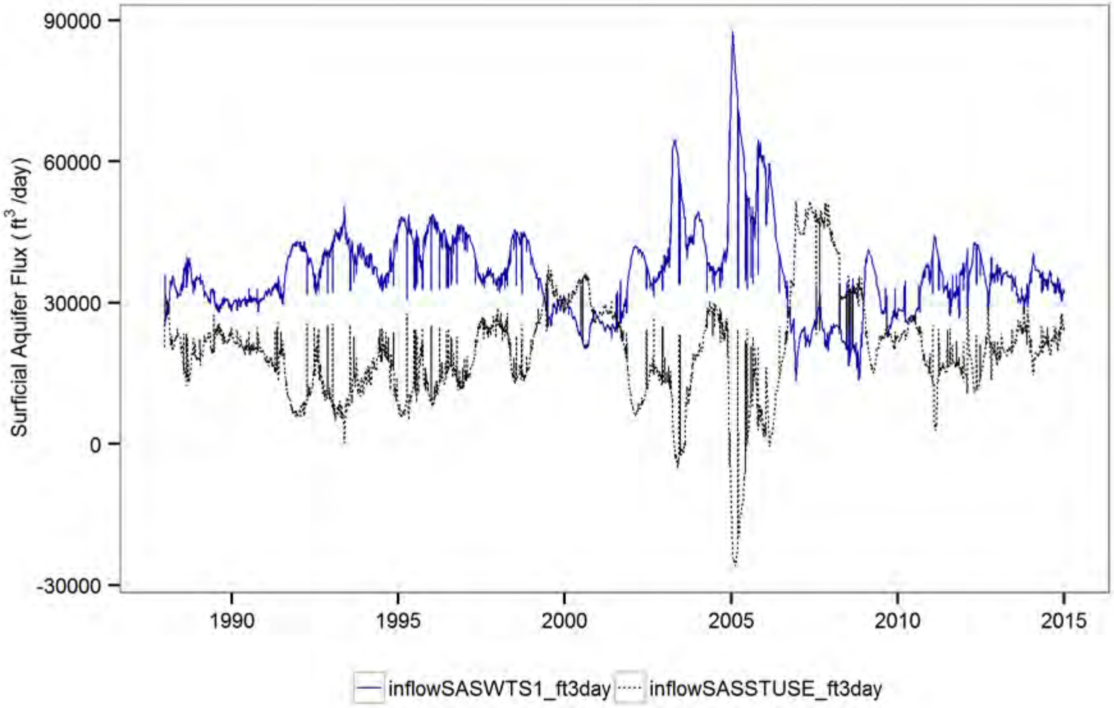

Figure 19: SAS flow ft3/day in water budget model.

Groundwater flow from the surface was provided by the effective curve number and had an average of 90,497 ft.^{3}/day of overland flow into the lake. The mean contribution from direct connected impervious area in the watershed was 5,082 ft.^{3}/day.

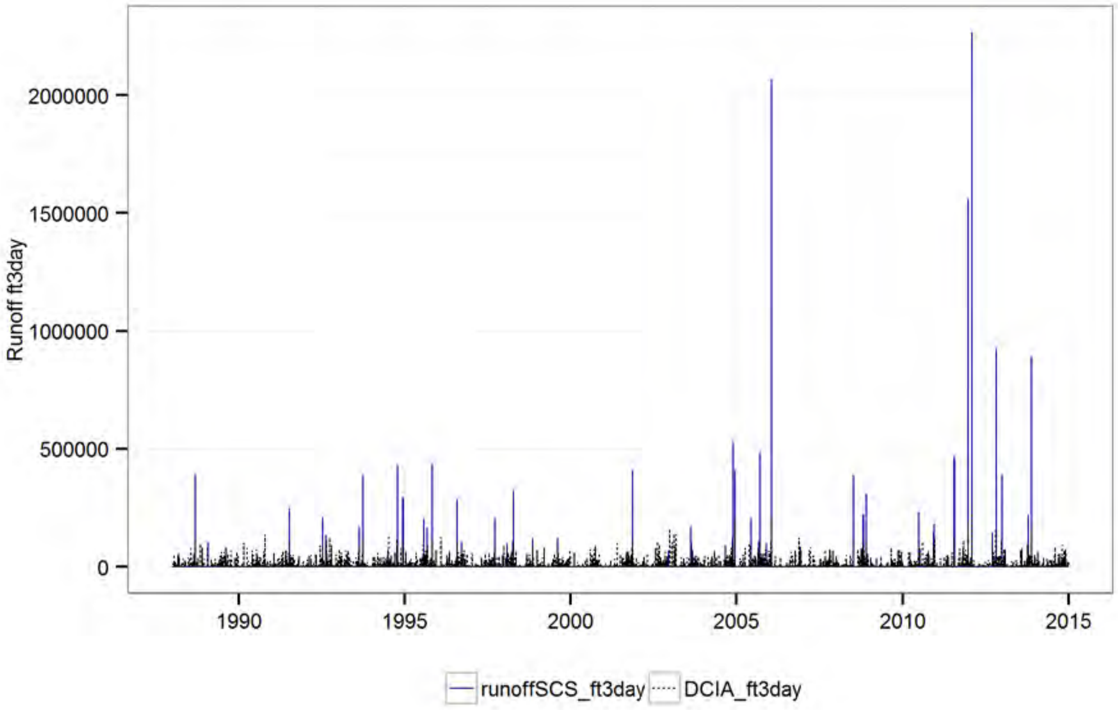

Figure 20: SCS and DCIA runoff ft^3/day for Lake Starr.

Rainfall Regression Model

Aquifer levels provided strong evidence that groundwater withdrawal patterns appear to have changed sometime in the early to mid-1990s and have remained reasonably consistent since that time. The results of the LOC are also consistent with this conclusion. For this reason, the water budget model results used in the LOC model were limited to a period of relatively consistent groundwater impacts from 1992 to 2014. The rainfall model was calibrated over the period 1992-2014 and the predicted values are developed for the period 1946-1992. For this assessment, the final 5-year weighted model had the highest coefficient of determination, with R^2 of 0.62. The model fit metrics are listed in Table 6 and the results can be seen in Figure 21.

Table 6: Rainfall regression model performance metrics

Obs	R^2	Residual Std Error
8399	0.62	1.58 ft.

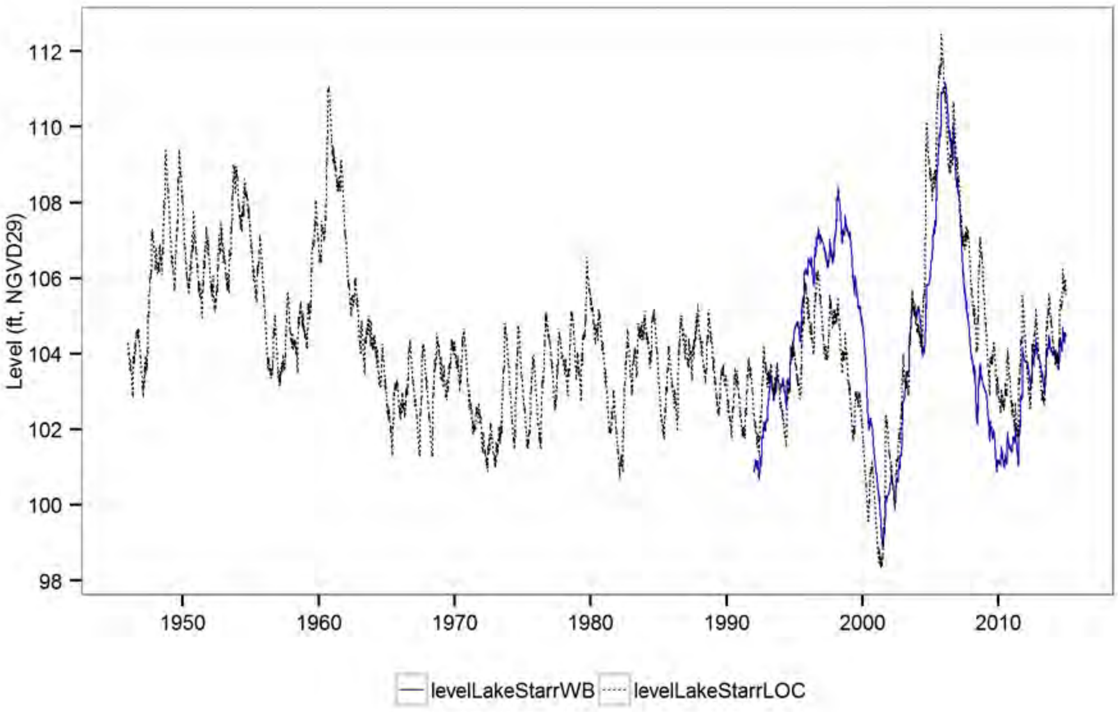

Figure 21: Water Budget model and rainfall regression model results.

In an attempt to produce Historic percentiles that apply significant weight to the results of the water budget models, the rainfall LOC results for the period of the water budget model were replaced with the water budget model results. Therefore, the LOC rainfall model results are used for the period of 1946-1991, while the water budget results are used for the period of 1992-2014. These results are referred to as the "hybrid model." The resulting Historic percentiles for the hybrid model are presented in Table 7 and visually shown in Figure 22 in comparison to the original Lake Starr levels. Overall lake levels would have been exceeded 107.2 feet ten percent of the time in absence of human influence. The median P50 of 104.0 feet is used primarily for MFL development. The 90th percentile P90 of 101.4 feet is an estimate of how low the lake would have been 10 percent of the time with the absence of human influence. These levels were corroborated with other lakes in the area as well as historical imagery to further substantiate the results.

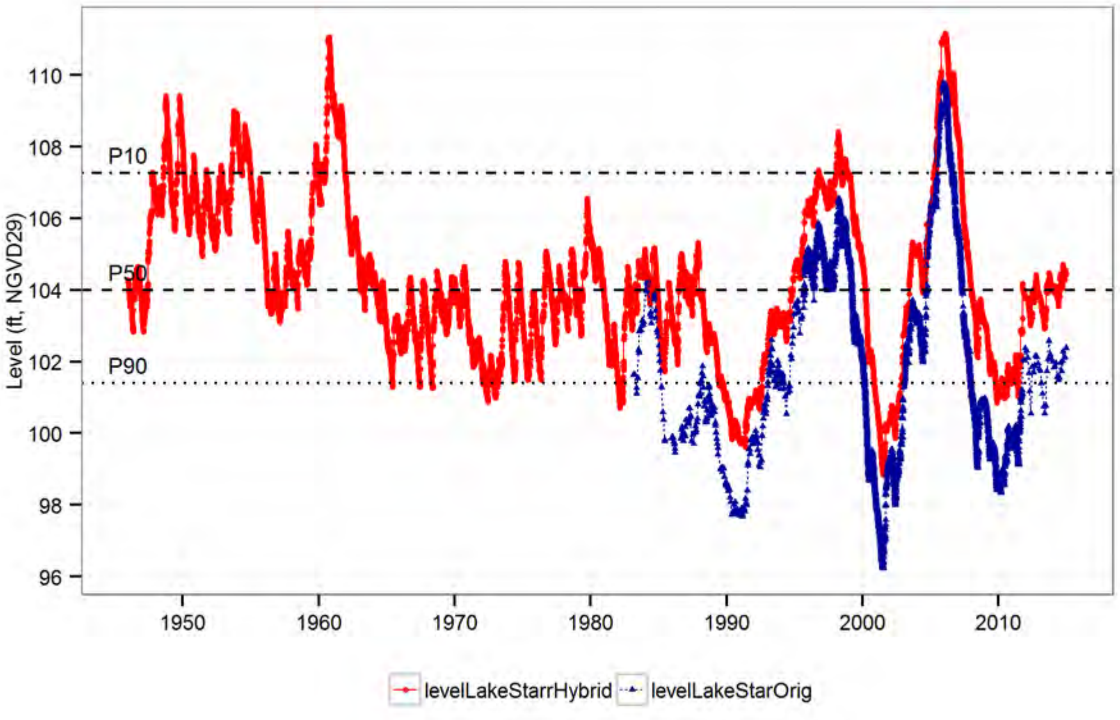

Figure 22: Hybrid model Historic lake levels with percentiles and original levels (1946-2014).

Table 7: Percentiles for long-term hybrid model of unimpacted Historic lake levels (1946-2014).

Percentile	Level (ft., NGVD29)
P10	107.2
P50	104.0
P90	101.4

Conclusions

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

Limitations

Several limitations in modeling are present within the development of MFLs that are acknowledged in this section. Most limitations introduce uncertainty into the estimation of the final Historic percentiles. As SWFWMD continues to improve methods, the uncertainty in the model results and data will continue to be reduced.

Adjustment for centroid of lake

Lake Starr is unique in that it is located in an area with a steep potentiometric gradient. An adjustment to the Hart UFA well to adjust to the centroid of the lake was performed to lump the potentiometric surface into a single level.

Non-unique water budget solution

Water budgets are developed for many applications including lake augmentation projects, reservoir projects, hydrologic studies, etc. Often limited data suggests an estimation of many of the variables present within water budget models. Sensitivity analysis on the water budget model estimates the impact of individual parameters and data on lake levels. Limited time for the development of the water budget models often restricts the sensitivity analysis to very course estimations. To further refine the water budget, sensitivity analysis could be performed on the resulting model and uncertainty quantified for individual parameters and variables. With this information, more time can be devoted to estimation of the most sensitive parameters.

Composite rainfall data for rainfall regression model

Rainfall stations exist in various conditions and record completeness. When developing the rainfall regression models, several rainfall stations were combined based on the proximity to the lake of interest. Currently the rainfall dataset is developed by using the nearest rainfall dataset and when rainfall data is not available, the next nearest rainfall station with data is used. As such, a composite rainfall dataset is used for the development of the model. Best practice would use one rainfall dataset for both the calibrated and predicted portions of the regression model.

ECFT model output

The ECFT model was developed for regional water supply planning for Central Florida. This model has been applied to other scenarios at a more local scale. The validation process at the local level has posed several opportunities for improvement and further development of the drawdown due to pumping. The uncertainty within the model should be summarized for the area of interest and considered when using the results to provide guidance to the MFL process.

Rainfall regression modeling

The rainfall regression model is used to extend results of the water budget model to incorporate a long-term level in the Historic record which would otherwise not be evaluated. Current practices of this predictive modeling uses a linear assumption which is a simplification of the non-linear system. For example, the response of the aquifer often depends on the antecedent conditions for infiltration and leakance using physically based models. In addition, the rainfall regression models are used outside of the range of model calibration which is should be used with caution.

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APPENDIX B

Draft Technical Memorandum

November 30, 2015

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

FROM: Nathan T Johnson, P.E., Groundwater Engineer, Water Resources Bureau
David Carr, Staff Environmental Scientist, Water Resources Bureau

Subject: Lake Starr Initial Minimum Levels Status Assessment

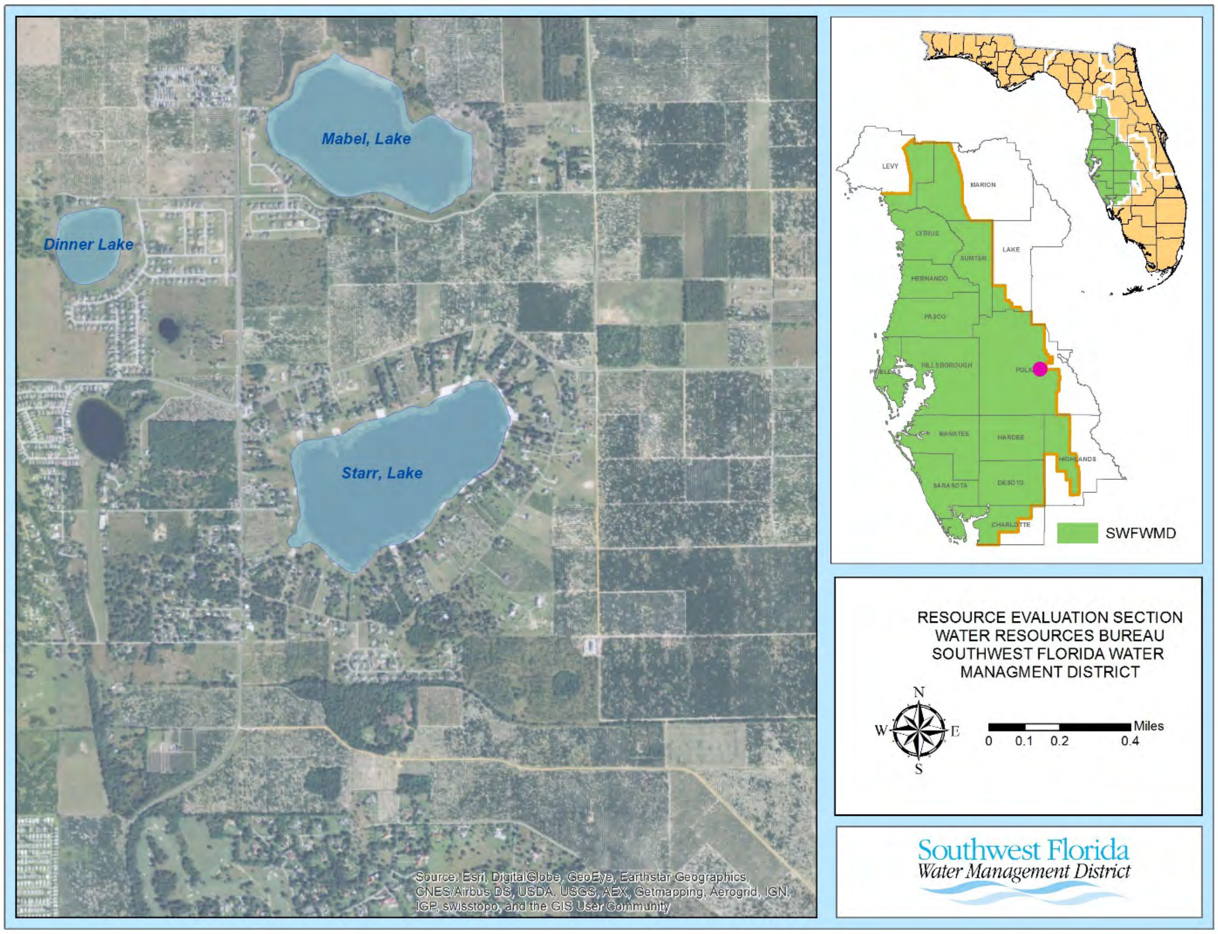
A. Introduction

The Southwest Florida Water Management District (District) is reevaluating adopted minimum levels for Lake Starr and is proposing revised minimum levels for the lake, in accordance with Section 373.042 and 373.0421, Florida Statutes (F.S). Documentation regarding development of the revised minimum levels is provided by Hancock and Barcelo (2015) and Carr and others (2015).

Section 373.0421, F.S. requires that a recovery or prevention strategy be developed for all water bodies that are found to be below their minimum flows or levels, or are projected to fall below the minimum flows or levels within 20 years. In the case of Lake Starr and other waterbodies with established minimum flows or levels in the Southern Water Use Caution Area (SWUCA), an applicable regional recovery strategy, referred to as the SWUCA Recovery Strategy, has been developed and adopted into District rules (Rule 40D-80.074, F.A.C.). One of the goals of the SWUCA Recovery Strategy is to achieve recovery of minimum flow and level water bodies such as Lake Starr. This document provides information and analyses to be considered for evaluating the status of the revised minimum levels proposed for Lake Starr and any recovery that may be necessary.

B. Background

Lake Starr is located in Polk County, Florida (sections 14 and 23, Township 29 South, Range 27 East) in the Peace River Basin of the Southwest Florida Water management District (Figure 1).



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 1. Location of Lake Starr in Polk County, Florida.

C. Revised Minimum Levels Proposed for Lake Starr

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

Table 1. Proposed Minimum Levels for Lake Starr.

Proposed Minimum Levels	**Elevation in Feet** NGVD 29
High Minimum Lake Level	106.4
Minimum Lake Level	103.2

D. Status Assessment

The lake status assessment approach involves using actual lake stage data for Lake Starr from 1992 through 2014, which was determined to represent the “Current” period. The Current period represents a recent “short-term” period when hydrologic stresses (including groundwater withdrawals) and structural alterations are reasonably stable. “Long-term” is defined as a period that has been subjected to the full range of rainfall variability that can be expected in the future. To create a data set that can reasonably be considered to be “Long-term”, a line of organic correlation (LOC) analysis was performed on the lake level data from the Current period. The LOC is a linear fitting procedure that minimizes errors in both the x and y directions and defines the best-fit straight line as the line that minimizes the sum of the areas of right triangles formed by horizontal and vertical lines extending from observations to the fitted line (Helsel and Hirsch, 2002). The LOC is preferable for this application since it produces a result that best retains the variance (and therefore best retains the "character") of the original data. This technique was used to develop the minimum levels for Lake Starr. By using this technique, the limited years of Current lake level data can be projected back to create a simulated data set representing over 60 years of lake levels, based on the current relationship between lake water levels and actual rainfall.

The same rainfall data set used for setting the minimum levels for Lake Starr was used for the status assessment. The best resulting correlation for the LOC model created with measured data was the 6-year weighted period, with a coefficient of determination of 0.65. The resulting lake stage exceedance percentiles are presented in Table 2.

Table 2. Comparison of lake stage exceedance percentiles derived from the lake stage/LOC results, exceedance percentiles of the 1992 to 2014 data, and the revised minimum levels proposed for Lake Starr.

Percentile	**Lake Stage/LOC Model Current Withdrawal (1946-2014) Scenario Results** Elevation in feet NGVD 29	**1992 to 2014 Data** Elevation in feet NGVD 29	**Proposed Minimum Levels** Elevation in feet NGVD 29
P10	105.6	105.9	106.4
P50	102.0	101.9	103.2

As an additional piece of information, Table 2 also presents the same percentiles calculated directly from the measured lake level data for Lake Starr for the period from 1992 through 2014. A limitation of these values is that the resulting lake stage exceedance percentiles are representative of rainfall conditions during only the past 22 years, rather than the longer-term rainfall conditions represented in the 1946 to 2014 LOC model simulations.

A comparison of the LOC model with the revised minimum levels proposed for Lake Starr indicates that the Long-term P10 is 0.8 feet lower than the proposed High Minimum Lake Level, and the Long-term P50 is 1.2 feet lower than the proposed Minimum Lake Level. The P10 elevation derived directly from the 1992 to 2014 lake data is 0.5 feet lower than the proposed High Minimum Lake Level and the P50 elevation is 1.3 feet lower than the proposed Minimum Lake Level. Differences in rainfall between the shorter 1992 to 2014 period and the longer 1946 to 2014 period used for the LOC modeling analyses likely contribute to the differences between derived and measured lake stage exceedance percentiles. Additionally, differences between actual withdrawal rates and those used in the models may have contributed to some of the differences in the percentiles.

E. Conclusions

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

Minimum flow and level status assessments are completed by the District on an annual basis and a five-year basis as part of the regional water supply planning process. In addition, Lake Starr is included in the Recovery Strategy for the Southern Water Use Caution Area Recovery Strategy (40D-80.074, F.A.C). Therefore, the analyses outlined in this document for Lake Starr will be reassessed by the District as part of this plan.

F. References

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