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

February 8, 2018

Resource Evaluation Section
Water Resources Bureau
Southwest Florida
Water Management District

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Cover: 2014 Natural Color Imagery of Lake Dan (Southwest Florida Water Management District files).

Contents

Introduction

Reevaluation of Minimum Flows and Levels

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

Lake Dan 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. Previously adopted levels for Lake Dan were also reevaluated to support ongoing District assessment of minimum flows and levels and the need for additional recovery in the Northern Tampa Bay Water Use Caution Area (NTB WUCA), a region of the District where recovery strategies are being implemented to support recovery to minimum flow and level thresholds.

Following Governing Board approval on August 30, 2016, the revised levels became effective on February 19, 2017.

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 revised minimum levels report; additional information on all tasks associated with the District's MFLs Program is summarized by Hancock *et al.* (2010).

The District's MFLs Program is implemented based on 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), Hoyer *et al*. (2006), Leeper (2006), Hancock (2006, 2007) and Emery *et al.* (2009). Independent scientific peer-review findings regarding the lake level methods are summarized by Bedient *et al.* (1999), Dierberg and Wagner (2001) and Wagner and Dierberg (2006).

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

Categorical significant change standards and other available information are developed to identify criteria that are sensitive to long-term changes in hydrology and can be used for establishing minimum levels. For all lake categories, the most sensitive, appropriate criterion or criteria are used to develop recommended minimum levels. For Category 1 or 2 Lakes, a significant change standard, referred to as the Cypress Standard, is developed. For Category 3 lakes, six significant change standards are typically developed. Other available information, including potential changes in the coverage of herbaceous wetland and submersed aquatic plants is also considered when establishing minimum levels for Category 3 Lakes. The standards and other available information are associated with the environmental values identified for consideration in Rule 62-40.473, F.A.C., when establishing MFLs (Table 1). The specific standards and other information evaluated to support development of revised minimum levels for Lake Dan are provided in subsequent sections of this report. More general information on the standards and other information used for consideration when developing minimum lake levels is available in the documents identified in the preceding sub-section of this report.

Table 1. Environmental values identified in the state Water Resource Implementation Rule for consideration when establishing minimum 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	NA[1]
Water quality	Cypress Standard, Wetland Offset, Lake Mixing Standard, Dock-Use Standard, Herbaceous Wetland Information, Submersed Aquatic Macrophyte Information
Navigation	Basin Connectivity Standard, Submersed Aquatic Macrophyte Information

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

Lake Classification
Lakes are classified as Category 1, 2, or 3 for the purpose of Minimum Levels development. According to (Chapter 40D-8.624, F.A.C.) Lake Dan meets the classification as a Category 1 lake: "Those lakes with lake-fringing cypress swamp(s) greater than 0.5 acres in size where Structural Alterations have not prevented the Historic P50 from equaling or rising above an elevation that is 1.8 feet below the normal pool of the cypress swamp(s)". The Historic P50 for Dan (31.0 ft.) is higher than 1.8 feet below the Normal Pool elevation (32.7 ft.). For comparison purposes, the standards associated with Category 3 lakes described below will be developed in a subsequent section of this report.

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.

Minimum Levels

Two Minimum Levels and two Guidance Levels are typically established for lakes. Upon completion of a public input/review process and, if necessary completion of an independent scientific review, either of which may result in modification of the revised levels, the levels are adopted by the District Governing Board into Chapter 40D-8, F.A.C. Code (see Hancock *et al.* 2010 for more information on the adoption process). The levels, which are expressed as elevations in feet above the National Geodetic Vertical Datum of 1929 (NGVD29), may include the following (refer to Rule 40D-8.624, F.A.C.).

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

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

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

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

The District is in the process of converting from use of the NGVD29 datum to use of the North American Vertical Datum of 1988 (NAVD 88). While the NGVD29 datum is used for elevation values included within this report, in some circumstances, notations are made for elevation data that was collected or reported relative to mean sea level or relative to NAVD88 and converted to elevations relative to NGVD29. Based on measured survey elevation data, the NGVD to NAVD measuring point datum shift is -0.88 ft.

Development of Minimum and Guidance Levels for Lake Dan

Lake Setting and Description

Watershed

Lake Dan is located in Northwest Hillsborough County (Section 6, Township 27 South, Range 17 East) and within the Brooker Creek Watershed (Figure 1 & Figure 2). The lake has a drainage area of 194.6 acres (URS, 2006) (Figure 3). Inlets include a ditch along the southeastern lakeshore that used to carry groundwater pumped from the Floridan aquifer for augmentation of the lake, and two ditches that connect the lake to cypress wetlands to the north (Figure 4). Discharge occurs on the western end of Lake Dan through a small ditch and 24-inch reinforced concrete pipe, then under a maintenance road and into a wetland west of the road. There are no surface water withdrawals from the lake currently permitted by the District. There are, however, numerous permitted groundwater withdrawals in the area, including major withdrawals associated with operation of the Eldridge-Wilde Wellfield.

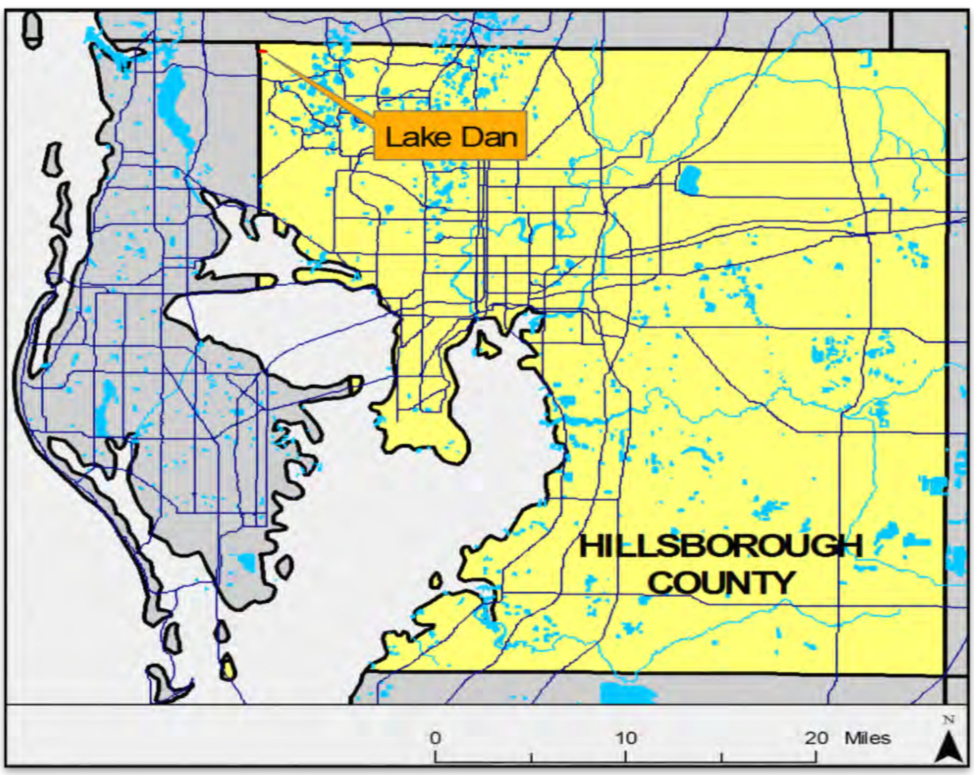


Figure 1. Location of Lake Dan in Hillsborough County, Florida.

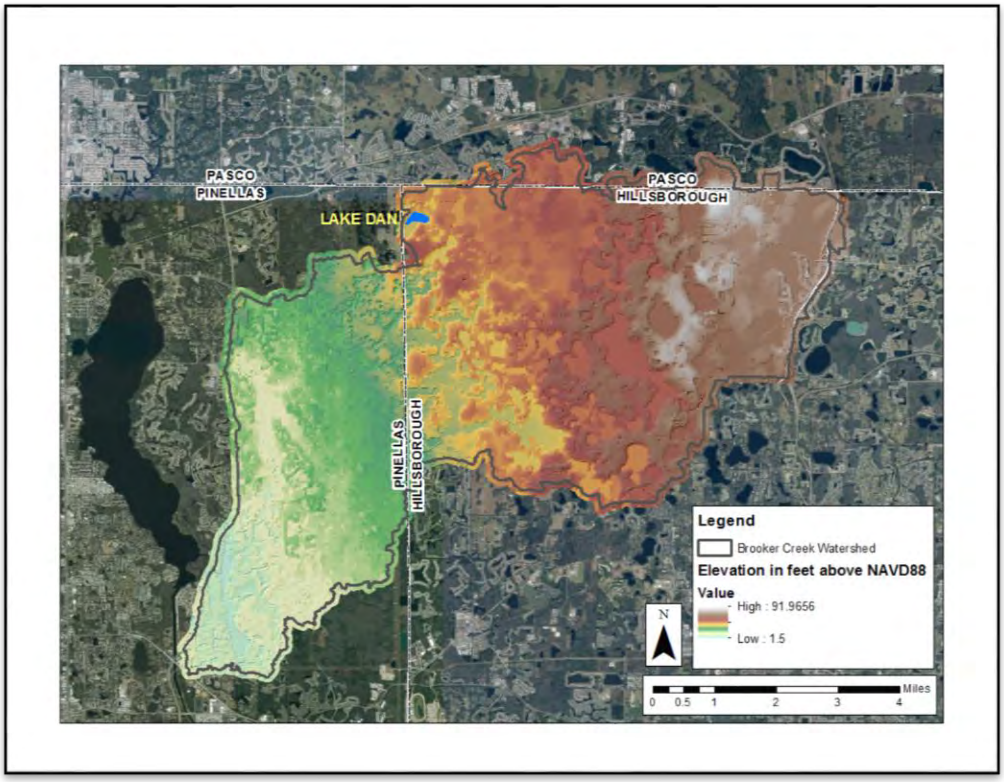


Figure 2. Watershed Delineation and Topography.

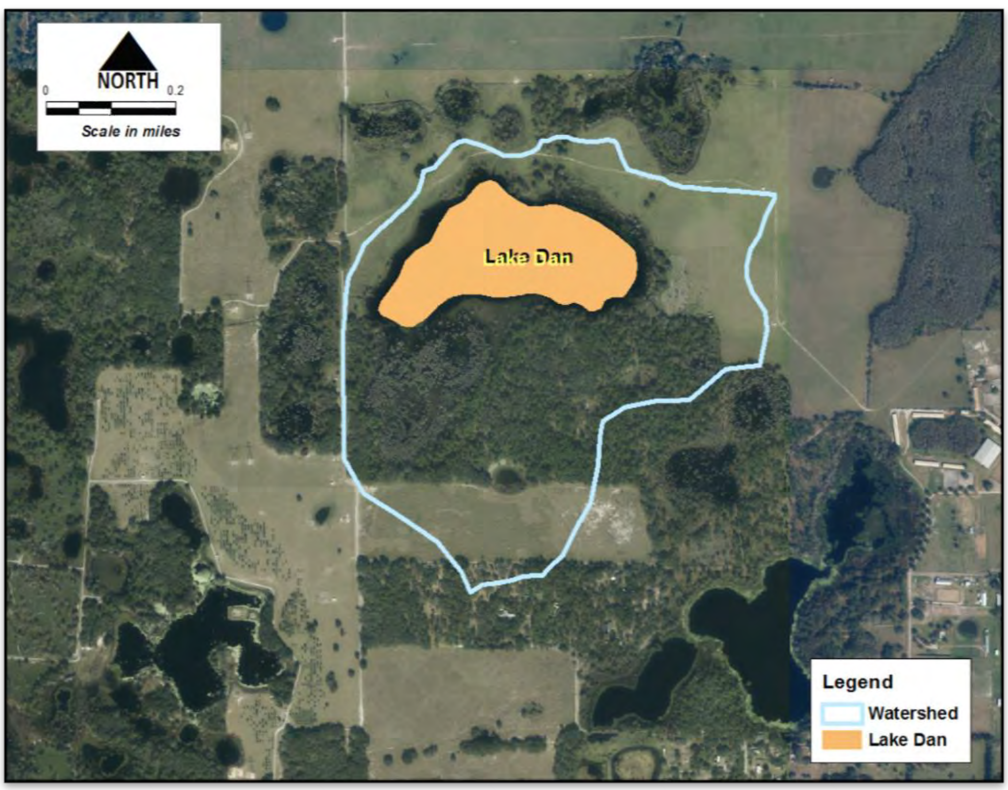


Figure 3. Lake Dan Drainage Basin.

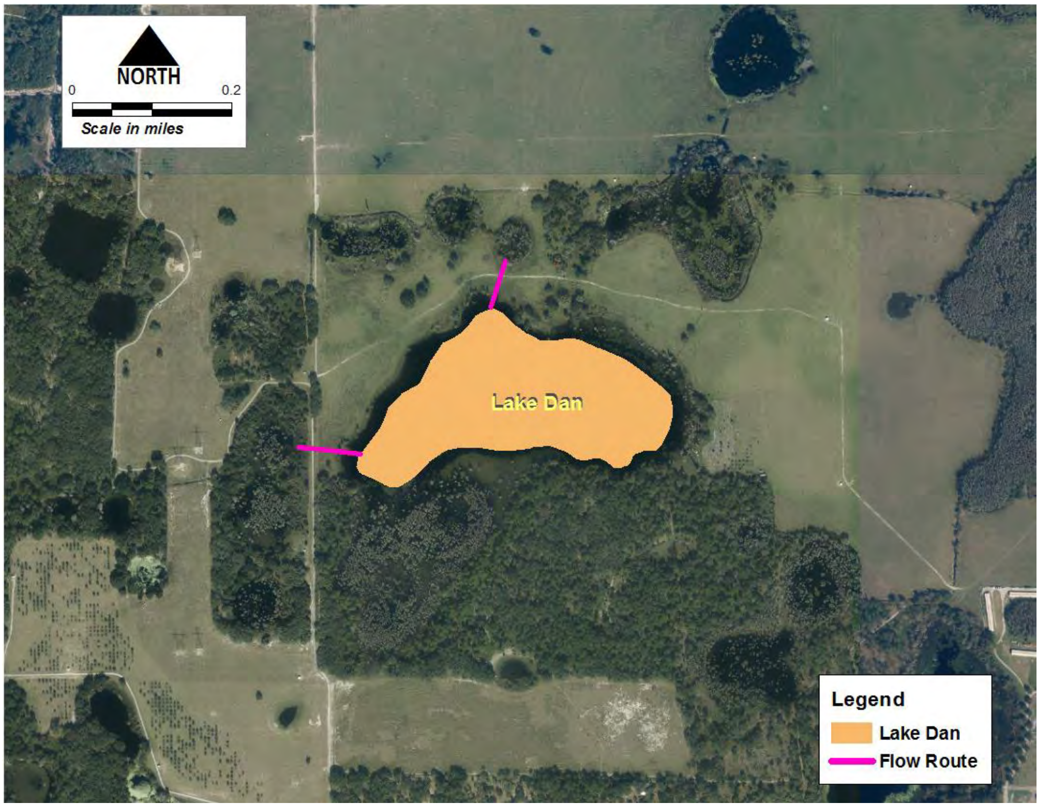


Figure 4. Location of Lake Dan Inflow and Outflow.

Site Specific Details

Lake Dan is located within the Eldridge-Wilde Wellfield, a Tampa Bay Water public water supply production facility that has been in service since 1956. The Hillsborough County Parks, Recreation and Conservation Department opened the property around Lake Dan to the public in March 2012 as part of the nearly 3,000 acre Lake Dan and Lake Frances Nature Preserves. The uplands surrounding Lake Dan are used for cattle grazing, and approximately half of the lake shoreline has been cleared of woody vegetation. Although much of the forested wetland contiguous with the lake has been destroyed, an intact cypress-dominated wetland remains along the southwest lakeshore.

Land Use Land Cover

An examination of the 1950 and more current 2011 Florida Land Use, Cover and Forms Classification System (FLUCCS) maps revealed that there has been considerable changes to the landscape in the region during this period. The 1950 FLUCCS map documents that the region was primarily bahiagrass (*Paspalum notatum*) pasture. Other cover classes in the region also included: a mix of hardwood-conifer forest, which includes water oak (*Quercus nigra*), tupelo, (*Nyssa* sp.), cypress (*Taxodium* sp.), and slash pine (*Pinus elliotii*); shrub /brushland cover class, which includes saw palmetto (*Serenoa repens*) and gallberry (*Ilex glabra*); and pine flatwood upland forest, which includes a thin canopy of *Pinus elliottii* and longleaf pine (*Pinus palustris*) and a shrub/brushland understory. By 2011, pasture land had increased by approximately 20 percent, replacing most of the shrub/brushland and much of the pine flatwoods (Figure 5). Figures 6 and 7 aerial photography chronicles landscape changes to the immediate lake basin from 1941 to 1970s. Tree clearing occurred between the 1968 and 1970s aerial photographs.

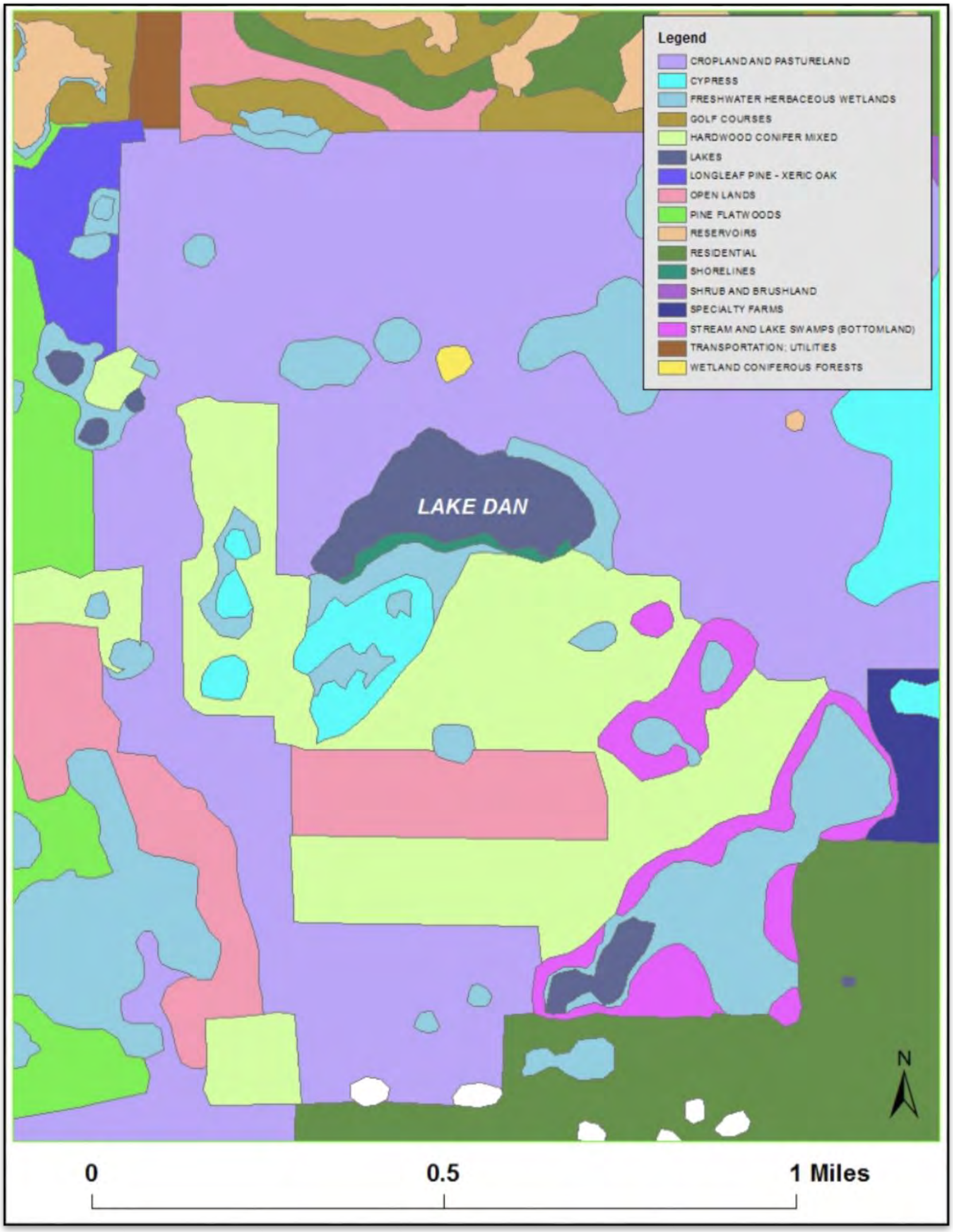
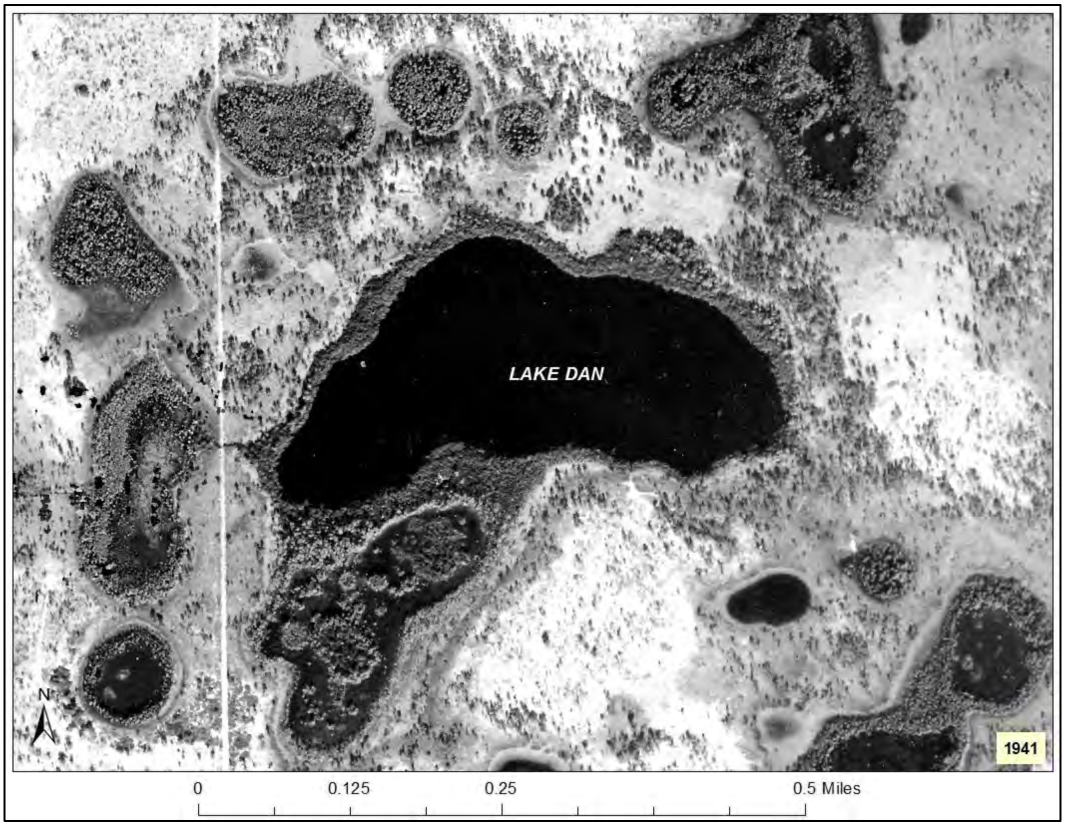


Figure 5. 2011 Land Use Land Cover Map of the Lake Dan Vicinity.



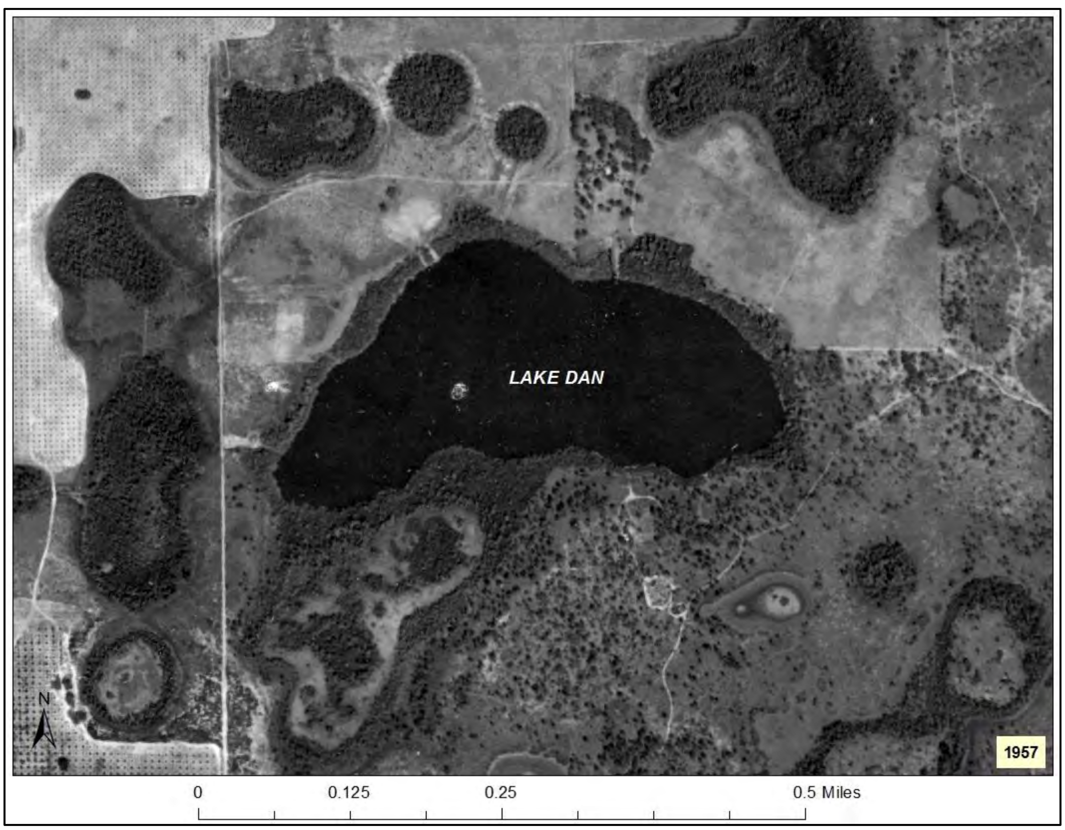


Figure 6. 1941 and 1957 Aerial Photographs of Lake Dan.

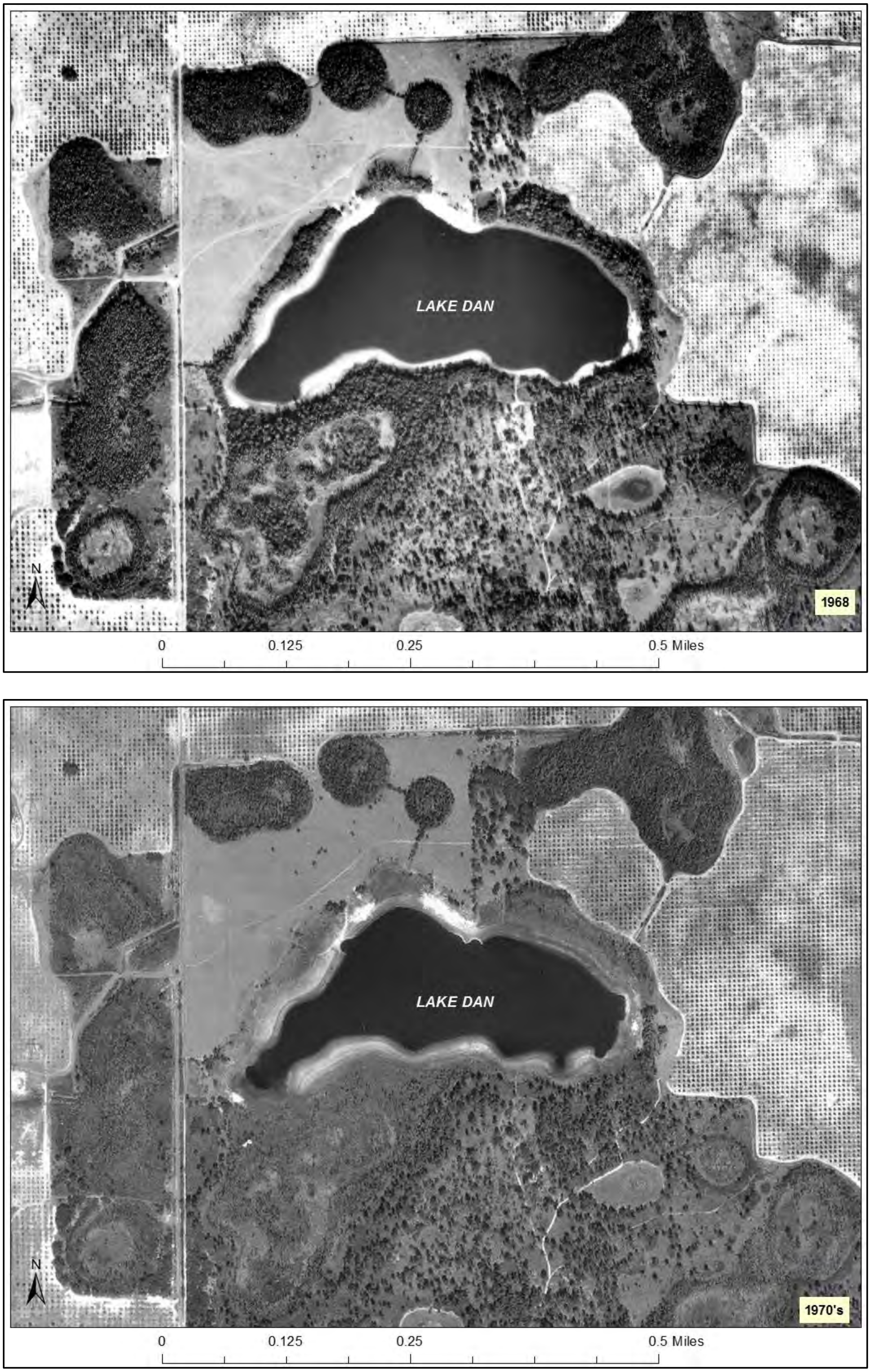


Figure 7. 1968 and 1970's Aerial Photographs of Lake Dan.

Physiographic Region

White (1970) classified the area of west-central Florida containing Lake Dan as the Gulf Coastal Lowlands physiographic region, which is a lowland area between the Brooksville Ridge and the Coastal Swamp (continuous areas of swamp adjacent to the coast). Brooks (1981) characterized the area surrounding the lake as the Odessa Flats subdivision of the Tampa Plain, and described the subdivision as a poorly dissected low sandy plain where karst features are related to the occurrence of the Tampa Limestone. As part of the Florida Department of Environmental Protection's Lake Bioassessment/Regionalization Initiative, the area has been identified as the Keystone Lakes region, and described as well-drained, sandy upland with numerous slightly acidic, clear-water lakes with low nutrient levels (Griffith *et al.* 1997).

Bathymetry Description and History

One-foot interval bathymetric data gathered from recent field surveys resulted in lake contour lines from the bottom of the lake up to an elevation of 33 ft. (Figure 8). These data revealed that the lowest lake bottom contour (16 ft.) is located in about a 150 ft.-diameter circular depression near the northwestern edge of the lake. At the high guidance level established in 2004 (32.5 ft., Table 3), the lake surface area was 69 acres based on stage volume date calculated support of minimum levels development at that time. However, the 2016 revised stage volume calculations reveal the lake being closer to 96.5 acres at the same elevation. Additional morphometric or bathymetric information for the lake basin is discussed in the Methods, Results and Discussion section of this report.

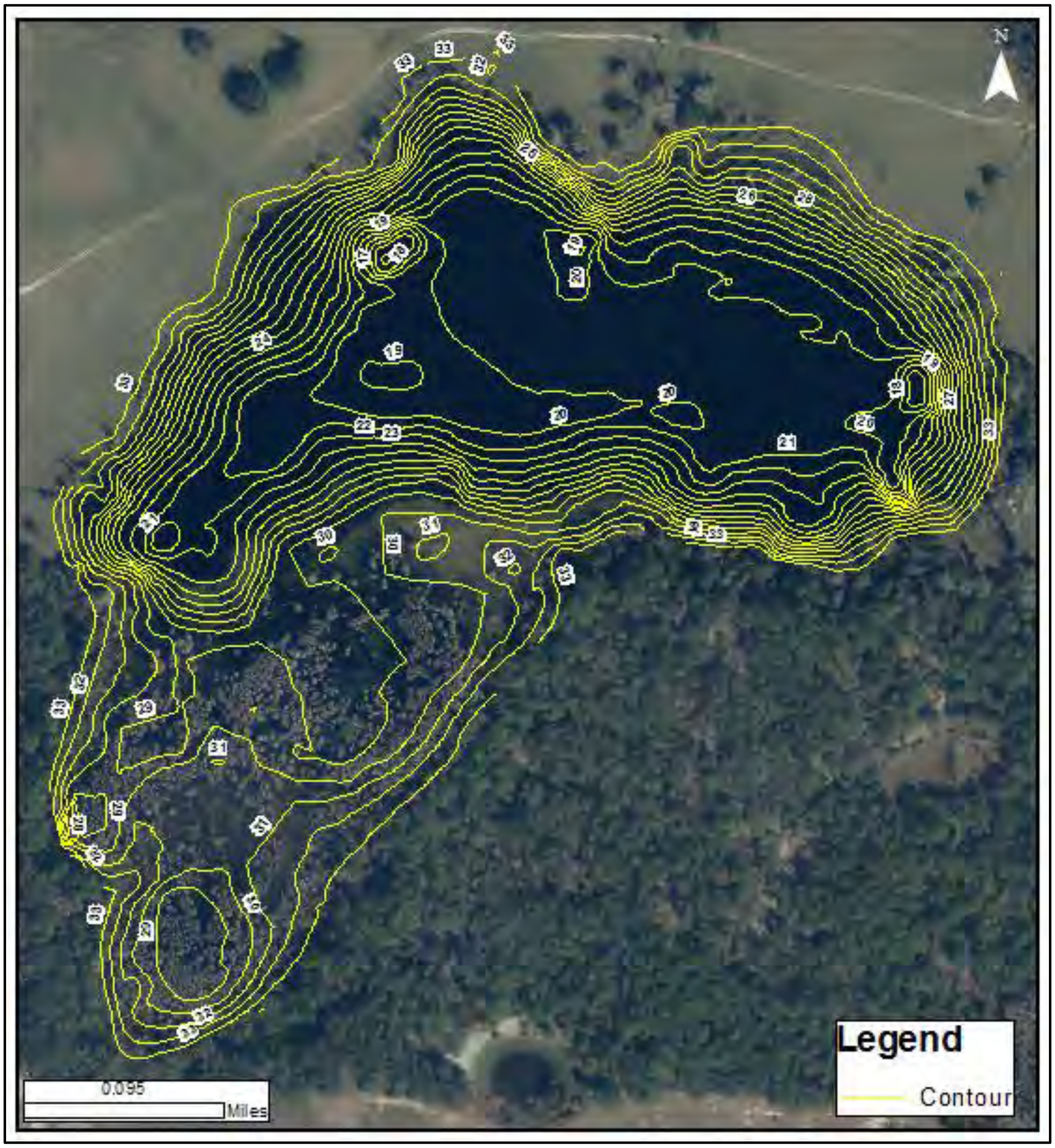


Figure 8. Lake Bottom Elevation Contours in feet above NGVD29 on a 2014 Natural Aerial Photograph

Water Level (Lake Stage) Record

Lake stage data, i.e., surface water elevations for Lake Dan are collected from water level gages (Figure 9). Water level data collection for Lake Dan began in 1965 by the US Geological Survey and continued through 1988. The District began collecting water level data in 1980 and currently continues to collect water level data. A continuous series of water level data was compiled by merging US Geological Survey Data collected from August 27, 1965 to mid-September 1988 with District-collected water level data from mid-September 1988 to current (Figure 10). There are no water level data for the lake that predate wellfield withdrawals (wellfield withdrawals began in 1956). The highest lake stage elevation on record was 34.72 ft. and occurred in August 6, 2015. The lowest lake stage elevation on record was 18.84 ft. and occurred on June 22, 1973. Figure 11 shows the lake at a relatively high water level (2006) and low water level (2009) in historic aerial photographs of Lake Dan.

Figure 9. Lake Dan Gauge SID 19723 on January 27, 2016.

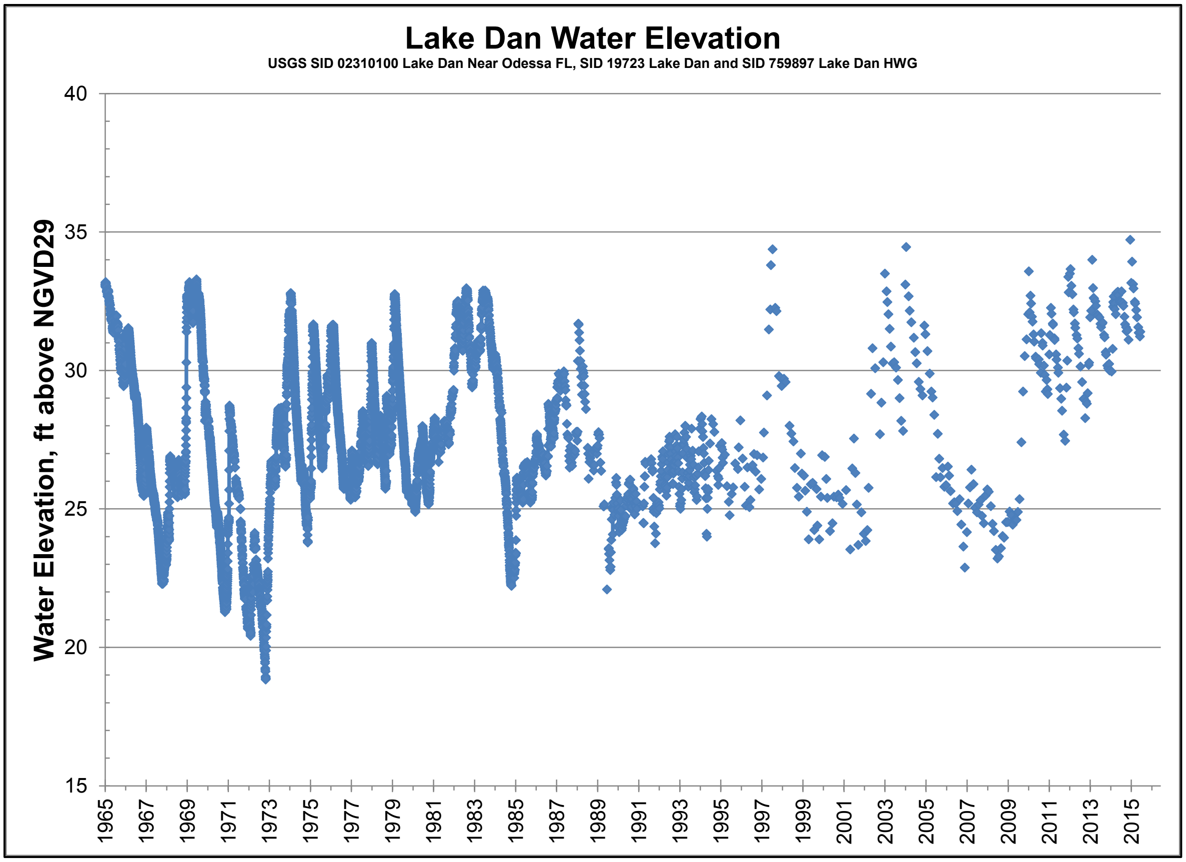


Figure 10. Lake Dan Period of Record Stage Data USGS SID 02310100 and District SIDs 19723 and 759897 (SWFWMD Water Management Information System database).

Figure 11. High water level (2006) and low water level (2009) Historic Aerial Photographs of Lake Dan.

Methods, Results and Discussion

Historical and Previous Management Levels

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

Previously adopted Lake Management Levels were based on work conducted in the 1970s (see SWFWMD 1996). The District Governing Board adopted management levels (currently referred to as Guidance Levels) for Lake Dan in September 1980 (Table 2). A Maximum Desirable Level of 30.00 ft. above NGVD was also developed, but was not adopted by the Governing Board. Previously adopted guidance levels and associated surface areas for Lake Dan in Hillsborough County, Florida are presented in Table 2.

Table 2. Guidance levels adopted September 1980 and associated surface areas for Lake Dan.

Level	Elevation (ft., NGVD)	Total Lake Area (acres)
Ten Year Flood Guidance Level	35.00	NA
High Level	32.00	66
Low Level	28.00	37
Extreme Low Level	25.00	30

Previously adopted Flood Guidance, Minimum and Guidance Lake Levels were based on work concluded in 2004 (see SWFWMD 2004). The District Governing Board approved Guidance and Minimum levels for Lake Dan (Table 3) which were subsequently adopted into Chapter 40D-8, Florida Administrative Code on December 2004 using the methodology for Category 1 Lakes described in SWFWMD (1999a and 1999b).

Table 3. Guidance levels adopted December 2004 and associated surface areas for Lake Dan.

Level	Elevation (ft., NGVD)	Total Lake Area (acres)
Ten Year Flood Guidance Level	34.9	NA
High Guidance Level	32.5	69
High Minimum Level	31.9	65
Minimum Level	30.9	58
Low Guidance Level	30.4	55

Revised levels along with lake surface area for each level are listed in Table 4, 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 4. Lake Stage Percentiles, Normal Pool and Control Point Elevations, Significant Change Standards, and revised Minimum and Guidance Levels, and associated lake surface areas for Lake Dan.

Revised Levels	**Elevation in Feet NGVD 29**	**Lake Area (acres)**
Lake Stage Percentiles		
Historic P10 (1946 to 2015)	32.5	97
Historic P50 (1946 to 2015)	31.0	76
Historic P90 (1946 to 2015)	29.5	46
Normal Pool and Control Point		
Normal Pool	32.7	101
Control Point	32.3	93
Significant Change Standards		
Recreation/Ski Standard*	30.5	66
Dock-Use Standard*	NA	NA
Wetland Offset Elevation*	30.2	56
Aesthetics Standard*	29.5	46
Species Richness Standard*	30.5	66
Basin Connectivity Standard *	NA	NA
Lake Mixing Standard*	21.6	19
Minimum and Guidance Levels		
High Guidance Level	32.5	97
High Minimum Lake Level	32.3	93
Minimum Lake Level	30.9	75
Low Guidance Level	29.5	46

NA - not appropriate; * Developed for comparative purposes only; not used to establish Minimum Levels

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

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

Development of Exceedance Percentiles

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

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

The initial approach included creating a water budget model that incorporated the effects of precipitation, evaporation, overland flow, and groundwater interactions (Appendix A). Using the results of the water budget model, regression modeling for lake stage predictions was conducted using a linear line of organic correlation statistical model (LOC) (see Helsel and Hirsch 1992). The procedure was used to derive the relationship between daily water surface elevations for Lake Dan and composite regional rainfall.

A combination of model data produced a hybrid model which resulted in a 69-year (1946-2015) 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 32.5 ft. The Historic P50, the elevation the lake water surface equaled or exceeded fifty percent of the time during the historic period, was 31.0 ft. The Historic P90, the lake water surface elevation equaled or exceeded ninety percent of the time during the historic period, was 29.5 ft. (Table 4 and Figure 12).

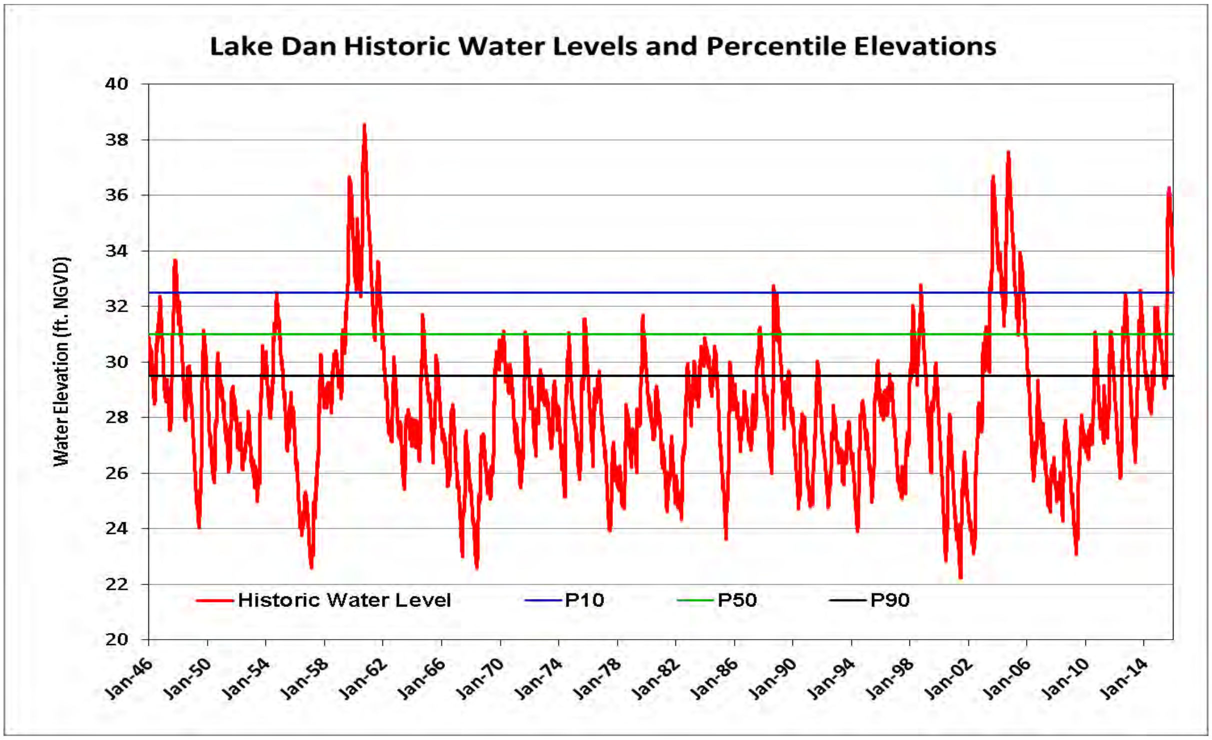


Figure 12. Historic Water Levels (hybrid) Used to Calculate Percentile Elevations Including P10, P50, and P90.

Normal Pool Elevation and Additional Information

The Normal Pool elevation, a reference elevation used for development of minimum lake and wetland levels, is established based on the elevation of hydrologic indicators of sustained inundation. The inflection points (buttress swelling) and moss collars on the trunks of cypress trees have been shown to be reliable biologic indicators of hydrologic Normal Pool (Carr, et al. 2006). Ten good quality examples of cypress buttress swelling where measured on the lake in January 2016 (Table 5). The spread between the minimum and maximum buttress elevations (2.2 ft.) is greater than most lakes in the Northern Tampa Bay area, though not without precedence. This spread is likely due to subsidence that has occurred in the past. Based on the survey of these biologic indicators, the Normal Pool elevation was established at the median normal pool of 32.7 ft.

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 at the high end. The highest point in the outflow conveyance system is in the ditch at the west side of the lake and serves as the control point at 32.3 ft. It appears to be relatively stable (i.e., not eroded) and is similar to the one determined during the original MFL development (32.5 ft.) (Leeper, 2004). There are no buildings in the lake basin, therefore consideration for a low floor slab elevation was not applicable.

Table 5. Summary statistics for 2016 hydrologic indicator measurements used for establishing Normal Pool elevations for Lake Dan.

Summary Statistic	Number (N) or Elevation
N	10
Median	32.7
Mean	32.5
Minimum	31.1
Maximum	33.3

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 Dan, the revised High Guidance Level was established at the Historic P10 elevation, 32.5 ft. (Table 4). The measured data have exceeded the High Guidance Level several times over the data period of record (Figure 10).

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 Low Guidance level is established using Historic or Current lake stage data and, in some cases, reference lake water regime (RLWR) 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 (see SWFWMD 1999a for a discussion of the RLWR statistics). Based on the availability of Historic data for Lake Dan, the revised Low Guidance Level was established at the Historic P90 elevation, 29.5 ft. (Table 4). Measured water levels have periodically been lower than the Low Guidance Level over the period of record (Figure 10).

Significant Change Standards

For comparative purposes, minimum level standards used for establishing Minimum Lake Levels for lakes without fringing cypress wetlands were developed for Lake Dan (Table 4). The Category 3 significant change standards were established for Lake Dan and include Lake Mixing, Dock Use, Basin Connectivity, Species Richness, Herbaceous Wetland, Submerged Aquatic Macrophyte, Aesthetics, and Recreation/Ski Standards. These standards are described earlier in this report and the methodology used to calculate them is described in 40D-8.624(8). Each standard was previously defined in the Lake Classification section of this report. Each standard was evaluated for minimum levels development for Lake Dan and presented in Table 4.

- The Mixing Standard was established at 21.6 ft. due to the shift in the dynamic ratio (basin slope) value from <0.8 to a value of >0.8, (as the rule requires). This indicates that potential changes in basin susceptibility to wind-induced sediment re-suspension were considered for minimum levels development, though did not qualify to be used to set the minimum levels.
- There was only one dock on the lake; therefore, the Dock-Use Standard was not established or used to set the minimum levels.
- The Basin Connectivity Standard was not applicable and was not established because the lake is one continuous basin. This was demonstrated by the historical aerial photography and lake bathymetry (Figures 6, 7, and 8).
- The Species Richness Standard was established at 30.5 ft., which is establish at an elevation corresponding to the lowest elevation associated with less than a 15% reduction in lake surface area relative to the area at the Historic P50 elevation of 31.0 ft. (Figure 13).
- Review of changes in potential herbaceous wetland area associated with change in lake stage (Figure 14), 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.
- An Aesthetic-Standard for Lake Dan was established at the Low Guidance Level elevation of 29.5 ft.
- The Recreation/Ski Standard was calculated at 30.5 ft. based on a ski elevation of 29.0 ft.

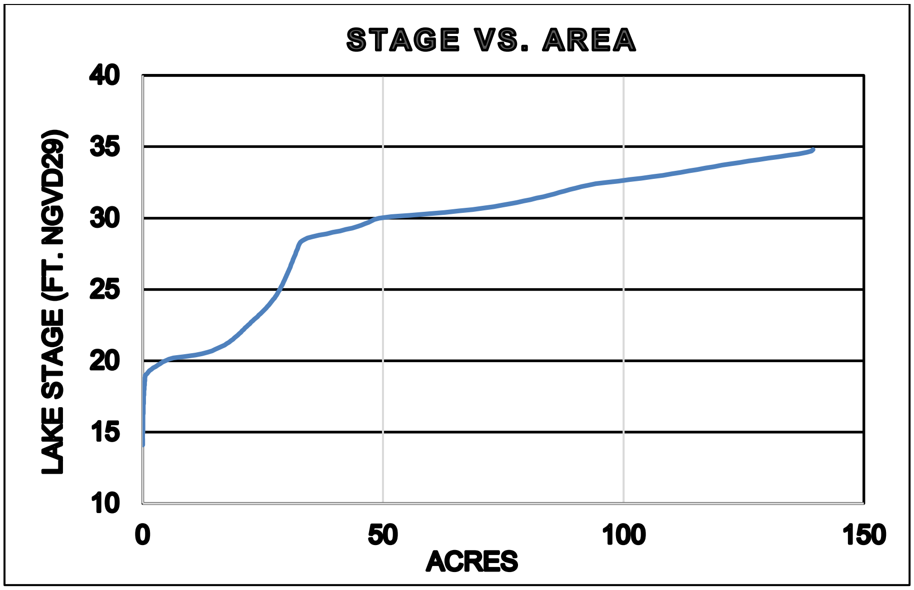


Figure 13. Lake Stage (ft. NGVD29) to Surface Area (Acres).

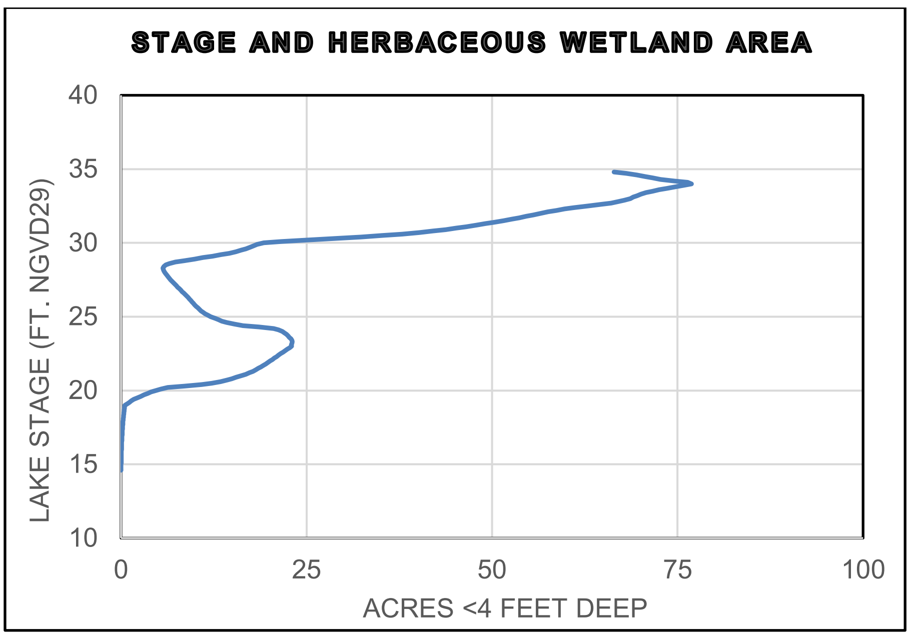


Figure 14. Lake Stage Compared to Available Herbaceous Wetland Area.

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 1 lake, the Minimum Lake Level is established at the Cypress Standard of the Historic Normal Pool minus 1.8 ft. In the case of Lake Dan, the revised minimum level is 30.9 ft. The most recent stage reading that corresponds to the revised minimum level was on May 3, 2011, at 30.9 ft.

The High Minimum Lake Level is the elevation that a lake's water levels are required to equal or exceed ten percent of the time on a long-term basis. For a Category 1 lake, the High Minimum Lake Level is established at the Historic Normal Pool minus 0.4 ft. Therefore, the revised High Minimum Lake Level for Lake Dan is established at 32.3 ft.

Revised Minimum and Guidance levels for Lake Dan are plotted on the modeled "hybrid" Historic water level record in Figure 15. The hybrid model is a combination of water budget model results from October 1989 to December 2015 and rainfall LOC results for the period January 1946 through September 1989. Modeling used to develop the Historic record is further explained in Appendix A. To illustrate the approximate locations of the lake margin when water levels equal the revised minimum and guidance levels, these levels are imposed onto a 2014 natural color photograph in Figure 16.

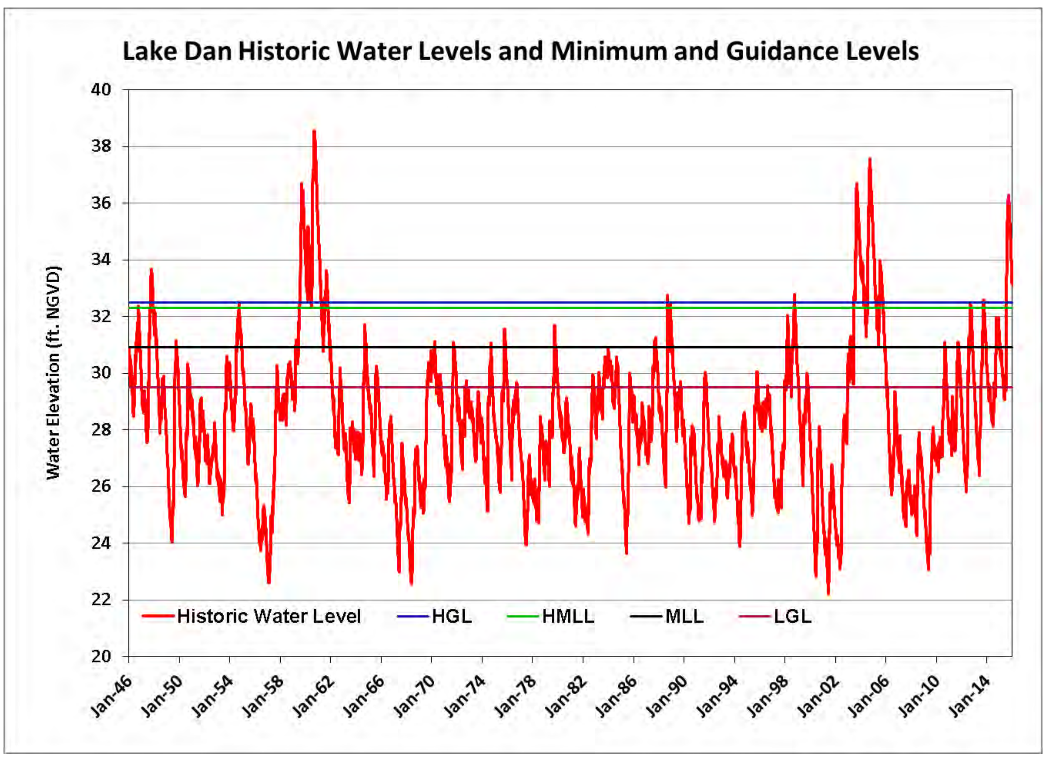


Figure 15. Historic water levels (hybrid) used to calculate the revised Minimum and Guidance Levels. The revised levels include the High Guidance Levels (HGL), High Minimum Lake Levels (HMLL), Minimum Lake Levels (MLL), and Low Guidance Levels (LGL).

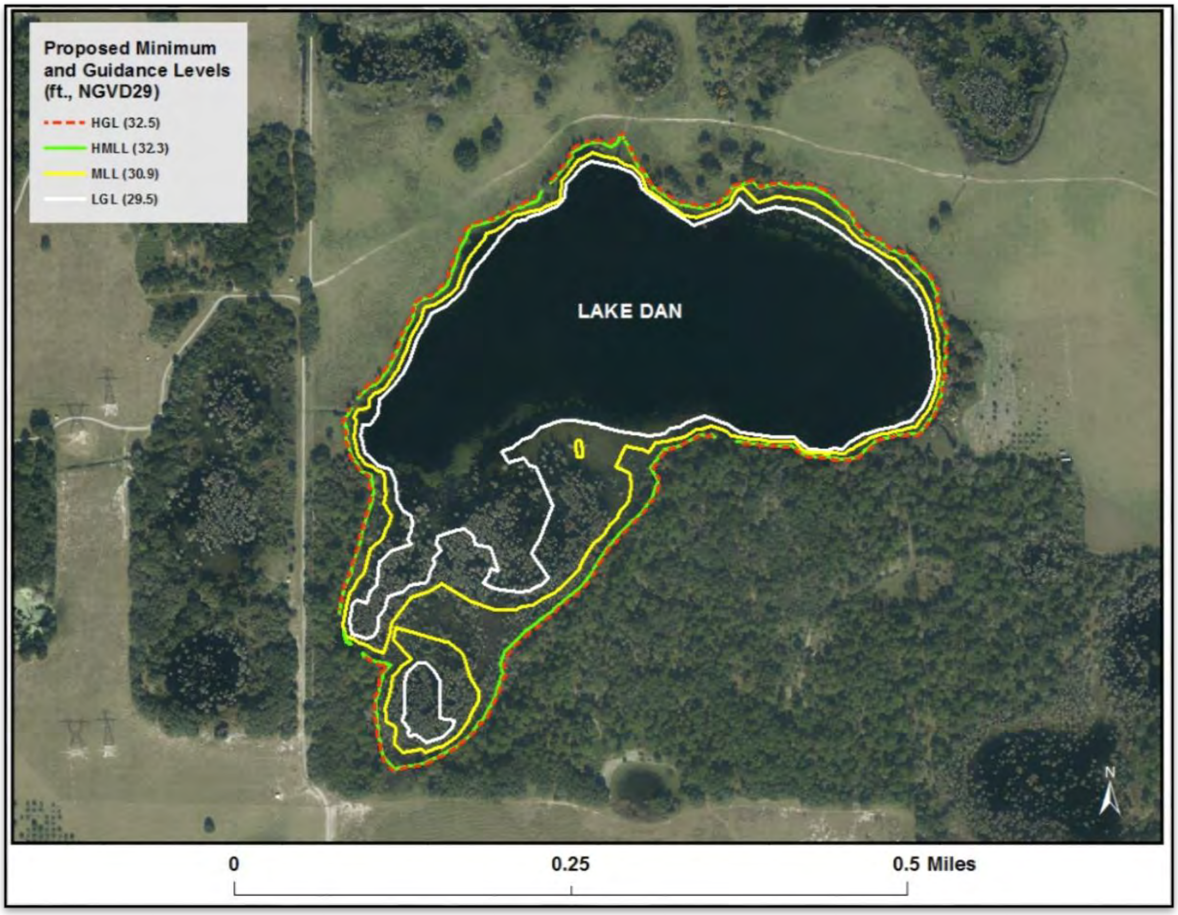


Figure 16. Lake Dan Minimum and Guidance Levels Contour Lines Imposed Onto a 2014 Natural Color Aerial Photograph.

Many federal, state, and local agencies, such as the U.S. Army Corps of Engineers, the Federal Emergency Management Agency, United States Geological Survey, and Florida's water management districts are in the process of upgrading from the National Geodetic Vertical Datum (NGVD29) standard to the North American Vertical Datum (NAVD88) standard. For comparison purposes, the revised MFLs for Lake Dan are presented in both datum standards (Table 6). 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 of 1988. The NGVD29 datum was converted to NAVD88 using the Corpscon conversion of 0.88 ft.

Table 6. Revised Minimum and Guidance Levels for Lake Dan in NGVD29 and NAVD88.

Minimum and Guidance Levels	Elevation in Feet NGVD29	Elevation in Feet NAVD88
High Guidance Level	32.5	31.6
High Minimum Lake Level	32.3	31.4
Minimum Lake Level	30.9	30.0
Low Guidance Level	29.5	28.6

Consideration of Environmental Values

The revised minimum levels for Lake Dan are protective of relevant environmental values identified for consideration in the Water Resource Implementation Rule when establishing minimum flows and levels (see Rule 62-40.473, F.A.C.). As presented above, when developing minimum lake levels, the District evaluates categorical significant change standards and other available information to identify criteria that are sensitive to long-term changes in hydrology and represent significant harm thresholds.

A Cypress Standard of Historic Normal Pool was identified to support development of minimum levels for Lake Dan based on the occurrence of lake-fringing cypress wetlands of one-half acre or greater in size. The standard is associated with protection of several environmental values identified in the Water Resource Implementation Rule, including: fish and wildlife habitats and the passage of fish, transfer of detrital material, aesthetic and scenic attributes, filtration and absorption of nutrients and other pollutants, and water quality (Table 1). Ultimately, the Cypress Standard of Historic Normal Pool was used for developing the minimum levels for Lake Dan based on its classification as a Category 1 Lake. Given this information, the levels are as protective of all relevant environmental values as they can be. In addition, the environmental value, maintenance of freshwater storage and supply is also expected to be protected by the minimum levels based on inclusion of conditions in water use permits that stipulate permitted withdrawals will not lead to violation of adopted minimum levels.

Comparison of Revised and Previously Adopted Levels

The revised High Guidance Level and Low Guidance Level for Lake Dan are respectively equal to, and 0.9 ft. lower than the previously adopted guidance levels. Although there is no difference between the previously adopted and revised High Guidance Levels, the previously adopted level was established at the Control Point and the revised High Guidance Level was established based on application of a more recent modeling approach for characterization of Historic water level fluctuations. The previously adopted Low Guidance Level was established by subtracting the Northern Tampa Bay Region RLWR90 statistic (2.1 ft) from the High Guidance Level. The revised Low Guidance Level was established using a newer 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 and augmentation effects given existing structural conditions. This resulted in a difference between the previously adopted and revised Low Guidance Levels.

The revised High Minimum Lake Level for Lake Dan is 0.4 ft. higher than the previously adopted High Minimum Lake Level. The previously adopted High Minimum Lake Level was established at the Minimum Lake Level plus the Northern Tampa Bay RLWR50 statistic (1.0 ft). The revised High Minimum Lake Level is based on subtracting 0.4 feet from the Historic Normal Pool. The previously adopted and revised Minimum Lake Levels are based on a 1.8-foot offset from the Historic Normal Pool. The Historic Normal Pool did not change with this reassessment, and, thus, resulted in no change to the adopted Minimum Lake Level.

As of January 31, 2017, the District Governing Board has approved the revised Minimum and Guidance Levels identified in this report and have replaced the previously adopted levels for Lake Dan. These levels were made Effective on February 19, 2017.

Minimum Levels Status Assessment

To assess whether the revised Minimum Lake Level is being met, observed stage data in Lake Dan 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 (2003-2015, Appendix B).

For the status assessment, the 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 Lake Dan water levels are currently 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 Northern Tampa Bay Water Use Caution (Rule 40D-80.073, F.A.C.). The District plans to continue regular monitoring of water levels in Lake Dan 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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Technical Memorandum

August 29, 2016

TO:

David Carr, Staff Environmental Scientist, Water Resources Bureau

Jaime Swindasz, Staff Environmental Scientist, Water Resources Bureau

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

FROM: Tamera S. McBride, P.G., Senior Hydrogeologist, Water Resources Bureau

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

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A. Introduction

Water budget and rainfall correlation models were developed to assist the Southwest Florida Water Management District (District) in the establishment of minimum levels in Lake Dan, located in northwest Hillsborough County near the Pasco and Pinellas County lines. Lake Dan currently has adopted minimum levels, which are scheduled to be re-assessed in FY 2016. This document will discuss the development of the Lake Dan models, as well as the development of the Historic percentiles using the models.

B. Background and Setting

Lake and Watershed Characteristics

Lake Dan is located in northwest Hillsborough County, in the center of the Eldridge-Wilde Wellfield, which is one of eleven regional water supply wellfields operated by Tampa Bay Water (Figure 1). Most of the property surrounding the lake is owned by Hillsborough County, with the exception of a small parcel adjacent to the northern shore owned by Pinellas County, and two parcels on the southeastern part of the lake owned by private entities.

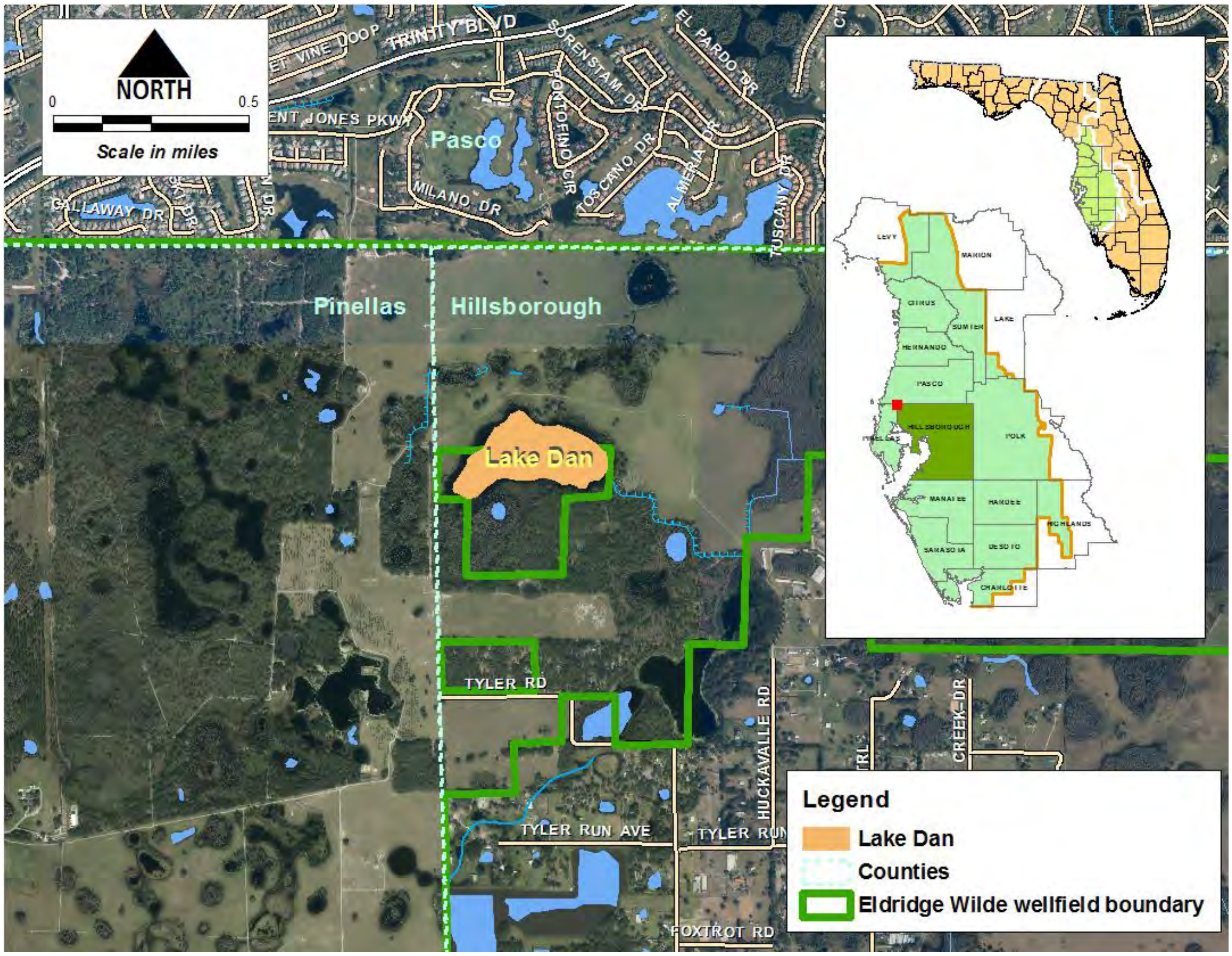

Figure 1. Location of Lake Dan in Hillsborough County, Florida

Lake Dan is located in the Brooker Creek watershed midway between the watershed's eastern and western boundaries and adjacent to the northern watershed boundary (see Figure 2). Wetlands to the north of the lake can flow into the lake via a small ditch, and discharge can occur through a small ditch on the west side of the lake (Figure 3). However, the lake is generally isolated, since there is relatively little inflow to and outflow from the lake. Surface water inflow to Lake Dan occurs as overland flow from the drainage basin immediately surrounding the lake.

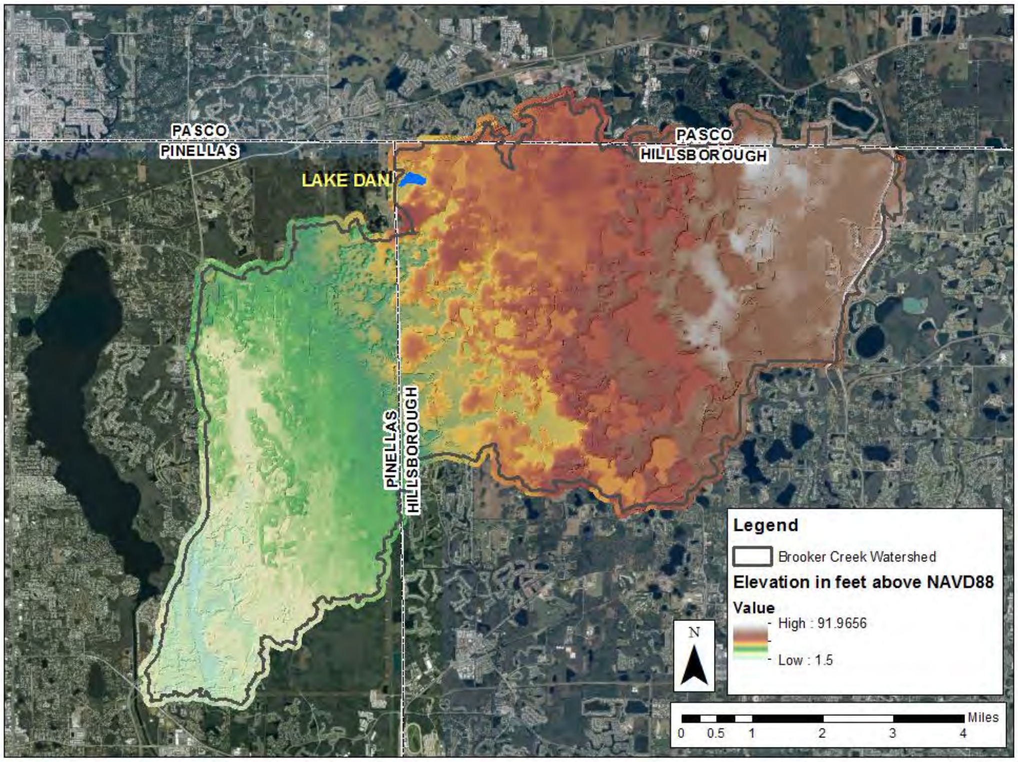

Figure 2. Brooker Creek Watershed and Lake Dan

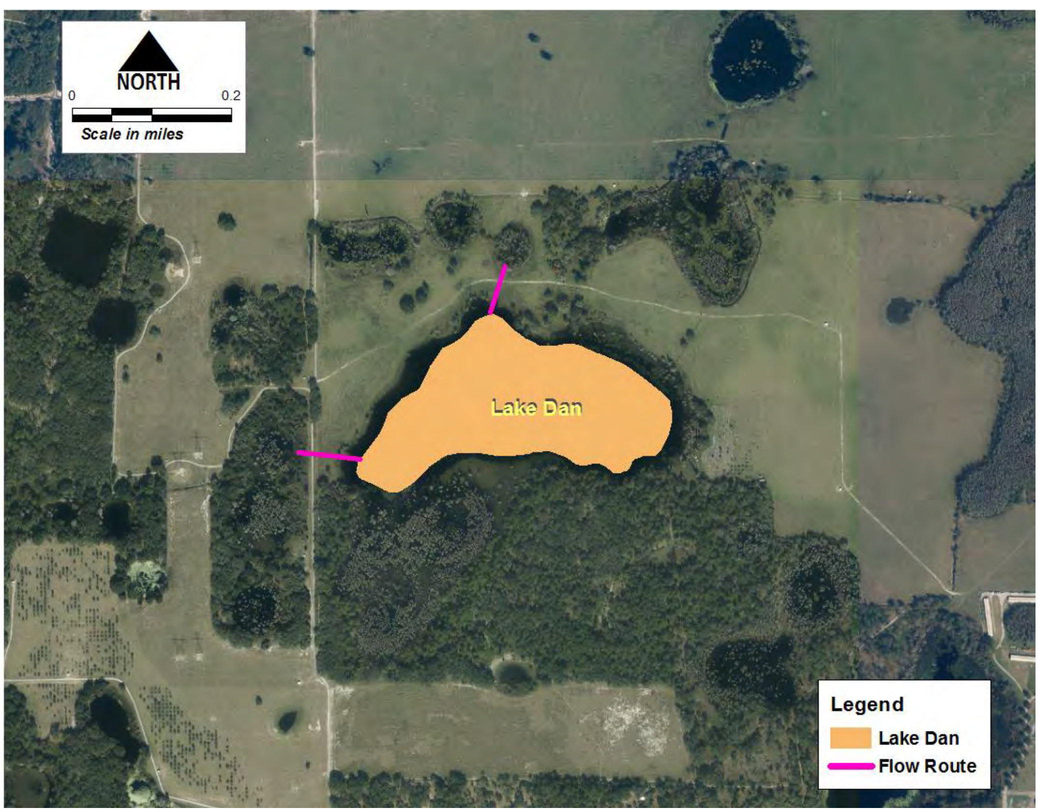

Figure 3. Flow into and out of Lake Dan

Physiographic Setting

White (1970) classified the physiographic area where Lake Dan is located as the Gulf Coastal Lowlands physiographic region, which is a lowland area between the Brooksville Ridge and the Coastal Swamp (continuous areas of swamp adjacent to the coast). Brooks (1981) categorizes the Lake Dan area as the Odessa Flats area of the Tampa Plain. The Tampa Plain is described as a lowland area where karst features are related to the occurrence of the Tampa Limestone. The Odessa Flats area is described as a poorly dissected low sand plain with flatwoods. The topography is very flat, and drainage to the lake is a combination of overland flow and flow through drainage swales.

Hydrogeologic Setting

The hydrogeology of the area includes a sand surficial aquifer; a discontinuous, intermediate clay confining unit; and the thick carbonate Upper Floridan aquifer. Lithology data shows the surficial aquifer in the Eldridge-Wilde Wellfield ranges from 0 to 35 feet thick and averages about 10 feet thick (Leggett, et al., 2006). Hutchinson (2003) shows the range of the surficial aquifer in the wellfield is 0 to 60 feet below land surface, with the 60 foot depth being attributed to a sinkhole anomaly. The average thickness was about 33 feet. The clay confining layer is discontinuous across the wellfield and ranges up to 35 feet thick and averages 12 feet thick, according to Leggett, et al. (2006). Hutchinson (2003) indicates the clay layer ranges from 5 to 31 feet thick across the wellfield, with an average thickness of about 13.6 feet. Hancock and Basso (1996) noted that the Hawthorn Group clay thickness is known to be variable and discontinuous in the northern Tampa Bay area where there are karst features. The top of the Upper Floridan aquifer ranges from 26 to 91 feet below land surface, with the 91 foot depth being attributed to a sinkhole anomaly (Hutchinson, 2003). The average depth to the top of the Upper Floridan aquifer is about 47 feet below land surface.

Flow in the Upper Floridan aquifer in the vicinity of Lake Dan is generally east to west (Lopez and Fretwell, 1992). Flow in the surficial aquifer is general from the east. The surficial aquifer flows radially away from the lake to the north, west, and south (Lopez and Fretwell, 1992 and Mills, 1978). More recent potentiometric and surficial water levels and maps were reviewed and indicate flow patterns are still similar to those documented in the older reports.

Lake Dan is in the center of the Eldridge-Wilde Wellfield (Figure 4). The wellfield began operating in 1956, with the first 19 production wells constructed during the period of 1954 to 1968 (Leggett, et al., 2006). Monthly withdrawals steadily increased until they peaked at over 44 million gallons per day (mgd) in 1973 (Figure 5). Production decreased in the early 1980s as other wellfields began production and peaked again in the late 1980s. Wellfield withdrawals steadily declined until 2002, and production leveled off to an average of about 13 mgd, with some months of little or zero withdrawals in 2013. Reductions were the result of Tampa Bay Water bringing new water sources online.

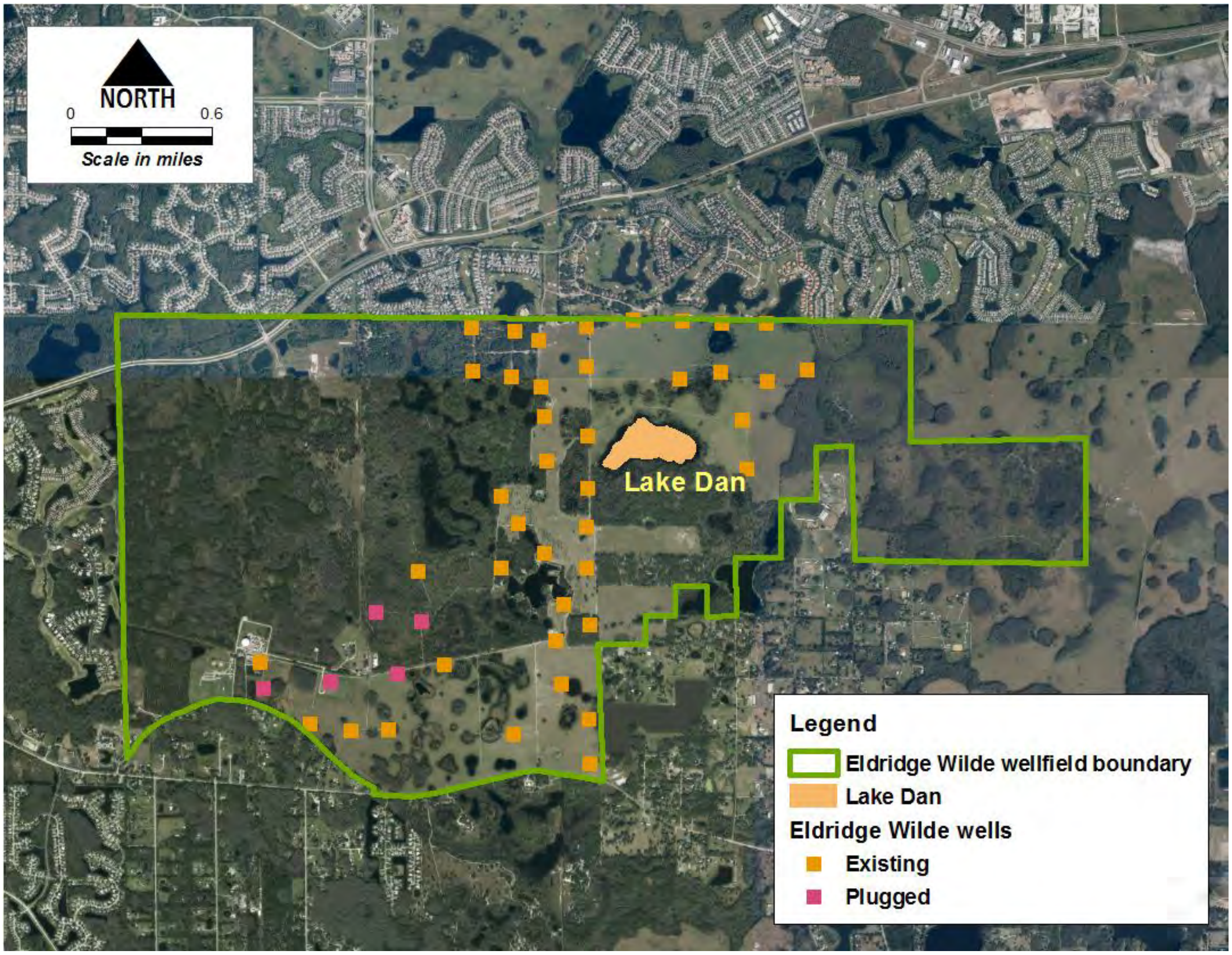

Figure 4. Eldridge-Wilde wellfield configuration

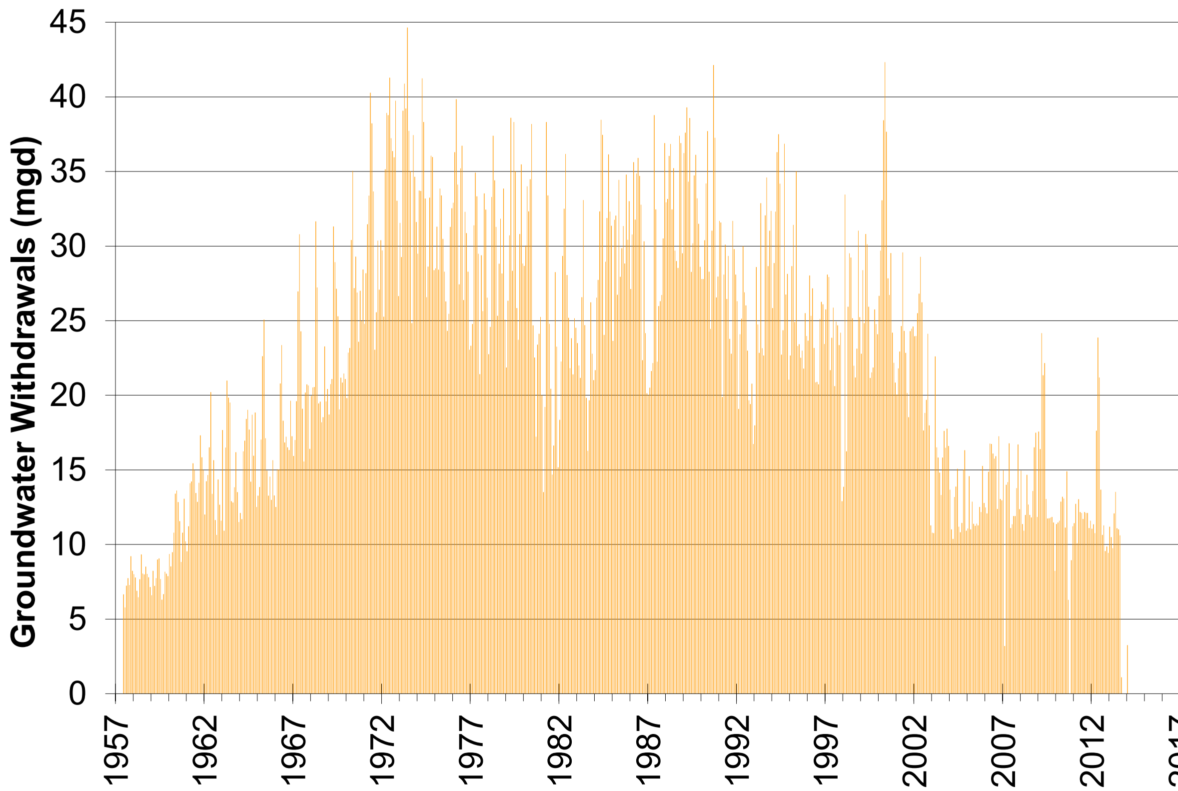

Figure 5. Monthly Eldridge-Wilde wellfield withdrawals

Data

Water level data collection for Lake Dan began in 1965 by the US Geological Survey and continued through 1988. The District began collecting water level data in 1980 and currently continues to collect water level data. A continuous series of water level data was generated by merging US Geological Survey Data collected from August 1965 to mid-September 1988 with District-collected water level data from mid-September 1988 to current (Figure 6). There are no water level data for the lake that predate wellfield withdrawals (wellfield withdrawals began in 1956), and annual average withdrawal rates were over 13 mgd at the time water level data collection began.

The Eldridge-Wilde N2 Upper Floridan aquifer monitor well (District SID 19900), located about one-quarter mile northwest of Lake Dan, was used in the water budget model (Figure 7). Water level measurements for this well started in March 1973 (Figure 8). This was the closest Upper Floridan aquifer monitor well with the most complete period of record. The Eldridge-Wilde 1A East Upper Floridan aquifer monitor well (SID 19707) is a little closer to the lake; however, the Eldridge-Wilde N2 Upper Floridan aquifer monitor well had more frequent data.

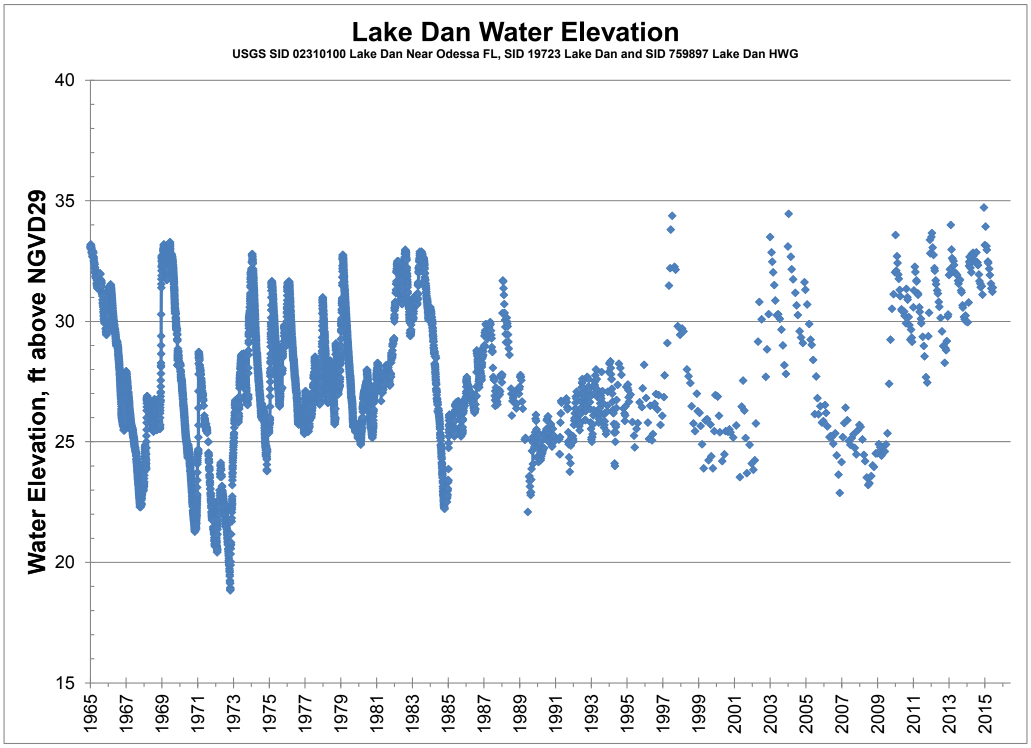

Figure 6. Lake Dan water elevation

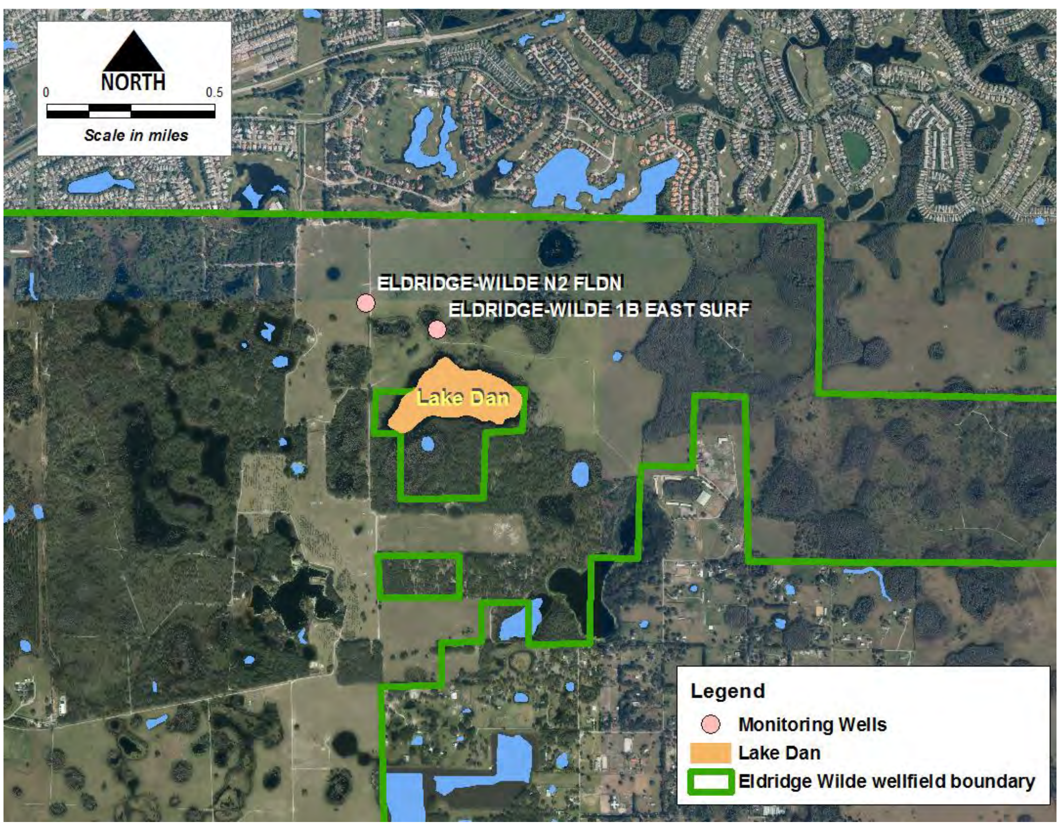

Figure 7. Locations of monitor wells near Lake Dan

The Eldridge-Wilde 1B East surficial aquifer monitor well (District SID 19710), located about less than one-tenth of a mile north of Lake Dan and near the Eldridge-Wilde N2 Upper Floridan aquifer well, was used in the water budget model (Figure 7). It was the closest surficial aquifer well with a reasonable water level record. Water level measurements for this well started in February 1989 (Figure 9).

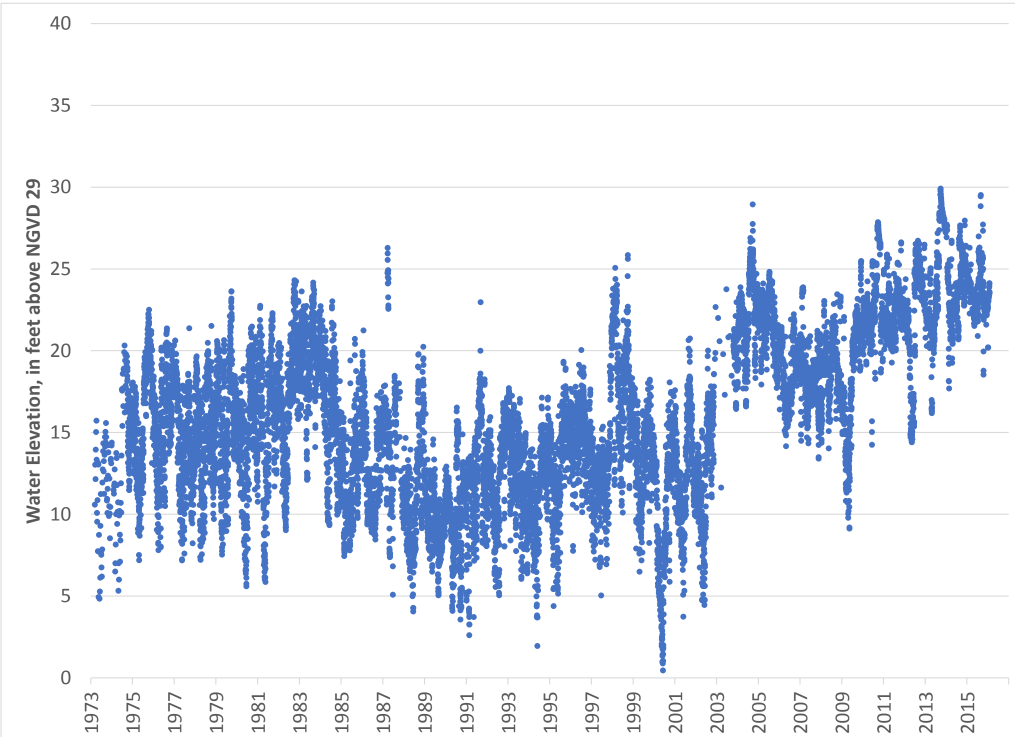

Figure 8. Water levels in Eldridge-Wilde N2 Floridan aquifer monitor well (SID 19900)

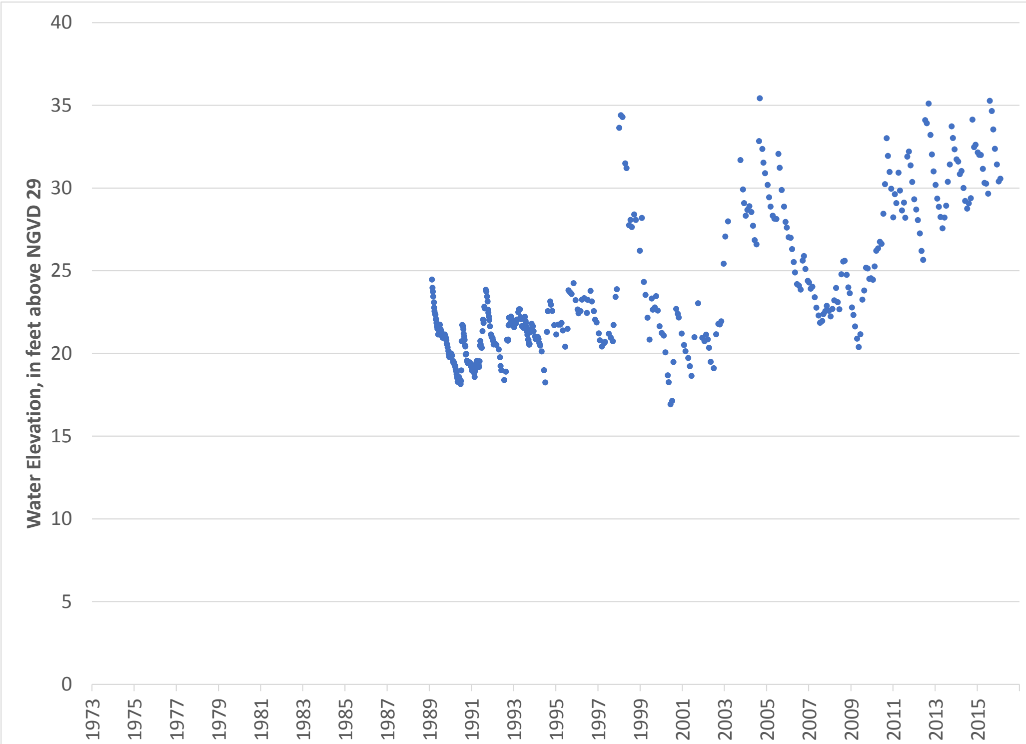

Figure 9. Water levels in Eldridge-Wilde surficial well (SID 19710)

Water Use

It is apparent that water levels in Lake Dan dropped during peak withdrawals from the Eldridge-Wilde wellfield (Figures 5 and 6, 10 and 11), based on lake stage compared to field indicators of historic normal pool (an elevation of biologic indicators representing approximately P10 conditions.

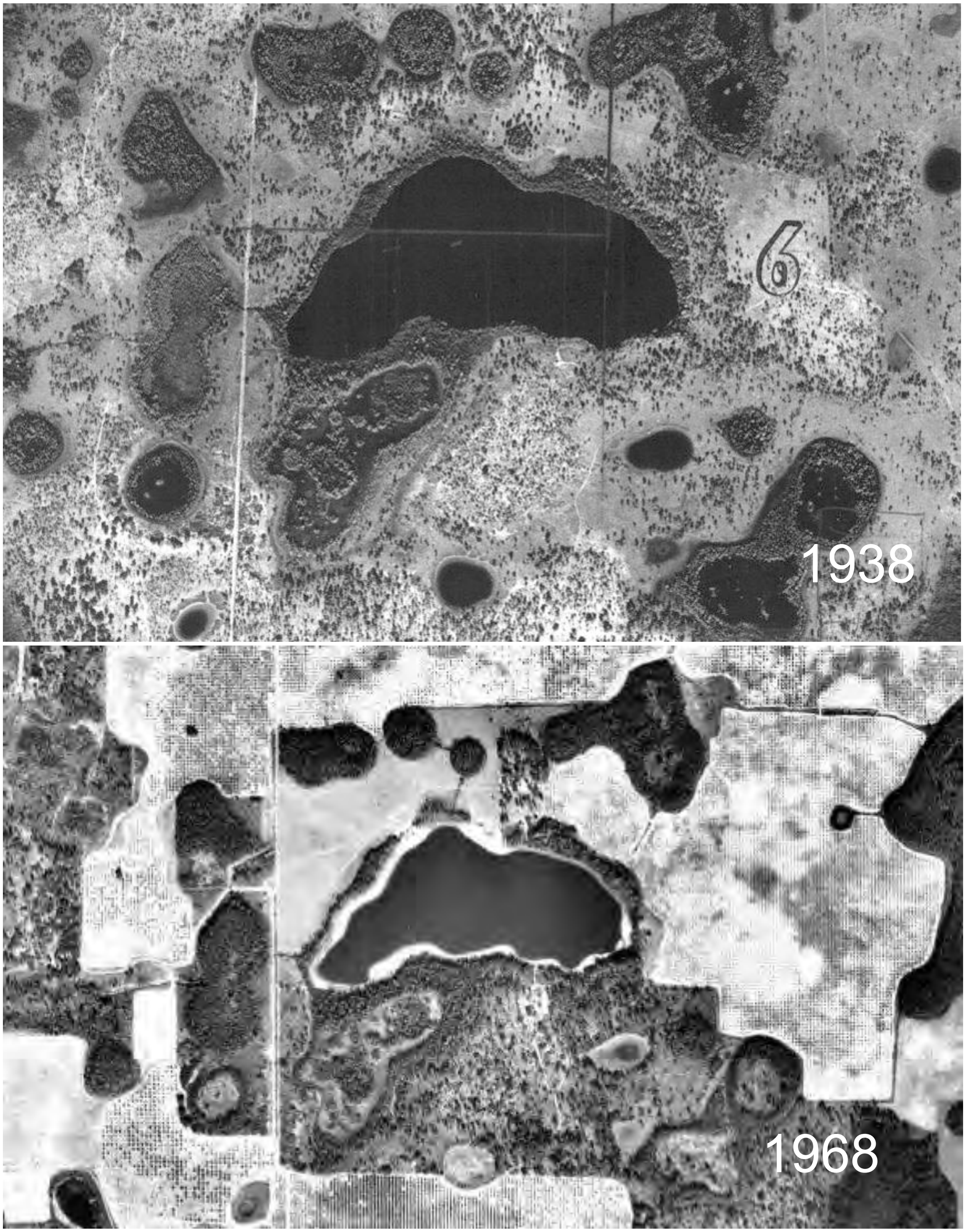

Figure 10. Water level changes in Lake Dan

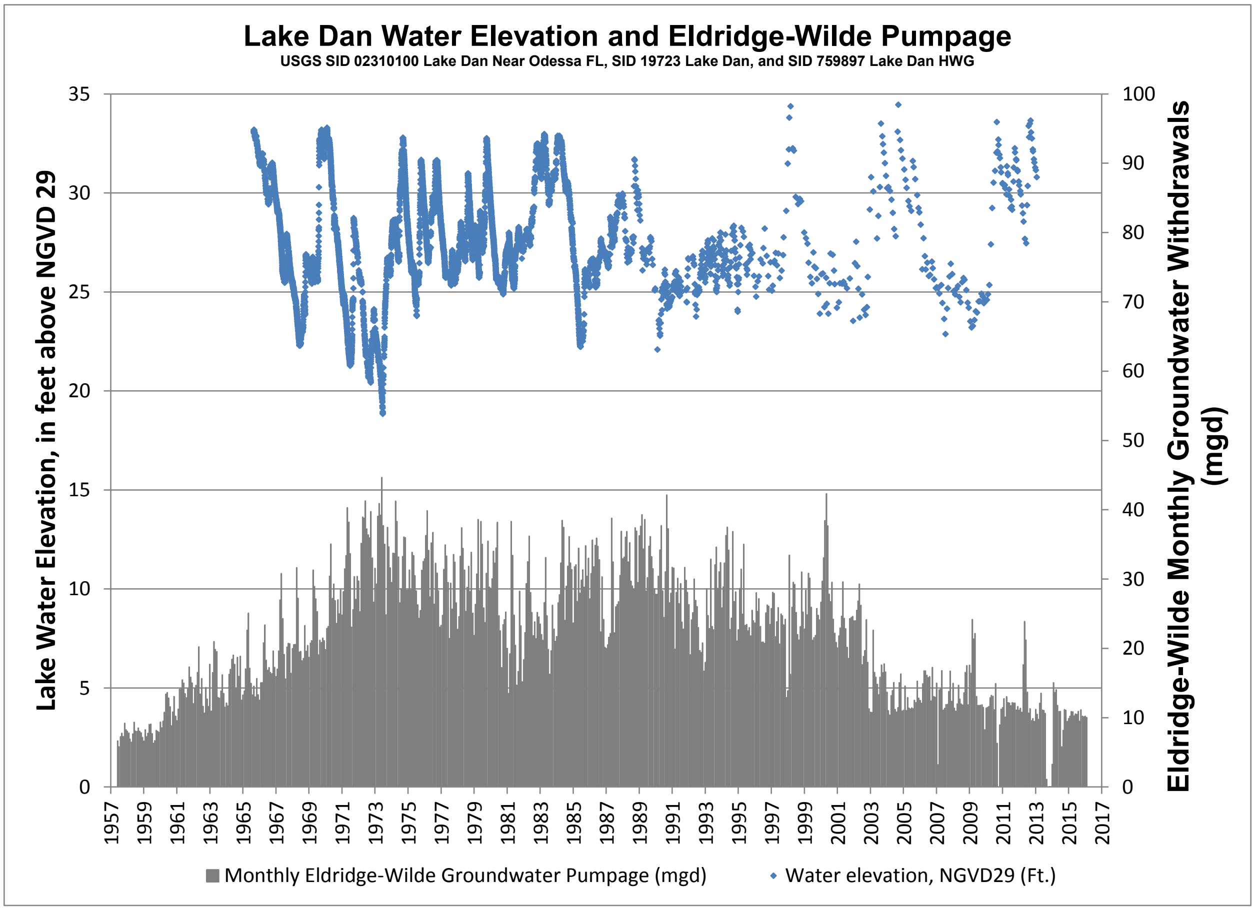

Figure 11. Water levels in Lake Dan and Eldridge-Wilde wellfield groundwater withdrawals

Augmentation

Lake Dan was previously augmented under WUP No. 2673 Eldridge-Wilde and is now augmented under WUP No. 11771 Tampa Bay Water Consolidated Permit. Augmentation began in 1972 according to historical files from by Tampa Bay Water (Doug Keesecker, personal communications, 2016). The current main augmentation well (Tampa Bay Water well ELW-139) is shown in Figure 12; however, augmentation may have also occurred over the period of augmentation from other wells at the wellfield. Well ELW-139 is metered and is connected to a transmission line that connects other wells in the wellfield. Based on a comparison of metered augmentation and metered withdrawal records for ELW-139, it appears that augmentation may have occasionally occurred from other wells on the transmission line.

Augmentation records from the District and Tampa Bay Water start in October 1989 and show lake augmentation was greatest in the early part of this record (Figure 13). Augmentation from 2011 to 2015 is relatively minimal. Augmentation data prior to 1989 were provided to the District by Tampa Bay Water; however the origin of the data are uncertain. This data series includes records from 1972 to 2001. Data for years 1989 to 2001 from this data set did not match data from the District's and Tampa Bay Water's databases; therefore, the data set that begins in 1972 was not used.

Pinellas County oversaw augmentation from 1972 to 2009, but operations were likely controlled by a land manager with a cattle operation on the wellfield property. Anecdotal information implies that augmentation during this period was for aesthetics, cattle watering, and for maintaining boundaries created by fences that extended into the lake (Doug Keesecker, personal communications, 2016). For at least part of this period, augmentation did not appear to be related to any type of organized operating schedule and water was pumped when needed. Tampa Bay Water assumed operation of the augmentation in 2009 and continues to operate it currently. Augmentation stopped when Tampa Bay Water took over augmentation in 2009, since permitted withdrawal quantities were close to being exceeded. No augmentation occurred between June 2009 and March 2010. Augmentation between April 2010 and June 2010 was relatively significant; however, augmentation was mostly zero after June 2010 with some relatively short periods where augmentation occurred with relatively small quantities (Figure 13). Records show that the augmentation meter was replaced in September 2004 (Doug Keesecker's communication with Joe Kehoe, Tampa Bay Water, 2016). About 2004 (maybe when meter was replaced) the augmentation pipeline from the augmentation well was rerouted. The original pipeline route was observed in 1998 to be routed from well ELW-139 to a location due south of the well and into a ditch that flows westward toward Lake Dan (Doug Keesecker, personal communications, 2016). All augmentation water sent to the ditch did not flow into Lake Dan, because it sometimes overflowed into adjacent wetlands south of the ditch. The re-routed pipeline currently flows from well ELW-139 due west and directly into an area connected to Lake Dan without loss of augmentation to the nearby wetlands.

Augmentation effects on water levels could not be tightly correlated to water level changes in the lake with the water budget model, perhaps due to the following: augmentation has been performed by different parties with different record-keeping and measurement practices; augmentation has occurred over most of the water level record period; a documented augmentation schedule for the period of augmentation was not available; augmentation management goals have changed over time; metering has changed over the period of augmentation; and the augmentation route changed during the augmentation period.

The augmentation record available in current District and Tampa Bay Water databases begins in October 1989. The data source is mixed from October 1989 through December 2005 with some data shown in the database as originating from Tampa Bay Water and some from the District's WMIS Database. All daily data values for the period

October 1989 to December 2005 were estimated by dividing monthly totals evenly across the days of the month. Records appear to be daily from January 2, 2006 to current.

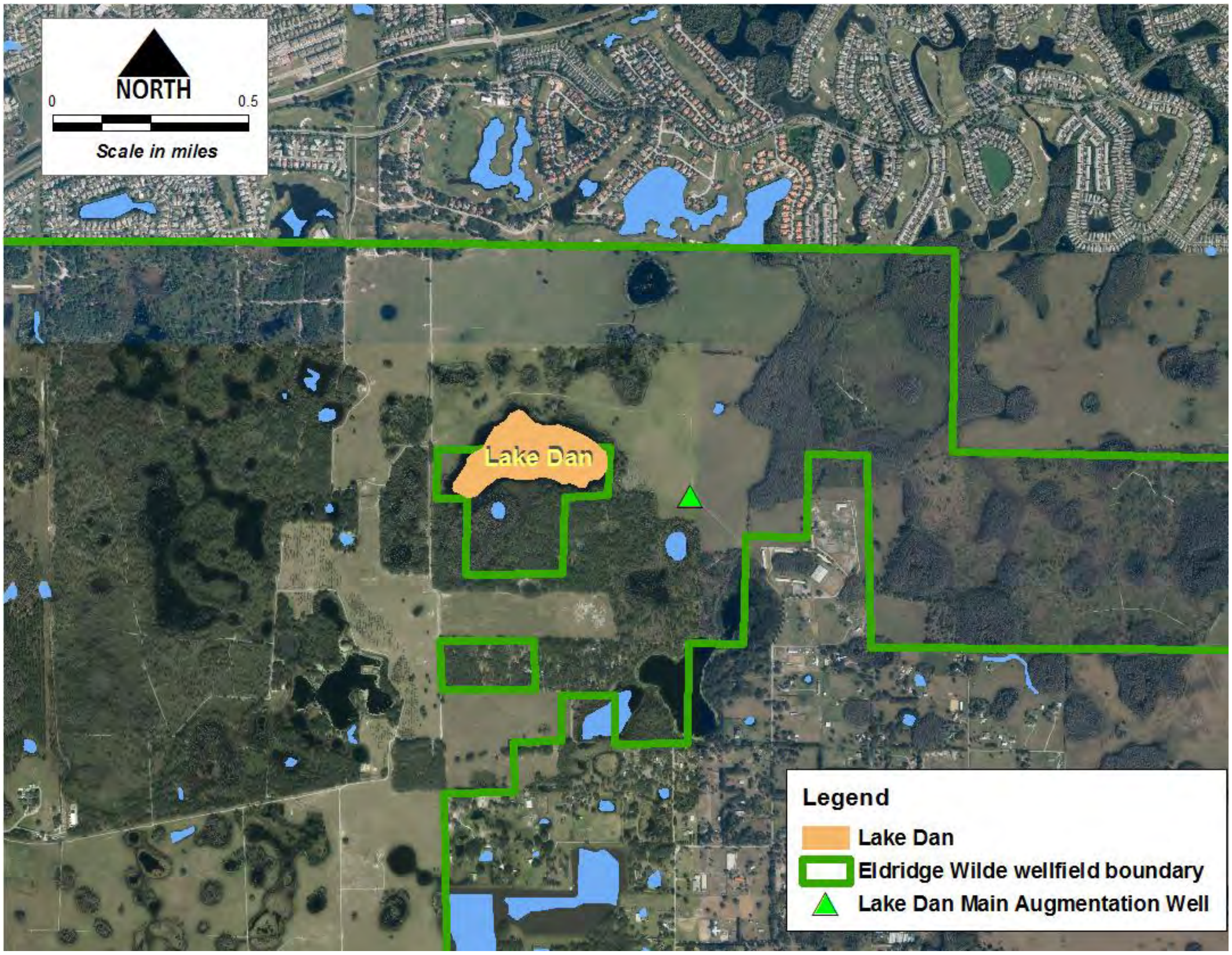

Figure 12. Lake Dan augmentation well location

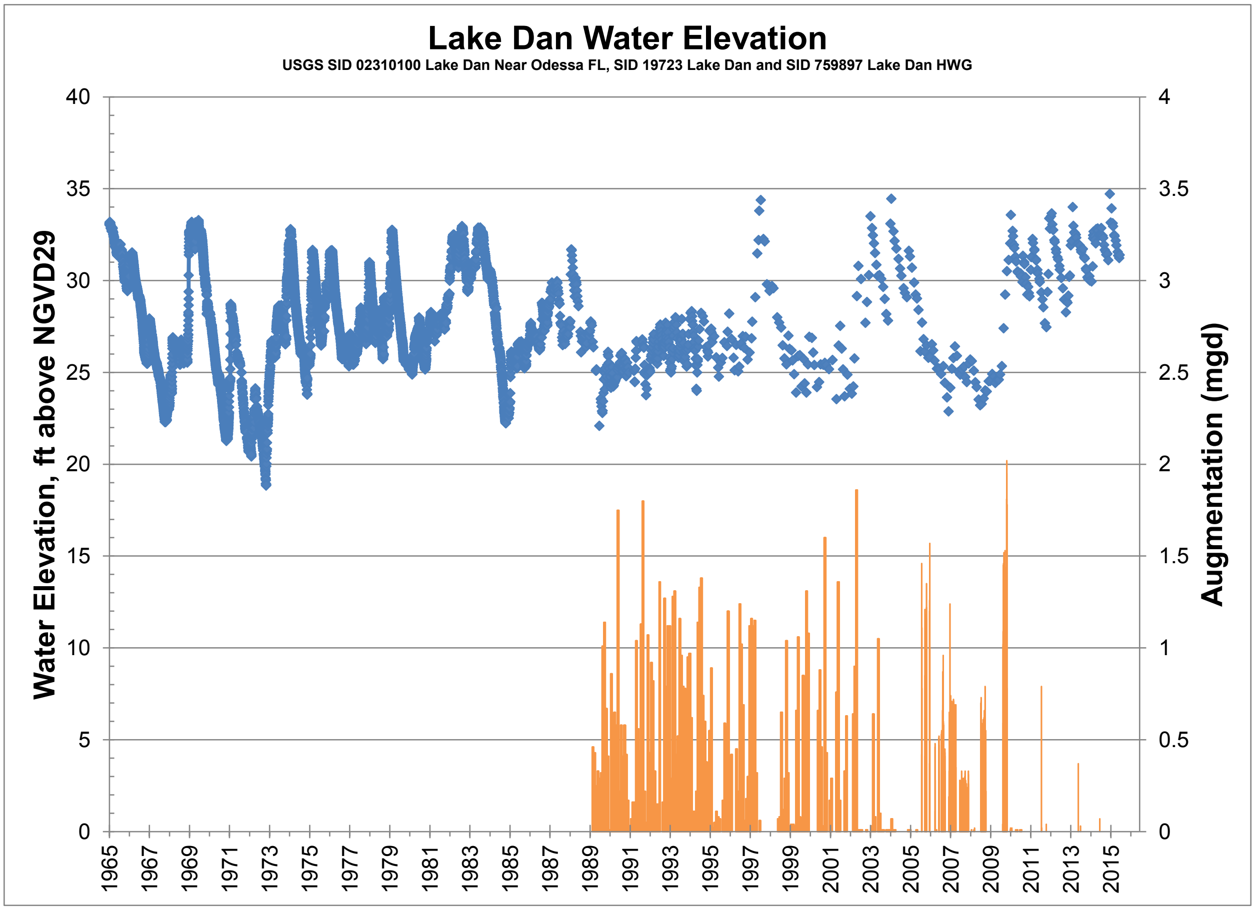

Figure 13. Lake Dan augmentation and measured water level. Note that augmentation occurred prior to 1989; however, the origin of the data is unknown and not shown.

C. Purpose of Models

Prior to establishment of Minimum Levels (ML), Long-term lake stage percentiles are developed. These lake stage percentiles assist with determining the approach to be used for determining MLs, and serve as the starting elevations for the determination of the lake's Minimum Lake Levels and Guidance Levels for Category 2 and 3 lakes. 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 the lake water levels and natural stresses. This relationship can then be used to assess the effect of groundwater withdrawals on lake levels, and to calculate a long-term Historic lake exceedance percentiles such as the P10, P50, and P90 (respectively, the water levels equaled or exceeded ten, fifty, and ninety percent of the time). If data representative of a Historic time period do not exist, or available Historic time period data are considered too short to represent long-term conditions, then models are developed to approximate long-term Historic time period data.

In the case of Lake Dan, because the wellfield has affected water levels in the lake since before the beginning of data collection, no Historic data exist for this lake. The development of a water budget model coupled with a rainfall correlation model of this lake can be used to estimate a long-term time series of Historic data, account for changes in the lake's drainage system, and allow for simulations of the effects of changing groundwater withdrawal rates.

D. Water Budget Model Overview

The Lake Dan water budget model is a spreadsheet-based tool that includes natural hydrologic processes and engineered alterations acting on the control volume of each lake. The control volume consists of the free water surface within the lake extending down to the elevation of the greatest lake depth. A stage-volume curve was derived for each lake that produced a unique lake stage for any total water volume within the control volume.

The hydrologic processes in the water budget model include:

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

The water budget model uses a daily time-step, and tracks inputs, outputs, and lake volume to calculate a daily estimate of lake levels for each lake. The water budget model is calibrated from 2011 to 2015. This period also provides the best balance of using available data for all parts of the water budget and the desire to have a long-term period. The calibration for this water budget model was limited to a period of time where augmentation of the lake was minimal and the augmentation record appeared to be the most refined.

E. Model Components

Lake Stage/Volume

Stage-area-volume relationships were determined 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 involved 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 was then used to calculate area of the lake and the associated volume of the lake at different elevations, starting with 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. 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. A LEI HS-WSPK transducer (operating frequency = 192kHz, cone angle = 20) mounted to a boat hull was used, as well as 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.

Precipitation

Precipitation gages were selected based on distance from Lake Dan, period of available data, completeness of data series, and ability to calibrate the water budget model. The rainfall gages used in the water budget model are shown in Figure 14. The Eldridge-Wilde gage (SID 19725) was used for the period October 1989 to April 2003 with a few missing days infilled with the Eldridge-Wilde ET (SID 22888), Island Ford (SID 19487), Sunset Lake (SID 19501), Tampa Bay Water's RN-ELW-Meter Pit, and Eldridge-Wilde 2N (SID 19526) gages. A mixture of data from Tampa Bay Water's RN-ELW-Meter Pit and Eldridge-Wilde 2N (SID 19526) gages were used from May 2003 to July 2003. Data from the Eldridge-Wilde 2N (SID 19526) gage were used for the period August 2003 to 2015 with missing infilled data from Tampa Bay Water's RN-ELW-Meter Pit gage. The majority of the rainfall data used were from the Eldridge-Wilde gage located about one-tenth of a mile northwest of Lake Dan and the Eldridge-Wilde 2N gage, located about one-quarter of a mile northwest of Lake Dan.

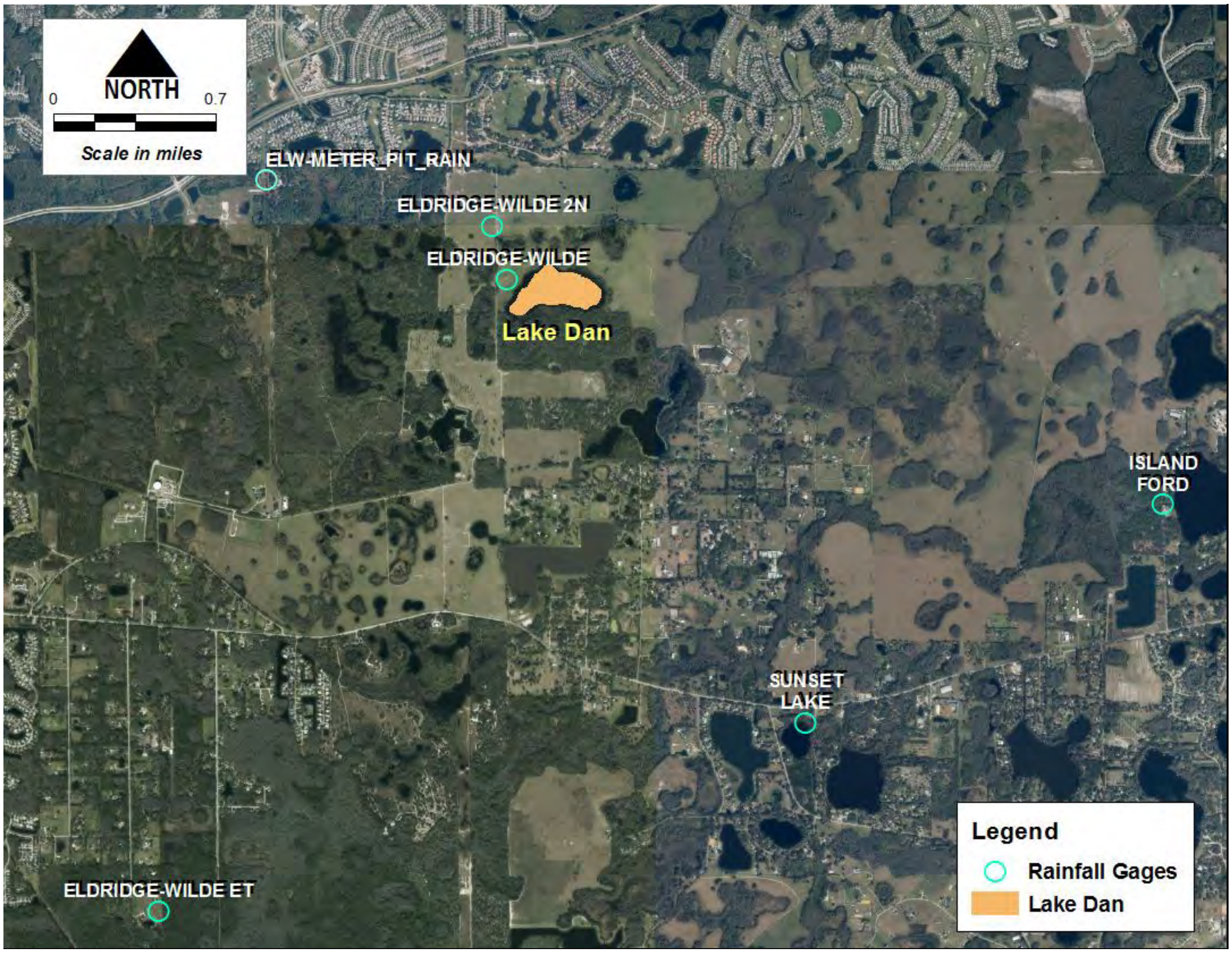

Figure 14. Rain gage used in the water budget model

Lake Evaporation

Lake evaporation was estimated through use of monthly energy budget evaporation data collected by the U.S. Geological Survey (USGS) at Lake Starr in Polk County (Swancar and others, 2000) (Figure 15). The data were 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 water budget model when Lake Starr evaporation data were not available.

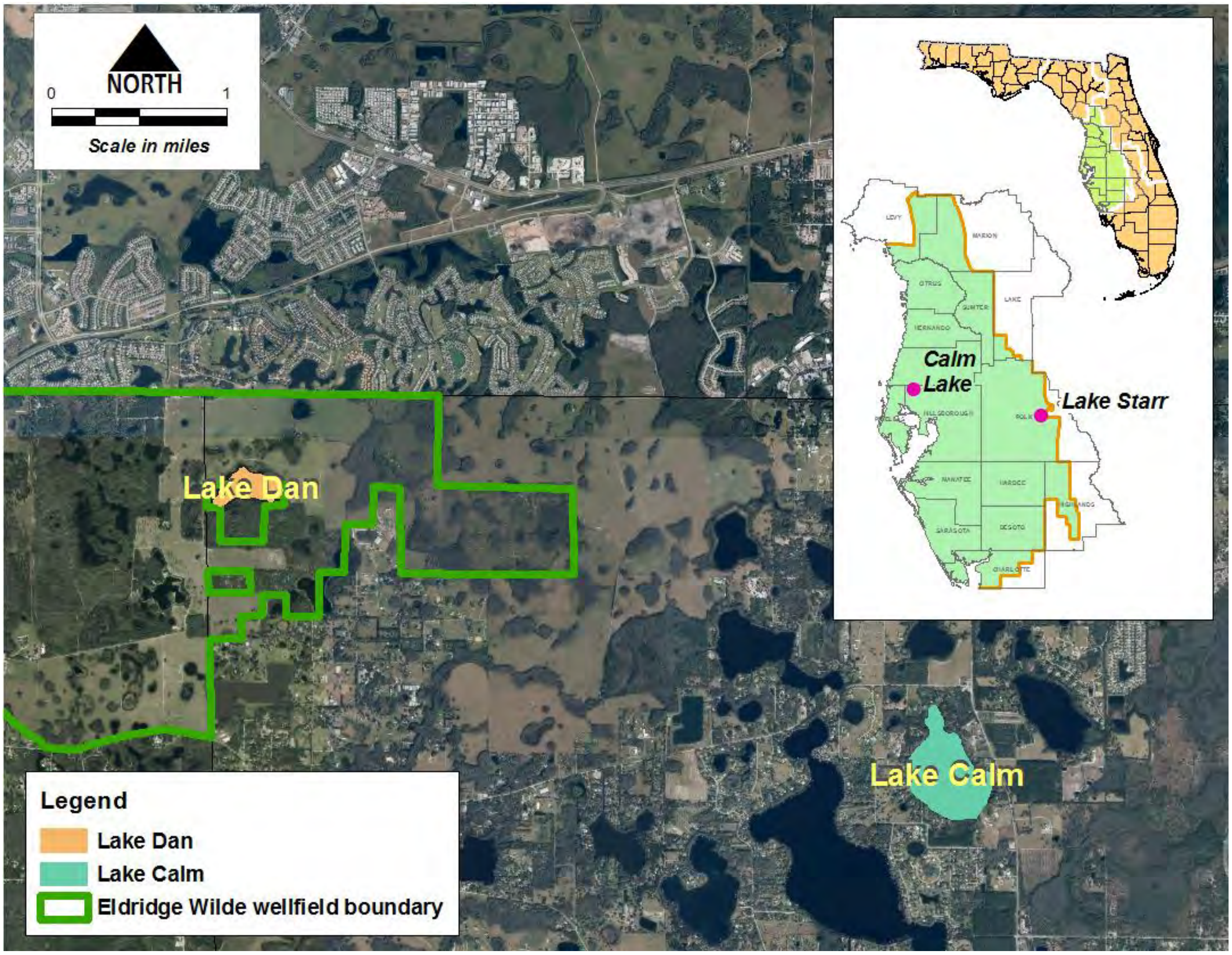

Figure 15. Location of Lakes Starr and Calm

A recent study compared monthly energy budget evaporation data collected from both Lake Starr and Calm Lake (Swancar, 2011, personal communications). Calm Lake is located less than four miles southeast of Lake Dan (Figure 15). The assessment concluded that the evaporation rates between lakes Starr and Calm were essentially the same, with small differences attributed to measurement error and monthly differences in latent heat (due to differences in lake depth).

Jacobs (2007) produced daily potential evapotranspiration (PET) estimates on a 2-square kilometer grid for the entire state of Florida. The estimates began in 1995, and are updated annually. These estimates, available on the USGS website, 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 the Lake Starr data since the GOES data nodes typically include both upland and lake estimates, with no clear way of subdividing the two. It was thought that this would introduce more error than using the Lake Starr data directly.

Augmentation withdrawn from the Upper Floridan aquifer

As described Section B, Lake Dan has been augmented (heavily, at times) since the early 1970s. Augmentation quantities that affected the lake are uncertain. This is due to several reasons including the following:

- The measurement record and source of early records are unclear.
- Early records are monthly instead of daily and had to be evenly distributed over the month to create a daily record for use in the water budget model.
- The augmentation route changed over time.
- The method of measuring augmentation likely changed over time (calculated based on time of operation versus metered data, as well as different meters used over the record).
- Augmentation overflowed into nearby wetlands prior to about 2005 before entering the lake. The augmentation route was rerouted to directly augment the lake around 2004-2005.

For these reasons, augmentation effects on the lake are uncertain, although a lengthy augmentation data record exists.

A water budget model period of October 1989 (start based on available water level measurements) through 2015 was evaluated; however, due to uncertainty in the lake's response to augmentation changes over the early data record, the water budget model calibration period was limited to a timeframe where augmentation was minimal (2011-2015). When applicable, augmentation quantities withdrawn from the Upper Floridan aquifer were added to the lake on a daily basis, based on the available metered values reported to the District by the permittee.

Overland Flow

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

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

The topography in the area of lake is relatively flat, so determining the watershed based on relatively subtle divides can be challenging. The most recent watershed boundary estimate was performed as part of an effort to model the Brooker Creek watershed for flood assessment purposes (URS, 2006). The watershed boundary size delineated by URS was adopted for the water budget model (Table 1 and Figure 16). The watershed is 194.6 acres and the topography is relatively flat. Although there is flow from Lake Dan into a small ditch on the west side of the lake, outflow is not significant and only occurs only during large rainfall events.

The DCIA and SCS CN used is listed in Table 1. Most of the soils directly around the lake have a hydrologic classification of Group A/D. The first letter pertains to the drained and the second to the undrained condition. Group A soils have low runoff potential, whereas Group D soils have high runoff potential. The other major soil groups in the watershed are A and a small area of B/D soils north of the lake. Group B soils have a moderate rate of infiltration. Because water levels have been historically lowered by groundwater withdrawals in the early part of the record, soils in the area may have had lower and different runoff rates than more recent periods that have higher water levels due to significant reductions in groundwater withdrawals. Therefore, the area may have begun to exemplify runoff properties that are more characteristic of "D" soils in recent years. The SCS CN used also incorporates the wetland area south of and adjacent to the lake that has a high runoff potential.

Table 1. Model inputs for the Lake Dan water budget model

Input Variable	Value
Overland Flow Watershed Size (acres)	194.6
SCS CN of watershed	75
Percent Directly Connected Area	0
Floridan Aquifer Monitor Well Used	Eldridge-Wilde N2 FLDN (District SID 19900)
Surficial Aquifer Monitor Well Used	Eldridge-Wilde 1B East Surf (District SID 19710)
Floridan Aquifer Leakance Coefficient (ft/day/ft)	5×10^{-4}
Surf. Aq. Leakance Coefficient (ft/day/ft)	3.8×10^{-3}
Outflow K	4×10^{-2}
Outflow Invert (ft NGVD 29)	32.3
Inflow K	8×10^{-2}
Inflow Invert (ft NGVD 29)	34.0

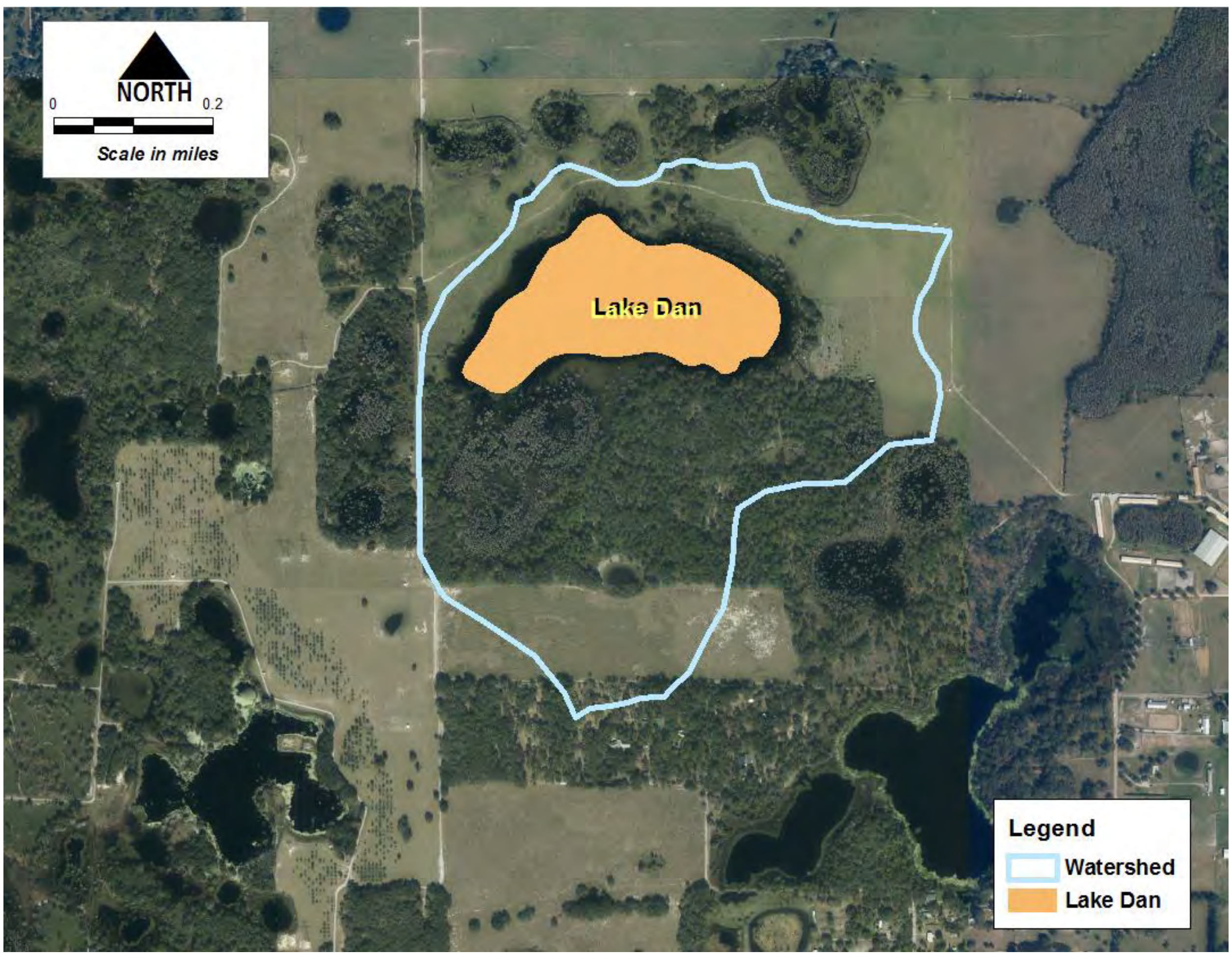

Figure 16. Lake Dan watershed

For purposes of the water budget model, taking into account the range of conditions experienced and the large wetland on the south side of the lake, a value of 75 was used. No direct discharges to the lake were identified, so the DCIA of the watershed is zero.

Inflow and Discharge via Channels from Outside Watersheds

Inflow and discharge via channels from the lake's immediate watershed (i.e., "channel flow") are minor components of the Lake Dan water budget. Since the topography is relatively flat, lake discharge and inflow are likely to only occur during very high rainfall events.

To estimate flow out of the lake, the predicted elevation of the lake from the previous day is compared to the controlling elevation. Control elevations were obtained via professional surveying performed in the area. If the lake elevation is above the controlling elevation, the difference is multiplied by the current area of the lake and an "outflow coefficient." The coefficient represents a measure of channel and structure efficiency, and produces a rough estimate of volume lost from the lake. This volume is then subtracted from the current estimate of volume in the lake.

Discharge occurs on the western end of Lake Dan through a small ditch, a 24-inch reinforced concrete pipe under a maintenance road, and then into a wetland west of the road. The control elevation was measured by a professional survey and determined to be 32.3 feet NGVD29. The control elevation for the lake is the bottom of a ditch between the lake and the road. The high elevation of the culvert is 31.68 feet, but was not used, since the ditch bottom was higher and appeared relatively stable (not significantly eroded).

Inflow to the lake is possible via two separate ditches connected to wetlands north of the lake. There are no water level data for the northeastern inlet; however, the control elevation between the wetland and the lake is relatively high and likely rarely contributes water to the lake. There are water level data available for the north-central inlet, which expected to contribute flow during periods of high rainfall and has a control elevation 1.7 feet lower than that of the northeastern inlet. This inlet was incorporated into the water budget model and provides water to the lake when the water level elevation exceeds the control.

In addition to the two northern inlets, there is a ditch between the augmentation well and the western side of the lake. Augmentation flow used to be directed to this ditch and toward Lake Dan; however, a pipeline was installed between 2004 and 2005 that enabled more direct input into the lake. Adjacent wetlands may, at times, overflow into the ditch; however, no water level information for these wetlands are available.

However, they are relatively small and not expected to contribute significantly to the water budget.

To estimate flow into of the lake, the north-central wetland water level elevation from the previous day is compared to the controlling elevation. The control elevation used in the water budget model was between the lake and the nearest wetland and was obtained via professional surveying performed in the area. If the lake elevation is above the controlling elevation, the difference is multiplied by the current area of the lake and an "inflow coefficient." The coefficient represents a measure of channel efficiency, and produces a rough estimate of volume gained by the lake. This volume is then added to the current estimate of volume in the lake.

Flow from and into the surficial aquifer and Upper Floridan aquifer

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

The Eldridge-Wilde N2 Floridan aquifer monitoring well (District SID 19900) was used to represent the Upper Floridan aquifer. The well period of record begins in March 1973, prior to the beginning of the water budget model. To represent the surficial aquifer, the Eldridge-Wilde 1B East surficial aquifer monitor well (District SID 19710) was used in the water budget model. Water level measurements for this well started in February 1989, prior to the beginning of the water budget model. Data during the water budget model calibration period (2011-2015) were collected daily for the Upper Floridan aquifer well and monthly for the surficial aquifer well; however, a daily series was necessary to complete the water budget model. A simple approach was used to fill in missing data by using the last recorded data value until a new value was recorded.

F. Water Budget Model Calibration

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

Measured data from the lake were used for comparison to the water budget model's predicted water levels. Daily values are generated from the water budget model, but only measured lake data points are used for calibration.

Figure 17 shows the calibration results of the water budget model. Table 2 presents a comparison of the percentiles of the data versus the predicted water budget model results for the calibration scenario. Table 3 presents the modeled water budget for the model calibration scenario.

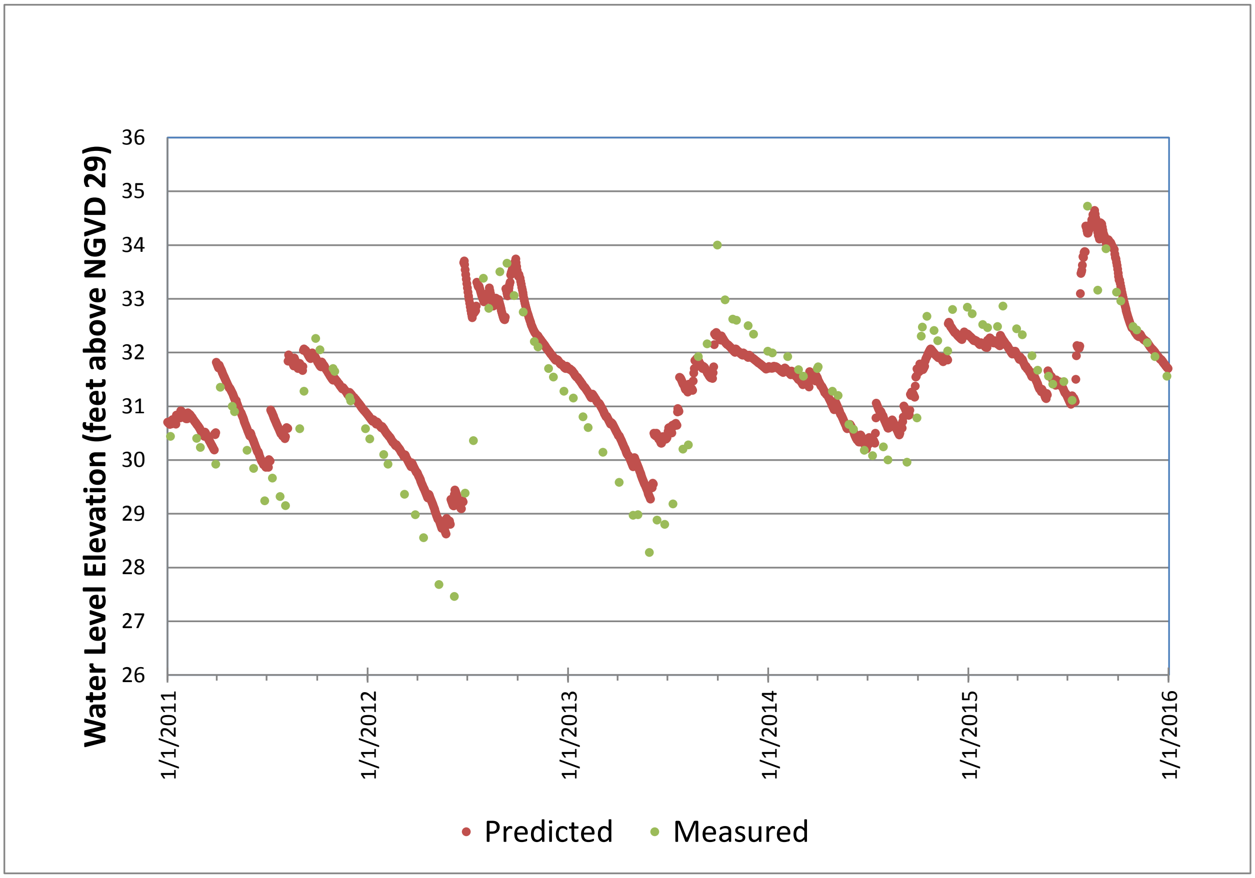

Figure 17. Lake Dan calibration in the water budget model

Table 2. Comparison of long-term percentiles of measured water level data to long-term calibration percentiles from the water budget model calculated on measure days (all in feet above NGVD 29).

	Lake Dan Data	Lake Dan Water Budget Model
P10	32.9	32.9
P50	31.6	31.6
P90	29.2	30.4

Note: Differences could be slightly more or less than those shown due to rounding.

Table 3. Lake Dan Water Budget from the water budget model for the long-term calibration scenario (January 2011-December 2015)

Inflows	Rainfall	SURF GW Inflow	FL GW Inflow	Runoff	DCIA Runoff	Inflow via channel	Augmen-tation	Total
Inches/year	61.2	1.9	0.0	32.3	0.0	17.0	0.2	112.6
Percentage	54.3	1.7	0.0	28.7	0.0	15.1	0.2	100.0
Outflows	**Evap-oration**	**SURF GW Outflow**	**FL GW Outflow**			**Outflow via channel**		**Total**
Inches/year	58.4	8.8	20.0			23.1		110.3
Percentage	52.9	8.0	18.1			21.0		100.0

Note: Figures in table rounded to sum evenly.

G. Water Budget Model Calibration Discussion

Based on a visual inspection of Figure 17, the calibration of the water budget model appears to be reasonable. There are a few periods when the peaks or lows in the modeled hydrograph are a bit low or high, but the overall representation of the data is reasonable.

A review of the figures in Table 2 shows there is no difference between the measured and water budget model predicted median (P50) and P10 percentiles. The difference in the measured and water budget model predicted P90 percentiles is 1.2 feet. The water budget model was calibrated with emphasis on optimal calibration of the P50 and P10 percentiles while attaining reasonable water budget results. Although there was a calibration difference between the measured and modeled P90, the effect of this difference on the P50 is expected to be dampened. Some of the difference between the measured and modeled P90 could be due to inaccuracies in rainfall estimates caused by the distance between rainfall gages and the lake during certain time periods, data collection frequency or issues, errors in stage-area-volume calculations, undocumented structural changes, and other complicating issues.

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

H. Water Budget Model Results

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

The Integrated Northern Tampa Bay (INTB) model (Geurink and Basso, 2013) is an integrated model developed for the northern Tampa Bay area using the Integrated Hydrologic Model (IHM) code (Geurink and others, 2013). The IHM code combines the groundwater model MODFLOW (McDonald and Harbaugh, 1988), and the surface-water model HSPF (Johanson and others, 1984) to create a model code that can be used to represent the complete groundwater/surface-water system. The domain of the INTB application includes the Eldridge-Wilde wellfield area, and represents the most current understanding of the hydrogeologic system in the area.

The INTB was used to determine the drawdown in the surficial aquifer and Upper Floridan aquifer in response to groundwater withdrawals in the area. Drawdown in both aquifers was calculated for two withdrawal rates representing the effects of Tampa Bay Water's regional wellfields before and after cutbacks from approximately 150 mgd to 90 mgd.

Although a water budget model calibrated to the period October 1989 through December 2015 was attempted, calibration was unattainable and attributed to uncertainty in the effects of significant augmentation occurring over that period. Several iterations were explored (15, in all) to arrive at the final water budget model, which is calibrated for the period 2011 through 2015, a time of limited augmentation.

Trials completed in an attempt to obtain a reasonable water budget model calibration and water balance included the following:

- Calibration to the October 1989 to December 2015 period that included estimated augmentation values. The result was relatively high leakage (over 150 inches per year) from the lake to the surficial aquifer. The validity of the resultant leakage was unknown, but atypical.
- Calibration to the October 1989 to December 2015 period using a lower leakage coefficient to the surficial aquifer that resulted in a predicted-measured calibration difference of over 2 feet for the Historic P10.
- Calibration with a larger watershed size to evaluate the effect.

- Calibration to the October 1989 to December 2015 period with the addition of inflow from northern wetlands, which did not significantly improve calibration unless the control point was lowered two feet below the actual elevation.
- Reduction of the calibration window to 2006-2015 to exclude at the period where augmentation quantities were denoted as “estimated values” in the data record. This calibration attempt presented improved results; however the predicted-measured calibration difference was over 2 feet for the Historic P90.
- Calibration that limited the predicted-measured comparison to only days when there was no augmentation that resulted in a Historic P10 difference of nearly 1.5 feet.
- Experimentation with replacing the standard water budget model evaporation data with evaporation data collected near the lake by Tampa Bay Water. The change in evaporation input had little effect on the water budget model.
- Reduction of the calibration window to the year 2005, a year of low rainfall and low augmentation quantities, to assess resulting calibration parameters during a period where the effects of these inputs were minimized. This iteration showed the water budget model could be well-calibrated with both a higher and more normal leakage to the surficial aquifer. It was not evident from this trial that one leakage coefficient was more appropriate than the other.
- Reduction in the calibration period to 2009 to 2015, a timeframe that matched the period for which augmentation was operated by Tampa Bay Water. An acceptable calibration could not be achieved, most likely due to the effects of significant augmentation over this time frame.
- Reduction of the calibration period to 2011 to 2015, a period with relatively little augmentation. Using best professional judgement, this iteration was determined to best represent the lake based on water budget model calibration trials; had relatively small differences between the measured and predicted P10 and P50 percentiles; and had a reasonable water budget.

While the water budget model calibration period (2011-2015) was reduced due to the effects of augmentation, the water budget model period used to determine historic percentiles was expanded to a longer period that had available data (October 1989 to December 2015). The pre-cutback period in the water budget model is from October 1989 to December 2002, while the post-cutback period is January 2003 to December 2015. This allowed drawdowns associated with permitted withdrawals to be calculated before and after wellfield cutbacks (assuming all other withdrawals are consistent within the water budget model period).

The INTB model was run from 1996 to 2006 using a daily integration step. Drawdown amounts were calculated by running the model with and without groundwater withdrawals, and were calculated for each node in the model. The INTB model uses a one-quarter mile grid spacing in the area of the wellfields. Groundwater withdrawal rates from the Eldridge-Wilde wellfield in each scenario were 23.6 mgd and 13.8 mgd, respectively.

Results from the scenarios showed that there is about 0.5 feet of drawdown in the Upper Floridan for every one mgd of groundwater withdrawn from Eldridge-Wilde wellfield. Because of the leaky nature of the confining unit in the area, the relationship between groundwater withdrawals in the Upper Floridan and water levels in the surficial was also of interest. The same scenarios described above showed that one mgd of groundwater withdrawals result in approximately 0.3 to 0.4 feet of drawdown in the water table. Using the drawdowns determined through the INTB model, the Upper Floridan aquifer and surficial monitor well data in the water budget model can be adjusted to complete scenarios with different rates of groundwater withdrawals.

To estimate lake levels without the influence of groundwater withdrawals, the Upper Floridan aquifer and surficial aquifer wells in the water budget model were adjusted to represent zero withdrawals. For the October 1989 to December 2015 water budget model period, two adjustment periods were used to reflect the cutbacks that took place at the Eldridge-Wilde wellfield. The adjustments to each Upper Floridan aquifer and surficial aquifer well are found in Table 4. Table 4. Aquifer water level adjustments applied to the water budget model to predict daily values used to calculate representative Historic percentiles

Well	Adjustment (feet) October 1989 to December 2002	Adjustment (feet) January 2003 to December 2015
Floridan aquifer	13.3	7.1
Surficial aquifer	8.8	4.0

The lake was augmented with groundwater during the water budget model period. Reported augmentation quantities were removed from the water budget model for calculation of Historic percentiles.

Figure 18 presents actual lake water levels along with the water budget model's forecast for water levels in the lake under Historic condition (no augmentation and no groundwater withdrawals). Table 5 presents the Historic percentiles as estimated by the water budget model.

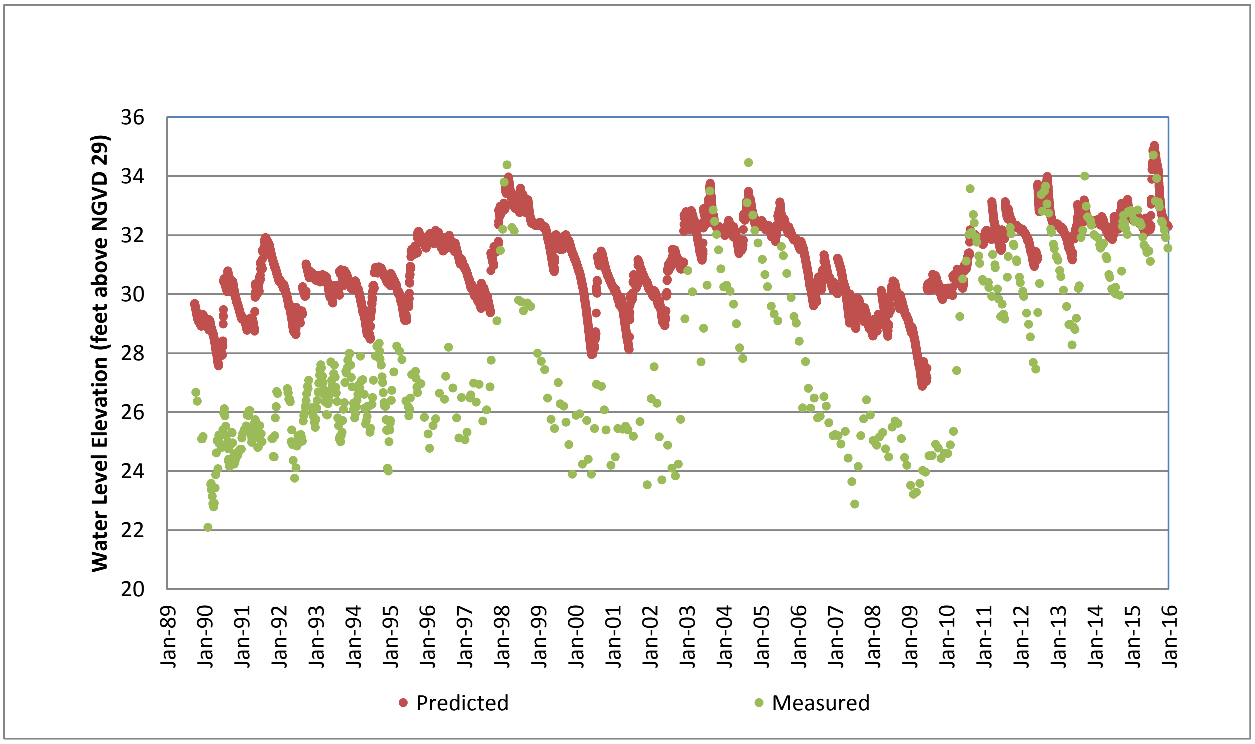

Figure 18. Water Budget Model Historic condition scenario for Lake Dan

Table 5. Historic percentiles based on daily predictions as estimated by the water budget model (all in feet NGVD29).

Percentile	Lake Dan
P10	32.7
P50	31.0
P90	29.1

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

Historic normal pools were determined on inflection points of remaining cypress trees. The historic normal pool for Lake Dan is 32.7 feet above NGVD 29.

While the Historic normal pool and natural P10 in lakes and wetlands in the northern Tampa Bay area may differ by several tenths of a foot in many cases, the water budget model's estimated P10 is the same as the Historic normal pool elevation.

I. Rainfall Correlation Model

In an effort to extend the period of record of the water levels used to determine the Historic percentiles to be used in the development of the lake's Minimum Levels, a line of organic correlation (LOC) was performed using the results of the water budget model and long-term rainfall (Ellison, 2012). The LOC is a linear fitting procedure that minimizes errors in both the x and y directions and defines the best-fit straight line as the line that minimizes the sum of the areas of right triangles formed by horizontal and vertical lines extending from observations to the fitted line (Helsel and Hirsch, 1997). LOC is preferable for this application since it produces a result that best retains the variance (and therefore best retains the "character") of the original data.

In this application, the simulated lake water levels representing Historic conditions were correlated with Long-term rainfall. For the correlation, additional representative rainfall records were added to the rainfall records used in the water budget model (October 1989 to December 2015). The rainfall data set used in the rainfall correlation model was assembled using data from the closest gage with available data. Missing daily data were infilled using data from the next closest gage. Data from the Tarpon Springs Sewage Plant NWS gage (SID 22881) were used for the period 1935 to 1944, and a few missing daily data points were filled in with data from the Saint Leo NWS gage (SID 18901). Data from Tampa Bay Water's "Cosme" rain gage (RNF-197), which were eventually replaced by the Cosme 18 rain gage due to quality control issues, were used for the period 1945 through 1971. The quality control issues occurred after 1995, and there is no evidence that there were quality control issues at the Cosme gage prior to that time. Rainfall data from the Island Ford Lake gage (SID 19631) were used for the period 1972 to March 1973. Data from the Eldridge-Wilde gage (SID 19725) were used for the period April 1973 to April 2003 with a few missing days infilled with data from the Eldridge-Wilde ET (SID 22888), Island Ford (SID 19487), Sunset Lake (SID 19501), Tampa Bay Water's RN-ELW-Meter Pit, and Eldridge-Wilde 2N (SID 19526) gages. Data for all National Weather Service gages were downloaded directly from the NOAA National Climatic Data Center website (2016). The rainfall gage locations are shown in Figure 19.

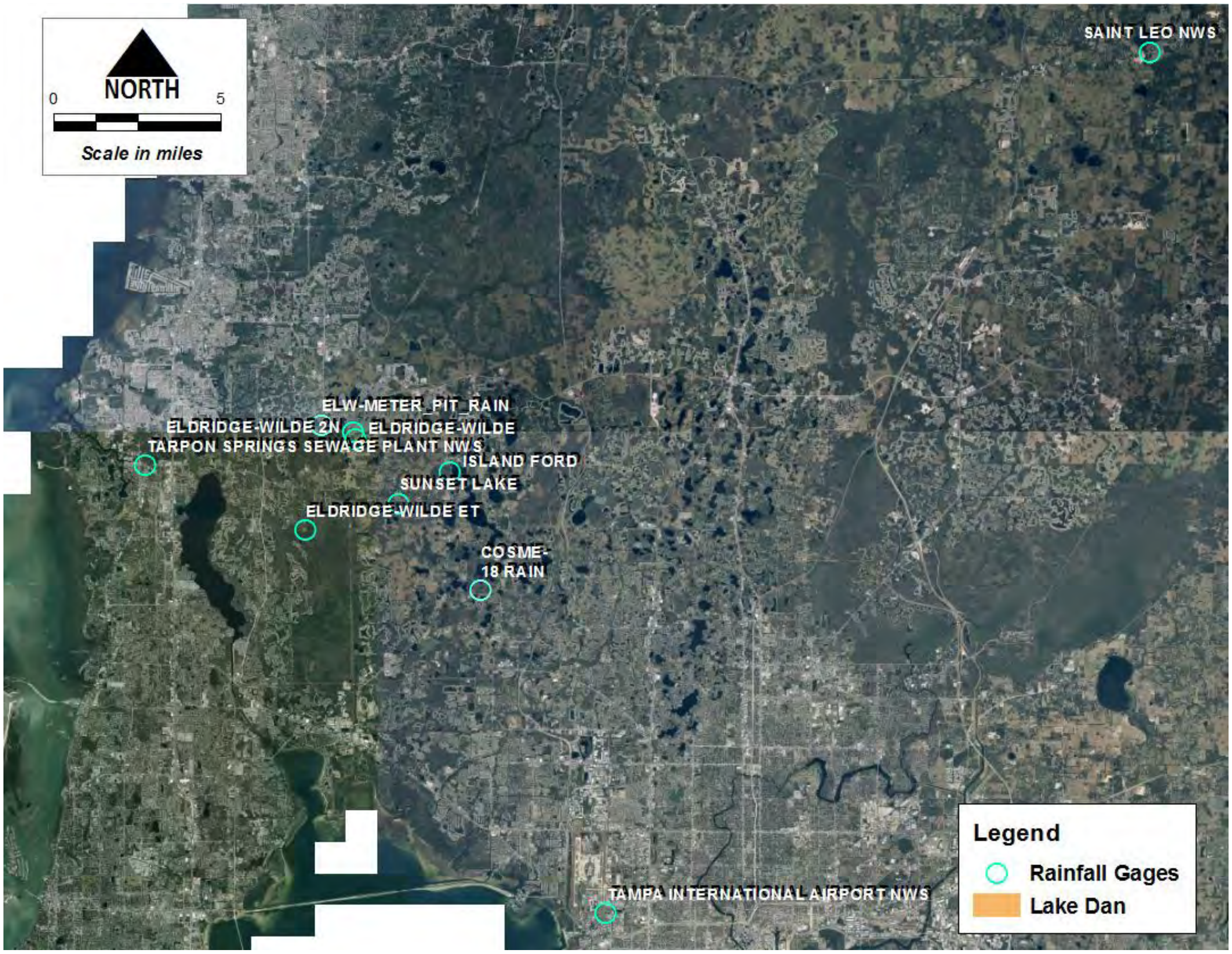

Figure 19. Rain gages used in the rainfall correlation model

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 water budget model period (October 1989 to December 2015), and rainfall correlation model predicted results from 1946-2015 (70 years) were produced. The 3-year weighted rainfall correlation model had the highest correlation coefficient, with an R^2 of 0.70. Previous correlations for lakes in the northern Tampa Bay area have consistently had best correlation coefficients in the 2- to 5-year range, so this rainfall correlation model was considered reasonable. The results are presented in Figure 20.

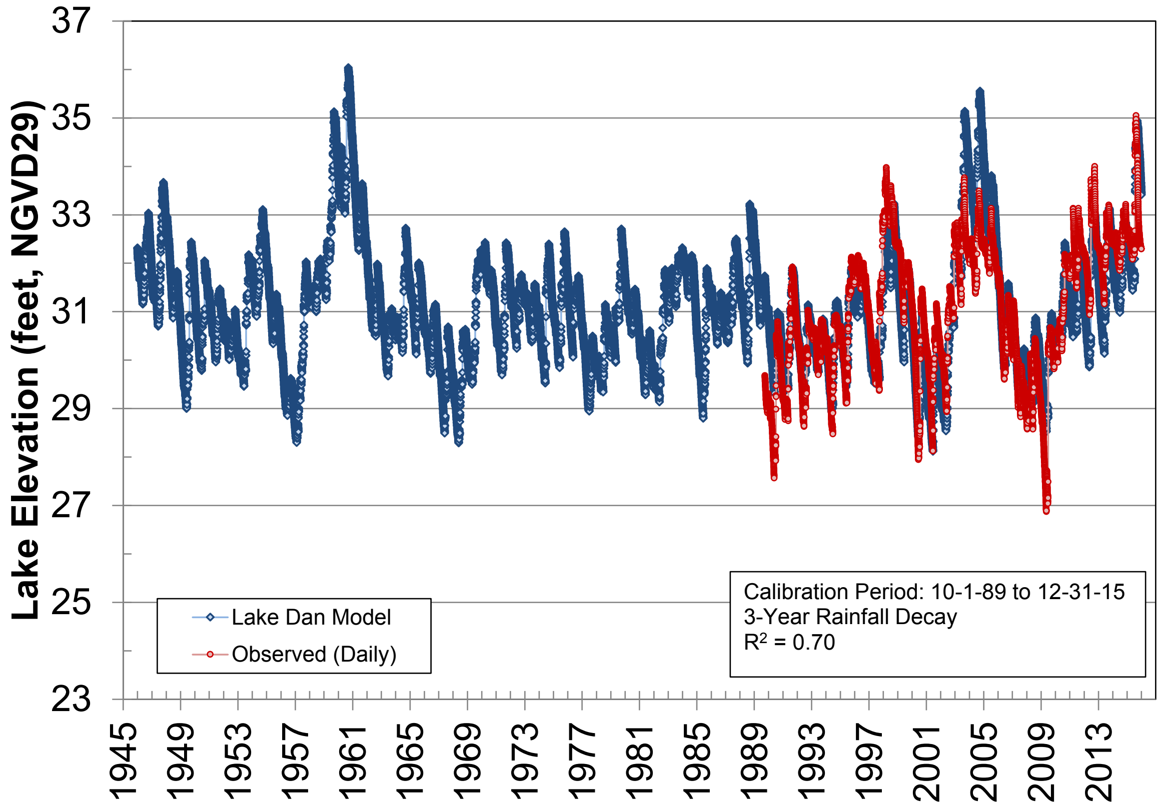

Figure 20. Rainfall correlation model results for Lake Dan

In an attempt to produce Historic percentiles that apply significant weight to the results of the water budget model, the rainfall LOC results for the period of the water budget model are replaced with the water budget model results. Therefore, the rainfall correlation model results are used for the period of 1946 to September 1989, while the water budget results are used for the period of October 1989 to December 2015. These results are referred to as the "hybrid model." The resulting Historic percentiles for the hybrid model are presented in Table 6. Note that the difference between the P10, P50, and P90 percentiles from the water budget model (Table 5) and those from the hybrid model (Table 6) for are 0.2, 0.0, and 0.4 feet, respectively. Therefore, the change to the Historic percentiles between the two models is small.

Table 6. Historic percentiles as estimated by the hybrid model from 1946 to 2015 (all in feet above NGVD 29).

Percentile	Lake Dan
P10	32.5
P50	31.0
P90	29.5

J. Conclusions

Based on the model results and the available data, the water budget and LOC rainfall models are useful tools for assessing long-term percentiles in Lake Dan. Based on the same information, the percentiles produced via this process appear to be reasonable estimates for Historic conditions.

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APPENDIX B

Technical Memorandum

August 29, 2016

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

FROM: Tamera McBride, P.G., Senior Hydrogeologist, Water Resources Bureau

David Carr, Staff Environmental Scientist, Water Resources Bureau

Jaime Swindasz, Staff Environmental Scientist, Water Resources Bureau

Subject: Lake Dan Initial Minimum Levels Status Assessment

A. Introduction

The Southwest Florida Water Management District (District) is reevaluating adopted minimum levels for Lake Dan 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 McBride (2016) and Carr and others (2016).

Section 373.0421, F.S. requires that a recovery or prevention strategy be developed for all water bodies that are found to be below their minimum flows or levels, or are projected to fall below the minimum flows or levels within 20 years. In the case of Lake Dan and other waterbodies with established minimum flows or levels in the northern Tampa Bay area, an applicable regional recovery strategy, referred to as the "Comprehensive Plan", has been developed and adopted into District rules (Rule 40D-80.073, F.A.C.). One of the goals of the Comprehensive Plan is to achieve recovery of minimum flow and level water bodies such as Lake Dan that are located in the area affected by the Consolidated Permit wellfields (i.e., the Central System Facilities) operated by Tampa Bay Water. This document provides information and analyses to be considered for evaluating the status (i.e., compliance) of the revised minimum levels proposed for Lake Dan and any recovery that may be necessary for the lake.

B. Background

Lake Dan is located in northwest Hillsborough County, in the center of the Eldridge-Wilde Wellfield, which is one of eleven regional water supply wellfields operated by Tampa Bay Water (Figures 1 and 2). Groundwater withdrawals at the Eldridge-Wilde wellfield began in 1956 and recorded withdrawal quantities starting in 1957 are presented in Figure 3. The first 19 production wells were constructed during the period of 1954 to 1968 (Leggett, et al., 2006). Monthly withdrawals steadily increased until they peaked at over 44 million gallons per day (mgd) in 1973. Production decreased in the early 1980s as other wellfields began production and peaked again in the late 1980s. Wellfield withdrawals steadily declined until 2002, and production leveled off to an average of about 13 mgd, with some months of little or zero withdrawals in 2013. Reductions were the result of Tampa Bay Water bringing new water sources online.

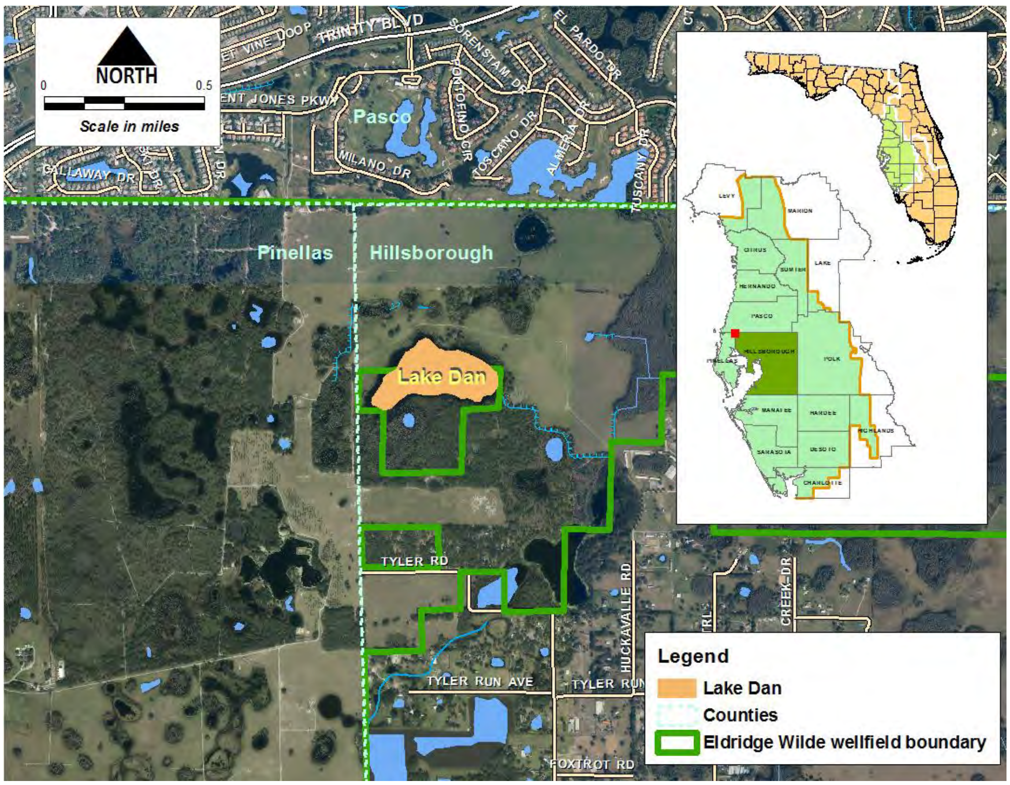

Figure 1. Location of Lake Dan in Hillsborough County, Florida

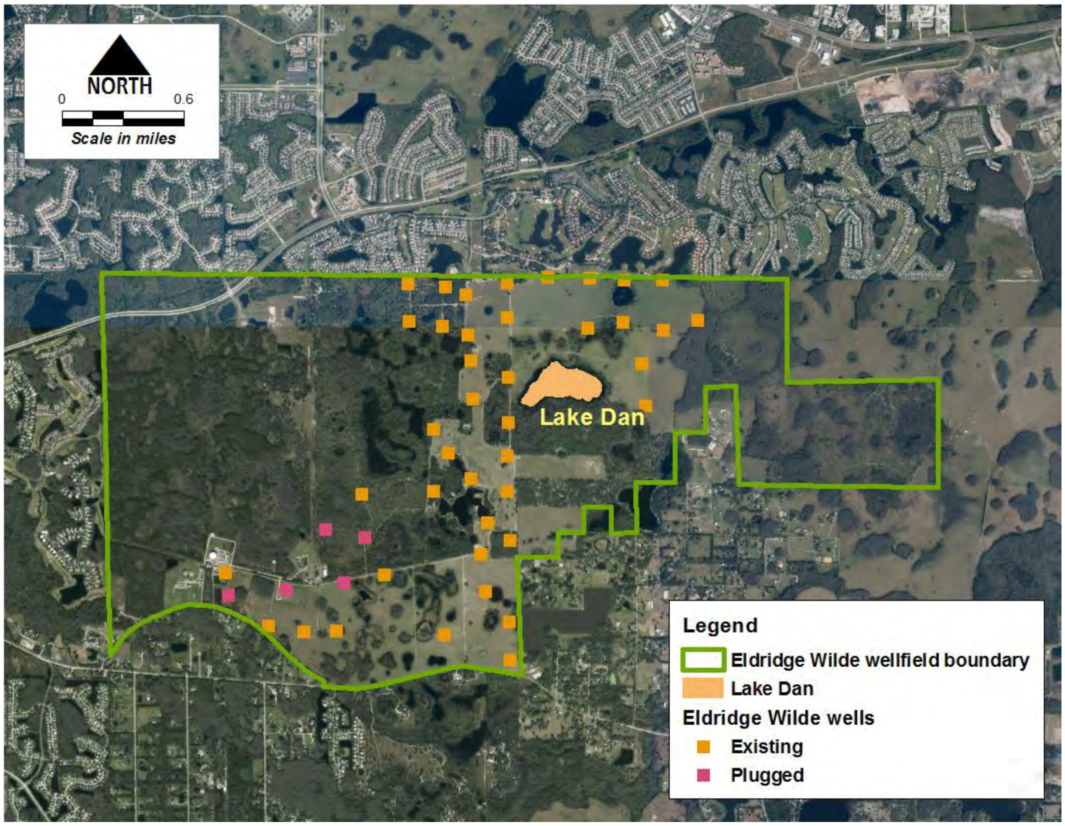

Figure 2. Eldridge-Wilde wellfield configuration

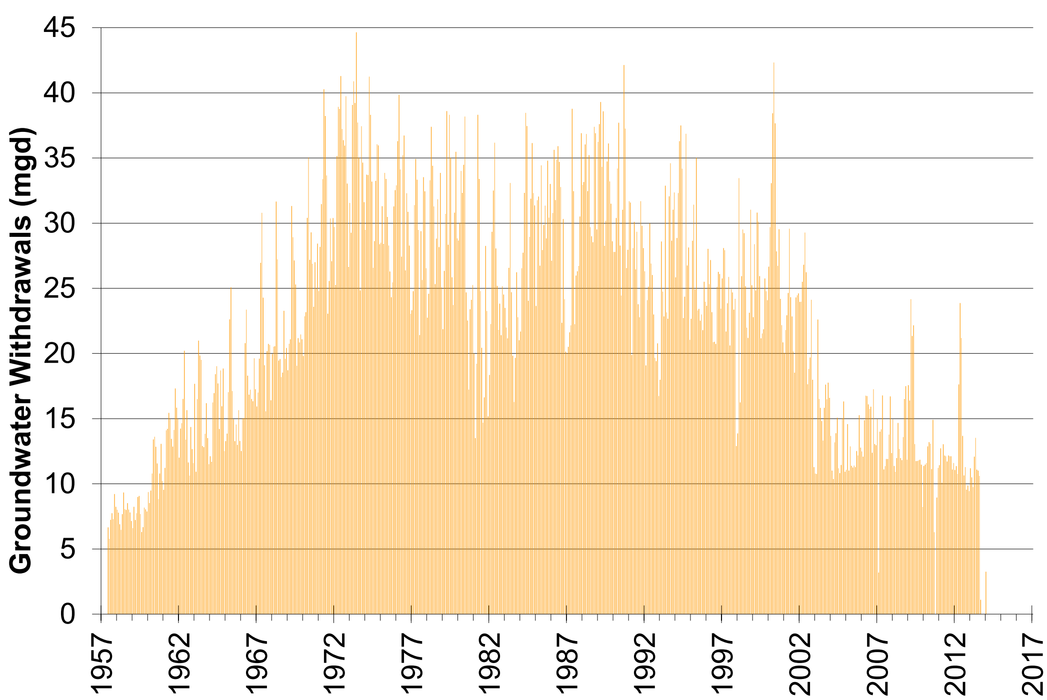

Figure 3. Eldridge-Wilde wellfield withdrawals

According to historical files from Tampa Bay Water (Doug Keesecker, personal communications, 2016), Lake Dan's water levels have been augmented with water withdrawn from the Upper Floridan aquifer since 1972. Augmentation data back to 1972 are available, but not much is known about how the early data were collected or the source. Lake Dan was previously augmented under WUP No. 2673 Eldridge-Wilde and is now augmented under WUP No. 11771 Tampa Bay Water Consolidated Permit. Augmentation records from the District and Tampa Bay Water start in August 1989 and show lake augmentation was greatest in the early part of this record (Figure 4). Augmentation from 2011 to 2015 is relatively minimal.

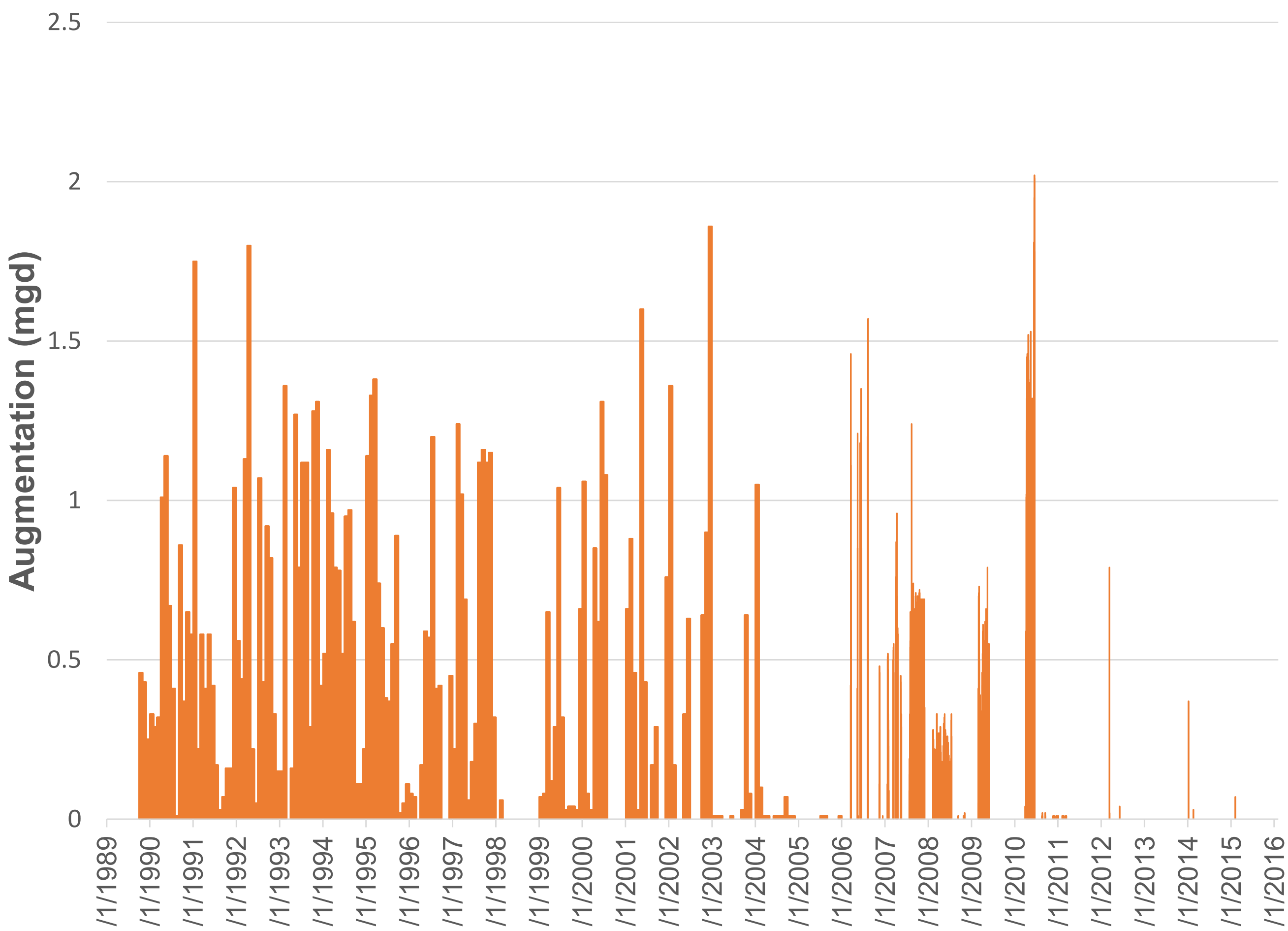

Figure 4. Reported augmentation withdrawals at Lake Dan

C. Revised Minimum Levels Proposed for Lake Dan

Revised minimum levels proposed for Lake Dan are presented in Table 1 and discussed in more detail by Carr and others (2016). Minimum levels represent long-term conditions that, if achieved, are expected to protect water resources and the ecology of the area from significant harm that may result from water withdrawals. The

Minimum Lake Level is the elevation that a lake's water levels are required to equal or exceed fifty percent of the time on a long-term basis. The High Minimum Lake Level is the elevation that a lake's water levels are required to equal or exceed ten percent of the time on a long-term basis. The Minimum Lake Level therefore represents the required 50th percentile (P50) of long-term water levels, while the High Minimum Lake Level represents the required 10th percentile (P10) of long-term water levels. To determine the status of minimum levels for Lake Dan 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 Dan.

Proposed Minimum Levels	**Elevation in Feet** NGVD 29
High Minimum Lake Level	32.3
Minimum Lake Level	30.9

D. Status Assessment

The lake status assessment approach involves using actual lake stage data for Lake Dan from 2003 through 2015, which was determined to represent the “Current” period. The Current period represents a recent “Long-term” period when hydrologic stresses (including groundwater withdrawals) and structural alterations are reasonably stable. “Long-term” is defined as a period that has been subjected to the full range of rainfall variability that can be expected in the future. As demonstrated in McBride (2016), groundwater withdrawals during this period were relatively consistent. To create a data set that can reasonably be considered to be “Long-term”, a line of organic correlation (LOC) analysis was performed on the lake level data from the Current period. The LOC is a linear fitting procedure that minimizes errors in both the x and y directions and defines the best-fit straight line as the line that minimizes the sum of the areas of right triangles formed by horizontal and vertical lines extending from observations to the fitted line (Helsel and Hirsch, 2002). The LOC is preferable for this application since it produces a result that best retains the variance (and therefore best retains the "character") of the original data. This technique was used to develop the minimum levels for Lake Dan (McBride, 2016). By using this technique, the limited years of Current lake level data can be projected back to create a simulated data set representing over 60 years of lake levels, based on the current relationship between lake water levels and actual rainfall.

The same rainfall data set used for setting the minimum levels for Lake Dan was used for the status assessment (McBride, 2016). The best resulting correlation for the LOC model created with measured data was the 3-year weighted period, with a coefficient of determination of 0.58. A hybrid model was created for the purposes of calculating lake stage exceedance percentiles by replacing LOC predicted values with measured data during the Current period, when available. The resulting lake stage exceedance percentiles are presented in Table 2.

As an additional piece of information, Table 2 also presents the same percentiles calculated directly from the measured lake level data for Lake Dan for the period from 2003 through 2015. A limitation of these values is that the resulting lake stage exceedance percentiles are representative of rainfall conditions during only the past 13 years, rather than the longer-term rainfall conditions represented in the 1946 to 2015 LOC model simulations.

Table 2. Comparison of lake stage exceedance percentiles derived from the lake stage/LOC results, exceedance percentiles of the 2003 to 2015 data, and the revised minimum levels proposed for Lake Dan.

Percentile	**Lake Stage/LOC Model Current Withdrawal Scenario Results** Elevation in feet NGVD 29	**2003 to 2015 Data** Elevation in feet NGVD 29	**Proposed Minimum Levels** Elevation in feet NGVD 29
P10	31.5	32.7	32.3
P50	28.1	30.5	30.9

A comparison of the LOC model with the revised minimum levels proposed for Lake Dan indicates that the Long-term P10 is 0.8 feet lower than the proposed High Minimum Lake Level, and the Long-term P50 is 2.8 feet lower than the proposed Minimum Lake Level. The P10 elevation derived directly from the 2003 to 2015 lake data is 0.4 feet higher than the proposed High Minimum Lake Level, and the P50 elevation is 0.4 feet lower than the proposed Minimum Lake Level. Differences in rainfall between the shorter 2003 to 2015 period and the longer 1946 to 2015 period used for the LOC modeling analyses likely contribute to the differences between derived and measured lake stage exceedance percentiles.

E. Conclusions

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

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Appendix C
Draft Technical Memorandum

August 29, 2016

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

FROM: Jason Patterson, Hydrogeologist, Resource Evaluation Section

Subject: Evaluation of Groundwater Withdrawal Impacts to Lake Dan

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1.0 Introduction

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

2.0 Hydrogeologic Setting

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

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

3.0 Evaluation of Groundwater Withdrawal Impacts to Lake Dan

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

Pasco County and the surrounding area is the Integrated Northern Tampa Bay (INTB) model (Geurink and Basso, 2013). The construction and calibration of this model was part of a cooperative effort between the SWFWMD and Tampa Bay Water (TBW), a regional water utility that operates 11 major

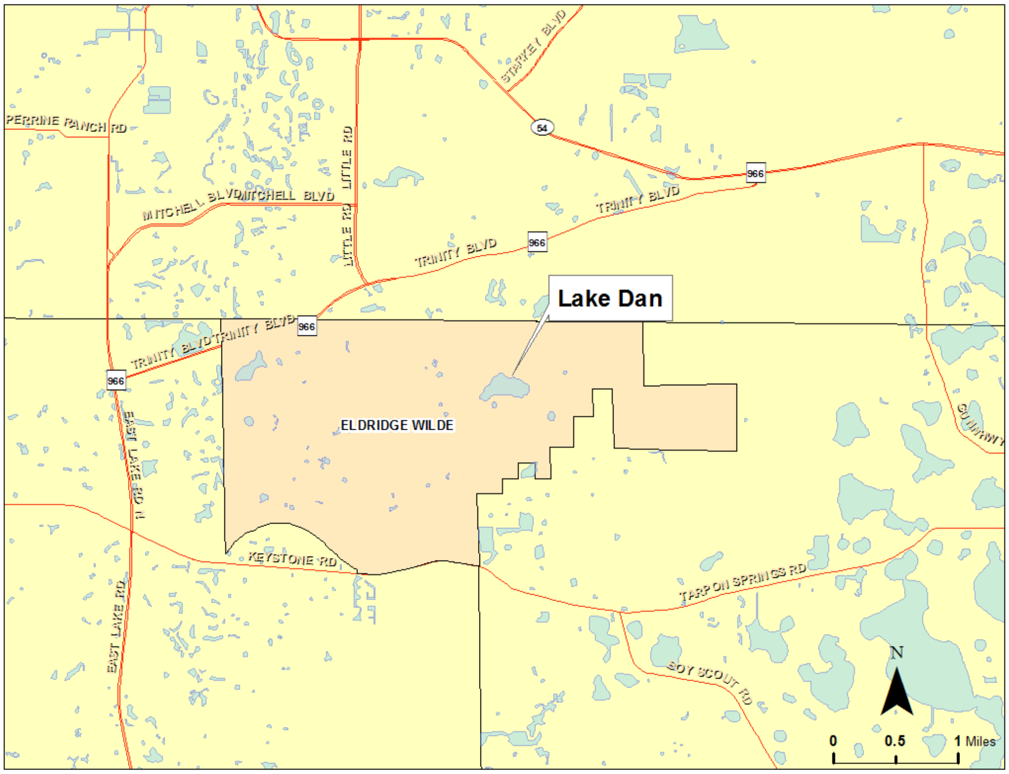

Figure 1. Location of Lake Dan.

wellfields. The Integrated Northern Tampa Bay Model covers a 4,000 square-mile area of the Northern Tampa Bay region (Figure 2).

An integrated model represents the most advanced simulation tool available to the scientific community in water resources investigations. It combines the traditional ground-water flow model with a surface water model and contains an interprocessor code that links both systems. One of the many advantages of an integrated model is that it simulates the entire hydrologic system. It represents the "state-of-art" tool in assessing changes due to rainfall, drainage alterations, and withdrawals.

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

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

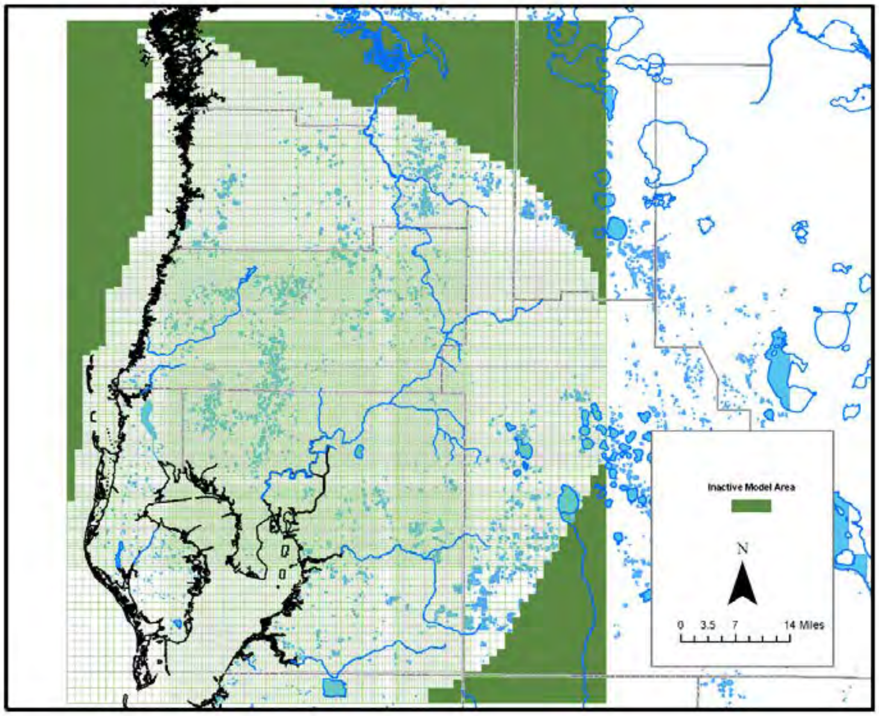

Figure 2. Groundwater grid used in the INTB model

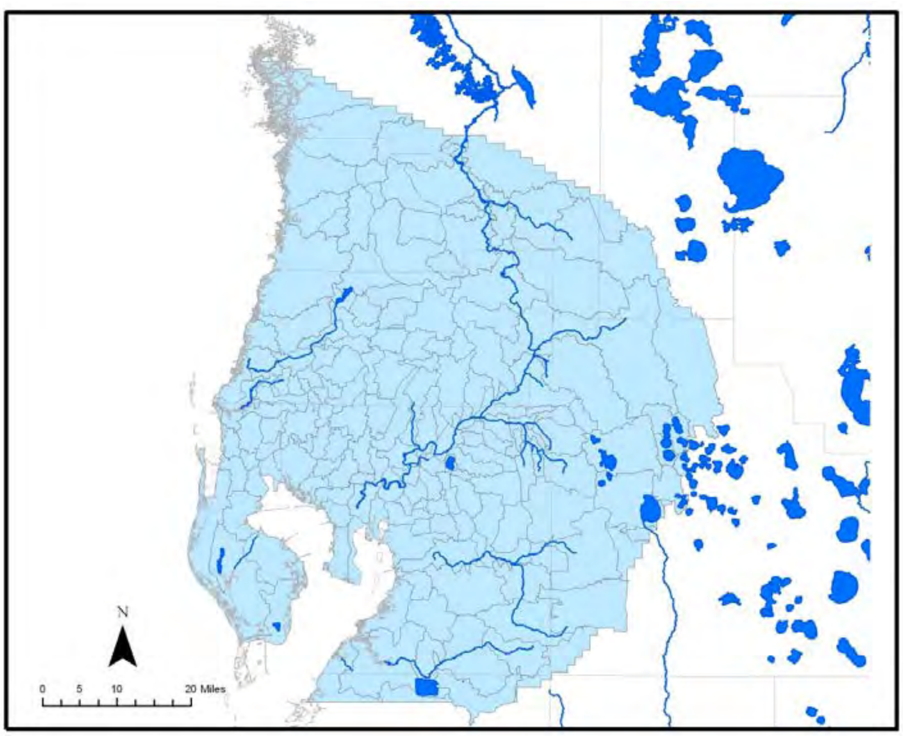

Figure 3. HSPF subbasins in the INTB model.

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

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

The INTB model is a regional simulation and has been calibrated to meet global metrics. The model is calibrated using a daily integration step for a transient 10-year period from 1989-1998. A model Verification period from 1999 through 2006 was also added. Model-wide mean error for all wells in both the surficial and Upper Floridan aquifers is less than 0.2 feet during both the calibration and verification periods. Mean absolute error was less than two feet for both the surficial and Upper Floridan aquifer. Total stream flow and spring flow mean error averaged for the model domain is each less than 10 percent. More information summarizing the INTB model calibration can be found in Geurink and Basso (2013).

3.1 INTB Model Scenarios

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

Taking the difference in simulated heads from the 1989-2000 pumping to non-pumping runs, the average predicted drawdown in the surficial aquifer near Lake Dan was 10.0 ft, and 13.6 ft in the Upper Floridan aquifer (Figure 5 and 6). Taking the difference in modeled heads from the TBW recovery pumping to non-pumping runs, the average predicted drawdown in the surficial aquifer near Lake Dan was 5.6 ft and 7.2 ft in the Upper Floridan aquifer (Figure 7 and 8). Table 1 presents the predicted drawdown in the surficial and the Upper Floridan aquifer based on the INTB model results.

Table 1. INTB model results for Lake Dan.

Lake Name	**Predicted Drawdown (ft) in the Surficial Aquifer due to 1989-2000 Withdrawals***	**Predicted Drawdown (ft) in the Surficial Aquifer with TBW Withdrawals reduced to 90 mgd***
Dan	10.0	5.6
Lake Name	**Predicted Drawdown (ft) in the Upper Floridan Aquifer due to 1989-2000 Withdrawals***	**Predicted Drawdown (ft) in the Upper Floridan Aquifer with TBW Withdrawals reduced to 90 mgd***
Dan	13.6	7.2

* Average drawdown from model cells intersecting lake

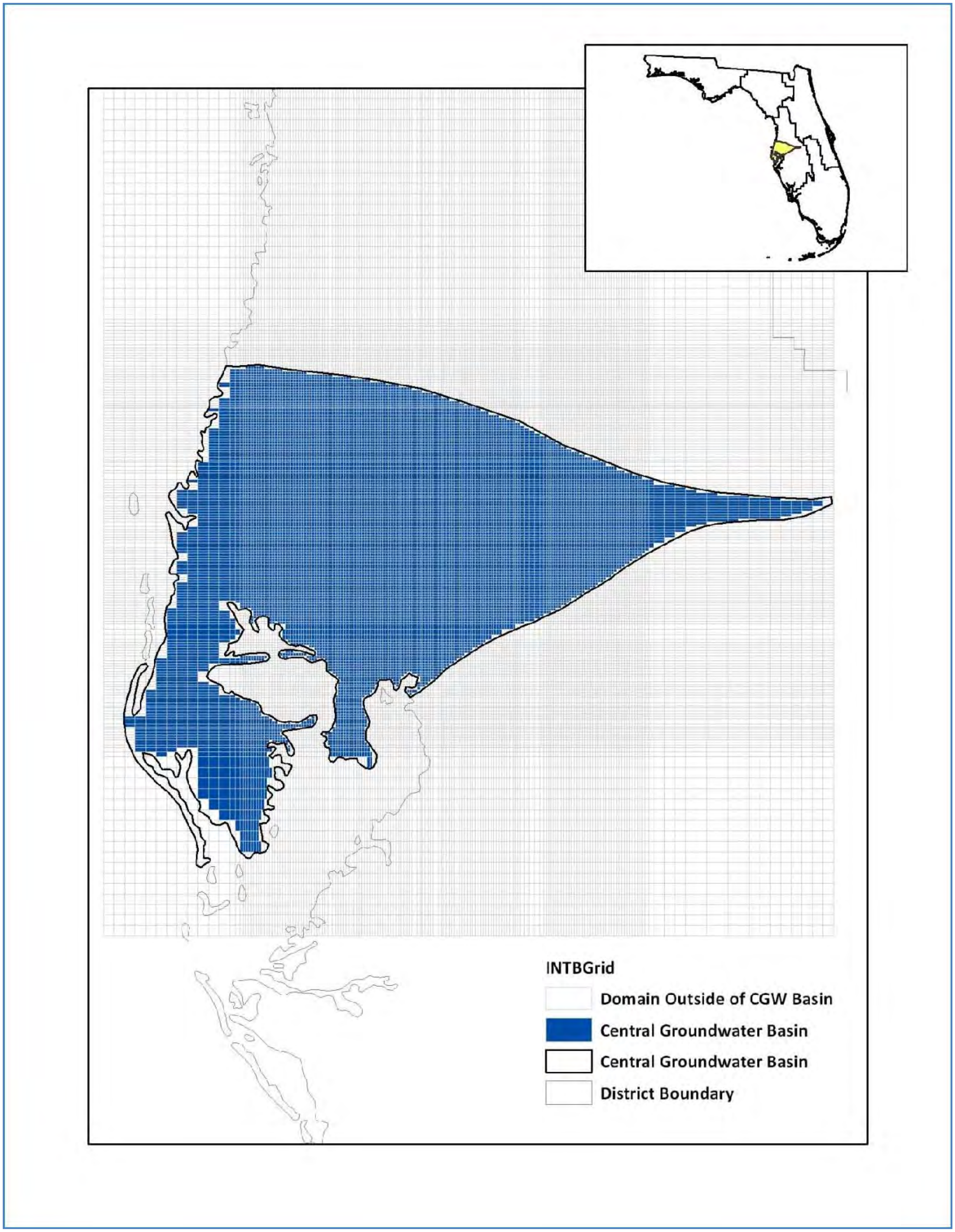

Figure 4. INTB scenarios where impacts to the hydrologic system were simulated due to groundwater withdrawals in the Central West-Central Florida Groundwater Basin.

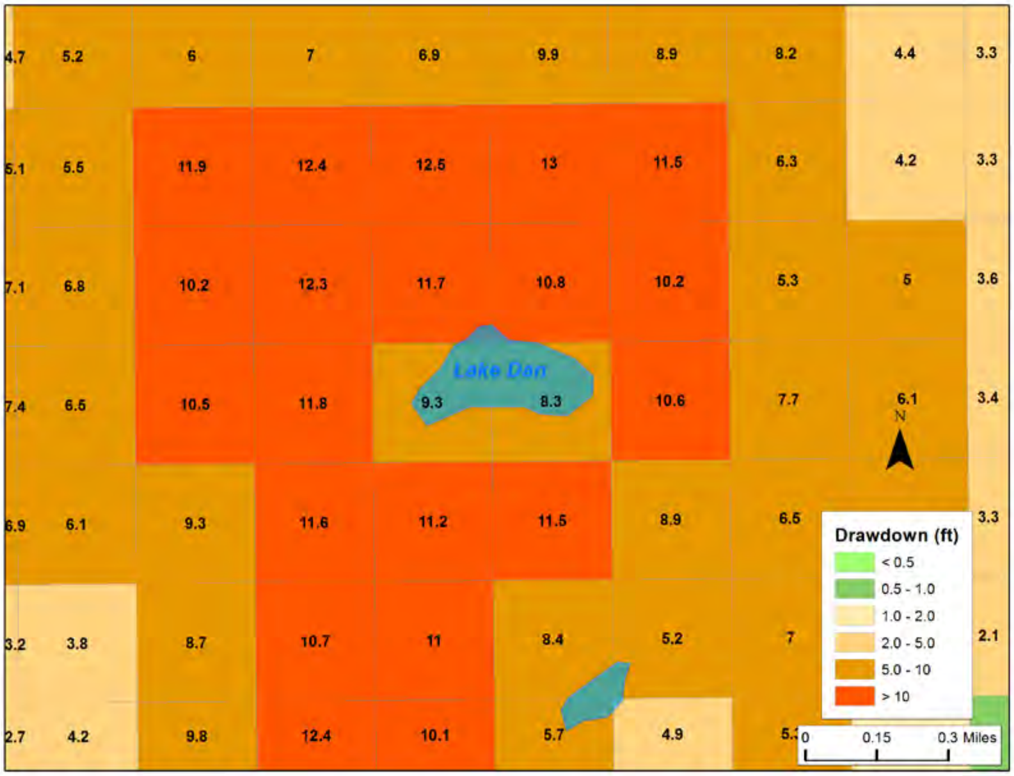

Figure 5. Predicted mean drawdown in the surficial aquifer due to 1989-2000 groundwater withdrawals.

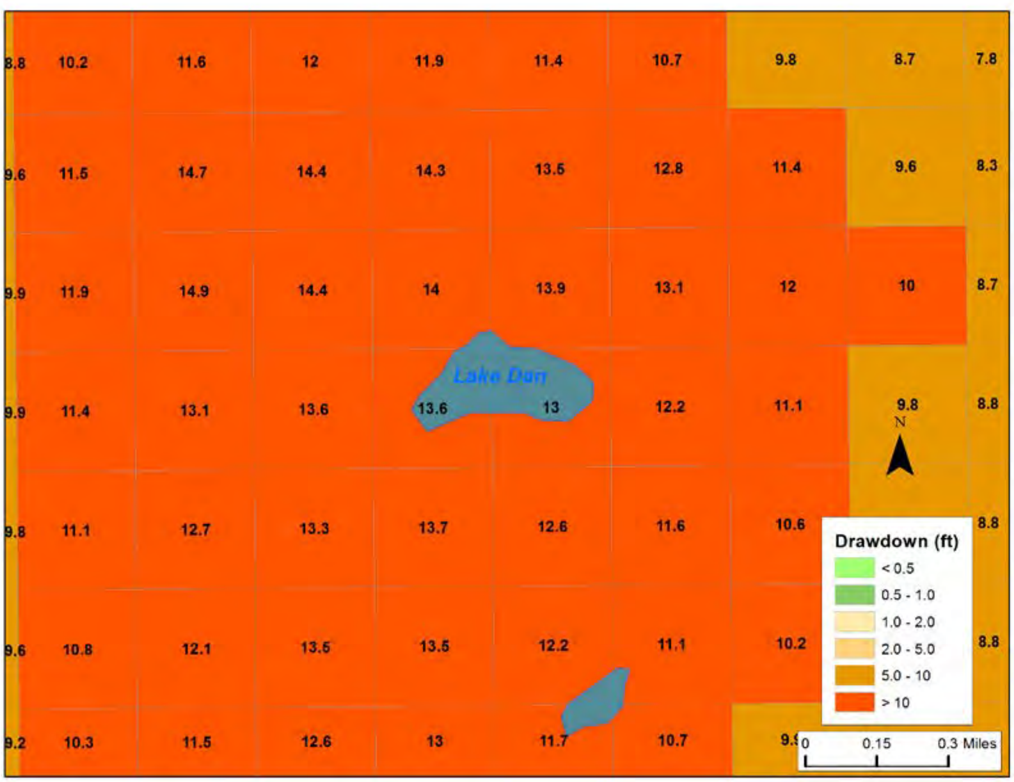

Figure 6. Predicted mean drawdown in the Upper Floridan aquifer due to 1989-2000 groundwater withdrawals.

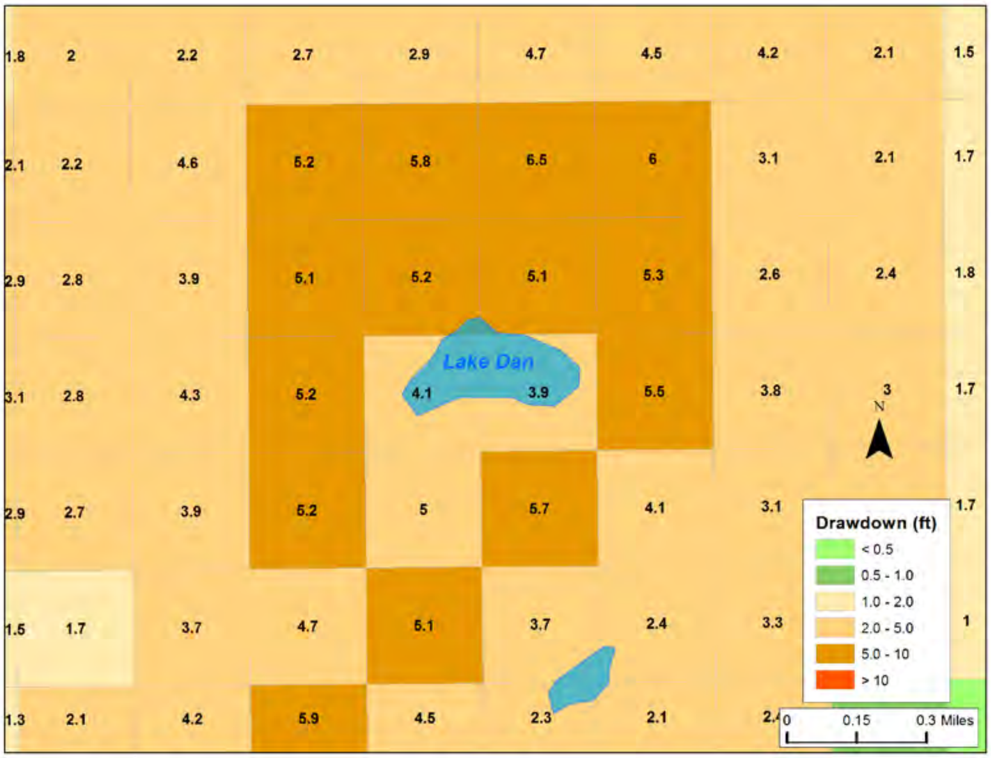

Figure 7. Predicted mean drawdown in the surficial aquifer due to TBW 90 mgd groundwater withdrawals.

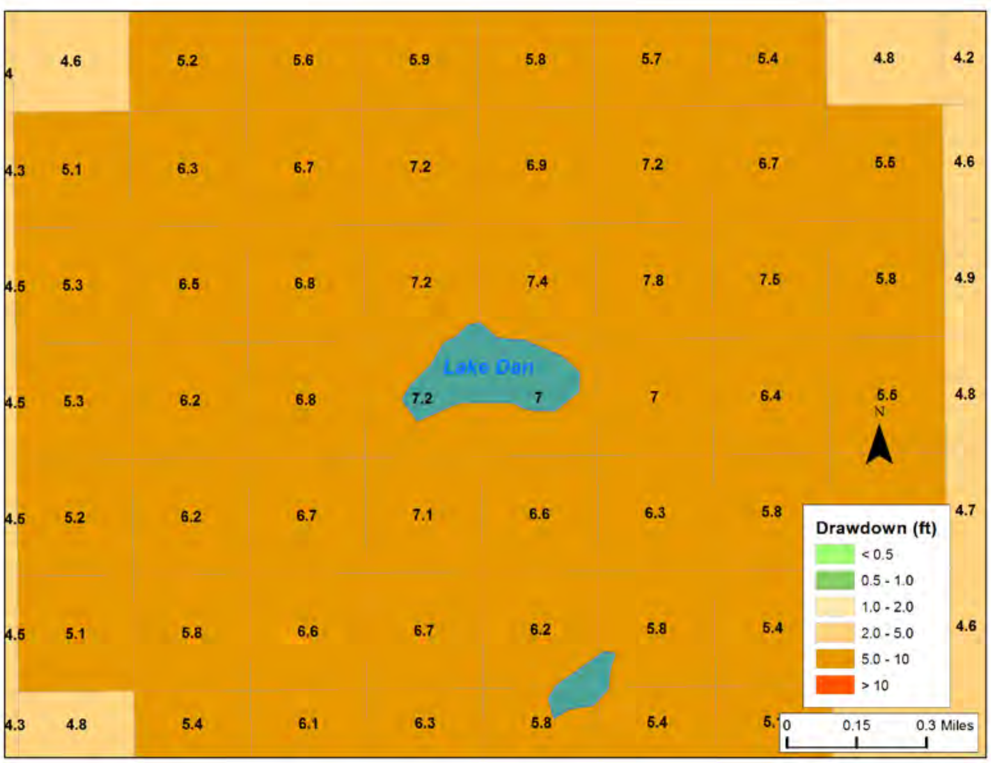

Figure 8. Predicted mean drawdown in the Upper Floridan aquifer due to TBW 90 mgd groundwater withdrawals.

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