

CITY OF LAKELAND WATER QUALITY MANAGEMENT PLAN

Prepared for:

City of Lakeland
407 Fairway Avenue
Lakeland, FL 33801

October 2019



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LIST OF ABBREVIATIONS

Abbreviation	Name
AMEC	AMEC Foster And Wheeler, Inc.
ATKINS	Atkins North America, Inc.
BACI	Before, After, Control and Impact
BCI	BCI Engineers And Scientists, Inc.
BMAP	Basin Management Action Plan
BMPS	Best Management Practices
BSM	Bureau Of Survey And Mapping
CDOM	colored Dissolved Organic Matter
City	City of Lakeland
CMAC	Continuous Monitoring And Adaptive Control
CSI	Chastain Skillman, Inc.
CV	Coefficient Of Variation
CWA	Clean Water Act
DEM	Digital Elevation Model
DO	Dissolved Oxygen
EAV	Emergent Aquatic Vegetation
ECT	Environmental Consulting And Technology, Inc.
EMC	Event Mean Concentration
ENSO	El Nino/Southern Oscillation
EPA	Environmental Protection Agency
ESA	Environmental Science Associates, Inc.
F.A.C	Florida Administrative Code
FDEP	Florida Department Of Environmental Protection
FDOT	Florida Department Of Transportation
FFWCC	Florida Fish And Wildlife Conservation Commission
FLUCCS	Florida Land Use Cover Classification System
FTW	Floating Treatment Wetland
GIS	Geographic Information Systems
GLOS	General Land Office Survey
Hydrilla	<i>Hydrilla Verticillata</i>
IWR	Impaired Surface Waters Rule
LAS	Load Allocations
LIDAR	Light Detection And Ranging Data
MS4's	Municipal Separate Storm Sewer Systems
NNC	Numeric Nutrient Concentration

Abbreviation	Name
NOC	Nutrient Of Concern
NPDES	National Pollutant Discharge Elimination System
OSTDS	Onsite Sewage Treatment And Disposal Systems
PAC	Percent Area Covered
PAH	Polycyclic Aromatic Hydrocarbon
PCU	Platinum-Cobalt Units
PLRG	Pollutant Load Reduction Goal
POR	Period Of Record
RCRA	Resource Conservation And Recovery Act
SAV	Submerged Aquatic Vegetation
SFWMD	South Florida Water Management District
SIA	Stormwater Infiltration Areas
SWFWMD	Southwest Florida Water Management District
SWIM	Surface Water Improvement And Management
SWMM	Stormwater Management Model
SWMP	Stormwater Management Program
TBEP	Tampa Bay Estuary Program
TFMA	Tenoroc Fish Management Area
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
TRPH	Total Recoverable Petroleum Hydrocarbons
TSI	Trophic State Index
TSS	Total Suspended Solids
USGS	United States Geological Survey
WAM	Watershed Assessment Model
WASP	Water Quality Assessment Program
WBID	Waterbody Identification
WLA	Wasteload Allocations
WMM	Watershed Management Model
WQMP	Water Quality Management Plan
WWTF	Wastewater Treatment Facility

EXECUTIVE SUMMARY

In the state of Florida, the determination of “impairment” of water quality is, by rule, followed by the development of an estimate of the amount of reduction in stormwater nutrient loads that must be implemented to allow a water body to improve to the point that it meets water quality standards commensurate with its designated use. These estimates of required reductions in nutrient loads are developed and formalized within an adopted Total Maximum Daily Load (TMDL). The load reductions called for in TMDLs are then apportioned out to local governments to implement through the Basin Management Action Plan (BMAP) process. Finally, BMAP actions are to be implemented through the National Pollutant Discharge Elimination System (NPDES) program. The NPDES program is in turn meant to be implemented via each local government’s Municipal Separate Storm Sewer System (MS4) stormwater discharge permit. In this way, and through these mechanisms, a determination of water quality impairment, and the development of a course of action to ameliorate that impairment, can have a direct impact on the amount of time and resources that the City of Lakeland (the “City”) would have to spend on various lake management activities.

This Water Quality Management Plan (WQMP) for the City’s priority lakes (Beulah, Bonnet, Bonny, Crystal, Gibson, Hollingsworth, Hunter, Mirror, Morton, Parker, and Wire) differs from past and current guidance documents produced by and for various regulatory programs. Each of the eleven priority lakes was evaluated to verify the impairment status, identify the nutrient of greatest importance to water quality and finally, what type of projects are required to restore water quality. In addition to nutrients and chlorophyll-a (a surrogate for algal biomass), factors affecting quality in the lakes include long-term land use and hydrologic alterations, stormwater runoff, historic point source discharges (particularly phosphorus), extent of submerged aquatic vegetation (SAV) and emergent aquatic vegetation (EAV), lake water levels, and hydrologic connections to forested wetlands and other lakes. A decision key was developed for the City’s lakes as a means of selecting the types of restoration projects that best address stressors on a lake by lake basis. These components were included as part of a holistic lake management approach for the priority lakes. The link between water quality issues and lake-specific water quality restoration projects for the priority lakes are presented in the context of state and federal regulations (e.g. TMDL status), as well as current lake management science.

Each of the eleven priority lakes was originally determined to be impaired for nutrients in a prior study by the City. Most of those determinations of impairment were based upon the State of Florida’s previous criteria, the Trophic State Index (TSI). However, Florida developed newer criteria, codified in FAC 62-302.531, and adopted in 2013 by both the Florida Department of Environmental Protection (FDEP) and the US Environmental Protection Agency (EPA). Using the

newer Numeric Nutrient Concentration (NNC) criteria, Lake Wire is no longer impaired for nutrient-related water quality problems; however, the remaining priority lakes do not meet the current NNC. Therefore, while the City may wish to monitor Lake Wire water quality as there is currently no evidence that water quality is problematic from a regulatory aspect (for nutrients).

Additionally, the science of lake management has evolved to the point that several of the traditional management actions that typically arise from the TMDL-BMAP approach may not be the best methods to address water quality issues in some of the City's priority lakes. For example, Lakes Beulah, Bonnet and Hunter are the only lakes where water quality is worse in wet years than in dry years. Since pollutant loads from stormwater runoff are positively correlated with rainfall, this means that for the other seven nutrient-impaired priority lakes poor water quality is not primarily caused by stormwater runoff. For these lakes, internal lake processes appear to be more causative than stormwater runoff. Consequently, stormwater retrofit projects are an appropriate lake management approach, worthy of the significant time and resources required, for three of the City's eleven priority lakes. For the remaining seven nutrient-impaired lakes, other types of projects are required for successful lake management.

Alternative lake management activities are likely to be equally beneficial, if not more so, than traditional stormwater retrofit projects for a number of the City's priority lakes. For example, whole lake circulation via artificial aeration systems has been successfully used to improve water quality in small lakes both in Florida and elsewhere. Such an approach should be investigated for its application for Lakes Beulah, Crystal, Mirror and Morton. Also, the reestablishment of the water quality benefits associated with the influences of intact historical wetland fringes should be investigated as a management tool for Lakes Bonnet, Bonny, Crystal and Parker, and potentially for Lake Gibson as well. In those lakes, one of the primary stressors on water quality appears to be the reduced amount of colored dissolved organic matter (aka "tannins") in the lake, due to hydrologic alterations that have lowered these lakes below their historical wetland fringes.

The application of paleolimnological techniques has determined that Lake Hollingsworth has better water quality at present than it had in the 1960 to 1970s. The improvement in water quality in Lake Hollingsworth is thought to be due to the loss of citrus groves as the watershed transitioned from an agricultural landscape to a more urbanized one; an influence on water quality not captured in Lake Hollingsworth's current TMDL. Additionally, results from paleolimnological work conducted on Lake Hollingsworth shows that the water quality targets used by FDEP for its TMDL are overly restrictive and unrealistic, as FDEP's TMDL for Lake Hollingsworth is based on a target water quality condition that would have resulted in a finding of impairment as far back as the 1890s. Similar paleolimnological work in Lake Bonny shows that the likely largest impact to water quality is not nutrients from external loads, but the loss of tannins from its historical wetland fringes, in response to lowering the lake elevation through drainage canals. Evidence of lost wetland influences in Lake Bonny correlates with the lowering of the lake sometime between the 1890s and the 1920s.

This WQMP provides a compilation of information relevant to water quality in these lakes, an analysis of water quality and water quality trends in these lakes, identification of primary

degradation sources (in-lake and external), and lake-specific potential restoration, preservation, and/or treatment plans (including narrative descriptions of proposed project(s)). One of the primary features of this plan is the recommendation of scientifically proven methods for managing lakes as integrated ecological systems, rather than management based on external nutrient loads alone. Recommendations have been made in consideration of management projects implemented in the past that have had successful, documented system responses. Using results from a lake by lake assessment of water quality and a determination and ranking of the most important stressors to water quality, lake-specific management actions were identified. A brief summary of these lake-specific management activities is listed below.

LAKE BEULAH

The lake is impaired for nutrients, with evidence that stormwater loads contribute to ongoing water quality problems. As such, stormwater loads should be reduced, with a focus on raingarden-type projects that are capable of reducing pollutant loads and recharging the surficial aquifer to supplement dry season water levels. Additionally, Lake Beulah is small enough that artificial circulation would be expected to improve water quality. A Before and After, Control and Impact (BACI) study on the benefits of whole-lake circulation should be undertaken to test the response to whole lake circulation, involving some combination of Lake Beulah, Crystal Lake, Lake Mirror and Lake Morton. There is no evidence that Lake Beulah would benefit from projects designed to increase the influence of wetland-related tannin loads to the lake. However, the expansion of SAV within the lake and EAV along the lake fringe is recommended to improve water quality via assimilation of nutrients from the water column and the soil-pore water.

LAKE BONNET

The lake is impaired for nutrients, with evidence that stormwater loads contribute to ongoing water quality problems. As such, stormwater loads should be reduced, with a focus on both raingarden-type projects that are capable of reducing pollutant loads and recharging the surficial aquifer to supplement dry season water levels as well as larger stormwater treatment/retention projects. Additionally, Lake Bonnet would benefit from projects that could increase the influence of wetland-related tannin loads to the lake, as the lake appears to have been lowered to an elevation below that of its historical fringing wetlands. However, Lake Bonnet is too large for artificial circulation to be able to improve water quality. The bottom sediments in Lake Bonnet appear to be having an adverse impact on water quality, and further investigations are warranted to determine if sediment removal or sediment inactivation would be appropriate lake management strategies. Additionally, the expansion of SAV within the lake and EAV along the lake fringe is recommended to improve water quality via assimilation of nutrients from the water column and the soil-pore water.

LAKE BONNY

The lake is impaired for nutrients and has a TMDL produced by FDEP which allows for restoration activities which address internal as well as external nutrient loads. However, while smaller projects may be appropriate in selected areas, there is no evidence of the need for large regional stormwater

retrofit projects to address external nutrient loading. Lake Bonny would likely benefit from projects that could increase the influence of wetland-related tannin loads to the lake, as the lake appears to have been lowered to an elevation below that of its historical fringing wetlands. Lake Bonny is too large for artificial circulation to be effective for water quality improvement. The bottom sediments in Lake Bonny appear to be having an adverse impact on water quality, and further investigations are warranted to determine if sediment removal or sediment inactivation would be appropriate lake management strategies. Additionally, the expansion of SAV within the lake and EAV along the lake fringe is recommended to improve water quality via assimilation of nutrients from the water column and the soil-pore water.

CRYSTAL LAKE

The lake is impaired for nutrients, but has a recent Nutrient Management Plan that has been reviewed and approved by FDEP. While smaller projects may be appropriate in selected areas including improvements or retrofits to existing stormwater infrastructure, there is no evidence of the need for large regional stormwater retrofit projects. Crystal Lake would likely benefit from projects that could increase the influence of wetland-related tannin loads to the lake, as the lake appears to have been lowered to an elevation below that of its historical fringing wetland. Additionally, Crystal Lake is small enough that artificial circulation would be expected to be able to improve water quality. The bottom sediments in Crystal Lake appear to be having an adverse impact on water quality, and further investigations are warranted to determine if sediment removal or sediment inactivation would be appropriate lake management strategies. Additionally, the expansion of SAV within the lake and EAV along the lake fringe is recommended to improve water quality via assimilation of nutrients from the water column and the soil-pore water.

LAKE GIBSON

Recently, Lake Gibson has recently shifted from an unimpaired to an impaired surface water body. While smaller projects may be appropriate in selected areas, there is no evidence of the need for large regional stormwater retrofit projects in the watershed. However, Lake Gibson would benefit from projects that could increase the influence of wetland-related tannin loads to the lake, particularly for a large wetland feature located north of the lake, which appears to have been compromised by a ditch running down through the middle of the wetland. The lake is too large for artificial circulation to be able to improve water quality. No evidence was found of the influence of the resuspension of bottom sediments influencing water quality. However, the expansion of SAV within the lake and EAV along the lake fringe is recommended to improve water quality via assimilation of nutrients from the water column and the soil-pore water.

LAKE HOLLINGSWORTH

While the lake is impaired for nutrients, paleolimnological studies have found that water quality in Lake Hollingsworth is better now than it was in the 1960 and 1970s. The improvement in water quality is thought to be due to the reduction of agricultural land use (historical citrus groves) as a dominant feature of the watershed. Also, and with potential implications to other lakes in the City, the paleolimnological work on Lake Hollingsworth shows that the water quality targets used by

FDEP in its TMDL would have resulted in a finding of impairment more than 100 years ago, although development existed prior that timeframe. While smaller scale and opportunistic projects may be appropriate in selected areas, there is no evidence of the need for additional large regional stormwater retrofit projects for Lake Hollingsworth. Lake Hollingsworth is too large for artificial circulation to improve water quality. There is no evidence that Lake Hollingsworth would benefit from projects designed to increase the influence of wetland-related tannin loads to the lake. However, sediments in Lake Hollingsworth continue to adversely impact water quality, despite a fairly recent and large-scale dredging project aimed at sediment removal. A severe drought coincided with the sediment removal project, which created conditions that made it impossible to remove all the targeted sediments. Although there is evidence of improvements in water quality associated with the sediment removal project and a follow up whole-lake alum application project, the sediment impact remains, and additional efforts to act on the sediment nutrient supply appear to be appropriate. Additionally, the expansion of SAV within the lake and EAV along the lake fringe is recommended to improve water quality via assimilation of nutrients from the water column and the soil-pore water.

LAKE HUNTER

The lake is impaired for nutrients, and has an existing FDEP-approved TMDL. This assessment found evidence that stormwater loads contribute to ongoing water quality problems. As such, stormwater loads should be reduced, with a focus on raingarden-type projects that are capable of reducing pollutant loads and recharging the surficial aquifer to supplement dry season water levels. However, the lake is too large for artificial circulation to be able to improve water quality. There is also no evidence that Lake Hunter would benefit from projects designed to increase the influence of wetland-related tannin loads to the lake. Additionally, the expansion of SAV within the lake and EAV along the lake fringe is recommended to improve water quality via assimilation of nutrients from the water column and the soil-pore water.

LAKE MIRROR

The lake is impaired for nutrients. However, while smaller projects may be appropriate in selected areas, there is no evidence of the need for large regional stormwater retrofit projects. Additionally, the lake is not likely to benefit from projects that could increase the influence of wetland-related tannin loads to the lake. However, Lake Mirror is small enough that artificial circulation would be expected to be able to improve water quality. A BACI study on the benefits of whole-lake circulation should be undertaken to test the response to whole lake circulation, involving some combination of Lake Beulah, Crystal Lake, Lake Mirror and Lake Morton. Additionally, the expansion of SAV within the lake and EAV along the lake fringe is recommended to improve water quality via assimilation of nutrients from the water column and the soil-pore water.

LAKE MORTON

The lake is impaired for nutrients. However, while smaller projects may be appropriate in selected areas, there is no evidence of the need for large regional stormwater retrofit projects. Additionally, the lake is not likely to benefit from projects that could increase the influence of wetland-related

tannin loads to the lake. However, Lake Morton is small enough that artificial circulation would be expected to be able to improve water quality. A BACI study on the benefits of whole-lake circulation should be undertaken to test the response to whole lake circulation, involving some combination of Lake Beulah, Crystal Lake, Lake Mirror and Lake Morton. Additionally, the expansion of SAV within the lake and EAV along the lake fringe is recommended to improve water quality via assimilation of nutrients from the water column and the soil-pore water.

LAKE PARKER

The lake is impaired for nutrients, and has a TMDL that has been approved by FDEP. And while smaller projects may be appropriate in selected areas, there is no evidence of the need for large regional stormwater retrofit projects. However, Lake Parker would benefit from projects that could increase the influence of wetland-related tannin loads to the lake, particularly for a large wetland feature located west of the lake, which appears to have been compromised by a drainage ditch running down through the middle of the wetland. Lake Parker is too large for artificial circulation to be able to improve water quality. A unique feature of the Lake Parker watershed is the large Tenoroc Lakes system, located on the lake's northern and northeastern shoreline. While significant data gaps exist, it may be possible to create a flow-through water treatment system, if the Tenoroc system lakes are found to have the appropriate characteristics of depth and water quality to allow for the extensive non-native Hydrilla beds in those lakes to act as "polishing ponds" for water pumped into the Tenoroc lakes from Lake Parker before being discharged back into the lake. While permitting obstacles exist, there is the potential for such a system to be able to substantially improve water quality in Lake Parker.

LAKE WIRE

Lake Wire is not impaired for nutrients. While smaller projects may be appropriate in selected areas, there is no evidence of the need for large regional stormwater retrofit projects. There is, however, the need to carefully manage the Hydrilla in the lake, as it appears that the extensive Hydrilla beds are largely responsible for the very good water quality in the lake. Should an overly aggressive Hydrilla eradication effort be conducted in Lake Wire, it is almost certain that the nutrient pool contained within the Hydrilla would become available in the water column, with resultant algal blooms and the likelihood that the lake would become impaired for nutrients.

1. INTRODUCTION

Project Objective

The ecological integrity and aesthetic beauty of lakes in the City of Lakeland (“City”) are integral to its identity and economic sustainability, and the City is facing increasing pressures from both the public and regulatory agencies to maintain or improve water quality in its 38 named lakes. In some of the lakes, water quality is declining, and cost-effective solutions to remediate these problems are needed. In other lakes, water quality appears to be stable or improving; however, regulatory agencies have deemed them impaired based on recently adopted Numeric Nutrient Criteria (NNC), potentially requiring costly measures that may or may not be effective. In response to a request from the City, and in close coordination with City staff, Atkins North America, Inc. (Atkins) and Environmental Science Associates, Inc. (ESA) have combined their efforts to produce this Water Quality Management Plan (WQMP) for 11 priority lakes within the City’s boundaries. The priority lakes, chosen by the City based on their regulatory status (NNC impairment and/or TMDL assignment), public access, and natural water bodies (as opposed to manmade lakes (e.g., former phosphate mining pits), include the following:

- Lake Beulah
- Lake Bonnet
- Lake Bonny and Little Lake Bonny
- Crystal Lake
- Lake Gibson
- Lake Hollingsworth
- Lake Hunter
- Lake Parker
- Lake Mirror
- Lake Morton
- Lake Wire

The WQMP provides a compilation of information relevant to water quality in these lakes, an analysis of water quality and water quality trends in these lakes, identification of primary degradation sources (in-lake and external), and lake-specific potential restoration, preservation, and/or treatment plans (including narrative descriptions of proposed project(s)). One of the primary features of this plan is the recommendation of scientifically proven methods for managing lakes as integrated ecological systems, rather than projects based on external nutrient loads alone. Recommendations have been made in consideration of management projects implemented in the past that have had successful, documented system responses. More specifically, this WQMP:

- Characterizes water quality for the priority lakes in the City, as relates to regulatory criteria such as impairment determinations and the State of Florida's Total Maximum Daily Load (TMDL) program;
- Identifies potential restoration, preservation, and/or treatment projects to address water quality issues (if found);
- Links potential restoration, preservation, and/or treatment projects to lakes based on individual water quality needs; and
- Provides recommendations to prioritize lake restoration, preservation, and/or treatment actions.

While traditional stormwater treatment projects can successfully reduce external nutrient loadings to lakes, historic point and nonpoint source runoff and natural lake processes that may have resulted in internal nutrient loads that traditional stormwater projects don't address. Consequently, both traditional and non-traditional water quality management projects have been proposed to address both external and internal nutrient loading to the named lakes in this WQMP.

In addition to nutrients and chlorophyll-a (a surrogate for algal biomass), factors affecting water quality include long-term land use and hydrologic alterations, stormwater runoff, historic point source discharges (particularly phosphorus), presence and extent of submerged aquatic vegetation (SAV) and emergent aquatic vegetation (EAV), lake water levels, and hydrologic connections to forested wetlands and other lakes. A decision key was developed for the City's lakes as a means of selecting the types of restoration projects that best address stressors on a lake by lake basis, and the project types coming out of the decision tree process were included as part of a holistic lake management approach for the named lakes. The link between water quality issues and lake-specific water quality restoration projects for the named lakes are presented in the context of state and federal regulations (e.g. TMDL status), as well as lake management science.

This WQMP is focused on the 11 priority lakes selected by the City. Many of these lakes have been negatively impacted through historical point and non-point sources of pollution and many have been listed as impaired. The WQMP involves incorporating existing information and previously conducted water quality studies to develop improved water quality plans for the lakes. The additional information was used to evaluate alternatives and best management practices (BMPs) that could be used to improve water quality in the lakes. The WQMP could be incorporated into the TMDL Basin Management Action Plan (BMAP) process, which may include the involvement of stakeholders. Alternatively, the City may choose to pursue, in close coordination

with the Florida Department of Environmental Protection (FDEP), alternatives to the TMDL/BMAP process. Specifically, the City could decide to use FDEP's "4e" category for water quality guidance, more formally known as the "Ongoing Restoration Activities" category as is currently being utilized for Crystal Lake that previously was subject to the guidance outlined in its FDEP-approved TMDL. The benefit of a 4e plan is that non-traditional project types that may not fit into the traditional TMDL approach can more easily be considered by FDEP as a means to bring about lake restoration.

Project Area Description

The City is part of the rapidly urbanizing area of central Florida. Prior to urban development, citrus and agriculture (improved pasture) were the predominant land uses in the watershed.

High sandy ridges and lower 'valleys' characterize the City. Historically, virtually all of the rainwater that fell on the sandy ridge areas percolated into soils that are characterized by high infiltration rates (approximately 6.0 inches/hour, USDA/SCS Polk County Soil Survey 2007) while excess water was retained in the lower valley wetlands. During the dry season, ridge lakes were historically maintained by ground water from the sandy surficial aquifer, which is one of the highest recharge zones for the Floridan aquifer in the Southern West Central Ground Water Basin. Urban development in the City and adjacent areas occurred primarily on soils that have high infiltration rates (Figure 1-1). Consequently, rainfall that formerly infiltrated these high recharge areas is now surface water runoff. In contrast, the valley areas were historically characterized by forested and marshy shorelines which consist of mucky soils with low infiltration rates with limited development

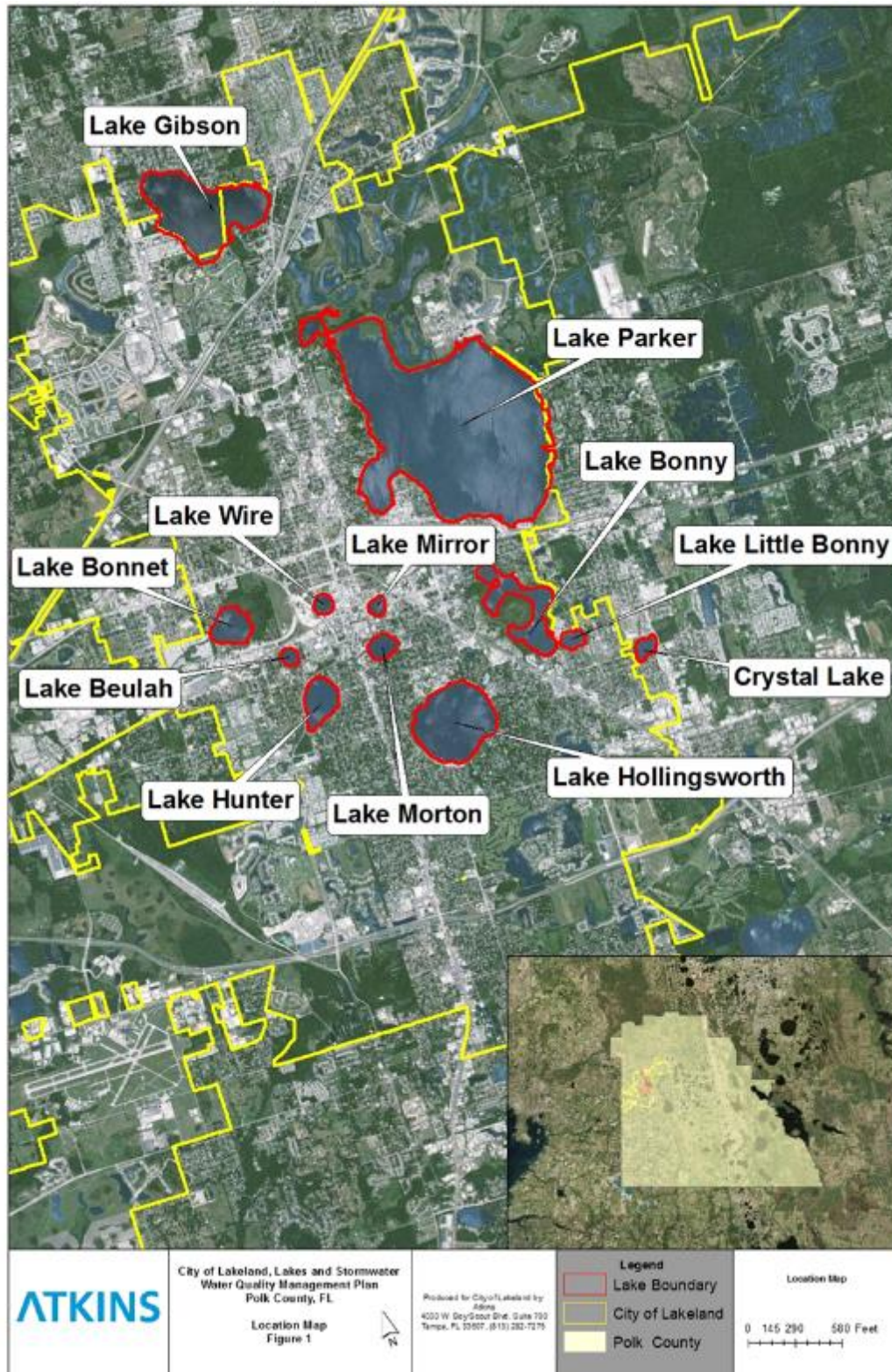


Figure 1-1. Location Map

2. STATE AND FEDERAL REGULATIONS AND WATER QUALITY IMPAIRMENT

EPA Clean Water Act

Section 303(d) of the Clean Water Act (CWA) requires that states develop impaired waters lists to identify rivers, lakes, and estuaries that do not meet water quality standards commensurate with their designated use. The intent of the CWA was that once an impaired waterbody was identified, a TMDL would then be developed. The intent of TMDLs is to specify the maximum amount of a pollutant that a water body can receive and still meet water quality standards. More specifically, a TMDL is “the sum of the individual wasteload allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources” (40 CFR 130.2 and 130.70). Discharges from municipal separate storm sewer systems (MS4s) are included as part of the wasteload allocations in TMDLs. An MS4 that contributes a pollutant of concern to an impaired waterbody or a waterbody with an approved TMDL is assigned a WLA to reduce pollutant loads and meet the TMDL. The MS4 program is implemented under the National Pollutant Discharge Elimination System (NPDES) stormwater permitting program and is intended to address the water quality goal of the CWA, i.e. “not cause or contribute to exceedance of water quality standards.” The City is considered a Phase I MS4 and is currently in Cycle 4 of their NPDES permit.

State Regulations: TSI vs. NNC

Until 2013, FDEP utilized the Trophic State Index (TSI) for the determination of nutrient imbalances in lakes and estuaries in the State of Florida. In 2012, the FDEP finalized a series of numeric nutrient concentration (NNC) criteria for Florida’s lakes, which was subsequently approved by the US Environmental Protection Agency (EPA) in 2013. The TSI was utilized by FDEP to determine nutrient impairment for lakes and estuaries until the adoption of the NNC in 2013. However, historically multiple TMDLs throughout the state of Florida were developed utilizing TSI, rather than NNC, to develop water quality goals and load allocation targets. The subsequent sections provide an overview of the two methods and the application to evaluate nutrient impairment status of a given waterbody.

Trophic State Index

TSI is calculated based on the calculated nutrient limitation (e.g., nitrogen, phosphorus or co-limited; Figure 2-1). In order to violate the TSI guidance criteria, only a single year’s exceedance was necessary. In regards to data sufficiency, one sample was required from each quarter of a calendar year. Specific to lakes, TSI targets were allocated based upon color classification. High color lakes (color > 40 platinum-cobalt units (PCU)) had a TSI threshold of 60 TSI which roughly equates to “do not exceed” values for chlorophyll-a of 20 µg/L, total phosphorus (TP) of 0.07 mg/L and total nitrogen (TN) of 1.2 mg/L. A low color lake (color ≤ 20 PCU) had a TSI threshold of 40

TSI which roughly equates to do not exceed values for chlorophyll-a of 5.0 µg/L, TP of 0.02 mg/L and TN of 0.45 mg/L. Low color lakes with paleolimnological work which indicate historically mesotrophic water quality conditions could qualify for a TSI of 60. Of relevance to the City, several of the lakes within the Winter Haven Chain of Lakes system were allowed to have TSI targets of 60, even though they were actually low-color lakes, based on results from paleolimnological work.

*For lakes: 0-59 is good, 60-69 is fair, 70-100 is poor.
For estuaries: 0-49 is good, 50-59 is fair, 60-100 is poor.*

Trophic State Index	Chlorophyll CHLA/ micrograms per liter (µg/l)	Total Phosphorus TP/ milligrams of phosphorus per liter (mgP/l)	Total Nitrogen TN/ milligrams of nitrogen per liter (mgN/l)
0	0.3	0.003	0.06
10	0.6	0.005	0.10
20	1.3	0.009	0.16
30	2.5	0.01	0.27
40	5.0	0.02	0.45
50	10.0	0.04	0.70
60	20.0	0.07	1.2
70	40	0.12	2.0
80	80	0.20	3.4
90	160	0.34	5.6
100	320	0.58	9.3

Trophic State Index equations that generate the above criteria

(LN = Natural Log):

$$CHLA_{TSI} = 16.8 + [14.4 \times LN(CHLA)]$$

$$TN_{TSI} = 56 + [19.8 \times LN(TN)]$$

$$TN2_{TSI} = 10 \times [5.96 + 2.15 \times LN(TN + .0001)]$$

$$TP_{TSI} = [18.6 \times LN(TP \times 1000)] - 18.4$$

$$TP2_{TSI} = 10 \times [2.36 \times LN(TP \times 1000) - 2.38]$$

** Limiting nutrient considerations for calculating NUTR_{TSI}*

If TN/TP > 30 then NUTR_{TSI} = TP2_{TSI}

If TN/TP < 10 then NUTR_{TSI} = TN2_{TSI}

If 10 < TN/TP < 30 then NUTR_{TSI} = (TP_{TSI} + TN_{TSI}) / 2

TSI = (CHLA_{TSI} + NUTR_{TSI}) / 2

Figure 2-1. TSI equations and associated targets (from FDEP 1996)

Numeric Nutrient Concentration Criteria

The FDEP NNC was implemented in 2013 to determine chlorophyll-a, TN and/or TP impairment for lakes. Each lake must be characterized as a low (color ≤ 40 PCU) or high color (color > 40 PCU) lake. Low color lakes are further classified as acidic (alkalinity ≤ 20 mg/L) or alkaline (alkalinity > 20 mg/L). The appropriate NNC criteria are assigned based upon the characterization and chlorophyll-a concentration on an annual basis (Figure 2-2). The criteria are compared to the annual geometric mean of each parameter.

Long Term Geometric Mean Lake Color and Alkalinity	Annual Geometric Mean Chlorophyll <i>a</i>	Minimum calculated numeric interpretation		Maximum calculated numeric interpretation	
		Annual Geometric Mean Total Phosphorus	Annual Geometric Mean Total Nitrogen	Annual Geometric Mean Total Phosphorus	Annual Geometric Mean Total Nitrogen
> 40 Platinum Cobalt Units	20 µg/L	0.05 mg/L	1.27 mg/L	0.16 mg/L ¹	2.23 mg/L
≤ 40 Platinum Cobalt Units and > 20 mg/L CaCO ₃	20 µg/L	0.03 mg/L	1.05 mg/L	0.09 mg/L	1.91 mg/L
≤ 40 Platinum Cobalt Units and ≤ 20 mg/L CaCO ₃	6 µg/L	0.01 mg/L	0.51 mg/L	0.03 mg/L	0.93 mg/L

Figure 2-2. Lake NNC chlorophyll-a, TN and TP criteria (from FDEP 2013)

FDEP allows for an acceptable range of annual geometric means of TN and TP, up to the values shown in the “maximum calculated numeric interpretation” column, as long as the applicable chlorophyll *a* criterion is achieved in that same year. These numeric interpretations for TN, TP, and chlorophyll *a* cannot be exceeded more than once in any consecutive three-year period.

If there is insufficient data to calculate the annual geometric mean for chlorophyll *a* for any given year, or the annual geometric mean for chlorophyll-*a* exceeds the values based on color and alkalinity, then the applicable NNC interpretations for TN and TP are the minimum calculated values. If there are sufficient data to calculate the chlorophyll annual geometric mean and the mean does not exceed the chlorophyll *a* values for the lake type, then the NNC interpretation is the annual geometric means of ambient TN and TP or the maximum calculated limits in the table.

More than one exceedance (for any parameter) in any three-year period is required for a waterbody to be declared impaired using NNC. Of particular importance for the City, for lakes with color values greater than 40 PCU in FDEP’s “West Central Nutrient Watershed Region” (which includes all of the City) the allowable maximum TP limit increases to 0.49 mg/L, if chlorophyll-*a* concentrations are below 20 µg/L.

Regulatory Programs and NPDES Permits

The NPDES program is intended to minimize or eliminate the pollution of waterbodies via stormwater runoff, illegal dumping, and illicit discharges. The City, as well as unincorporated portions of Polk County, is regulated under the NPDES system. Under its permit, the City is required to submit an annual report outlining progress on all elements covered under its NPDES permit. The City’s MS4 permit is issued by FDEP every five years.

The current MS4 permit for the City includes the requirement that the City implement a Stormwater Management Program (SWMP) that includes the following items: 1) pollution prevention measures, 2) stormwater treatment or removal techniques, 3) monitoring of stormwater runoff, 4) use of legal authority – when appropriate – to achieve MS4 permit goals, and 5) other appropriate means to control stormwater discharges from MS4 systems.

The City’s MS4 permit requires the City to prioritize waters with established TMDLs, and to initiate storm event monitoring to guide the development of the TMDL and/or the BMAP, if one exists for a given waterbody. A BMAP is essentially a document that formalizes the actions through which pollutant load reductions called for in a TMDL would be implemented. For a waterbody with an adopted BMAP, NPDES permits must be consistent with the requirements of adopted TMDLs. In this sense, a TMDL does not by itself create the need for implementation of pollutant load reduction projects for MS4 permittees, but an adopted BMAP does require implementation, and implementation is expected to be accomplished, at least in part, through the MS4 permit process.

For water bodies with an adopted TMDL from FDEP or an EPA-established TMDL but without a BMAP, FDEP requires approval of a final prioritization report that includes the list of adopted FDEP TMDLs or EPA-established TMDLs, the prioritization factors, the prioritized list, and the associated schedule for related activities.

As outlined above, in Florida the typical regulatory approach to lake management is a focus on reducing external nutrient loads, particularly those from stormwater, as a way to obtain in-lake water quality goals. However, it has been well documented in the scientific literature over the past few decades that reductions in external nutrient loads alone do not consistently correlate with significant reductions in phytoplankton populations in most Florida lakes (e.g., Terrell et al. 2000). Recent studies conducted on lakes in the City of Winter Haven (a neighboring City with similar lake classifications) have demonstrated that hydrologic alterations may impact phytoplankton composition and abundance much more so than external nutrient loads (PBS&J 2008, PBS&J 2011). These results suggest that hydrologic restoration should be a major consideration during effective lake management planning. To that end, where deemed appropriate, lake restoration projects should focus at least as much on hydrologic alterations and in-lake restoration projects as reducing external nutrient loads from stormwater runoff.

In-lake techniques to re-establish historical wetland influences and increase levels of colored dissolved organic matter (aka “tannins” or “CDOM”) for lakes that have lost their historical lake – wetland connections are one such potential technique to consider (i.e., Tomasko et al. 2016). For small hypereutrophic lakes, the use of whole-lake aeration and circulation systems has been documented to be well worth consideration as a lake improvement project (PBS&J 2011, Tomasko et al. 2013). Additionally, alum treatments used in conjunction with aeration projects can potentially increase water clarity significantly and quickly thereby allowing for more effective growth of SAV and other aquatic vegetation (PBS&J 2011).

Within its MS4 permit, the City is given an opportunity to assess the ability of “non-traditional” techniques to protect or restore water quality, as outlined on page 32 – “In particular, focus on

changes to the code that will promote: reductions in impervious surfaces, the use of swales, the incorporation of low impact development principles, reduction in flow and volume of stormwater, increase in natural hydrology, and adherence to the principles of the Florida Yards and Neighborhoods Program in new landscaping.” As such, lake management projects that focus on restoration of the influences on water quality of prior natural hydrologic conditions are not only likely to be important to managing water quality in the City, such projects appear to be consistent with guidance from FDEP on what types of activities can be covered by the City’s MS4 permit, as well as being consistent with guidance on elements that could be incorporated into a 4e Plan for the City’s priority lakes.

A summary of each lake’s nutrient-related impairment status is listed below:

LAKE BEULAH

Lake Beulah (waterbody identification [WBID] 1543B) does not appear on the 1998 303(d) list compiled by FDEP, nor is it listed in FDEP’s latest comprehensive verified impaired list (December 18, 2017). There is also no TMDL for Lake Beulah. Combined, these data indicate that Lake Beulah is not currently classified as impaired by FDEP. However, the City’s 2009 Lakes Report shows Lake Beulah to have exceeded a TSI value of 60 on multiple occasions between 2005 and 2009. This report found that Lake Beulah exceeds NNC criteria for its classification as a low-color alkaline lake. While a formal TMDL-type lake management approach may not be needed, a WQMP would be appropriate to address potentially problematic water quality in Lake Beulah, including the need to address the availability of both nitrogen and phosphorous from both internal and external loads.

LAKE BONNET

Lake Bonnet (WBID 1537A) does not appear on the 1998 303(d) list compiled by FDEP. On FDEP’s 2014 comprehensive verified impaired list, there is a “Bonnet Lake” listed as impaired for nutrients, but that particular lake is located in Highlands County, and is assigned WBID 1813E. Lake Bonnet is not included on FDEP’s comprehensive de-list from 2014, and there is also no TMDL for Lake Bonnet. However, Lake Bonnet is listed as impaired for nutrients and chlorophyll-a in FDEP’s latest comprehensive verified impaired list (December 18, 2017). In addition, the City’s 2009 Lakes Report shows that Lake Bonnet exceeded a TSI value of 60 on every occasion between 2005 and 2009. This report found that Lake Bonnet exceeds NNC criteria for its classification as a low-color alkaline lake. While a formal TMDL-type lake management approach may not be needed, a WQMP would be appropriate to address potentially problematic water quality in Lake Bonnet, including the need to address the availability of both nitrogen and phosphorous from both internal and external loads.

LAKE BONNY AND LITTLE LAKE BONNY

Lake Bonny, as well as Little Lake Bonny are both included in WBID 1497E and will be discussed throughout this report as “Lake Bonny”. Lake Bonny is on the 1998 303(d) list compiled by FDEP. Lake Bonny does not appear on FDEP’s latest comprehensive verified list (December 18, 2017) although this is likely due to the fact that Lake Bonny has a Final TMDL (FDEP 2014a) and the

development of a TMDL removes a waterbody from the impaired waters list. Lake Bonny appears on FDEP's comprehensive de-list in 2014, but for the impairment of lead. The lead impairment for Lake Bonny was blamed on an "administrative error." The City's 2009 Lakes Report shows that Lake Bonny exceeded a TSI value of 60 nearly every time when water quality data was tested between 2005 and 2009. Lake Bonny has a Final TMDL (FDEP 2014a) based on exceedance of NNC criteria for its classification as a low-color alkaline lake. The TMDL for Lake Bonny (FDEP 2014a) calls for reductions in TN and TP concentrations of 64 and 60 percent, respectively. The TMDL for Lake Bonny does not specifically call for reductions in stormwater loads, thus allowing for the achievement of water quality targets via acting on internal processes as well as external ones. This report found that Lake Bonny exceeds NNC criteria for its classification as a low-color alkaline lake; however, this report also found that nutrient-enriched sediments and lost wetland influences (due to lake lowering) were likely more important stressors to Lake Bonny's water quality than external stormwater loads.

CRYSTAL LAKE

Crystal Lake (WBID 1497A) appears on the 1998 303(d) list compiled by FDEP. Crystal Lake also appears on FDEP's 2014 comprehensive verified list, based on the finding that a TSI value of 40 was exceeded in 2003. The lake was determined by FDEP to be co-limited by both nitrogen and phosphorous, based on a TN/TP ratio median of 19.23. Crystal Lake also shows up on FDEP's 2014 comprehensive de-list, as it was determined that impairments for dissolved oxygen (DO) and unionized ammonia were no longer valid. Crystal Lake is listed as impaired in FDEP's latest comprehensive verified impaired list (December 18, 2017) based on an exceedance of the NNC criteria for TN, TP and chlorophyll-a, but the lake is not discussed in the 2009 Lakes Report. A TMDL was developed for Crystal Lake based with targets derived based upon previous standards (TSI; EPA 2010). As part of this effort, Crystal Lake was determined to be a low color lake, and so in its TMDL (EPA 2010) the threshold for impairment was set at a TSI value of 40. This report found that based on its characterization as a low-color and alkaline lake, Crystal Lake did not meet NNC criteria for TN, TP or chlorophyll-a. This report also determined that sediments and lost wetland influences (due to lake lowering) were likely more important stressors to Crystal Lake's water quality than external stormwater loads. In June 2018, FDEP approved a Nutrient Reduction Plan; therefore, delisting Crystal Lake from the Verified List reclassifying it in assessment category 4e on the Study List. The Nutrient Reduction Plan identifies several restoration activities proposed to improve lake water quality which includes regional projects to reduce external loads (e.g., street sweeping, fertilizer ordinance) as well as site-specific project to address internal loading (e.g. sediment removal).

LAKE GIBSON

Lake Gibson (WBID 1497B) does not appear on the 1998 303(d) list compiled by FDEP, nor does it appear on FDEP's most recent (December 18, 2017) comprehensive verified impaired list. But in its 2014 comprehensive verified impaired list, Lake Gibson was included, as TSI was found to exceed the threshold value of 60 in the years 1997 and 2000. In 2014, FDEP determined that Lake Gibson was a nitrogen-limited lake, based on a TN:TP ratio of 3.6, as listed in the 2014 comprehensive verified list from FDEP. In the City's 2009 Lakes Report, 3 of 18 TSI values shown

for Lake Gibson exceeded the threshold value of 60. This report determined that Lake Gibson did not exceed NNC criteria during the years 2007 to 2014, but did exceed NNC criteria in 2015 and 2016. There are no TMDLs for Lake Gibson, and while a formal TMDL-type lake management approach may not be needed, a WQMP would be appropriate to address potentially problematic water quality in the lake, including the need to address the availability of both nitrogen and phosphorous from both internal and external loads.

LAKE HOLLINGSWORTH

Lake Hollingsworth (WBID 1549X) does not appear on the 1998 303(d) list compiled by FDEP. Lake Hollingsworth does appear on both FDEP's 2014 comprehensive verified impaired list, but not its most recent (December 18, 2017) comprehensive verified impaired list, although this is likely due to the fact that Lake Hollingsworth has a Final TMDL (FDEP 2018) and the development of a TMDL removes a waterbody from the impaired waters list. FDEP determined that Lake Hollingsworth was co-limited by both nitrogen and phosphorous, based on a TN:TP ratio of 18.0, as listed in the 2014 comprehensive verified impaired list from FDEP. In the City of Lakeland 2009 Lakes Report, TSI values exceeded the threshold value of 60 for every sampling event from 2005 to 2009. This report determined that Lake Hollingsworth exceeded NNC criteria during the years 2009 to 2016. Lake Hollingsworth has a Final TMDL (FDEP 2018) based on exceedance of NNC criteria for its classification as a low-color alkaline lake. The TMDL for Lake Hollingsworth (FDEP 2018) calls for reductions in concentrations of TN and TP of 68 and 75 percent, respectively. The TMDL for Lake Hollingsworth does not specifically call for reductions in stormwater loads, thus allowing for the achievement of water quality targets via acting on internal processes as well as external ones. The TMDL report determined that sediments and internal loads were likely more important stressors to Lake Hollingsworth's water quality than external stormwater loads. However, the target TP value used in the TMDL (0.033 mg TP / liter) is unreasonably restrictive, and would have been exceeded TP concentrations more than 100 years ago, based on paleolimnological studies cited in the TMDL itself (i.e., Brenner et al. 1999). In addition, based on equations in the TMDL (Figure 5.5) even if the target TP concentration of 0.033 mg / liter was achieved, the resultant chlorophyll-a value would be expected to be more than 50 percent higher than the default value (20 µg / liter) used in the TMDL.

LAKE HUNTER

Lake Hunter (WBID 1543) appears on the 1998 303(d) list compiled by FDEP. In the City's 2009 Lakes Report, TSI values for Lake Hunter equaled or exceeded the threshold value of 60 for every sampling event from 2005 to 2009. Lake Hunter Outlet (WBID 1543A) appears on FDEP's 2014 comprehensive verified impaired list, based on having DO values less than 5 mg/L. Lake Hunter itself is shown on FDEP's 2014 comprehensive de-list file for lead, nutrients (TSI) and turbidity. The reasons for de-listing for lead and turbidity are attributed to FDEP excluding water quality data from the City. The reason for "de-listing" for nutrients is that a TMDL was produced by FDEP. The Final TMDL for Lake Hunter (FDEP 2004) is based on a threshold TSI value of 60, and it calls for 80 percent reductions in stormwater loads for both TN and TP. The Lake Hunter outlet, but not Lake Hunter, is included FDEP's latest comprehensive verified impaired list (December 18, 2017) for a combination of fecal coliform bacteria, DO and nutrients. This report determined that Lake

Hunter exceeded NNC criteria during the years 2009 to 2016, that the lake's water quality problems were mostly related to the availability of phosphorous, and that stormwater runoff was an important source of TP loads to the lake.

LAKE MIRROR

Lake Mirror does not appear on FDEP's 2014 verified impaired list, but it is listed as impaired for nutrients in FDEP's latest list (December 18, 2017). There is no TMDL for Lake Mirror. Combined, these data indicate that Lake Mirror is currently classified as impaired by FDEP, despite not being listed as impaired in 2014. In the City's 2009 Lakes Report, TSI values for Lake Mirror equaled or exceeded the threshold value of 60 on 14 of 16 sampling events between 2005 and 2009. This report determined that Lake Mirror exceeded NNC criteria on multiple occasions during the years 2009 to 2016, that the lake's water quality problems were mostly related to the availability of nitrogen, and that artificial circulation would more likely improve water quality in the lake, as compared to reducing external TN loads.

LAKE MORTON

Lake Morton (WBID 1497H) does not appear on the 1998 303(d) list compiled by FDEP. Lake Morton does not appear on FDEP's 2014 verified impaired list, but it is listed as impaired for nutrients in FDEP's latest list (December 18, 2017). There is no TMDL for Lake Morton. Combined, these data indicate that Lake Morton is currently classified as impaired by FDEP, despite not being listed as impaired in 2014. The City's 2009 Lakes Report shows that Lake Morton has exceeded a TSI value of 60 on 15 of 17 occasions between 2005 and 2009. This report found that Lake Morton exceeded NNC criteria several times during the years 2009 to 2016, that the lake's water quality problems were mostly related to the availability of nitrogen, and that artificial circulation would more likely improve water quality in the lake, as compared to reducing external TN loads. While a formal TMDL-type lake management approach may not be needed, a WQMP would be appropriate to address problematic water quality in Lake Morton.

LAKE PARKER

Lake Parker (WBID 1497B) appears on the 1998 303(d) list compiled by FDEP. Lake Parker appears on both the FDEP comprehensive verified list from 2014, as well as its most recent list (December 18, 2017) based on exceedances of the threshold value of 20 µg chlorophyll-a / liter each year, between 2008 and 2014. FDEP's 2014 comprehensive verified list determined that Lake Parker is co-limited by nitrogen and phosphorous, based on a TN:TP ratio of 15.0. In the City's 2009 Lakes Report, TSI values for Lake Parker equaled or exceeded the threshold value of 60 for every sampling event from 2005 to 2009. Lake Parker is also included on FDEP's 2014 comprehensive de-list file for lead, with the basis for de-listing cited as an administrative error by FDEP. The Draft TMDL for Lake Parker (FDEP 2005) is based on a threshold TSI value of 60, and it calls for 57 percent reductions in stormwater loads for both TN and TP. This report determined that Lake Parker exceeded NNC criteria each year between 2009 and 2016, that the lake's water quality problems were mostly related to the availability of phosphorous, that lost wetland influences were an important stressor to the lake, and that stormwater runoff was not the primary source of excessive TP loads to the lake.

LAKE WIRE

Lake Wire (WBID 1537) does not appear on the 1998 303(d) list compiled by FDEP. Lake Wire appears on the 2014 comprehensive verified impaired lists from FDEP for both lead and nutrients (TSI) but in the latest comprehensive verified impaired list (December 18, 2017) Lake Wire is listed as impaired for lead only. In the 2014 list, nutrient impairment was based on annual average TSI values exceeding a threshold value of 40, based on Lake Wire's classification as a low color lake. In the 2014 comprehensive verified impaired list, a TSI value of 50.1 was recorded by FDEP in 2007. Nitrogen was considered the limiting nutrient, based on a TN:TP ratio of 9.8. In the City's 2009 Lakes Report, TSI values for Lake Wire regularly exceeded a threshold value of 40 during the period of 2005 to 2009. In this report, it was determined that Lake Wire did not exceed NNC criteria during the years 2009 to 2016, but several years did not have sufficient data to apply NNC criteria. There are no nutrient-related TMDLs for Lake Wire, and while a formal TMDL-type lake management approach may not be needed, a WQMP would be appropriate to address potentially problematic water quality in the lake, including the need to control the abundance of *Hydrilla verticillata* (Hydrilla) without resorting to widespread application of herbicides, and to simultaneously encourage the development of native species of submerged aquatic vegetation.

Problematic Issues Related to Regulatory Status

Each of the eleven priority lakes has been determined to be impaired for nutrients, using the State of Florida's previous criteria, the TSI, or via prior studies from the City. However, Florida has recently developed newer criteria (NNC), codified in FAC 62-302.531, and adopted by both the FDEP and the EPA in 2013.

Water Quality Targets

An unresolved issue for the City's priority lakes is related to the various water quality targets used in the development of TMDLs. The Winter Haven Southern Chain of Lakes TMDL (FDEP 2007) used a TSI value of 60 for these lakes, even though they would be classified as "low" color, as paleolimnological studies had previously provided evidence of the historically mesotrophic water quality conditions within Lake Hollingsworth and Lake Parker (Brenner et al. 1999) as well as various other lakes in Polk County (Whitmore and Brenner 1995). In essence, a TSI target value of 40 had previously been determined to be overly restrictive for a variety of lakes in Polk County, due to the unique geology of the region (i.e., the existence of the phosphorus-rich Bone Valley Formation).

However, the TMDL for Crystal Lake (EPA 2010) was based on a TSI value of 40, which is likely both inappropriate and unattainable. Similarly, the inclusion of Lake Wire on FDEP's 2014 verified impaired list is based on Lake Wire exceeding a TSI value of 40, not the value of 60 used for the Winter Haven Chain of Lakes system.

The water quality targets for Lake Hunter (FDEP 2004) and Lake Parker (FDEP 2005) are based on comparing expectations of water quality from existing and historical watershed configurations, as informed by mechanistic water quality models. Unfortunately, the vast majority of rate

coefficients used in those water quality models have not been locally measured, and so the appropriateness of the model output is questionable. More recent TMDLs for Lakes Bonny and Hollingsworth (FDEP 2014a and 2018, respectively) are based on empirically-derived relationships between nutrient concentrations and chlorophyll-a, rather than the use of a mechanistic water quality model. These recent TMDLs are also based on the use of NNC criteria, rather than TSI. However, and consistent with NNC criteria, the highest possible chlorophyll-a concentration allowed in the TMDL calculations is 20 µg/L, which is likely lower (by more than a third) compared to a water quality target that would be consistent with paleolimnological work from local lakes (Atkins and ESA 2015).

TMDLs based on TSI versus NNC criteria

If a lake is impaired with both TSI and NNC, then the lake clearly has problematic water quality. In such a situation, while the water quality targets and the types of projects required to restore water quality may require additional attention, the lake most likely would need management attention such as occurs with a TMDL. However, the State of Florida has not yet clarified what actions should be undertaken for lakes that were previously declared impaired using TSI, but not with NNC. Recently, it was determined that approximately 20 percent of the lakes in Polk County that were previously found to be impaired with the use of TSI were not impaired using NNC criteria (Atkins and ESA 2014) as is the case for Lake Wire. Of greater importance, a number of lakes that were designated as impaired by FDEP (based on TSI) also have TMDLs based on TSI. A TMDL based on TSI might have very different implications, in terms of restoration plans and projects, than a TMDL that would be based on NNC. For example, the recent TMDLs for Lakes Bonny and Hollingsworth (FDEP 2014a and 2018, respectively) are based on NNC and use empirically-derived relationships between nutrient concentrations and concentrations of chlorophyll-a, which are then compared to both NNC criteria and results from paleolimnological studies. These TMDLs also allow for the possibility that in-lake processes can be used to achieve water quality goals. In prior TMDLs, internal processes could not be considered, and the only types of projects that could get credit in terms of meeting TMDL targets were projects that focused on external nutrients loads such as those from stormwater runoff.

Review of TMDLs for Priority Lakes

The TMDLs reviewed here are those related to impairments from nutrients. Each TMDL was assessed in terms of the basis for impairment, the water quality targets used in the TMDL, the assumptions associated with the various pollutant loading models, and a brief summary as to whether or not the City should view the TMDL as being appropriately detailed in its understanding of eutrophication processes that they might be viewed as ready for implementation. It should be remembered that TMDLs do not have to be implemented if they are considered to be overly problematic. However, in the absence of any request to modify a TMDL, FDEP would then transition into the BMAP phase, and BMAPs are intended to be self-implementing through the NPDES program. FDEP also has the ability to re-open MS4 permits after a BMAP is completed.

Lake Bonny & Little Lake Bonny (WBID 1497E)

Basis for Impairment

Lake Bonny is classified as a Class III freshwater waterbody, with a designated use of recreation, propagation and maintenance of a healthy, well-balanced population of fish and wildlife. The Class III water quality criterion applicable to the verified impairments (nutrients) for this water is the state of Florida's nutrient criterion in Paragraph 62-302.530(47) (b), Florida Administrative Code (F.A.C.).

FDEP had determined that Lake Bonny was impaired for nutrients based on elevated annual average TSI values during the Cycle 1 verification period for Group 3 basins (January 1997 to June 2004). At that time, the methodology used by FDEP was that TN, TP, and chlorophyll-a were used to calculate annual average TSI values to interpret Florida's narrative nutrient criteria. For high color lakes, an exceedance of an annual average TSI value of 60 in any one year of the verified period was sufficient for being declared impaired for nutrients. Even though Lake Bonny is a low color lake (FDEP 2014c) prior work in the Winter Haven Chain of Lakes had shown that many low color lakes in Polk County are naturally mesotrophic to eutrophic (Whitmore and Brenner 1995); therefore, a TSI target value of 60 is more appropriate. From 1996 to 2002, every annual average TSI value exceeded the impairment threshold of 60. In the more recent Cycle 2 verification period (January 2002 to June 2009) annual mean TSI values also exceeded the threshold of 60.

Water Quality Targets

Lake Bonny is classified as a lake with low color (<40 PCU) and high alkalinity (>20 mg/L CaCO₃). The new chlorophyll-a NNC for low color, high alkalinity lakes is an annual geometric mean value of 20 µg/L, which is not to be exceeded more than once in any consecutive three-year period. As Lake Bonny exceeded NNC guidance for chlorophyll-a, its default threshold values for TN and TP would be 1.05 and 0.03 mg/L, respectively, using NNC.

However, a more detailed assessment was conducted to develop TN and TP targets for Lake Bonny. For TN, a regression equation that examined the relationship between TN and chlorophyll-a was used to derive the TN concentration that would result in a chlorophyll-a value of 20 µg/L. Based on the derived equation, a TN concentration of 0.89 mg/L would be expected to result in a chlorophyll-a concentration of 20 µg/L. That TN concentration was used as the target for Lake Bonny.

The selection of a TP target for Lake Bonny was complicated by a discrepancy between two different approaches to setting targets. The TN target of 0.89 mg/L was chosen based on the correlation between TN and chlorophyll-a, and solving the equation for the TN target that corresponds to a chlorophyll-a concentration of 20 µg/L. Using this approach for TP, the target TP value for Lake Bonny would be approximately 0.025 mg/L. However, a paleolimnological study conducted on Lake Bonny (Whitmore and Brenner 2002) determined that TP values would have historically been somewhere between 0.032 and 0.043 mg/L, values 28 and 72 percent higher than the derived TP target (based on a chlorophyll-a vs. TP relationship) described above. FDEP's guidance is that no water quality standard can be stricter than conditions in an undisturbed

condition, therefore it was concluded (FDEP 2014c) that the derived value of 0.025 mg TP/L was inappropriate. Instead, the higher of the two values for “historical” TP values from the paleolimnological study (Whitmore and Brenner 2002) was used, and the TP target for Lake Bonny was thus set at 0.043 mg/L.

Pollutant Loading Model

As opposed to most of the TMDLs produced by FDEP, the TMDL for Lake Bonny is empirically derived based on relationships between nutrients and chlorophyll-a, as modified with results from paleolimnological studies. Consequently, there are no requirements that reduced nutrient concentrations have to be achieved by acting on external loads of TN and TP. While the TMDL for Lake Bonny summarized land use within the lake’s watershed, there are no estimates of external loads to the lake. Instead, lake management activities to meet the TMDL targets for TN and TP can be based solely on reducing nutrient concentrations by acting on internal processes such as bottom resuspension, by increasing the uptake of nutrients via submerged aquatic vegetation, or by increasing the role of wetlands as a moderating influence on the transformation of nutrients into algal biomass. While this approach may seem counter-intuitive to those who are more familiar with “traditional” TMDLs, it is consistent with data from the lake itself. For example, Figure 5.3 in the TMDL shows a strong inverse relationship between rainfall and chlorophyll-a values on an annual basis; years with the highest quantities of external stormwater loads do not have the worst water quality, they have the best water quality, on average. As such, acting on external stormwater loads alone is not likely to bring about improvements in water quality. By not focusing on external loads (in fact, not even quantifying them) the TMDL allows lake managers to act on those factors that are most important to the lake’s water quality.

The percent reductions in TN and TP are based on the following equation:

$$\frac{[\text{Measured exceedance} - \text{target}] \times 100}{\text{Measured exceedance}}$$

The term “measured exceedance” as used in the TMDL for Lake Bonny (FDEP 2014a) refers to the median values of the annual geometric mean values for TN and TP values that exceeded the water quality targets of 0.89 mg TN/L and 0.04 mg TP/L. The TMDL (FDEP 2014a) lists a geometric mean value of 2.46 mg TN/L; a 64 percent reduction in TN concentrations is thus required to meet the target TN value of 0.89 mg/L. With a geometric mean value of 0.10 mg TP/L, a 60 percent reduction in concentrations is required to meet the target TP value of 0.04 mg/L.

The TMDL for Lake Bonny (FDEP 2014a) appears to be less problematic than most of the other TMDLs for the City’s lakes. The TMDL is based on empirically-derived relationships, which are then compared to NNC criteria and results from paleolimnological studies. The TMDL also allows for the possibility that in-lake processes can be used to achieve water quality goals, a major oversight for most other TMDLs. The combination of using actual data, rather than overly complex mechanistic models, and the inclusion of in-lake processes makes the TMDL more realistic than most. It will be a serious challenge for the City to achieve the water quality improvements laid out in this TMDL, but the targets are more realistic than those of most other TMDLs.

In 2016, Whitmore et al. completed a detailed assessment of historical water quality conditions in Lake Bonny using paleolimnological techniques. In that report, it was concluded that pre-development TP concentrations were likely in the range of 0.04 to 0.045 mg TP/L, values mostly in line with the TMDL target. However rather than being accompanied by a chlorophyll-a value of 20 µg/L, Whitmore et al. (2016) concluded that pre-development values were approximately half that, at 10 µg/L.

During pre-development conditions, the diatom communities in Lake Bonny were representative of more acidic conditions. It was concluded that Lake Bonny had previously been more greatly influenced by compounds such as tannic, fulvic and humic acids that are associated with waters in forested wetlands. In the case of Lake Bonny, Whitmore et al. (2016) not only suggested TP reductions were in order, but that a holistic water quality management approach for the lake would require “...restoring water color from fringe swamps and wetlands...”

Crystal Lake (WBID 1497A)

Basis for Impairment

Crystal Lake is a Class III freshwater lake, with a designated use for recreational purposes and the propagation and maintenance of a healthy, well-balanced population of fish and wildlife. The lake was identified as impaired for nutrients pursuant to EPA commitments related to the 1998 Consent Decree (Florida Wildlife Federation et al. v. Carol Browner et al., Civil Action No. 4: 98CV356-WS). In that Consent Decree, the EPA committed to developing TMDLs for a number of waterbodies, including a TMDL that addresses Lake Alfred, Crystal Lake, and Lake Ariana (EPA 2010).

The TMDL for Crystal Lake, described below, has been effectively superseded by the recently approved (by FDEP) Nutrient Reduction Plan for the lake. The Plan, which has been informally approved via email communication, should result in the delisting of Crystal Lake from the Verified List, as it will be placed into a 4e assessment category on FDEP’s Study List. The Nutrient Reduction Plan identifies several restoration activities proposed to improve lake water quality which includes regional projects to reduce external loads (e.g., street sweeping, fertilizer ordinance) as well as site-specific project to address internal loading (e.g. sediment removal).

The superseded TMDL for Crystal Lake used water quality data from 1992 to 2007 to calculate TSI values for those years when data for TN, TP and chlorophyll-a were available. The majority of the water quality data collected in Crystal Lake was collected over the entire 16-year period of 1992 to 2007. The TMDL (EPA 2010) determined that sufficient data were available to characterize water quality for the entire period of 1992 to 2007. As Crystal Lake was determined to be a low color lake (PCU < 40) the threshold for impairment was set at a TSI value of 40. Although annual average values are not shown in the TMDL report (EPA 2010) every TSI value calculated exceeded 40, which was determined to be sufficient evidence to support Crystal Lake being classified as impaired.

The TMDL for Crystal Lake (EPA 2010) was found to be problematic for a number of reasons:

- The TMDL for Crystal Lake is based on the attainment of a TSI target of 35, which would give a 5-unit margin of safety over the chosen TSI impairment level of 40
- However, prior work on low color lakes in Polk County (i.e., Conine, Hartridge, Howard and May; Whitmore and Brenner 1995) has shown that a TSI target of 60 is more appropriate, as lakes in this portion of Central Florida were historically mesotrophic to eutrophic
- Consequently, the water quality targets for chlorophyll-a, TN and TP are inappropriately low, and most likely unattainable
- Perhaps related to the utilization of an inappropriately strict water quality target, the TMDL calls for unrealistic reductions in benthic fluxes (which were not measured) and stormwater runoff

However, when using lake data and NNC guidance, the amount of improvement in water quality required for Crystal Lake to reach unimpaired status is still significant; suggesting that Crystal Lake requires significant improvements in water quality, and that stormwater loads and internal loads could both be significant stressors for the lake.

The Nutrient Reduction Plan for Crystal Lake addresses many of these shortcomings, by focusing on both external and internal nutrient loads, and by outlining a number of projects that are needed to comprehensively address the issues that affect water quality in Crystal Lake.

Lake Hollingsworth (WBID 1549X) TMDL

Basis for Impairment

Lake Hollingsworth is classified as a Class III freshwater waterbody, with a designated use of recreation, propagation and maintenance of a healthy, well-balanced population of fish and wildlife. The Class III water quality criterion applicable to the verified impairments (nutrients) for this water is the state of Florida's nutrient criterion in Paragraph 62-302.530(47) (b), F.A.C.

FDEP (2018) had determined that Lake Hollingsworth was impaired for nutrients using the methodology in the IWR Rule 62-303, F.A.C. and was included on the Verified List of impaired waters for the Sarasota Bay – Peace River – Myakka River Group 3 Basin that was adopted by Secretarial Order on June 17, 2005. FDEP verified the lake as being impaired for nutrients based on elevated annual average TSI values during the Cycle 1 verification period (January 1997 to June 2004). At the time the Cycle 1 assessment was performed, the IWR methodology used the water quality variables TN, TP, and chlorophyll-a to calculate annual TSI values. An exceedance of an annual average TSI value of 60 in any single year of the verified period was sufficient for identifying a lake as impaired for nutrients. As every annual mean TSI value from 1996 to 2002 exceeded 60 in the Cycle 1 period, and also for the Cycle 2 period as well (January 2002 to June 2009), Lake Hollingsworth easily met the criteria for being declared impaired for nutrients.

While FDEP has not formally examined Lake Hollingsworth using NNC, a preliminary assessment by FDEP has found that Lake Hollingsworth would still be impaired with NNC, as it is with the

use of TSI. Lake Hollingsworth is a Group 3 waterbody as part of the Upper Peace River, the most recent impairment evaluation was performed for the verified period of January 1, 2008 to June 30, 2015 (Cycle 3) which applied TSI as the numeric criteria. The cycle 4 assessment period will occur in 2021 for the verified period of January 1, 2013 to June 30, 2020 and implement the NNC criteria.

Water Quality Targets

Lake Hollingsworth is classified as a lake with low color (<40 PCU) and high alkalinity (>20 mg/L CaCO_3). The chlorophyll-a NNC for low color, high alkalinity lakes is an annual geometric mean value of 20 $\mu\text{g/L}$, which is not to be exceeded more than once in any consecutive three-year period. As Lake Hollingsworth exceeded NNC guidance for chlorophyll-a, it's default threshold values for TN and TP would be 1.05 and 0.03 mg/L, respectively, using NNC.

However, a more detailed assessment was conducted to develop TN and TP targets for Lake Hollingsworth. For TN, a regression equation that examined the relationship between TN and chlorophyll-a was used to derive the TN concentration that would result in a chlorophyll-a value of 20 $\mu\text{g/L}$. Based on the derived equation, a TN concentration of 0.86 mg/L would be expected to result in a chlorophyll-a concentration of 20 $\mu\text{g/L}$. That TN concentration was used as the target for Lake Hollingsworth.

The selection of a TP target for Lake Hollingsworth was complicated by a discrepancy between two different approaches to setting targets. The TN target of 0.86 mg/L was chosen based on the correlation between TN and chlorophyll-a, and solving the equation for the TN target that corresponds to a chlorophyll-a concentration of 20 $\mu\text{g/L}$. Using this approach for TP, the target TP value for Lake Hollingsworth would be approximately 0.015 mg/L. However, a paleolimnological study conducted on Lake Hollingsworth (Brenner et al. 1999) determined that TP values would have historically been somewhere between 0.020 and 0.036 mg/L, values 33 and 140 percent higher than the derived TP target (based on a chlorophyll-a vs. TP relationship) described above. FDEP's guidance is that no water quality standard can be stricter than conditions in an undisturbed condition, therefore it was concluded (FDEP 2018) that the derived value of 0.015 mg TP/L was inappropriate. Instead, the higher of the two values for "historical" TP values from the paleolimnological study (Brenner et al. 1999) was used, and the TP target for Lake Hollingsworth was subsequently set at 0.036 mg/L.

The combination of problematic water quality targets and issues associated with the identification of pollution sources for Lake Hollingsworth suggest that the lake management could be best supported through the development of a locally-derived Nutrient Reduction Plan for Lake Hollingsworth, as was done for Crystal Lake. The Nutrient Reduction Plan for Lake Hollingsworth should be focused on obtaining a realistic water quality condition for the lake, likely with TP and chlorophyll-a targets of perhaps 0.036 mg/L and 30 $\mu\text{g/L}$, respectively.

Pollutant Loading Model

As opposed to most of the TMDLs produced by FDEP, the TMDL for Lake Hollingsworth is empirically derived based on relationships between nutrients and chlorophyll-a, as modified with results from paleolimnological studies. Consequently, there are no requirements that reduced

nutrient concentrations have to be achieved by acting on external loads of TN and TP. Instead, lake management activities to meet the TMDL targets for TN and TP can be based solely on reducing nutrient concentrations by acting on internal processes such as bottom resuspension, by increasing the uptake of nutrients via submerged aquatic vegetation, or by increasing the role of wetlands as a moderating influence on the transformation of nutrients into algal biomass.

While the TMDL for Lake Hollingsworth summarized land use within the lake's watershed, there are no estimates of external loads to the lake. Instead, lake management activities to meet the TMDL targets for TN and TP can be based solely on reducing nutrient concentrations by acting on internal processes such as bottom resuspension, by increasing the uptake of nutrients via submerged aquatic vegetation, or by increasing the role of wetlands as a moderating influence on the transformation of nutrients into algal biomass. While this approach may seem counter-intuitive to those who are more familiar with traditional TMDLs, it is consistent with data from the lake itself. For example, Figure 5.3 in the TMDL shows a strong inverse relationship between rainfall and chlorophyll-a values on an annual basis; years with the highest quantities of external stormwater loads do not have the worst water quality, they have the best water quality, on average. As such, acting on external stormwater loads alone is not likely to bring about improvements in water quality. By not focusing on external loads (in fact, not even quantifying them) the TMDL allows lake managers to act on those factors that are most important to the lake's water quality.

The percent reductions in TN and TP are based on the following equation:

$$\frac{[\text{Measured exceedance} - \text{target}] \times 100}{\text{Measured exceedance}}$$

The measured exceedances in this case are the medians of the TN and TP annual geometric mean values that exceed the water quality targets. For the existing geometric mean TN value of 1.78 mg/L to achieve the target TN concentration of 0.86 mg/L, a 52 percent reduction in TN concentrations is necessary. A 57 percent reduction in the existing annual geometric mean TP concentration of 0.07 mg/L is needed to meet the target TP concentration of 0.036 mg/L. Based on a statistical relationship from Florida lakes in general, the target of 0.036 mg TP/L derived above was then converted into an annual geometric mean value of 0.033 mg TP/L, which serves as the final TP target for Lake Hollingsworth.

The TMDL for Lake Hollingsworth (2018) appears to be less problematic than most of the other TMDLs for the City's Lakes. The TMDL is based on empirically-derived relationships, which are then compared to NNC criteria and results from paleolimnological studies. The TMDL also allows for the possibility that in-lake processes can be used to achieve water quality goals, a major oversight for most other TMDLs. The combination of using actual data, rather than overly complex mechanistic models, and the inclusion of in-lake processes makes the TMDL more realistic than most. It will be a serious challenge for the City to achieve the water quality improvements laid out in this TMDL, as paleolimnological work conducted on the lake (Brenner et al. 1999) suggests that the TP target is restrictive enough that the lake would have been declared impaired for nutrients more than 100 years ago. Also, the empirically-derived relationship between TP and chlorophyll-a in the TMDL shows that even if the proposed target of 0.036 mg TP / liter was achieved, the

lake's chlorophyll-a value would continue to be at least 50% higher than the default NNC target of 20 µg / liter.

Lake Hunter (WBID 1543)

Basis for Impairment

Lake Hunter is a Class III freshwater lake, with a designated use for recreational purposes and the propagation and maintenance of a healthy, well-balanced population of fish and wildlife. The lake was verified as impaired for nutrients in 2004 using the method in the IWR Rule 62-303, F.A.C.

The Final TMDL for Lake Hunter (FDEP 2004), adopted by FDEP and approved by EPA, used water quality data from 1988 to 2002 to calculate TSI values for those years when data for TN, TP and chlorophyll-a were sufficient to calculate annual averages. As such, TSI values were not calculated in 1988, 1989, 1990, and 1995 due to insufficient data. Annual average TSI values exceeded the threshold value of 60 in all of the years where sufficient data existed (1991 through 1994, and also 1996 to 2002) with an annual average TSI value of 79.7. As only a single year's exceedance was sufficient for a lake to be placed on the verified Impaired list, Lake Hunter easily exceeded the impairment threshold.

Water Quality Targets

The TMDL for Lake Hunter (FDEP 2004) determined that there were no permitted wastewater treatment facility (WWTF) discharges to the lake. For non-point sources, the TMDL (FDEP 2004) noted that stormwater systems owned and operated by local governments and the Florida Department of Transportation (FDOT) are covered by a MS4 NPDES permit.

The water quality target setting process for Lake Hunter was inconsistent with other TMDL efforts in Polk County, which have mostly used the mechanistic water quality model components of WASP or BATHTUB nor did it use a more traditional empirical approach whereby nutrient loads (or concentrations) would be compared to a potential response variable such as chlorophyll-a. Instead, chlorophyll-a concentrations, as the primary response variable, were predicted based on a series of equations, as shown below:

Chlorophyll-a concentrations in the lake (µg/L) were predicted using the following equation:

$$Chla = C_c \times B_x / [(1 + 0.025 B_x \times G) (1 + G \times a)]$$

Where;

C_c is a calibration coefficient (to better fit predicted vs. observed values) set at 1.6

B_x is derived from the following equation:

$$B_x = X_{pn} 1.33 / 4.31, \text{ where:}$$

$$X_{pn} = \{p - 2 + [(n - 150) / 12] - 2\} - 0.5, \text{ where:}$$

p = concentration of TP (µg/L), and

n = concentration of TN (µg/L)

Where:

$$G = Z_{\text{mix}} (0.14 + 0.0039 F_s), \text{ where}$$

Z_{mix} = mean depth of mixed layer (m), and
 F_s = flushing rate of the lake (estimated elsewhere in the report)

Where:

a – non-algal turbidity (m⁻¹), where:
 $a = S - 1 - 0.025 (\text{Chla}), \text{ where:}$
 S = Secchi disk depth, approximated as:
 $S = C_s 16.2 \times X_{\text{pn}}^{-0.79}; \text{ where}$
 C_s is given a value of 1, and X_{pn} is as defined above

Of the equations shown above which are used to predict chlorophyll-a concentrations in Lake Hunter, the only directly measured water quality parameters in those series of equations are TN, TP and chlorophyll-a. As such, most of the equations used to predict water quality are based, directly or indirectly, on assumptions or derived coefficients that are themselves either assumed or are further derived from additional assumptions. The equations themselves appear to be based on logical assumptions of water quality “behavior” but they are not locally measured, and they may not be locally relevant. For Lake Hunter, it would appear that nutrient load reduction targets derived in the TMDL might be somewhat spurious.

The TMDL for Lake Hunter calls for 80 percent reductions in the loads of both TN and TP. While there is a statistically significant correlation found between TN and chlorophyll-a in Lake Hunter, the majority of TN values higher than 2.4 mg/L cannot be ascribed to stormwater loads alone, as those values are higher than the highest Event Mean Concentration (EMC) values shown for urban land uses in Harper and Baker (2007). Instead, it is more likely that the highest TN concentrations (>2.4 mg/L) are likely reflecting the influence of nitrogen fixation by cyanobacteria, as has been previously documented in Lake Hancock (Tomasko et al. 2009) and Lake Jesup (PBS&J 2006). A comparison of TP and chlorophyll-a concentrations from IWR Run 47 found no significant correlation between those two parameters.

Based on an examination of water quality data during the Verified Impaired time period for Lake Hunter (IWR Run 47) the mean reduction in chlorophyll-a concentrations required to meet NNC criteria was estimated at 79 percent. Also using NNC criteria, the average reduction in TN and TP concentrations required would be 57 and 79 percent, respectively. However, TN concentrations in Lake Hunter are likely elevated via nitrogen-fixation by cyanobacteria, and there is no clear evidence that TP concentrations correlate with chlorophyll-a concentrations.

Pollutant Loading Model

The pollutant loading model for the Lake Hunter TMDL (FDEP 2004) used the Watershed Management Model (WMM) to estimate loads of TN and TP from stormwater runoff. The volume of stormwater runoff generated is based on the equation:

$$R_L = [C_p + (C_i - C_p) \text{IMP}_L] * I$$

Where: R_L = average surface water runoff;
 C_p = pervious runoff coefficient;

C_i = impervious area runoff coefficient;
 IMP_L = fraction of the land use that is impervious; and
 I = average rainfall

The volume of stormwater runoff generated is then converted into a loading rate of pollutants via the equation:

$$M_L = EMC_L * R_L * I * K$$

Where:
 M_L = loading factor for each land use (lbs. per acre per year);
 EMC_L = land use specific EMC (mg/L);
 R_L = average surface water runoff (calculated above); and
 K = a unit conversion equation

As such, WMM uses an approach similar to a standard spreadsheet-derived loading estimate, with stormwater pollutant quantities based on GIS-based data on soils and land use, rainfall, estimated runoff, and then EMC values for TN and TP. EMC values came from Harper and Baker (2007).

As is the case with other pollutant loading models used in Polk County, there does not appear to be an exercise within the TMDL for which model output on pollutant loads is compared to measured data of flows and concentrations. Instead, the pollutant loading model and the water quality model are “calibrated” against in-lake concentrations. More often than not, this model calibration effort is accomplished via the modification of rate coefficients that have never been locally measured (e.g., TP settling rates).

Additional pollutant loading model elements are included, such as atmospheric deposition, groundwater inflows, and inflows from upstream areas. Septic tanks are assumed (based on Haith et al. 1992) to load potentially significant amounts of TN to the lake, in part due to the model not accounting for denitrification (nitrate loads are removed from groundwater only via plant uptake). Perhaps related to the potentially over-estimated influence of septic tank systems, the TMDL predicts that unimpaired water quality would occur only after TN and TP loads from stormwater are reduced by 80 percent and septic tank systems are replaced with central sewage throughout the watershed. In an earlier TMDL for a different water body, however, it was determined by FDEP that thousands of septic tank systems had a negligible effect on downstream TN loads into Roberts Bay (FDEP 2004).

Four main considerations suggest that the TMDL for Lake Hunter requires significant review prior to implementation: 1) the water quality targets are dependent upon a series of overly complex equations that are dependent, either directly or indirectly on numerous assumptions, 2) the relationship between TN and chlorophyll-a could be strongly influenced by TN “made” by nitrogen-fixing cyanobacteria, rather than chlorophyll-a being controlled by TN itself, 3) there is no statistically significant correlation between TP and chlorophyll-a, 4) the pollutant loading model appears to not sufficiently account for the potential role of in-lake processes for both TN and TP, and 5) the role of septic tank systems on the TN load is assumed, not measured, and is at odds with estimates of such loads from other systems.

Further work is justified, focusing on the discrepancies above, prior to the investment of time and resources to implement the TMDL for Lake Hunter (FDEP 2004).

Lake Parker (WBID 1497B)

Basis for Impairment

Lake Parker was verified as impaired for nutrients using the methodology in IWR Rule 62-303, F.A.C. The lake and canal were included on the Verified List of impaired waters that was adopted by Secretarial Order on June 17, 2005. Lake Parker is a Class III freshwater lake, with a designated use for recreational purposes and the propagation and maintenance of a healthy, well-balanced population of fish and wildlife.

The Draft TMDL for Lake Parker (FDEP 2005) used water quality data from January 1, 1997 to June 30, 2004. The annual average value for color averaged 48.2 PCU. As such, the default target TSI value for TMDL development would have been set at 60, as Lake Parker is considered a high color lake (i.e., color levels in excess of 40 PCU). However, paleolimnological work conducted on Lake Parker concluded that in an undisturbed condition, Lake Parker's water quality would have been equivalent to a TSI value of 68.4. The average TSI value for the years 1997 to 2003 was 83.6, with each year exceeding the target TSI value. As only a single year's exceedance was sufficient for a lake to be placed on the Verified Impaired list, Lake Parker easily exceeded the impairment threshold. As noted above, the State of Florida no longer uses TSI to determine impairment status of lakes, or to develop water quality targets for TMDLs.

Water Quality Targets

The TMDL for Lake Parker (FDEP 2005) determined that there were no permitted WWTP discharges to the lake, although the lake waters are used for cooling purposes for two power generation facilities. Also, the northern portion of the lake has been substantially altered by phosphate mining activities. For non-point sources, the TMDL (FDEP 2005) noted that stormwater systems owned and operated by local governments and the FDOT are covered by an NPDES MS4 permit.

The water quality target setting process for Lake Parker took into account findings from paleolimnological work conducted for the lake. These paleolimnological results suggested an historical TSI value of 68.4. However, the target TSI value was based on the use of linked watershed and water quality response models previously conducted in Lakes Bonny and Gibson, which was then further modified.

The pollutant loading models for Lakes Bonny, Gibson, and Parker were modified to represent historical conditions by setting "leakance" rates to groundwater to 50 percent of current estimates (i.e., the lakes would lose more water historically) and then an estimate of excess nutrients that could not be accounted for in those lakes in their current condition was reduced by 75 percent to represent historical conditions. However, the use of these steps resulted in a TSI score for historical conditions that exceeded the current TSI scores. As a result, FDEP used a natural land use loading estimates alone, which gave rise to a TSI target of 67.9, a value fairly close to the TSI target from

paleolimnological work. A 5-unit TSI increase was used to develop the final TSI target value of 72.9 for Lake Parker.

The Lake Parker TMDL (FDEP 2005) used the WAM (Soil and Water Engineering Technology, Inc., 2005) to estimate pollutant loads, and WAM output was then the input for the BATHTUB model (Quantitative Environmental Analysis, LLC, 2005) to simulate water quality within Lake Parker.

The TMDL for Lake Parker calls for 57 percent load reductions for both TN and TP. Since there are no current point source discharges into Lake Parker, external load reductions of such a magnitude are impossible to bring about with any known technology of stormwater treatment, even if applied to 100 percent of the watershed of the lake. Quite a few of the TN values are higher than 2.8 mg/L, and cannot be ascribed to stormwater loads alone, as those values are higher than the highest EMC values shown for both urban and agricultural land uses in Harper and Baker (2007). Instead, it is more likely that the highest TN concentrations are likely reflecting the influence of nitrogen fixation by cyanobacteria, as has been previously documented in Lake Hancock (Tomasko et al. 2009) and Lake Jessup (PBS&J 2006); TN concentrations in Lake Parker are likely elevated via nitrogen-fixation by cyanobacteria.

Pollutant Loading Model

The pollutant loading model for the Lake Parker TMDL (FDEP 2005) incorporates standard spreadsheet-derived loading estimate, based on rainfall, runoff, and EMC values for TN and TP. The pollutant loads developed from the WAM were the input into the BATHTUB water quality model. The first model runs for “existing conditions” gave rise to results where measured TN values were often twice as high as model output. In the years 2000 and 2001, average TN values were as much as three-times higher than model output. For TP, an even more severe discrepancy was found; measured TP values were as much as eight-times higher than model output. Clearly, the combination of WAM and BATHTUB did not sufficiently characterize the water quality of Lake Parker.

In accommodate the discrepancy between model output and measured data for existing conditions, “...the primary calibration for TN and TP was achieved by invoking BATHTUB’s internal loading rate functions for both TN and TP to match the measured in-lake mass” (FDEP 2005). The term “internal loading rate” is meant to include not only in-lake processes such as nitrogen fixation (for TN) but “...all other missing mass.” Figures 5.1 and 5.2 in the TMDL show the differences between the initial model runs of TN and TP, respectively, vs. measured data, and also how the calibration step of invoking internal loading results in model output that exactly matches measured data. In essence, the TMDL for Lake Parker used a two-step process: 1) initial model runs resulted in significant underestimates of the TN and TP concentrations in the lake, 2) a model factor referred to as internal loading was then used to “calibrate” model output so that modeled and measured data would exactly coincide.

With any model, the term “calibration” refers to the process through which the modification of a state variable or rate coefficient is conducted in an attempt to better align model output and

measured data. Ideally, model calibration would involve relatively minor adjustment to model components, using state variables or rate coefficients that had been measured directly, hopefully in a somewhat similar environment. In the case of the Lake Parker TMDL, model calibration was not based on any measured processes (e.g., bottom resuspension, in-situ nitrogen fixation) from any nearby lake. Instead, calibration involved using the term “internal process” as a substitute for all the potential reasons why model output and measured values differed by so much. Since measured data on TN and TP were often 3 to 7 times higher than model output, this seriously compromises the validity of the TMDL. The lack of sufficient knowledge of the actual mechanisms behind the discrepancies between modeled and measured TN and TP values could result in a TMDL model that is calibrated via the modification of model variables that are not representative of actual field conditions.

Four main considerations suggest that the TMDL for Lake Parker requires significant review prior to implementation: 1) measured water quality has 3 to 7 times the level of TN and TP, respectively, vs. initial model runs, 2) calibration of the water quality model was accomplished via the inclusion of a term called “internal loading” that is neither fully explained as to its processes, nor is it derived from actual measurements of any processes in Lake Parker, 3) based on prior work in Lake Hancock (Tomasko et al. 2009) it is likely that bottom resuspension of phosphorus-rich sediments could be a significant source of the excess and unaccounted for TP concentration in the lake, and 4) based on prior work in Lake Hancock (Tomasko et al., 2009) it is likely that nitrogen-fixation by cyanobacteria within Lake Parker could be a significant source of the excess and unaccounted for TN concentrations in the lake.

Since neither bottom resuspension of TP-rich sediments nor in-situ nitrogen fixation have been measured in Lake Parker, the model calibration effort included in the TMDL (FDEP 2005) is problematic. In terms of meeting TMDL obligations, since neither bottom resuspension of TP rich sediments nor nitrogen fixation are processes included in the water quality model, they are not currently identified as activities through which TMDL reductions could be applied.

Further work is justified, focusing on the discrepancies above, prior to the investment of time and resources to implement the TMDL for Lake Parker (FDEP 2005).

3. FACTORS AFFECTING WATER QUALITY IN THE CITY'S PRIORITY LAKES

Lake eutrophication is a natural process of increasing nutrient enrichment and biological productivity that can be exacerbated by anthropogenic land uses (Gill et al. 2005). The accelerated eutrophication due to human activities is termed “cultural eutrophication”. Increased nutrients associated with eutrophication can increase algal growth (algal blooms) (Smith et al. 1999), in turn increasing turbidity, particulate organic matter, and dissolved organic particulate matter in lakes.

Historical water quality impacts in the City are presented in this section, thereby establishing the need for management projects. In addition to nutrients and chlorophyll-a, several other factors may influence water quality, including: long-term hydrologic alterations, stormwater runoff, historical point source discharges (particularly phosphorus), land use configurations, extent of SAV and EAV, and hydrologic connections to forested wetlands. The potential effects of these factors on water quality in the City's Priority Lakes are discussed here.

Historical Regional Impacts

In Florida, and particularly in Polk County, historical drainage projects have altered the hydrology of numerous watersheds and lowered lake levels below the elevations of their previously contiguous wetland fringes. These drainage features have resulted in long-term impacts to water quality and fish and wildlife habitats. In addition, urban development often occurs first in the highest, driest areas with the greatest potential for aquifer recharge, which not only increases wet season runoff (via increased impervious features) but also decreases the potential for dry season recharge of lake levels through groundwater seepage.

Hydrologic alterations such as dams, control structures, and drainage canals can adversely affect volumes, locations, and timing of natural stormwater and stream flows, and natural hydrologic functions in the watershed. These changes may be anthropogenic or climate induced. Hydrologic impacts due to urbanization are reported to cause water quality problems such as sedimentation, increased temperatures, habitat changes, and the loss of fish populations and several case studies indicate that these problems are caused by increased runoff volumes and velocities from urbanization and associated increases in watershed imperviousness (EPA 2010b). For example, floodplains with substantial hydrologic connection to streamflow may trap (riparian retention) large amounts of sediment and associated nutrients and other contaminants (Brinson 1988, Hupp et al. 2008, Noe and Hupp 2005, 2009). Unfortunately, these water quality functions of floodplains may not apply where there has been widespread alteration of fluvial processes by human activity, e.g.

dam construction, channelization, and concentrated land use (Sharitz and Mitsch 1993). In general, these alterations typically disrupt fluvial dynamic equilibrium (Hack 1960) such that the normal floodplain to streamflow connectivity may be decreased or increased (Hupp et al. 2008).

Prior to the enactment of the Federal Clean Water Act (CWA) and subsequent amendments to the CWA in the early 1970s, wastewater discharges to flowing waters were largely unregulated and streams were used to dilute and transport wastes from their sources. While environmental regulations have resulted in substantial improvements in wastewater treatment, wastewater discharges can still contribute to increased stream flows and pollutant concentrations in waterbodies.

Stormwater runoff increases pollutant loads and stormwater collection and conveyance systems. Consequently, pollutants may rapidly wash into downstream receiving waters and adversely impact water quality (Figure 3-1).

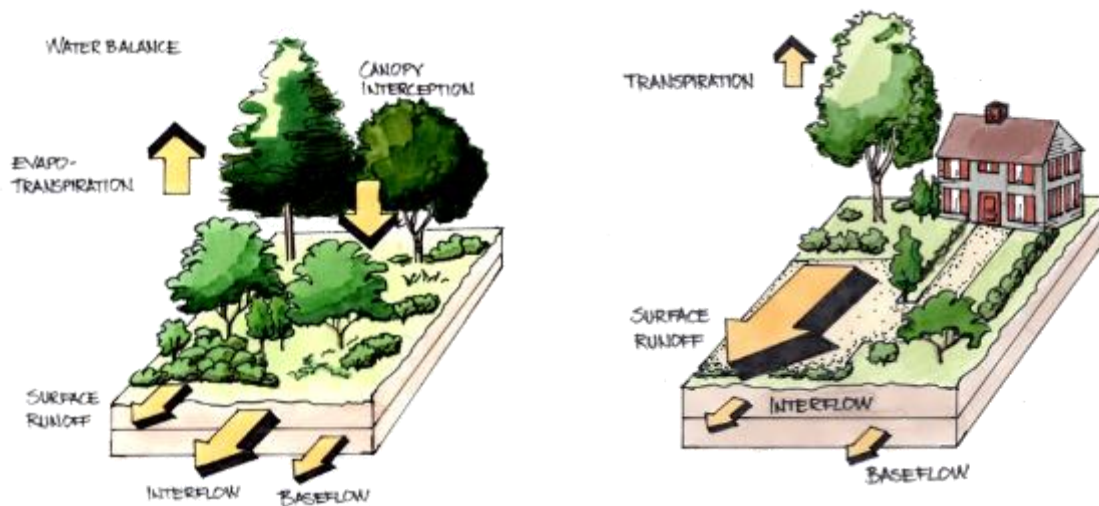


Figure 3-1. Impacts to watershed due to conversion from natural landscapes to urban development (from PBS&J 2007)

Pollution from nonpoint sources accounts for most of the water quality problems in the State of Florida. Typically, nonpoint source pollution is associated with stormwater runoff from residential, urban, and agricultural activities and the associated transport of sediments, nutrients, pathogens and pesticides.

In addition to stormwater runoff, agricultural activities can lead to potential nutrient loading to downstream waterways. Polk County has established itself as a leader in citrus production within the state of Florida harvesting 16.8 million boxes of citrus during the 2014-2015 growing season (Bouffard 2015). As such, the impact of fertilizer application on active citrus groves can degrade groundwater quality having deleterious impacts to receiving waterbodies. However, the County has experienced a reduction in land area available for citrus farming in the past 10 years (NASS 2015). Therefore, a reduction in active citrus groves has likely resulted in a reduction of nitrogen inputs to surface water bodies, thus resulting in potential water quality improvements. The role of

citrus production on lake water quality with contributing watersheds comprised of predominantly well-drained soils can be an important source load to evaluate in regards to water quality restoration efforts.

The City's Priority Lakes are located within the Lakeland Ridge/Bone Valley Upland physiographic region. According to Griffith et al. (1997) this physiographic region contains substantial phosphate deposits which are likely to result in high phosphorus, nitrogen and chlorophyll-a concentrations. Overall, the lakes are typically alkaline attributed partially to contribution by limestone-enriched groundwater. Those lakes within the Lakeland Ridge are located at a higher elevation likely resulting in rapid dewatering due to high infiltration soils. Those lakes within the Polk Upland but adjacent to the Lakeland Ridge are subject to lower elevations with lower infiltration soils resulting in poorly drained areas. Both watersheds have undergone substantial alteration for the purpose of agricultural, urban development as well as phosphate-mining, particularly in the Peace River watershed. The higher, drier areas in the headwaters/ridge portion of the Peace River watershed were developed first for residential and business use. These high-recharge areas historically helped maintain dry season water levels in the lakes, streams, and aquifer systems. Historical drainage projects diverted rainwater that once percolated into the surficial aquifer into the lakes.

In addition to anthropogenic impacts to water quality, natural, long-term seasonal rainfall patterns and associated hydrologic (ground water and surface water) changes affect water quality. Large rainfall events can increase stormwater and associated pollutant loads into lakes, while low rainfall can result in declining aquifers and low lake levels. In central Florida, the summer wet season accounts for nearly 60 percent of the 52 inches of total average annual precipitation. Streams, wetlands, and surficial ground water levels are typically at their lowest during May (end of dry season) and highest during September and October (end of wet season). Intense El Niño/Southern Oscillation (ENSO) events can result in atypical, extended periods of heavy rainfall during the typically dry season and dramatically alter the annual hydroperiod. Short term extremes of high and low flows influence the watershed budget over periods of years, while larger cyclic periods may cover a number of decades.

Urbanization

Development (residential and commercial / industrial) often results in the dramatic alteration of water quantity, water quality and natural systems. Increased impervious surfaces, which are often synonymous with urbanization; increase the surface water runoff and pollutant loads while negatively impacting the habitat and ecology of the natural system. Impervious surface has emerged as a measurable, integrating concept used to describe the overall health of a watershed. Numerous studies have documented the cumulative effects of urbanization on stream and watershed ecology (Schueler 1995, Arnold and Gibbons 1996, Shaver and Maxted 1996).

Prior to the replacement of natural surfaces with impervious surfaces and structures, the natural hydrology and ecology are impacted due to initial site clearing and grading. Even before impervious surfaces are constructed, much of the natural storage capacity of the developing area is often eliminated and rainfall subsequently flows off site as stormwater runoff. This loss of vegetation

and top soils results in a subsequent reduction in rainfall interception by canopy vegetation, as well as evapotranspiration and interflow, and increases surface water runoff. Vegetation that once intercepted rainfall is removed and natural depressions that temporarily held water are often graded to a uniform slope. The soil and associated litter and humus in floodplain forests that previously absorbed rainfall are usually removed or eroded away.

Construction of buildings, roads, parking lots, sidewalks, and driveways all increase the amount of impervious area, decrease rainfall precipitation into the ground, and subsequently increase the amount of stormwater runoff. The resulting excess runoff may be too large for the natural drainage system to manage and the existing drainage must be “improved” to convey the increased amounts of runoff away from the site by installing culverts, curbs, gutters, storm sewers, or lined channels. The stormwater improvements impact not only the water delivery but also the accompanying pollutants. Urbanization typically results in increasing pollutant loads as well as introduces new pollutants to the area. Previously, natural depressions provided storage as well as reduced the velocity of the run-off which resulted in evaporation and filtration through the associated vegetation and soil. Pollutants of concern include sediments, nutrients, pathogens and pesticides.

Citrus

Citrus-related agriculture is predominantly located within well-drained soils which are commonly found throughout Polk County. Historically, nutrient-laden fertilizer was applied to the citrus groves in an effort to enhance production. The fertilizer application rate generally exceeded the capacity for removal by the citrus trees alone and as such, elevated nutrient concentrations were observed within the underlying groundwater. A lag-time exists between the introduction of fertilizer within the sandy soils of the more elevated ridges and seepage of nutrient-laden groundwater to the base of the ridge ultimately discharging into the downstream lakes. Therefore, there appears to be a delay between the decline in fertilizer application due to the implementation of best management productions and an overall reduction in citrus production with improvements in water quality within the adjacent lakes.

A reduction in citrus-related agriculture is widespread throughout Florida. Due to a combination of land development (commercial or residential), citrus canker and citrus-greening, citrus acreage has declined since the 1960’s (Figure 3-2). State-wide, citrus was at the peak of production in the late 1960’s, followed by declines in the 1980s perhaps precipitated by hard freezes in 1983 and 1985, followed by slight increases during the 1990s, and then a more recent reduction perhaps associated with citrus greening. The Florida citrus production is estimated to remain constant or decline over the next ten years (Florida Department of Citrus 2011).

Previous studies in Polk, Seminole and Orange Counties have linked recent improvements in water quality within various lakes and springs to declining citrus production within the receiving water body watershed or (for spring-fed systems) groundwater recharge zones (Atkins 2009, ESA and Atkins, 2015). Although there is no specific evidence indicating that nitrogen loads were higher in the early-1950s, it is likely that that was the case, as citrus groves were a much more dominant feature throughout the Polk County landscape.

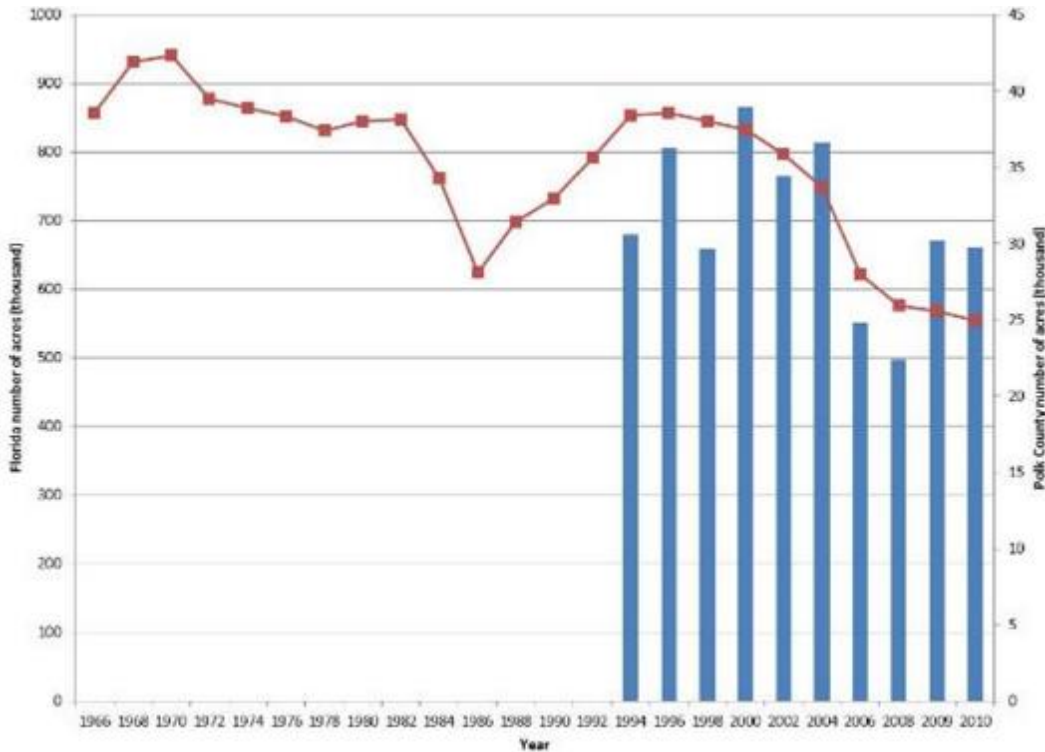


Figure 3-2. Florida (red line) and Polk County (blue bars) citrus acreage decline from 1966 to 2010 (data taken from Florida Department of Citrus 2011 and NASS 2015)

Historical Point Source Discharges and Legacy Sediments

Although there are no current wastewater discharges to lakes in the City, “legacy effects” of prior discharges could delay or preclude improvements in water quality until and unless accumulated sediments are appropriately addressed. The impact of phosphorus inputs from lake sediments on water quality has been examined for a limited number of lakes of within City’s Priority Lakes, including Lake Parker and Hollingsworth sediment cores indicated nutrient content elevated above which was found in Lake Seminole (Pinellas County). It is important to note that a substantial sediment removal and inactivation effort was performed on Lake Hollingsworth since the sediment analysis was completed and as such, result should be considered dated and not applicable to future project recommendations. Regardless of the lack of existing data to document the potential impact of “legacy” point source discharges on lake water quality, the potential nutrient pool available within lake sediments should be part of the development of lake restoration strategies.

Phosphorus inputs into lakes include external sources from the watershed and internal sources from the lake sediments. Phosphorus flux from sediments is sometimes sufficient to maintain anthropogenic eutrophication of a lake even when external phosphorus loads have been reduced or eliminated (Larsen et al. 1979, Ryding 1981). Consequently, after watershed management strategies reduce external phosphorus flux (e.g. stormwater treatment), recovery to a steady state (no net efflux of phosphorus from sediments into the water column) can be delayed many years if

mechanisms controlling internal phosphorus flux due to sediments are not included in restoration plans (Haggard et al. 2005, van Hullebusch et al. 2005) (Figure 3-3).

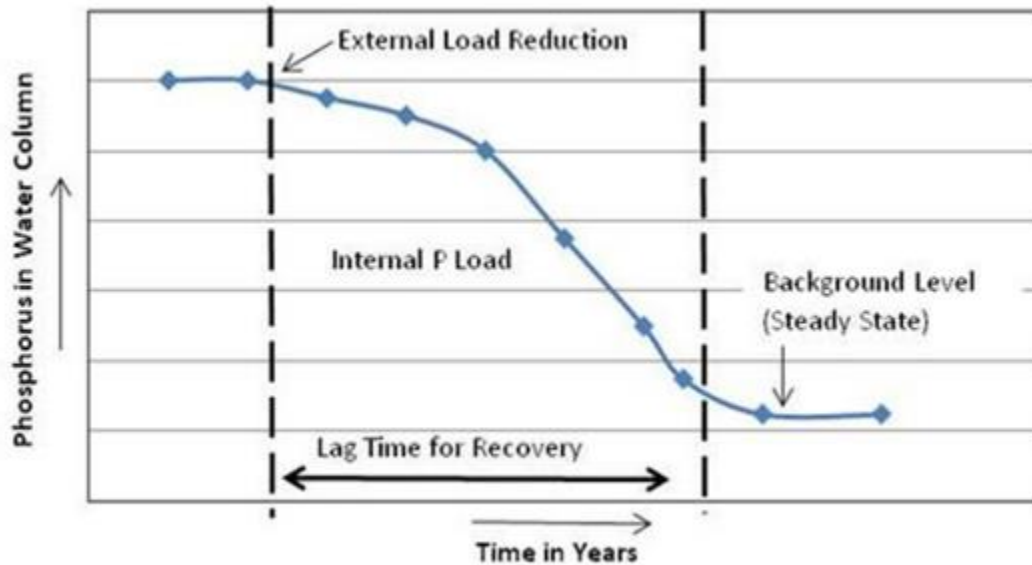


Figure 3-3. Influence of reduced external phosphorus reductions on phosphorus in water column (after Reddy et al. 1999)

The type of lake may also influence the effect of legacy phosphorus on water quality in the City's Priority Lakes. Lakes can be characterized as ridge or valley lakes. Ridge lakes are typically associated with sandy areas with the potential for higher rates of ground water recharge, compared with valley lakes, which are often dominated by surface water inflow. Ridge lakes typically have marsh-dominated shorelines, while valley lakes typically have forested wetlands along their shoreline. Ridge lakes, particularly those with a history of point source discharges, can be more susceptible to impacts from nutrient-enriched bottom sediments when compared with valley lakes (i.e. see Bachman et al. 2000). Sediments disturbed by wind or wave action can re-introduce nutrients into the water column and cause phytoplankton blooms. For valley lakes, lower lake levels can "disconnect" the lake from historical swamp shorelines, reducing the benefits of wetland-derived tannins that buffer the effects of increased nutrients (PBS&J 2008, Tomasko et al. 2016).

Phosphorus release into the water column can result from wind-induced sediment resuspension with shallower water depths that can be brought about by regional drainage systems. As an example, the Lake Dynamic Ratio concept for Florida lakes (Bachman et al. 2000) was used to predict decreases in sediment resuspension frequency (from once/week to once/two weeks) due to a 4 ½ feet increase in water levels in Lake Hancock (Tomasko et al. 2009). In that study, the authors concluded that "...increases in effective water depth of Lake Hancock would likely bring about an improvement in water quality, due in part to conditions being less favorable for resuspension of bottom sediments." For some lakes in the Winter Haven Chain of Lakes system, reduced lake levels (due to regional drainage systems) have created conditions which may increase the suspension of bottom sediments by 30-50 percent under windy conditions (ERD 2010).

Rainfall and Lake Levels

Monthly average total rainfall data for Polk County were obtained from the SWFWMD for the 1915-2016 period of record (POR). To test for trends over time, both parametric and non-parametric statistical tests were run. Parametric statistical analyses require the data sets to meet assumptions of normality and homogeneity of variance, which were not met. As such, the non-parametric Spearman's correlation test was run. The Spearman's test uses ranks, and does not require data to meet normality or homogeneity of variance, although it may be less able to detect trends if data were to meet those two requirements. For all timelines and rainfall groupings discussed below, there was no finding of a monotonic trend over time; while wet and dry years are evident, there is no evidence of a trend in rainfall with the data set analyzed.

The POR trend in annual rainfall is shown in Figure 3-4. In addition, the shorter timeline of 1980 to 2015 was examined for annual, total wet season, and total dry season rainfall, as shown in Figures 3-5, 3-6 and 3-7, respectively.

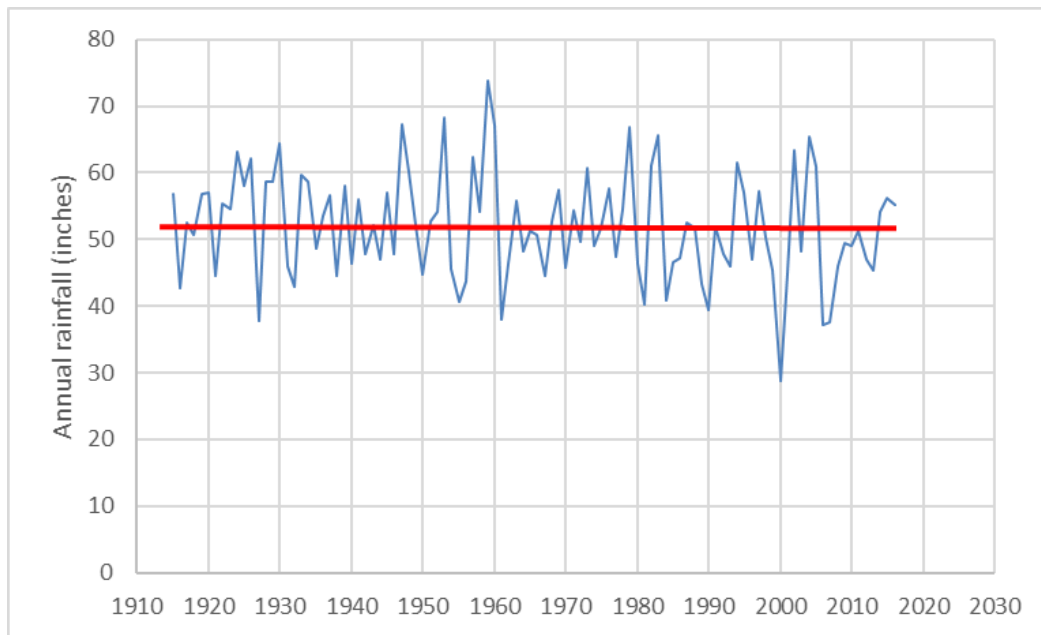


Figure 3-4. Mean annual rainfall for Polk County for 1915 to 2016 (data from SWFWMD). Red line equals average value of 52.01 inches.

Comparing the period of record (1915 to 2016) to the more recent period of 1980 to 2016, it appears that there has been slightly less rainfall over the past 36 years than the long-term average. Over the period of record, annual rainfall averaged 52.01 inches, while the average from 1980 to 2016 is 50.07, a value 3.7 percent lower.

As shown in Figure 3-4, the year 2000 had the lowest rainfall amount, across Polk County, in over 100 years (i.e., 1915 to 2016). The annual rainfall in 2000 of 28.8 inches is 45% lower than the POR average of 52.0 inches. The very low annual rainfall of 2000 was then followed by the dry season of 2001, which had the lowest amount of dry season rainfall in over 100 years (Figure 3-7).

Just four years later, the busy 2004 hurricane season produced the 6th greatest amount of annual rainfall over the past 100 years, and the highest amount of wet season rainfall since 1915. Although there is no evidence of a monotonic trend in rainfall over the POR or the last 25 years, the period of 2006 to 2013 constitutes eight years in a row with annual rainfall below the POR average of 52.01 inches.

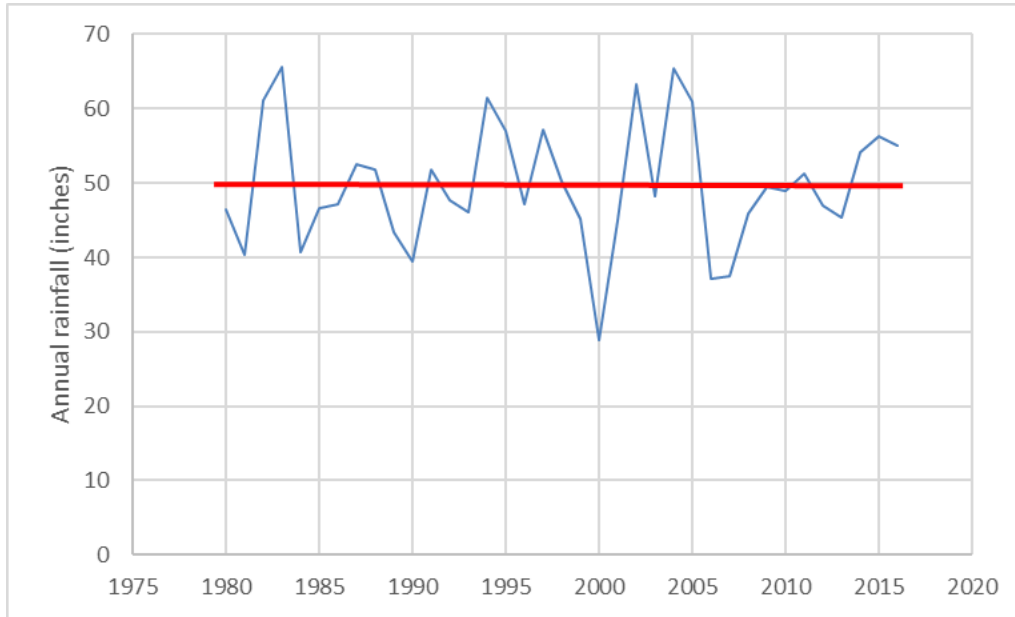


Figure 3-5. Mean annual rainfall for Polk County for 1980 to 2015 (data from SWFWMD). Red line equals average value of 50.07 inches.

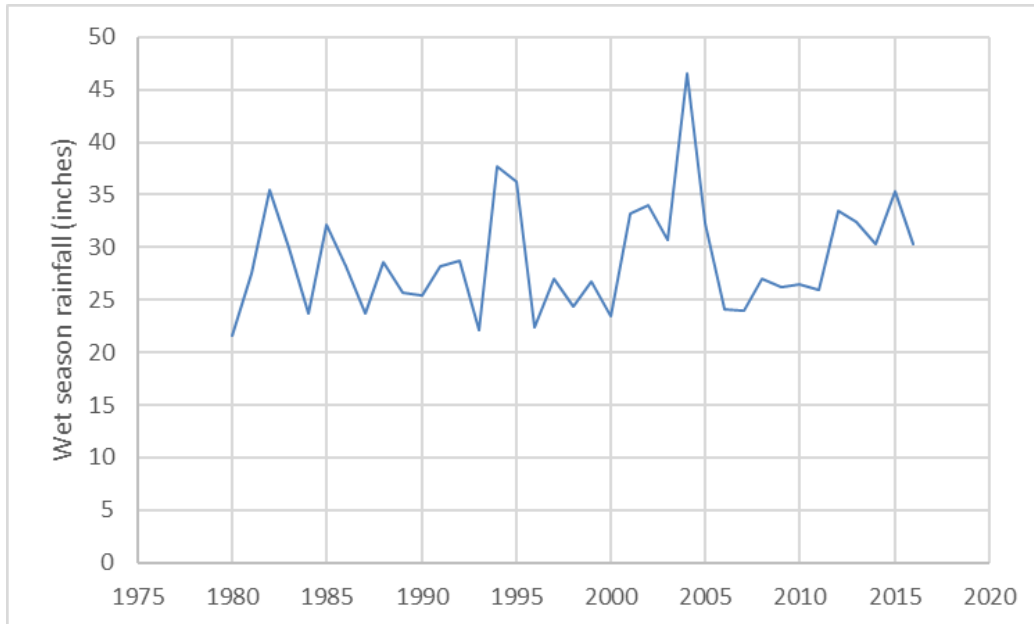


Figure 3-6. Mean wet season rainfall for Polk County for 1980 to 2015 (data from SWFWMD)

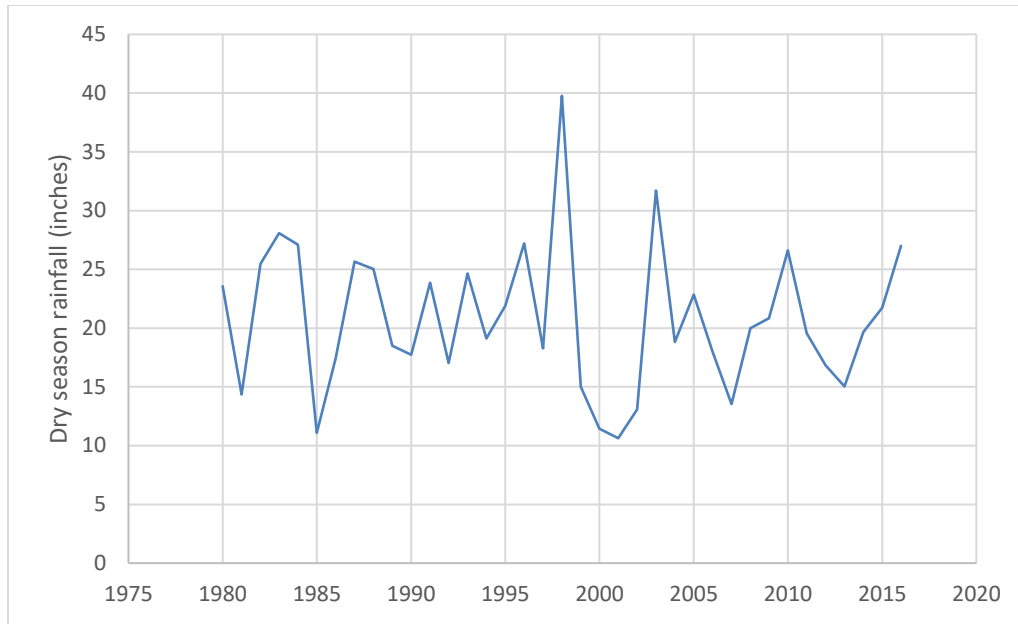


Figure 3-7. Mean dry season rainfall for Polk County for 1980 to 2015 (data from SWFWMD)

For illustrative purposes, lake elevation data are shown for Lakes Beulah, Bonnet, Hollingsworth, Mirror and Morton (Figures 3-8 to 3-12, respectively).

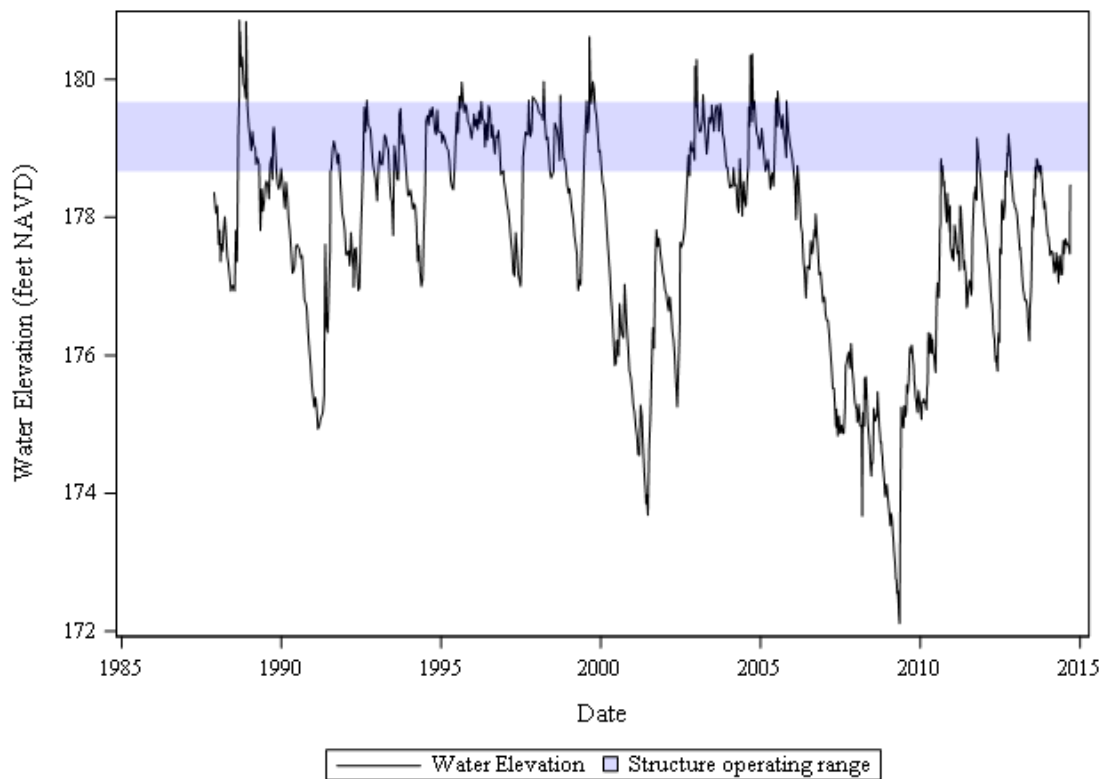


Figure 3-8. Period of Record water elevation for Lake Beulah (data from SWFWMD)

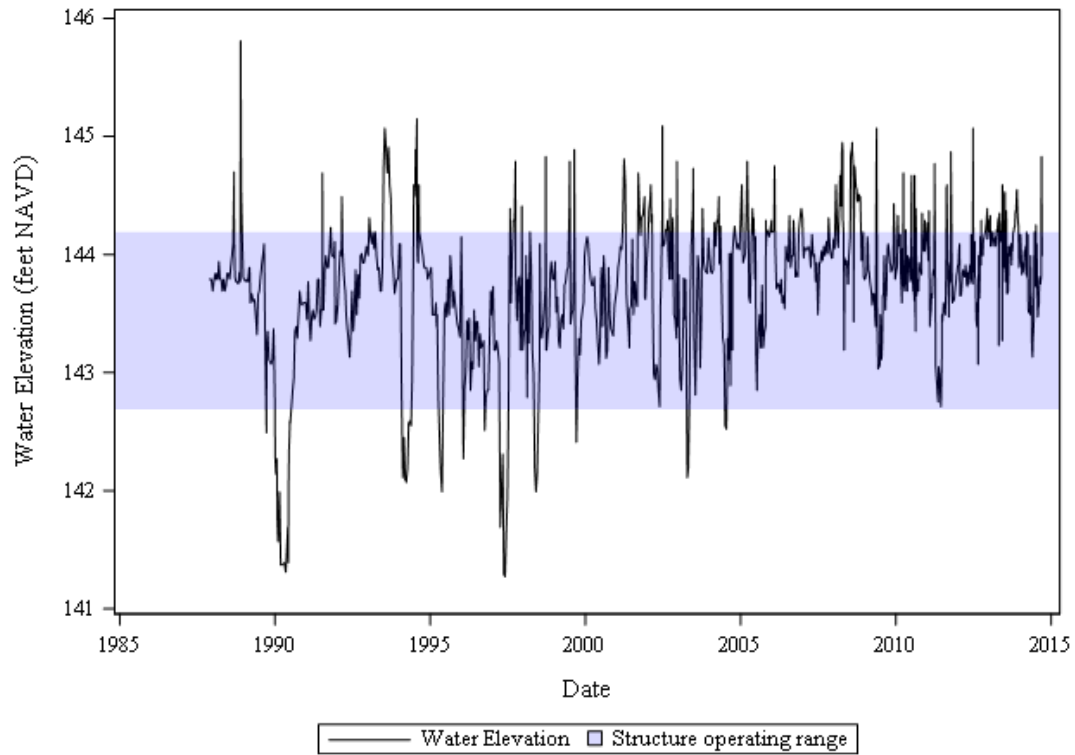


Figure 3-9. Period of Record water elevation for Bonnet (data from SWFWMD)

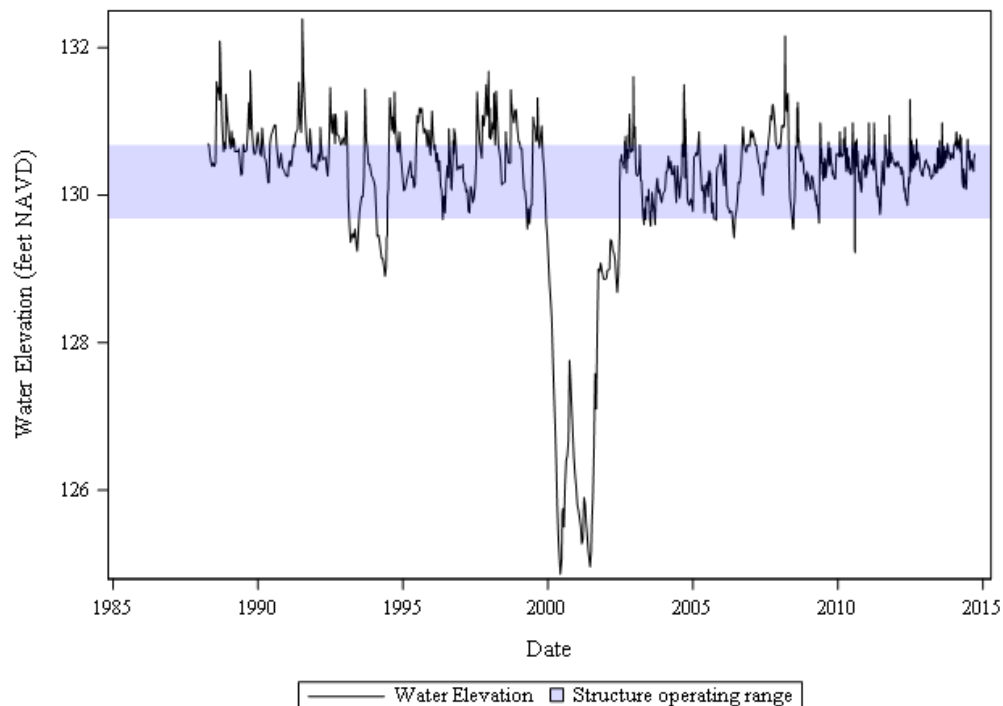


Figure 3-10. Period of Record water elevation for Lake Hollingsworth (data from SWFWMD)

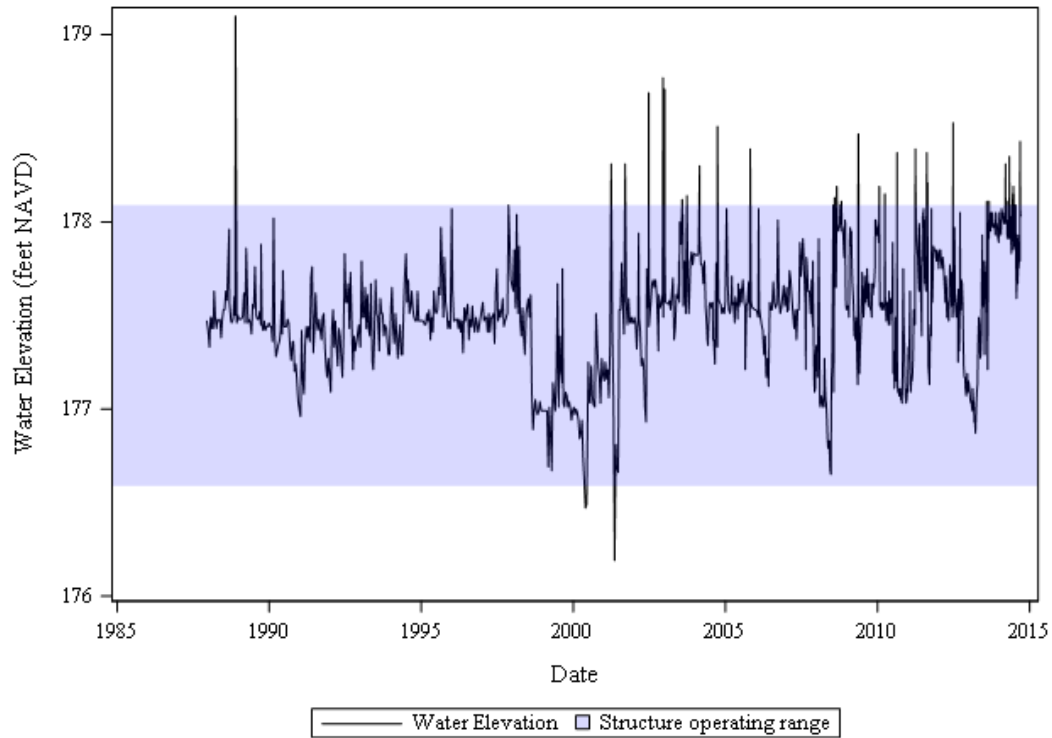


Figure 3-11. Period of Record water elevation for Lake Mirror (data from SWFWMD)

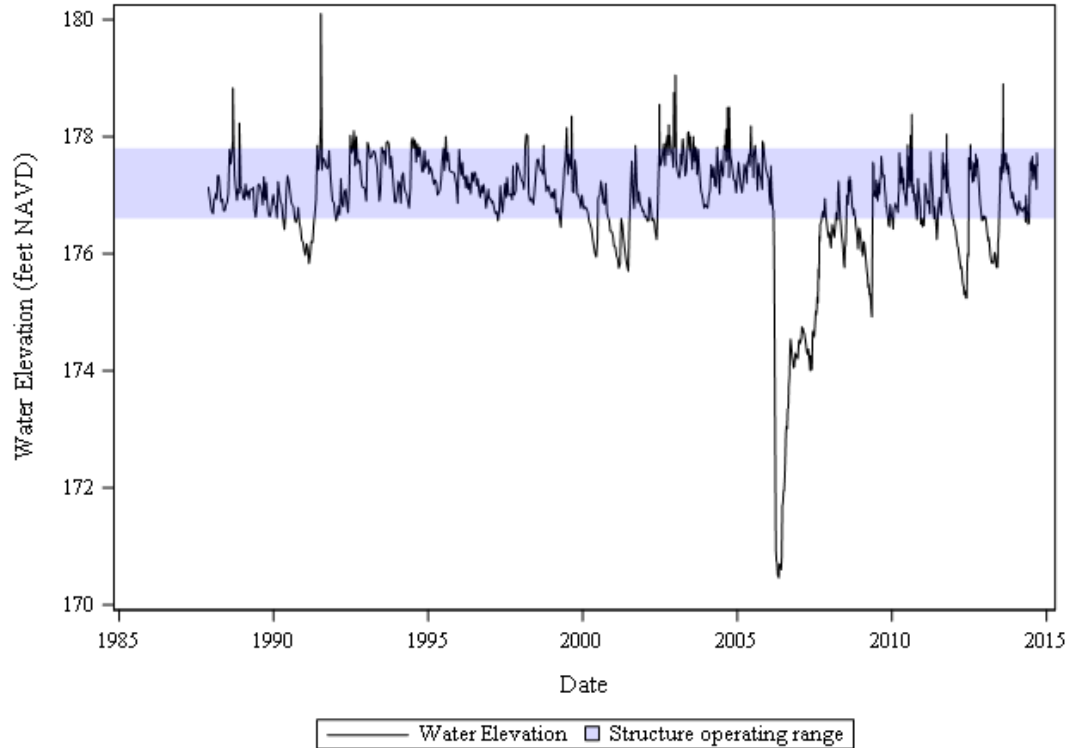


Figure 3-12. Period of Record water elevation for Lake Morton (data from SWFWMD)

Variation in lake elevations differ between lakes, in patterns not obviously linked to rainfall. Lake levels can fluctuate dependent on the drainage area, pretreatment facilities present/not present, and lake level adjustment strategies due to upstream/downstream conditions at the time of rain events. For example, the years of 2000 and 2001 represent the driest annual and dry season rainfall amounts, respectively, over the past 100 years, yet water elevations in Lakes Beulah, Bonnet and Morton were not at their lowest levels during those two years. In contrast, those two years of record low rainfall are associated with very low lake elevations in Lake Hollingsworth, which complicated the sediment removal project that was being conducted at that time, as the barge-mounted dredging project found it difficult to maneuver around the lake due to the very shallow waters.

The results shown here do not support the finding of a monotonic trend in rainfall, although it does appear that the period of 2006 to 2013 represents a period of eight years with rainfall below the long-term average. This dry period was preceded by the hurricane season of 2004, which had the greatest wet season rainfall amount in over 100 years. The record high rainfall amount in the wet season of 2004 (Figure 3-6) was in turn preceded by the lowest annual rainfall amount in over 100 years (2000) and then the lowest amount of dry season rainfall in over 100 years (2001).

This observation of what appeared to be increased variability in rainfall led to an exercise to see if that was supported by rainfall data. The rainfall values for Polk County were accessed (http://swfwmd.state.fl.us/data/hydrologic/rainfall_data_summaries/) and annual, wet season, and dry season yearly values were grouped into decades, starting in the 1920s and ending in the 2000s. Mean values for each decade were derived, as well as the standard deviation. The coefficient of variation (CV) for each decade was calculated by dividing the standard deviation by the mean, and multiplying that value by 100. The CV value is a way to “normalize” variability across data sets with different raw values, as it represents the amount of variability about the mean, regardless of the actual value of the mean. Results from that analysis are shown in Figure 3-13.

Across all decades, the variability in rainfall is always greater in the dry season than in both the wet season or annual rainfall. This might reflect the fact that the main cause of rainfall in the dry season, the passage of cold fronts, might be less predictable than the main cause of wet season rainfall, the typical convective storms associated with differential heating of Florida’s landmass vs surrounding coastal waters. Across all groupings – annual, wet season and dry season - the decade of the 2000s exhibits the greatest variability in rainfall of any the nine decades examined. It would seem that for the City, situated as it is in Polk County, there isn’t a trend of more or less rainfall over time (for annual, wet or dry seasons). But, rainfall appears to be more variable now than at any time over the last 90 years. This poses particular challenges for both water managers and lake managers.

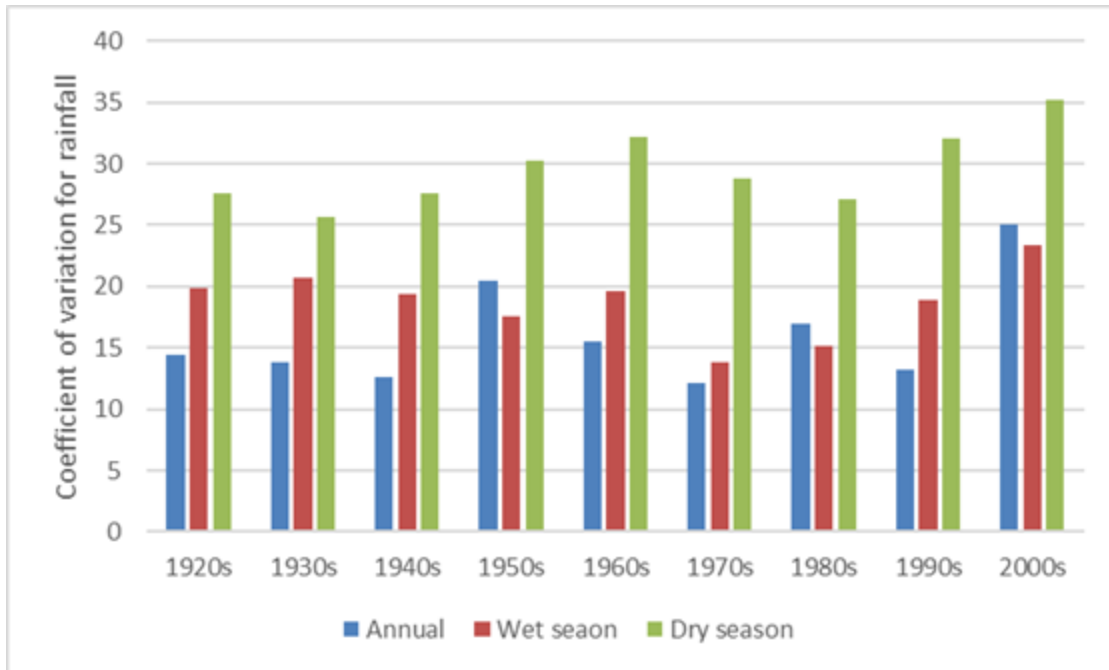


Figure 3-13. Coefficient of variation for rainfall by decade for Polk County

Lake Color: Importance of Forested Wetlands

Water quality in central Florida lakes is often more strongly correlated with lake levels than nutrient concentrations (PBS&J 2008, 2011; Tomasko et al. 2009), which is consistent with a state-wide assessment conducted by Terrell et al (2000). Regardless of the degree of watershed urbanization, lakes that have been lowered below their historical condition via regional drainage networks were shown to be more likely to be impaired for water quality (PBS&J 2011). The extent of forested wetlands along the lake boundary, which can be expressed by the levels of CDOM within the lake, moderate the transformation of nutrients into phytoplankton (PBS&J 2008 and 2011), a finding consistent with the results obtained by Terrell et al. (2000). In 2016, Lake Bonny, Whitmore et al. (2016) concluded that pre-development TP concentrations were likely in the range of 0.04 to 0.045 mg TP/L, values mostly in line with the lake's TMDL target. However, the pre-development TP values in Lake Bonny were accompanied by chlorophyll-a values that were approximately half those expected with the same TP concentration in current conditions. An assessment of the diatom communities in sediments concluded that Lake Bonny previously had been more acidic, and its waters had been more greatly influenced by compounds associated forested wetlands. The lake's prior forested wetlands are now hydrologically disconnected from the lake as a result of the lowering of the lake via various drainage projects. For Lake Bonny, and likely for other lakes as well, Whitmore et al. (2016) not only suggested TP reductions were in order, but that for water quality to be restored to pre-development conditions, projects would be needed for "...restoring water color from fringe swamps and wetlands..."

Within the City, large portions of historical wetland fringes adjacent to lakes are now heavily developed which exacerbates related water quality issues. For Florida, lakes with limited development along their shorelines, such as Cypress Lake in Osceola County, raising the lake water

elevation is considered a valuable way to improve water quality (Atkins 2013). Unfortunately, it appears that intensive lakeside development precludes such an approach in most of the City's lakes.

For lakes in which raising lake levels to reconnect the lake with the adjacent forested wetlands are not feasible due to urban encroachment, the maintenance, re-creation, and/or restoration of wetland influences could be pursued. For example, the extensive wetland located west of Lake Parker is an ideal location for restoration, as it appears that a drainage ditch has reduced both the nutrient assimilative capacity of the wetland as well as the likely reduction in tannin exportation to the lake. These wetland areas should be preserved and, where feasible, their hydroperiod and vegetation quality be restored.

For lakes where wetland influences have been lost and cannot be recovered via hydrologic restoration, water quality treatments through the use of barley straw and/or cypress leaf bundles which ostensibly mimic the influence of forested wetlands by increasing CDOM concentrations. The addition of cypress needles has been shown to be useful for reducing cyanobacteria populations, however, the study was limited to 10-gallon aquaria and it is not known at this time if results would scale up proportionally (Tomasko et al, 2016). Supplemental work to ascertain the applicability of barley straw and/or cypress needle bundles should be performed, prior to implementation on a whole-lake basis.

Alternative considerations for increasing tannins and providing other important water quality and ecological benefits in applicable City lakes are 1) in-lake hydrophilic hardwood (e.g. cypress and bay trees) and herbaceous wetland creation projects and 2) where un-aided wetland flow-through by raising lake water elevations is not possible, constructing pumping stations to move lake water through the remaining lakeshore wetland areas.

Submerged Aquatic Vegetation (SAV)

Removal of nutrients from the water column by SAV communities is well documented (Kadlec and Wallace 2009, Knight et al. 2003, Blindow et al. 2002, Canfield et al. 1984, Havens 2003, Shireman et al. 1985) and, as such, SAV is an important consideration for improving water quality in lakes. Prior work has found that the amount of lake volume occupied by SAV can strongly influence phytoplankton biomass (e.g., Canfield et al. 1984, Moreno 2009). Quantifying the relationship between SAV and nutrients in central Florida lakes is impossible in the absence of SAV abundance data. Robison and Eilers (2013) correlated SAV data from 98 Hillsborough County lakes with corresponding water quality which indicated an inverse correlation between chlorophyll-a and percent area covered (PAC). In other words, greater SAV coverage resulted in lower chlorophyll-a concentrations within the lake. Managing SAV lakes using PAC as a metric was proposed whereby a $PAC \geq 45$ percent was considered optimal (Robison and Eilers 2014).

SAV communities are categorized into two categories: native and non-native. Unfortunately, the results of water quality improvements and non-native invasive species control sometimes conflict. However, there is information regarding the impact of SAV eradication on water quality in other lakes in Florida, as well as anecdotal information from various lakes in central Florida. Lakes such as Lake Tarpon in Pinellas County show a pattern wherein the acreage of Hydrilla chemically

treated (and left to decay in situ) is positively correlated with chlorophyll-a concentration (Figure 3-10). Herbicide treatments to eradicate non-native invasive SAV are an important component of lake management because of the negative impacts of these species in the lakes, including replacement of native plant species and habitat and adverse impacts to recreation and fishing. Hydrilla is the primary target of herbicide treatments in lakes. However, eradication of SAV also removes a nutrient reduction mechanism and can result in a decline in water quality.

Combining these two paradigms, lake management actions should seek to maximize the abundance of native SAV species, while also being careful to not “flip” a lake into an algal-dominated system via chemically eradicating Hydrilla in situ. Lake Wire, for example, appears to be a lake where the abundance and careful maintenance of native SAV and Hydrilla might be responsible for the relatively low average chlorophyll-a concentration in any given year.

Ideally, SAV abundance should be mapped and assessed in all eleven City priority lakes. At the very least, it is highly recommended to map SAV for the smaller lakes in the City (Mirror, Morton, Wire, and Beulah). The techniques used by Moreno (2010) should be replicated as the author found that quantifying the abundance of SAV in terms of the percent of the water column occupied was a good predictor of water quality. The techniques used by Moreno (2010) include the following: 1) simultaneous recording of “soft” and “hard” bottom returns generated through the use of a recording fathometer (e.g., Lowrance model LCX-28CHD) at 100 points per lake sampled and 2) direct observations for verification at 10 percent of the points sampled. Using such data, the percentage of lake volume occupied by SAV can be determined as follows:

$$\frac{\sum_{0}^{100} \left(\frac{(\text{Lake depth} - \text{Depth of vegetation})}{\text{Lake depth}} \right)}{100} = \text{PVI}$$

Where: Lake depth = the hard return depth
 Depth of vegetation = the depth to the top of the vegetation at each site (soft return)
 PVI = Percent Volume Infested (or the volume of the lake occupied by SAV).

Should PVI be similarly important for Lakes Beulah, Mirror, Morton and Wire as was found by Moreno (2010) then target values for SAV could be developed based on empirically-derived relationships between PVI and water quality parameters. This could give rise to guidance related to the establishment of native SAV populations. If sufficient data exist from applicable aquatic vegetation control efforts, it may be possible to find out if there is an inverse relationship within a given lake between Hydrilla eradication via chemical treatment and subsequent levels of chlorophyll-a, as was found in Lake Tarpon (Figure 3-14). If a positive correlation between Hydrilla eradication efforts and levels of chlorophyll-a occur in Lakeland’s lakes as well, then guidance criteria could be developed in terms of maximum acreages to be treated via herbicide application efforts.

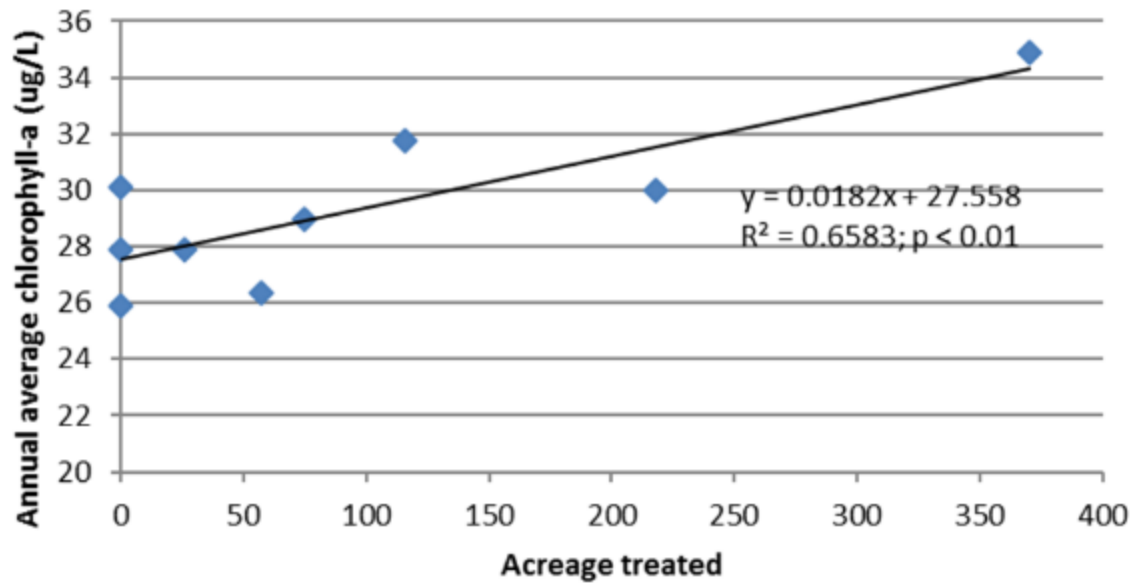


Figure 3-14. Annual Average chlorophyll-a Concentrations vs. Acreage of Hydrilla Treated in the Same Year. Data from Lake Tarpon from 1993 to 2014

4. RESTORATION PROJECTS TO ADDRESS WATER QUALITY ISSUES

Restoration project concepts were developed to address water quality issues specific to the City as part of this WQMP. Some projects are proposed to address issues that have persisted despite previously implemented stormwater quality improvement projects. The projects and the science on which they are based are described in this section and rely heavily on the water quality characteristics of each individual lake.

Lakes in the City range from 4 feet to up to 28 feet in depth; therefore, some would be classified as shallow and others as deep lakes. In general, the responsiveness of lakes to nutrient loading vary dependent upon the lake characterization. Restoration projects proposed as part of the WQMP are consistent with general characteristics of the lakes. For example, shallow lakes are less sensitive to significant reductions in external nutrient loading because interactions at the sediment-water interface tend to maintain high nutrient levels (Cooke et al. 2005). Therefore, diverting external nutrient loads, although necessary, may not be sufficient to reduce nutrient loads to the lake and sediment treatment may be necessary. Cooke et al. (2005) describe two alternative and often stable states of shallow lakes: algae-dominated turbid state at high nutrient concentrations or clear water with macrophytes (aquatic submergent, emergent, or floating plants). Therefore, projects that increase the cover of macrophytes are proposed for most lakes in the City. In contrast, deep lakes tend to have a small drainage area with water quality more responsive to external versus internal nutrient loadings. As such, reduction of external nutrient loads and artificial circulation to ensure stratification is not an issue may be necessary.

The following section presents seven potential projects identified for the improvement of water quality. The selection of lake-specific restoration projects is dependent upon the water quality issues such as those described in Section 3, e.g. stormwater inputs, lake color (ridge and valley), and sediment phosphorus. The decision key presented in the Section 5 incorporates the lake-specific water quality information through empirical analysis to select individual projects for recommendation.

- If appropriate, additional paleolimnological work
- Sediment removal/inactivation;
- Stormwater infiltration areas (SIAs);
- Forested wetland rehydration;

- SAV planting;
- Floating treatment wetland;
- EAV planting; and
- Artificial circulation (aeration).

Paleolimnological Work

The value of paleolimnological work for the City's priority lakes can be shown by the implications of the work done in two of the City's lakes, Hollingsworth and Bonny.

Paleolimnological work conducted on Lake Hollingsworth (Brenner et al. 1999) suggests that the TP target in the current TMDL is overly restrictive, in that the lake would have exceeded its TP target with water quality conditions from the 1890s. Also, the empirically-derived relationship between TP and chlorophyll-a in Lake Hollingsworth's TMDL is such that even if the proposed target of 0.036 mg TP / liter was achieved, the lake's chlorophyll-a value would continue to be at least 50% higher than the default NNC target of 20 µg / liter.

In Lake Bonny, Whitmore et al. (2016) developed estimates of pre-development (i.e., 1840s era) water quality conditions using paleolimnological techniques. For Lake Bonny, it was concluded that pre-development TP concentrations were likely in the range of 0.04 to 0.045 mg TP/L, which matches up fairly well with FDEP's TMDL targets for the lake. However, it was concluded that pre-development values were approximately half the TMDL target, at 10 µg/L, vs. the current target of 20 µg/L for low-color alkaline lakes.

The 1800's-era diatom communities in Lake Bonny were general that are typically associated with more acidic conditions, which led Whitmore et al. (2016) to conclude that Lake Bonny had previously been more strongly influenced by compounds such tannic, fulvic and humic acids; compounds that are associated with the influence of forested wetlands. In the case of Lake Bonny, Whitmore et al. (2016) suggested that restoring water quality would require "...restoring water color from fringe swamps and wetlands..."

When incorporated into lake management actions, paleolimnological work can help derive locally-relevant and scientifically-sound water quality targets, as in Lake Hollingsworth. Additionally, paleolimnological work can help determine additional projects that might be needed, such as the need for wetland restoration work as was found for Lake Bonny.

Sediment Removal or Inactivation

Internal phosphorus loading originates from phosphorus accumulated in sediment under high external loading. Removing or inactivating the phosphorus-laden sediments reduces or eliminates the phosphorus that can be released into the water column of the lake and result in increased nutrient availability to algae and subsequently, increased chlorophyll-a in the lake. The time for the lake to recover to a steady state between sediment and water column phosphorus can be calculated using

phosphorus flux rates from sediments, sediment depth, sediment organic matter, and sediment bulk density (Reddy et al. 2011). The internal loading can be reduced significantly by various restoration methods, such as removal of phosphorus-rich surface layers or by the addition of iron or alum to increase the sediment's sorption capacity.

Sediment removal and inactivation are a means of reducing available nutrients in a lake and have been successful in Florida. Sediment removal physically removes the source of internal nutrient cycling, while phosphorus inactivation lowers lake phosphorus by inhibiting the release of mobile phosphorus from lake sediments.

Significant amounts of phosphorus in lake sediments may be bound to redox-sensitive iron compounds or fixed in labile organic forms and may eventually be released to the lake water. Many factors influence the release of phosphorus. Redox sensitive mobilization from the anoxic zone just below the sediment surface and microbial processes are considered important, but the phosphorus release mechanisms are to a certain extent lake specific (Sondergaard et al. 2002). Phosphorus inactivation is an in-lake technique designed to lower phosphorus content in a lake by removal of phosphorus from the water column (phosphorus precipitation) and retarding the release of mobile phosphorus from lake sediments (phosphorus inactivation). Phosphorus inactivation (alum treatment) is generally accomplished via addition of an aluminum salt to the lake that forms aluminum phosphate and an aluminum floc to which certain phosphorus fractions are bound. The floc settles to the lake bottom and continues to adsorb and retain phosphorus. Phosphorus inactivation is considered more economical and effective, while sediment removal has the long term benefit of nutrient source removal (Cooke et al. 2005). In contrast to iron, low or zero DO concentrations in lake sediments do not solubilize the floc and allow phosphorus release, although phosphorus may be released if the pH is high (Cooke et al. 2005). Sediment phosphorus inactivation treatments must reduce sediment phosphorus release for at least several years, lower the phosphorus concentration in the lake photic zone, and be non-toxic.

Alternatively, phosphorus inactivation provides long-term control of algal biomass by reducing the availability of nutrients (phosphorus), in contrast with algaecides that are directly toxic to algae and are effective for only brief periods. The primary objective of in-lake alum treatment is to cover the sediment with aluminum hydroxide. Mobile phosphorus is sorbed and internal loading is reduced. The formation of aluminum hydroxide may also remove particulate organic and inorganic matter with phosphorus from the water column. Phosphorus inactivation is an attempt to permanently and extensively bind phosphorus in lake sediments and essentially eliminate sediments as a phosphorus source to the water column.

Sediment removal has become an established fisheries management technique for lakes throughout Florida (Aresco and Gunzburger 2004) based on studies in which immediate positive fisheries response followed a water level drawdown and sediment removal in Lake Tohopekaliga, Florida (e.g. Moyer et al. 1995). However, sediment removal may negatively impact herpetofauna (Aresco and Gunzburger 2004). Sediment inactivation via alum treatment requires periodic maintenance and treatment and if hydrologically connected, may affect downstream waters.

Sediment removal entails either the partial or full removal of organic sediments. Sediments are removed using a hydraulic dredge and transported to a shoreline dewatering facility (if possible). Dredged material can then be used as an agricultural soil amendment if recipient sites can be identified. The location of an appropriate dewatering area within close proximity to the dredge location can assist in reducing project costs. In contrast, chemical inactivation relies on the properties of the water and sediment. Two potential methods available for chemical inactivation: Alum or Phoslock®.

- *Alum Treatment.* Alum (aluminum sulphate) is typically applied to lake water with a pH of 6 to 8. Due to the alkalinity of the water, hydrolysis of the alum ion occurs resulting in the formation of aluminum hydroxide, which binds to both inorganic and particulate phosphorus creating aluminum phosphate and other compounds. Aluminum phosphate is an insoluble compound which settles to the lake bottom creating a barrier restricting phosphorus release from the sediments. Due to the initial hydrolysis of alum, fluctuations in the pH concentration of the lake can result in acidification of the waterbody depending on the initial alkalinity and alum dose applied. When required, a buffering agent is applied in concert with alum or the required dosage is spread over several applications to minimize the fluctuations in pH. Lake acidification can result in aluminum toxicity within the waterbody. Alum has been shown to be effective in binding phosphorus for 2 to 20 years. The resuspension or accumulation of organic material can shorten the longevity of alum treatment. Alum has been used to bind phosphorus in both lakes and stormwater management facilities in Florida since at least the 1980's.
- *Phoslock® Treatment.* Phoslock® (lanthanum modified bentonite clay) binds with inorganic phosphate most successfully when pH conditions are within the range of 6 to 9. However, the application of Phoslock® does not rely on the pH nor does it alter the pH of the waterbody. Rhabdophane, a stable mineral, is formed from the adsorption of phosphate to the lanthanum portion of Phoslock®. Rhabdophane is an insoluble clay structure which settles to the lake bottom creating a barrier restricting phosphorus release from the sediments. Ambient concentrations of lanthanum in the waterbody remain low due to structure of the bentonite clay. It should be noted that Phoslock acts on inorganic phosphate, not the phosphorus that is associated with algal biomass. As such, Phoslock and Alum treatment differ substantially in their modes of phosphorus control for waters with substantial amounts of algal biomass.

The estimated time required for legacy phosphorus in sediments to become biologically unavailable is especially important for those lakes that received historical point source discharges or still receive nonpoint source inputs and can be estimated using sediment phosphorus flux data. If sufficient data are unavailable for phosphorus flux or sediment volume, a feasibility study is necessary and should include the components listed below.

- Quantification of the sediment nutrient release to the overlying water column;
- Quantification of the depth and volume of organic (labile) material;
- Sediment characteristic profiles; and
- Assessment of available sites for dredging operation facility once extent of internal phosphorus load is evaluated.

Once external nutrient loads to lakes are eliminated or reduced to the extent possible, a reasonable time frame could be selected that balances the expense of a project with the long-term benefit of the project. For example, if it takes less than 20 years for the phosphorus enriched sediment in a particular lake to become biologically unavailable, alternative water quality restoration projects should be considered. However, if the time frame for phosphorus to become unavailable is greater than 20 years, sediment removal or inactivation could be warranted.

Aquatic and Wetland Vegetation

Aquatic and wetland vegetation, including forested wetlands, SAV, EAV, and floating treatment wetlands (FTWs) have been proven effective for improving water quality. Rehydrating forested wetlands along a lake can increase the level of CDOM (aka “tannins”) of a lake and reduce the light available to algae, while EAV and SAV communities provide sustainable means of removing phosphorus from the water column and making it permanently unavailable. FTWs are an alternative form of water quality treatment wetland that floats, rather than being rooted, in a lake or water body.

The removal or diversion of phosphorus from lakes via more traditional sediment removal/inactivation and stormwater treatment wetlands and SIAs can be quantified, as described in previous sections, because a known quantity of sediment or water is captured, diverted, detained, removed, or inactivated. However, while it can be “treated”, stormwater runoff that is not captured or diverted before it flows into a lake directly or through a wetland cannot be quantified. Phosphorus removal by EAV and SAV systems have been quantified using measured inflow and outflow concentrations and flow (e.g. the Orlando Easterly Wetlands at Iron Bridge and the South Florida Water Management District (SFWMD) stormwater treatment systems). In the absence of these data, phosphorus removal via aquatic and wetland vegetation in the City’s priority lakes cannot be estimated.

Wetland and aquatic vegetation projects for water quality improvement are described, and the mechanisms by which the projects improve water quality are documented, in the following sections.

Forested Wetland Rehydration

Restoring forested wetlands to hydrologically reconnect a lake with the adjacent floodplain can improve water quality by reducing nutrients and sediment delivery to the lake (Richardson and Pahl 2005) and restoring former CDOM levels to the lake. Both herbaceous (marshes) and forested (swamps) wetlands have been used extensively for water quality improvement (Mitsch and Gosselink 2000). Flooded forests receive a large sediment load during the wet season from surface runoff, providing the substrate for phosphorus adsorption and subsequent burial when waters subside during the dry season. Nitrogen and phosphorus reductions in the soils of a restored floodplain will occur via nitrification/denitrification and sedimentation and soil sorption. During wet periods, the ground water hydraulic gradient is from land to lake.

Depth and duration of water are important to the maintenance of forested wetlands by excluding upland species. Based on physiological tolerances of wetland vegetation, two-year with 14- and

21- day inundation periods and five-year with 14- and 21- day inundation periods are important in that these periods of inundation limit the invasion of wetlands by upland species (Demaree 1932, Hosner 1960, Brown 1984, Fowells 1965, Conner and Askew 1993, after Light et al. 2002). At a depth of approximately one meter, previously established seedlings of upland species will die and faster growing wetlands species will remain.

The purpose of reconnecting or re-establishing forested wetlands associated with the valley lakes is to improve lake water quality (i.e. reduce chlorophyll-a). In addition to nitrogen and phosphorus reductions, tannic and humic acids from the forested wetlands can reduce chlorophyll-a concentrations in waterbodies (Terrell et al. 2000). The CDOM in valley lakes appears to moderate the transformation of nutrients in the water column, thereby allowing a colored lake to tolerate more nutrients than a clear ridge lake before exhibiting an increase in chlorophyll-a. While the benefit of improved water quality due to CDOM increases has not been quantified, significant improvements to water quality due to restored forested wetlands is well documented.

The effect of CDOM on water quality is explained by the organic matter exported from forested wetlands into the valley lakes and the subsequent reductions in available sunlight in the water column. Leaves decay on forest floor and may form peat soils or partially decay into loose organic matter. These humic and tannic substances leach from decaying leaves and are transported by stormwater runoff into the lake and can color the water. CDOM can reduce the amount of sunlight available in the water column and decrease algal and plant growth. In some waterbodies, CDOM is the limiting environmental factor. For example, high CDOM concentrations (> 50 PCU) may limit both the quantity and types of algae in a waterbody (IFAS 2003). Even most blue-green algae are obligate phototrophs and those that grow heterotrophically in the dark have extremely low growth rates (VanBaalen et al. 1971). Consequently, the location of a waterbody in relation to associated forested wetlands has a strong influence on its color (Richardson and Pahl 2005).

Valley lakes typically have greater CDOM than ridge lakes, due at least in part to forested wetland inputs. Valley lakes with less than 20 percent of the shoreline characterized by functional forested wetlands were evaluated to determine if historical forested wetlands are available for rehydration. Historical forested wetlands that are hydrologically disconnected from an adjacent lake were proposed as areas for wetland rehydration. In some instances, the former wetlands may now be cropland/pastureland.

A feasibility study is required to evaluate current soils conditions, develop design plans, and identify constraints to inundation. The feasibility study should include the components listed below.

- Review of existing aerials, elevation, vegetation, and soils GIS data;
- Ecological and engineering site evaluation;
- Detailed analysis of existing hydraulic system;
- Identification/Analysis of necessary hydraulic modifications to existing system;
- Soil boring and biochemical and geotechnical evaluation of site conditions;

- Supplemental topographic survey of project area;
- Proposed project area property ownership evaluation;
- Review of required utility service to pumping station;
- Monthly surficial aquifer water level monitoring for one year;
- Evaluation of environmental permitting issues; and
- Preliminary project design and construction cost estimate.

Based on the results of the feasibility study, a cost: benefit analysis could be completed to ascertain if rehydration is possible and cost-effective. One conceptual design for each proposed project area would require the construction of one pump station to convey water from the lake into the constructed containment area as well as a water level/discharge structure. The pumping schedule would be developed based on the soils/surficial aquifer data acquired during the feasibility study. The identified project areas would be kept saturated throughout the year and flooded during the wet season if possible. For approximately one month in the wet season, at least six inches of water would be sustained above the surface in order to reduce encroachment of upland vegetation species.

There are other means of restoring forested wetland hydrology that do not include pumping structures. One includes raising lake levels via the use of control structures and purchase of adjacent lands that may be part of the forested wetland. Another method includes the use of control structures to detain water in the wetland for a long period of time before releasing the water back into the lake. In addition, restoring hydrology in a former forested wetland will result in a pulse of phosphorus to the receiving lake and should be considered as part of a feasibility study.

However, large portions of the City's priority lakes historical wetland fringes are now heavily developed, thus, removing the landscape needed for wetland restoration. For lakes where wetland influences have been lost and cannot be recovered via hydrologic restoration, water quality treatments through the use of barley straw and/or cypress leaf bundles could be tested for their ability to reduce cyanobacteria abundance as has been tested (at the aquarium scale) for Lake Hancock (Tomasko et al., 2016).

Alternative considerations for increasing CDOM and providing other important water quality and ecological benefits in applicable City lakes are 1) in-lake hydrophilic hardwood (e.g. cypress and bay trees) and herbaceous wetland creation projects and 2) where un-aided wetland flow-through by raising lake water elevations is not possible, constructing pumping stations to move lake water through the remaining lakeshore wetland areas.

SAV Planting

Planting and restoring native SAV where appropriate in the City's lakes is expected to improve water quality via assimilation of nutrients from the water column and the soil-pore water. SAV can reduce nutrient and chlorophyll-a concentrations in a lake and subsequently increase transparency in the water column (Blindow et al. 2002, Canfield et al. 1984, Havens 2003, Shireman et al. 1985)

and provide fish and wildlife habitat. Water quality improvements due to SAV can be attributed to direct uptake and nutrient assimilation, sediment stabilization that reduces sediment resuspension (Vermaat et al. 2000), as well as associated nutrient sequestration by epiphytes. Canfield et al. (1984) reported that SAV abundance is inversely related to phytoplankton levels for Florida lakes. In Lake Okeechobee, chlorophyll-a concentrations were two to three times lower at locations with high submerged aquatic vegetation biomass compared with locations without aquatic vegetation (Havens 2003). Increased levels of TP and chlorophyll-a, and decreased water clarity, occurred in Lake Baldwin (near Orlando) in response to Hydrilla eradication efforts (Shireman et al. 1985).

At a minimum, Hydrilla control efforts should be coordinated with other lake management efforts such that the benefits of one project (i.e. Hydrilla control) do not offset the benefits of other projects (i.e. water quality improvement projects). An optimal course of action would be to focus Hydrilla control physical removal and replanting efforts as a means of substituting the water quality benefits of “non-native” SAV with the water quality benefits of “native” SAV. A reasonable lake restoration goal for the City’s system is the threshold value of 30 to 50 percent recommended by Canfield and Hoyer (1992). In lakes with native SAV, invasive species management is recommended to eliminate competition and allow the expansion of existing SAV, thereby reducing the costs associated with planting. However, if SAV is absent from a lake but conditions in the lake are conducive to SAV, planting is recommended.

Aquatic vegetation distribution is affected by multiple factors: sediment type, water depth and clarity, bottom slope, wave disturbance, and benthic algae (as cited in Havens 2003). An SAV survey is recommended for each lake to calculate the percent of the lake surface area covered by SAV. The SAV cover data would be assessed to determine if present SAV cover exceeds the targeted 30 to 50 percent proposed by the Florida Fish and Wildlife Conservation Commission (FFWCC) (Canfield and Hoyer 1992) and represents desirable aquatic plants. SAV planting is not recommended for those lakes with greater than 30 percent cover. For those lakes with insufficient SAV cover, an evaluation of the sediment type, water depth, water column transparency, bottom slope, wave disturbance, and benthic algae is recommended to determine if conditions are favorable for aquatic vegetation planting. If conditions are favorable, desirable plants would be planted to the maximum allowable water depth.

All lakes in the City have SAV projects proposed as part of their restoration strategy. In the absence of light measurements, Secchi depth is used as an indicator of available light for photosynthesis. Plants would not be planted in water depths greater than the median Secchi depth to ensure light penetration. The maximum possible area for planting is calculated for each lake based upon current two-foot contour bathymetry data. If additional water quality improvement projects are performed, which may alter the bottom geometry of the lake (e.g. sediment removal), updated bathymetry information would be required to quantify the maximum allowable area for planting based on water depth. Nursery grown *Vallisneria*, a desirable freshwater SAV species, could be planted using a three-foot center grid pattern. Planting would occur in early spring to allow sufficient time for the plants to establish during the growing season.

Maintenance is required for SAV plantings in the first year to reduce herbivory and remove encroaching plants. As part of a feasibility study, a Lake Vegetation Index – water quality

relationship may be established if data are available. In addition, for individual lakes, an SAV survey and an evaluation of the anticipated water quality improvement if less than 30 percent of the lake is planted should be completed.

Emergent Aquatic Vegetation (EAV) Planting

Both EAV and SAV are critical to the removal and permanent burial of available phosphorus from the water column. Treatment wetlands are constructed based on the phosphorus removal facilitated by emergent and aquatic vegetation. While the plants themselves may assimilate less than 10 percent of the phosphorus from the water column into plant biomass, the plants facilitate the microbial activity and chemical sorption processes (Richardson and Marshall 1986) that account for most of the phosphorus removal (Pietro et al. 2006a, Noe et al. 2003). Importantly, phosphorus is released back into the water column following plant senescence and decay and herbaceous vegetation provides only a temporary nutrient sink to ameliorate eutrophic conditions. Freeze events (e.g. winter 2010) may increase the amount of dead EAV and therefore result in a temporary increase in phosphorus release following the freeze. It is the nutrient transformations among the plants, soils, and water that can make the phosphorus permanently unavailable. Phosphorus removal is a function of inflow phosphorus loadings (Kadlec and Wallace 2009), water levels, microorganism populations, seasonal phosphorus adsorption, and phosphorus soil adsorption capacity (Richardson and Marshall 1986).

The accretion and permanent burial of phosphorus into the sediments via EAV and SAV is the only sustainable removal mechanism for phosphorus in these lake systems. Organic, adsorbed, and mineral phosphorus are unavailable to plants and adsorption and precipitation are major mechanisms of phosphorus retention. Sediment characteristics affecting phosphorus availability are briefly outlined below.

- *Adsorption/desorption.* Adsorption is the chemical binding of plant available phosphorus to soil particles, making the phosphorus unavailable to plants. Desorption is the release of adsorbed phosphorus from its bound state into the soil solution. Higher iron and/or aluminum content of the sediment increases adsorption.
- *Precipitation/dissolution.* Phosphorus can become unavailable via precipitation of plant available inorganic phosphorus with dissolved iron, aluminum, manganese (in acid soils), or calcium (in alkaline soils) to form phosphate minerals. Precipitation is more permanent when compared with adsorption (see previous discussion of sediment inactivation). High concentrations of calcium, aluminum, or iron can also precipitate phosphorus into the water column. The presence of redox-insensitive phosphorus binding systems such as $\text{Al}(\text{OH})_3$ and unreducible $\text{Fe}_{(\text{III})}$ minerals can enhance the phosphorus retention and completely prevent phosphorus release even in case of anoxic conditions (Hupfer and Lewandowski 2008).
- *Immobilization/mineralization.* Mineralization is the microbial conversion of organic phosphorus to plant available orthophosphates. Immobilization occurs when the plant available phosphorus is consumed by microbes and thereby converted to unavailable organic phosphorus.

The littoral zones of lakes are typically less than three meters in depth, thereby allowing sunlight penetration adequate for plant growth. The littoral zone includes EAV and SAV at different depths, but typically overlapping (Figure 4-2).

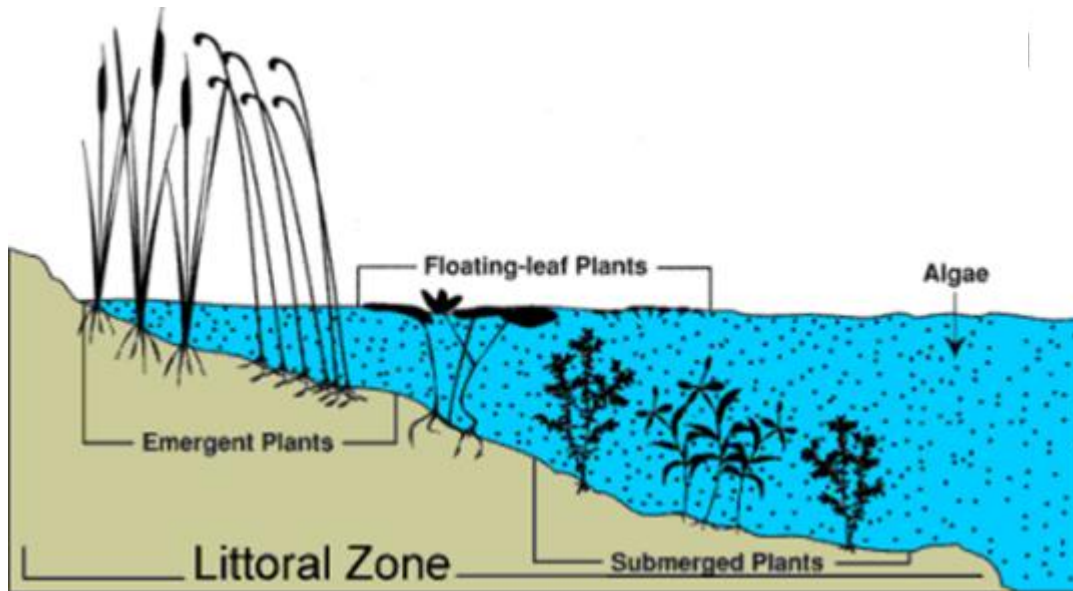


Figure 4-1. EAV and SAV distribution in the lake littoral zone (after MDNR 2010)

The width of the littoral zone will vary in a lake and among lakes and where the slope of the lake bottom is steep, the littoral area may be narrow, extending several feet from the shoreline. In contrast, if the lake is shallow and has a gradual slope, the littoral area may extend hundreds of feet into the lake or may even cover it entirely. EAV includes aquatic plants that are rooted in the lake bottom but protrude above the water surface, e.g. floating water lilies (*Nuphar spp.* and *Nymphaea spp.*), bulrushes (*Scirpus validus*), wild rice (*Zizaniopsis miliaceae*), duck potato (*Sagittaria spp.*), and cattails (*Typha latifolia*).

A vegetated wetland buffer between land development and the water intercepts nutrients and sediments and can improve or restore biodiversity (Wall et al. 2001, Dosskey 2001, Brinson et al. 2002, Fiener and Auerswald 2003). Vegetated buffer zones decrease nutrient and sediment transport by detaining water, allowing particle sedimentation, and increasing soil infiltration capacity (Cooke et al. 2005, Lee et al. 2003). Wetzel (1992, 2001) refers to this EAV dominated portion of the littoral zone as the riparian zone and describes it as a gradient community between the lake and the upland. The riparian zone reduces nonpoint nutrient loading (Cooke et al. 2005, Dosskey 2001) and restoration of this zone is an important part of lake rehabilitation (Cooke et al. 2005). VanNess (2002) also reports that the re-establishment and conservation of aquatic plants within shallow lakes is a vital component for successful restoration of shallow lakes (van Ness et al. 2002).

Consequently, re-establishing native EAV vegetation, where appropriate, is expected to improve water quality in the City's lakes. As an example, the Lakes Education/Action Drive of Polk County (LE/AD) program recommends shoreline aquascaping for lake residents and has published on the benefits of the practice and a list of several desirable EAV species (e.g. duck potato, bulrush,

maiden cane, and pickerel weed) that can be planted along shorelines for aquascaping (Selser 2010). Lakescaping is another common term used to describe the establishment of EAV along lake edges and is typically designed to return 50 to 75 percent of the shoreline to a vegetated condition, without obscuring views (Cooke et al. 2005). This approach differs from forested wetland rehydration in that it includes planting vegetation only along the shoreline and does not rely on restored hydrologic connects. SAV planting projects are limited to deeper portions of the littoral zone.

A good example of the effectiveness of vegetated wetland buffers (compared with no EAV or SAV) is illustrated in a comparison of a control site with a seven-meter-wide switchgrass (*Panicum virgatum*) wetland buffer, and the same buffer with an additional 13-meter-wide forested buffer (Zaimes et al. 2004). The switchgrass buffer alone removed more than 90 percent of sediments and 80 percent of TP over the 18-month study period. The combined buffer zone reduced TP from 200 g/hectare to 19 g/hectare and sediments from 587 g/hectare to 16 kg/hectare (Lee et al. 2003). Wider vegetated zones promote more water infiltration and nutrient retention (Schmitt et al. 1999). Wetland species other than switchgrass would also be effective buffers.

In addition to EAV and SAV, forested lake edges (wetlands) also remove nutrients from the water column. Effective nutrient reduction of secondarily treated effluent in forested wetlands in Louisiana has been successfully demonstrated (Hunter et al. 2009). Removal efficiencies for TN and TP are typical of other forested wetlands receiving treated effluent in Louisiana, ranging between 65 and 90 percent (Hunter et al. 2009). Wetland trees cannot germinate under water and EAV has a limited tolerance to inundation, consequently, the most important component of shoreline vegetation is water level (elevation). Vegetation must be planted at appropriate inundation intervals. If water levels are too high, the vegetation will shift landward if space is available, while water levels that are too low will result in invasion by upland species and loss of wetland species and commensurate water quality functions. Success of a shoreline planting is also strongly affected by other plant species as well and invasion by upland or non-native invasive species can eliminate the desirable wetland plant species.

An evaluation of shoreline and littoral vegetation data should be completed for each lake. For those lakes without shoreline vegetation, an evaluation of the sediment type, water level and inundation frequency, slope, and wave disturbance, is recommended to determine if conditions are favorable for shoreline planting. Plants appropriate for typical water levels and water level variation should be selected and planted. Non-native and invasive plants should be removed prior to planting and controlled post-planting for a minimum of one year. If conditions are favorable, desirable plants should be identified for shoreline vegetation planting (Figure 4-3; Table 4-2).

The first step in planting a shoreline is site preparation to remove undesirable species that may be non-native, invasive, or both. Sod can be removed in a number of ways: through herbicide application, removal with a sod cutter, or by smothering sod with black plastic or other materials. An advantage of herbicides or smothering techniques is erosion prevention. Appropriate permits should be obtained. Bare-root or larger transplants should be planted rather than seeding so that no additional soil preparation, fertilizer, or soil supplements will be needed. Plants should be selected to be compatible with existing elevation and soils.

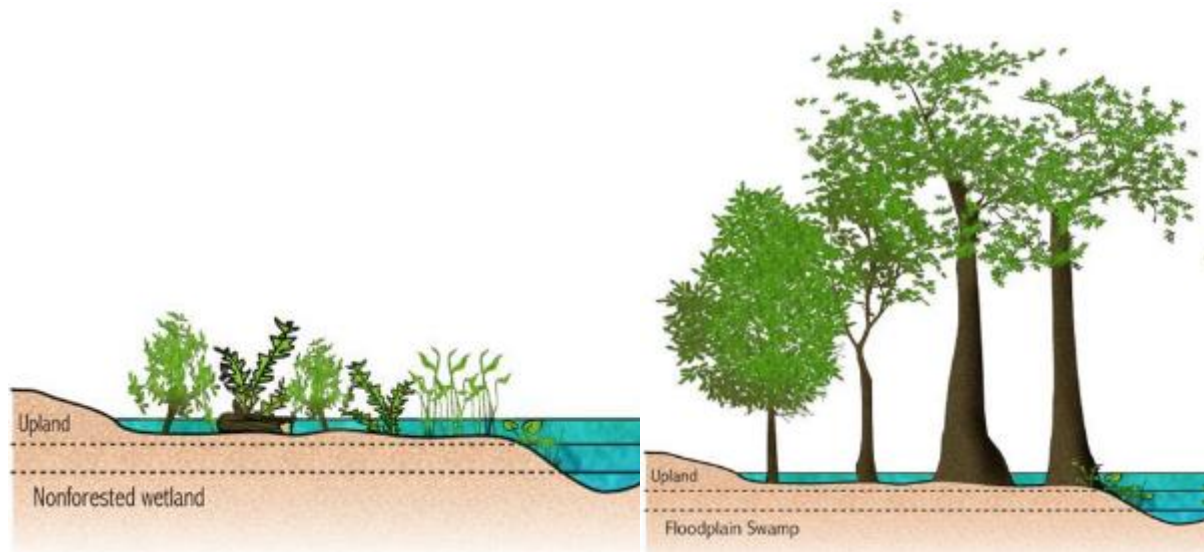


Figure 4-2. Conceptual diagram of EAV and SAV (left) and forested (right) wetlands lake restoration projects

TABLE 4-1. LIST OF POTENTIAL PLANT SPECIES FOR A TYPICAL EAV PLANTING PROJECT

Common Name	Scientific Name	Elevations based on Mean High Water Level (feet)
Softstem bulrush	<i>Scirpus validus</i>	-2.0 to -3.0
Pickereel weed	<i>Pontedaria cordata</i>	-1.0 to -2.0
Maidencane	<i>Panicum hemitomon</i>	-1.0 to -1.5
Arrowhead	<i>Sagittaria lancifolia</i>	-1.0 to -1.5
Spikerush	<i>Eleocharis interstincta</i>	-0.5 to -1.0
Sand Cord Grass	<i>Spartina bakeri</i>	0 to +2.0
Muhly grass	<i>Muhlenbergia capillaris</i>	0 to +2.0

One planting technique on shallow slopes is to cover existing vegetation with a four-inch thick layer of mulch. However, mulch must be retained in the planting area. Biodegradable erosion control blankets can be used to retain the exposed disturbed soil. In areas subject to wave action, temporary wave breaks may need to be installed to prevent erosion. Protective fencing might need to be installed to protect the sapling plants from birds. Install the container plants using a minimum three foot on center pattern and water thoroughly. Plants should be installed in the late fall/early winter to encourage below ground biomass and successful plant establishment.

Floating Treatment Wetlands (FTWs)

FTWs can provide an alternate means of reducing nutrients in the water column and improving water quality in the City. Water quality improvements in water that flows through wetlands have been documented extensively (Kadlec and Wallace 2009, DeBusk et al. 2005, Kadlec and Knight 1996) and SFWMD has constructed over 40,000 acres of stormwater treatment wetlands to treat surface water runoff in the Everglades. Water leaving a wetland has lower dissolved and organic

nutrient loads (via multiple pathways, e.g. plant assimilation, denitrification, immobilization, physical settling) when compared with the water flowing into the wetland. Even though FTWs are not specific to stormwater treatment or flow-through systems, they are anticipated to provide this same function.

A FTW is composed of emergent wetland vegetation suspended on the water surface by a buoyant raft (Figure 4-4). In contrast to wetland systems, research on FTWs is more limited (Hubbard 2010, Hubbard et al. 2004). However, it appears that much of the nutrient reduction is associated with plant uptake, rather than burial or other processes. Therefore, FTWs must be harvested or their assimilated nutrients will be returned to the water column following plant senescence. The nutrient removal efficiency is related to the amount of biomass produced by the selected vegetation (Hubbard 2010) and can therefore be maintenance intensive. Biomass harvesting can also be required of naturally floating vegetation (water hyacinths and duckweed). It is anticipated that the aesthetic vegetation islands also provide food and habitat for wildlife, including waterfowl, songbirds, frogs, and turtles (Floating Island International 2010).

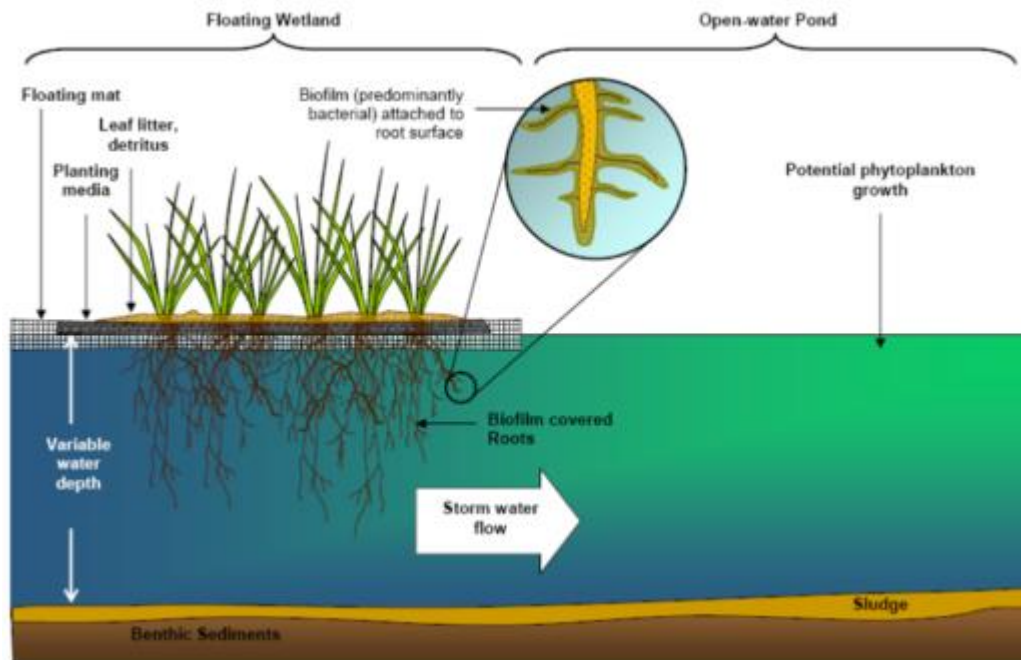


Figure 4-3. Cross-section of a typical FTW and pond showing main structural elements (from Headley and Tanner 2006)

The raft systems and plant species are the most important considerations for a FTW (Headley and Tanner 2006). Design criteria to establish the size and distribution of FTWs required to treat a waterbody is presently unavailable (Headley and Tanner 2006).

Reduced DO levels in the water column below FTWs have been reported (Headley and Tanner 2006) and FTWs should not, therefore, extend across an entire lake. Several small FTWs throughout a lake are recommended for water quality restoration. Annual maintenance including plant harvesting is required. Plant biomass is a short term sink and annual harvesting of the plant biomass is required to permanently sequester the nutrient uptake and should occur in late fall/ early

winter before the plants senesce and decay. Both cattails and maidencane were successfully documented to perform well in a FTW constructed in Georgia (Hubbard et al. 2004).

Artificial Circulation

Whole lake aeration via artificial circulation is another lake management activity examined as a potential water quality improvement project for the City. Artificial circulation is designed to pump deeper water to the lake surface where the water becomes aerated (Pastorak et al. 1981, 1982). The technique was originally developed to prevent winter fish kills but its primary application is now treating eutrophication. Artificial circulation also transports phytoplankton biomass to the deeper, light limited portion of the water column, thereby reducing the light available for photosynthesis and phytoplankton productivity (Cooke et al. 1993). Associated changes in CO₂ and pH, buoyant cell (blue-green algae) distribution, and zooplankton grazing have also been reported to alter phytoplankton composition. Finally, reduced internal phosphorus loading is possible if iron is the factor controlling sediment phosphorus release. The aeration of the sediment-water interface can result in phosphorus adsorption to ferric-hydroxy complexes resulting in a decrease in phosphorus release to the overlying water column (Stumm and Leckie 1971). However, colloidal organic matter can retard the formation of the nonreactive iron (Fe⁺³) and allow phosphorus to remain free in solution and therefore biologically available (Koenings and Hooper 1976).

There are examples in the literature of improved water quality following lake aeration, but many appear to be insufficient in terms of experimental design. However, results of a whole-lake aeration system installed in Lake Persimmon, a hypereutrophic lake in Highlands County, were documented by SWFWMD scientists. Kolasa and Kang (2005) concluded that “...several parameters have shown improvements including the reduction of ammonia and also chlorophyll” in Lake Persimmon. While nitrate loads to the lake did not decline, local homeowners have noted the improvements. The aeration system was taken offline due to maintenance problems. Grochowska and Gawronska (2004) also documented water quality improvements as a result of lake aeration in a eutrophic lake in Poland. Lake water quality improved substantially but was not sufficient to reduce phytoplankton production or improve the trophic state.

Artificial circulation is accomplished using electric powered pumps to pull water from the lower water depths to the water surface (Figure 4-5). The water intake system can be positioned in the water column based upon the unique water depth and sediment quality characteristics of the lake. Solar powered pumps (e.g. SolarBee®) have been developed to reduce operation costs. The number and size of the pumps for an individual lake depend on water quality and depth, lake size, and non-point source inputs. Artificial circulation is only recommended for small lakes (< 75 acres) with poor water quality.

Operations and maintenance costs were difficult to examine. However, estimates for the Township of Wiconisco in Dauphin County, PA, indicated savings of approximately \$251,000 in operations costs over 20 years by replacing seven mechanical aerators with SolarBee solar aerators. Total installation and operation of mechanical aerators totaled approximately \$404,000, compared with \$182,000 for the solar powered aerators (SolarBee.com). Further work to might be appropriate to

evaluate the efficacy of incorporating bacteria inoculation (e.g., bio-block) in concert with artificial circulation to reduce sediment nutrient loading.

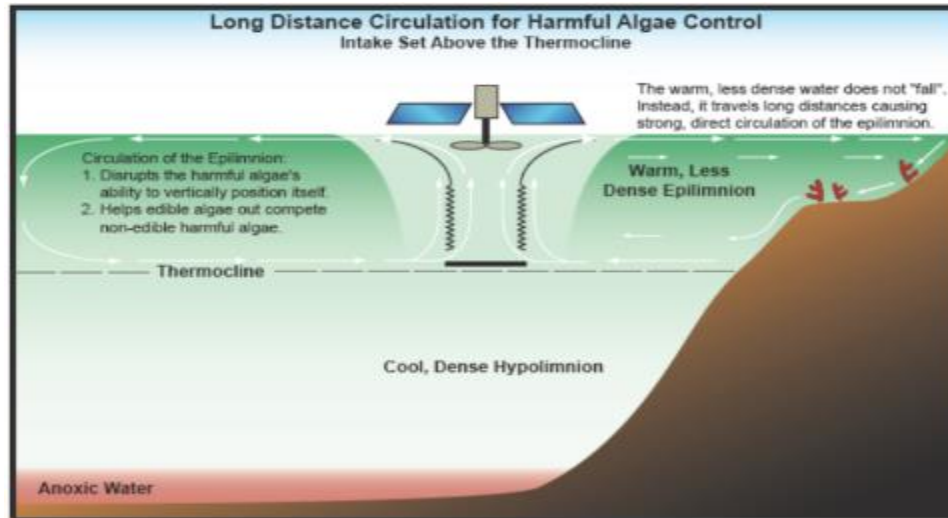


Figure 4-4. Schematic of proposed artificial circulation system using SolarBee system

Stormwater Reduction (Stormwater Infiltration Areas)

The most common stormwater treatment system in Florida is wet detention, which can assist with both flood control and stormwater treatment. While wet detention ponds are extremely effective at reducing toxic compounds such as metals, their documented load reduction efficiency for nitrogen is less than 40 percent (Harper and Baker 2007). Increasing the size of wet detention ponds to increase their residence times does not appear to bring about further increases in nitrogen removal (Harper and Baker 2007). In contrast, dry retention ponds may be able to reduce nitrogen loads by perhaps 90 percent (Harper and Baker 2007) which suggests that they could be used to adopt a “hold the line” approach to nitrogen loads from stormwater. However, dry retention ponds require a one to three-foot separation between the bottom of the pond and the seasonal high water table (Harper and Baker 2007). As such, the mechanism for addressing stormwater can be driven by multiple factor.

Stormwater Infiltration Areas (SIAs) are dry retention basins intended, in this case, to reduce direct stormwater runoff (and associated nutrients) to lakes by increasing surface water infiltration into ground water via permeable soils. SIAs are also referred to as rain gardens, dry retention ponds, French drains, infiltration pipes, and bio-infiltration basins. SIAs differ from traditional stormwater treatment projects in that they direct surface water to ground water and have the benefit of increasing aquifer recharge due to greater surface water infiltration. In addition, SIAs can be constructed with minimal to no infrastructure and can be very small and located throughout urban settings.

Historical surface water runoff in the City may have been imperceptible due to high infiltration rates of the natural landscape (pre-development). Similar conditions have been identified in adjacent watersheds in Polk County in which the results of a pollutant loading model indicated

surface water was negligible under pre-development conditions (McCary and Ross 2005). Under present conditions, surface water runoff from urban areas of the City produce much more runoff than undisturbed areas, as so much of the urbanization has occurred on soil types with high infiltration rates (i.e., Harper and Baker 2007). Due to extensive development, a substantial loss of storage in the surficial aquifer, i.e. the volume of rainfall that no longer percolates into the surficial aquifer, has occurred resulting in an increase in surface water runoff to the lakes.

If the water was re-directed into ground water infiltration, stormwater runoff and associated nutrients into the lakes would be reduced. Increased ground water recharge could contribute to ground water levels in the surficial aquifer and possibly increase recharge to adjacent lakes via seepage and/or contribute to deeper aquifer recharge. Re-establishing soil infiltration and surficial aquifer recharge as a water source in the City could decrease the variability, or “flashiness”, in water levels, while dry season lake levels could be held higher due to increased ground water seepage during periods of reduced rainfall.

SIA's have a documented phosphorus removal efficiency of 85 percent (Harper 2008), i.e. 85 percent of phosphorus in the stormwater runoff captured by the SIA's will be removed. The location and sizing of SIA's vary, but SIA's are designed to capture the total treatment volume (from the contributing watershed) and be conducive to infiltration of the treatment volume within two hours.

Increased surface water infiltration would provide additional stormwater treatment via particle filtration, phosphorus absorption to carbonate sediments, and (potentially) nitrogen reduction via denitrification. In addition, recent studies have demonstrated that in-situ practices such as bio-swales, bio-infiltration, engineered soil media systems or engineered permeable pavement that receive runoff from impervious urban areas can greatly reduce runoff and help restore the pre-development hydrology (Harper and Baker 2007). A recent study showed that water level fluctuations in Lake Haines, City of Winter Haven, were correlated with the level of the surficial aquifer, but only when the surficial aquifer was at a higher elevation than the lake itself (PBS&J 2009). Together, these findings indicate that maintaining higher water table levels in the City watershed may be a useful lake management strategy for improving water quality.

The decision key included as part of the draft WQMP has identified three lakes (Beulah, Bonnet, and Hunter) that would potentially benefit from stormwater retrofits due to the likelihood that each is potentially impacted by stormwater loads and shows a direct correlation with rainfall.

For stormwater systems with direct connection with the lakes listed above, it is recommended that the Continuous Monitoring and Adaptive Control (CMAC) systems be evaluated for installation and implementation. There are now reliable, robust, and secure solutions for cost-effective CMAC of stormwater infrastructure. These solutions are important for accelerating the enhancement and conversion of existing stormwater facilities and construction of new facilities. CMAC solutions integrate information directly from field-deployed sensors with real-time weather forecast data (i.e., NOAA forecasts) to directly monitor performance and make automated and predictive control decisions to actively manage stormwater storage and flows. CMAC technology has achieved water quality, flood control, hydromodification, and water reuse objectives at over 130 sites across 21 US states.

CMAC can provide stormwater solutions in several ways, including:

1. Improving quality of stormwater runoff by increasing residence time and/or improving unit process effectiveness (e.g., settling, denitrification, infiltration);
2. Restoring pre-development hydrology and base flows by actively modulating stormwater release rates based on forecast information;
3. Increasing the runoff volume retained on site for water reuse;
4. Reducing the frequency of flooding events; and
5. Being adaptable to future climatic conditions or changes in site characteristics by reconfiguring the software.

Further, CMAC solutions can help mitigate technical, regulatory, and compliance risk by:

1. Providing auditable performance and supporting data;
2. Decreasing downtime of facilities through alerting of operational or maintenance issues; and
3. Providing direct verification of facility performance.

Summary

There are several lake management approaches and techniques that can be used to address water quality issues and concerns in the City. Even if external loads to lakes are reduced or eliminated, internal nutrient loads should also be managed. In addition to documented successes of sediment removal and inactivation and wetlands treatment, water quality improvements may also be accomplished using less traditional methods, including artificial circulation, SAV/EAV planting, forested wetland rehydration, SIAs, and shoreline vegetation establishment. Water quality improvements expected as a result of projects such as forested wetland rehydration and SIAs will occur as a result of the water quality/hydrologic restoration benefits. Applications of these methods to individual lakes in the City are presented in Section 6: Lake-Specific Restoration Projects.

In addition to these lake-specific restoration projects, it is important that the City of Lakeland have locally-relevant and scientifically-sound water quality targets to guide its lake restoration activities. Paleolimnological work in Lake Hollingsworth suggests that the TP and chlorophyll-a targets set by FDEP in the lake's state-approved TMDL are unrealistic and would have resulted in the lake exceeding guidance criteria in the 1890s. Paleolimnological work conducted in Lake Bonny has shown that hydrologic alterations that lowered the lake below its previously fringing forested wetlands has had an important impact on water quality, and that addressing nutrient loads from external sources alone would not result in the hoped-for improvements in water quality.

5. DECISION KEY

Based on the assimilation of the information derived from site visits and data analysis efforts a data-driven decision key was developed for project selection to inform the City about the types of projects that make the most sense for each lake. To determine the most appropriate management approach for each of the City's priority lakes, a three-step process was developed. These steps are sequential, but project identification can come about at different stages in each of the three steps. Briefly stated, these steps are:

Step I – Verification that lakes are actually impaired for nutrients using the State of Florida's most recent lake classification system;

Step II – Identifying the nutrient (nitrogen or phosphorous) that is most strongly influencing the expression of eutrophication in each lake; and

Step III – Identifying and/or verifying the types of projects most capable of restoring and/or improving water quality in each lake.

Techniques

The techniques used in this three-step process differ between and within each step. However, each process is guided by the concept that lake restoration plans could differ substantially between lakes, and that each lake restoration plan would be guided by well-developed scientific principles, rather than focusing strictly on policy or existing regulatory guidance. Although there are instances where the project types suggested for implementation might be fully consistent with guidance from regulatory programs, such as the TMDL program, there are also project types that could be very different from typical guidance from regulatory agencies.

The Steps involved in this process are outlined below:

Step I – Is the lake truly impaired for water quality?

Topic: Differences between different water quality classification systems used over time by FDEP can result in different determinations of impairment status.

Question 1: Is the lake on FDEP's most up-to-date Verified Impaired List, based on exceeding guidance criteria using TSI or is guidance criteria (i.e., based on TSI)?

Yes - Go to Question 2

No - The lake is not considered impaired based on TSI. If not impaired with NNC criteria as well, maintenance of water quality should be the focus of management actions. Trend analysis, using tools such as a Seasonal Kendall Tau test, could be used to determine if the lake is likely to become impaired in the near future. Go to Question 2.

Question 2: Is the lake also impaired, using NNC criteria?

Yes - The lake is impaired for nutrients and/or indicators of eutrophication. Go to Step II.

No - The lake is not impaired using NNC guidance. Discuss with FDEP the most appropriate approach to removing the lake from the verified impaired list. Maintenance of water quality should be the focus of management actions. Trend analysis, using tools such as a Seasonal Kendall Tau test, could be used to determine if the lake is likely to become impaired in the near future. Go to Step II.

Step II – Which nutrient is of greatest importance to water quality?

Topic: Is algal biomass limited by the availability of nitrogen, or phosphorous, or both?

Question 1: Which nutrient, nitrogen or phosphorous, better explains variation in the abundance of phytoplankton?

Test: Compare the coefficient of correlation (r-square) values of the two separately calculated plots of TN vs. chlorophyll-a and TP vs. chlorophyll-a

Outcome 1 - TP vs. chlorophyll-a has a statistically significant correlation, but not TN. Algal growth likely limited by the availability of phosphorous. Lake management activities should focus on external and/or internal sources of phosphorous. Go to Step III.

Outcome 2 - TN vs. chlorophyll-a has a statistically significant correlation, but not TP. Go to Question 1a.

Outcome 3 - Both TN and TP have statistically significant correlations with chlorophyll-a, with similar r-squared values. Algal growth likely limited by the availability of both nitrogen and phosphorous. Lake management activities should focus on external and/or internal sources of both nitrogen and phosphorous. Go to Question 1a.

Outcome 4 - Neither TN nor TP are positively correlated with chlorophyll-a. Algal growth likely not limited by availability of nutrients. Examine potential that impairment status is in error, or that wetland influences moderate transformation of nutrients into phytoplankton.

Question 1a: Over the past 10 years, are more than 25% of TN values higher than 3 mg/L?

Yes - Correlation between TN and chlorophyll-a likely spurious, and indicative of nitrogen fixation via cyanobacteria. Algal growth likely limited by availability of phosphorous. Go to Step III.

No - Algal growth likely limited by the availability of nitrogen. Lake management activities should focus on external and/or internal sources of nitrogen. Go to Step III.

Step III – What types of projects are required to restore water quality?

Topic: Are nutrient loads from external sources such as stormwater runoff the dominant influence on water quality?

Question 1: Does the concentration of the nutrient of greatest concern (derived in Step II) correlate with rainfall, as a surrogate for stormwater loads?

Test: Does the annual average concentration of the limiting nutrient(s) from Step II vary in a positive direction with annual rainfall in a statistically significant relationship?

Yes - Stormwater loads are likely a dominant influence on water quality.

Project types needed – stormwater retrofits, public education, etc. Manage for healthy populations of native vegetation. Go to Question 2a.

No - Internal loads are likely a dominant influence on water quality. Go to Question 2.

Topic: How important are sediments to water quality?

Question 2: Is there evidence of a prior or ongoing point source load or landscape feature (e.g., citrus groves, etc.) that would be expected to load nutrients at rates higher than those associated with an urbanized watershed?

Yes - go to Question 2a.

No - go to Question 3.

Not Known - go to Question 2a.

Question 2a: Is there evidence of elevated concentrations of the limiting nutrient(s) with lower lake levels?

Test: Does the concentration of the limiting nutrient (derived in Step II) vary in an inverse direction with lake level in a statistically significant relationship?

Yes - Re-suspended sediments are likely a source of internal nutrient concentrations.

Project types needed – sediment removal and/or sediment inactivation. Potentially, whole-lake circulation, if lake is less than 75 acres in size. Manage for healthy populations of native vegetation. Go to Question 3.

No - Re-suspended sediments not likely a dominant source of nutrients, but internal loads are important via other mechanisms.

Project types needed – Potentially, whole-lake circulation, if the lake is less than 75 acres in size.

Manage for healthy populations of native vegetation. Go to Question 3.

Topic: How important are potentially lost wetland influences?

Question 3: Is there evidence of the lake having been lowered below its historical level?

Yes - Go to Question 3a.

No - Lake sediments not likely an ongoing source of nutrients in terms of bottom resuspension or internal nutrient loads.

Project types needed – Potentially, whole lake circulation, if lake is less than 75 acres in size. Manage for healthy populations of native vegetation.

Question 3a: Is there evidence of a lost connection to historical wetland fringes?

Yes - Reestablishment of wetland influences on water quality required.

Project types needed: Consider activities to re-introduce wetland influences via pumping water into drained wetlands to reenter the lake, lowering wetlands to current lake levels to enhance lake-wetland interaction, or implement projects to add tannin influences to the lake's water column. Manage for healthy populations of native vegetation.

No - Neither stormwater nor sediment resuspension are obvious impacts on water quality. No evidence of lost wetland influences as a major impact on water quality.

Project types needed: Potentially, whole lake circulation, if lake is less than 75 acres in size. Manage for healthy populations of native vegetation.

Status and Trends of Water Quality

To maximize the comparability of information across all the lakes, POR water quality data as provided by the City and/or Polk County Natural Resources, were used as the primary data source. Prior to 2007, water quality data from the City were not collected at a discrete depth within the water column; instead the samples were collected as a composite ("comp") taken throughout the water column. To determine if this sampling technique might make trend analysis problematic due to changes in techniques alone, a comparison of the discrete and "comp" water quality data were completed to ascertain if a noticeable discrepancy in concentrations was observed due to the different sampling method (Appendix A). A visual inspection of the data indicated that there was not a distinct change in parameter concentrations that could be attributed to the sampling methods alone. While there is evidence of difference in results for chlorophyll-a in Lake Wire in recent years (Appendix B) this appears to be due to a likely change in the minimum detection limit used, rather than a change in sample collection techniques. As Lake Wire is not impaired for water quality, the

effects of this discrepancy is minor, and not relevant for the other impaired lakes. As such, data over the POR were included in the analysis presented below. Water quality data for Crystal Lake (WBID 1497A) were retrieved from the FDEP IWR Run 49, because Crystal Lake is not included in the City ambient water quality monitoring program at this time. Outlier data points were identified through the graphical display of the data and removed from analysis as necessary (Appendix C). Any data points excluded from analysis are specifically identified for each lake.

Prior to performing statistical analysis, the data have to be characterized in such a manner that the appropriate technique can be utilized. Parametric statistical analysis requires the data being analyzed to satisfy three assumptions: that they come from independent sampling events, that there is a “normal” (i.e., bell-shaped curve) distribution of the data, and that the data have equal variances for variables tested against each other. Prior to selecting the appropriate statistical tool, a test to determine the normality and variance for each dataset was performed. Overall, the majority of datasets did not satisfy the last two assumptions; therefore, non-parametric analysis was performed for all lakes. Non-parametric statistical analyses are performed on the ranks of individual observations, which is a data transformation in which discrete values are replaced for further analysis by their ranks within the dataset. A p-value statistic of less than or equal to 0.05 was used to identify statistically significant relationships. In lieu of a coefficient of determination (r^2) which indicates how well data fit a parametric statistical model, non-parametric statistical analysis provides a correlation coefficient (ρ) which demonstrates the association between the variables of interest as well as directionality (values range between -1 to +1). For example, a correlation coefficient of -0.68 indicates a strong, inverse correlation, while a correlation coefficient of +0.20 would indicate a weak, direct correlation. It should be noted that the symbols for probability due to chance (p) and correlation coefficient (ρ) appear similar, but they are different in their meaning.

The decision key was applied to each lake to identify recommended projects for water quality improvements. Multiple water quality analysis techniques were used to ascertain specific influences on water quality. These techniques included the following analysis:

- General lake and watershed characterization;
- Impairment designation using NNC;
- Determination of the limiting nutrient of concern (NOC);
- Correlation between NOC and annual rainfall;
- Correlation between NOC and lake water elevation;
- Evidence of lowered lake water elevation (as necessary);
- Land Use-land cover change analysis (as necessary); and
- Seasonal Kendall Tau (as necessary).

Methods

A brief description of the analysis performed and applied to the decision key is provided below.

General Lake and Watershed Characterization

As part of the effort to develop WQMPs for the City, watersheds were delineated for each lake by using 2007 Light Detection and Ranging (LiDAR) data from the SWFWMD combined with relevant infrastructure information contained in the “City of Lakeland Annual Lake Report” (City of Lakeland 2010; Figure 5-1). Information related to lake and watershed size was generated from the most current land use/land cover layer (2011) as provided by the SWFWMD and the subsequent delineated watersheds. The water depths for each lake are from the “City of Lakeland Annual Lake Report” (City of Lakeland 2010).

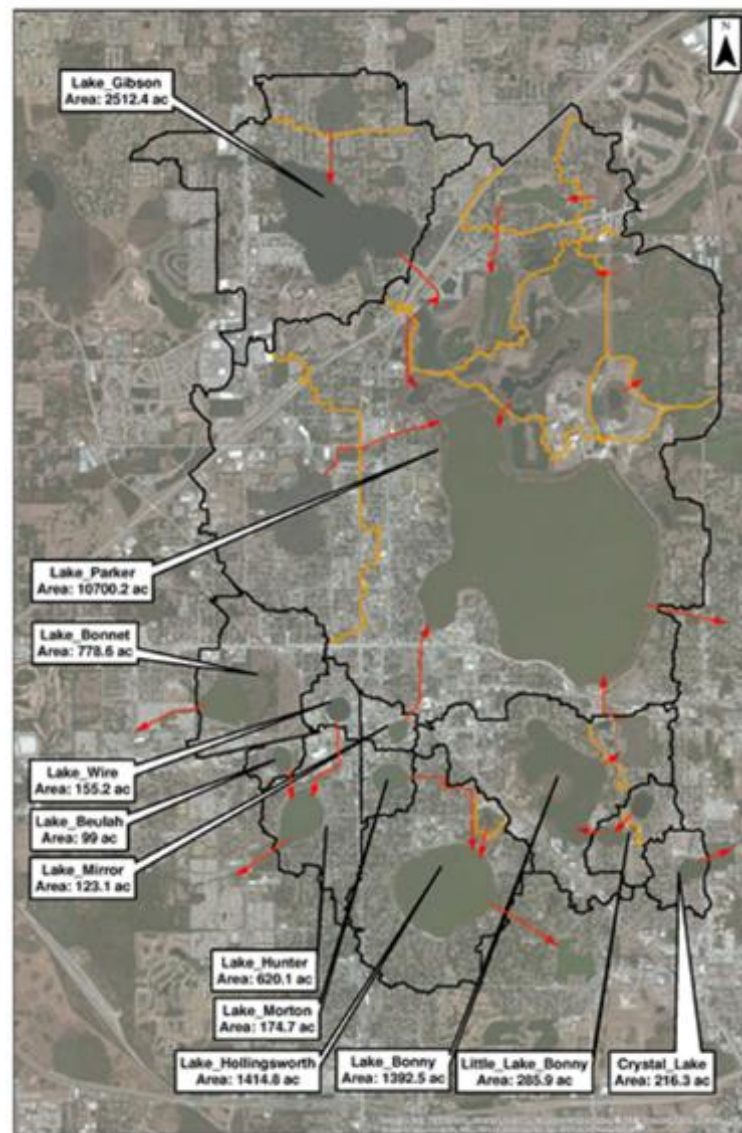


Figure 5-1. Watershed Delineations for Each Lake

Impairment designation using NNC

Consistent with the FDEP NNC, the annual geometric means for chlorophyll-a, TN, and TP, as well as an average of the respective annual geometric means, are provided for each of the 11 lakes over the period of 2007-2016. Water quality targets outlined in NNC are based on the amount of color as quantified with PCU and alkalinity as quantified by milligrams per liter of Calcium Carbonate (mg/L CaCO₃). Lakes are first divided into low-color (< 40 PCU) and high-color (> 40 PCU) categories. For low-color lakes, they are then divided into either low-alkalinity (≤ 20 mg/L CaCO₃) or high-alkalinity (> 20 mg/L CaCO₃) categories. For lakes with no data on alkalinity, the more commonly measured term of specific conductance can be used; the value of 100 μmhos/cm serves as a proxy for the 20 mg/L CaCO₃ alkalinity threshold. The lake-specific data sets provided were used to characterize each of the 11 lakes in terms of the NNC targets with lake classifications compared to those in Atkins and ESA (2014).

An interesting component of the NNC guidance for lakes (F.S. 62-302.531) is that TN and TP targets can be higher if the chlorophyll-a concentration is below the target for each lake classification type (Figure 5-2).

Long Term Geometric Mean Lake Color and Alkalinity	Annual Geometric Mean Chlorophyll <i>a</i>	Minimum calculated numeric interpretation		Maximum calculated numeric interpretation	
		Annual Geometric Mean Total Phosphorus	Annual Geometric Mean Total Nitrogen	Annual Geometric Mean Total Phosphorus	Annual Geometric Mean Total Nitrogen
> 40 Platinum Cobalt Units	20 μg/L	0.05 mg/L	1.27 mg/L	0.16 mg/L ¹	2.23 mg/L
≤ 40 Platinum Cobalt Units and > 20 mg/L CaCO ₃	20 μg/L	0.03 mg/L	1.05 mg/L	0.09 mg/L	1.91 mg/L
≤ 40 Platinum Cobalt Units and ≤ 20 mg/L CaCO ₃	6 μg/L	0.01 mg/L	0.51 mg/L	0.03 mg/L	0.93 mg/L

Figure 5-2. Lake NNC chlorophyll-a, TN and TP Criteria (FDEP 2013)

If some feature of a lake (e.g. SAV abundance, high tannin levels, etc.) keeps the chlorophyll-a concentration below the respective target value, then concentrations of TN and TP can be quite a bit higher than otherwise permissible. Subsequently, if “non-nutrient (TN and TP)” factors can be acted upon to decrease the chlorophyll-a concentration then TN and TP concentrations can increase.

Of particular local relevance, high-color lakes located within the “West Central Nutrient Watershed” region, (F.S. 62-302.531) have target TP concentration of 0.49 mg/L TP if they also have chlorophyll-a concentrations below 20 μg/L. Lakes impacted by this stipulation are generally located within the Peace, Myakka and Hillsborough River watersheds which have been documented

to have a naturally phosphorus-rich geology. All of the lakes included within this assessment fall within the watersheds of the Peace or Hillsborough River watersheds, and thus would fall within the West Central Nutrient Watershed, as defined by FDEP.

The impairment designation as defined by the NNC was determined for each of the 11 priority lakes. Additionally, the percent reduction in concentrations required to meet NNC criteria has been calculated, where applicable, for City lakes. For those lakes that exceed the NNC guidance for either chlorophyll-a, TN, and/or TP, the following equation was used:

$$\text{Percent reduction} = [(\text{average value} - \text{NNC target}) / \text{average value}] \times 100$$

Determination of the Limiting NOC

Correlation (Spearman's rank) analysis was completed for TN or TP and chlorophyll-a to determine if two variables are monotonically (consistently increasing or decreasing in value) related, using linear or non-linear models. The non-parametric analysis was performed as the water quality data did not typically satisfy the three required assumptions to apply parametric statistics. Additionally, a correlation analysis was completed so as to not suggest causation between the two variables.

Correlation between NOC and Annual Rainfall

Correlation (Spearman's rank) analysis was completed for the annual average concentration of the limiting NOC and annual rainfall to determine if a monotonic trend existed between the two variables. A significant direct, correlation was indication that external stormwater loads are likely a dominant influence on water quality within the lake.

Correlation between NOC and Lake Water Elevation

Correlation (Spearman's rank) analysis was completed for the monthly median concentration of the limiting NOC and the monthly median lake water elevation to determine if a monotonic trend existed between the two variables. A correlation analysis was completed so as to not suggest causation between the two variables. A significant inverse, correlation was indication that re-suspended sediments are likely a dominant influence on water quality within the lake.

Evidence of Lowered Lake Water Elevation (as necessary)

GIS was used to obtain elevation data around historical and existing lake edges. Pre-settlement maps, surveyors' notes, elevation data, current aerial photographs, and existing land use data were overlaid in GIS. Figure 5-3 shows an example of this process.

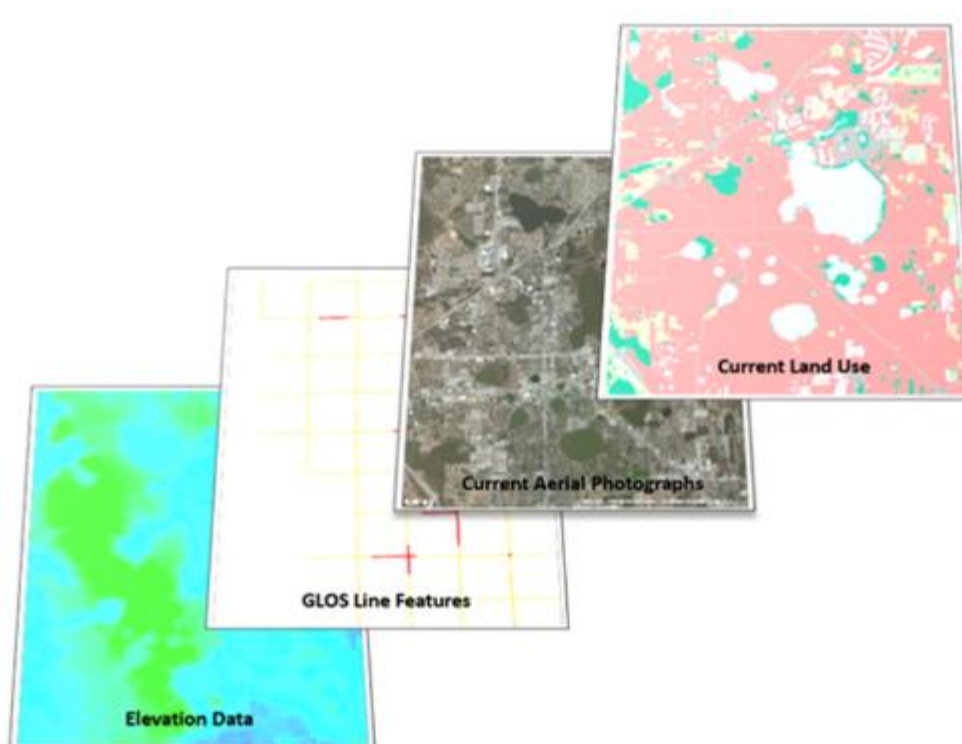


Figure 5-3. Example of How Data Was Overlaid in GIS to Obtain Elevation Data around Historical and Existing Lake Edges

LiDAR data was processed to create a 3D raster image based on topography. This digital elevation model (DEM) was used to interpolate topographic data at historical and existing lake edges.

Historical lake edges were obtained from the General Land Office Survey (GLOS) maps and GLOS line features. GLOS maps were downloaded from the FDEP, Bureau of Survey and Mapping (BSM), Land Boundary Information System (LABINS) website. Historical GLOS line features were created from surveyors' notes and obtained from SWFWMD. Notes indicate that the GLOS maps and line features were generated circa 1850. Line features with associated notes indicating lake edges were selected and used for this analysis.

Existing lake edges were established by referencing SWFWMD 2011 land use data and 2014 aerial photographs. Figure 5-4 shows the GLOS line features used on a current aerial photograph. Table 5-1 lists the historical and current elevation from the GLOS line features.

GLOS line features were found around five of the lakes. In addition, elevation information for one lake not in the City but in the general area was included. Figures 5-5 and 5-6 display the data points indicating the historical and current lake edge around Lake Hollingsworth, respectively.



Figure 5-4. GLOS Data Points Used in Analysis of the City's Priority Lakes

TABLE 5-1. HISTORICAL AND CURRENT ELEVATION FROM GLOS LINE FEATURES

Lake	Historical Elevation (feet)	Current Elevation (feet)
Crystal Lake	141	136
Lake Beulah	-	-
Lake Bonnet	-	-
Lake Bonny (north side)	133	129
Lake Bonny (south side)	134	131
Lake Gibson (east side)	145	142
Lake Gibson (west side)	149	142
Lake Hollingsworth (east side)	137	130
Lake Hollingsworth (west side)	134	130
Lake Hunter	-	-
Lake Mirror	-	-
Lake Morton	-	-
Lake Parker (north side)	134	129
Lake Parker (south side)	133	129
Lake Wire	-	-
Lake Deeson (northwest side)	141	126
Lake Deeson (southwest side)	141	128

Gray shading indicates a lake not in the City priority lakes



Figure 5-5. Lake Hollingsworth Historical Lake Edge



Figure 5-6. Lake Hollingsworth Current Lake Edge

Land Use-Land Cover Change Analysis

A review of available historical aerial photography and land use-land cover data was performed to identify historical citrus and wetland features. Changes in significant watershed features were documented to ascertain discernible alteration to the water quality within a selected waterbody.

Based on the results of the analyses conducted here, the project types suggested for each of the City's priority lakes were derived, as shown in Table 5-2.

The next section of the WQMP, Chapter 6, will describe in greater detail the application of the processes used in the Decision Tree for each lake, along with a description of the types and likely costs associated with addressing water quality projects for the City's priority lakes.

TABLE 5-2. PROJECT TYPES DETERMINED TO BE NEEDED FOR EACH OF THE CITY'S PRIORITY LAKES. GREEN CELLS INDICATE PROJECT SELECTED.

Lake	Artificial circulation	Enhanced SAV	Wetland influence re-establishment	Sediment removal or inactivation	Stormwater reduction as priority action
Beulah					
Bonnet					
Bonny					
Crystal					
Gibson					
Hollingsworth					
Hunter					
Mirror					
Morton					
Parker					
Wire					

6. LAKE-SPECIFIC RESTORATION APPROACH

Lake eutrophication in general is a natural process whereby nutrient enrichment and biological productivity increase. Lake eutrophication can be exacerbated by anthropogenic land uses (Gill et al. 2005) or other anthropogenic activities. The accelerated eutrophication due to human activities is termed “cultural eutrophication.” Increased nutrients associated with eutrophication can increase algal growth (algal blooms) (Smith et al. 1999), in turn increasing turbidity, particulate organic matter, and dissolved organic matter in lakes. Many factors may influence in-lake water quality including: long-term hydrologic alterations, stormwater runoff, historical and current point source discharges, septic tank discharge, accumulated sediment, extent of SAV and EAV, and hydrologic connections to forested wetlands. The potential effects of these factors on water quality (e.g., nutrient enrichment, algal growth, transparency, etc.) were investigated and are presented below for each lake.

Priority lakes in the City for which restoration projects are proposed are individually characterized in this section of the WQMP (in alphabetical order). For each lake, the historical water quality patterns, the implications of relevant state and federal regulations for water quality restoration, and existing water quality are described in the below sections, thereby establishing the need for management projects. If insufficient data or data gaps were identified that could affect the successful development of a WQMP, the City was notified and recommendations of additional monitoring efforts were provided. Physical, chemical, and regulatory characteristics are presented in table format and maps illustrating land use and topography are provided for each lake. General data sources include the following:

- SWFWMD Shapefile Library, including land use (1995 and 2011), 1-foot contour, potentiometric (September 2011), and soils;
- FDEP GeoData Directory, including Wastewater Facility Regulation;
- United States Geological Survey (USGS) land use (1970 to 1985);
- University of Florida Map Library, historical aerial photographs and Sanborn maps; and
- City Community Development Department, septic tank location data.

Watershed boundaries for each lake were identified using 2007 LiDAR data from the SWFWMD combined with relevant infrastructure information contained in the “City of Lakeland Annual Lake

Report,” as described in Section 5.3. Those sub-basins contributing to each lake were grouped to delineate the contributing drainage area. The decision key presented earlier was applied to the existing water quality data for each lake. Based on the results produced from the decision key, proposed restoration projects specific to each lake are listed and described

Lake Beulah

Physical and chemical characteristics specific to Lake Beulah are presented here in the context of relevant regulatory criteria and requirements.

Historical and Recent Conditions in Lake and Watershed

Lake Beulah is a 19-acre lake located in the City within the eastern portion of Polk County, Florida (Figure 6-1). Maximum water depth is reportedly 28 feet, with an average water depth of 17 feet (City of Lakeland 2010). The lake is located within the Lakeland/Bone Valley Upland lake region of Florida, which according to Griffith et al. (1997), can be characterized with “high phosphorus, nitrogen, and chlorophyll-a values” and “alkaline, [with] some [lakes] receiving limestone-influenced groundwater.” In accordance, Lake Beulah is categorized as a low color, alkaline lake based on the long-term geometric mean of 18 PCU and 25 mg/L, respectively.

Lake Beulah is located within the Hillsborough River watershed and the immediate contributing watershed to the lake is 99 acres in size, resulting in a watershed to open water ratio of 5.2 to 1 (Table 6-1; Figure 6-1). Watershed to open water ratios can be used to compare the relative amount of influence that a lake experiences from its contributing watershed, such as stormwater runoff. Typically, lakes with “low” watershed to open water ratios (i.e. less than 10) may not experience the degree of influence from external loads of stormwater as do lakes with “high” values. However, no absolute threshold value for this ratio exists and there is no definitive value at above which stormwater is problematic and below which stormwater is not an important stressor. Comparisons of watershed to open water ratios can be valuable but should be used with caution.

Lake Beulah is not influenced by any upstream lakes and is connected (at high water levels) to Lake Hunter via an adjustable control structure (City of Lakeland 2010). Prior to 2007, the lake water elevation was frequently above the minimum operating range for Lake Beulah (Figure 6-2). Since 2007, the lake water elevation has only infrequently exceeded the lower elevation of its structure operating range. The operation water elevation range for Lake Beulah is 178.67 to 179.67 feet NAVD. Within the Lake Beulah watershed, there is a moderate elevation gradient ranging from 179 to 213 feet NAVD (Figure 6-3). Lake Beulah is located between 80 and 90-foot potentiometric surface elevations and south of the potentiometric peak, as of September 2011 (Figure 6-4). Additionally, the northern boundary of the intermediate aquifer system is just north of Lake Beulah (Spelcher and Kroening 2007). Therefore, it is unlikely that there is direct connectivity with the Floridan aquifer.

A review of historical aerial photography (from 1941) indicates the shoreline has not been obviously modified compared to recent photography (2014). By 1917, Sanborn maps identify numerous single family dwellings, boarding homes, and churches along the eastern border of Lake

Beulah (Figure 6-5). A combination of residential and commercial development continued into the 1950's with major development and improvements stagnating around 1968, which is representative of existing development conditions (Figure 6-6). The extensive development within the watershed is reflected in the land use/land cover data provided by both USGS and SWFWMD (Table 6-2). Specifically, the SWFWMD land use data from 2011 classifies 78 acres (98%) as developed lands compared to 2 acres (2%) of undeveloped land (Figure 6-7).

There are 20 minor stormwater outfalls, 1 major outfall, two end of pipes, and one lake/creek outlet which discharge to Lake Beulah (Figure 6-8). In regards to infrastructure, the majority of the existing residential developments within the watershed utilize sanitary sewer for wastewater treatment provided by the City (City of Lakeland 2010). No permitted Onsite Sewage Treatment and Disposal Systems (OSTDS) systems were identified within the watershed (Figure 6-9). Based on a review of SWFWMD soil survey geographic data, soils within the watershed have a low runoff potential with high, moderate, and low infiltration rates and are classified either as hydrologic soil group A (6 acres), B (1 acres), or C (67 acres), respectively (Figure 6-10).

As reported by City of Lakeland (2001), up to 65% of Lake Beulah was historically covered with Hydrilla and alligator weed. In the late 1980s, Hydrilla was removed by a combination of mechanical harvesting and herbicide application. The City has planted clusters of *Nuphar* sp. in the lake and completed extensive revegetation along the shoreline. The majority of the shoreline vegetation has been modified as a result of residential encroachment, predominantly including landscaping activities. Sparse EAV is apparent on Google Earth imagery.

TABLE 6-1. PHYSICAL CHARACTERISTICS OF LAKE BEULAH AND ADJACENT WATERSHED

Physical			
Location	City of Lakeland; Polk County	High infiltration soils (acres)	5.6
Relation to other lakes	Discharges to Lake Hunter	Developed land (acres)	98
Watershed area (acres)	99	Undeveloped land (acres)	2
Lake area (acres)	17	Mean water depth (ft)	16.4
Perimeter (feet)	3,287	Maximum water depth (ft)	27.9
Surface area: lake volume ratio	0.06	Volume (acre-feet)	287
Watershed to surface area ratio	5.8		5.6

TABLE 6-2. CHANGES IN LAND USE WITHIN THE LAKE BEULAH WATERSHED OVER TIME

Land Use	1970-1985*		1995		2011	
	Acres	Percent	Acres	Percent	Acres	Percent
Industrial	-	-	6	8	6	8
Commercial and Services	28	34	31	39	28	36
Institutional			9	11	12	14
Open Land			2	3	2	3
Residential (High Density and Multi-family)	51	62	33	42	33	42
Transportation, Communications, and Services**	4	5	N/A	N/A	N/A	N/A

*Metadata for USGS land use data identifies data collection dates as a period between 1970 and 1985

**Land use types differ between USGS and SWFWMD classification schemes. Please note that SWFWMD data does not include "transportation, communications, and services."

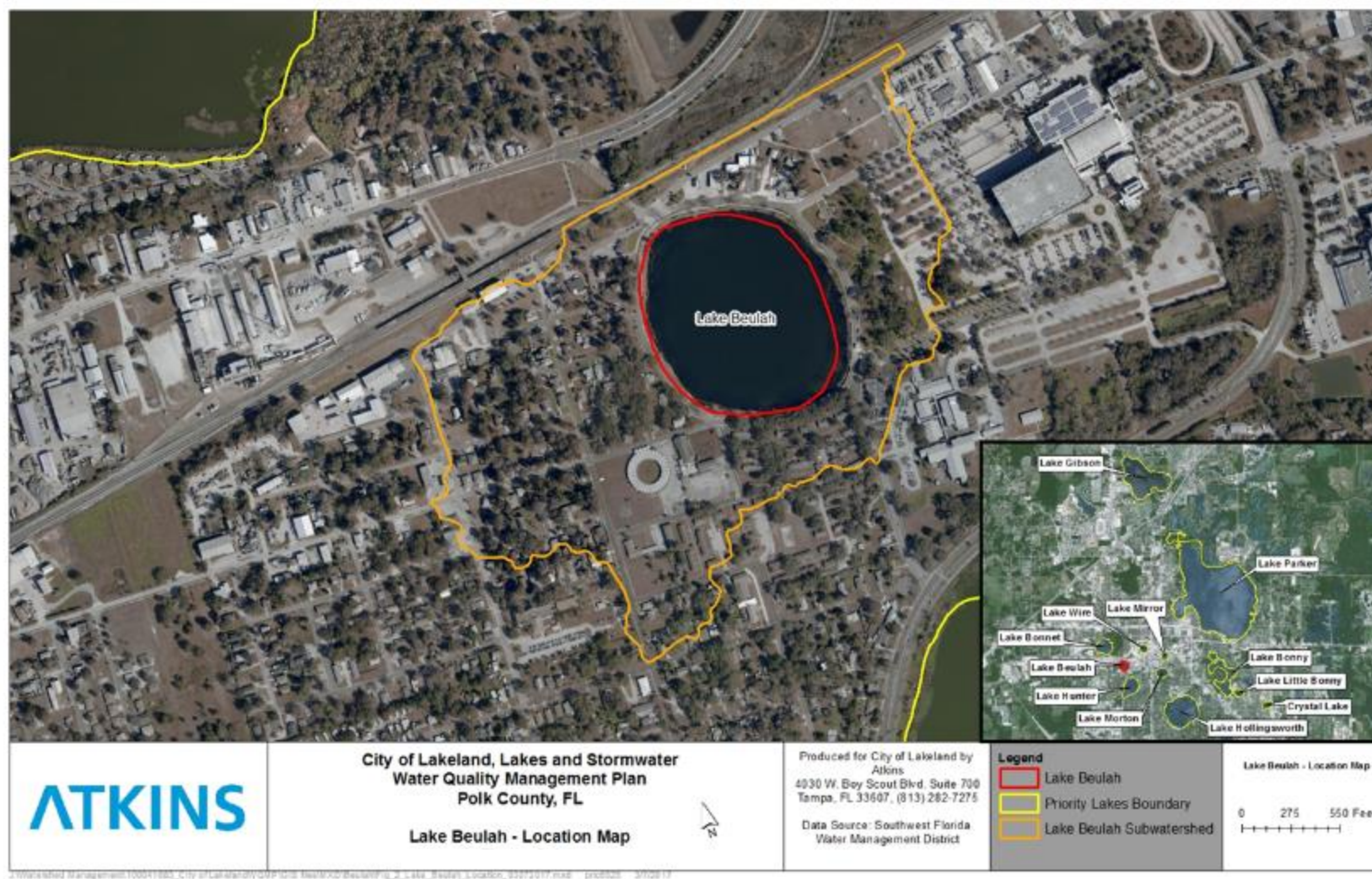


Figure 6-1. Lake Beulah location map

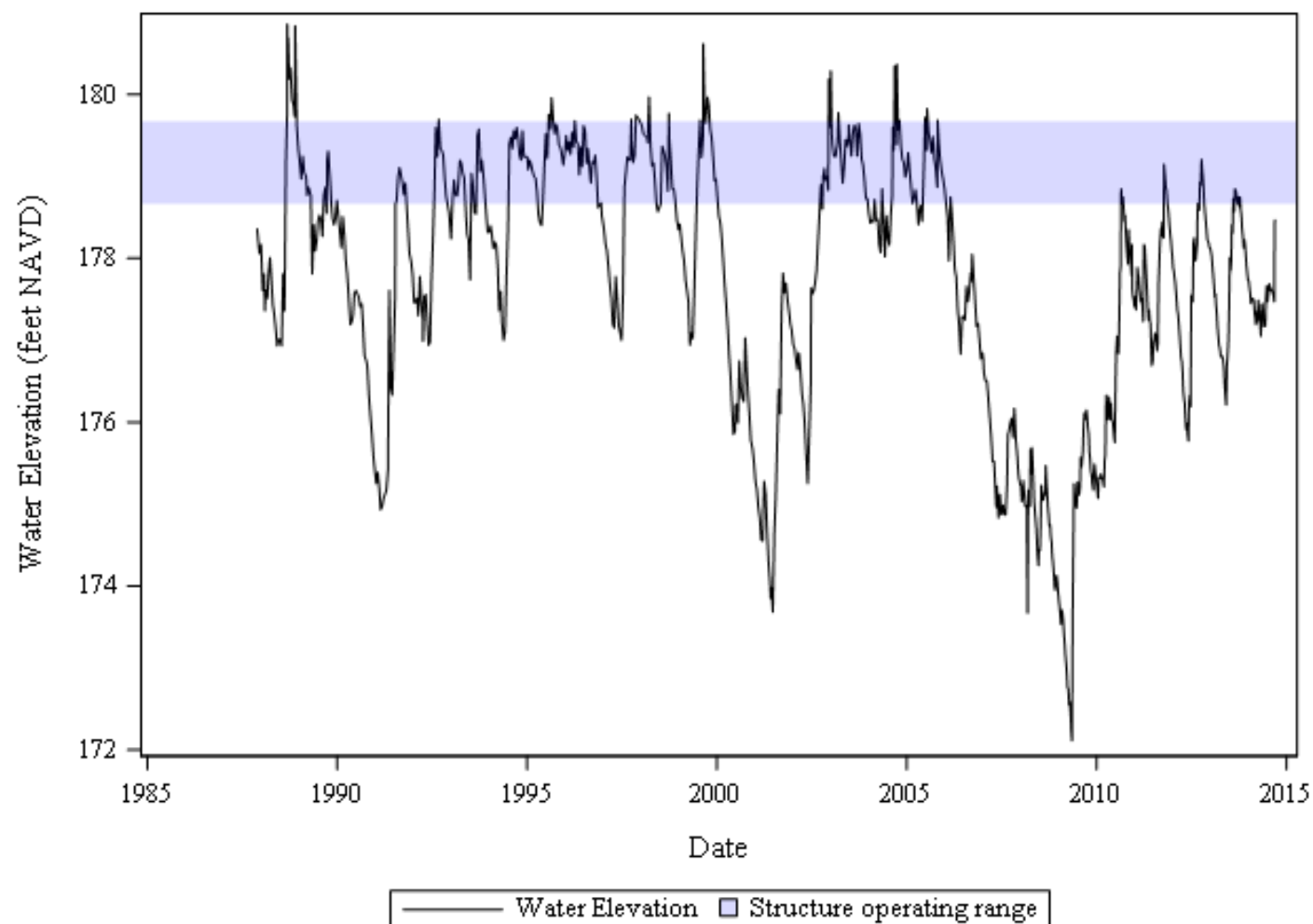


Figure 6-2. Period of Record Lake Beulah water elevation

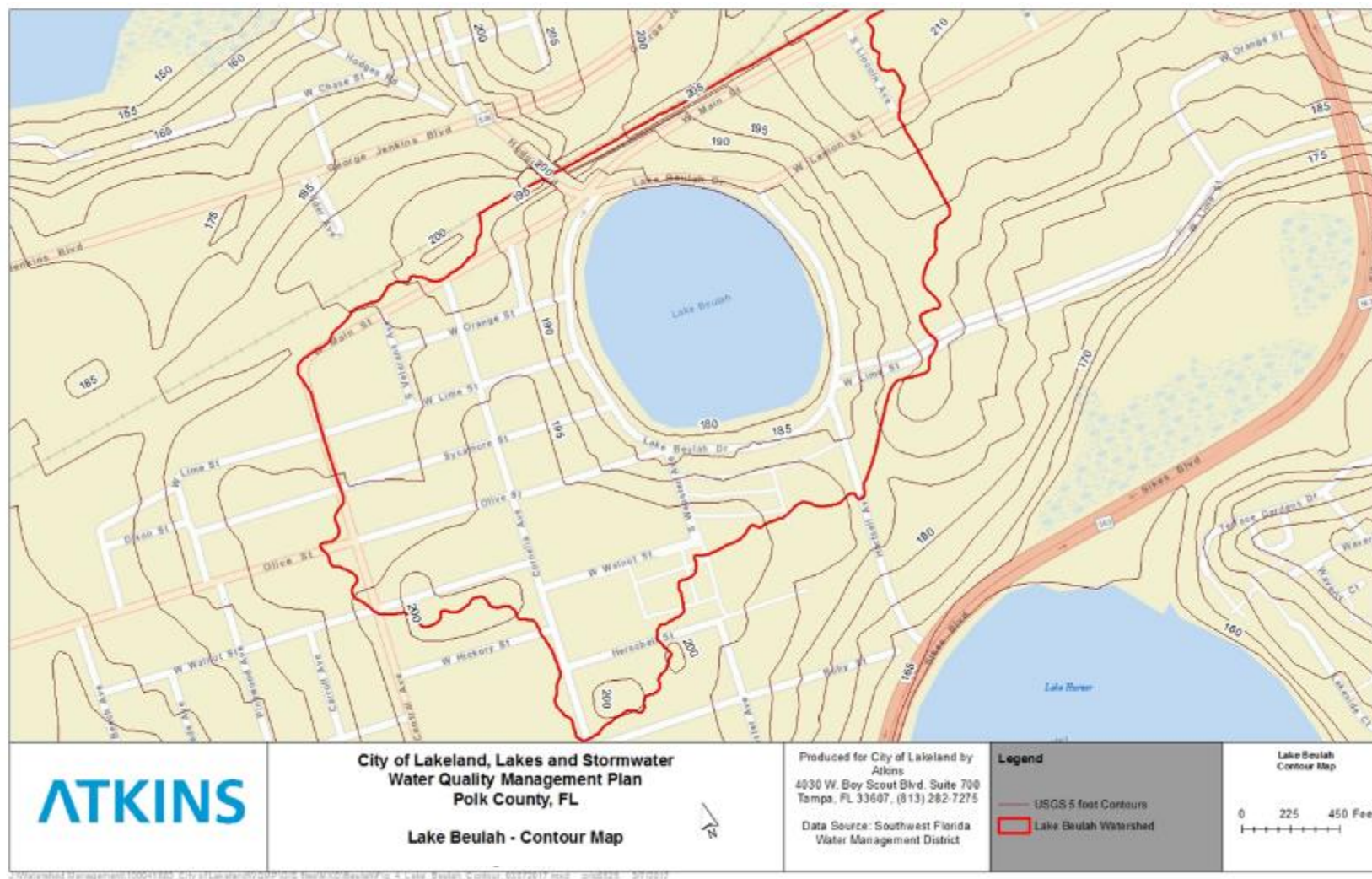


Figure 6-3. Lake Beulah contour map

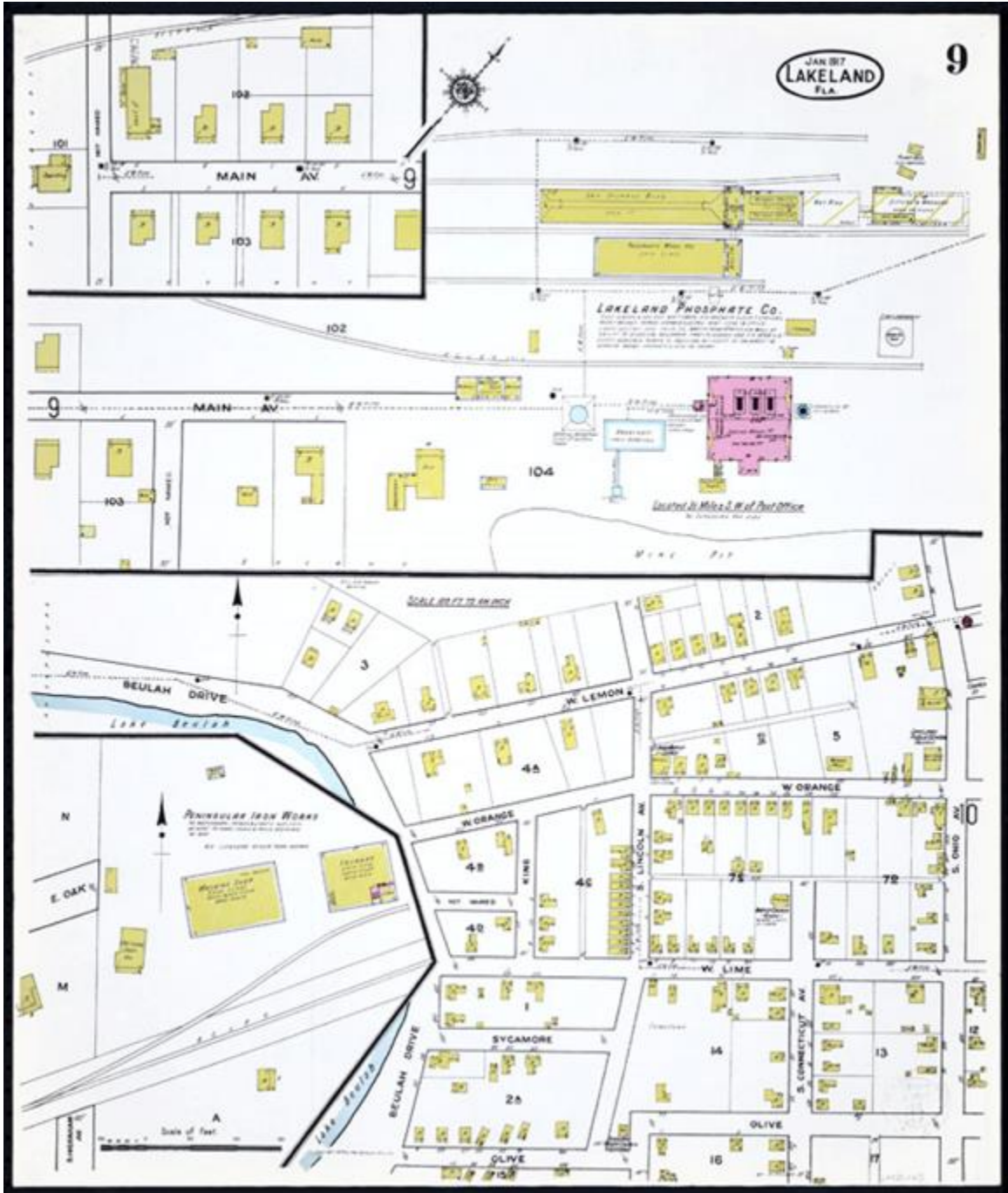


Figure 6-5. Lake Beulah 1917 Sanborn map



Figure 6-6. Lake Beulah historical aerial imagery. Left Photo: 1958. Right Photo: 1968

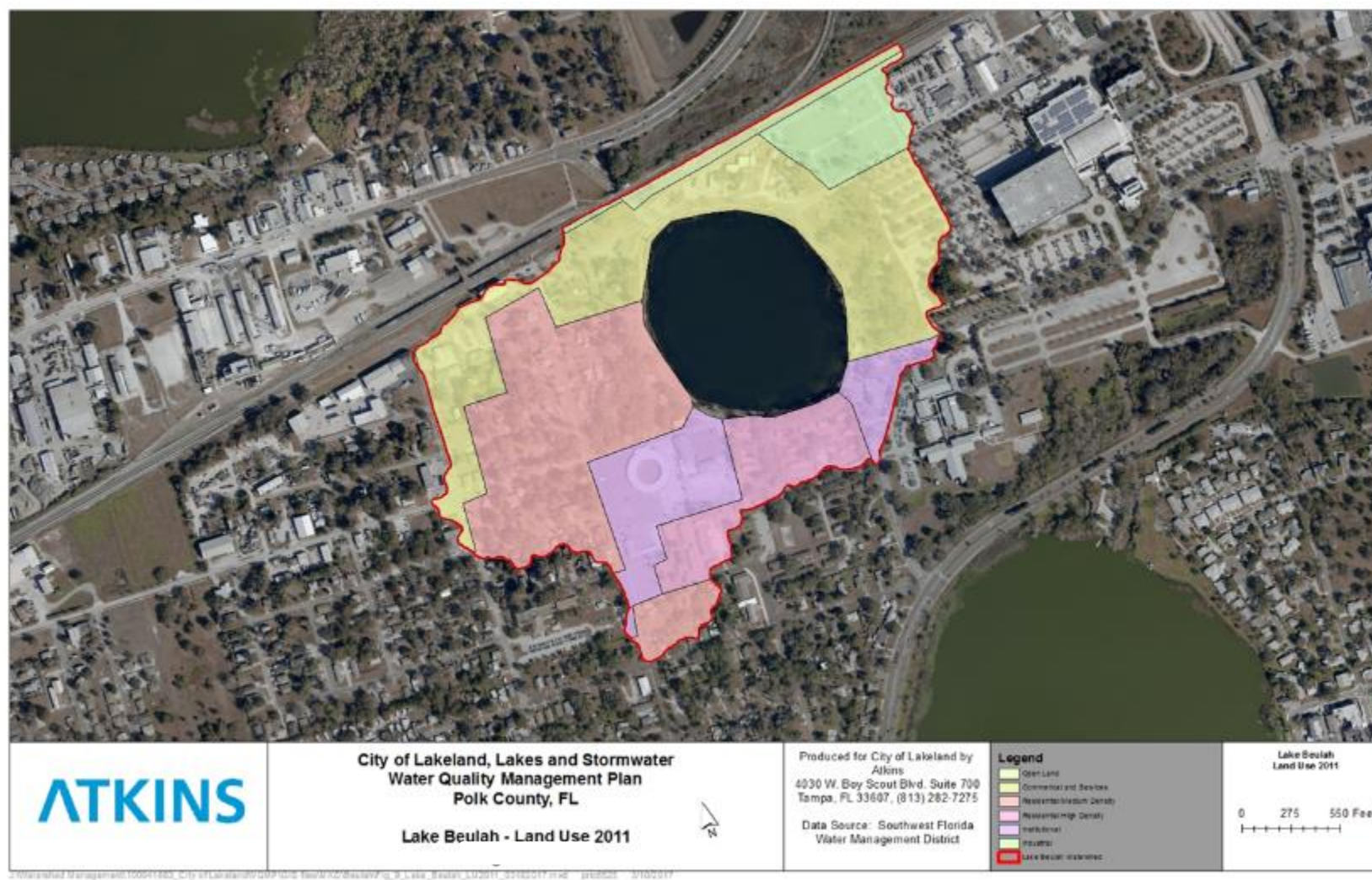


Figure 6-7. Lake Beulah 2011 land use map



Figure 6-8. Lake Beulah stormwater map



Figure 6-9. Lake Beulah OSTDS map

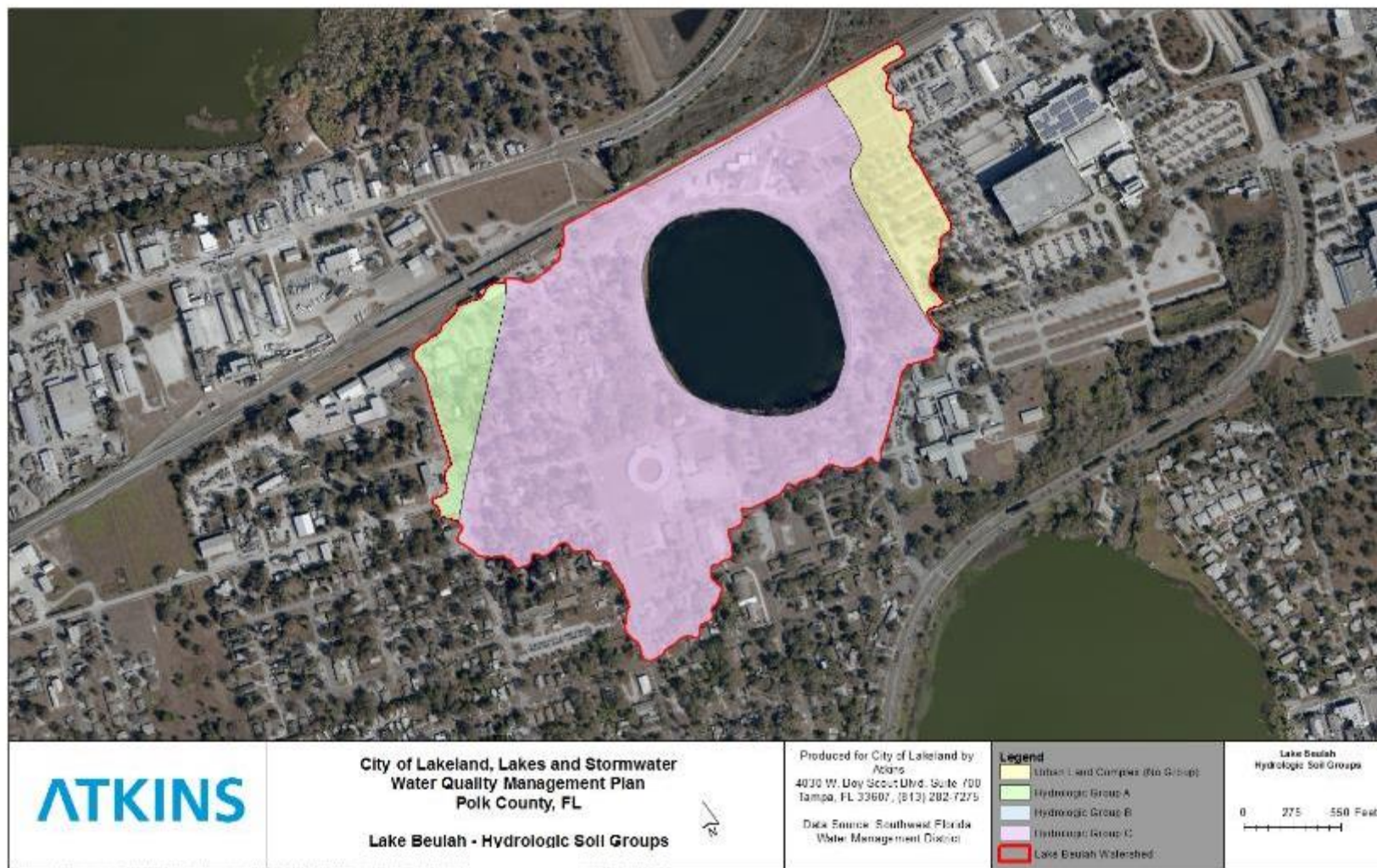


Figure 6-10. Lake Beulah soils map

Water Quality

Lake Beulah was not listed by the City of Lakeland (2010) as impaired, nor is it listed as impaired in FDEP's latest version of the Comprehensive Verified Impaired List (December 18, 2017). Lake Beulah is a Group 2 waterbody as part of the Tampa Bay Tributaries, the most recent impairment evaluation was performed for the verified period of January 1, 2007 to June 30, 2014. (Cycle 3) applied the NNC criteria. The cycle 4 assessment period will occur in 2020 for the verified period of January 1, 2012 to June 30, 2019.

To minimize the impacts different verified periods, the report summarized water quality for each of the City's priority lakes during the same time period, 1/1/2009 to 6/30/2016. These dates correspond to the latest Verified Period for which data are available from all of the City's priority lakes, for determining impairment status.

Water quality data were downloaded from FDEP, and used to determine the classification of Lake Beulah. The lake was classified as a low-color, alkaline lake based on a geometric mean value for color of 15.5 PCU and a geometric mean alkalinity value of 23.1 mg (as CaCO₃) / liter. Based on that classification, the water quality targets for TN and TP were determined based on whether or not the annual geometric mean for a given year exceeds the threshold target of 20 µg chlorophyll-a / liter. The relevant water quality criteria for TN and TP for Lake Beulah are highlighted in yellow in Table 6-3. Based on the criteria listed below, Lake Beulah has the following exceedances (Table 6 – 4).

TABLE 6-3. WATER QUALITY CRITERIA FOR LAKE BEULAH, WITH RELEVANT TARGETS FOR CHLOROPHYLL-A, TN AND TP HIGHLIGHTED IN YELLOW

Long Term Geometric Mean Lake color and Alkalinity	Annual Geometric Mean chlorophyll-a	Minimum calculated numeric interpretation		Maximum calculated numeric interpretation	
		Annual Geometric Mean TP	Annual Geometric Mean TN	Annual Geometric Mean TP	Annual Geometric Mean TN
> 40 PCU	20 µg/L	0.05 mg/L	1.27 mg/L	0.16 mg/L ¹	2.23 mg/L
≤ 40 PCU and > 20 mg/L CaCO ₃	20 µg/L	0.03 mg/L	1.05 mg/L	0.09 mg/L	1.91 mg/L
≤ 40 PCU and ≤ 20 mg/L CaCO ₃	6 µg/L	0.01 mg/L	0.51 mg/L	0.03 mg/L	0.93 mg/L

TABLE 6-4. SUMMARY OF WATER QUALITY IMPAIRMENT DETERMINATIONS FOR LAKE BEULAH BY YEAR. YEARS WITH INSUFFICIENT DATA FOR COMPARISON WITH NNC CRITERIA ARE NOTED BY “-”

Year	chlorophyll-a (µg / liter)	TN (mg / liter)	TP (mg / liter)
2009	24.41	0.999	0.042
2010	20.08	0.925	0.040
2011	11.85	1.130	0.029
2012	8.58	0.742	0.036
2013	-	-	-
2014	-	-	-
2015	-	-	-
2016	-	-	-
Average percent reduction required (when needed)	9	-	27

For two of the four years with sufficient data to apply NNC criteria, Lake Beulah exceeded chlorophyll-a criteria by an average of less than 10 percent, and did not exceed NNC criteria for TN. Of the two of four years when Lake Beulah exceeded NNC criteria for chlorophyll-a, TP criteria were exceeded by an average of 27 percent. Based on examples contained within both PBS&J (2011) and Tomasko et al. (2013) the TP reductions required are within the range of reduction obtainable by implementing traditional lake restoration projects such as stormwater retrofits.

There was no evidence of a relationship between TN and chlorophyll-a (Figure 6-11) but TP and chlorophyll-a were significantly correlated (Figure 6-12). A significant, direct correlation between annual average TP concentrations and annual rainfall was found indicating that external sources such as stormwater runoff likely influence in-lake water quality ($p=0.0391$, $\rho=0.433$). Based upon these results, projects which focus on stormwater retrofits and public education are good candidates toward restoring water quality in Lake Beulah.

An evaluation of the surrounding landscape to determine if point source discharges or landscape features capable of loading nutrient rates higher than “normal” loads are present in the watershed was completed. Evidence of prior or ongoing point source loads to the lake which could lead to nutrient enriched sediments is unknown, and there are no landscape features (historical or current) that would be expected to exceed “normal” urban landscape nutrient loads to the lake. Lake sediment resuspension was not identified as a likely source of internal nutrient loads to the overlying water column based on the lack of a significant, inverse correlation between nutrient

concentrations and lake water elevation. An evaluation into the potential loss of wetland influences was performed through the analysis of the historical versus current lake extent. This analysis indicated that the lake has not been lowered compared to its original configuration. However, internal nutrient loads remain a potential source and, as such, Lake Beulah is a candidate for whole-lake circulation given the lakes size (19 acres). The maintenance/enhancement of native emergent and submerged aquatic vegetation is also recommended.

Based on the techniques used by FDEP of calculating nutrient reductions based on the maximum annual value, and comparing those percent reductions to examples contained within both PBS&J (2011) and Tomasko et al. (2013), the TP reductions required for Lake Beulah to meet NNC guidance for applicable years are within the range for lakes where whole-lake aeration has historically been applied.

Site-specific chlorophyll-a, TN, and TP targets have not been established and thus may be appropriate for Lake Beulah. Collection and analysis of locally-derived paleo data is advisable if the City decides to pursue establishing site-specific criteria. The decision of whether or not to pursue paleo studies for the 11 lakes is discussed in greater detail herein.

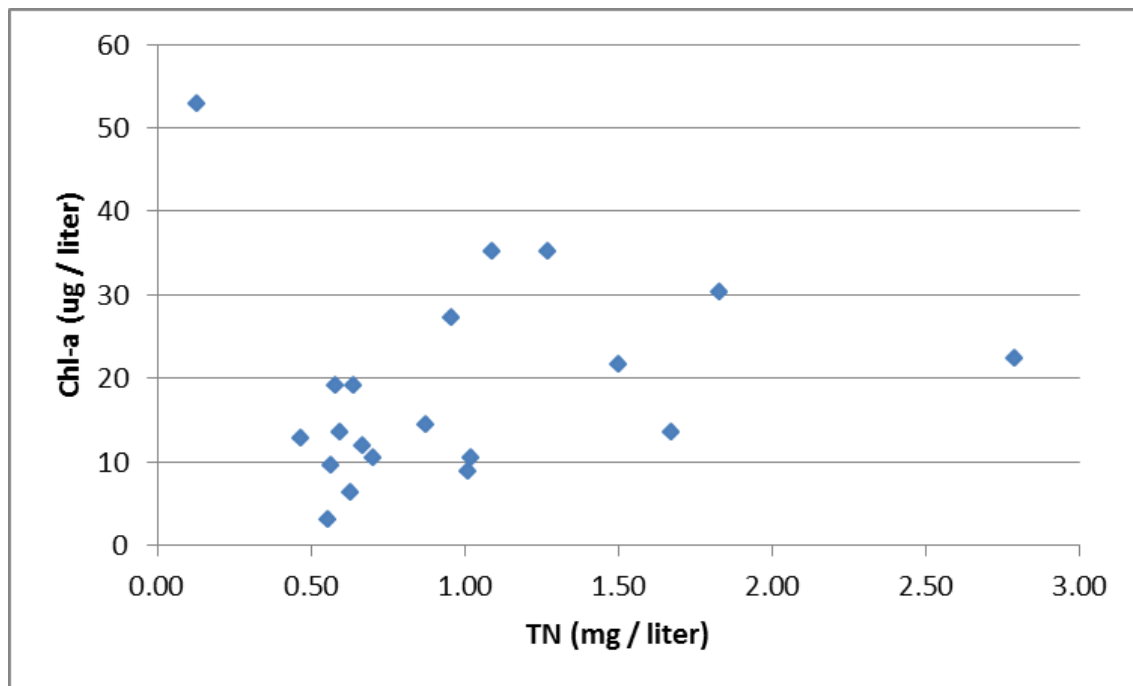


Figure 6-11. Relationship between TN and chlorophyll-a

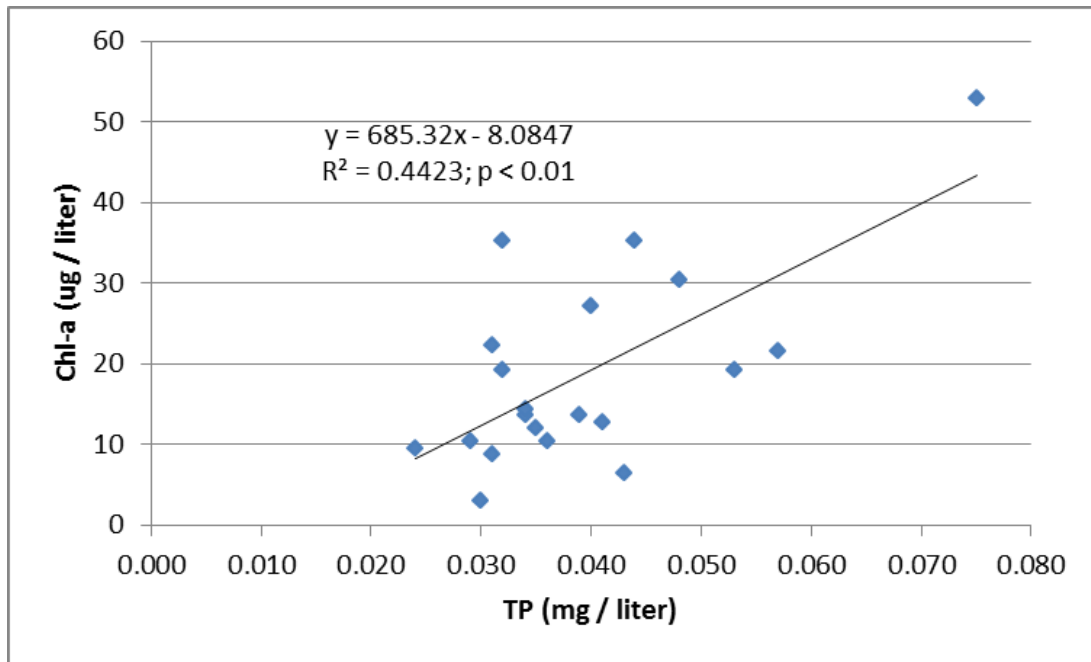


Figure 6-12. Relationship between TP and chlorophyll-a. Line is best-fit equation of statistically significant ($p < 0.05$) relationship

Water Quality Restoration Project Selection and Priorities

Based on Lake Beulah water quality and the surrounding watershed characteristics, five potential water quality restoration projects were identified using the City's WQMP decision key. Projects to address water quality, nutrient and sediment loading, and reduced lake levels are proposed. A detailed discussion of the potential water quality restoration implications for each project can be found in Section 4.0.

Project 1: Artificial Circulation

Project 2: EAV Planting/Management

Project 3: SAV Planting/Management or FTWs

Project 4: SIAs

Project 5: Develop reasonable water quality targets through paleolimnology and coordination with FDEP

Project 1: Artificial Circulation

The project design is based on the assumption that the system configuration developed by SolarBee® for previous lake circulation projects is applicable to Lake Beulah. Therefore, each circulation pump is assumed to effectively circulate 16 to 20 acres. The surface area of Lake is 19 acres requiring the purchase and installation of one SB10000 v 18 machines. Prior to

implementation of artificial circulation, a feasibility study to characterize the sediment quality, water column profiles and water depth within the lake.

Cost Estimate: \$100,000 (estimate based on cost provided by Solar Bee® for the purchase, delivery and installation of one unit). Based upon prior experience, the feasibility study could be completed for approximately \$50,000.

Project 2: EAV Planting

A survey of existing shoreline vegetation surrounding Lake Beulah is recommended due to the lack of sufficient data at this time. Based on the results of the shoreline survey, conclusions and recommendations regarding emergent aquatic or woody vegetation planting can be determined. If limited shoreline vegetation is present, shoreline conditions should be evaluated, preferably by City staff, to assess if vegetation planting is viable based on the soil conditions, slope, water level and inundation frequency and wave disturbance.

EAV Planting/Management Cost Estimate: A cost estimate will be generated upon receipt of the shoreline survey data.

Project 3: SAV Planting/Management or FTWs

SAV Planting

A survey of existing SAV cover in Lake Beulah is recommended due to the lack of sufficient, recent data to calculate percent lake cover. Based on the results of the SAV survey, conclusions regarding SAV planting can be determined. If SAV cover is less than 30 percent, lake conditions should be evaluated to assess if additional SAV is viable based on the soil condition, water clarity and water depth.

Based on the median Secchi depth (1.3 meter) from the POR, plants would not be planted in water depths greater than 1.5 meter. The maximum planting effort for Lake Beulah cannot be calculated until digital bathymetry data are acquired.

Bathymetric Survey Cost Estimate: \$10,000

SAV Planting/Management Cost Estimate: A cost estimate will be generated upon receipt of the bathymetry data.

FTWs

If the feasibility study indicates that more than 30 percent of Lake Beulah has SAV cover, FTW may be considered. The installation of floating mats with appropriate aquatic vegetation would be expected to assimilate nutrients from the water column.

Project 4: SIAs

The Lake Beulah watershed has approximately 73 acres of the watershed classified as high infiltration soils. FDEP has not identified Lake Beulah as an impaired WBID at this time; therefore, a TMDL has not been prepared. Additionally, data are currently not available to estimate the SIA acres required for a TP load reduction. However, SIA implementation could have the additional benefit of increasing storage to supplement dry season lake levels and a reduction in stormwater loads that can be later applied to a TMDL TP load reduction, if necessary. As such, SIA design should be focused on recharging the surficial aquifer.

SIA Cost Estimate: \$20,000 per raingarden for design, permitting, and construction; however, costs are highly dependent on availability of land and whether construction efforts are completed by the City or outsourced.

Project 5: Paleolimnology Study

A recurring issue is the need for site-specific water quality targets for each of the 11 lakes. A consideration, however, is the ability of FDEP to allow for target values of chlorophyll-a, TN, and TP that are higher than those contained within NNC (as outlined in FAC 62-302.531). If FDEP allows for the use of these proposed site specific alternative criteria under a BMAP scenario, a valid argument could also be made that all City lakes classified as low-color, alkaline, valley lakes should have the same target values (City lakes classified as ridge lakes may warrant additional paleo studies and subsequent water quality target derivations for ratification by the FDEP). This would not be an unreasonable request as FDEP has used paleo data in the past to set TMDL water quality targets for the Southern Chain of Lakes in Winter Haven (FDEP 2007). Locally-derived paleo data and corresponding TN, TP, and chlorophyll-a targets should ideally be determined for Lake Beulah and used as interim lake management goals.

Cost estimate: \$30,000 to \$50,000 per lake including coordination with FDEP to develop site-specific water quality targets for chlorophyll-a and nutrients to be used in impairment determinations and/or TMDLs.

Lake Bonnet

Physical and chemical characteristics specific to Lake Bonnet are presented here in the context of relevant regulatory criteria and requirements.

Historical and Recent Conditions in Lake and Watershed

Lake Bonnet is a 79-acre lake located in the City within the eastern portion of Polk County, Florida (Figure 6-13). Maximum water depth is reportedly 13.1 feet, with an average water depth of 4.0 feet (City of Lakeland 2010). The lake is located within the Lakeland/Bone Valley Upland lake region of Florida, which according to Griffith et al. (1997) can be expected to have “high phosphorus, nitrogen, and chlorophyll-a values” and which would be expected to have alkaline, rather than acidic, water chemistry.

Lake Bonnet is located within the Hillsborough River watershed and the immediate contributing watershed to the lake is 778 acres in size, resulting in a watershed to open water ratio of 8.84 to 1 (Table 6-5; Figure 6-13). The watershed to open water ratio can be used to compare the relative amount of influence that a lake experiences from its contributing watershed, such as stormwater runoff.

Lake Bonnet is not influenced by any upstream lakes and is connected (at high water levels) to Lake Blanton and Itchepackesassa Creek via an adjustable control structure (City of Lakeland 2010). With the exception of July 2005, the lake water elevation was above the minimum operating range for Lake Bonnet (Figure 6-14). Since 2005, the lake water elevation has only occasionally exceeded the lower elevation of its maximum structure operating range. The operational water elevation range for Lake Bonnet is 142.89 to 144.19 feet NAVD. Within the Lake Bonnet watershed, there is an elevation gradient ranging from 145 to 233 feet NAVD (Figure 6-15). Lake Bonnet is located between 80 and 90-foot potentiometric surface elevations and southwest of the potentiometric peak, as of September 2011 (Figure 6-16). Additionally, the northern boundary of the intermediate aquifer system is just north of Lake Bonnet (Spelcher and Kroening 2007). Therefore, it is unlikely that there is direct connectivity between Lake Bonnet and the Floridan aquifer.

A review of historical aerial photography (from 1941) indicates the open water portion of the lake expanded substantially compared to recent photography (2016). In 1941, citrus agriculture is apparent along the northeastern wetland portion of Lake Bonnet and areas to the south were cleared for development. By 1958, a majority of the land south of Lake Bonnet was improved and the construction of the Brunnell Parkway created a dam effect resulting in increased water storage within the lake itself (Figure 6-17). In 1968, residential development was present along the northwest border of the lake and citrus agriculture continued to the northeast (Figure 6-17). The extensive development within the watershed is reflected in the land use/land cover data provided by both USGS and SWFWMD (Table 6-6). Specifically, the SWFWMD land use data from 2011 classifies 451 acres (58%) as developed lands compared to 327 acres (42%) of undeveloped land (Figure 6-18).

There are 44 stormwater inputs that discharge to Lake Bonnet watershed, including 12 minor outfalls, four retention/detention outfalls, six stormwater discharges, 17 end of pipe inputs, and five major outfalls (Figure 6-19). In regards to infrastructure, the majority of the existing residential developments within the watershed utilize sanitary sewer for wastewater treatment provided by the City (City of Lakeland 2010). Ten OSTDS construction permits were identified within the Lake Bonnet watershed (Figure 6-20). Based on a review of SWFWMD soil survey geographic data, soils within the watershed have a low runoff potential with high, moderate, and low infiltration rates and are classified either as hydrologic soil group A (39 acres), B (115 acres), B/D (84 acres) or C (400 acres), respectively (Figure 6-21).

As reported by City of Lakeland (2001) cattails and primrose willow densely populate approximately 1.5 acres of the western shoreline of Lake Bonnet along Brunnell Parkway. Historically, the shoreline vegetation was controlled by herbicide application, burning, harvesting, and hand removal. Currently, City staff occasionally harvest floating mats of uprooted vegetation,

and apply herbicide to control the abundance of water hyacinth and water lettuce. The northwestern, western, and southwestern portions of the shoreline vegetation have been modified as a result of residential development. However, the northern and eastern portions of the shoreline are dominated by a large wetland. Sparse EAV is apparent in the lake.

In 2002, Environmental Consulting & Technology, Inc. (ECT) submitted the Lake Bonnet Diagnostic Study to the City and the City's Lakes and Stormwater Division. The diagnostic study concluded that Lake Bonnet's water quality is the poorest of the sixteen major lake systems within the City. The lake appeared to be impacted by internal loading from existing organic sediments, groundwater discharge, and storm water runoff, resulting in high phosphorus, nitrogen, and chlorophyll-concentrations. In addition, the lake volume was determined to be 28% of its original capacity due to sedimentation. Sediment analysis identified polycyclic aromatic hydrocarbon (PAH) concentrations "at levels of concern" in comparison to the FDEP's Sediment Quality Assessment Guidelines within the vicinity of an existing 36" storm sewer outfall. ECT recommended further assessment to characterize and quantify pollutant loadings in order to evaluate pollutant removal and management programs to improve water quality and long term lake restoration efforts.

TABLE 6-5. PHYSICAL CHARACTERISTICS OF LAKE BONNET AND ADJACENT WATERSHED

Physical			
Location	City of Lakeland; Polk County	High infiltration soils (acres)	39
Relation to other lakes	Discharges to Lake Blanton and Itchepackesassa Creek	Developed land (acres)	451
Watershed area (acres)	788	Undeveloped land (acres)	327
Lake area (acres)	79	Mean water depth (ft)	4.0
Perimeter (feet)	11,442	Maximum water depth (ft)	13.1
Surface area: lake volume ratio	0.26	Volume (acre-feet)	306
Watershed to surface area ratio	2.6		

TABLE 6-6. CHANGES IN LAND USE WITHIN THE LAKE BONNET WATERSHED OVER TIME

Land Use	1970-1985*		1995		2011	
	Acres	Percent	Acres	Percent	Acres	Percent
Residential	402	51.7				
Residential (Medium Density)			243		234	30.1
Residential (High Density)			23		23	29.6
Commercial and Services	67	86.2	75		66	8.5
Industrial	50	6.4	65		86	11.1
Institutional			6		6	0.8
Recreational			3		1	0.1
Golf Courses					2	0.3
Open Land			166		163	30
Hardwood and Conifer Mix			12		5	0.6
Lakes	69	8.88	81		87	11.2
Reservoirs			0		1	0.1
Stream and Lake Swamps			68		29	3.7
Freshwater Marshes					41	5.3
Emergent Aquatic Vegetation			7		1	0.1
Forested Wetland	88	11.3				
Transportation			27		33	4.2
Transportation, Communications, Services	101	13				

*Metadata for USGS land use data identifies data collection dates as a period between 1970 and 1985

**Land use types differ between USGS and SWFWMD classification schemes. Please note that SWFWMD data does not include "transportation, communications, and services".



Figure 6-13. Lake Bonnet location map

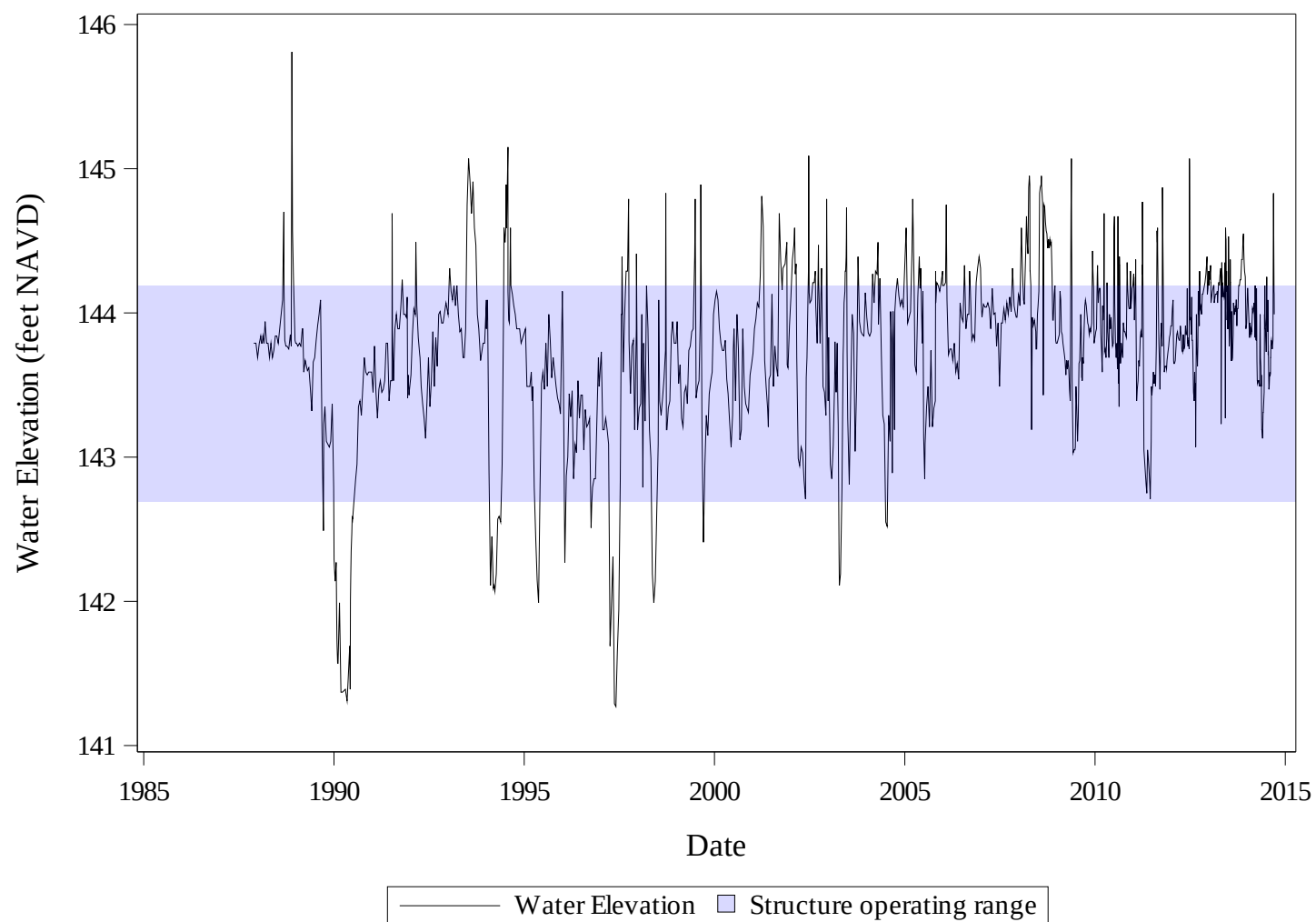


Figure 6-14. Period of Record Lake Bonnet water elevation

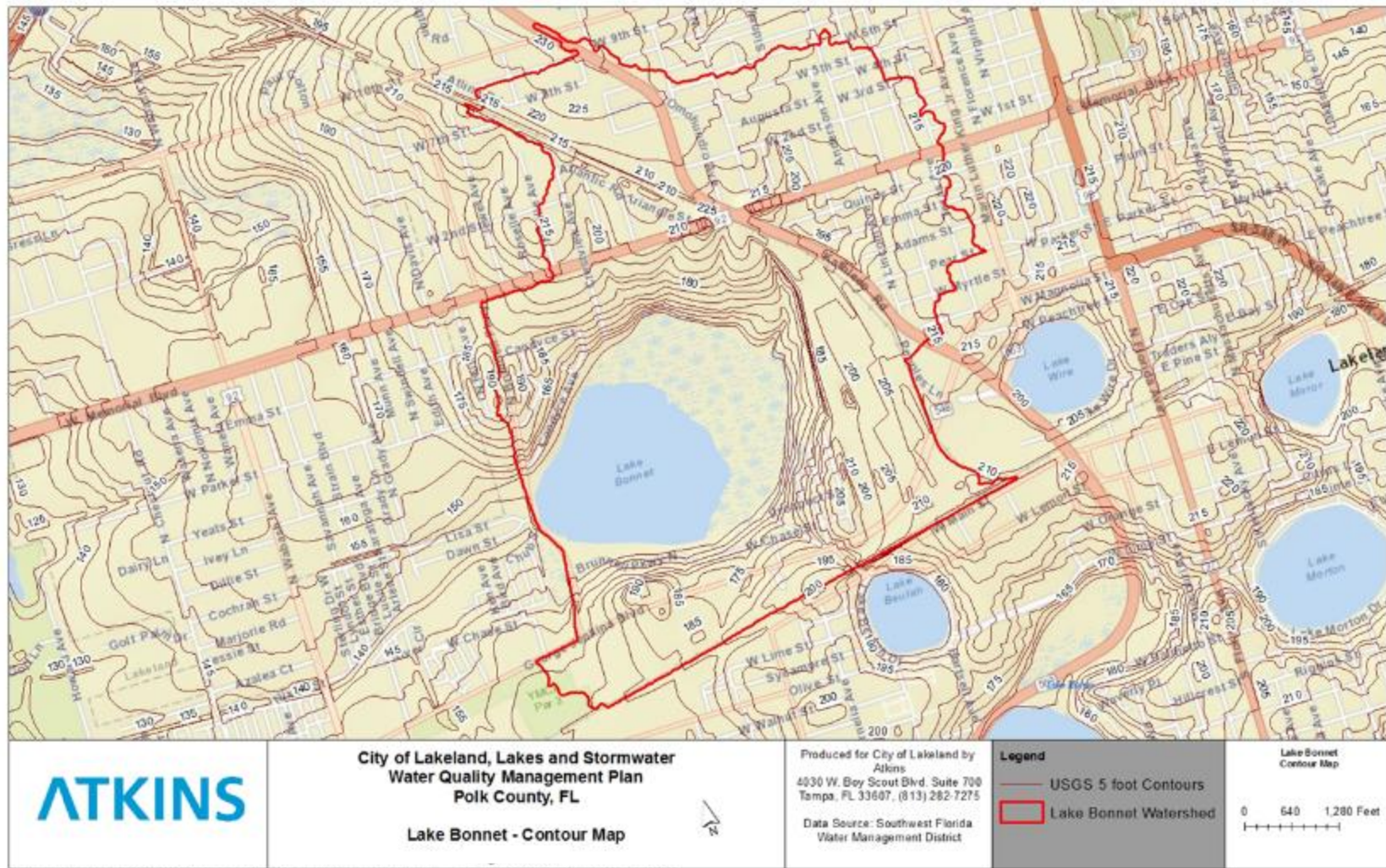


Figure 6-15. Lake Bonnet contour map



Figure 6-16. Lake Bonnet potentiometric map



Figure 6-17. Lake Bonnet historical aerial imagery. Left Photo. 1958. Right Photo. 1968

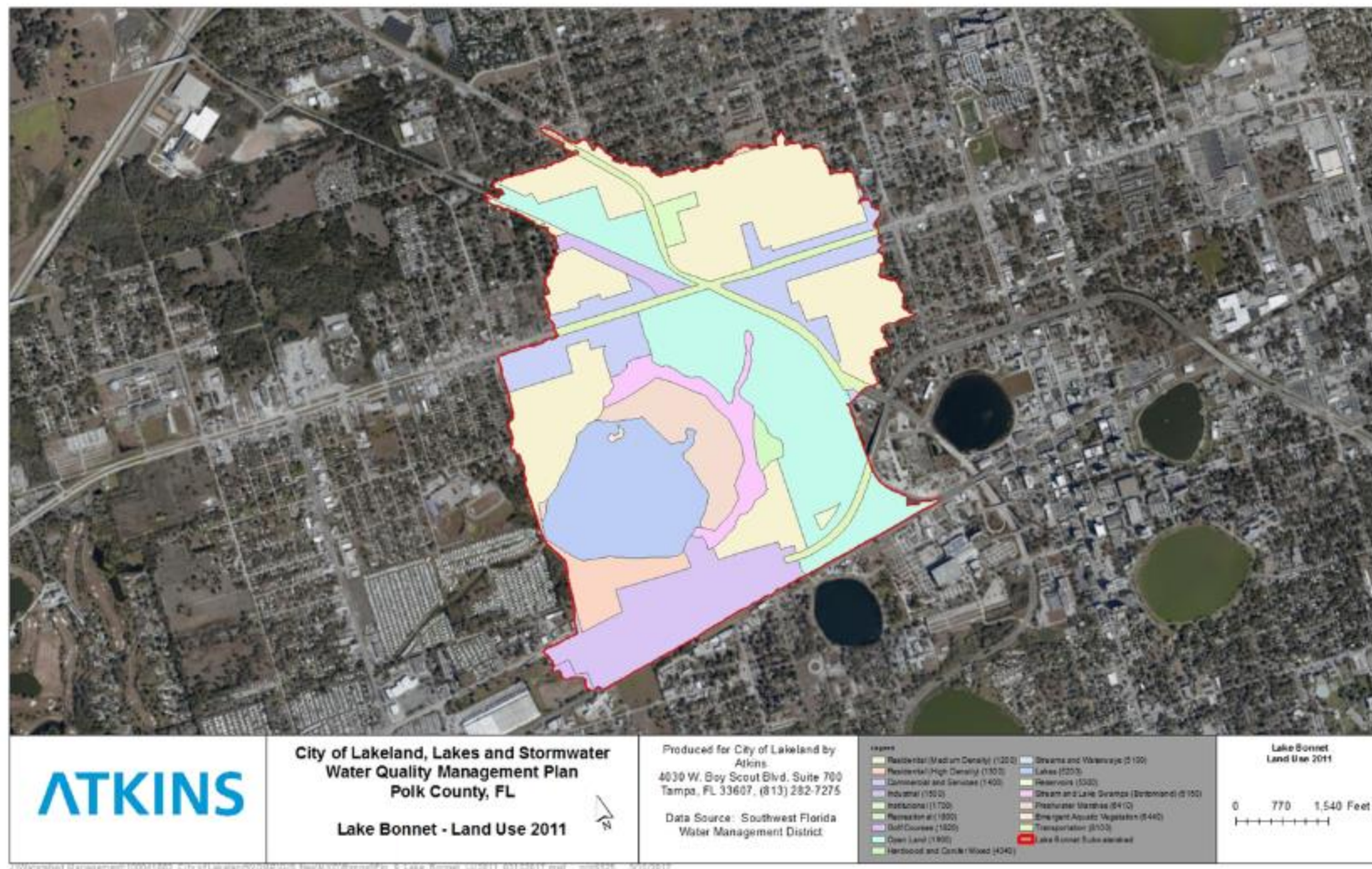




Figure 6-19. Lake Bonnet stormwater map

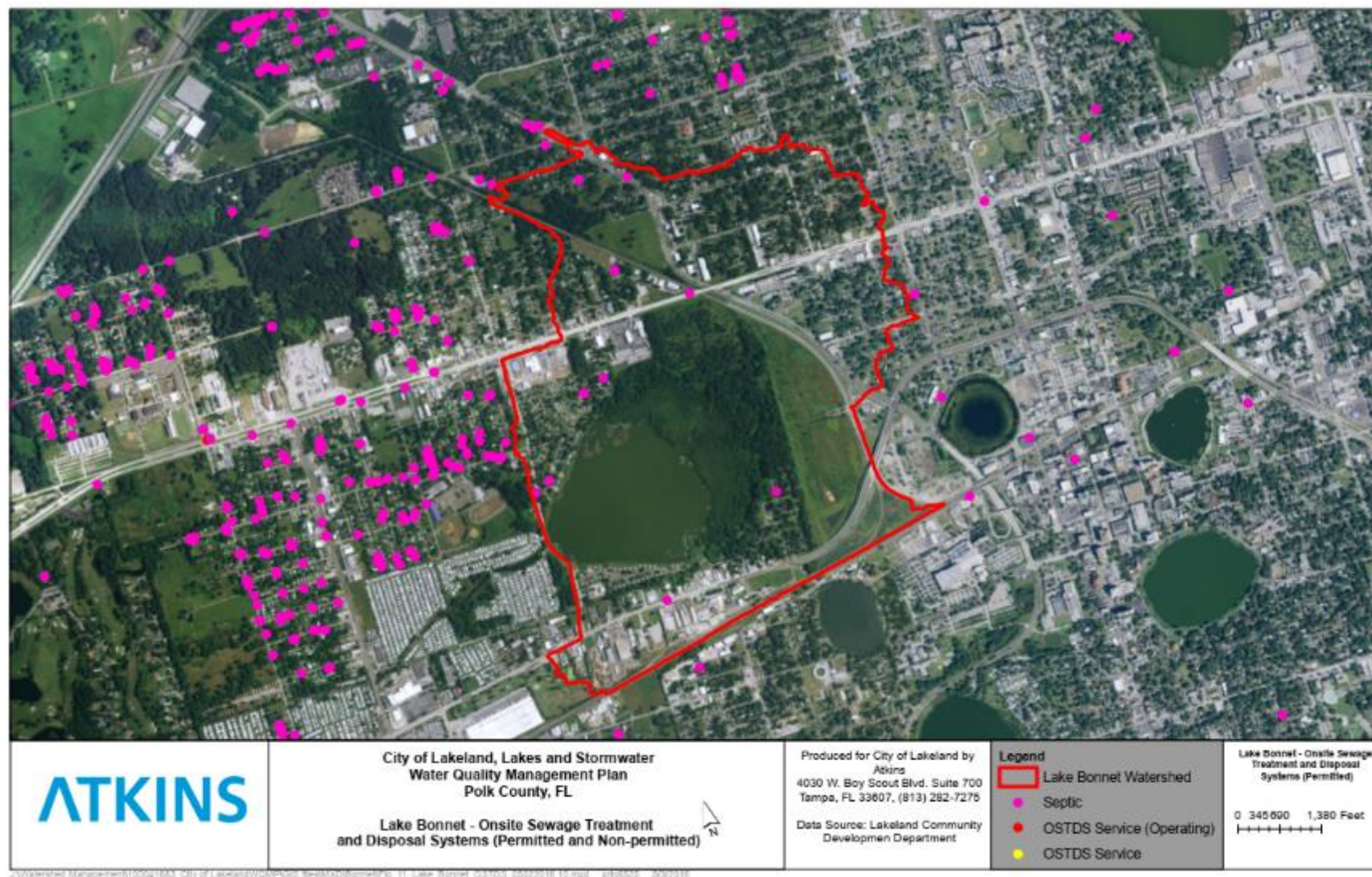


Figure 6-20. Lake Bonnet OSTDS map

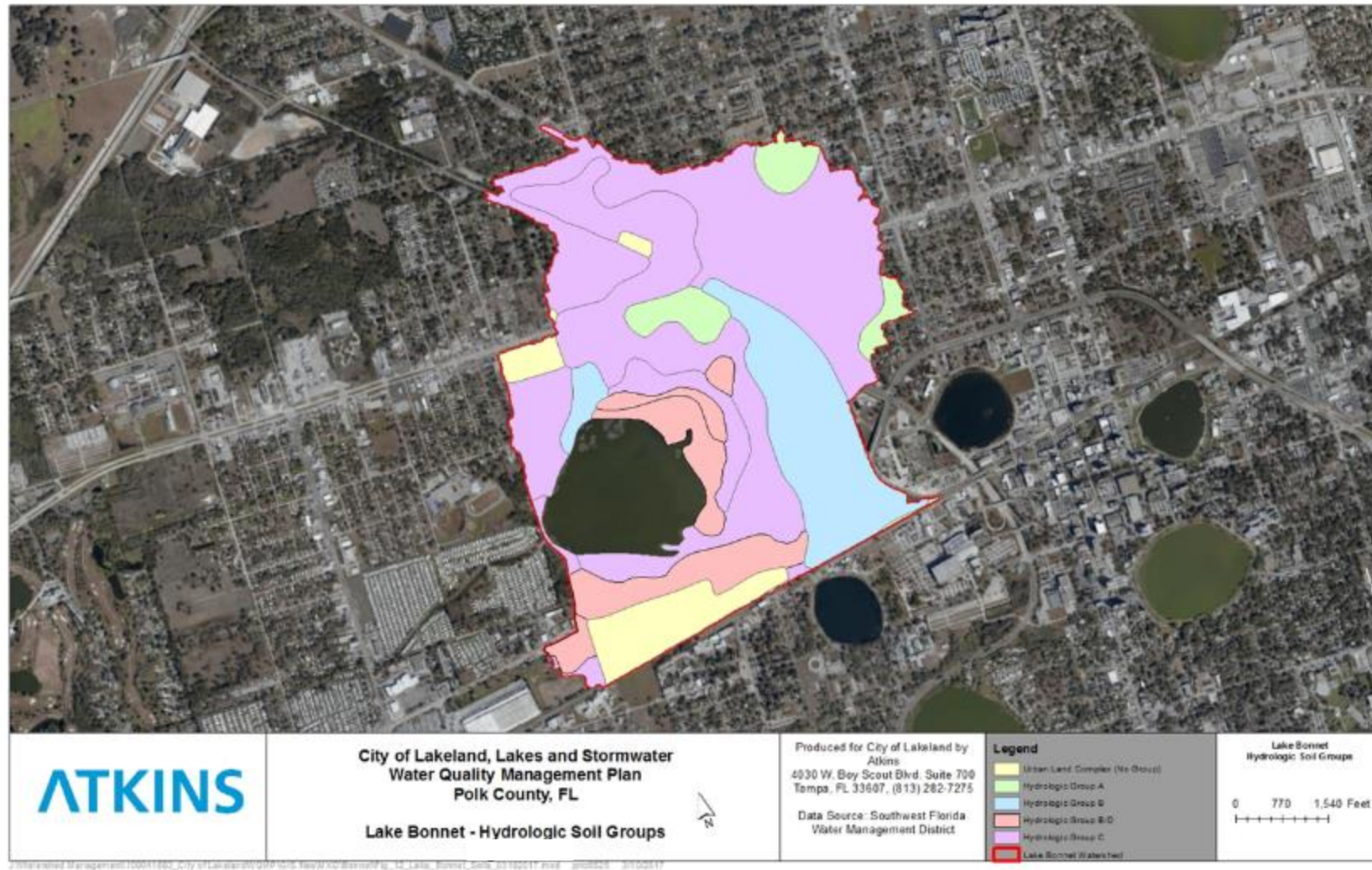


Figure 6-21. Lake Bonnet soils map

Water Quality

Previously, Lake Bonnet was listed as impaired by the City of Lakeland (2010) based on TSI. In FDEP's latest version of the Comprehensive Verified Impaired List (December 18, 2017) Lake Bonnet is listed as impaired for chlorophyll-a, based on annual geometric mean values exceeding the chlorophyll-a threshold of 20 µg / liter during the years 2010, 2011 and 2012. Lake Bonnet is a Group 2 waterbody as part of the Hillsborough River planning unit, the most recent impairment evaluation was performed for the verified period of January 1, 2007 to June 30, 2014 (Cycle 3) using the NNC criteria. The cycle 4 assessment period will occur in 2020 for the verified period of January 1, 2012 to June 30, 2019. To minimize the impacts of different verified periods, this report characterizes water quality for each of the City's priority lakes during the same time period, 1/1/2009 to 6/30/2016. These dates correspond to the most recent Verified Period assessment used by FDEP during which water quality data are fully available for analysis for determining impairment status.

Water quality data were downloaded from FDEP, and used to determine the classification of Lake Bonnet. The lake was classified as a low-color, alkaline lake, based on a geometric mean value for color of 32 PCU and a geometric mean alkalinity value of 46.7 mg (as CaCO₃) / liter. Based on that classification, the water quality targets for TN and TP were then determined based on whether or not the annual geometric mean for a given year exceeds the threshold target of 20 µg chlorophyll-a / liter. The relevant water quality criteria for TN and TP for Lake Bonnet are highlighted in yellow in Table 6-7. Based on the Table 6-7 criteria, Lake Bonnet has the following exceedances (Table 6-8).

Lake Bonnet has water quality that far exceeds NNC criteria for low-color, alkaline lakes. Based on examples contained within both PBS&J (2011) and Tomasko et al. (2013), the TN and TP reductions required for Lake Bonnet to meet NNC guidance are outside the range of reduction obtainable by implementing traditional lake restoration projects such as stormwater retrofits. Instead, more intensive project types are warranted, up to and including sediment removal and/or inactivation, and hydrologic restoration.

TABLE 6-7. WATER QUALITY CRITERIA FOR LAKE BONNET, WITH RELEVANT TARGETS FOR CHLOROPHYLL-A, TN AND TP HIGHLIGHTED IN YELLOW

Long Term Geometric Mean Lake color and Alkalinity	Annual Geometric Mean chlorophyll-a	Minimum calculated numeric interpretation		Maximum calculated numeric interpretation	
		Annual Geometric Mean TP	Annual Geometric Mean TN	Annual Geometric Mean TP	Annual Geometric Mean TN
> 40 PCU	20 µg/L	0.05 mg/L	1.27 mg/L	0.16 mg/L	2.23 mg/L
≤ 40 PCU and > 20 mg/L CaCO ₃	20 µg/L	0.03 mg/L	1.05 mg/L	0.09 mg/L	1.91 mg/L
≤ 40 PCU and ≤ 20 mg/L CaCO ₃	6 µg/L	0.01 mg/L	0.51 mg/L	0.03 mg/L	0.93 mg/L

TABLE 6-8. SUMMARY OF WATER QUALITY IMPAIRMENT DETERMINATIONS FOR LAKE BONNET BY YEAR. YEARS WITH INSUFFICIENT DATA FOR COMPARISON WITH NNC CRITERIA ARE NOTED BY “-”.

Year	chlorophyll-a (µg / liter)	TN (mg / liter)	TP (mg / liter)
2009	134.4	3.78	0.263
2010	94.3	3.00	0.201
2011	155.9	4.98	0.281
2012	120.8	4.16	0.244
2013	-	-	-
2014	81.5	2.97	0.204
2015	-	-	-
2016	-	-	-
Average percent reduction required	82	71	87

Positive relationships were found between both TN and chlorophyll-a (Figure 6-22) and TP and chlorophyll-a (Figure 6-23).

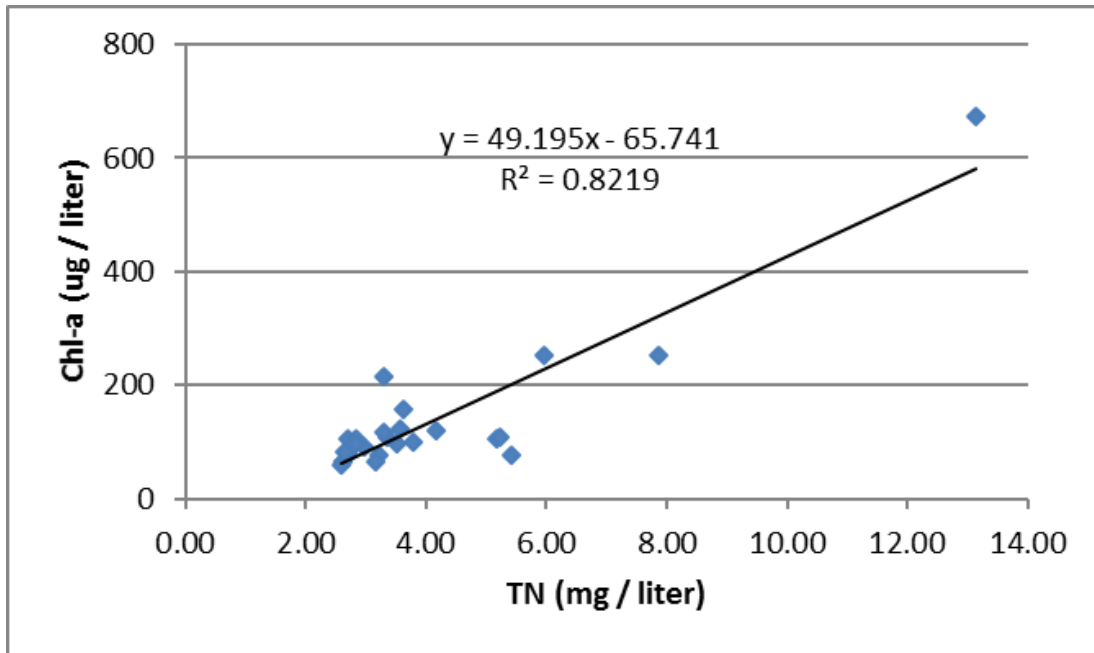


Figure 6-22. Relationship between TN and chlorophyll-a. Line is best fit equation of statistically significant ($p < 0.05$) relationship

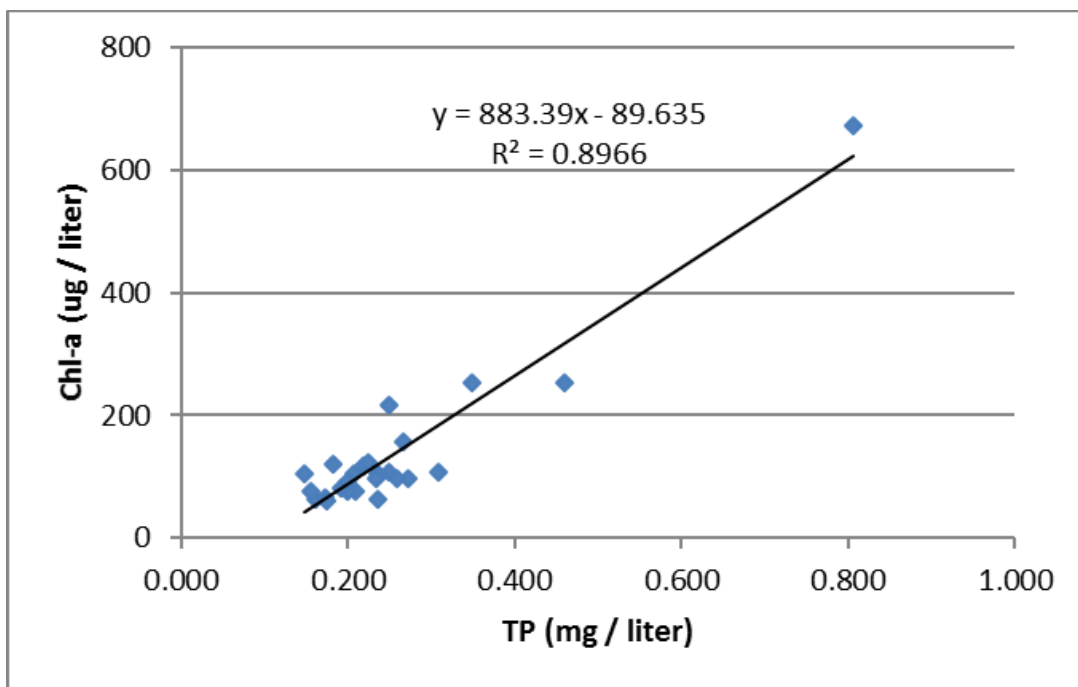


Figure 6-23. Relationship between TP and chlorophyll-a. Line is best fit equation of statistically significant ($p < 0.05$) relationship

As previously shown in PBS&J (2011) and Atkins and ESA (2014) concentrations of TN in excess of ca. 2.5 mg / liter likely indicate the influence of nitrogen-fixing cyanobacteria, as such values are in excess of the highest TN concentrations expected in most urban and agricultural stormwater runoff. As such, Lake Bonnet's phytoplankton levels can be best reduced by focusing on reducing the availability of TP.

A statistically significant and positive correlation was found between annual average TP concentrations and annual rainfall, indicating that stormwater runoff likely influences in-lake water quality ($p=0.0029$, $\rho =0.604$). Based upon these results, projects which focus on stormwater retrofits and public education are good candidates toward restoring water quality in Lake Bonnet. The maintenance/enhancement of native emergent and submerged aquatic vegetation is also recommended.

In addition to external TP loads, the potential for the re-suspension of lake-bottom sediments was identified as a possible source of internal phosphorus loads to the overlying water column. A statically significant and inverse correlation was found between monthly median TP concentrations and lake water elevations ($p=0.0024$; Figure 6-23). Consequently, sediment removal and/or sediment inactivation projects which focus on reducing the influence of lake-bottom sediments are recommended for this lake. Whole-lake circulation is not recommended, based on the lake size.

An analysis of the historical versus current lake extent indicated that the lake has been lowered compared to its original configuration. Evidence of a lost hydrologic connection with the adjacent historical wetland fringe was identified along the eastern shoreline of the lake. Lake Bonnet's color values averaged above 40 PCU in 2001, 2002, 2006, 2007 and 2008, possibly suggesting significant import of wetland tannins during years with higher water-levels.

Lake Bonnet is thus a candidate for wetland rehydration activities, which may enhance the lake-wetland interaction which could restore the tannin influence to Lake Bonnet. Color levels within Lake Bonnet vary from well below to well above the 40 PCU threshold, indicating possible increased wetland – lake interactions and the associated increased tannin importation during higher water level years. The lake's geomorphology suggests it is more of a "valley" lake than a "ridge" lake, as outlined in PBS&J (2008). As such, hydrologic restoration might be appropriate for Lake Bonnet. Further evaluation of the feasibility for hydrologic restoration is recommended to ascertain the feasibility of raising Lake Bonnet water elevations. If development around the lake makes hydrologic restoration impractical, water quality treatments through the use of barley straw and/or cypress leaf bundles should be tested for their ability to reduce cyanobacteria abundance; preliminary tests from Lake Hancock suggest that such an approach may have local relevance (Tomasko et al., 2016).

Site-specific chlorophyll-a, TN, and TP targets have not been established and thus may be appropriate for Lake Bonnet. collection and analysis of locally-derived paleo data is advisable if the City decides to pursue establishing site-specific criteria.

Water Quality Restoration Project Selection and Priorities

Based on Lake Bonnet water quality and the surrounding watershed characteristics, six potential water quality restoration projects were identified using the City's WQMP decision key. Projects to address water quality, nutrient and sediment loading, and reduced lake levels are proposed. A detailed discussion of the potential water quality restoration implications for each project can be found in Section 4.0.

Project 1: SAV Planting/Management or FTWs

Project 2: EAV Planting/Management

Project 3: Forested Wetland Rehydration

Project 4: Sediment Removal/Inactivation

Project 5: SIAs for Stormwater Treatment

Project 6: Develop reasonable water quality targets through paleolimnology and coordination with FDEP

Project 1: SAV Planting/Management or FTWs

SAV Planting

A survey of existing SAV cover in Lake Bonnet is recommended due to the lack of sufficient, recent data to calculate SAV occurrence. Based on the results of the SAV survey, conclusions regarding SAV planting can be determined. If SAV cover is less than 30 percent, lake conditions should be evaluated to assess if additional SAV is viable based on the conditions of substrate, water clarity and water depth.

Based on the median Secchi depth (0.28 meter) from the POR (1988 - 2017), plants should not be planted in water depths greater than 0.48 meter, to allow them to experience sufficient light for long-term survival. The maximum planting effort for Lake Bonnet cannot be calculated until digital bathymetry data are acquired.

Bathymetric Survey Cost Estimate: \$10,000

SAV Planting/Management Cost Estimate: A cost estimate will be generated upon receipt of the bathymetry data.

FTWs

If the SAV feasibility study indicates that less than 30 percent of Lake Bonnet has SAV cover, FTWI may be considered. The installation of floating mats with appropriate aquatic vegetation would be expected to assimilate nutrients from the water column.

Project 2: EAV Planting

A survey of existing shoreline vegetation surrounding Lake Bonnet is recommended due to the lack of sufficient data at this time. Based on the results of the shoreline survey, conclusions and recommendations regarding emergent aquatic or woody vegetation planting can be determined. If limited shoreline vegetation is present, shoreline conditions should be evaluated, preferably by City staff, to assess if vegetation planting is viable based on the soil conditions, slope, water level and inundation frequency and wave disturbance.

EAV Planting/Management Cost Estimate: A cost estimate will be generated upon receipt of the shoreline survey data.

Project 3: Forested Wetland Rehydration

Approximately 69 acres of the land cover within the 500-foot buffer surrounding Lake Bonnet is classified as stream and lake swamps (bottomland) and freshwater marsh wetlands using the 2011 FLUCCS data (Figure 6-24). Forested wetlands encompass approximately 29 percent of the total wetland area, which is greater than the 10 to 20 percent recommended forested wetland cover required to maintain color levels above 50 PCU. While FLUCCS classifies the land cover as forested wetland, the hydrologic connection between the lake and adjacent land might be partly severed.

The project areas that were identified adjacent to Lake Bonnet are expected to rehydrate wetlands along the northern and eastern border of the lake. The feasibility study is recommended in order to evaluate the proposed project areas for inundation, perhaps associated with projects to “filter” the volume of the lake by pumping water from the lake back up into the wetland fringe.

Feasibility study cost estimate: \$150,000.

Project 4: Sediment Removal / Inactivation

Non-point source discharges to Lake Bonnet may have resulted in substantial internal nutrient loads due to phosphorus release from sediments. Presently, sediment capping and dredging are both potential remedial options; however, costs associated with dredging are typically highly elevated in comparison to capping. A feasibility study is recommended to evaluate sediment capping versus sediment dredging.

Feasibility study cost estimate: \$150,000

Project 5: Stormwater Treatment via SIAs

The Lake Bonnet watershed has approximately 39 acres of the watershed classified as high infiltration soils. Although data are currently not available to estimate the SIA acres required for a given TP load reduction, SIA implementation could have the additional benefit of increasing storage to supplement dry season lake levels and a reduction in stormwater loads that can be later applied to a TP load reduction, if necessary.

SIA Cost Estimate: \$20,000 per raingarden for design, permitting, and construction; however, costs are highly dependent on availability of land and whether construction efforts are completed by the City or outsourced.



Figure 6-24. Proposed forested wetland rehydration project area (in red) for Lake Bonnet

Project 6: Paleolimnology Study

The paleolimnological study for Lake Bonny (Whitmore et al. 2016) is current enough that its findings should be discussed with FDEP to ensure that the State's agencies are aware of the impractical nature of the existing NNC criteria for lakes such as Lake Bonnet, which appears to have been lowered below their historical elevation, thus reducing their lake-wetland connection in such a way that the lake has likely become more susceptible to nutrient concentrations than it was historically. The complexity of the tannin-nutrient-phytoplankton relationships found for Lake Bonny are such that it was concluded that nutrient reduction alone, even if to pre-development concentrations, would not result in the lake also obtaining pre-development values for chlorophyll-a. The need for restoration of the lake's historical lake-wetland connectivity supports conclusions related to the need for such projects that was also reached for Lake Hancock (Tomasko et al. 2009).

Cost estimate: \$30,000 to \$50,000 per lake including coordination with FDEP to develop site-specific water quality targets for chlorophyll-a and nutrients to be used in impairment determinations and/or TMDLs.

Lake Bonny and Little Lake Bonny

Physical and chemical characteristics specific to Lake Bonny and Little Lake Bonny are presented here in the context of relevant regulatory criteria and requirements.

Historical and Recent Conditions in Lake and Watershed

As of December 2015, no specific studies appear to have been completed explicitly on Lake Bonny or Little Lake Bonny. The FDEP designated Lake Bonny as impaired based on the TSI (FDEP 2014a).

Lake Bonny is a 249-acre lake located in the City within the eastern portion of Polk County, Florida (Figure 6-25). Maximum water depth is reportedly 11.2 feet, with an average water depth of 3.0 feet (City of Lakeland 2010). Little Lake Bonny is a lobe of Lake Bonny that is 26 acres in size. Little Lake Bonny's specific applicable physical characteristics are not provided in the latest available Lakes Report (City of Lakeland 2010) or the summary report on Polk County lakes produced by Atkins and ESA (2014). The lake is located within the Lakeland/Bone Valley Upland lake region of Florida, which according to Griffith et al. (1997), can be characterized with "high phosphorus, nitrogen, and chlorophyll-a values" and "alkaline, [with] some [lakes] receiving limestone-influenced groundwater."

Lake Bonny is located within the Peace River watershed and the immediate contributing watershed to the lake is 1,144 acres in size, resulting in a watershed to open water ratio of 4.6 (Table 6-9; Figure 6-25). The Little Lake Bonny watershed is 153 acres in size and has a watershed to open-water ratio of 5.9. Watershed to open water ratios can be used to compare the relative amount of influence that a lake experiences from its contributing watershed, such as stormwater runoff.

Lake Bonny receives contributions from Lake Holloway and Lake Parker and discharges to (at high water levels) to Lake Parker via an adjustable control structure (City of Lakeland 2010). Prior to 2006, the lake water elevation was frequently above the minimum operating range for Lake Bonny (Figure 6-26). Since 2006, the lake water elevation has continually declined and remained below the structure's minimal operating range. The operational water elevation range for Lake Bonny is 128.70 to 129.70 feet NAVD. Within the Lake Bonny watershed, there is a moderate elevation gradient ranging from 130 to 205 feet NAVD (Figure 6-27). Similarly, Little Lake Bonny is located at an elevation of approximately 130 feet NAVD. Within the Little Lake Bonny watershed, the elevation gradient ranges from 130 to 155 feet NAVD. Lake Bonny and Little Lake Bonny are located between 90 and 110-foot potentiometric surface elevations and south of the potentiometric peak, as of September 2011 (Figure 6-28). Additionally, the northern boundary of the intermediate aquifer system is north of Lake Bonny (Spelcher and Kroening 2007). Therefore, it is unlikely that there is direct connectivity with the Floridan aquifer.

A review of historical aerial photography (from 1941) indicates the shoreline has undergone minor modification compared to recent photography (2016). In 1941, all areas surrounding Lake Bonny and Lake Little Bonny had been cleared for development and citrus agriculture was present along the southeast boundary of the lake. In 1958, dense citrus agriculture is present along the west,

south, and southeastern boundaries of the lakes (Figure 6-29). No Sanborn maps were available for review. The extensive development within the watershed is reflected in the land use/land cover data provided by both USGS and SWFWMD (Table 6-10). Specifically, the SWFWMD land use data from 2011 classifies 908 acres (70%) as developed lands compared to 389 acres (30%) of undeveloped land (Figure 6-30).

There are 113 inputs that discharge to Lake Bonny and Little Lake Bonny watersheds, including 39 minor outfalls, 15 retention/detention outfalls, 2 flumes, 49 end of pipe inputs, and 8 major outfalls (Figure 6-31). A prioritization of those sub-basins was conducted by AMEC (2017) which focused on those sub-basins with elevated nutrient loads to the lake.

In regards to infrastructure, the majority of the existing residential developments within the watershed utilize sanitary sewer for wastewater treatment provided by the City (City of Lakeland 2010). Ninety-seven OSTDS construction permits were identified within the watershed (Figure 6-37). Based on a review of SWFWMD soil survey geographic data, soils within the watershed have a low runoff potential with high, moderate, low, and very low infiltration rates and are classified either as hydrologic soil group A (431 acres), B (20 acres), B/D (260 acres), C (68 acres), or D (47 acres), respectively (Figure 6-32).

As reported by the City of Lakeland (2001), dense populations of Cattails and Primrose Willow are present along Main Street. The City applied herbicide, burned, and mechanically removed approximately two acres and “revegetated” approximately 1,000-feet of shoreline. As of 2001, City staff continually applied herbicide for American lotus. A portion of the shoreline vegetation has been modified as a result of residential encroachment, predominantly including landscaping activities. Sparse EAV is apparent on Google Earth imagery.

TABLE 6-9. PHYSICAL CHARACTERISTICS OF LAKE BONNY, LITTLE LAKE BONNY, AND ADJACENT WATERSHEDS

Physical			
Location	City of Lakeland; Polk County	High infiltration soils (acres)	431
Relation to other lakes	Contributions from Lake Holloway and Lake Parker; Discharges to Lake Parker	Developed land (acres)	70
Watershed area (acres)	1,297	Undeveloped land (acres)	30
Lake area (acres)	275	Mean water depth (ft)	3.0*
Perimeter (feet)	8,537	Maximum water depth (ft)	11.2*
Surface area: lake volume ratio	0.2*	Volume (acre-feet)	1,196*
Watershed to surface area ratio	4.7		

*Values for Lake Bonny only

TABLE 6-10. CHANGES IN LAND USE WITHIN THE LAKE BONNY AND LITTLE LAKE BONNY WATERSHED OVER TIME

Land Use	1970-1985*		1995		2011	
	Acres	Percent	Acres	Percent	Acres	Percent
Residential	666	58	409	36	501	39
Commercial and Services	179	15	226	20	207	16
Communications					3	1
Industrial			9	1	9	1
Institutional			38	4	92	7
Recreational				52	4	
Cropland and Pastureland			6	1		
Tree Crops			10	1		
Other Open Lands			18	2		
Tree Plantations			29	3		
Lakes	239	21	227	20	281	22
Reservoirs					2	1
Freshwater Marshes			54	6	69	6
Emergent Aquatic Vegetation			64	1	22	2
Stream and Lake Swamps			9	1	15	1
Forested Wetland	8	1				
Non-forested Wetland	53	5				
Transportation			44	4	44	4

*Metadata for USGS land use data identifies data collection dates as a period between 1970 and 1985

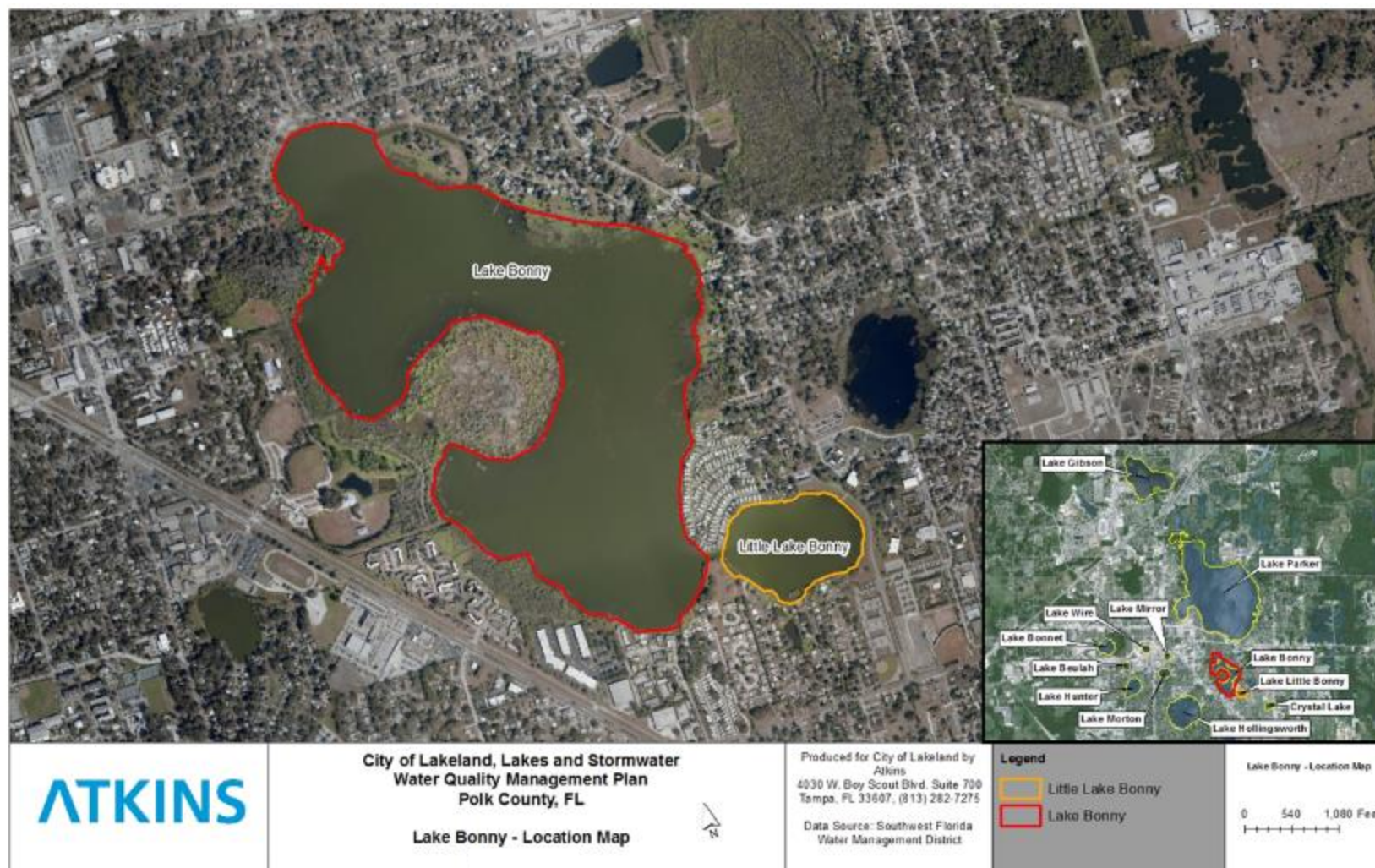


Figure 6-25. Lake Bonny location map

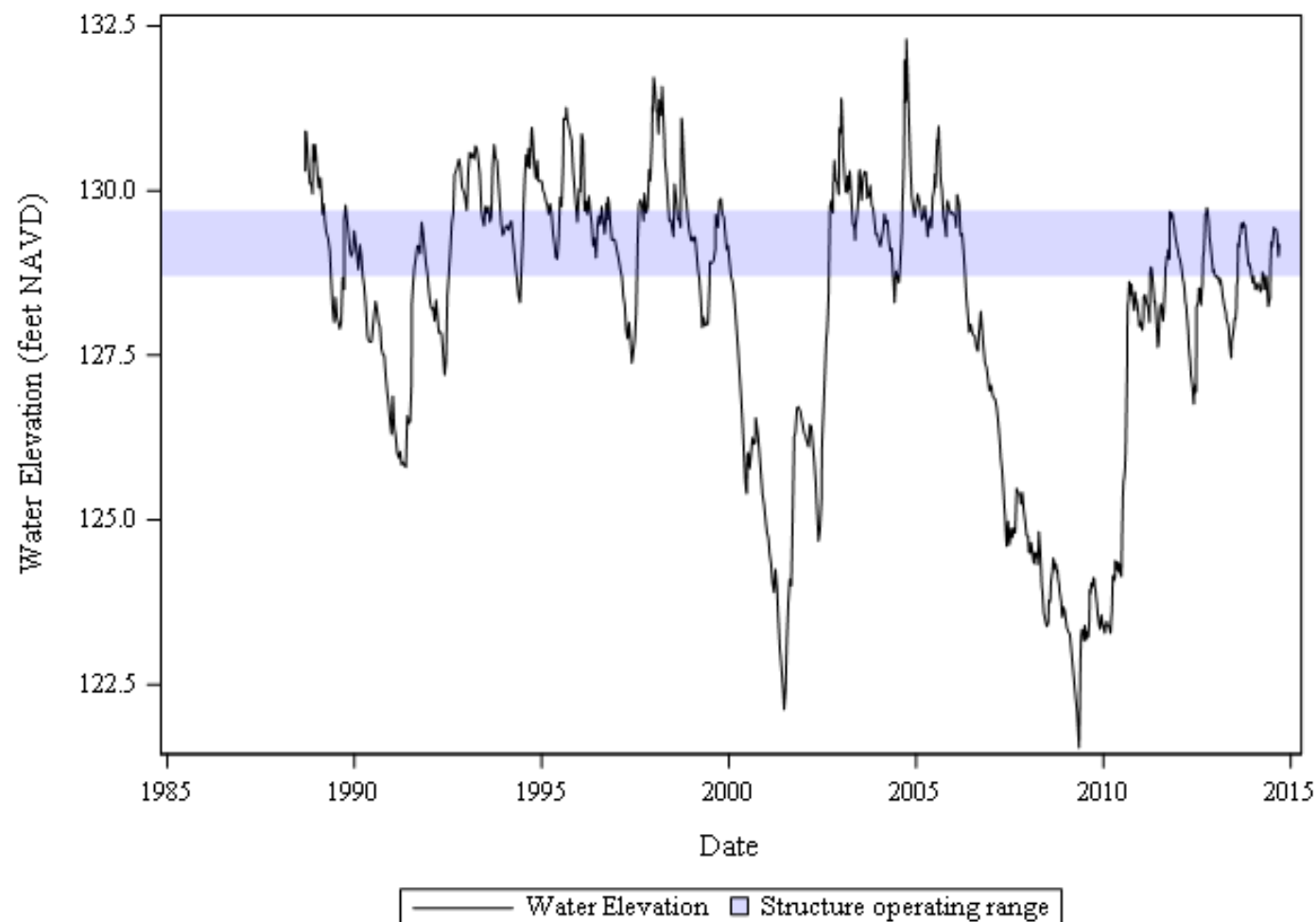


Figure 6-26. Period of Record Lake Bonny water elevation.

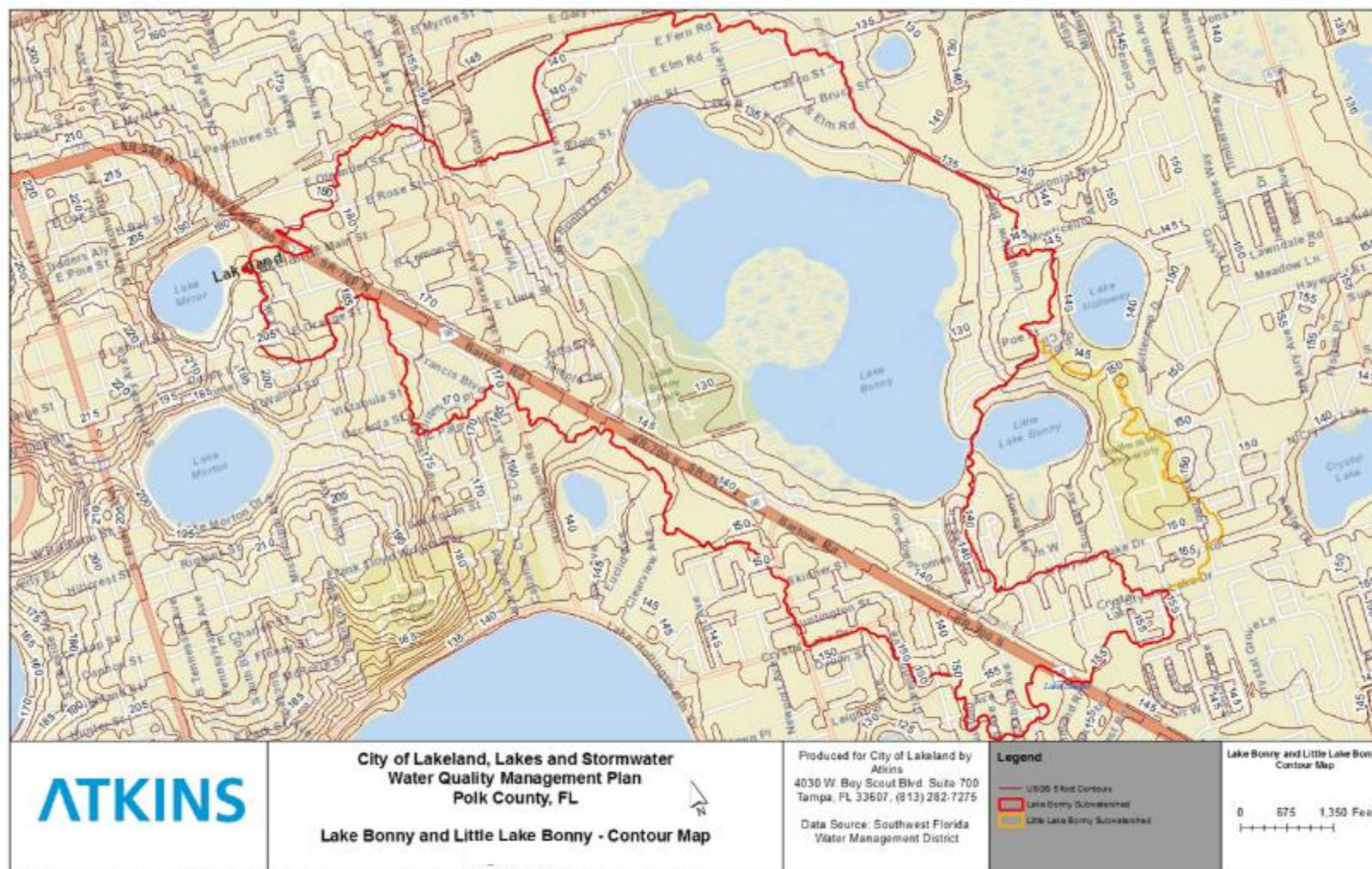


Figure 6-27. Lake Bonny contour map

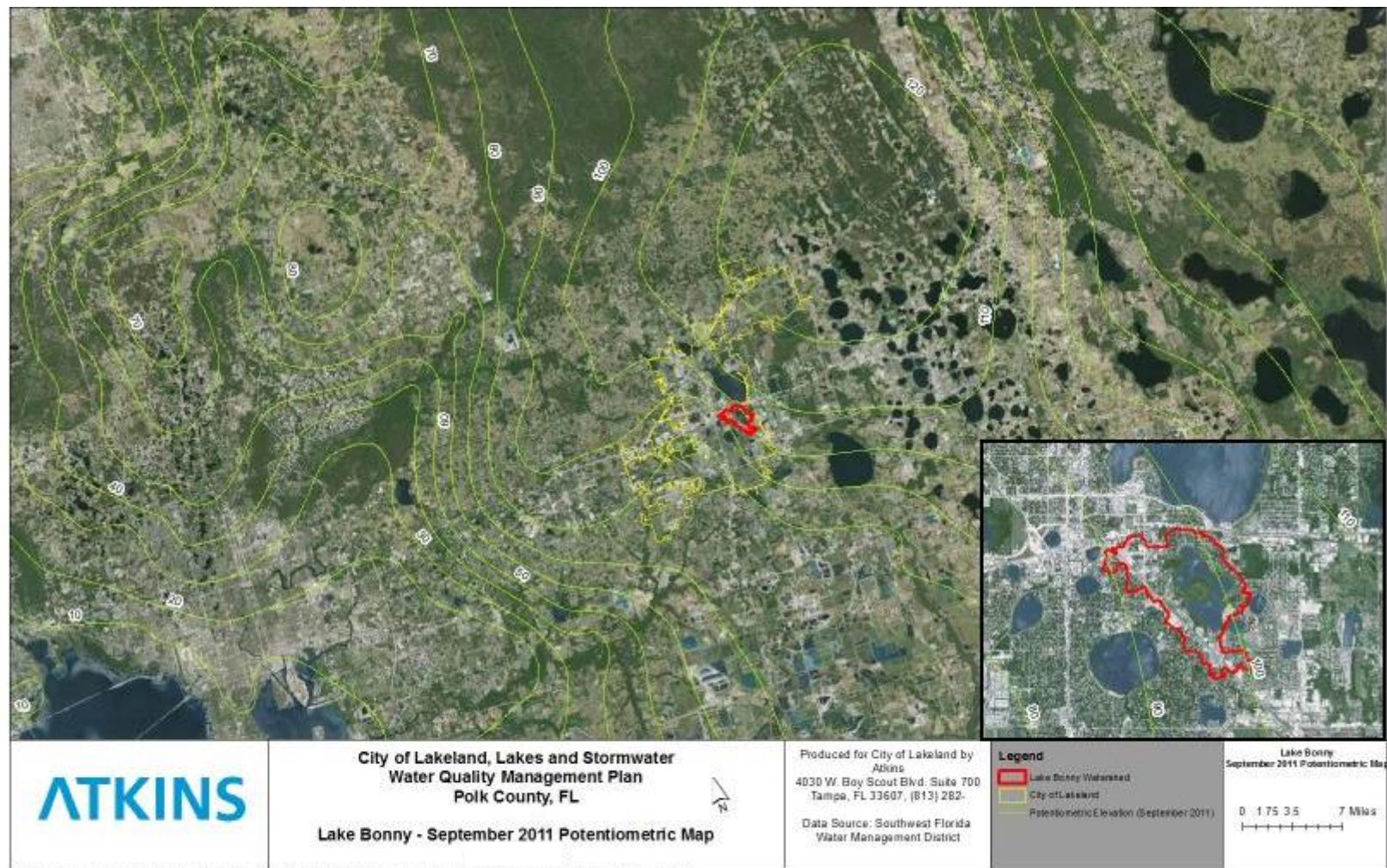


Figure 6-28. Lake Bonny potentiometric map



Figure 6-29. Lake Bonny historical aerial imagery. Left Photo. 1958. Right Photo. 1968

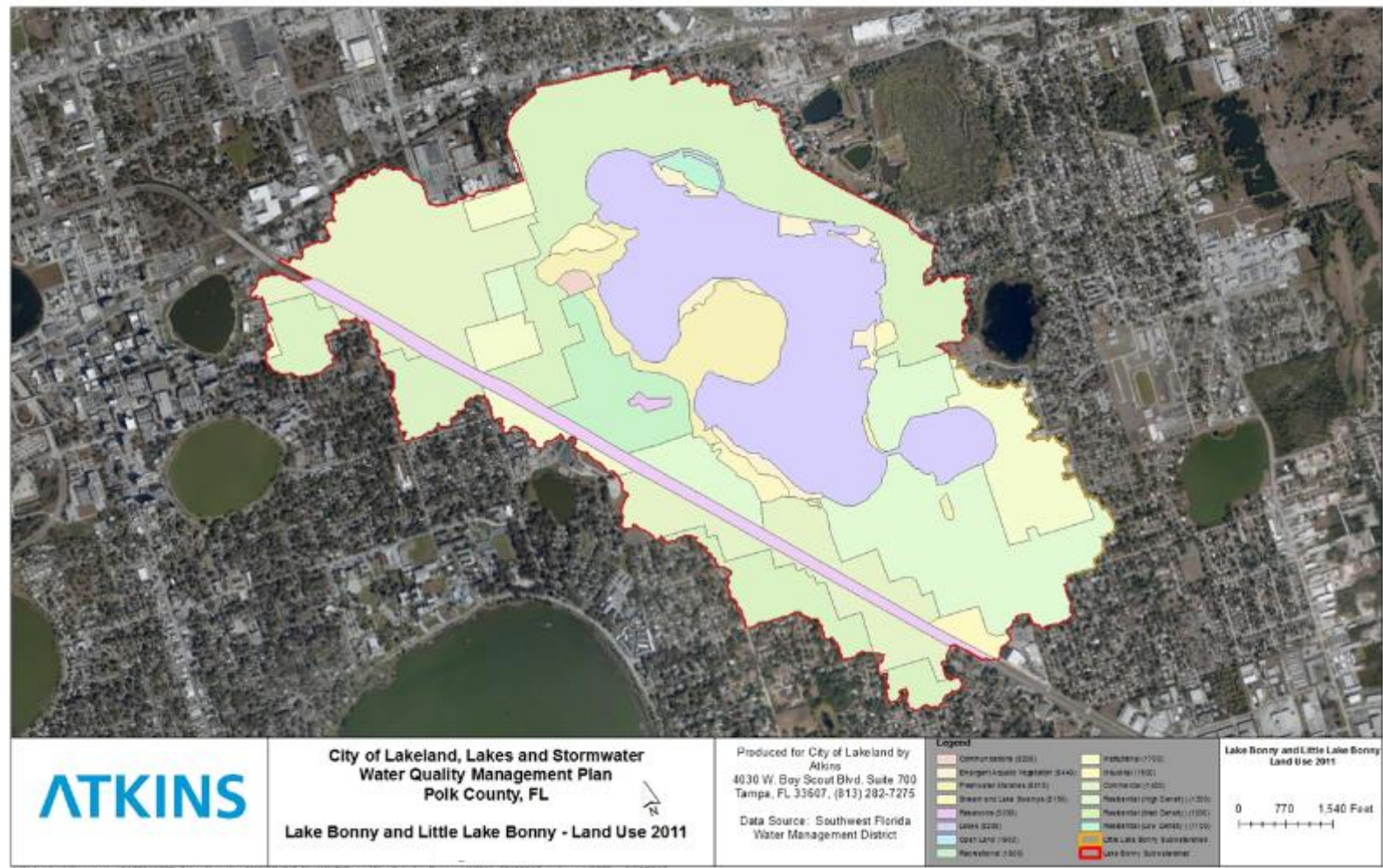


Figure 6-30. Lake Bonny 2011 land use map



Figure 6-31. Lake Bonny stormwater map

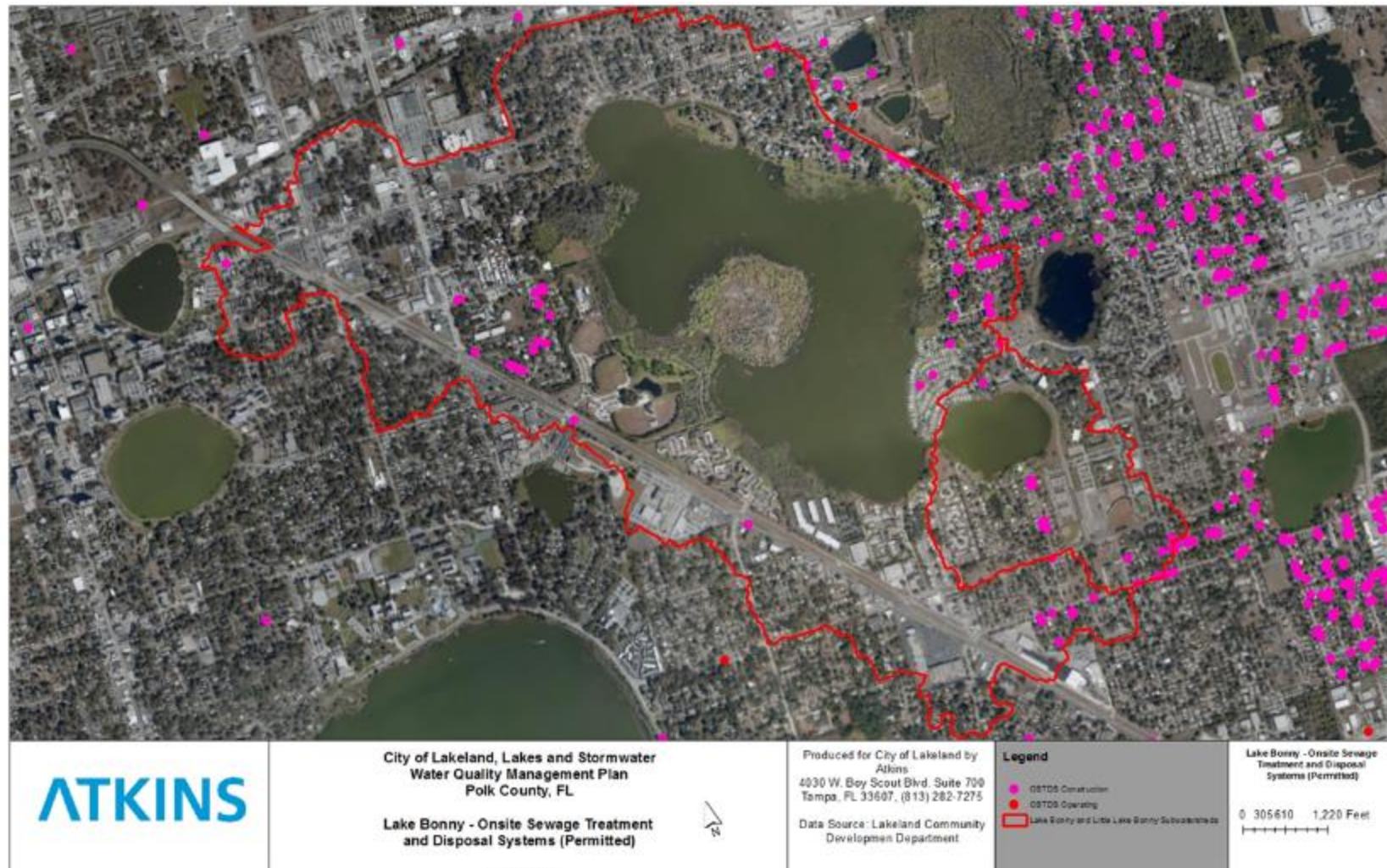


Figure 6-32. Lake Bonny OSTDS map

Water Quality

Lake Bonny is listed as impaired for nutrients by FDEP (City of Lakeland 2010, Atkins and ESA 2014) and has a TMDL for nutrients (FDEP 2014a). This study supports the conclusion that the lake has water quality that exceeds general NNC guidance for low-color, alkaline lakes (Table 6-11). However, the paleolimnological study on Lake Bonny (Whitmore 2016) concludes that the loss of wetland influence is equally if not more important stressor to water quality than nutrient availability. The TMDL for Lake Bonny (FDEP 2014a) includes Little Lake Bonny as a portion of Lake Bonny and as such the water quality targets for Lake Bonny apply to Little Lake Bonny as well. The nutrient reductions required for Lake Bonny to meet NNC guidance for TP and TN are outside the range of reduction obtainable for lake restoration projects such as stormwater retrofits, sediment removal, sediment inactivation, and whole-lake aeration (PBS&J 2011). Lake Bonny is a Group 3 waterbody as part of the Upper Peace River, the most recent impairment evaluation was performed for the verified period of January 1, 2008 to June 30, 2015 (Cycle 3) which applied NNC as the numeric criteria. The cycle 4 assessment period will occur in 2021 for the verified period of January 1, 2013 to June 30, 2020.

To minimize the impacts of different verified periods, this report characterizes water quality for each of the City's priority lakes during the same time period, 1/1/2009 to 6/30/2016. These dates correspond to the most recent Verified Period assessment used by FDEP during which water quality data are fully available for analysis for determining impairment status.

Water quality data was downloaded from FDEP, and used to determine the classification of Lake Bonny and Little Lake Bonny. The lake was classified as a low-color, alkaline lake, based on a geometric mean value for color of 34 PCU and a geometric mean alkalinity value of 47 mg (as CaCO₃) / liter. Based on that classification, the water quality targets for TN and TP were then determined based on whether or not the annual geometric mean for a given year exceeded the threshold target of 20 µg chlorophyll-a / liter. The relevant water quality criteria for TN and TP for Lake Bonny are highlighted in yellow in Table 6-11. Based on the criteria listed below, Lake Bonny has the following exceedances (Table 6-12).

TABLE 6-11. WATER QUALITY CRITERIA FOR LAKE BONNY, WITH RELEVANT TARGETS FOR CHLOROPHYLL-A, TN AND TP HIGHLIGHTED IN YELLOW

Long Term Geometric Mean Lake color and Alkalinity	Annual Geometric Mean chlorophyll-a	Minimum calculated numeric interpretation		Maximum calculated numeric interpretation	
		Annual Geometric Mean TP	Annual Geometric Mean TN	Annual Geometric Mean TP	Annual Geometric Mean TN
> 40 PCU	20 µg/L	0.05 mg/L	1.27 mg/L	0.16 mg/L ¹	2.23 mg/L
≤ 40 PCU and > 20 mg/L CaCO ₃	20 µg/L	0.03 mg/L	1.05 mg/L	0.09 mg/L	1.91 mg/L

≤ 40 PCU and ≤ 20 mg/L CaCO_3	6 $\mu\text{g/L}$	0.01 mg/L	0.51 mg/L	0.03 mg/L	0.93 mg/L

TABLE 6-12. SUMMARY OF WATER QUALITY IMPAIRMENT DETERMINATIONS FOR LAKE BONNY BY YEAR

Year	chlorophyll-a (μg / liter)	TN (mg / liter)	TP (mg / liter)
2009	85.5	6.891	0.209
2010	82.5	3.161	0.115
2011	66.0	3.385	0.095
2012	43.6	2.287	0.083
2013	38.6	1.917	0.079
2014	38.8	1.983	0.059
2015	33.9	1.515	0.049
2016	28.4	1.360	0.042
Average percent reduction required (when needed)	49	53	59

Lake Bonny has water quality that greatly exceeds NNC criteria for low-color, alkaline lakes. Based on examples included within PBS&J (2011) and Tomasko et al. (2013) the TN and TP reductions required for Lake Bonny to meet NNC guidance are beyond the range of reductions obtainable by typical lake restoration techniques using projects such as stormwater retrofits. Instead, more intensive projects are warranted, up to and including sediment removal and/or inactivation, and hydrologic restoration.

Positive relationships were found between both TN and chlorophyll-a (Figure 6-34) and TP and chlorophyll-a (Figure 6-35). However, the very high TN values in Lake Bonny are indicative of nitrogen-fixing cyanobacteria, and thus the TN vs. chlorophyll-a likely reflects TN “made” by phytoplankton in the lake, rather than stimulation of phytoplankton by external TN loads.

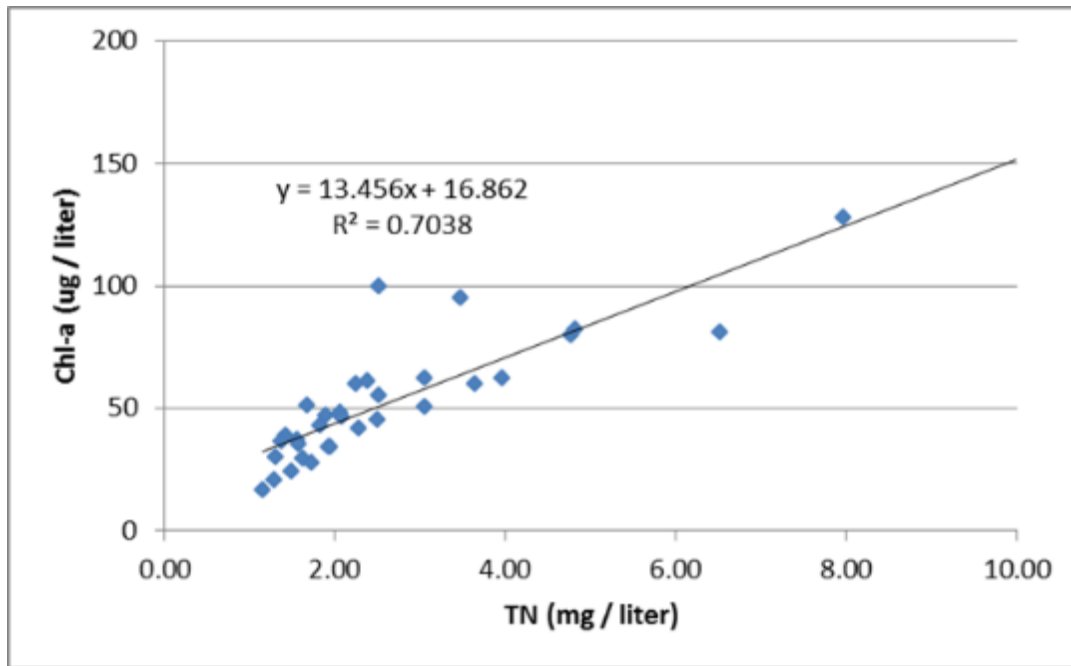


Figure 6-34. Relationship between TN and chlorophyll-a. Line is best-fit equation of statistically significant ($p < 0.05$) relationship

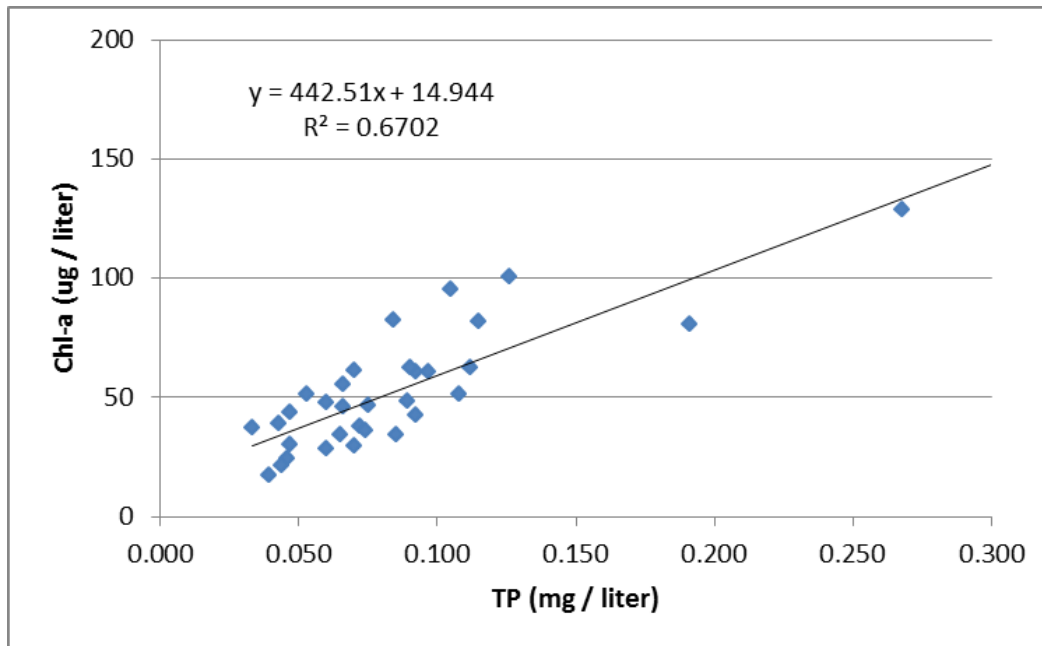


Figure 6-35. Relationship between TP and chlorophyll-a. Line is best-fit equation of statistically significant ($p < 0.05$) relationship

The very high levels of TN in Lake Bonny are likely due to the presence of nitrogen-fixing cyanobacteria. As such, reductions in external loads of TN are likely not capable of reducing TN concentrations significantly within the lake. Therefore, TP was identified as the nutrient of concern and proposed lake management activities focused on the reduction of TP concentrations.

A statistical correlation between annual average TP concentrations and annual rainfall was not found indicating that external sources such as stormwater runoff are not likely dominant influences on in-lake water quality. Based upon these results, projects which focus on stormwater retrofits are not good candidates toward restoring water quality in Lake Bonny. However, the maintenance/enhancement of native emergent and submerged aquatic vegetation is recommended.

The existence of prior or ongoing point source loads to the lake which could have led to nutrient enriched sediments is unknown. Additionally, there are not any landscape features (historical or current) that would be expected to exceed “normal” urban landscape nutrient loads to the lake. However, lake sediment resuspension was identified as a likely source of internal nutrient loads to the overlying water column based evidence of a significant, inverse correlation between TP concentrations and lake water elevation ($p=0.0002$, $\rho=-0.336$). Sediment removal and/or sediment inactivation are projects focused on the control of nutrient releases for lake-bottom sediments which is recommended for Lake Bonny. Whole-lake circulation is not recommended based on the lake size.

An analysis of the historical versus current lake extent indicated that the lake has been lowered compared to its original configuration. Historical data suggest that the lake elevation has been lowered between 3 and 4 feet since the 1850s and is therefore primarily cut-off from its historical wetland fringe. The majority of the historical wetland extent has been developed; therefore, water quality treatments through the use of barley straw and/or cypress leaf bundles should be tested for their ability to reduce cyanobacteria abundance. Additionally, establishing a large enough in-lake hardwood and herbaceous wetland community may increase color and thus moderate chlorophyll-a expression.

The 5-year average value for color in the report by the City of Lakeland (2010) indicates Lake Bonny is a high-color lake. However, the report from Atkins and ESA (2014) indicates the lake is actually a low-color, alkaline lake. This current analysis corroborates the latter (long-term geometric mean color of 39). However, Lake Bonny’s color values averaged above 40 PCU in 2001, 2003, 2005, 2006, 2007, 2008 and 2011. The geomorphology of the lake is such that Lake Bonny is classified as a “valley” lake. The fact that it can be classified as either low-color or high-color depending on the period of data assessed indicates that wetlands surrounding the lake may play a significant role in importing tannins during higher water-level years. A decline in tannin loads may have occurred due to reduction in water elevation disconnecting the lake from the wetland fringe.

Using a longer time period for color analysis determines that Lake Bonny is in fact primarily a low-color, alkaline lake. While this does not change the chlorophyll-a target for the lake, the TP and TN targets are lower (more stringent) for low-color alkaline lakes than they are for high-color lakes. The TP and TN concentration reductions required for Lake Bonny to meet NNC guidance are substantial as corroborated in both the report by Atkins and ESA (2014) and the TMDL for Lake Bonny (FDEP 2014a).

Although Lake Bonny clearly exhibits signs of nutrient enrichment, site-specific chlorophyll-a, TN, and TP targets have not been established and thus may be appropriate for Lake Bonny. A site-

specific paleo study is advisable if the City decides to pursue establishing site-specific criteria. Moreover, site-specific paleo data for Lake Bonny could potentially be used to establish by proxy site-specific nutrient and chlorophyll targets for all low-color, alkaline lakes in the City.

Water Quality Restoration Project Selection and Priorities

Based on Lake Bonny water quality and the surrounding watershed characteristics, seven potential water quality restoration projects were identified using the City WQMP decision key. Projects to address water quality, nutrient and sediment loading, and reduced lake levels are proposed. A detailed discussion of the potential water quality restoration implications for each project can be found in Section 4.0.

Project 1: SAV Planting/Management or FTWs

Project 2: EAV Planting/Management

Project 3: Wetland Influence Reestablishment

Project 4: SIAs

Project 5: Sediment Removal/Inactivation

Project 6: Develop reasonable water quality targets through paleolimnology and coordination with FDEP

Project 7: Effect of Tannins and Tannin Sources on Cyanobacteria Populations

Project 1: SAV Planting/Management or FTWs

SAV Planting

A survey of existing SAV cover in Lake Bonny is recommended due to the lack of sufficient, recent data to calculate percent lake cover. Based on the results of the SAV survey, conclusions regarding SAV planting can be determined. If SAV cover is less than 30 percent, lake conditions should be evaluated to assess if additional SAV is viable based on the soil condition, water clarity and water depth.

Based on the median Secchi depth (0.5 meter) from the POR, plants would not be planted in water depths greater than 0.7 meter. The maximum planting effort for Lake Bonny cannot be calculated until digital bathymetry data are acquired.

Bathymetric Survey Cost Estimate: \$10,000

SAV Planting/Management Cost Estimate: A cost estimate will be generated upon receipt of the bathymetry data.

FTWs

If the feasibility study indicates that more than 30 percent of Lake Bonny has SAV cover, FTW may be considered. The installation of floating mats with appropriate aquatic vegetation would be expected to assimilate nutrients from the water column.

Project 2: EAV Planting

A survey of existing shoreline vegetation surrounding Lake Bonny is recommended due to the lack of sufficient data at this time. Based on the results of the shoreline survey, conclusions and recommendations regarding emergent aquatic or woody vegetation planting can be determined. If limited shoreline vegetation is present, shoreline conditions should be evaluated, preferably by City staff, to assess if vegetation planting is viable based on the soil conditions, slope, water level and inundation frequency and wave disturbance.

EAV Planting/Management Cost Estimate: A cost estimate will be generated upon receipt of the shoreline survey data.

Project 3: Wetland Influence Reestablishment

There are two wetland areas adjacent to Lake Bonny identified for potential rehydration within the 500-foot buffer surrounding Lake Bonny which are classified as forested wetland mixed or freshwater wetlands using the 2011 FLUCCS data (Figure 6-36). The first area is approximately 14 acres located northeast of the lake while the second area is an approximately 35-acre lobe of wetland which protrudes into the lake from the west. Depending on findings from site investigations, these may offer an opportunity to increase tannin levels in the lake, if sufficient amount of impacted (i.e., drained) forested wetlands could be rehydrated so that the percentage of the lake's shoreline could exceed 10 to 20 percent of the adjacent watershed, which may allow for color levels above 50 PCU. While FLUCCS classifies the land cover as identifies the smaller parcel as forested wetland, the hydrologic connection between the lake and adjacent land might be partly severed. In regards to the second larger parcel, a more comprehensive evaluation of current land cover would be necessary to determine if rehydration or management of the area to enhance wetland treatment is a more viable option. A feasibility study is recommended in order to evaluate the proposed project areas for inundation or wetland treatment enhancement.

Feasibility study cost estimate: \$150,000.



Figure 6-36. Proposed forested wetland rehydration project areas for Lake Bonny

Project 4: Sediment Removal / Inactivation

Non-point source discharges to Lake Bonny may have resulted in substantial internal nutrient loads due to phosphorus release from sediments. Presently, sediment capping and dredging are both potential remedial options; however, costs associated with dredging are typically highly elevated in comparison to capping. A feasibility study is recommended to evaluate sediment capping versus sediment dredging.

Feasibility study cost estimate: \$150,000

Project 5: SIAs

The Lake Bonny watershed has approximately 431 acres of the watershed classified as high infiltration soils. The Lake Bonny TMDL may allow for the development of an estimate of the SIA acres required for the TMDL-required TP load reductions. Our analysis did not support the need for stormwater retrofits to improve water quality in the lake. However, SIA implementation could have the additional benefit of increasing storage to supplement dry season lake levels and a reduction in stormwater loads that can be later applied to a TMDL TP load reduction, if necessary. As such, SIA design should be focused on recharging the surficial aquifer.

SIA Cost Estimate: \$20,000 per raingarden for design, permitting, and construction; however, costs are highly dependent on availability of land and whether construction efforts are completed by the City or outsourced.

Project 6: Paleolimnology Study

The paleolimnological study for Lake Bonny (Whitmore et al. 2016) is current enough that its findings should be discussed with FDEP to ensure that the State's agencies are aware of the impractical nature of the existing NNC criteria for Lakeland's priority lakes. The complexity of the tannin-nutrient-phytoplankton relationships found for Lake Bonny are such that it was concluded that nutrient reduction alone, even if to pre-development concentrations, would not result in the lake also obtaining pre-development values for chlorophyll-a. The need for restoration of the lake's historical lake-wetland connectivity supports conclusions related to the need for such projects that was also reached for Lake Hancock (Tomasko et al. 2009).

Project 7: Effect of Tannins and Tannin Sources on Cyanobacteria Populations

Water chemistry data in Lakes Bonnet, Bonny, Hollingsworth, Hunter, Little Lake Bonny and Parker suggest that TN concentrations are well above values that can be explained by stormwater runoff alone. That these lakes also have chlorophyll-a concentrations often in excess of 90 µg/L is suggestive of high rates of nitrogen-fixation by cyanobacteria, as has been documented in nearby Lake Hancock (Tomasko et al. 2009). It is evident that the aforementioned six lakes have also been adversely impacted by lowered lake water elevations such that lake water elevations now fluctuate below the respective historical wetland fringe. For Florida, lakes with limited development along their shorelines, such as Cypress Lake in Osceola County, raising the lake water elevation is considered a valuable way to improve water quality (Atkins 2013). Unfortunately, it appears that intensive lakeside development precludes such an approach in most City lakes.

For lakes where wetland influences have been lost and cannot be recovered via hydrologic restoration, water quality treatments through the use of barley straw and/or cypress leaf bundles could be tested for their ability to reduce cyanobacteria abundance as has been tested (at the aquarium scale) for Lake Hancock (Tomasko et al., accepted for publication). Although the addition of cypress needles has been shown to be useful for reducing cyanobacteria populations, the study was limited to 10-gallon aquaria and it is not known at this time if results would scale up proportionally. To conduct this experiment at the level of a whole lake involves significant costs and the approach may not work as well on the level of a whole lake as it did in an aquarium.

An interim approach might be to conduct a replicated mesocosm study using "limno-corrals", as was done for assessing the role of sediment removal on cyanobacteria biomass reduction in Lake Hancock (Tomasko et al. 2009). Such an experiment ideally should be conducted in Lake Bonny for the following reasons: 1) water quality data suggest the lake is strongly influenced by cyanobacteria, 2) data exist that suggest Lake Bonny is now 3 to 4 feet lower than it was historically, and 3) deployment of and access to the limno-corrals to test the technique would be relatively easy. It is further recommended that such a study be conducted in a replicated manner, with three treatments (limno-corrals with cypress leaves), three controls (limno-corrals without cypress leaves) and three locations with neither cypress leaves nor cylinders. The experiment should be conducted twice; once at the end of the dry season (May) and again at the end of the wet season (September).

As a placeholder, an initial assessment was completed in October of 2017 and the Technical Memorandum is provided as Appendix D. An excerpt from the Technical Memorandum is copied here:

The interpretation of results from the mesocosm study is complicated by two factors. First, the mesocosms appear to have “captured” water masses that differed at the beginning of the experiment. While levels of chlorophyll-a were similar across the four treatments, levels of TN and TP were higher in the controls and barley straw treatments on the initial sampling date. The reasons for this are unclear, as the mesocosm were randomly assigned, and no obvious differences were noted on the initial day of deployment. The second factor that needs to be accounted for is related to the mesocosm design. While the mesocosms looked appropriate on the day of deployment (see Figures 1 and 2) they did not prove to be capable of withstanding wind-induced wave action. As well, the mesocosms appear to have been deployed in waters that were too shallow, which reduced the volume of water in each mesocosm, and which resulted in the “buckling” of the mesocosm sides due to insufficient water depth.

Despite these complications, it does appear that there is some evidence of the value of the cypress leaves and pine straw treatments. In the controls, concentrations of TN and TP increased over the two weeks (although the increase was less than 5 percent for TN). In contrast, concentrations of TN decreased by at least 17 percent over that same time period for the cypress leaves and pine straw treatments. TP concentrations were similar over the two-week deployment for the barley straw, cypress leaves and pine straw treatments, while they had increased by more than 90 percent in the controls over the same time period.

While the initial results were not as unambiguous as what was hoped for, there was still evidence of a potential benefit, in terms of phosphorus concentrations. A follow up study is warranted, but with greater attention paid to producing a mesocosm design better able to withstand the combination of waves and water depths required for results to be valid for further assessments.

Cost estimate: \$ 25,000 to \$50,000, depending on availability of City staff to collect samples, and whether or not water quality samples can be processed by City or Polk County laboratories.

Crystal Lake

Physical and chemical characteristics specific to Crystal Lake are presented here in the context of relevant regulatory criteria and requirements.

Historical and Recent Conditions in Lake and Watershed

Crystal Lake is unique among the City’s priority lakes in that it has a TMDL produced by EPA, not FDEP. Normally, once a waterbody has a TMDL produced for it, it is removed from the impaired waters list. However, despite the TMDL (EPA 2010) Crystal Lake was placed in the 4e assessment category by FDEP in June 2018. The TMDL for Crystal Lake (EPA 2010) calls for reductions in NPDES MS4 discharges of 51 and 70 percent for TN and TP, respectively, as well as a 75 percent reduction in nutrient loads from “benthic fluxes”. Although there is a TMDL implementation report

(i.e., a Nutrient Reduction Plan) to guide the City in how to achieve these reduction (AMEC 2017) there are not examples in Florida that would suggest that load reductions of such a magnitude are possible, or that stormwater load reductions would be expected to improve Crystal Lake's water quality to the point of it no longer be impaired for nutrients.

Crystal Lake is a 27-acre lake located in the City within the eastern portion of Polk County, Florida (Figure 6-37). Crystal Lake's applicable physical characteristics are not provided in the latest available Lakes Report (City of Lakeland 2010) or the summary report on Polk County lakes produced by Atkins and ESA (2014). The lake is located within the Lakeland/Bone Valley Upland lake region of Florida, which according to Griffith et al. (1997), can be characterized with "high phosphorus, nitrogen, and chlorophyll-a values" and "alkaline, [with] some [lakes] receiving limestone-influenced groundwater."

Crystal Lake is located within the Peace River watershed and the immediate contributing watershed to the lake is 216 acres in size, resulting in a watershed to open water ratio of 8 (Table 6-12; Figure 6-37). Watershed to open water ratios can be used to compare the relative amount of influence that a lake experiences from its contributing watershed, such as stormwater runoff.

Crystal Lake is an isolated waterbody that does not receive inflows from the adjacent waterbodies. Over the past 25 years, the lake water elevation has ranged from approximately 127.5 to 140.0 feet. Since 2007, water elevations have been increasing, rising from below 130 feet to over 136 feet (Figure 6-38). Crystal Lake is situated at an elevation of approximately 136 NAVD. Within the Crystal Lake watershed, there is a moderate elevation gradient ranging from 135 to 156 feet NAVD (Figure 6-39). Crystal Lake is located between 100 and 110-foot potentiometric surface elevations and south of the potentiometric peak, as of September 2011 (Figure 6-40). Additionally, the northern boundary of the intermediate aquifer system is just north of Crystal Lake (Spelcher and Kroening 2007). Therefore, it is unlikely that there is direct connectivity with the Floridan aquifer.

A review of historical aerial photography (from 1941) indicates the shoreline has not been obviously modified compared to recent photography (2016). In 1941, citrus agriculture was present to the west and south of Crystal Lake. In 1957, residential development is apparent to the west and south of the lake (Figure 6-41). Additionally, citrus agriculture continues. Sanborn maps for the areas surrounding Crystal Lake were unavailable for review. The extensive development within the watershed is reflected in the land use/land cover data provided by both USGS and SWFWMD (Table 6-13). Specifically, the SWFWMD land use data from 2011 classifies 184 acres (83%) as developed lands compared to 32 acres (17%) of undeveloped land (Figure 6-42).

There are 6 inputs that discharge to Crystal Lake watershed, including three minor outfalls, two end-of-pipe inputs, and one major outfall (Figure 6-43). In regards to infrastructure, the majority of the existing residential developments within the watershed utilize sanitary sewer for wastewater treatment provided by the City (City of Lakeland 2010). One hundred and eight OSTDS construction permits were identified (Figure 6-44). Based on a review of SWFWMD soil survey geographic data, soils within the watershed have a low runoff potential with high, moderate, and low infiltration rates and are classified either as hydrologic soil group A (154 acres), B/D (5 acres), or C (28 acres), respectively (Figure 6-45).

TABLE 6-13. PHYSICAL CHARACTERISTICS OF CRYSTAL LAKE AND ADJACENT WATERSHED

Physical			
Location	City of Lakeland; Polk County	High infiltration soils (acres)	154
Relation to other lakes	Unknown	Developed land (acres)	184
Watershed area (acres)	216	Undeveloped land (acres)	32
Lake area (acres)	27	Mean water depth (ft)	Unknown
Perimeter (feet)	5,348	Maximum water depth (ft)	Unknown
Surface area: lake volume ratio	Unknown	Volume (acre-feet)	Unknown
Watershed to surface area ratio	8		

TABLE 6-14. CHANGES IN LAND USE WITHIN THE CRYSTAL LAKE WATERSHED OVER TIME

Land Use	1970-1985*		1995		2011	
	Acres	Percent	Acres	Percent	Acres	Percent
Industrial	17	7.8				
Commercial and Services	18	8.3	24	11.1	20	9.3
Institutional			23	10.6	39	18.1
Open Land			10	4.6		
Orchards, Groves, Vineyards, Nurseries	24	11				
Forested Wetland	18	8.3				
Freshwater Marsh					2	0.9
Intermittent Ponds					1	0.4
Lake	19	8.8	31	14.4	25	11.6
Shorelines					3	1.4
Stream and Lake Swamps					1	0.5
Residential	121	55.8			125	57.8

*Metadata for USGS land use data identifies data collection dates as a period between 1970 and 1985



Figure 6-37. Crystal Lake location map

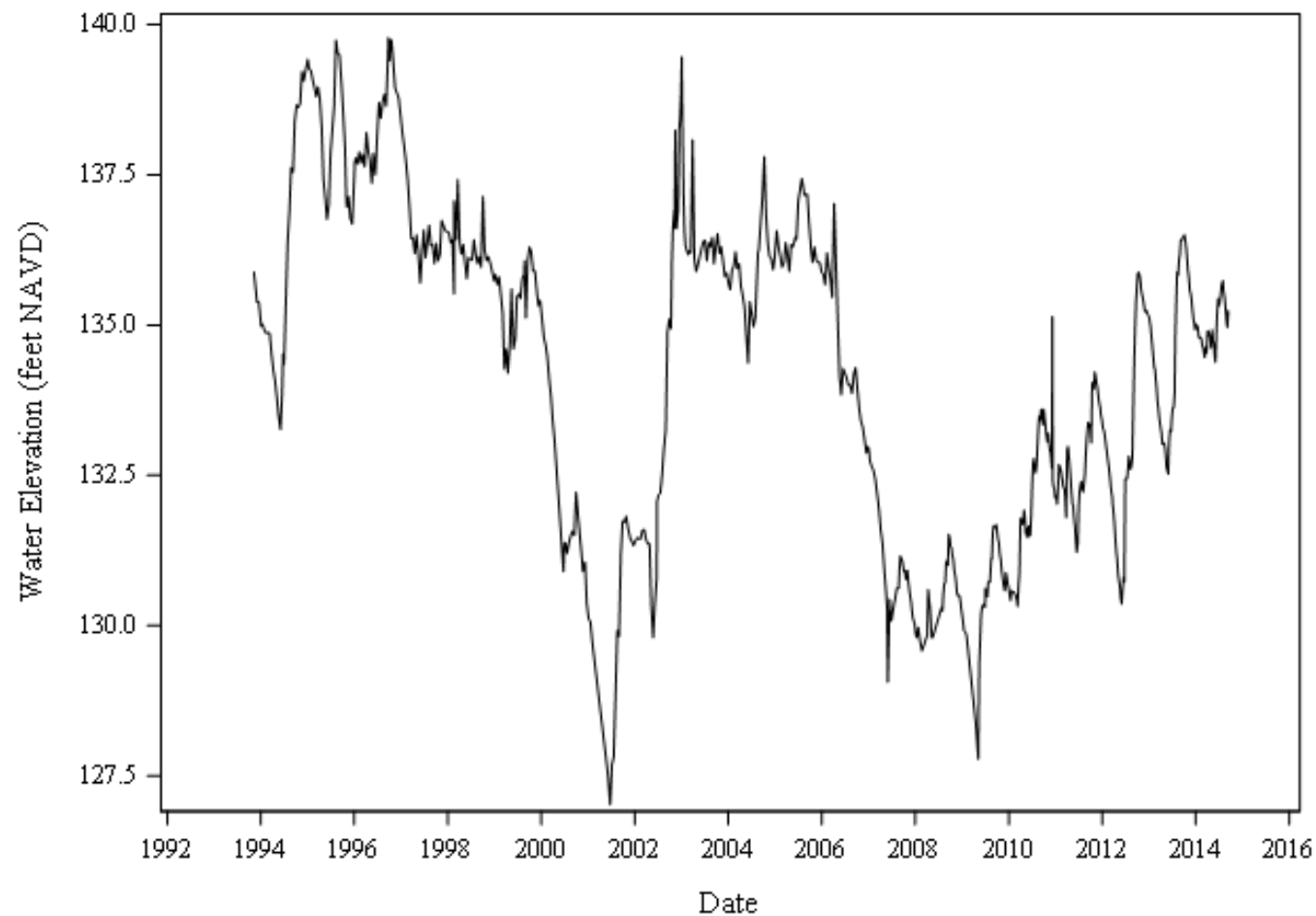


Figure 6-38. Period of Record Lake Crystal water elevation

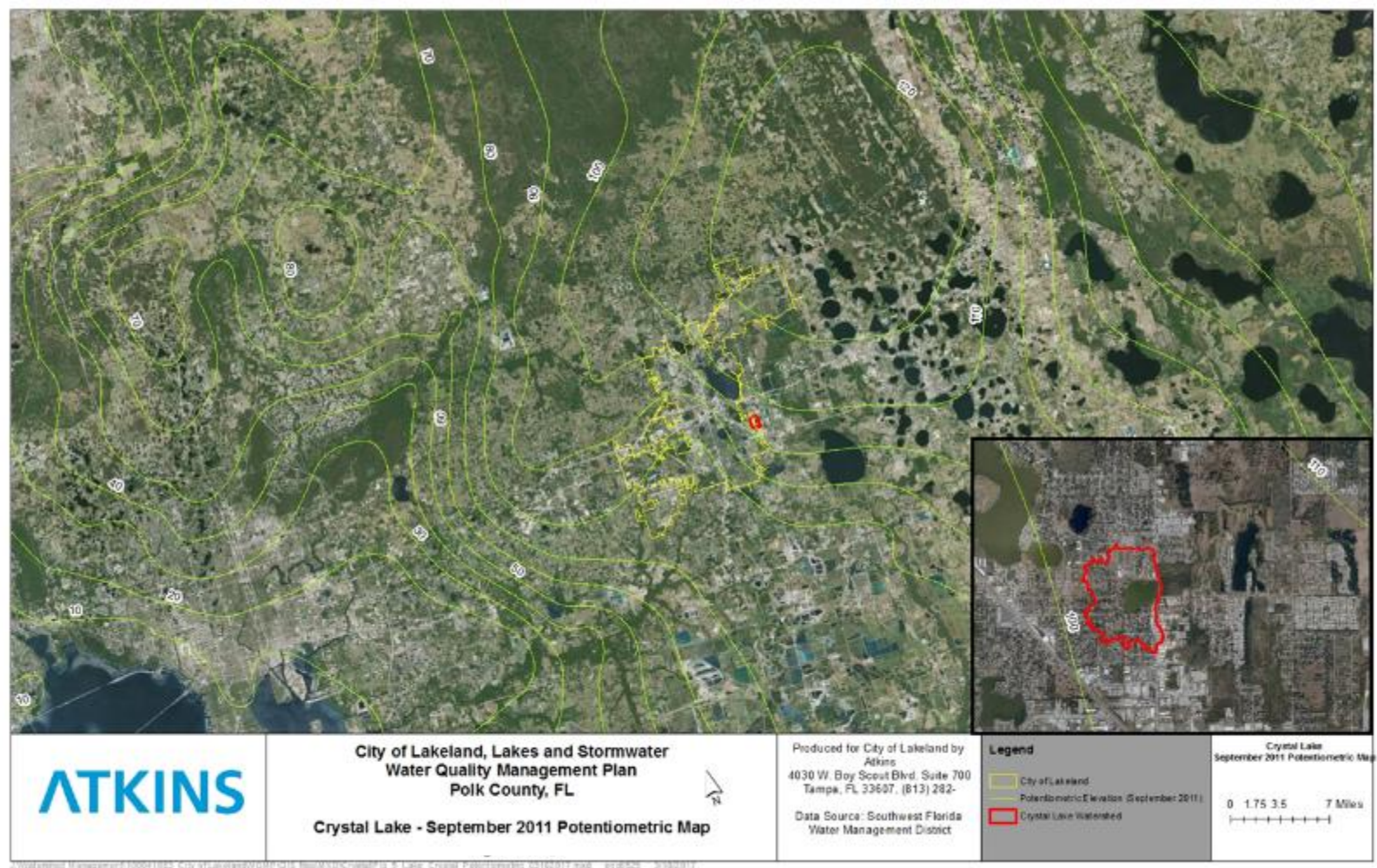


Figure 6-40. Crystal Lake potentiometric map



Figure 6-41. Crystal Lake historical aerial imagery. Left Photo. 1958. Right Photo. 1968

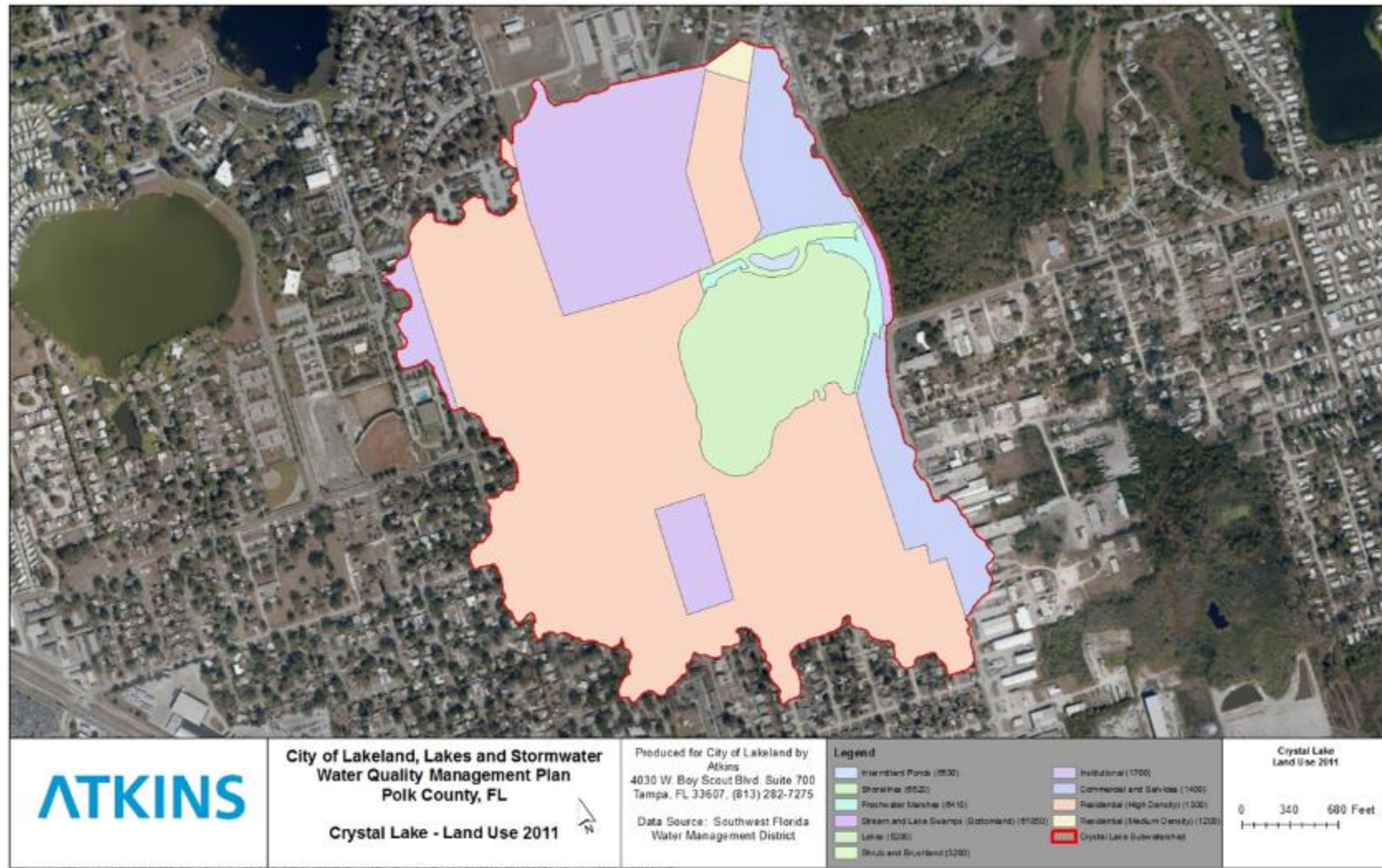


Figure 6-42. Crystal Lake 2011 land use map

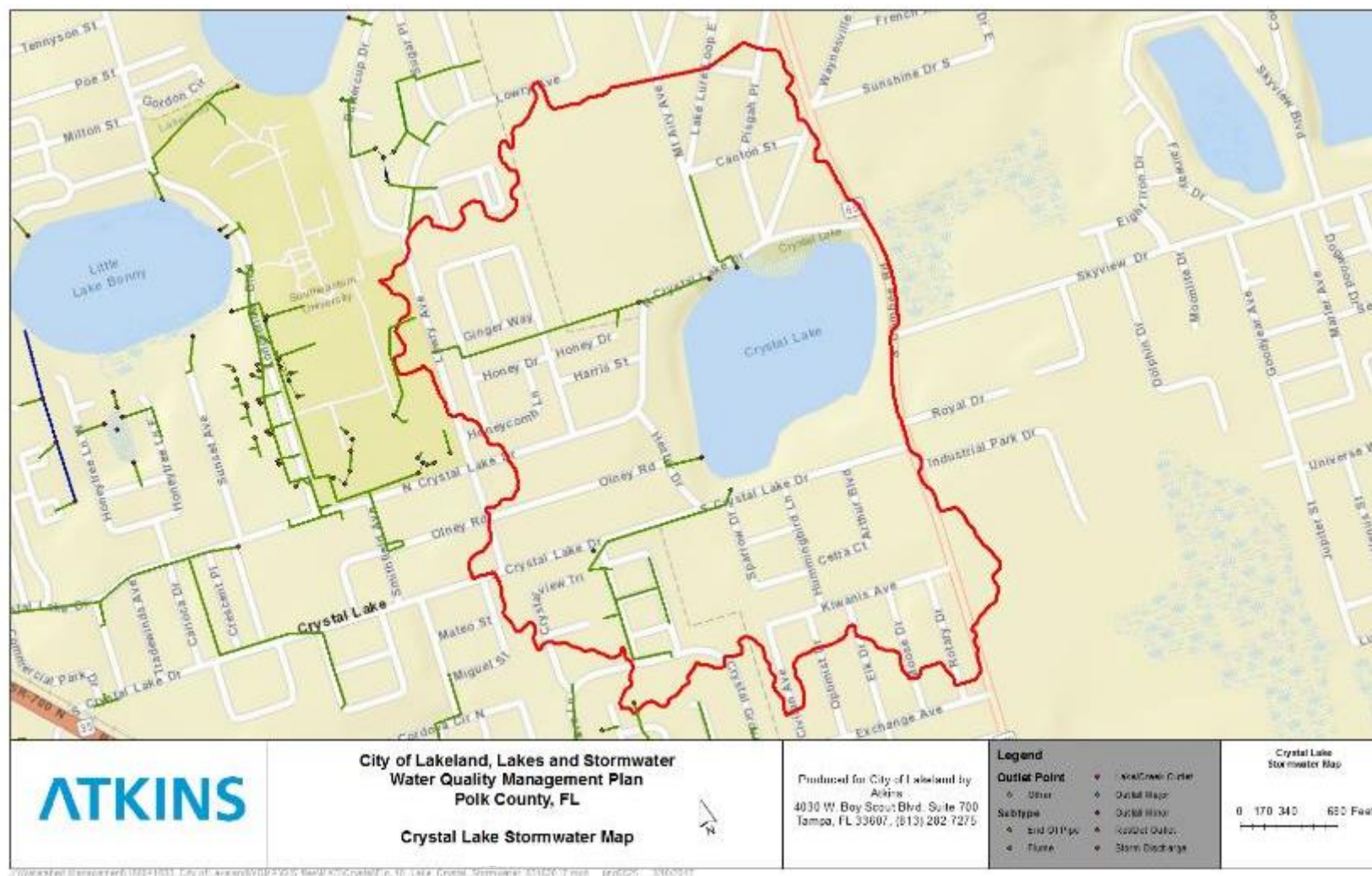


Figure 6-43. Crystal Lake stormwater map

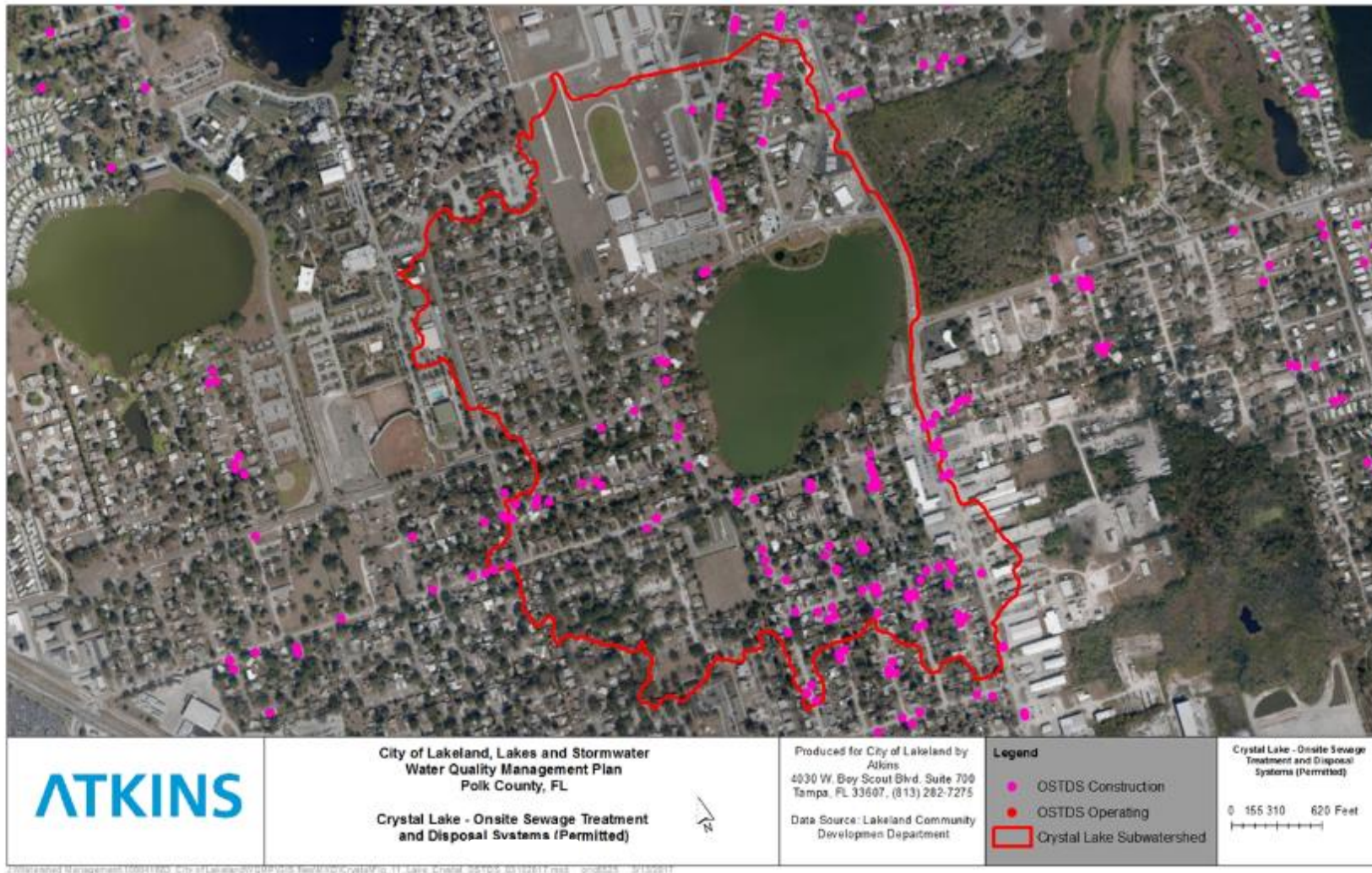


Figure 6-44. Crystal Lake OSTDS map

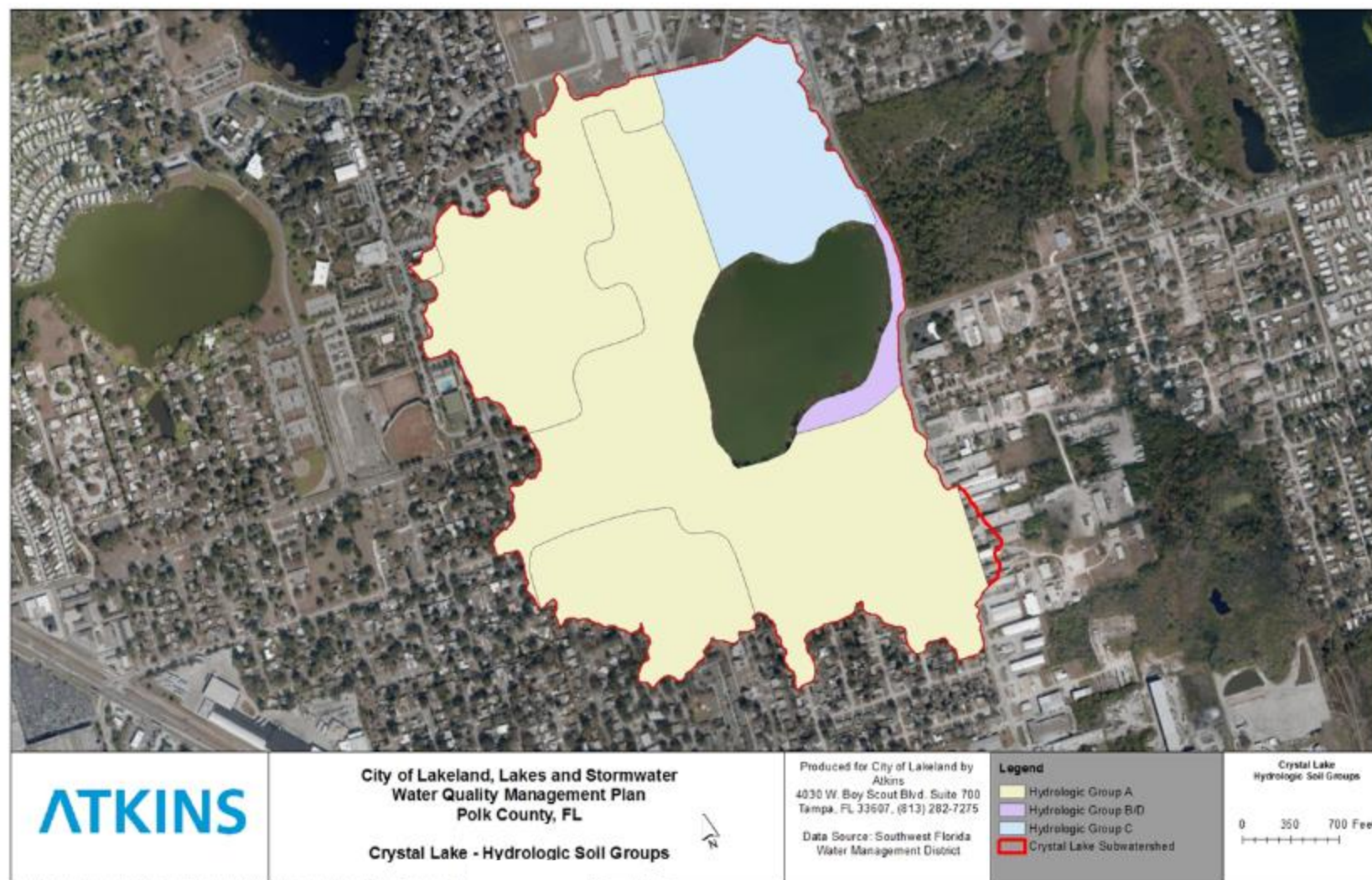


Figure 6-45. Crystal Lake soils map

Water Quality

In FDEP's December 2017 version of the Comprehensive Verified Impaired List, Crystal Lake was listed as impaired for nutrients based upon a determination that Crystal Lake had geometric mean chlorophyll-a values that exceeded NNC criteria between 2011 and 2014. Crystal Lake was previously classified as a clear, alkaline lake based on a long-term geometric mean color of 26 PCU and alkalinity of 60 mg/L (Atkins and ESA 2014). Based on the clear, alkaline characterization, nutrient criteria were determined based on the use of a chlorophyll-a concentration of 20.0 µg/L. In response, the City of Lakeland submitted a Nutrient Reduction Plan to FDEP for evaluation in lieu of a TMDL. In June 2018, FDEP approved the Nutrient Reduction Plan; therefore, delisting Crystal Lake from the Verified List reclassifying it in assessment category 4e on the Study List. The Nutrient Reduction Plan identifies several restoration activities proposed to improve lake water quality which includes regional projects to reduce external loads (e.g., street sweeping, fertilizer ordinance) as well as site-specific project to address internal loading (e.g. sediment removal).

To minimize the impacts of different verified periods, this report characterizes water quality for each of the City's priority lakes during the same time period, 1/1/2009 to 6/30/2016. These dates correspond to the most recent Verified Period for which FDEP's water quality data are available for all the City's priority lakes.

Water quality data were downloaded from FDEP, and used to determine the classification status of Crystal Lake. As was found previously, Crystal Lake was classified as a low-color, alkaline lake, based on a geometric mean value for color of 28 PCU and a geometric mean alkalinity value of 60 mg (as CaCO₃) / liter. Based on that classification, the water quality targets for TN and TP were then determined based on whether or not the annual geometric mean for a given year exceeded the threshold chlorophyll-a value of 20 µg / liter. The relevant water quality criteria for TN and TP for Crystal Lake are highlighted in yellow in Table 6-15. Based on the below-listed criteria, Crystal Lake has the following exceedances (Table 6-16).

Crystal Lake has water quality that far exceed NNC criteria for low-color, alkaline lakes. Based on case studies examined in PBS&J (2011) and Tomasko et al. (2013) the TN and especially the TP reductions required for Crystal Lake to meet NNC guidance are outside the range of reductions obtained by traditional lake management approaches, such as stormwater retrofits. Instead, more intensive project types are required, up to and including sediment inactivation or removal and hydrologic restoration.

TABLE 6-15. WATER QUALITY CRITERIA FOR CRYSTAL LAKE, WITH RELEVANT TARGETS FOR CHLOROPHYLL-A, TN AND TP HIGHLIGHTED IN YELLOW.

Long Term Geometric Mean Lake color and Alkalinity	Annual Geometric Mean chlorophyll-a	Minimum calculated numeric interpretation		Maximum calculated numeric interpretation	
		Annual Geometric Mean TP	Annual Geometric Mean TN	Annual Geometric Mean TP	Annual Geometric Mean TN
> 40 PCU	20 µg/L	0.05 mg/L	1.27 mg/L	0.16 mg/L ¹	2.23 mg/L
≤ 40 PCU and > 20 mg/L CaCO ₃	20 µg/L	0.03 mg/L	1.05 mg/L	0.09 mg/L	1.91 mg/L
≤ 40 PCU and ≤ 20 mg/L CaCO ₃	6 µg/L	0.01 mg/L	0.51 mg/L	0.03 mg/L	0.93 mg/L

TABLE 6-16. SUMMARY OF WATER QUALITY IMPAIRMENT DETERMINATIONS FOR CRYSTAL LAKE BY YEAR. YEARS WITH INSUFFICIENT DATA FOR COMPARISON WITH NNC CRITERIA ARE NOTED BY “-”.

Year	chlorophyll-a (µg / liter)	TN (mg / liter)	TP (mg / liter)
2009	-	-	-
2010	-	-	-
2011	70.2	1.96	0.091
2012	70.9	1.99	0.189
2013	88.6	2.15	0.188
2014	104.9	2.70	0.172
2015	42.9	1.27	0.081
2016	27.3	1.06	0.059
Average percent reduction required (when needed)	64	37	72

Positive relationships were found between both TN and chlorophyll-a and TP and chlorophyll-a (Figures 6-46 and 6-47, respectively). The very high levels of TN shown in Figure 6-46 suggest the presence of nitrogen-fixing cyanobacteria, rather than external nitrogen loads with such high concentrations.

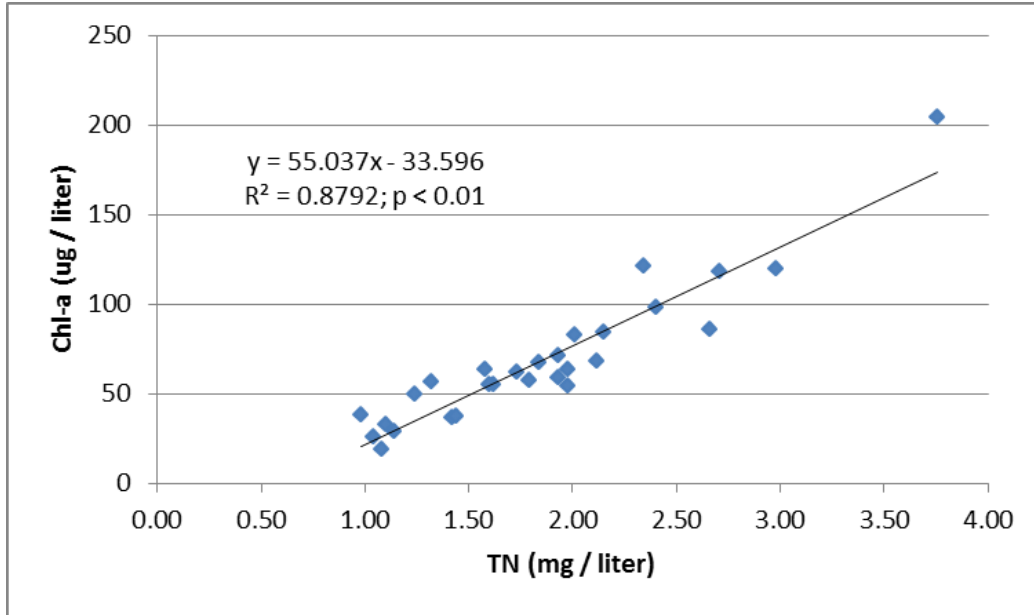


Figure 6-46. Relationship between TN and chlorophyll-a. Line is best fit equation of statistically significant ($p < 0.05$) relationship

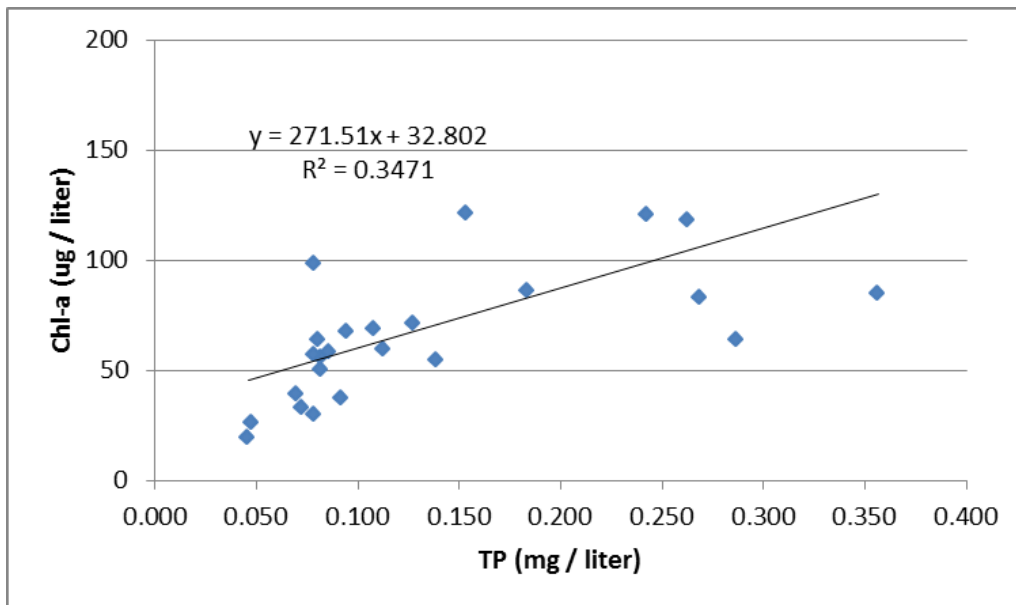


Figure 6-47. Relationship between TP and chlorophyll-a. Line is best fit equation of statistically significant ($p < 0.05$) relationship

No correlation was found between annual average nutrient concentrations and annual rainfall, indicating that external sources such as stormwater runoff are not likely dominant influences on in-lake water quality. Based upon these results, projects which focus on stormwater retrofits are not likely to be able to restore water quality in Crystal Lake. Additionally, there are no known ongoing or historical point source discharges to the lake. However, the presence of citrus groves in the 1950s and 1960s suggests that nutrient loads from potentially excessive fertilizer applications might have loaded Crystal Lake with nutrients that are now associated with the bottom sediments.

An evaluation of lake water elevation and TN was investigated to ascertain the likelihood for internal nutrient releases from the bottom sediments. Lake sediment resuspension was identified as a likely source of internal nitrogen loads to the overlying water column based on the significant, inverse correlation between nitrogen concentrations and lake water elevation ($p=0.0001$, $\rho = -0.483$). Based upon this analysis, sediment removal/inactivation is recommended to physically remove or inactivate the nutrient laden sediments responsible for nutrient releases. Prior to implementing these more expensive projects, it is recommended that artificial circulation be tested for its ability to improve water quality in Crystal Lake, along with the maintenance/enhancement of native emergent and submerged aquatic vegetation are recommended.

An analysis of the historical versus current lake extent indicated that the lake has been lowered compared to its original configuration. Review of existing aerial imagery shows a wetland feature on the eastern edge of the lake. Historically, the lake's water was in direct contact with this wetland feature, which has now been largely disconnected by a roadway. The re-establishment of the lake: wetland interaction may increase color and thus moderate chlorophyll-a concentrations. Alternately, water quality treatments through the use of barley straw and/or cypress leaf bundles should be tested for their ability to reduce cyanobacteria abundance. Additionally, establishing a large enough in-lake hardwood and herbaceous wetland community may increase color and thus moderate chlorophyll-a expression.

Crystal Lake clearly exhibits signs of nutrient enrichment. Site-specific chlorophyll-a, TN, and TP targets have not been established and default targets based on NNC might be problematic. Collection and analysis of locally-derived paleo data is advisable if the City decides to pursue establishing site-specific criteria for Crystal Lake. Based on examples contained within both PBS&J (2011) and Tomasko et al. (2013), the TN and TP reductions required for Crystal Lake to meet NNC guidance are outside the reasonable obtainable range for lakes where typical approaches such as stormwater retrofits have been applied. A more detailed assessment of Crystal Lake (AMEC 2017) concluded that more than 90 percent of the phosphorus in the water column was associated with fluxes from sediments, and that until and unless these sediments were addressed, the TMDL goals set by EPA (2010) could not be met, and that stormwater retrofits may not likely be able to bring about a recovery in water quality in Crystal Lake.

However, Crystal Lake is small enough to fit within the category of lakes where whole lake aeration has been suggested as a feasible management action (PBS&J 2010). Aeration may be well worth examining, as part of a paired study with Lakes Mirror and Morton, to ascertain the feasibility of implementing such projects in City lakes of this type and size. If aeration and other water-column improvement techniques such as alum applications can improve clarity in Crystal Lake, the chances

of rehabilitating SAV and other aquatic macrophyte communities will improve. If aeration and/or sediment inactivation are not able to restore water quality, then the more expensive option of sediment removal may need to be considered.

Water Quality Restoration Project Selection and Priorities

Based on Crystal Lake water quality and the surrounding watershed characteristics, seven potential water quality restoration projects were identified using the City WQMP decision key. Projects to address water quality, nutrient and sediment loading, and reduced lake levels are proposed. A detailed discussion of the potential water quality restoration implications for each project can be found in Section 4.0.

Project 1: Artificial Circulation

Project 2: SAV Planting/Management or FTWs

Project 3: EAV Planting/Management

Project 4: Re-establish Wetland Influence

Project 5: SIAs

Project 6: Sediment Removal/Inactivation

Project 7: Develop reasonable water quality targets through paleolimnology and coordination with FDEP

Project 1: Artificial Circulation

The project design is based on the assumption that the system configuration developed by SolarBee® for previous lake circulation projects is applicable to Crystal Lake. Therefore, each circulation pump is assumed to effectively circulate 16 to 20 acres. The surface area of Crystal Lake is 27 acres requiring the purchase and installation of one SB10000 v 18 machines. Prior to implementation of artificial circulation, a feasibility study to characterize the sediment quality, water column profiles and water depth within the lake.

Cost Estimate: \$100,000 (estimate based on cost provided by Solar Bee® for the purchase, delivery and installation of one unit). Based upon prior experience, the feasibility study could be completed for approximately \$50,000.

Project 2: SAV Planting/Management or FTWs

SAV Planting

Hydrilla infestations have not been a chronic problem in Crystal Lake. A survey of existing SAV cover in Crystal Lake is recommended due to the lack of sufficient data to calculate percent lake cover. Based on the results of the SAV survey, conclusions regarding SAV planting can be

determined. If SAV cover is less than 30 percent, lake conditions should be evaluated to assess if additional SAV is viable based on the soil condition, water clarity and water depth.

Based on the median Secchi depth (0.6 meter) from the POR (1992 – 2016), plants would not be planted in water depths greater than 0.8 meter (Water Atlas). The maximum planting effort for Crystal Lake cannot be calculated until digital bathymetry data are acquired.

SAV Planting/Management Cost Estimate: A cost estimate will be generated upon receipt of the bathymetry data.

Bathymetric Survey Cost Estimate: \$10,000

FTWs

If the feasibility study indicates that more than 30 percent of Crystal Lake has SAV cover, FTW may be considered. The installation of floating mats with appropriate aquatic vegetation would be expected to assimilate nutrients from the water column.

Project 3: EAV Planting

A survey of existing shoreline vegetation surrounding Crystal Lake is recommended due to the lack of sufficient data at this time. Based on the results of the shoreline survey, conclusions and recommendations regarding emergent aquatic or woody vegetation planting can be determined. If limited shoreline vegetation is present, shoreline conditions should be evaluated, preferably by City staff, to assess if vegetation planting is viable based on the soil conditions, slope, water level and inundation frequency and wave disturbance.

EAV Planting/Management Cost Estimate: A cost estimate will be generated upon receipt of the shoreline survey data.

Project 4: Re-establish Wetland Influence

Approximately 15 acres of the land cover within the 500-foot buffer surrounding Crystal Lake is classified as stream and lake swamps (bottomland) and freshwater marsh wetlands using the 2011 FLUCCS data (Figure 6-48). Depending on findings from site investigations, this may offer an opportunity to increase tannin levels in the lake, if sufficient amount of impacted (i.e., drained) forested wetlands could be rehydrated so that the percentage of the lakes adjacent shoreline could exceed 10 to 20 percent of the adjacent watershed, which may allow for color levels above 50 PCU. While FLUCCS classifies the land cover as forested wetland, the hydrologic connection between the lake and adjacent land might be partly severed.

The project areas that were identified adjacent to Crystal Lake expected to rehydrate approximately 13 acres. The feasibility study is recommended in order to evaluate the proposed project areas for inundation.

Feasibility study cost estimate: \$100,000.



Figure 6-48. Proposed forested wetland rehydration project area for Crystal Lake

Project 5: SIAs

The Crystal Lake watershed has approximately 154 acres of the watershed classified as high infiltration soils. Additionally, data are currently not available to estimate the SIA acres required for a TP load reduction. However, SIA implementation could have the additional benefit of increasing storage to supplement dry season lake levels and a reduction in stormwater loads that can be later applied to a TMDL TP load reduction, if necessary. As such, SIA design should be focused on recharging the surficial aquifer.

SIA Cost Estimate: \$20,000 per raingarden for design, permitting, and construction; however, costs are highly dependent on availability of land and whether construction efforts are completed by the City or outsourced.

Project 4: Sediment Removal / Inactivation

Non-point source discharges to Crystal Lake may have resulted in substantial internal nutrient loads due to phosphorus release from sediments. Presently, sediment capping and dredging are both potential remedial options; however, costs associated with dredging are typically highly elevated in comparison to capping. A feasibility study is recommended to evaluate sediment capping versus sediment dredging.

Feasibility study cost estimate: \$150,000

Project 6: Paleolimnology Study

The paleolimnological study for Lake Bonny (Whitmore et al. 2016) is current enough that its findings should be discussed with FDEP to ensure that the State's agencies are aware of the impractical nature of the existing NNC criteria for lakes such as Crystal Lake, which appears to have been lowered below their historical elevation, thus reducing their lake-wetland connection in such a way that the lake has likely become more susceptible to nutrient concentrations than it was historically. The complexity of the tannin-nutrient-phytoplankton relationships found for Lake Bonny are such that it was concluded that nutrient reduction alone, even if to pre-development concentrations, would not result in the lake also obtaining pre-development values for chlorophyll-a. The need for restoration of the lake's historical lake-wetland connectivity supports conclusions related to the need for such projects that was also reached for Lake Hancock (Tomasko et al. 2009).

Cost estimate: \$30,000 to \$50,000 per lake including coordination with FDEP to develop site-specific water quality targets for chlorophyll-a and nutrients to be used in impairment determinations and/or TMDLs.

Lake Gibson

Physical and chemical characteristics specific to Lake Gibson are presented here in the context of relevant regulatory criteria and requirements.

Historical and Recent Conditions in Lake and Watershed

The FDEP designated the lake as impaired based on TSI (FDEP 2014). However, Lake Gibson does not show up in FDEP's latest comprehensive verified impaired list (December 18, 2017) nor does it have a TMDL, although current water quality data indicate the lake does not meet NNC for chlorophyll-a, TN, or TP. Historically, Lake Gibson has elevated lead and nutrient (including nitrogen and phosphorus) concentrations (ECT 2006a).

Lake Gibson is a 485-acre lake located in the City within the eastern portion of Polk County, Florida (Figure 6-49). Maximum water depth is reportedly 20 feet, with an average water depth of 6.6 feet (City of Lakeland 2010). The lake is located within the Lakeland/Bone Valley Upland lake region of Florida, which according to Griffith et al. (1997), can be characterized with "high phosphorus, nitrogen, and chlorophyll-a values" and "alkaline, [with] some [lakes] receiving limestone-influenced groundwater."

Lake Gibson is located within the Peace River watershed and the immediate contributing watershed to the lake is 2,131 acres in size, resulting in a watershed to open water ratio of 4.4 (Table 6-17; Figure 6-49). Watershed to open water ratios can be used to compare the relative amount of influence that a lake experiences from its contributing watershed, such as stormwater runoff. Typically, lakes with "low" watershed to open water ratios (i.e. less than 10) may not experience the degree of influence from external loads of stormwater as do lakes with "high" values. However, no absolute threshold value for this ratio exists and there is no definitive value at above which stormwater is problematic and below which stormwater is not an important stressor. Comparisons of watershed to open water ratios can be valuable but should be used with caution.

Lake Gibson is not influenced by any upstream lakes and is connected (at high water levels) to Lake Crago via an adjustable control structure (City of Lakeland 2010). The water level in Lake Gibson has mostly fluctuated within its structure operating range for most of the past 25 years, with the exception of periods of low water levels over the years 2001 to 2003, and then again in 2009 (Figure 6-50). The operational water elevation range for Lake Gibson is 140.57 to 142.57 feet NAVD and is managed by SWFWMD. Within the Lake Gibson watershed, there is a moderate elevation gradient ranging from 140 to 218 feet NAVD (Figure 6-51). Lake Gibson is located between 90 and 120-foot potentiometric surface elevations and southwest of the potentiometric peak (Figure 6-52). Additionally, the northern boundary of the intermediate aquifer system is south of Lake Gibson (Spelcher and Kroening 2007). Therefore, it is unlikely that there is direct connectivity between Lake Gibson and either the Intermediate or the Floridan aquifers.

Historical aerial photography from 1958 shows that a majority of the border of Lake Gibson was undeveloped; however, citrus agriculture was present to the south and northeast of the lake (Figure 6-52). In addition, an artificial canal shows up along the northeastern portion of the lake's shoreline. By 1968, residential development and additional canal construction was evident along the northern shoreline (Figure 6-53). The extensive development within the watershed is reflected in the land use/land cover data provided by both USGS and SWFWMD (Table 6-18). Specifically, the SWFWMD land use data from 2011 classifies 1,447 acres (53%) as developed lands compared to 684 acres (47%) of undeveloped land (Figure 6-54).

There are 428 inputs that discharge to Lake Gibson watershed, including nine minor outfalls, 49 retention/detention outfalls, 87 stormwater discharges, six flumes, 272 end of pipe inputs, and five major outfalls (Figure 6-55). In regards to infrastructure, the majority of the existing residential developments within the watershed utilize sanitary sewer for wastewater treatment provided by the City (City of Lakeland 2010). Even so, 447 OSTDS construction permits were identified within the watershed (Figure 6-56). Based on a review of SWFWMD soil survey geographic data, soils within the watershed have a low runoff potential and are classified either as hydrologic soil group A (420 acres), B/D (782 acres), C (387 acres), or D (40 acres) respectively (Figure 6-57).

As reported by the City of Lakeland (2001), water hyacinths, water lettuce, and Hydrilla in open water areas and shorelines accessible to the public are maintained in Lake Gibson. No specific details were provided. The majority of the shoreline vegetation has been modified as a result of residential encroachment, predominantly including landscaping activities. No EAV is apparent on Google Earth imagery.

In April 2007, ECT submitted a Watershed Management Plan for Lake Gibson. During the review process, ECT identified a delta forming from an unnamed stream that delivers runoff from Lake Gibson Southwest Drainage Basin to Lake Gibson. According to ECT, the presence of the delta signified that water quality and bottom habitat may be impacted by material being transported by the unnamed stream. ECT (2007) also identified several areas prone to flooding. Ultimately, ECT recommended six BMPs for the Lake Gibson watershed, including a combination of attenuation ponds, a flow through marsh and sedimentation pond, and hydroperiod restoration in the existing wetland near the outfall to reduce sediment and nutrient loading to Lake Gibson. Total acquisition and construction costs were estimated to be between \$2,700,000 and \$3,000,000 (in 2007 USD).

TABLE 6-17. PHYSICAL CHARACTERISTICS OF LAKE GIBSON AND ADJACENT WATERSHED

Physical			
Location	City of Lakeland; Polk County	High infiltration soils (acres)	420
Relation to other lakes	Discharges to Lake Crago	Developed land (acres)	53
Watershed area (acres)	2,131	Undeveloped land (acres)	47
Lake area (acres)	485	Mean water depth (ft)	6.6
Perimeter (feet)	34,340	Maximum water depth (ft)	20
Surface area: lake volume ratio	0.16	Volume (acre-feet)	3,152.8
Watershed to surface area ratio	4.4		

TABLE 6-18. CHANGES IN LAND USE WITHIN THE LAKE GIBSON WATERSHED OVER TIME

Land Use	1970-1985*		1995		2011	
	Acres	Percent	Acres	Percent	Acres	Percent
Commercial and Services	13	1	177	8.3	217	10.4
Other Urban or Built Up	100	5				
Lakes	462	22	482	22.7	486	23.3
Confined Feeding Operations	16	1				
Cropland and Pasture	308	15	148	7.0	4	0.2
Emergent Aquatic Vegetation					9	
Freshwater Marsh			15	0.7	26	1.2
Golf Course					79	3.8
Hardwood Conifer Mix			43	2.0	13	0.6
Institutional			131	6.2	124	5.9
Intermittent Ponds					2	0.1
Orchards, Groves, Vineyard, Nurseries	284	13				

Land Use	1970-1985*		1995		2011	
	Acres	Percent	Acres	Percent	Acres	Percent
Open Land			69	3.3	78	
Other Open Land			13	0.6	12	0.6
Recreational			85	4.0	5	0.2
Reservoirs			16	0.8	23	
Residential	945	44.4	830	39.1	937	44.9
Stream and Lake Swamps			47	2.2	61	2.9
Transportation					40	1.9
Transportation, Communications, and Services**	2	1				
Tree Crops					7	0.3
Upland Coniferous Forest			3	0.1		
Upland Hardwood Forests			7	0.3	6	0.3
Wetland Coniferous Forests			4	0.2		

*Metadata for USGS land use data identifies data collection dates as a period between 1970 and 1985

**Land use types differ between USGS and SWFWMD classification schemes. Please note that SWFWMD data does not include "transportation, communications, and services."

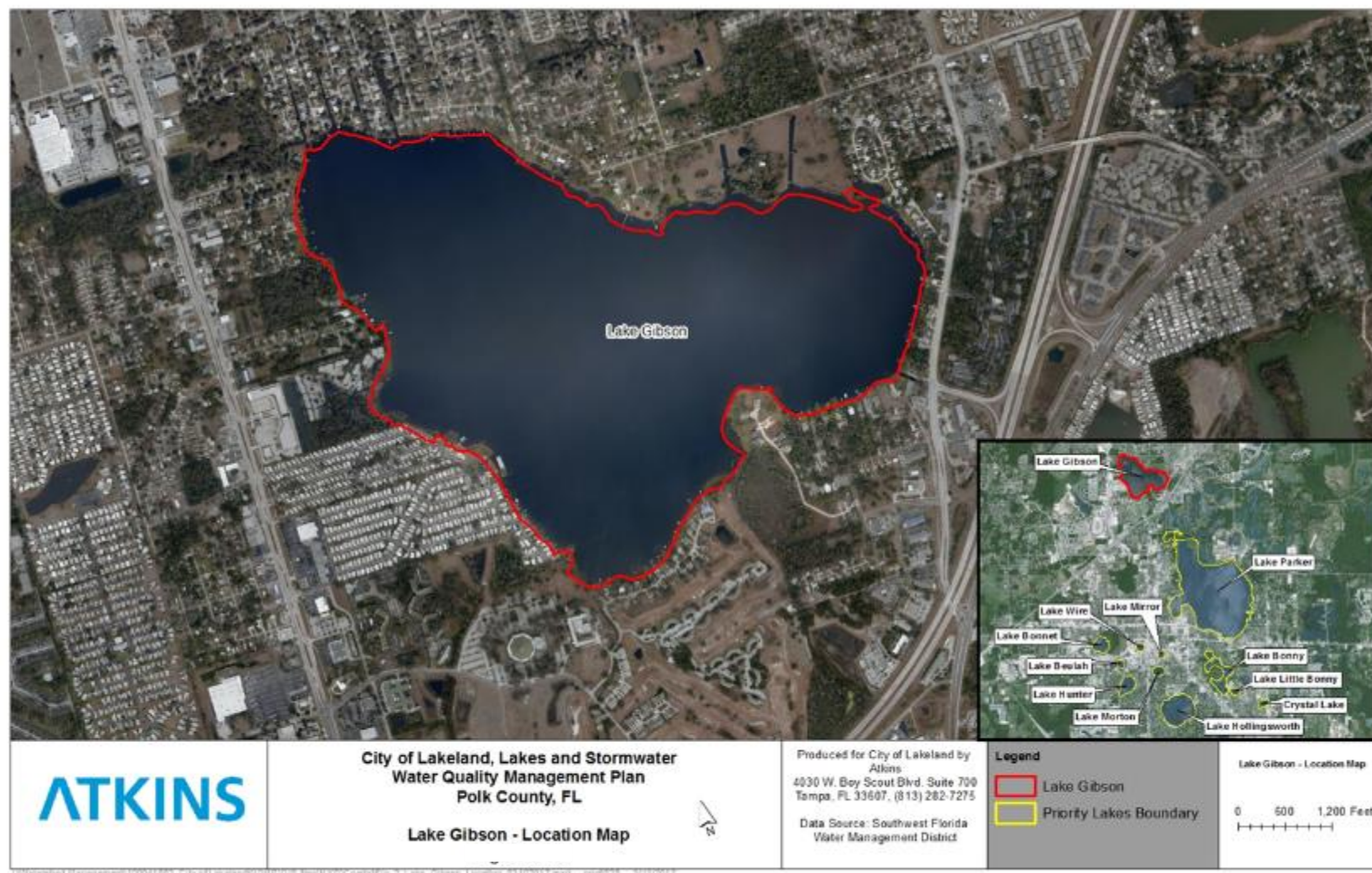


Figure 6-49. Lake Gibson location map

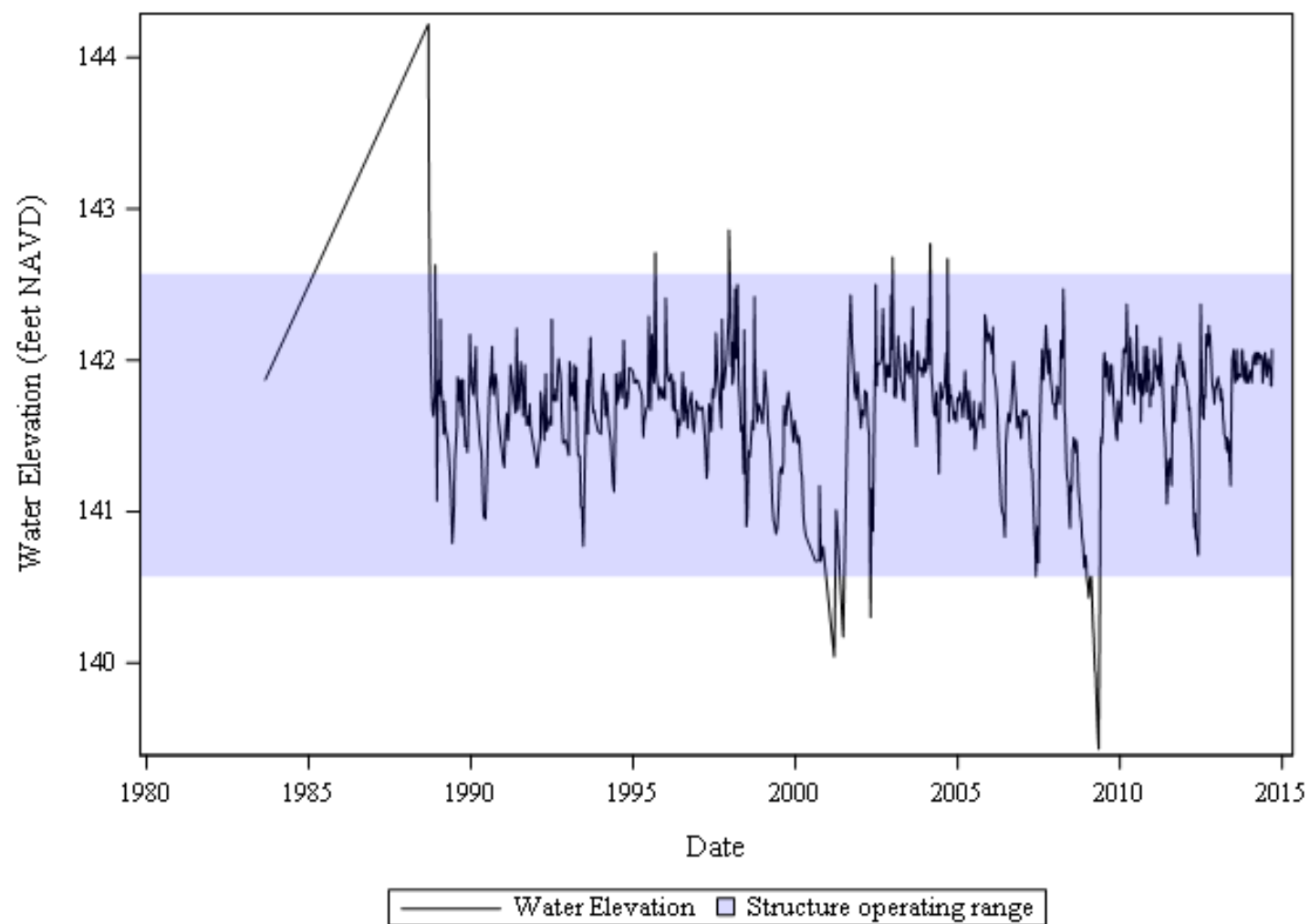


Figure 6-50. Period of Record Lake Gibson water elevation

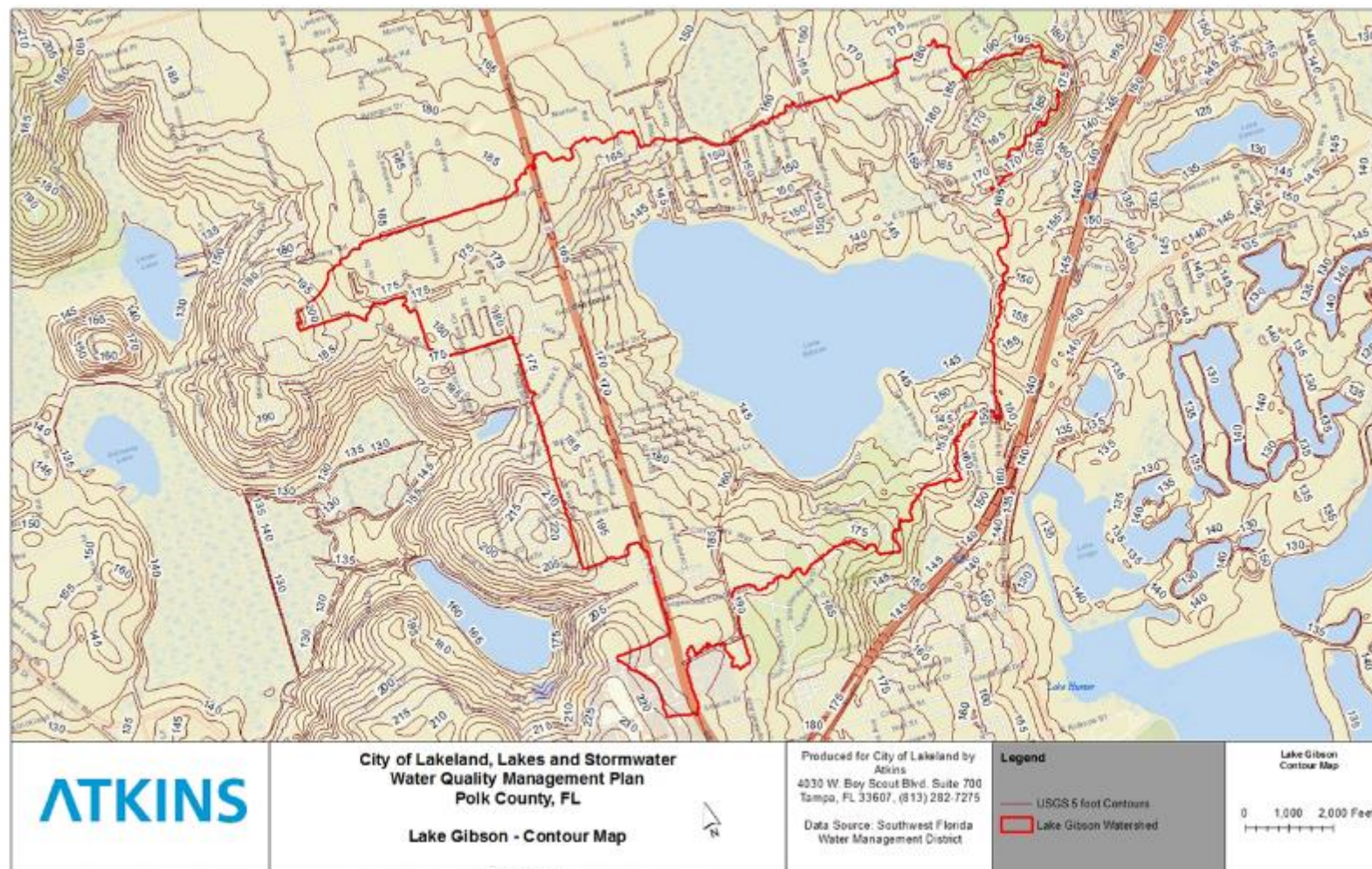


Figure 6-51. Lake Gibson contour map

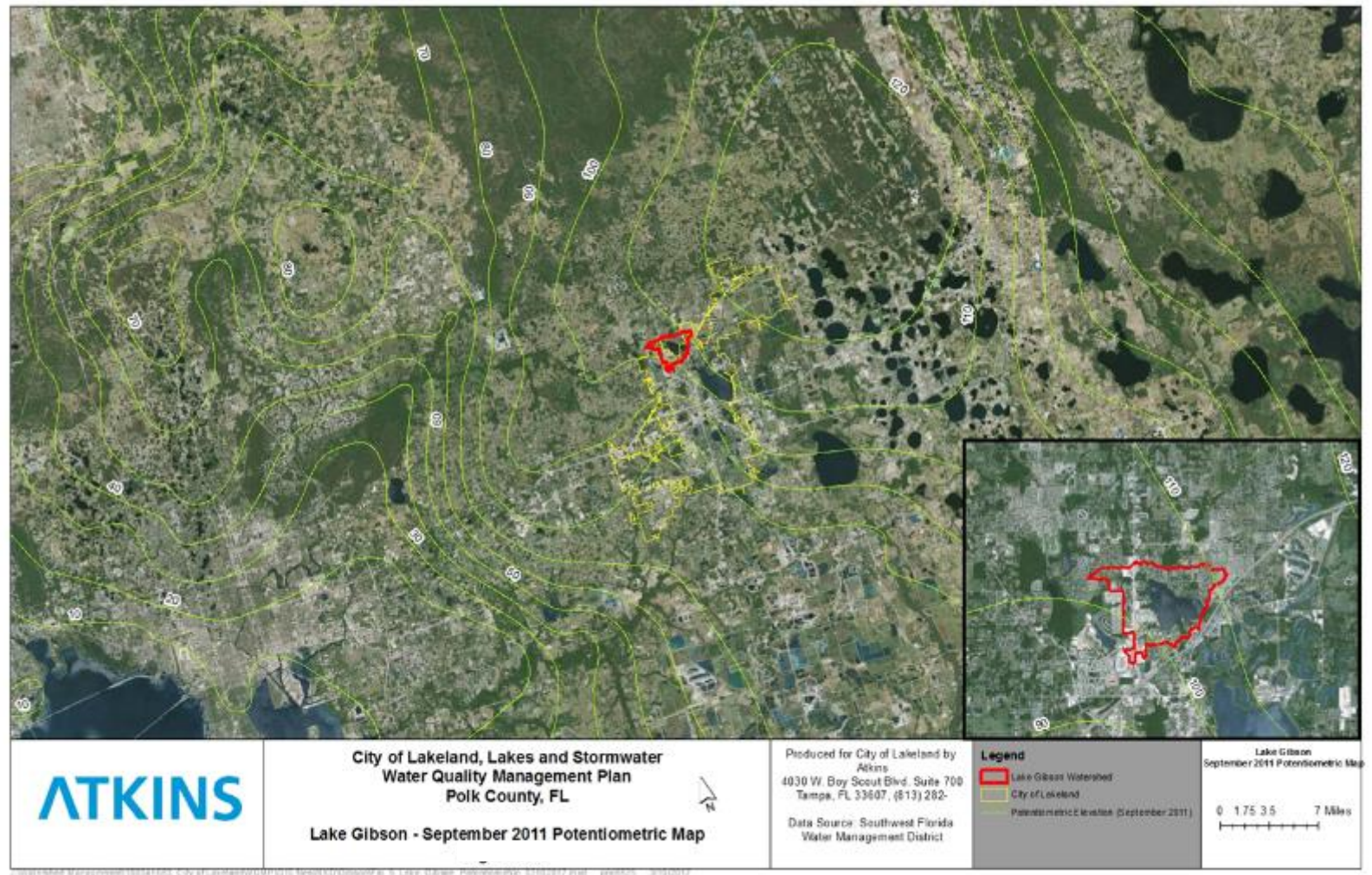


Figure 6-52. Lake Gibson potentiometric map



Figure 6-53. Lake Gibson historical aerial imagery. Left Photo. 1958. Right Photo. 1968

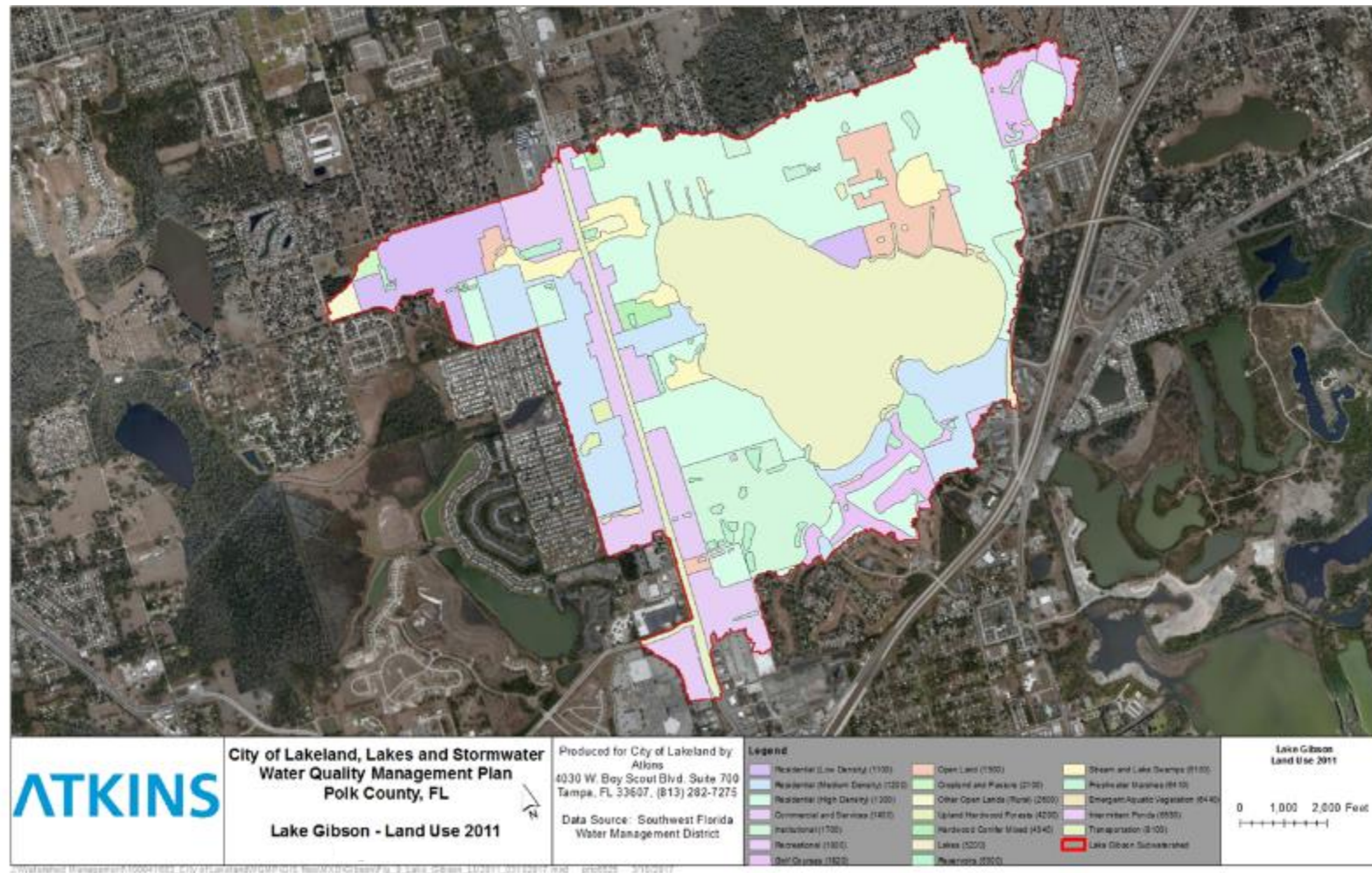


Figure 6-54. Lake Gibson 2011 land use map

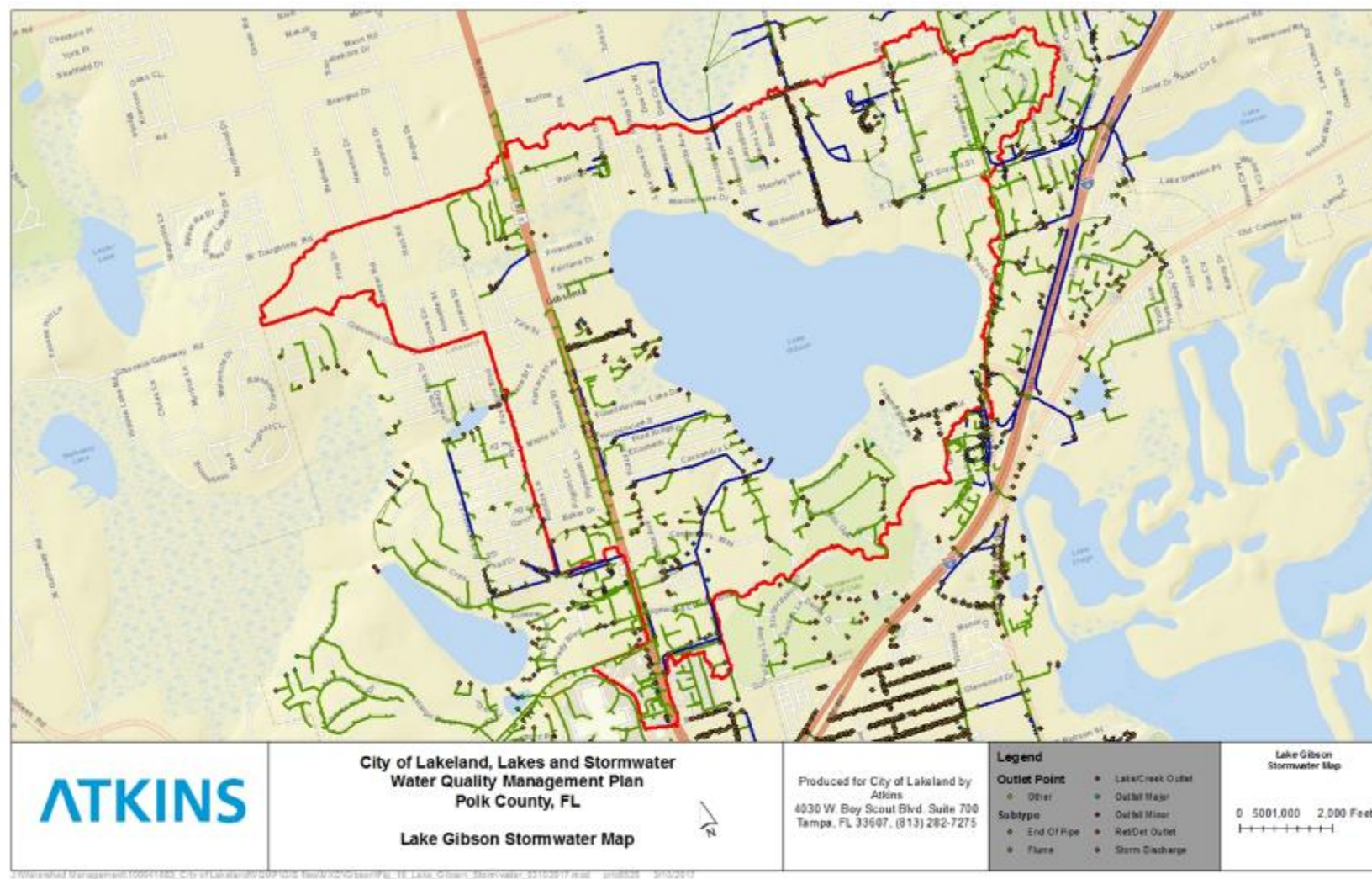


Figure 6-55. Lake Gibson stormwater map

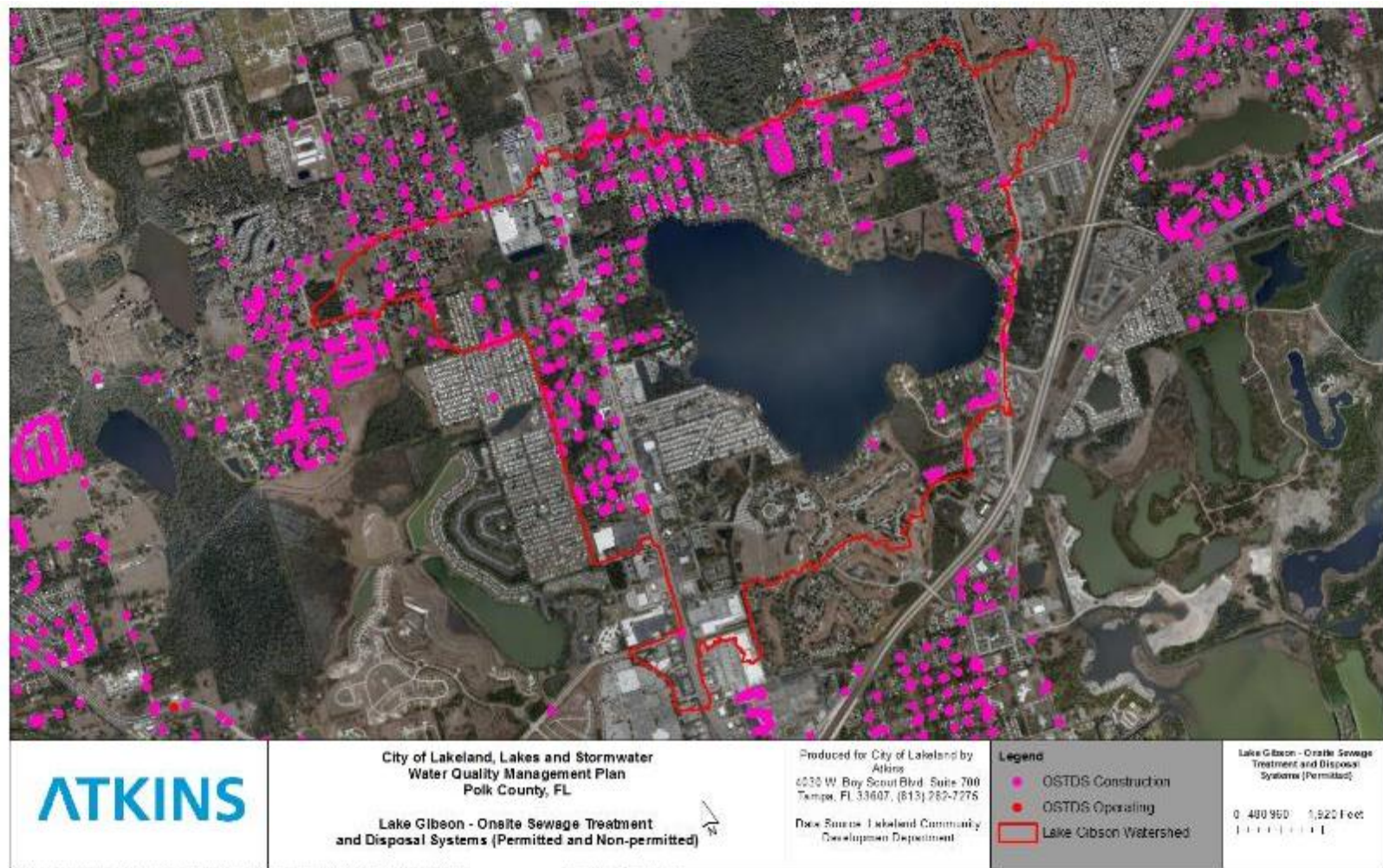


Figure 6-56. Lake Gibson OSTDS map

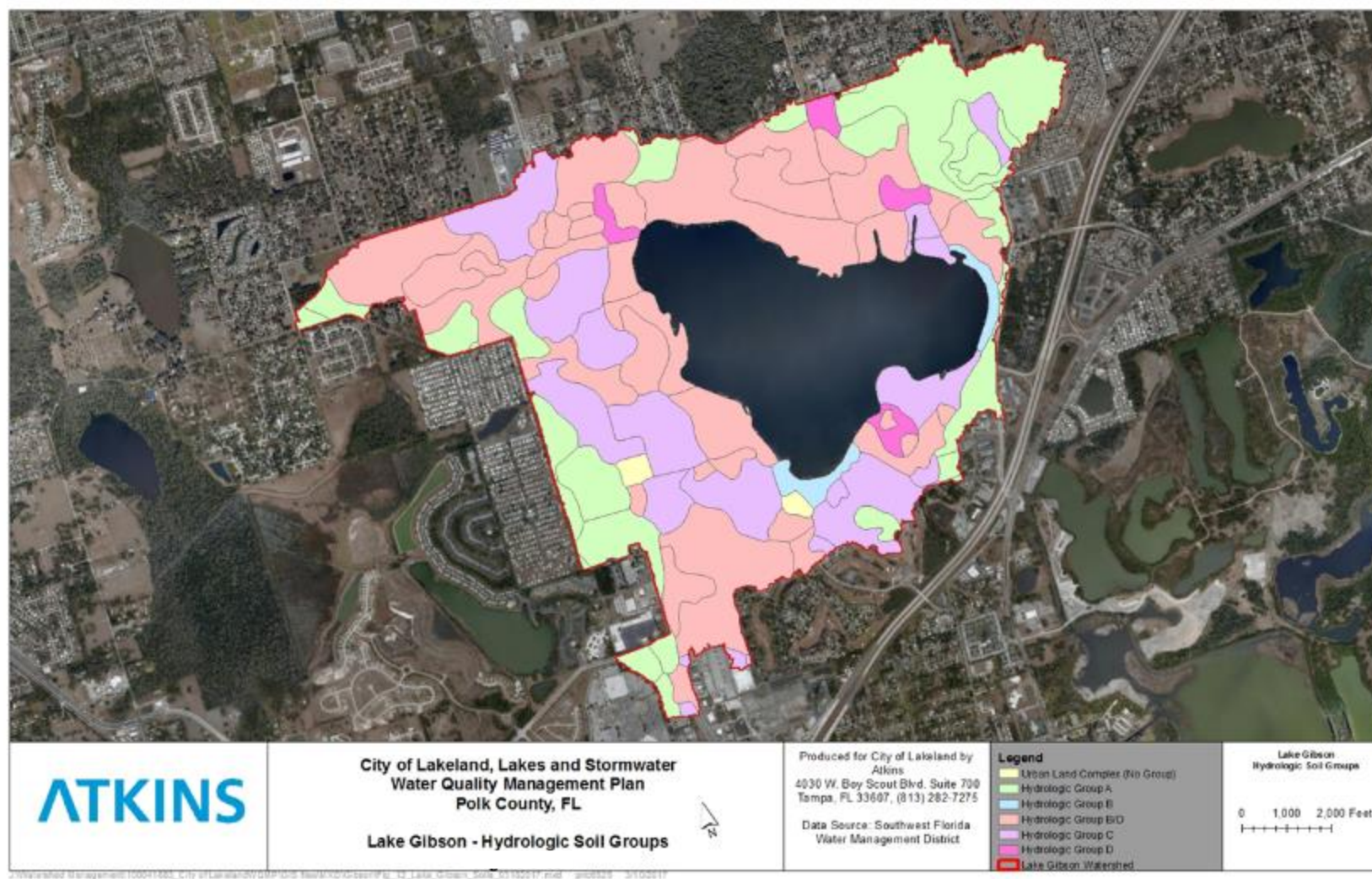


Figure 6-57. Lake Gibson soils map

Water Quality

Previously, Lake Gibson was listed as impaired for nutrients by the City even though the lake was not listed as impaired by FDEP (page 31 in City of Lakeland 2010). A few years later, Lake Gibson was listed as impaired for nutrients by FDEP (Atkins and ESA 2014). In FDEP's latest version of the Comprehensive Verified Impaired List (December 18, 2017) Lake Gibson is not listed as impaired for nutrients. Lake Gibson is a Group 3 waterbody as part of the Upper Peace River, the most recent impairment evaluation was performed for the verified period of January 1, 2008 to June 30, 2015 (Cycle 3) which NNC as the numeric criteria. The cycle 4 assessment period will occur in 2021 for the verified period of January 1, 2013 to June 30, 2020.

To minimize the impacts of different verified periods, this report characterizes water quality for each of the City's priority lakes during the same time period, 1/1/2009 to 6/30/2016. These dates correspond to the most recent Verified Period assessment used by FDEP during which water quality data are fully available for analysis for determining impairment status.

Water quality data were downloaded from FDEP, and used to determine the classification of Lake Gibson. The lake was classified as a low-color, alkaline lake, based on a geometric mean value for color of 28 PCU and a geometric mean alkalinity value of 37 mg (as CaCO₃) / liter. Based on that classification, the water quality targets for TN and TP were then determined based on whether or not the annual geometric mean for a given year exceeds the threshold target of 20 µg chlorophyll-a / liter. The relevant water quality criteria for TN and TP for Lake Gibson are highlighted in yellow in Table 6-19. Based on the criteria provided below, Lake Gibson has the following exceedances (Table 6-20).

Lake Gibson's impairment status varies from year to year. In 2009, the absence of sufficient data on chlorophyll-a shifted the TP target down to the same value as if the lake had exceeded 20 µg / liter for chlorophyll-a. In the years 2010 to 2014, chlorophyll-a values were collected in sufficient quantity (and seasonality) that annual geometric means could be calculated. Since those values were lower than 20 µg chlorophyll-a / liter, the TN and TP targets increased, and the lake was not impaired, even though TN values were higher in 2012 than in 2009 or 2015. The years 2015 and 2016 had elevated levels of chlorophyll-a, which shifted NNC criteria to lower values for TN and TP, and the lake was therefore in exceedance for all three parameters.

For the years of 2015 and 2016, values for chlorophyll-a and TP far exceeded NNC criteria for low-color, alkaline lakes. Based on examples included in both PBS&J (2011) and Tomasko et al. (2013) the chlorophyll-a and TP reductions required in 2015 and 2016 are in excess of the range of reductions seen with implementing traditional lake management techniques such as stormwater retrofits. But for the years 2010 to 2014, no reductions in TN or TP are needed.

TABLE 6-19. WATER QUALITY CRITERIA FOR LAKE GIBSON, WITH RELEVANT TARGETS FOR CHLOROPHYLL-A, TN AND TP HIGHLIGHTED IN YELLOW.

Long Term Geometric Mean Lake color and Alkalinity	Annual Geometric Mean chlorophyll-a	Minimum calculated numeric interpretation		Maximum calculated numeric interpretation	
		Annual Geometric Mean TP	Annual Geometric Mean TN	Annual Geometric Mean TP	Annual Geometric Mean TN
> 40 PCU	20 µg/L	0.05 mg/L	1.27 mg/L	0.16 mg/L	2.23 mg/L
≤ 40 PCU and > 20 mg/L CaCO ₃	20 µg/L	0.03 mg/L	1.05 mg/L	0.09 mg/L	1.91 mg/L
≤ 40 PCU and ≤ 20 mg/L CaCO ₃	6 µg/L	0.01 mg/L	0.51 mg/L	0.03 mg/L	0.93 mg/L

TABLE 6-20. SUMMARY OF WATER QUALITY IMPAIRMENT DETERMINATIONS FOR LAKE GIBSON BY YEAR. YEARS WITH INSUFFICIENT DATA FOR COMPARISON WITH NNC CRITERIA ARE NOTED BY “-”.

Year	chlorophyll-a (µg / liter)	TN (mg / liter)	TP (mg / liter)
2009	-	1.029	0.089
2010	18.47	0.988	0.072
2011	12.59	0.977	0.084
2012	19.19	1.329	0.078
2013	10.98	0.731	0.067
2014	16.76	0.881	0.068
2015	48.76	1.308	0.104
2016	51.73	1.505	0.117
Average percent reduction required (when needed)	60	25	71

Positive relationships were found between both TN and chlorophyll-a and TP and chlorophyll-a (Figures 6-58 and 6-59, respectively).

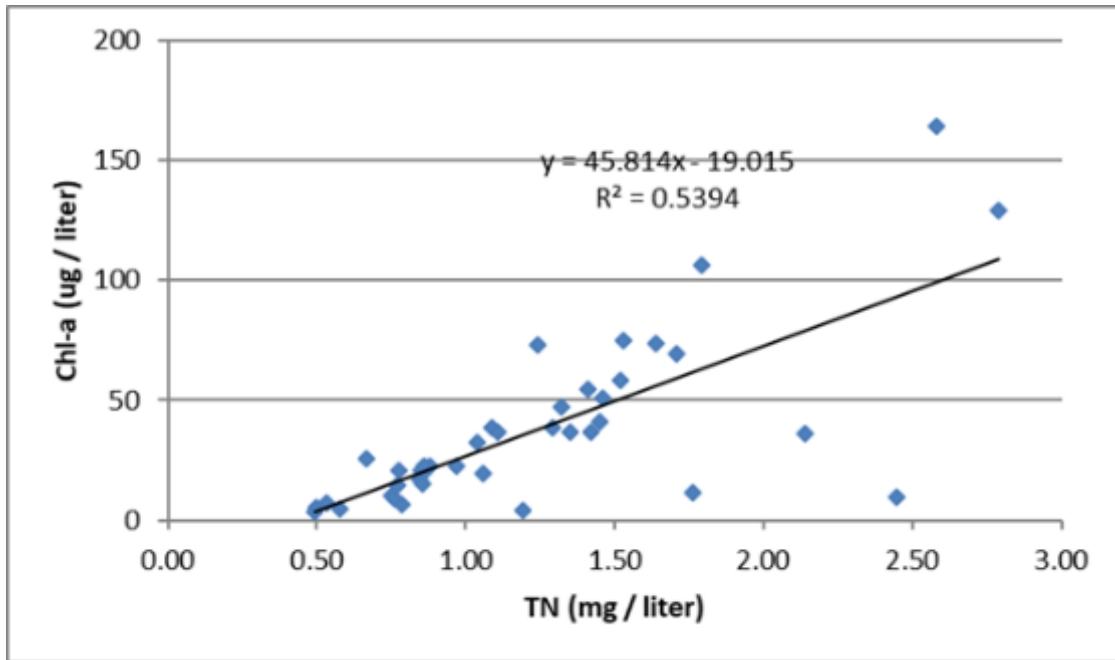


Figure 6-58. Relationship between TN and chlorophyll-a. Line is best fit equation of statistically significant ($p < 0.05$) relationship

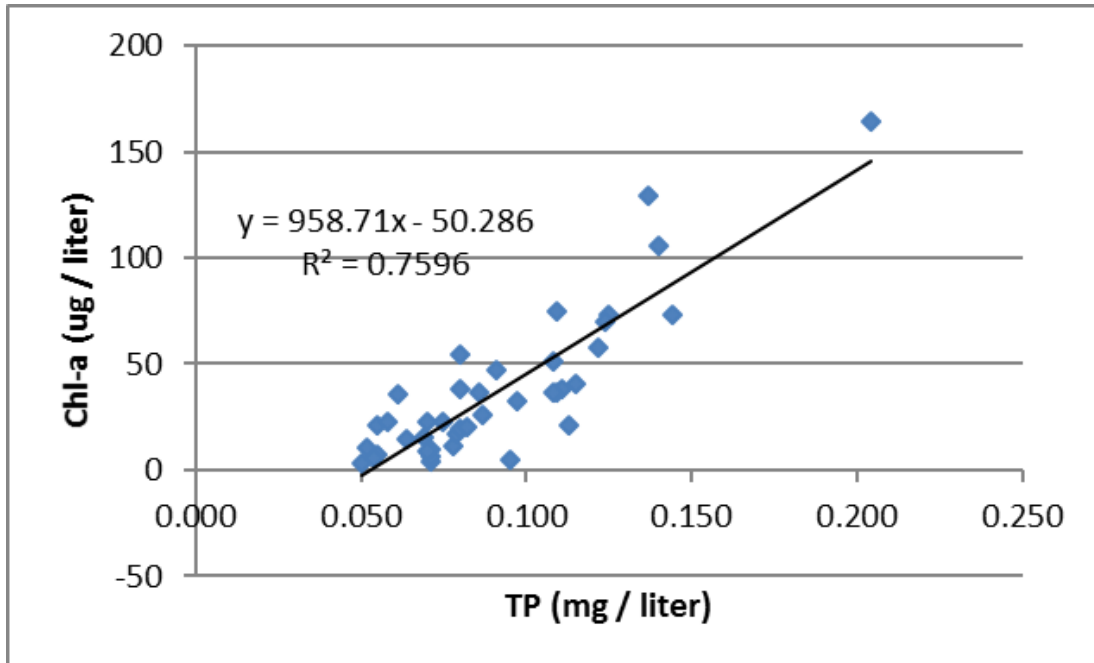


Figure 6-59. Relationship between TP and chlorophyll-a. Line is best fit equation of statistically significant ($p < 0.05$) relationship

As previously shown in PBS&J (2011) and Atkins and ESA (2014) concentrations of TN in excess of ca. 2.5 mg / liter likely indicate the influence of nitrogen-fixing cyanobacteria, as such values

are in excess of the highest TN concentrations expected in most urban and agricultural stormwater runoff. However, much of the TN data from Lake Gibson are lower than 2.5 mg / liter, which suggest that the lake is truly limited by the availability of both TN and TP. As such, Lake Gibson's phytoplankton levels may require reducing the availability of both TN and TPP.

A statistical correlation between annual average TN concentrations and annual rainfall was not found indicating that external sources such as stormwater runoff are not likely dominant influences on in-lake water quality. Based upon these results, projects which focus on stormwater retrofits may not be good candidates toward restoring water quality in Lake Gibson. However, the maintenance and enhancement of native emergent and submerged aquatic vegetation is recommended.

It is documented that a point source discharge associated with a WWTF was present discharging via an extensive wetland system on the north side of the lake. The treatment facility discontinued discharging into the lake in the mid-late 1980's. As such, it is likely that nutrient enriched sediments are present on the lake-bottom. However, a significant, inverse correlation between TN concentrations and lake water elevation was not identified. Additionally, current water quality conditions in Lake Gibson are mixed, as far as FDEP's NNC criteria, with most years not being impaired, although recent years show impairment. Therefore, sediment removal and/or sediment inactivation are not recommended for Lake Gibson. Additionally, whole-lake circulation projects are not recommended based on the lake size.

An analysis of the historical versus current lake extent indicated that the lake has been lowered compared to its original configuration. Historical data suggest that the lake elevation has been lowered between 3 and 7 feet since the 1850s. As a result, the lake's current elevation appears to be below the elevation of at least some of its historical wetland fringe. The 5-year average value for color in the report by the City of Lakeland (2010) indicate the lake is high-color (PCU > 40), while the report from Atkins and ESA (2014) shows the lake as being a low-color, alkaline lake. Lake Gibson's color values averaged above 40 PCU in 2001, 2002, 2003, 2004, 2006, 2007 and 2008, and with individual values higher than 40 PCU as recent as in 2013. The geomorphology of the lake is such that Lake Gibson is classified as a "valley" lake. The fact that it can be classified as either low-color or high-color depending on the period of data assessed indicates that wetlands surrounding the lake may play a significant role in importing tannins during higher water-level years. It is likely that the water level declines over its historical condition, or modification of drainage patterns in the large wetland located just north of the lake have significantly impacted the respective hydroperiod, a reduction in tannin loads to the lake may have occurred. It is likely that hydrologic restoration would restore wetland connectivity and thus should be considered a potential course of action to improve Lake Gibson water quality.

As noted above, current and prior analyses have resulted in the classification of Lake Gibson as primarily a low-color, alkaline lake. While this does not change the chlorophyll-a target for the lake if it was historically a high color lake, the TP and TN targets are lower (more stringent) for low-color, alkaline lakes than they are for high-color lakes. The fact that the color classification of Lake Gibson varies with the time interval examined indicates that the large wetland located to the north of the lake may import more tannins during higher water level periods. A site visits to the

lake and its watershed indicated that there was a drainage ditch located in the southern boundary of that wetland which, in turn, indicates the wetland is partially drained and thus partially disconnected from the lake. This would certainly impact water quality, especially water column color (i.e. tannins) and phytoplankton abundance. Site-specific chlorophyll-a, TN, and TP targets have not been established and thus may be appropriate for Lake Gibson. collection and analysis of locally-derived paleo data is advisable if the City decides to pursue establishing site-specific criteria.

Water Quality Restoration Project Selection and Priorities

Based on Lake Gibson water quality and the surrounding watershed characteristics, four potential water quality restoration projects were identified using the City's WQMP decision key. Projects to address water quality, nutrient and sediment loading, and reduced lake levels are proposed. A detailed discussion of the potential water quality restoration implications for each project can be found in Section 4.0.

Project 1: SAV Planting/Management or FTWs

Project 2: EAV Planting/Management

Project 3: Re-establish Wetland Influence

Project 4: Develop reasonable water quality targets through paleolimnology and coordination with FDEP

Project 1: SAV Planting/Management or FTWs

SAV Planting

A survey of existing SAV cover in Lake Gibson is recommended due to the lack of sufficient data to calculate percent lake cover. Based on the results of the SAV survey, conclusions regarding SAV planting can be determined. If SAV cover is less than 30 percent, lake conditions should be evaluated to assess if additional SAV is viable based on the soil condition, water clarity and water depth.

Based on the median Secchi depth (2.0 meter) from the POR (1973 – 2016), plants would not be planted in water depths greater than 2.2 meter (Water Atlas). The maximum planting effort for Lake Gibson cannot be calculated until digital bathymetry data are acquired.

Bathymetric Survey Cost Estimate: \$10,000

SAV Planting/Management Cost Estimate: A cost estimate will be generated upon receipt of the bathymetry data.

FTWs

If the feasibility study indicates that more than 30 percent of Lake Gibson has SAV cover, FTW may be considered. The installation of floating mats with appropriate aquatic vegetation would be expected to assimilate nutrients from the water column.

Project 2: EAV Planting

A survey of existing shoreline vegetation surrounding Lake Gibson is recommended due to the lack of sufficient data at this time. Based on the results of the shoreline survey, conclusions and recommendations regarding emergent aquatic or woody vegetation planting can be determined. If limited shoreline vegetation is present, shoreline conditions should be evaluated, preferably by City staff, to assess if vegetation planting is viable based on the soil conditions, slope, water level and inundation frequency and wave disturbance.

EAV Planting/Management Cost Estimate: A cost estimate will be generated upon receipt of the shoreline survey data.

Project 3: Re-establish Wetland Influence

Approximately 118 acres of the land cover within the 500-foot buffer surrounding Lake Gibson is classified as stream and lake swamps (bottomland) using the 2011 FLUCCS data (Figure 6-60). Depending on findings from site investigations, this may offer an opportunity to increase tannin levels in the lake, if a sufficient amount of impacted (i.e., drained) forested wetlands could be rehydrated, which may allow for color levels above 50 PCU. While FLUCCS classifies the land cover as forested wetland, the hydrologic connection between the lake and adjacent land might be partly severed.

The project areas that were identified adjacent to Lake Gibson expected to rehydrate approximately 118 acres. The feasibility study is recommended in order to evaluate the proposed project areas for inundation.

Feasibility study cost estimate: \$150,000.

Project 4: Paleolimnology Study

The paleolimnological study for Lake Bonny (Whitmore et al. 2016) is current enough that its findings should be discussed with FDEP to ensure that the State's agencies are aware of the impractical nature of the existing NNC criteria for lakes such as Lake Gibson, which appear to have been lowered below their historical elevation, thus reducing their lake-wetland connection in such a way that the lake has likely become more susceptible to nutrient concentrations than it was historically. The complexity of the tannin-nutrient-phytoplankton relationships found for Lake Bonny are such that it was concluded that nutrient reduction alone, even if to pre-development concentrations, would not result in the lake also obtaining pre-development values for chlorophyll-a. The need for restoration of the lake's historical lake-wetland connectivity supports conclusions related to the need for such projects that was also reached for Lake Hancock (Tomasko et al. 2009).

Cost estimate: \$30,000 to \$50,000 per lake including coordination with FDEP to develop site-specific water quality targets for chlorophyll-a and nutrients to be used in impairment determinations and/or TMDLs.



Figure 6-60. Proposed forested wetland rehydration project area for Lake Gibson

Lake Hollingsworth

Physical and chemical characteristics specific to Lake Hollingsworth are presented here in the context of relevant regulatory criteria and requirements. Lake Hollingsworth does not appear on FDEP's latest comprehensive verified impaired list, not because it's water quality meets regulatory guidelines, but because it has a recently completed TMDL (FDEP 2018)

Historical and Recent Conditions in Lake and Watershed

Lake Hollingsworth is a 336-acre lake located in the City within the eastern portion of Polk County, Florida (Figure 6-61). Maximum water depth is reportedly 14.2 feet, with an average water depth of 3.9 feet (City of Lakeland 2010). The lake is located within the Lakeland/Bone Valley Upland lake region of Florida, which according to Griffith et al. (1997) can be characterized with "high phosphorus, nitrogen, and chlorophyll-a values" and "alkaline, [with] some [lakes] receiving limestone-influenced groundwater."

Lake Hollingsworth is located within the Peace River watershed and the immediate contributing watershed to the lake is 1,366 acres in size, resulting in a watershed to open water ratio of 4.1 (Table 6-21; Figure 6-61). Watershed to open water ratios can be used to compare the relative amount of influence that a lake experiences from its contributing watershed, such as stormwater

runoff. Typically, lakes with “low” watershed to open water ratios (i.e. less than 10) may not experience the degree of influence from external loads of stormwater as do lakes with “high” values. However, no absolute threshold value for this ratio exists and there is no definitive value at above which stormwater is problematic and below which stormwater is not an important stressor.

Lake Hollingsworth is influenced by inflows from Lakes Morton and Horney and its waters discharge to Lake Bentley. All these lakes are interconnected (at higher water levels) via adjustable water control structures (City of Lakeland 2010). The water level in Lake Hollingsworth has fluctuated within its structure operating range for most of the past 25 years, with the exception of periods of low water levels over the years 2001 to 2003 (Figure 6-62). Since 2007, water elevations have remained within or slightly above the operating range with minor exceptions. The operational water elevation range for Lake Hollingsworth is 129.68 to 130.68 feet NAVD. Within the Lake Hollingsworth watershed, there is a moderate elevation gradient ranging from 130 to 215 feet NAVD (Figure 6-63). Lake Hollingsworth is located between 80 and 100-foot potentiometric surface elevations for the Floridan Aquifer and south of the potentiometric peak, as of September 2011 (Figure 6-64). Additionally, the northern boundary of the intermediate aquifer system is just north of Lake Hollingsworth (Spelcher and Kroening 2007). Therefore, it is unlikely that there is direct connectivity with the Floridan aquifer.

Lake Hollingsworth had been the focus of lake management activities for many years, as outlined below. In November 1994, CH2M Hill submitted a Watershed Management Plan for Lake Hollingsworth. Target pollutants included TN, total and dissolved phosphorus, biochemical oxygen demand, TSS, lead, and zinc. CH2M Hill modeled annual surface runoff volumes for each sub-basin, basin, and the entire watershed and determined that lake sediments were the greatest source of nutrient loading. Restoration goals included reducing the TSI from 95 to 65. For source control, street sweeping was recommended. Additionally, four stormwater treatment technologies were selected, including dry retention ponds, curb-cut swales, wet detention ponds, and wetlands.

Between February 1997 and March 2001, approximately 3 million cubic yards of dredged material were removed from Lake Hollingsworth (Unknown 2002). Subsequent to sediment removal, TSI averaged 64.8 between June and August 2002. Improvements in water clarity were documented, as Secchi depth increased from 0.7 feet to 2.4 feet after completion of the dredging project. Additionally, significant reductions in water column lead concentrations was reported. In December 2003, an aluminum sulfate (alum) treatment was applied to Lake Hollingsworth in an effort to further reduce nitrogen and algae concentrations (City of Lakeland communication 2003). To mitigate dredging impacts, the City was required to restore 16 acres of wetlands within the lake.

Between October 2000 and August 2007, City installed 49 curb inlet baskets throughout the drainage basin (City of Lakeland communication 2007), and in 2003, CH2M Hill converted a portion of Anchor Park located along the north shore of Lake Hollingsworth into a stormwater treatment wetland. Site designs included deep fore bays and shallow marsh zones within the wetland for sediment trapping and water treatment, the installation of eleven baffle boxes for debris collection, and boardwalks and interpretative signage for recreation and education.

A review of historical aerial photography (from 1941) indicates the shoreline has not been obviously modified compared to recent photography (2016), with the exception of a small protrusion along the northern shoreline in recent photography. By 1922, Sanborn maps identify numerous single family dwellings and Florida Southern College along Lake Hollingsworth Drive (Figures 6-65 and 6-66). By 1958, significant development and citrus agriculture surround Lake Hollingsworth continuing to be evident in 1968 (Figures 6-67). The extensive development within the watershed is reflected in the land use/land cover data provided by both USGS and SWFWMD (Table 6-22). Specifically, the SWFWMD land use data from 2011 classifies 1,008 acres (65%) as developed lands compared to 358 acres (35%) of undeveloped land (Figure 6-68).

There are 138 inputs that discharge to Lake Hollingsworth from its watershed, including 59 minor outfalls, 8 retention/detention outlets, three stormwater discharges, one lake/creek outlet, three flumes, 53 end of pipe inputs, and 11 major outfalls (Figure 6-69). In regards to infrastructure, the majority of the existing residential developments within the watershed utilize sanitary sewer for wastewater treatment provided by the City of Lakeland (2010). Five OSTDS construction permits were identified within the watershed (Figure 6-70). Based on a review of SWFWMD soil survey geographic data, soils within the watershed have a low runoff potential with high, moderate, and low infiltration rates and are classified either as hydrologic soil group A (901 acres), B (23 acres), B/D (12 acres), or C (44 acres), respectively (Figure 6-71).

The majority of the shoreline vegetation has been modified as a result of residential encroachment.

TABLE 6-21. CHANGES IN LAND USE WITHIN THE LAKE HOLLINGSWORTH WATERSHED OVER TIME

Physical			
Location	City of Lakeland; Polk County	High infiltration soils (acres)	901
Relation to other lakes	Inflows from Lakes Morton and Horney; Discharges to Lake Bentley	Developed land (acres)	65
Watershed area (acres)	1,366	Undeveloped land (acres)	35
Lake area (acres)	366	Mean water depth (ft)	3.9
Perimeter (feet)	16,667	Maximum water depth (ft)	14.2
Surface area: lake volume ratio	0.15	Volume (acre-feet)	2,433
Watershed to surface area ratio	4.1		

TABLE 6-22. CHANGES IN LAND USE WITHIN THE LAKE HOLLINGSWORTH WATERSHED OVER TIME

Land Use	1970-1985*		1995		2011	
	Acres	Percent	Acres	Percent	Acres	Percent
Commercial and Services	101	7.4			52	3.8
Institutional					133	9.7
Other Urban or Built-up Land	6	0.4				
Recreational					33	2.4
Emergent Aquatic Vegetation					16	1.2
Hardwood Conifer Mixed					6	0.4
Lakes	328	24			336	24.6
Residential	932	68.2			791	57.9

*Metadata for USGS land use data identifies data collection dates as a period between 1970 and 1985

**Land use types differ between USGS and SWFWMD classification schemes. Please note that SWFWMD data does not include "transportation, communications, and services."

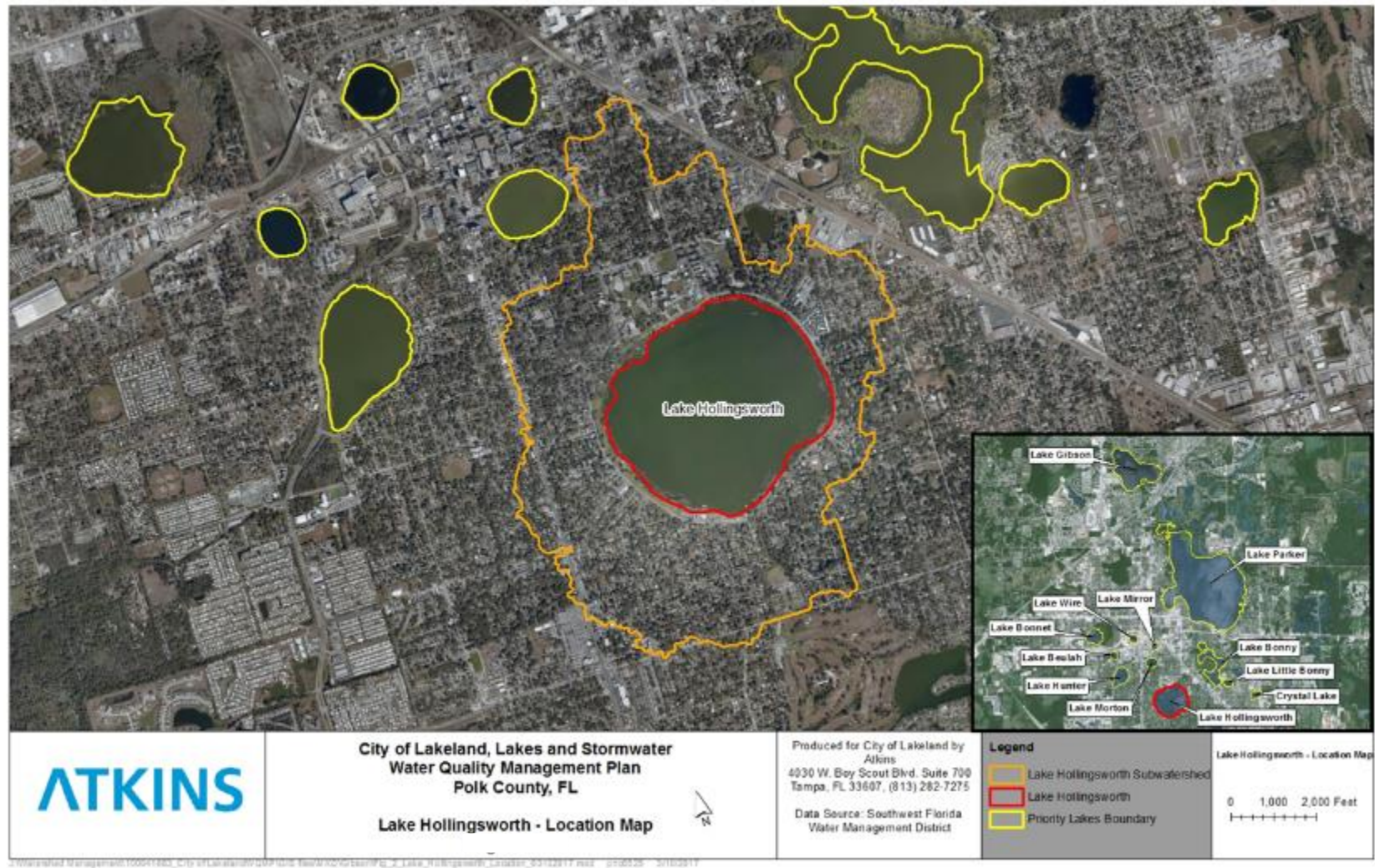


Figure 6-61. Lake Hollingsworth location map

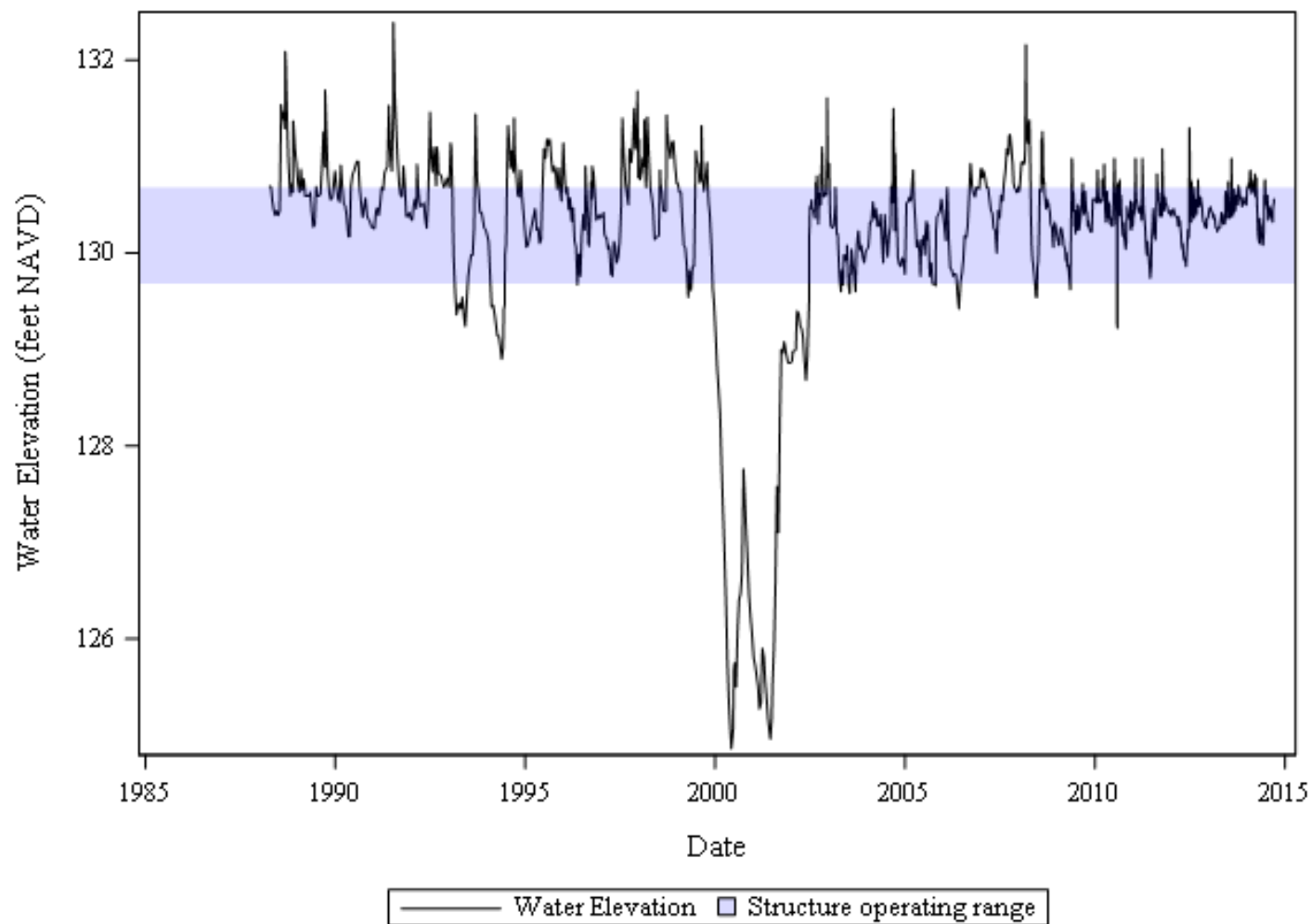


Figure 6-62. Period of Record Lake Hollingsworth water elevation

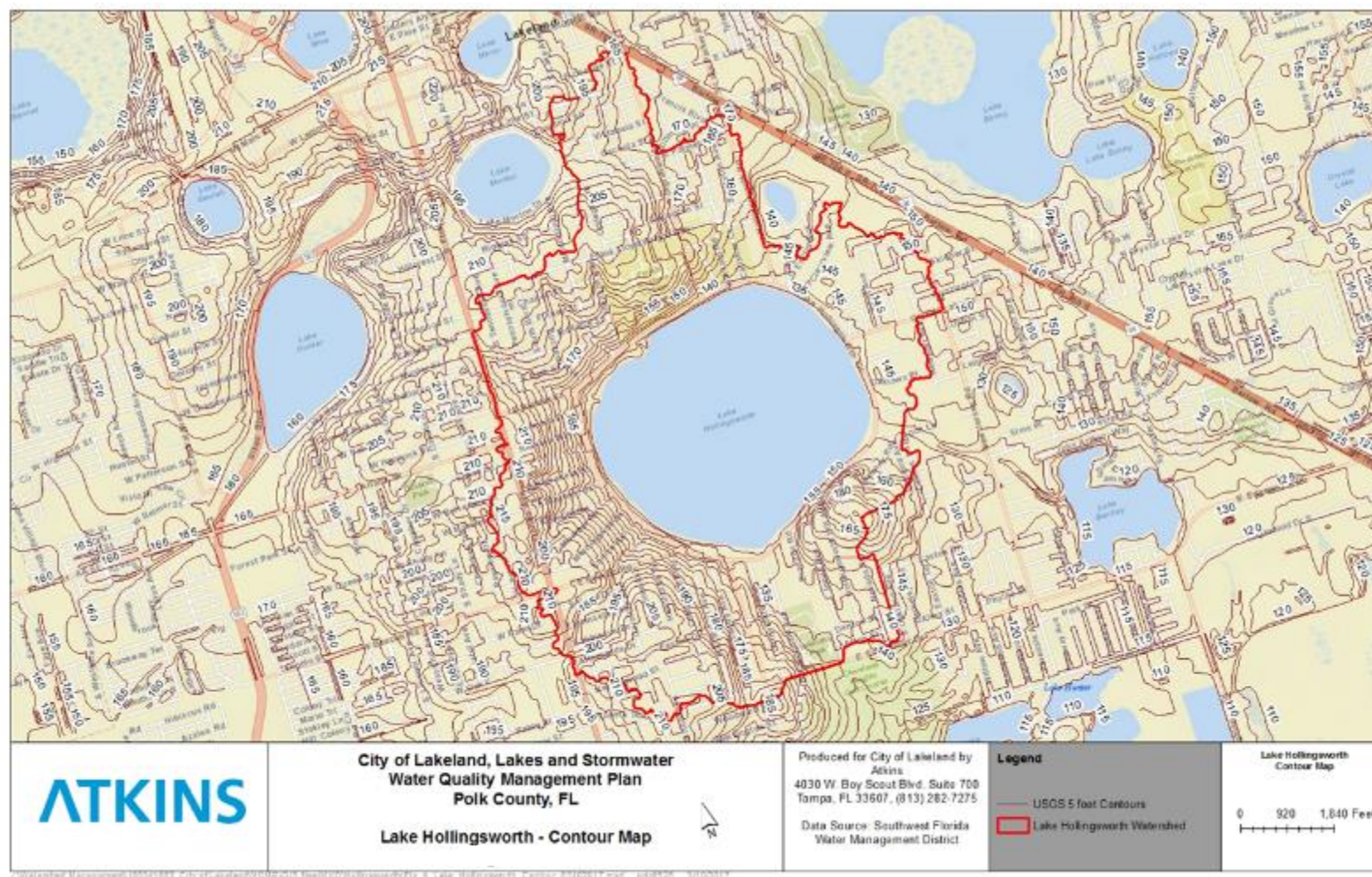


Figure 6-63. Lake Hollingsworth contour map

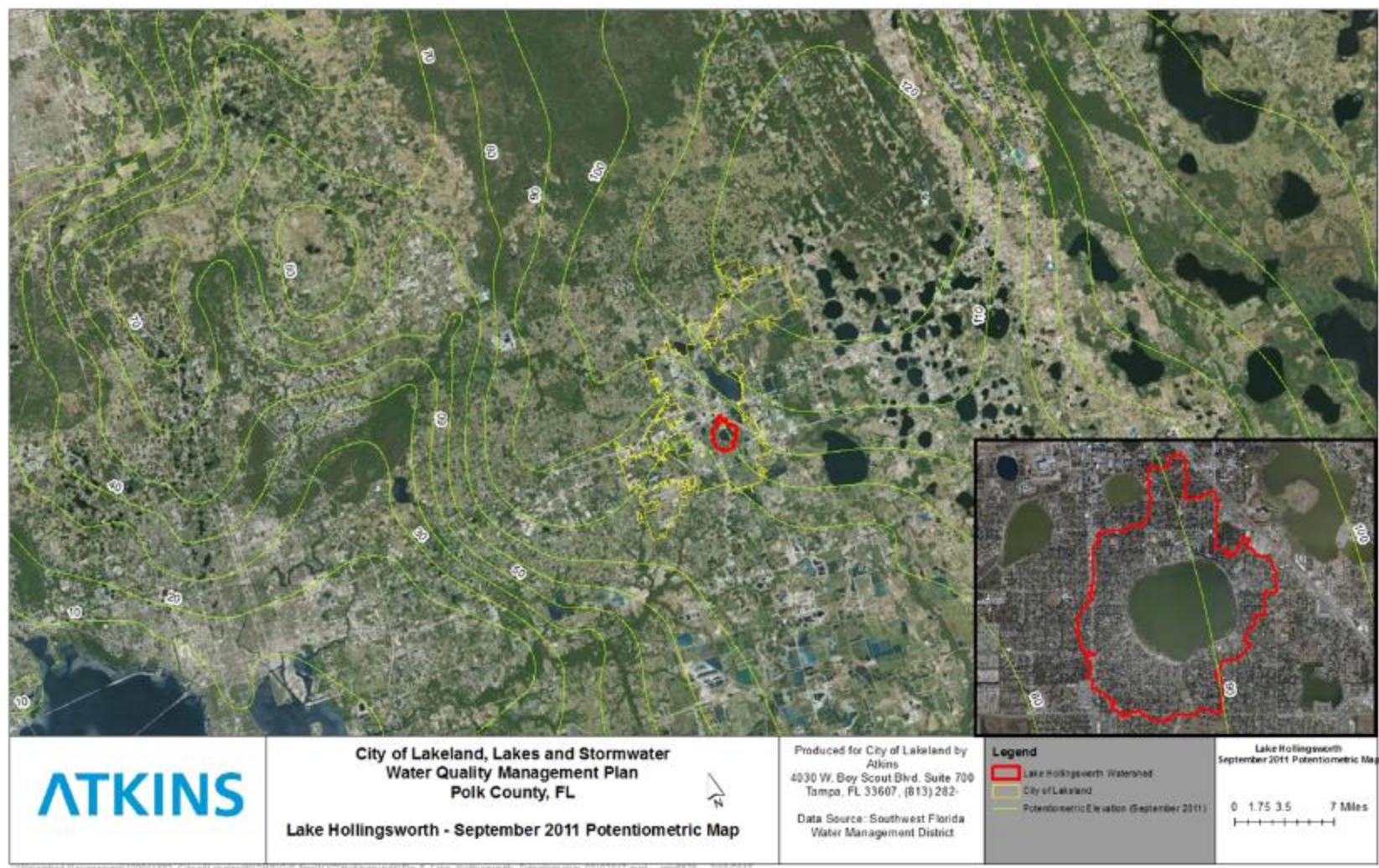


Figure 6-64. Lake Hollingsworth potentiometric map

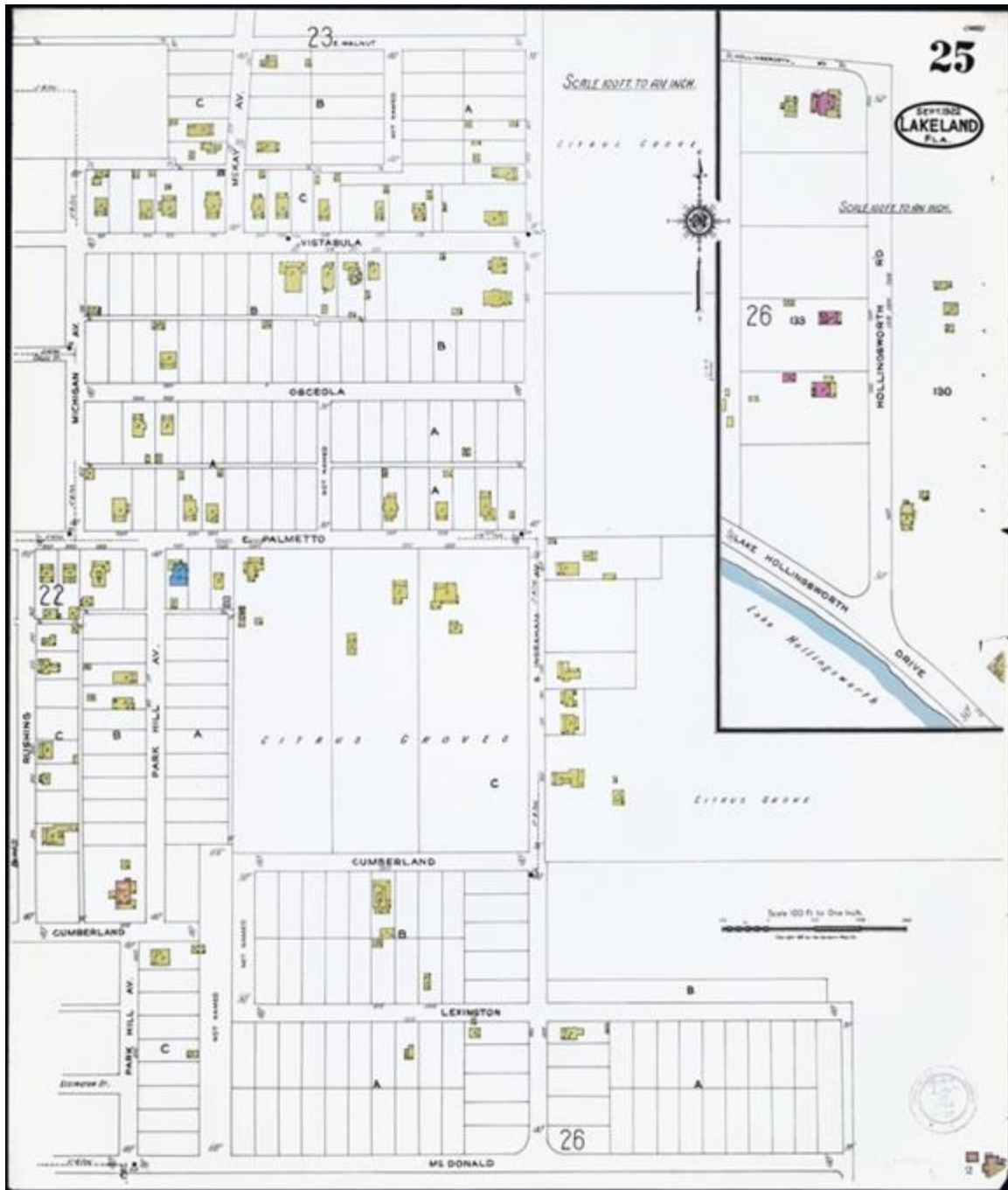


Figure 6-65. Lake Hollingsworth 1922 Sanborn map, northeastern shoreline.



Figure 6-66. Lake Hollingsworth 1922 Sanborn map, northwestern shoreline.

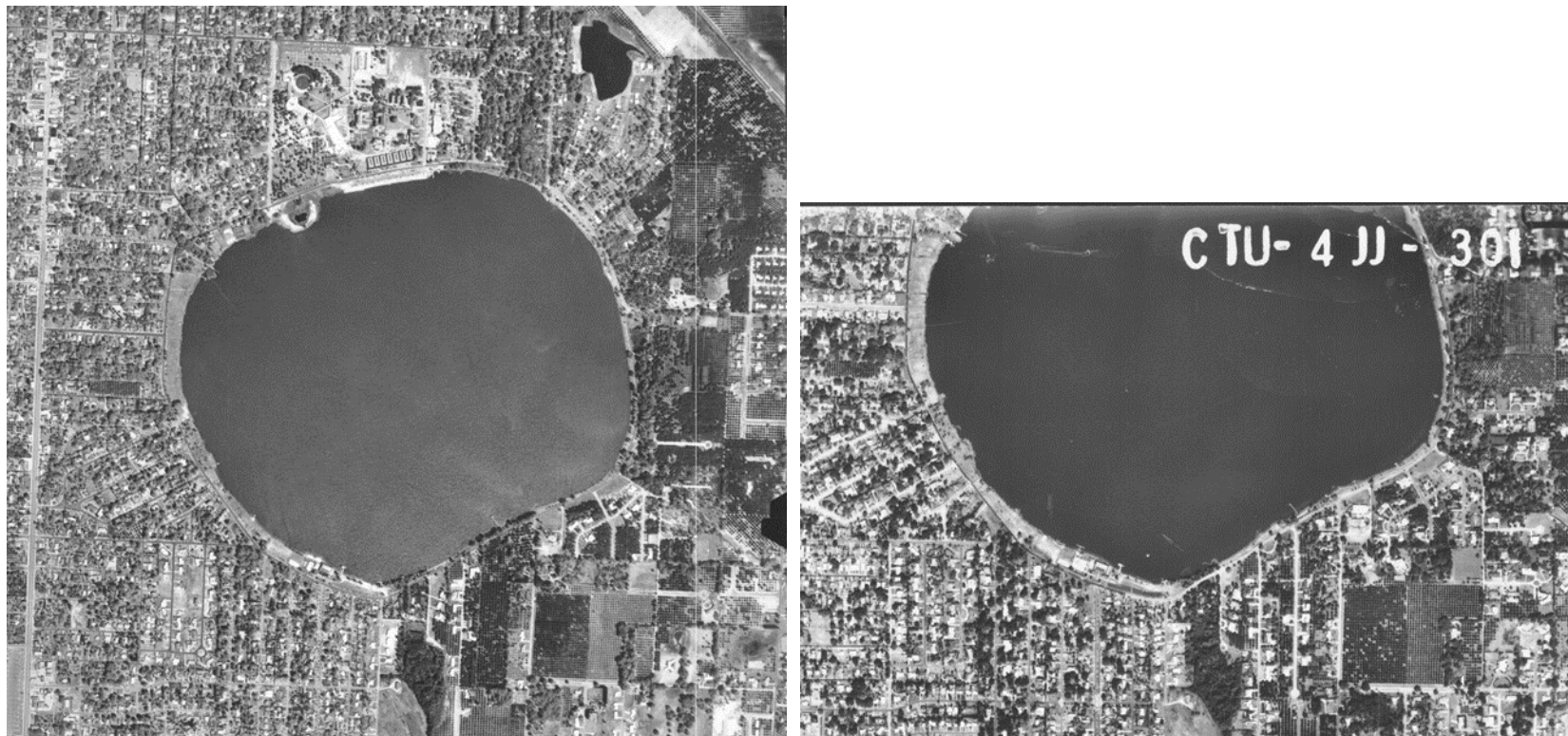


Figure 6-67. Lake Hollingsworth historical aerial imagery. Left Photo. 1958. Right Photo. 1968



Figure 6-69. Lake Hollingsworth stormwater map

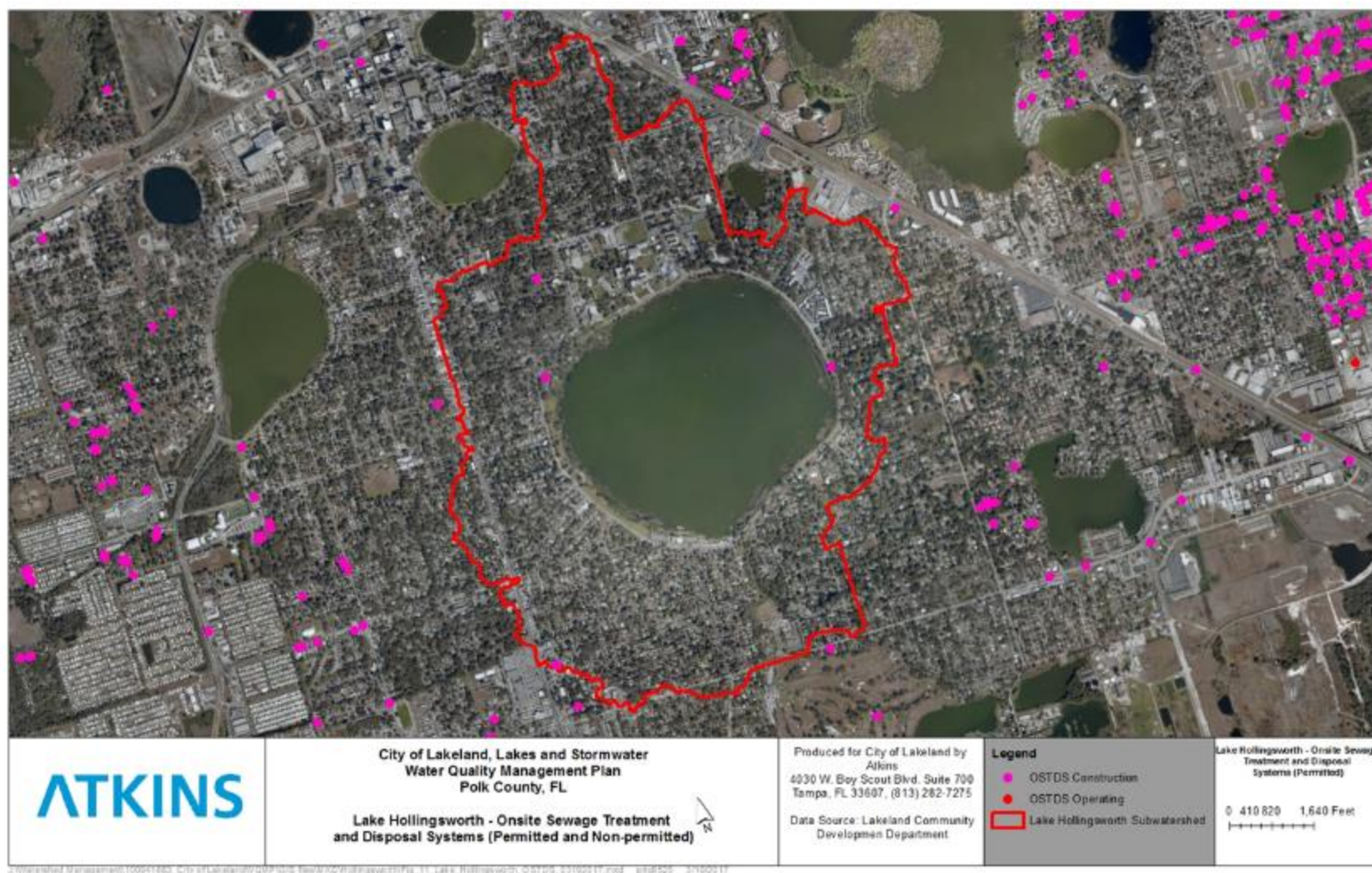


Figure 6-70. Lake Hollingsworth OSTDS map

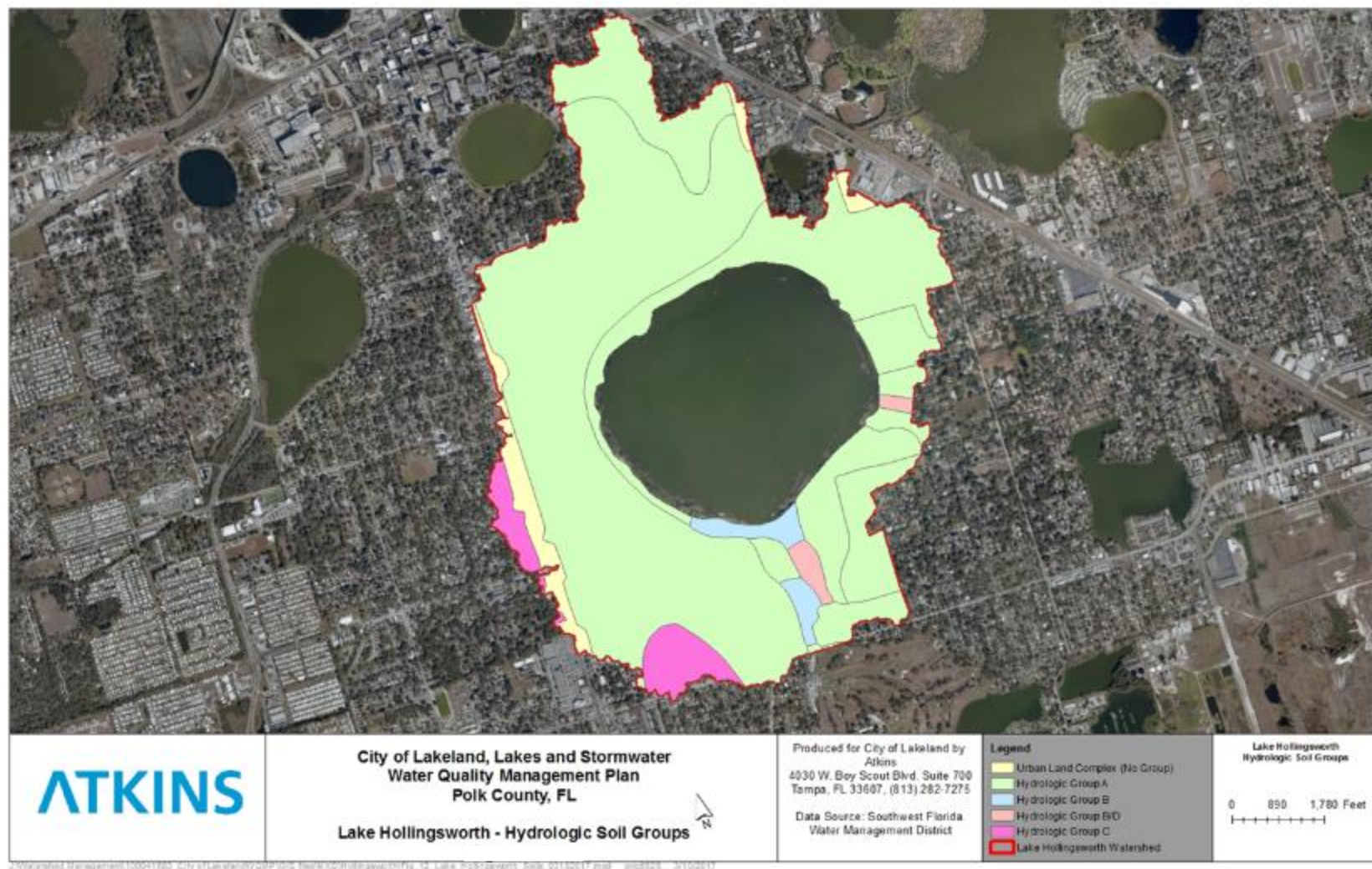


Figure 6-71. Lake Hollingsworth soils map

Water Quality

Lake Hollingsworth was previously classified as a clear, alkaline lake (Atkins and ESA 2014). Based on the clear, alkaline characterization, nutrient criteria were determined based on the use of a chlorophyll-a concentration of 20.0 µg/L. Lake Hollingsworth is a Group 3 waterbody as part of the Upper Peace River, the most recent impairment evaluation was performed for the verified period of January 1, 2008 to June 30, 2015 (Cycle 3) which applied NNC as the numeric criteria. The cycle 4 assessment period will occur in 2021 for the verified period of January 1, 2013 to June 30, 2020.

To minimize the impacts of different verified periods, this report characterizes water quality for each of the City's priority lakes during the same time period, 1/1/2009 to 6/30/2016. These dates correspond to the most recent Verified Period for which FDEP's water quality data are available for all the City's priority lakes.

Water quality data were downloaded from FDEP, and used to determine the classification status of Lake Hollingsworth. As was found previously, Lake Hollingsworth was classified as a low-color, alkaline lake, based on a geometric mean value for color of 18 PCU and a geometric mean alkalinity value of 39 mg (as CaCO₃) / liter. Based on that classification, the water quality targets for TN and TP were then determined based on whether or not the annual geometric mean for a given year exceeded the threshold chlorophyll-a value of 20 µg / liter. The relevant water quality criteria for TN and TP for Lake Hollingsworth are highlighted in yellow in Table 6-23. Based on the criteria provided below, Lake Hollingsworth has the following exceedances (Table 6-24).

TABLE 6-23. WATER QUALITY CRITERIA FOR LAKE HOLLINGSWORTH, WITH RELEVANT TARGETS FOR CHLOROPHYLL-A, TN AND TP HIGHLIGHTED IN YELLOW.

Long Term Geometric Mean Lake color and Alkalinity	Annual Geometric Mean chlorophyll-a	Minimum calculated numeric interpretation		Maximum calculated numeric interpretation	
		Annual Geometric Mean TP	Annual Geometric Mean TN	Annual Geometric Mean TP	Annual Geometric Mean TN
> 40 PCU	20 µg/L	0.05 mg/L	1.27 mg/L	0.16 mg/L	2.23 mg/L
≤ 40 PCU and > 20 mg/L CaCO ₃	20 µg/L	0.03 mg/L	1.05 mg/L	0.09 mg/L	1.91 mg/L
≤ 40 PCU and ≤ 20 mg/L CaCO ₃	6 µg/L	0.01 mg/L	0.51 mg/L	0.03 mg/L	0.93 mg/L

TABLE 6-24. SUMMARY OF WATER QUALITY IMPAIRMENT DETERMINATIONS FOR LAKE HOLLINGSWORTH BY YEAR. YEARS WITH INSUFFICIENT DATA FOR COMPARISON WITH NNC CRITERIA ARE NOTED BY “-”.

Year	chlorophyll-a (µg / liter)	TN (mg / liter)	TP (mg / liter)
2009	52.0	1.705	0.085
2010	47.8	1.901	0.082
2011	88.5	2.903	0.124
2012	88.1	2.683	0.091
2013	61.9	1.923	0.092
2014	65.0	2.015	0.070
2015	75.2	2.039	0.064
2016	82.3	2.214	0.073
Average percent reduction required (when needed)	70	50	81

Lake Hollingsworth has water quality that far exceed NNC criteria for low-color, alkaline lakes. Based on case studies examined in PBS&J (2011) and Tomasko et al. (2013) the TN and especially the TP reductions required for Lake Hollingsworth to meet NNC guidance are outside the range of reductions obtained by traditional lake management approaches, such as stormwater retrofits. Instead, more intensive project types are required, up to and including sediment inactivation or removal and hydrologic restoration.

Positive relationships were found between both TN and chlorophyll-a and TP and chlorophyll-a (Figures 6-72 and 6-73, respectively).

The very high levels of TN in Lake Hollingsworth are in excess of values expected from stormwater runoff and they likely represent the influence of nitrogen-fixing cyanobacteria (Figure 6-72, i.e., Tomasko et al. 2009). As such, reductions in external loads of TN are likely not capable of reducing TN concentrations significantly within the lake. Therefore, TP was identified as the most likely limiting nutrient, and activities focused on the reduction of TP concentrations are the focus of proposed lake management activities.

A statistical correlation between annual average TP concentrations and annual rainfall was not found indicating that external sources such as stormwater runoff are not likely dominant influences on in-lake water quality. Based upon these results, projects which focus on stormwater retrofits are not likely good candidates toward restoring water quality in Lake Hollingsworth.

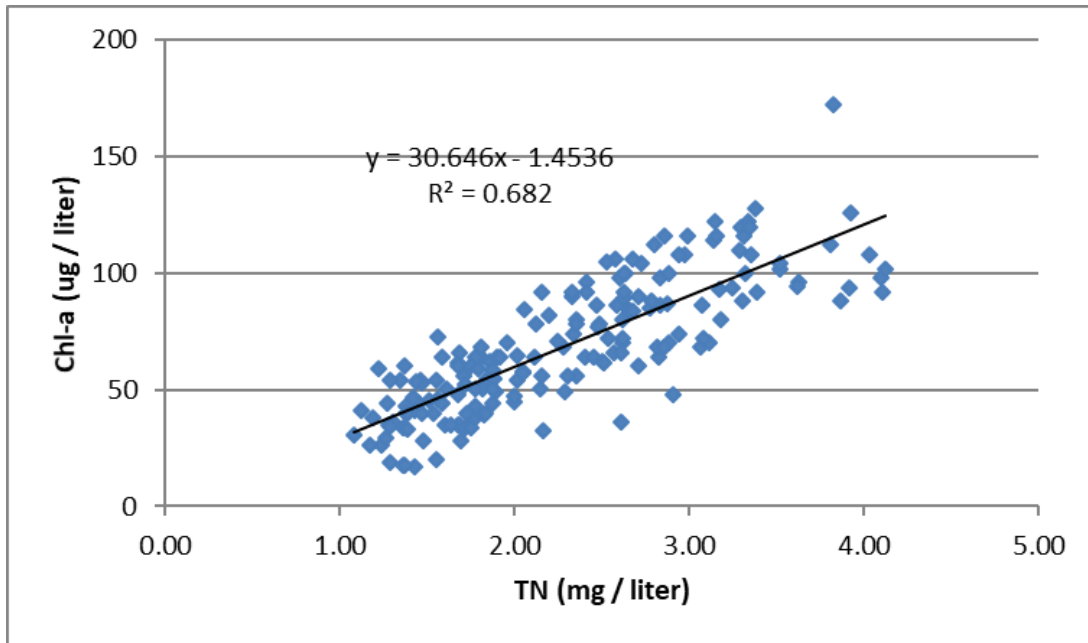


Figure 6-72. Relationship between TN and chlorophyll-a. Line is best fit equation of statistically significant ($p < 0.05$) relationship

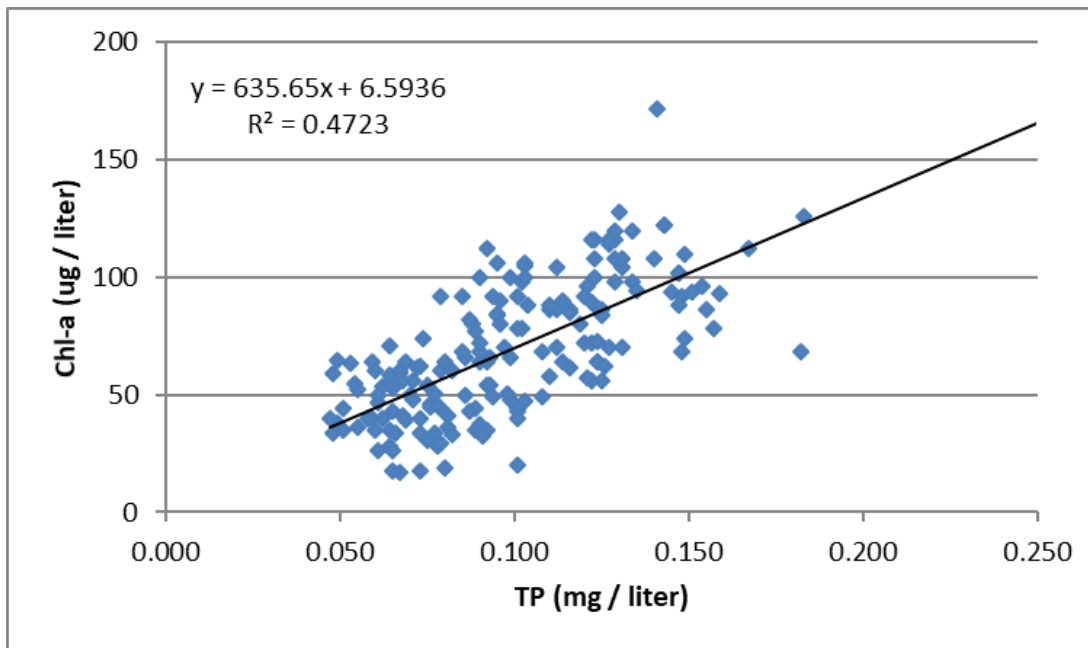


Figure 6-73. Relationship between TP and chlorophyll-a. Line is best fit equation of statistically significant ($p < 0.05$) relationship

There is evidence of a prior point source load to the lake are which lead to nutrient enriched sediments. Additionally, there are historical landscape features that would be expected to exceed “normal” urban landscape nutrient loads to the lake. Historically, citrus groves were present in the southeastern portion of the Lake Hollingsworth watershed. The transition of the citrus groves to

urban developed coincided with improvements in water quality within the lake itself. Lake sediment resuspension was identified as a likely source of internal nutrient loads to the overlying water column based on evidence of a significant, inverse correlation between TP concentrations and lake water elevation ($p < 0.0001$, $\rho = -0.295$). Sediment removal and/or sediment inactivation are projects focused on the control of nutrient releases for lake-bottom sediments and recommended for Lake Hollingsworth. Whole-lake circulation is not recommended based on the lake size.

An analysis of the historical versus current lake extent indicated that the lake has been lowered compared to its original configuration. Historical data suggest that the lake water elevation has been lowered between 3 and 7 feet since the 1850s. As a result, the lake's current water elevation appears to be below the water elevation of what little historical wetland fringe remains. Hydrologic restoration projects aimed at restoring historical wetland – lake interactions are not an option here since very little wetland fringe remains and the shoreline is heavily developed. Water quality treatments through the use of barley straw and/or cypress leaf bundles are one option for improving water quality. Additionally, establishing a large enough in-lake hardwood and herbaceous wetland community may increase color and thus moderate chlorophyll-a expression. Although Lake Hollingsworth clearly exhibits signs of nutrient enrichment, locally-derived chlorophyll-a, TN, and TP targets are recommended as a management tool. These targets have been partially provided by a paleolimnological study conducted by Brenner et al. (1999)

The average values for color in the report by the City of Lakeland (2010) indicate the lake is high-color (PCU > 40) while the report from Atkins and ESA (2014) as well as data analysis for this report shows the lake as being a low-color, alkaline lake. Lake Hollingsworth's color values averaged above 40 PCU in 2003, 2007 and 2008. Whether the lake is classified as a high color lake or a low-color, alkaline lake, the chlorophyll-a target remains 20 µg / liter. However, the TP and TN targets are lower for low-color, alkaline lakes than they are for high-color lakes. The TP and TN concentration reductions required for Lake Hollingsworth to meet NNC guidance are substantial, as corroborated in both the report by Atkins and ESA (2014) and the TMDL for Lake Hollingsworth (FDEP 2014b).

In FDEP's TMDL for Lake Hollingsworth, the TP target was set at 0.036 mg/L using data from the paleo study by Brenner et al. (1999). This TP value was chosen because it represented the "high value" of the allowable TP range (FDEP 2014b). The proposed target was then further modified to account for the fact that 0.036 mg/L TP represents a single value that was interpreted as indicating "average" conditions, while NNC is based on geometric means. FDEP then ran an analysis comparing average values (arithmetic means) vs. geometric means and thus derived a target of 0.033 mg/L TP for the TMDL (FDEP 2014b).

While the TMDL is to be applauded for its inclusion of the applicable paleo study, the "average" target of 0.036 mg/L TP corresponds to the year 1898 based on an analysis of data supplied by Dr. Mark Brenner. When the TP values from the paleo study are plotted out over time, it can be seen that not only are current TP concentrations in Lake Hollingsworth lower than they were in the 1940s and 1950s, but that the target FDEP TP concentration is lower than TP concentrations as far back as 1918 (Figure 6-74).

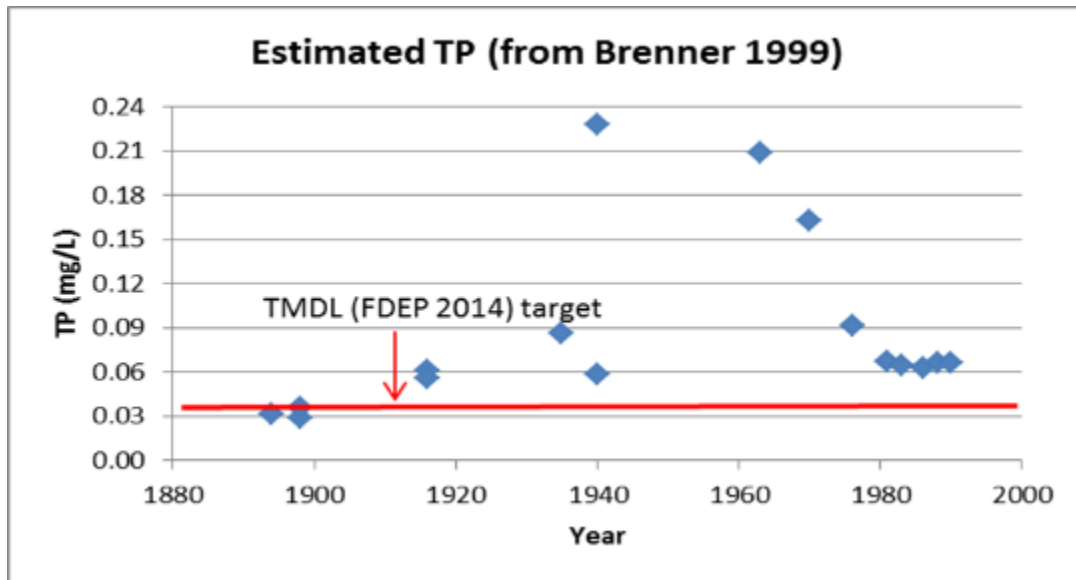


Figure 6-74. Display of TP Concentrations over Time (Results Derived from Brenner et al. 1999)

The TP target for the lake is one that was exceeded almost 100 years ago. This target value is not only unrealistic, it is inconsistent with the approach to target setting used in Tampa Bay (TBEP 2010) and Lake Hancock (FDEP 2005b) where a certain amount of leeway is allowed in terms of restoration goals. In contrast, the water quality targets for the Reasonable Assurance Plan for Tampa Bay are based on attempting to match water quality targets from about 1950 (Janicki Environmental, Inc. 2011). As shown above, TP concentrations in Lake Hollingsworth are already lower than what they were in 1950, but are still above their target as specified in the TMDL.

Rather than use a “pristine” lake condition (aka prior to 20th century) to set water quality targets, it may be more useful if an allowable amount of change from historical conditions was incorporated into the target setting process. In the TMDL for Lake Hancock (EPA 2006c) it was determined that EPA would allow for a 5-unit increase in TSI scores as an allowable change from historical conditions. The applicable conversion equation for determining a TSI score from a TP concentration is as follows:

Based on the estimated phosphorus concentration in 1898 of 0.036 mg/L, the TSI_{TP} value would be 48.25. Assuming a 5-unit increase in TSI is an acceptable change from historical conditions, Lake Hollingsworth should be held to a TSI standard of 53.25. The conversion of this TSI_{TP} value back to a phosphorus concentration results in a derived value of 0.047 mg/L. The value of 0.047 mg/L TP thus represents a more realistic water quality target for Lake Hollingsworth compared to the one stipulated in the current TMDL (FDEP 2014b).

Using the data set displayed in Table 2.1 (FDEP 2014b) a TP value of 0.047 mg/L and a TN value of 0.79 mg/L would equate to a chlorophyll-a value of 36.05 $\mu\text{g/L}$. While it is not known if the current relationship between TP and chlorophyll-a is the same as the historical one, the TMDL assumes that to be the case (FDEP 2014b) and therefore this appears to be a reasonable assumption

here. Therefore, appropriate targets for Lake Hollingsworth, and perhaps for additional lakes in the region, would be a chlorophyll-a target of 36 µg/L, a TP target of 0.047 mg/L, and a TN target of 0.79 mg/L.

These proposed targets still require substantial efforts to improve the water quality of Lake Hollingsworth, but they are more realistic expectations of what could be achieved with various lake restoration projects (at least for low-color, alkaline lakes in the West Central Nutrient Watershed region, as described in FS 62-302.531).

Lake Hollingsworth has been the focus of intensive lake management actions for many years. The lake's sediments have been dredged (> \$15 million), the open waters have been treated with whole-lake alum (> \$228,000), stormwater runoff from the watershed has reduced by numerous stormwater retrofit projects, from large wet detention systems treating hundreds of acres (> \$1.1 million) to the addition of 11 baffle boxes in individual stormwater drain outfalls and revegetation of the shoreline. Street sweeping of the immediate watershed is ongoing. The lake has also been the focus of ongoing public education and involvement programs, such as fertilizer ordinances, the placement of educational signage regarding actions the public can take to protect and restore the lake, and the installation of dog waste disposal stations. And yet Lake Hollingsworth continues to be classified as "impaired" for water quality, despite evidence of significant reductions (> 50%) in nutrient concentrations over the past few decades.

The current determination that Lake Hollingsworth's water quality continues to be determined to be impaired raises two important questions: 1) what more could be realistically done to further improve water quality in Lake Hollingsworth, and 2) are the water quality targets set for Lake Hollingsworth in its TMDL (FDEP 2014b) realistic?

Water Quality Restoration Project Selection and Priorities

Based on Lake Hollingsworth water quality and the surrounding watershed characteristics, four potential water quality restoration projects were identified using the City's WQMP decision key. Projects to address water quality, nutrient and sediment loading, and reduced lake levels are proposed. The projects are listed in order of priority, based on expected water quality improvements. A detailed discussion of the potential water quality restoration implications for each project can be found in Section 4.0.

Project 1: SAV Planting/Management or FTWs

Project 2: EAV Planting/Management

Project 3: Sediment inactivation or removal, particularly for areas not previously dredged during earlier efforts

Project 4: Develop reasonable water quality targets through paleolimnology and coordination with FDEP

Project 1: SAV Planting/Management or FTWs

SAV Planting

A survey of existing SAV cover in Lake Hollingsworth is recommended due to the lack of sufficient data to calculate percent lake cover. Based on the results of the SAV survey, conclusions regarding SAV planting can be determined. If SAV cover is less than 30 percent, lake conditions should be evaluated to assess if additional SAV is viable based on the soil condition, water clarity and water depth.

Based on the median Secchi depth (0.5 meter) from the POR (1966 -2016), plants would not be planted in water depths greater than 0.7 meter (Water Atlas). The maximum planting effort for Lake Hollingsworth cannot be calculated until digital bathymetry data are acquired.

Bathymetric Survey Cost Estimate: \$10,000

SAV Planting/Management Cost Estimate: A cost estimate will be generated upon receipt of the bathymetry data.

FTWs

If the feasibility study indicates that more than 30 percent of Lake Hollingsworth has SAV cover, FTW may be considered. The installation of floating mats with appropriate aquatic vegetation would be expected to assimilate nutrients from the water column.

Project 2: EAV Planting

A survey of existing shoreline vegetation surrounding Lake Hollingsworth is recommended due to the lack of sufficient data at this time. Based on the results of the shoreline survey, conclusions and recommendations regarding emergent aquatic or woody vegetation planting can be determined. If limited shoreline vegetation is present, shoreline conditions should be evaluated, preferably by City staff, to assess if vegetation planting is viable based on the soil conditions, slope, water level and inundation frequency and wave disturbance.

EAV Planting/Management Cost Estimate: A cost estimate will be generated upon receipt of the shoreline survey data.

Project 3: Sediment Removal / Inactivation

Non-point source discharges to Lake Hollingsworth may have resulted in substantial internal nutrient loads due to phosphorus release from sediments. Presently, sediment capping and dredging are both potential remedial options; however, costs associated with dredging are typically highly elevated in comparison to capping. A feasibility study is recommended to evaluate sediment capping versus sediment dredging.

Feasibility study cost estimate: \$150,000

Project 4: Paleolimnology Study

A recurring issue is the need for site-specific water quality targets for each of the 11 lakes. A consideration, however, is the ability of FDEP to allow for target values of chlorophyll-a, TN, and TP that are higher than those contained within NNC (as outlined in FAC 62-302.531). If FDEP allows for the use of these proposed site specific alternative criteria under a BMAP scenario, a valid argument could also be made that all City lakes classified as low-color, alkaline, valley lakes should have the same target values (City lakes classified as ridge lakes may warrant additional paleo studies and subsequent water quality target derivations for ratification by the FDEP). This would not be an unreasonable request as FDEP has used paleo data in the past to set TMDL water quality targets for the Southern Chain of Lakes in Winter Haven (FDEP 2007). Locally-derived paleo data and corresponding TN, TP, and chlorophyll-a targets such as those derived for Lake Hollingsworth by Brenner et al. (1999) should be used at least as interim lake management goals, pending review and comment from FDEP.

Cost estimate: \$30,000 to \$50,000 per lake including coordination with FDEP to develop site-specific water quality targets for chlorophyll-a and nutrients to be used in impairment determinations and/or TMDLs.

Lake Hunter

Physical and chemical characteristics specific to Lake Hunter are presented here in the context of relevant regulatory criteria and requirements.

Historical and Recent Conditions in Lake and Watershed

Lake Hunter is an 84-acre lake located in the City within the eastern portion of Polk County, Florida (Figure 6-75). Maximum water depth is reportedly 8.9 feet, with an average water depth of 5.6 feet (City of Lakeland 2010). The lake is located within the Lakeland/Bone Valley Upland lake region of Florida, which according to Griffith et al. (1997), can be characterized with “high phosphorus, nitrogen, and chlorophyll-a values” and “alkaline, [with] some [lakes] receiving limestone-influenced groundwater.”

Lake Hunter is located within the Hillsborough River watershed and the immediate contributing watershed to the lake is 620 acres in size, resulting in a watershed to open water ratio of 7.3 (Table 6-25; Figure 6-75). Watershed to open water ratios can be used to compare the relative amount of influence that a lake experiences from its contributing watershed, such as stormwater runoff. The relatively low ratio suggests that external influences could be less important to the lake’s water quality than is the case for lakes with higher ratios.

Lake Hunter is influenced by inflows (at higher water levels) by way of adjustable control structures from Lakes Beulah and Wire. Its waters discharge (at higher water levels) to Itchepackesassa Creek via an adjustable control structure (City of Lakeland 2010). For most of the past 30 years, the water level in Lake Hunter has fluctuated mostly within its operating range (Figure 6-76). The operational water elevation range for Lake Hunter is 160.31 to 161.61 feet NAVD. Within the Lake Hunter watershed, there is a moderate elevation gradient ranging from 161 to 215 feet NAVD

(Figure 6-77). Lake Hunter is located between 80 and 90-foot potentiometric surface elevations and south of the potentiometric peak, as of September 2011 (Figure 6-78). Additionally, the northern boundary of the intermediate aquifer system is just north of Lake Hunter (Spelcher and Kroening 2007). Therefore, it is unlikely that there is direct connectivity with the Floridan aquifer.

A review of historical aerial photography (from 1941) indicates the loss of a prior wetland area to the north of the lake that was present in earlier aerial photographs. Additionally, it appears that a man-made channel was already constructed at the southern point of the lake prior to 1941 which bisected a large wetland some of which is still intact. In 1941, citrus agriculture was present along the northeastern shoreline of Lake Hunter and residential development was apparent along the east and southeastern shorelines. By 1958, a majority of the area surrounding Lake Hunter was developed, with exception of the wetland area to the north (Figure 6-79). By 1968, the wetland area to the north had undergone further modification, as evidenced by what appear to be drainage canals and other features (Figure 6-79). The extensive development within the watershed is reflected in the land use/land cover data provided by both USGS and SWFWMD (Table 6-26). Specifically, the SWFWMD land use data from 2011 classifies 513 acres (82%) as developed lands compared to 107 acres (17%) of undeveloped land (Figure 6-80).

There are 70 inputs from the watershed that discharge to Lake Hunter, including 26 minor outfalls, 10 retention/detention outlets, one lake/creek outlet, three flumes, 22 end of pipe inputs, and eight major outfalls (Figure 6-81). In regards to infrastructure, the majority of the existing residential developments within the watershed utilize sanitary sewer for wastewater treatment provided by the City of Lakeland (2010). Four constructed OSTDS were identified within the watershed (Figure 6-82). Based on a review of SWFWMD soil survey geographic data, soils within the watershed have a low runoff potential with high, moderate, and low infiltration rates and are classified either as hydrologic soil group A (51 acres), B (14 acres), B/D (15 acres) or C (325 acres), respectively (Figure 6-83).

In 1983, the City and Florida Game and Fresh Water Fish Commission implemented a restoration program, which included a total pump down of Lake Hunter, mechanical removal of approximately 19,999 cubic yards of sediment, reforming and revegetating the lake's littoral areas, and redesigning the water level control structure.

In November 2007, BCI Engineers & Scientists, Inc. (BCI) submitted a Conclusions and Recommendations for Guiding the TMDL/BMAP Process in the Lake Hunter Watershed. BCI identified fertilizer loading as the largest single-source of nutrients to Lake Hunter basin and recommended investigating ground water transport of nutrients and reduction of fertilizer use within the watershed. Additionally, BCI recommended short-term diversion of inflows from Lakes Wire and Beulah to the wetlands on the north side of Lake Hunter to improve water quality.

In September 2013, AMEC prepared a NPDES Outfalls Basin Delineation and Pollutant Loading Report to delineate drainage basin boundaries, determine the extent of the associated land use types, and predict pollutant loading for 35 outfalls.

TABLE 6-25. PHYSICAL CHARACTERISTICS OF LAKE HUNTER AND ADJACENT WATERSHED

Physical			
Location	City of Lakeland; Polk County	High infiltration soils (acres)	51
Relation to other lakes	inflows from Lakes Beulah and Wire; discharge to Itchepackesassa Creek	Developed land (acres)	82
Watershed area (acres)	620	Undeveloped land (acres)	17
Lake area (acres)	84	Mean water depth (ft)	5.6
Perimeter (feet)	8,435	Maximum water depth (ft)	8.9
Surface area: lake volume ratio	0.15	Volume (acre-feet)	548
Watershed to surface area ratio	7.3		

TABLE 6-26. CHANGES IN LAND USE WITHIN THE LAKE HUNTER WATERSHED OVER TIME

Land Use	1970-1985*		1995		2011	
	Acres	Percent	Acres	Percent	Acres	Percent
Industrial			18	2.9	13	2
Commercial and Services	183	29.5	118	19	116	18.6
Institutional			6	1.0	41	6.6
Open Land			12	1.9	6	1
Cropland and Pasture	2	0.3				
Emergent Aquatic Vegetation			2	0.3	9	1.4
Freshwater Marsh			1	0.2	1	0.2
Lake	79	12.7	92	14.8	84	13.5
Recreational			9	1.4	9	1.4
Reservoirs					1	0.2
Residential	356	57.5	300	48.2	304	49
Stream and Lake Swamps			8	1.3	7	1.1
Transportation			56	9.0	31	5

*Metadata for USGS land use data identifies data collection dates as a period between 1970 and 1985



Figure 6-75. Lake Hunter location map

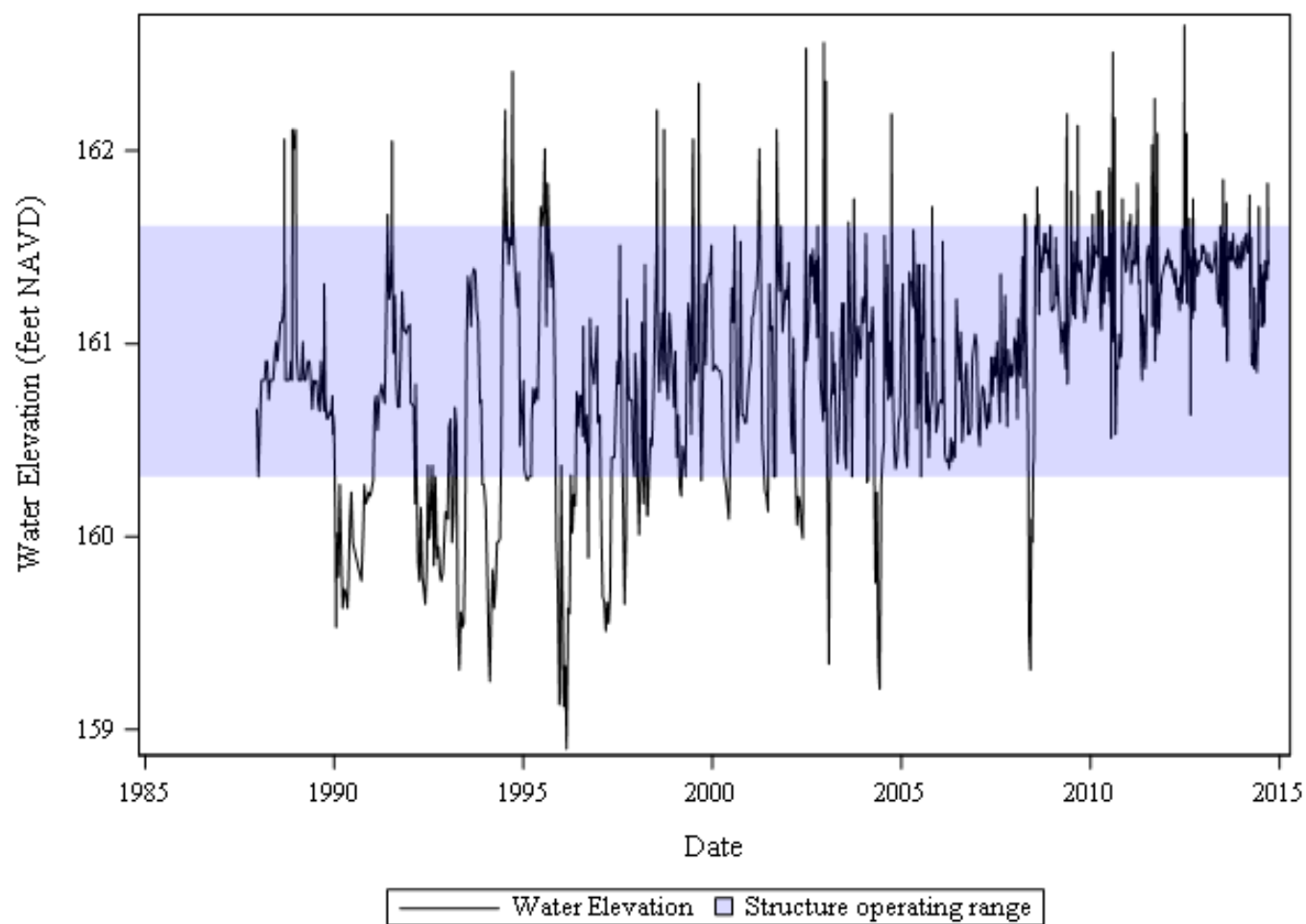


Figure 6-76. Period of Record Lake Hunter water elevations

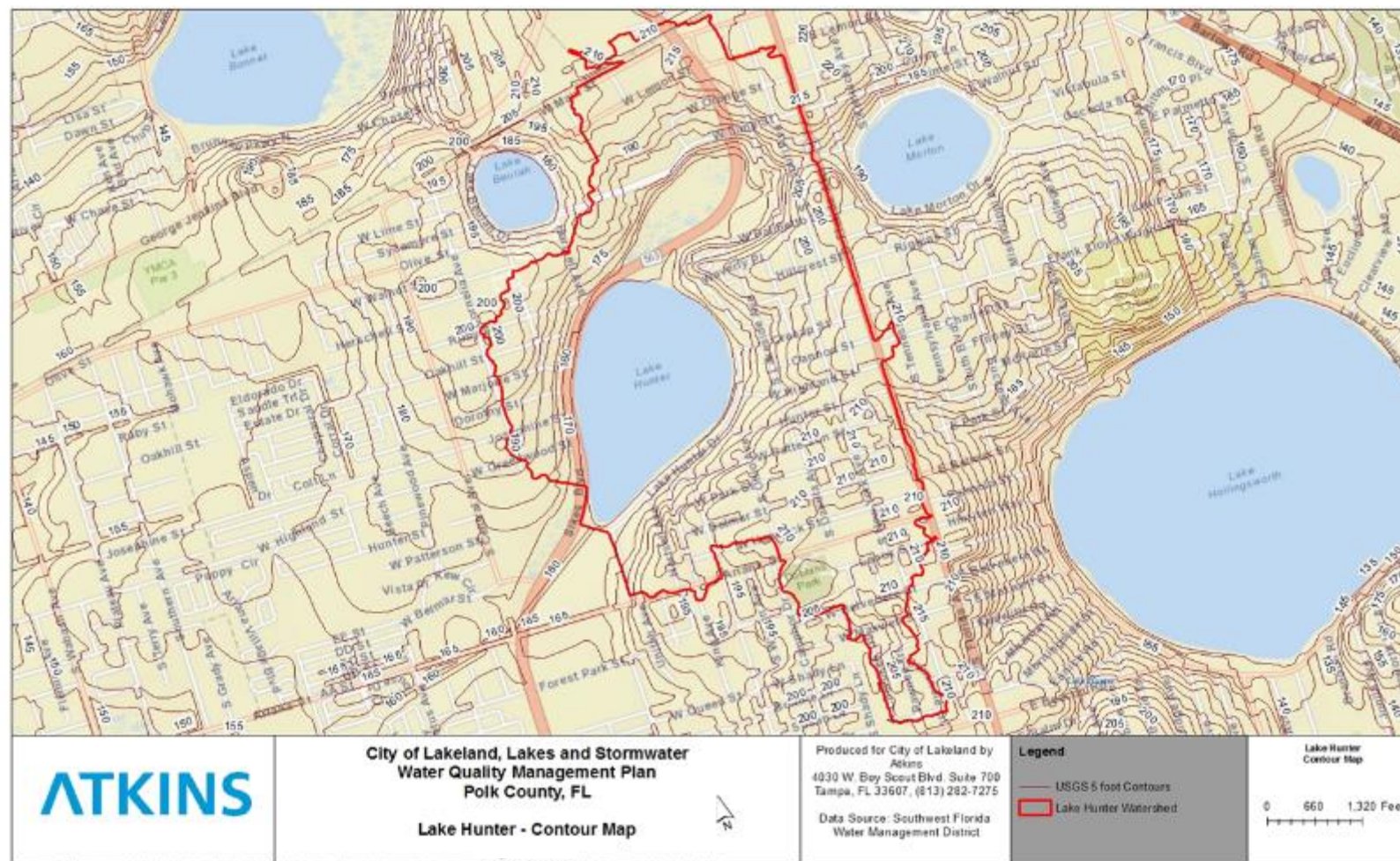


Figure 6-77. Lake Hunter contour map

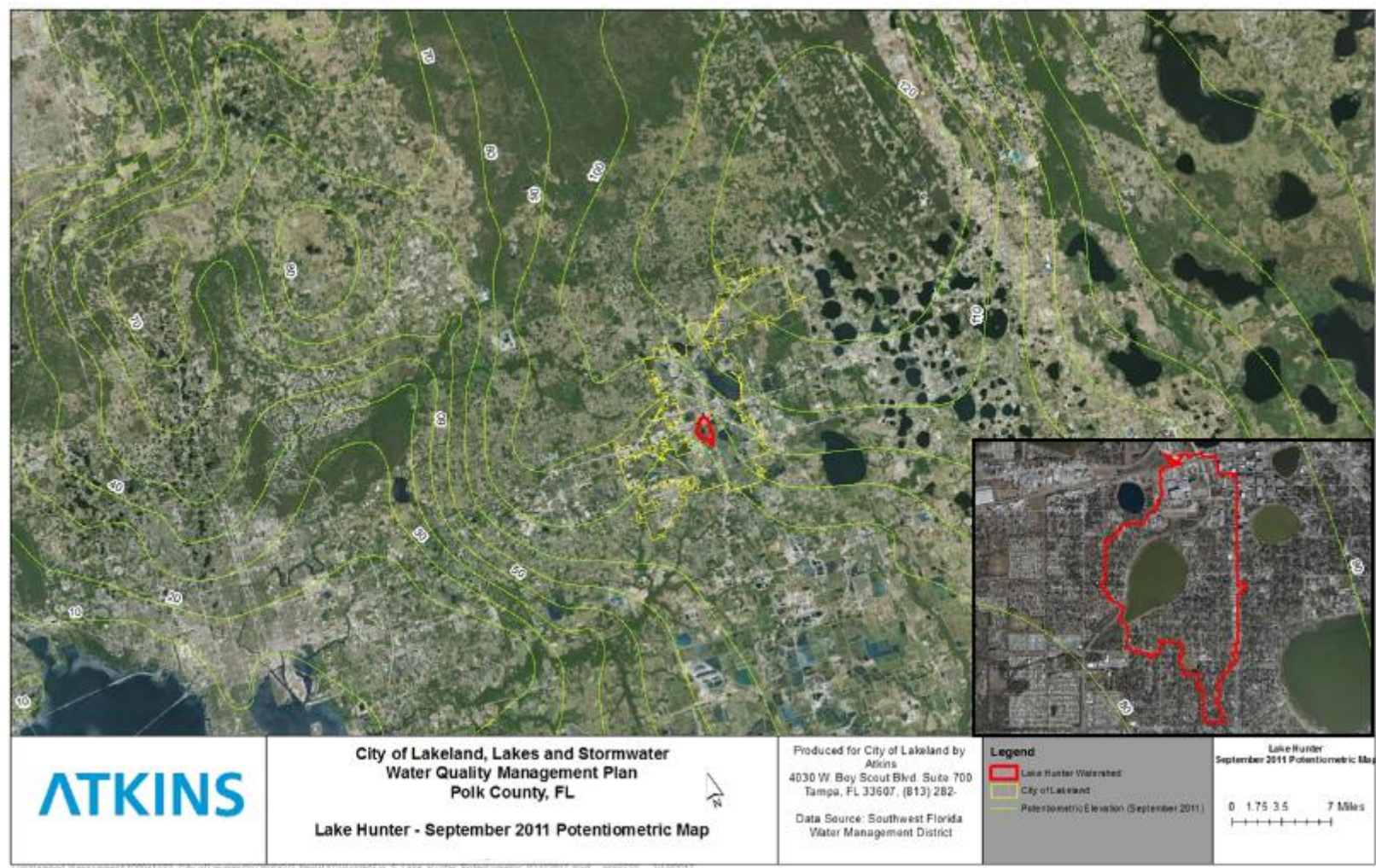


Figure 6-78. Lake Hunter potentiometric map

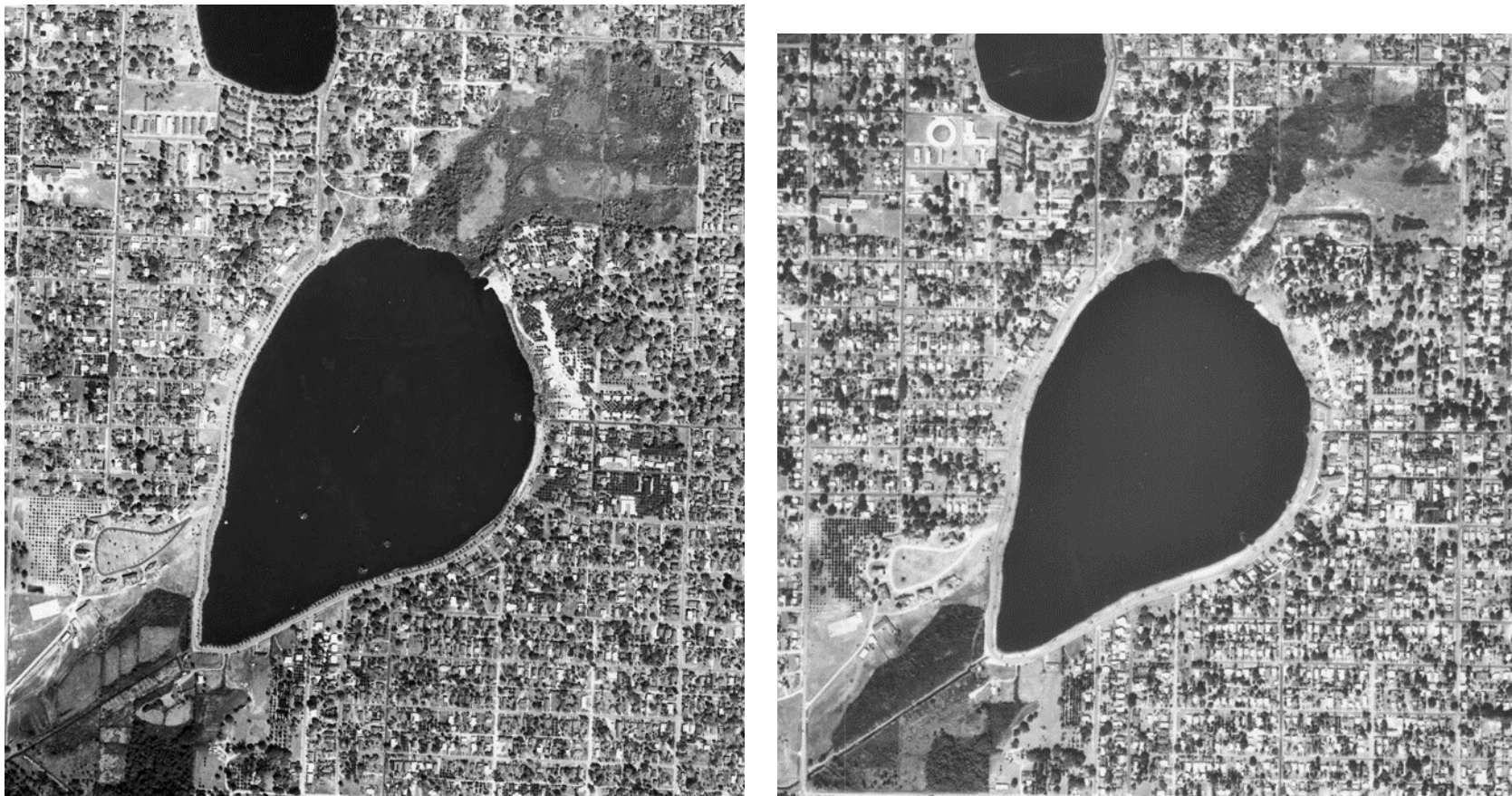


Figure 6-79. Lake Hunter historical aerial imagery. Left Photo. 1958. Right Photo. 1968

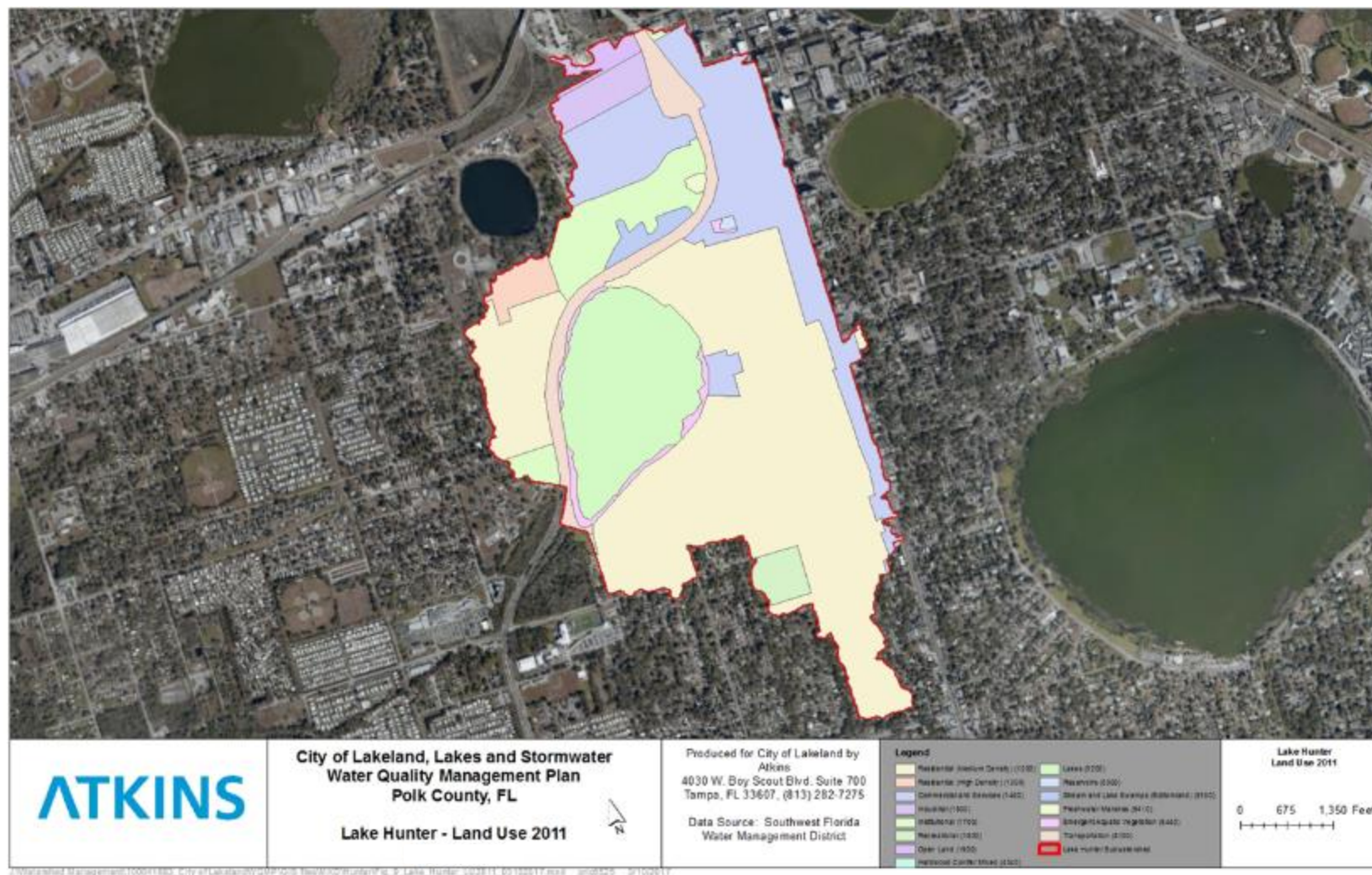


Figure 6-80. Lake Hunter 2011 land use map



Figure 6-81. Lake Hunter stormwater map

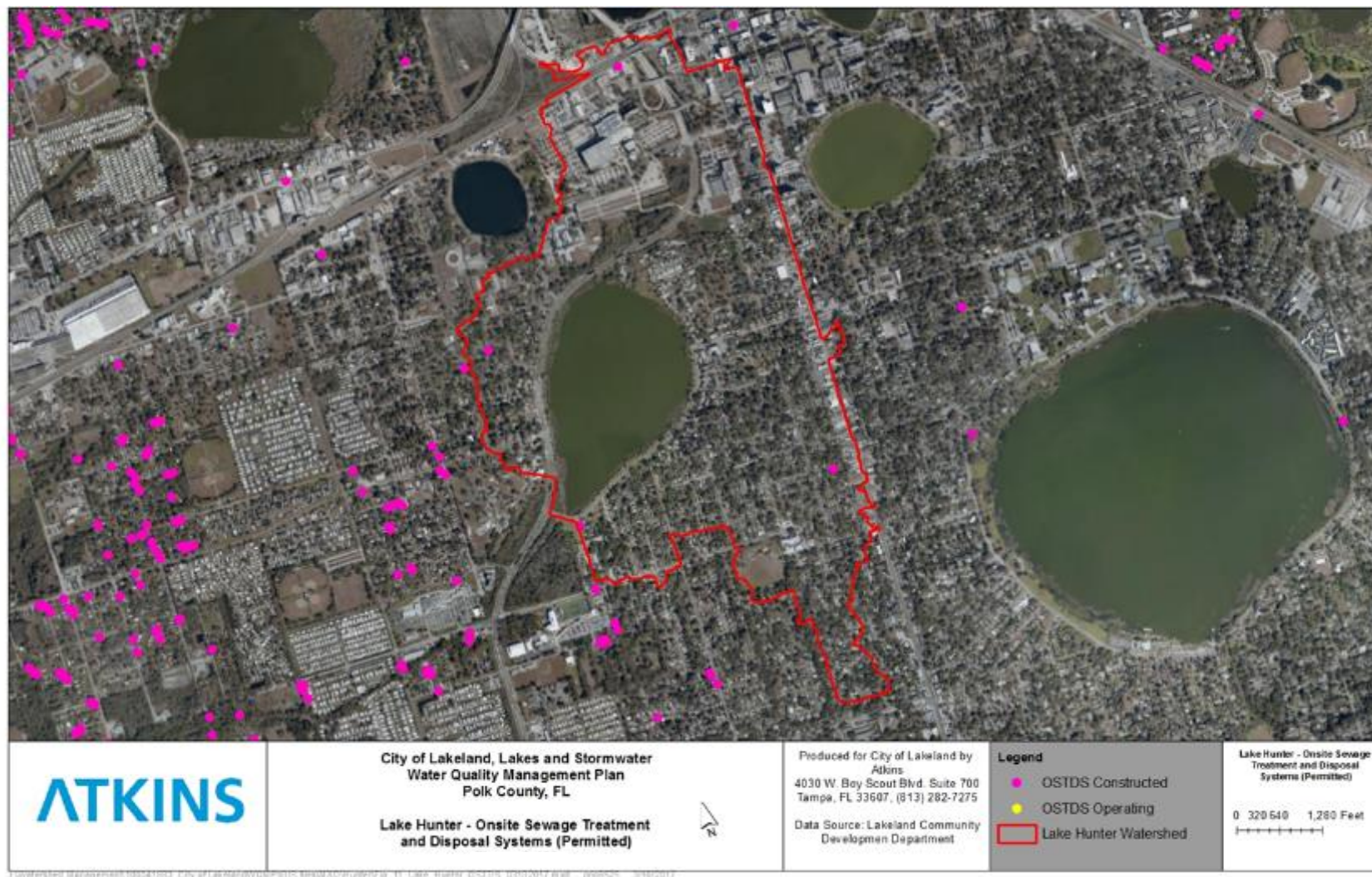


Figure 6-82. Lake Hunter OSTDS map

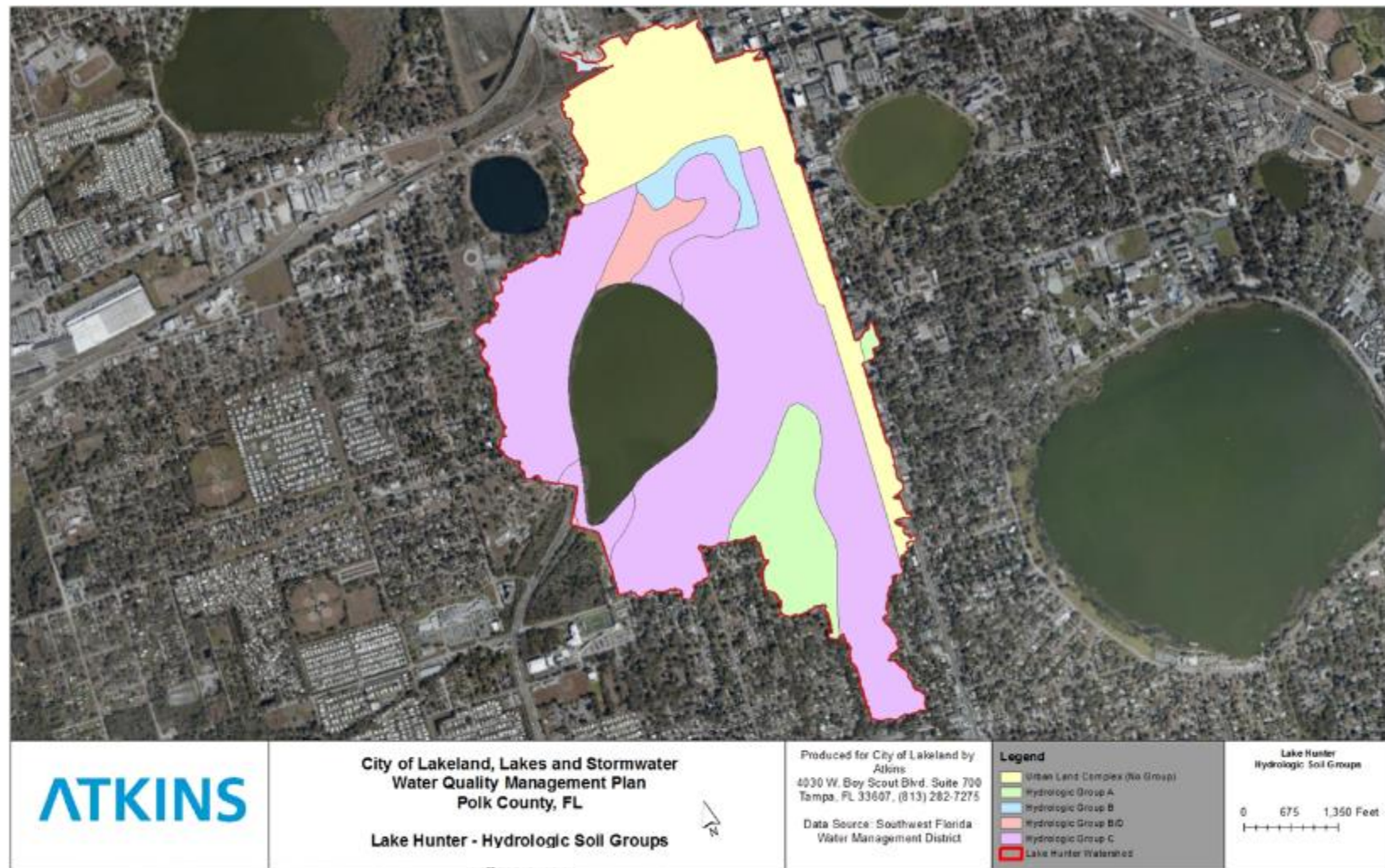


Figure 6-83. Lake Hunter soils map

Water Quality

Lake Hunter had previously been listed as impaired for nutrients by FDEP (Atkins and ESA 2014) and has a TMDL for nutrients (FDEP 2004). In FDEP's most recent version of the Comprehensive Verified Impaired List (December 18, 2017) the Lake Hunter Outlet is listed as impaired for "Dissolved Oxygen" based upon a determination that levels fell below 5 mg / liter. The causative basis for low levels of DO was listed as TP. The Lake Hunter Outlet was also listed as impaired for fecal coliform bacteria. Lake Hunter was previously classified as a clear, alkaline lake (Atkins and ESA 2014). Based on the clear, alkaline characterization, nutrient criteria were determined based on the use of a chlorophyll-a concentration of 20.0 µg/L. Lake Hunter is a Group 2 waterbody as part of the Hillsborough River, the most recent impairment evaluation was performed for the verified period of January 1, 2007 to June 30, 2014 (Cycle 3) which applied NNC as the numeric criteria. The cycle 4 assessment period will occur in 2020 for the verified period of January 1, 2012 to June 30, 2019.

To minimize the impacts of different verified periods, this report characterizes water quality for each of the City's priority lakes during the same time period, 1/1/2009 to 6/30/2016. These dates correspond to the most recent Verified Period for which FDEP's water quality data are available for all the City's priority lakes.

Water quality data were downloaded from FDEP, and used to determine the classification status of Lake Hunter. As was found previously, Lake Hunter was classified as a low-color, alkaline lake, based on a geometric mean value for color of 20 PCU and a geometric mean alkalinity value of 54 mg (as CaCO₃) / liter. Based on that classification, the water quality targets for TN and TP were then determined based on whether or not the annual geometric mean for a given year exceeded the threshold chlorophyll-a value of 20 µg / liter. The relevant water quality criteria for TN and TP for Lake Hunter are highlighted in yellow in Table 6-27. Based on the criteria provided below, Lake Hunter has the following exceedances (Table 6-28).

Lake Hunter has water quality that far exceed NNC criteria for low-color, alkaline lakes. Based on case studies examined in PBS&J (2011) and Tomasko et al. (2013) the TN and especially the TP reductions required for Lake Hunter to meet NNC guidance may be outside the range of reductions obtained by traditional lake management approaches, such as stormwater retrofits. Instead, more intensive project types are required, up to and including sediment inactivation or removal and hydrologic restoration.

TABLE 6-27. WATER QUALITY CRITERIA FOR LAKE HUNTER, WITH RELEVANT TARGETS FOR CHLOROPHYLL-A, TN AND TP HIGHLIGHTED IN YELLOW.

Long Term Geometric Mean Lake color and Alkalinity	Annual Geometric Mean chlorophyll-a	Minimum calculated numeric interpretation		Maximum calculated numeric interpretation	
		Annual Geometric Mean TP	Annual Geometric Mean TN	Annual Geometric Mean TP	Annual Geometric Mean TN
> 40 PCU	20 µg/L	0.05 mg/L	1.27 mg/L	0.16 mg/L	2.23 mg/L
≤ 40 PCU and > 20 mg/L CaCO ₃	20 µg/L	0.03 mg/L	1.05 mg/L	0.09 mg/L	1.91 mg/L
≤ 40 PCU and ≤ 20 mg/L CaCO ₃	6 µg/L	0.01 mg/L	0.51 mg/L	0.03 mg/L	0.93 mg/L

TABLE 6-28. SUMMARY OF WATER QUALITY IMPAIRMENT DETERMINATIONS FOR LAKE HUNTER BY YEAR. YEARS WITH INSUFFICIENT DATA FOR COMPARISON WITH NNC CRITERIA ARE NOTED BY “-”.

Year	chlorophyll-a (µg / liter)	TN (mg / liter)	TP (mg / liter)
2009	78.4	2.03	0.109
2010	59.1	1.84	0.118
2011	169.5	4.05	0.225
2012	125.8	3.31	0.185
2013	130.1	1.70	0.177
2014	95.9	2.76	0.150
2015	86.2	2.56	0.146
2016	93.3	2.44	0.173
Average percent reduction required (when needed)	79	56	80

Positive relationships were found between both TN and chlorophyll-a and TP and chlorophyll-a (Figures 6-84 and 6-85, respectively). The very high levels of TN shown in Figure 6-84 suggest the presence of nitrogen-fixing cyanobacteria, rather than external nitrogen loads with such high concentrations.

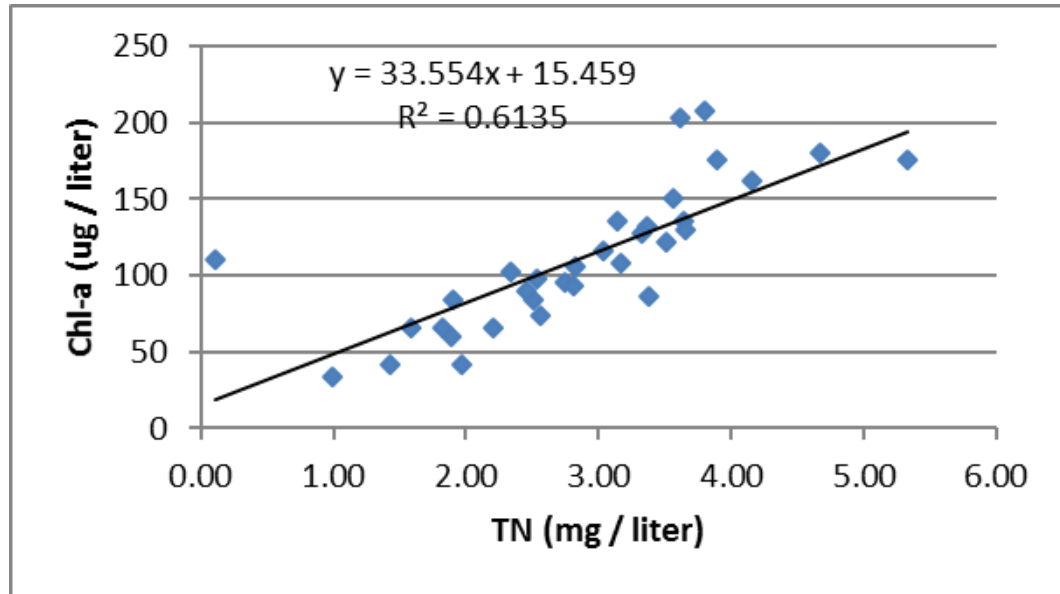


Figure 6-84. Relationship between TN and chlorophyll-a. Line is best fit equation of statistically significant ($p < 0.05$) relationship

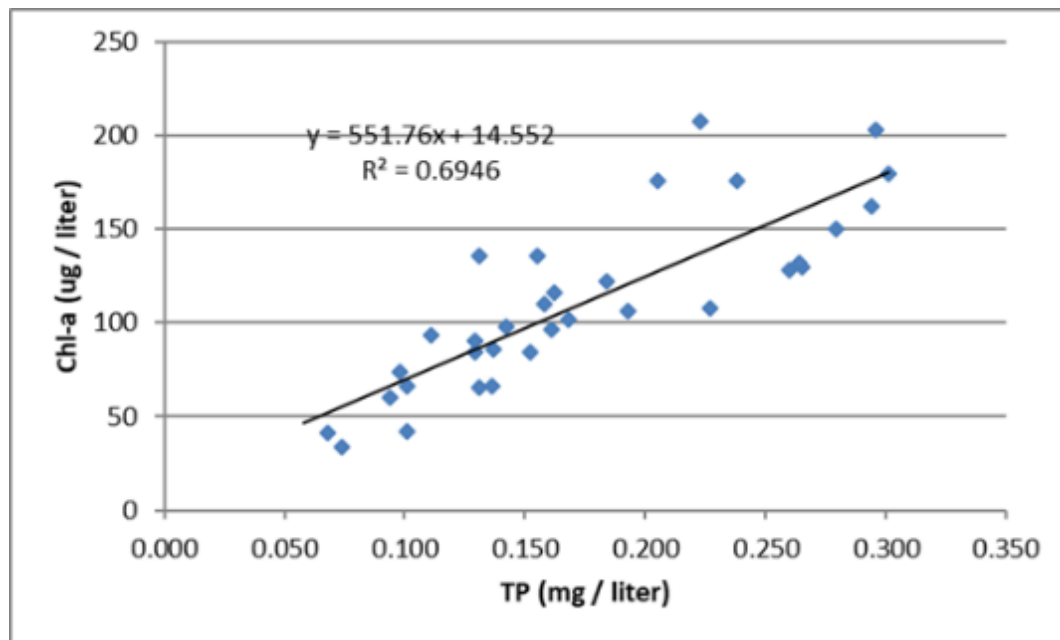


Figure 6-85. Relationship between TP and chlorophyll-a. Line is best fit equation of statistically significant ($p < 0.05$) relationship.

An evaluation of the TN data indicates that concentrations exceed 3.0 mg/L; therefore, nitrogen-fixing cyanobacteria are likely playing a role in nutrient cycling within the lake (Figure 6-84). As such, reductions in external loads of TN are not likely to significantly reduce TN concentrations within the lake. Therefore, TP was identified as the NOC and reducing TP concentrations are the focus of proposed lake management activities.

A significant, direct correlation between annual average TP concentrations and annual rainfall was found indicating that external sources such as stormwater runoff likely influence in-lake water quality ($p=0.0125$, $\rho =0.512$). Based upon these results, projects which focus on stormwater retrofits and public education are good candidates toward restoring water quality in Lake Hunter. The regional stormwater retrofit project outlined in AMEC (2016) appears to be a worthwhile project, as it is regional in nature, it takes advantage of existing publically owned land north of Sikes Boulevard, and Lake Hunter appears to be adversely impacted by stormwater inflows, as outlined above.

Lake sediment resuspension was not identified as a likely source of internal nutrient loads to the overlying water column based on the lack of a significant, inverse correlation between TP concentrations and lake water elevation. However, internal nutrient loads remain a potential source, but Lake Hunter is not a candidate for whole-lake circulation given the lakes size (84 acres). The maintenance and enhancement of native emergent and submerged aquatic vegetation is recommended.

An evaluation into the potential loss of wetland influences was performed through the analysis of the historical versus current lake extent, this analysis was inconclusive. The average values for color in the report by the City of Lakeland (2010) indicate the lake is high-color (PCU > 40) while the report from Atkins and ESA (2014) as well as data analysis for this report shows the lake as being a low-color, alkaline lake. However, Lake Hunter's color values averaged above 40 PCU in 2004, 2006, 2007 and 2008. The geomorphology of the lake is such that Lake Hunter is classified as a "valley" lake, as outlined in PBS&J (2008). The fact that it has been classified as low-color in the Atkins and ESA (2014) report may be due to lost wetland influences associated with a reduction in lake levels from their historical condition or from modification of drainage patterns in the wetland located just north of Sikes Boulevard on the north shore of the lake. It is recommended that the regional stormwater retrofit project outlined by AMEC (2016) seek to increase tannin loads to Lake Hunter, thus potentially offsetting some of the lost wetland influence that seems to have occurred over time.

The finding that the classification of Lake Hunter can switch from low-color to high-color may be an indication that the lake's historical wetland fringe (evident in aerial photographs) may not be contributing historical levels of tannin loads to the lake due to hydrologic modifications. As such, hydrologic restoration to improve wetland – lake interactions might be a course of action appropriate for Lake Hunter. Unfortunately, there is insufficient historical data to conclude if Lake Hunter has in fact been lowered such that its historical wetland influences have declined over time. If development around the lake makes hydrologic restoration impractical, water quality treatments through the use of barley straw and/or cypress leaf bundles could be tested for their ability to reduce cyanobacteria abundance. Although Lake Hunter clearly exhibits signs of nutrient enrichment, site-

specific chlorophyll-a, TN, and TP targets have not been established and thus may be appropriate for Lake Hunter. collection and analysis of locally-derived paleo data is advisable if the City decides to pursue establishing site-specific criteria.

Water Quality Restoration Project Selection and Priorities

Based on Lake Hunter water quality and the surrounding watershed characteristics, four potential water quality restoration projects were identified using the City's WQMP decision key. Projects to address water quality, nutrient and sediment loading, and reduced lake levels are proposed. A detailed discussion of the potential water quality restoration implications for each project can be found in Section 4.0.

Project 1: SAV Planting/Management or FTWs

Project 2: EAV Planting/Management

Project 3: Stormwater Reduction

Project 4: Develop reasonable water quality targets through paleolimnology and coordination with FDEP

Project 1: SAV Planting/Management or FTWs

SAV Planting

A survey of existing SAV cover in Lake Hunter is recommended due to the lack of sufficient data to calculate percent lake cover. Based on the results of the SAV survey, conclusions regarding SAV planting can be determined. If SAV cover is less than 30 percent, lake conditions should be evaluated to assess if additional SAV is viable based on the soil condition, water clarity and water depth.

Based on the median Secchi depth (0.4 meter) from the POR, plants would not be planted in water depths greater than 0.6 meter. The maximum planting effort for Lake Hunter cannot be calculated until digital bathymetry data are acquired.

SAV Planting/Management Cost Estimate: A cost estimate will be generated upon receipt of the bathymetry data.

Bathymetric Survey Cost Estimate: \$10,000

FTWs

If the feasibility study indicates that more than 30 percent of Lake Hunter has SAV cover, FTW may be considered. The installation of floating mats with appropriate aquatic vegetation would be expected to assimilate nutrients from the water column.

Project 2: EAV Planting

A survey of existing shoreline vegetation surrounding Lake Hunter is recommended due to the lack of sufficient data at this time. Based on the results of the shoreline survey, conclusions and recommendations regarding emergent aquatic or woody vegetation planting can be determined. If limited shoreline vegetation is present, shoreline conditions should be evaluated, preferably by City staff, to assess if vegetation planting is viable based on the soil conditions, slope, water level and inundation frequency and wave disturbance.

EAV Planting/Management Cost Estimate: A cost estimate will be generated upon receipt of the shoreline survey data.

Project 3: Stormwater Reduction

In addition to the regional stormwater retrofit project outlined in AMEC (2016) there appear to be opportunities for the adoption of stormwater infiltration projects in other parts of the watershed. The Lake Hunter watershed has approximately 51 acres of the watershed classified as high infiltration soils. Lake Hunter is listed by FDEP as an impaired WBID, and is listed impaired for nutrients. This study supports the conclusion that the lake has water quality exceeding general NNC guidance for low-color, alkaline lakes. Data are currently not available to estimate the SIA acres required for a TP load reduction. However, SIA implementation could have the additional benefit of increasing storage to supplement dry season lake levels and a reduction in stormwater loads that can be later applied to a TMDL TP load reduction, if necessary. As such, SIA design should be focused on recharging the surficial aquifer.

SIA Cost Estimate: \$20,000 per raingarden for design, permitting, and construction; however, costs are highly dependent on availability of land and whether construction efforts are completed by the City or outsourced.

Project 4: Paleolimnology Study

The paleolimnological study for Lake Bonny (Whitmore et al. 2016) is current enough that its findings should be discussed with FDEP to ensure that the State's agencies are aware of the impractical nature of the existing NNC criteria for lakes such as Lake Hunter, which appears to have been lowered below their historical elevation, thus reducing their lake-wetland connection in such a way that the lake has likely become more susceptible to nutrient concentrations than it was historically. The complexity of the tannin-nutrient-phytoplankton relationships found for Lake Bonny are such that it was concluded that nutrient reduction alone, even if to pre-development concentrations, would not result in the lake also obtaining pre-development values for chlorophyll-a. The need for restoration of the lake's historical lake-wetland connectivity supports conclusions related to the need for such projects that was also reached for Lake Hancock (Tomasko et al. 2009).

Cost estimate: \$30,000 to \$50,000 per lake including coordination with FDEP to develop site-specific water quality targets for chlorophyll-a and nutrients to be used in impairment determinations and/or TMDLs.

Lake Mirror

Physical and chemical characteristics specific to Lake Mirror are presented here in the context of relevant regulatory criteria and requirements.

Historical and Recent Conditions in Lake and Watershed

Lake Mirror is a 19-acre lake located in the City within the eastern portion of Polk County, Florida (Figure 6-86). Maximum water depth is 17.1 feet, with an average water depth of 8.9 feet (City of Lakeland 2010). The lake is located within the Lakeland/Bone Valley Upland lake region of Florida, which according to Griffith et al. (1997), can be characterized with “high phosphorus, nitrogen, and chlorophyll-a values” and “alkaline, [with] some [lakes] receiving limestone-influenced groundwater.”

Lake Mirror is located within the Peace River watershed and the immediate contributing watershed to the lake is 123 acres in size, resulting in a watershed to open water ratio of 6.5 (Table 6-29; Figure 6-86). Watershed to open water ratios can be used to compare the relative amount of influence that a lake experiences from its contributing watershed, such as stormwater runoff. Lake Mirror is not influenced by inflows from any other lakes and its waters discharge to Lake Parker (at higher water levels) through an adjustable control structure (City of Lakeland 2010). The lake level appears to have mostly fluctuated within its structure operating range over the past thirty years (Figure 6-87). The operational water elevation range for Lake Mirror is 176.59 to 178.09 feet NAVD and within the Lake Mirror watershed, there is a moderate elevation gradient ranging from 178 to 220 feet NAVD (Figure 6-88). Lake Mirror is located between 80 and 90-foot potentiometric surface elevations and south of the potentiometric peak for the Floridan Aquifer (Figure 6-89). Additionally, the northern boundary of the intermediate aquifer system is just north of Lake Mirror (Spelcher and Kroening 2007). Therefore, it is unlikely that there is direct connectivity between Lake Mirror and either the intermediate or the Floridan aquifers.

By 1913, Sanborn maps identify numerous single family dwellings, a livery, and a hotel along the western border of Lake Mirror (Figures 6-90 and 6-91). A combination of residential and commercial development continued into the 1950’s with major development and improvements appearing to plateau in the late 1950s to 1960s, which had land cover mostly representative of existing development conditions (Figure 6-92). The extensive development within the watershed is reflected in the land use/land cover data provided by both USGS and SWFWMD (Table 6-30). Specifically, the SWFWMD land use data from 2011 classifies 100 acres (82%) as developed lands compared to 23 acres (18%) of undeveloped land (Figure 6-93).

There are 57 stormwater discharges in the Lake Mirror watershed, including 17 minor outfalls, 8 retention/detention outlets, seven stormwater discharges, three flumes, and 22 end of pipe inputs (Figure 6-94). The majority of the existing residential developments within the watershed utilize sanitary sewer for wastewater treatment provided by the City of Lakeland (2010), as only two OSTDS construction permits were identified within the watershed (Figure 6-95). Based on a review of SWFWMD soil survey geographic data, soils within the watershed have a low runoff potential with high, moderate, and low infiltration rates and are classified either as hydrologic soil

group A (3 acres) or C (15 acres), respectively (Figure 6-96). The majority of soils in the watershed are classified as “Urban Land Complex” (105 acres) which denotes areas that are more than 85 percent covered by development and as such should be considered to be predominantly impermeable.

As reported by City of Lakeland (2001), torpedo grass and primrose willow have historically inhabited the entire shoreline and Hydrilla has covered a majority of Lake Mirror’s surface. Removal efforts have included herbicide application, crane and clamshell removal, and harvesters. The majority of the shoreline vegetation has been modified as a result of residential encroachment, predominantly including landscaping and hardscaping activities. Sparse EAV is apparent on Google Earth imagery.

In December 2003, Chastain Skillman, Inc. (CSI) submitted a Lake Mirror Stormwater Master Plan. CSI recommended off-line stormwater treatment systems, a variety of BMPs, and catch basin inserts to reduce external nutrient loads to the lake.

TABLE 6-29. PHYSICAL CHARACTERISTICS OF LAKE MIRROR AND ADJACENT WATERSHED

Physical			
Location	City of Lakeland; Polk County	High infiltration soils (acres)	3
Relation to other lakes	Discharges to Lake Parker	Developed land (acres)	82
Watershed area (acres)	123	Undeveloped land (acres)	18
Lake area (acres)	19	Mean water depth (ft)	8.9
Perimeter (feet)	3,453	Maximum water depth (ft)	17.1
Surface area: lake volume ratio	0.11	Volume (acre-feet)	160
Watershed to surface area ratio	6.5		

TABLE 6-30. CHANGES IN LAND USE WITHIN THE LAKE MIRROR WATERSHED OVER TIME

Land Use	1970-1985*		1995		2011	
	Acres	Percent	Acres	Percent	Acres	Percent
Commercial and Services	86	69.4	79	64.3	75	60.4
Institutional			23	18.7	23	18.6
Open Land					4	3.3
Lakes	19	15.3	18	14.6	19	15.3
Residential	19	15.3	3	2.4	3	2.4

*Metadata for USGS land use data identifies data collection dates as a period between 1970 and 1985

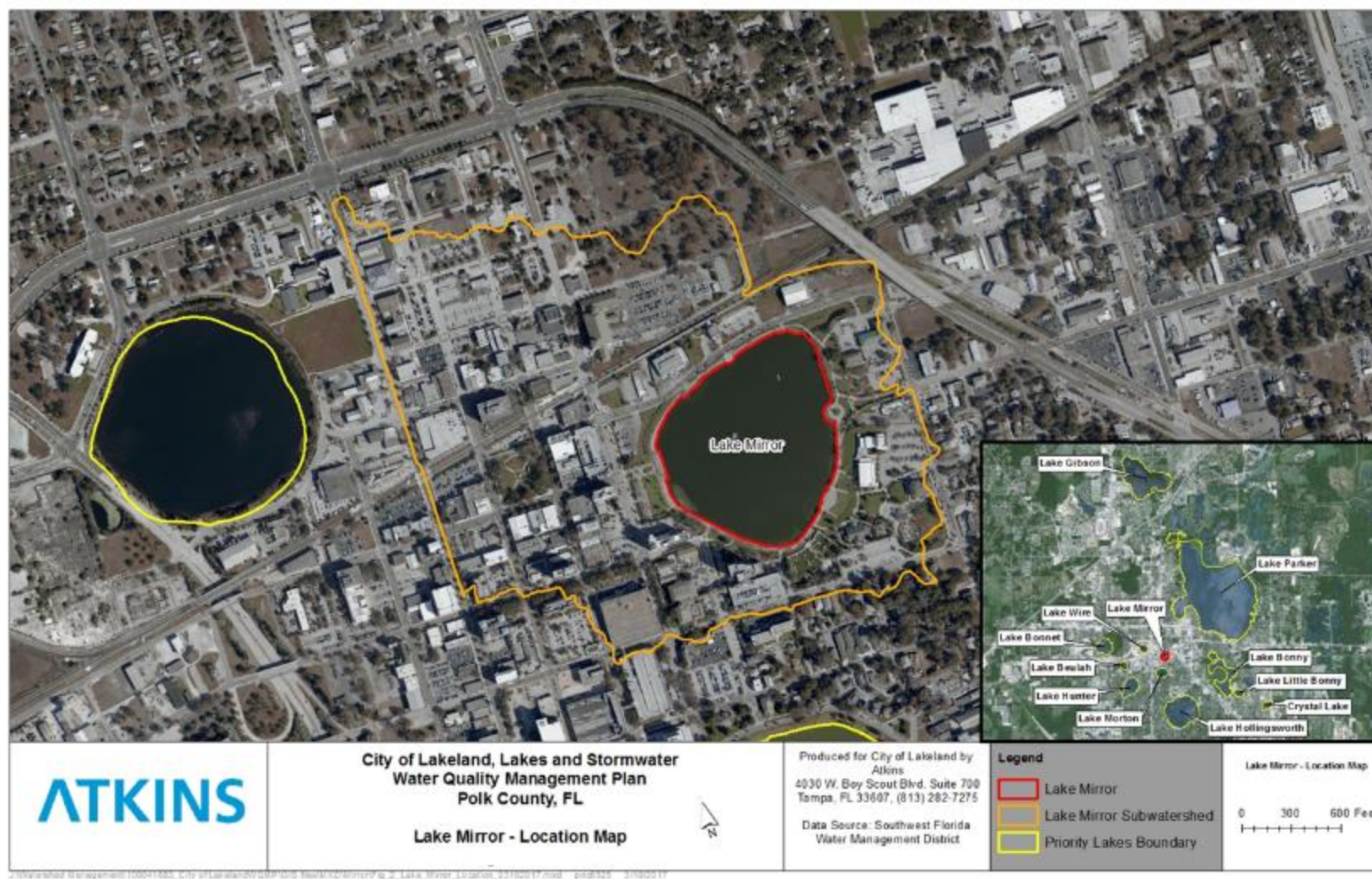


Figure 6-86. Lake Mirror location map

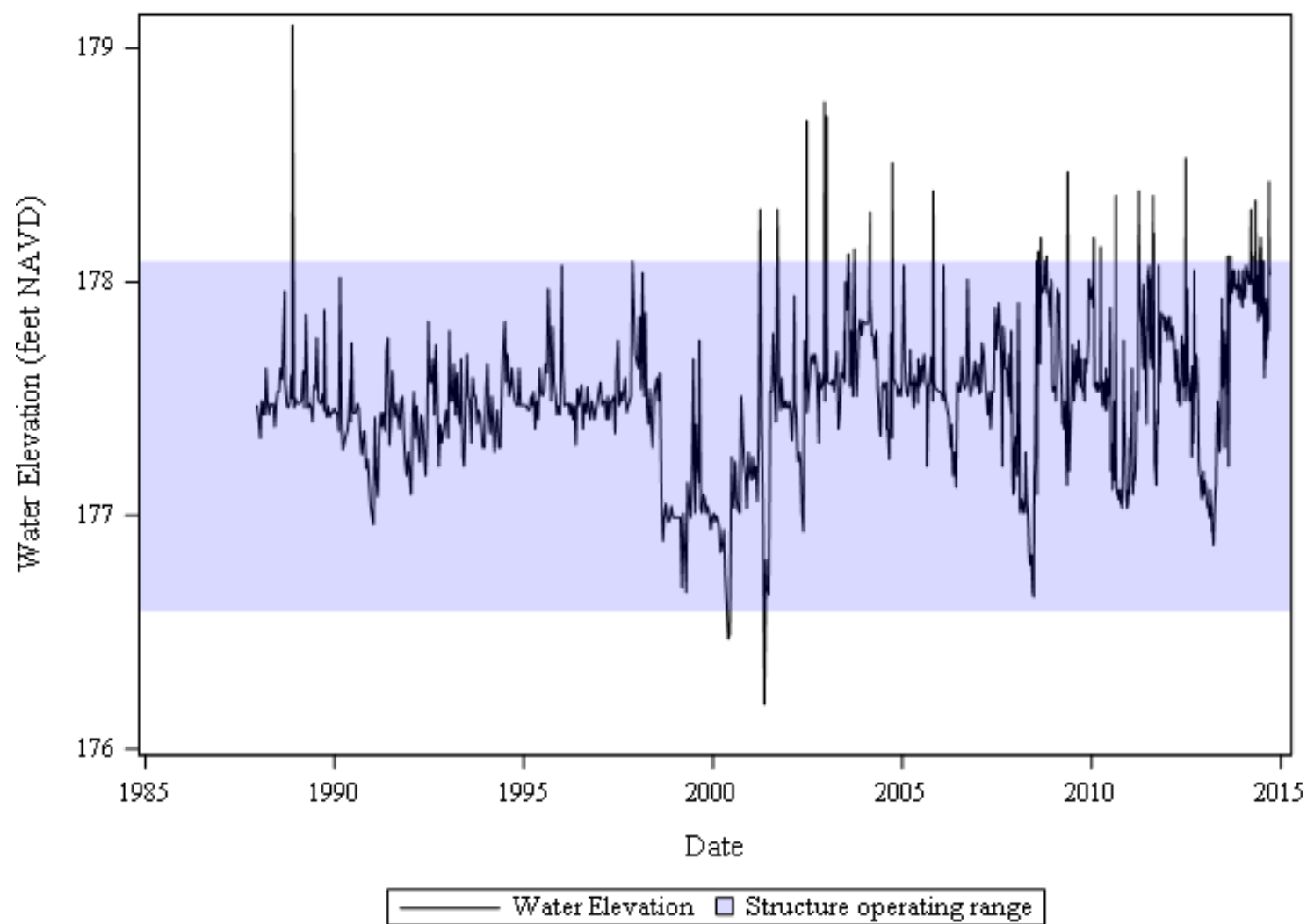


Figure 6-87. Period of record water elevation in Lake Mirror



Figure 6-88. Lake Mirror contour map

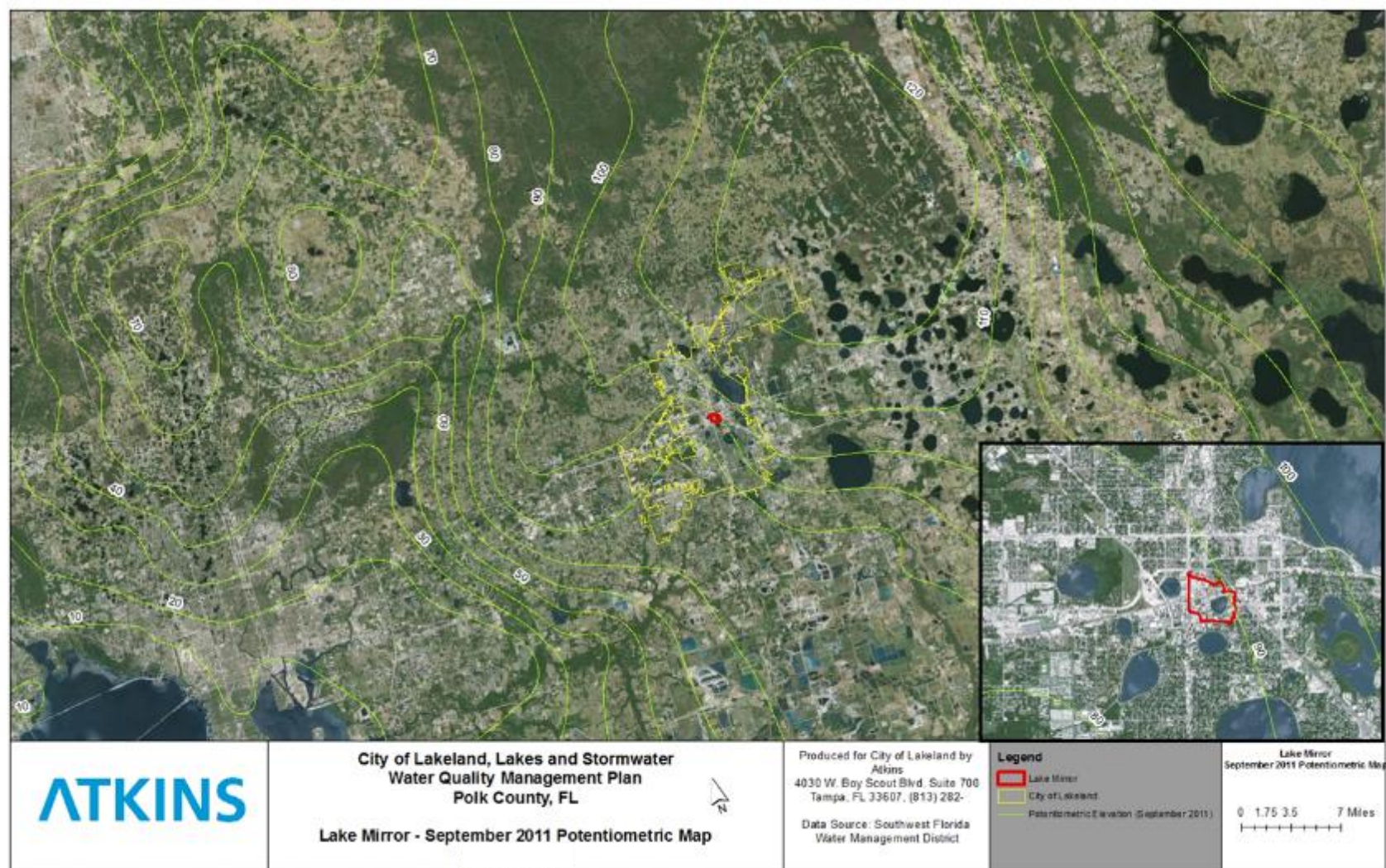


Figure 6-89. Lake Mirror potentiometric map

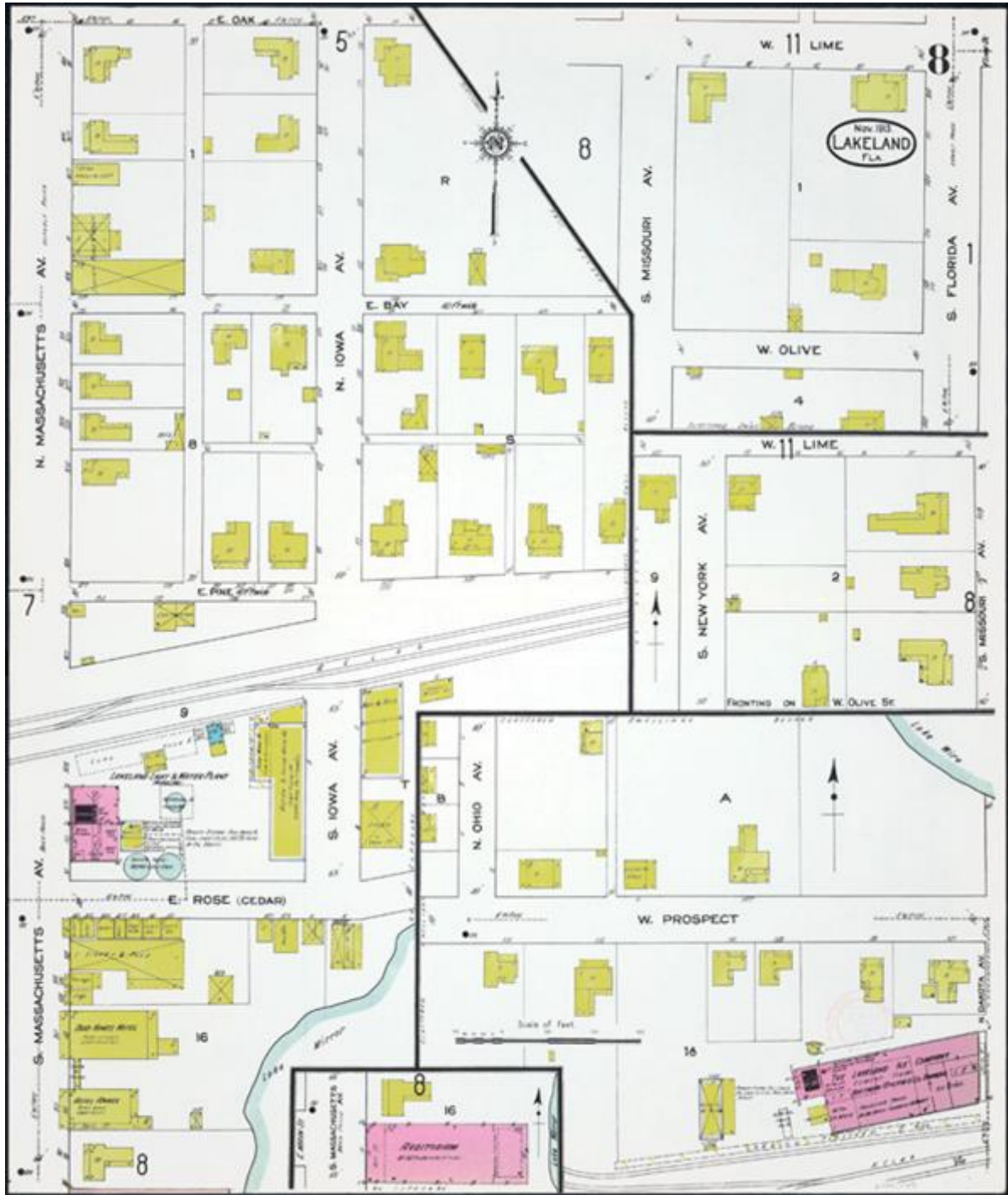


Figure 6-90. Northwestern portion of Lake Mirror watershed 1913 Sanborn map

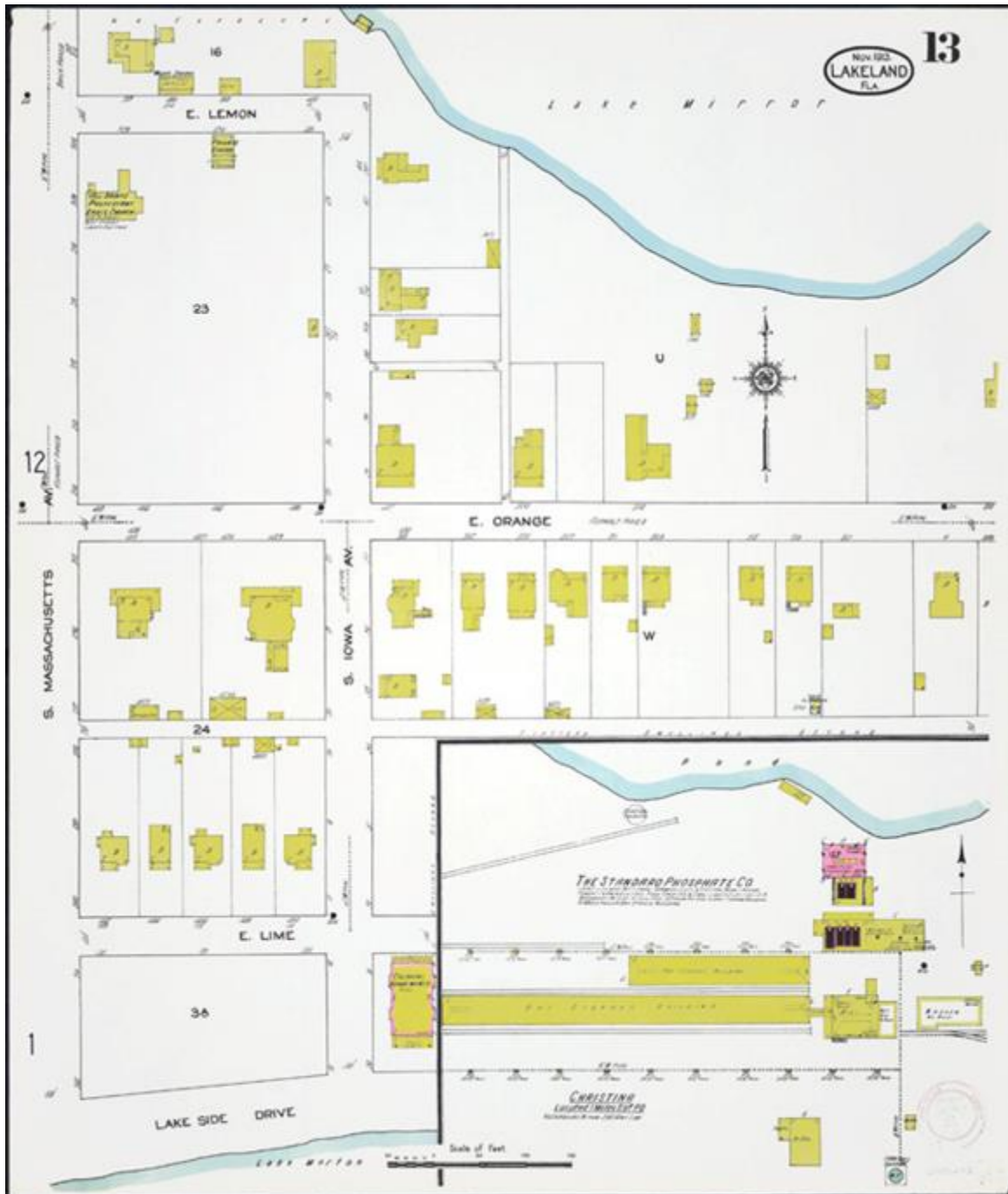


Figure 6-91. Southern portion of Lake Mirror watershed 1913 Sanborn map



Figure 6-92. Lake Mirror Historic aerial imagery. Left Photo: 1941. Right Photo: 1958

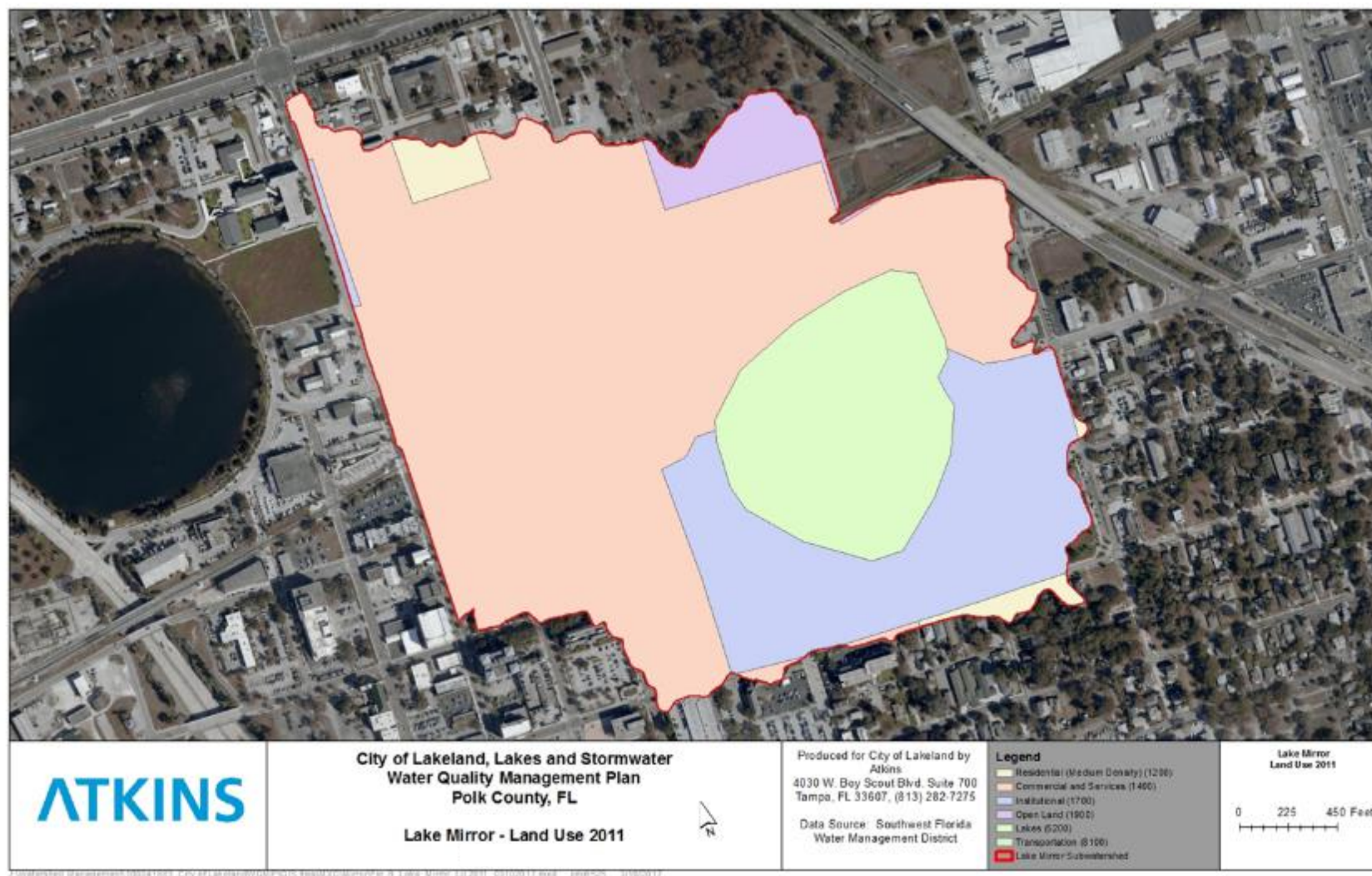


Figure 6-93. Lake Mirror 2011 land use map



Figure 6-94. Lake Mirror stormwater map

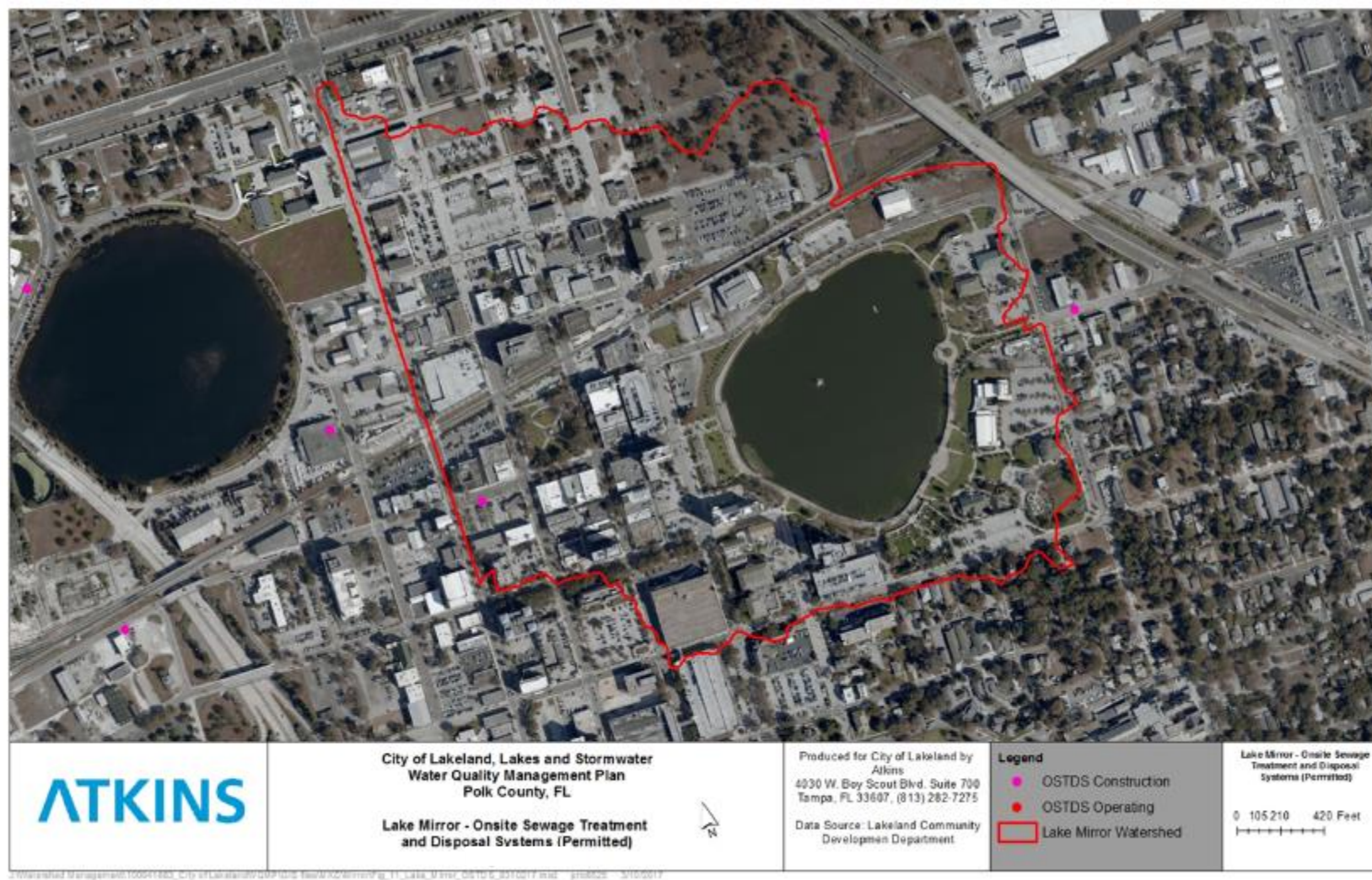


Figure 6-95. Lake Mirror OSTDS map

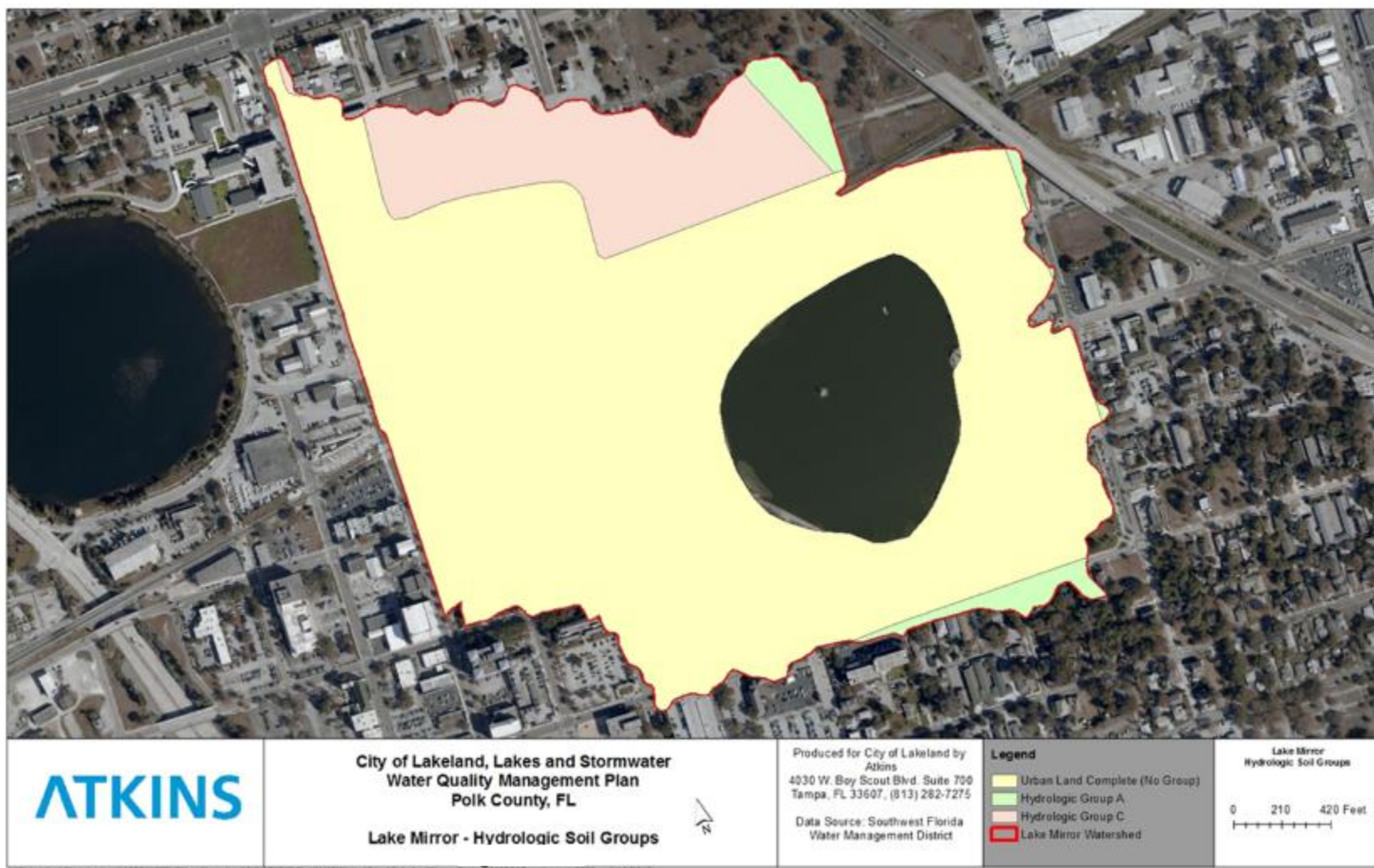


Figure 6-96. Lake Mirror soils map

Water Quality

Previously, Lake Mirror was listed as impaired for nutrients by the City even though the lake was not listed as impaired by FDEP (page 45 in City of Lakeland 2010). A few years later, Lake Mirror was listed as impaired for nutrients by FDEP (Atkins and ESA 2014). In FDEP's latest version of the Comprehensive Verified Impaired List (December 18, 2017) Lake Mirror is listed as impaired for nutrients. Lake Mirror is a Group 3 waterbody as part of the Upper Peace River, the most recent impairment evaluation was performed for the verified period of January 1, 2008 to June 30, 2015 (Cycle 3) which applied NNC as the numeric criteria. The cycle 4 assessment period will occur in 2021 for the verified period of January 1, 2013 to June 30, 2020.

To minimize the impacts of different verified periods, this report characterizes water quality for each of the City's priority lakes during the same time period, 1/1/2009 to 6/30/2016. These dates correspond to the most recent Verified Period assessment used by FDEP during which water quality data are fully available for analysis for determining impairment status.

Water quality data were downloaded from FDEP, and used to determine the classification of Lake Mirror. The lake was classified as a low-color, alkaline lake, based on a geometric mean value for color of 15 PCU and a geometric mean alkalinity value of 88 mg (as CaCO₃) / liter. Based on that classification, the water quality targets for TN and TP were then determined based on whether or not the annual geometric mean for a given year exceeds the threshold target of 20 µg chlorophyll-a / liter. The relevant water quality criteria for TN and TP for Lake Mirror are highlighted in yellow in Table 6-31. Based on the criteria provided below, Lake Mirror has the following exceedances (Table 6-32).

TABLE 6-31. WATER QUALITY CRITERIA FOR LAKE MIRROR, WITH RELEVANT TARGETS FOR CHLOROPHYLL-A, TN AND TP HIGHLIGHTED IN YELLOW.

Long Term Geometric Mean Lake color and Alkalinity	Annual Geometric Mean chlorophyll-a	Minimum calculated numeric interpretation		Maximum calculated numeric interpretation	
		Annual Geometric Mean TP	Annual Geometric Mean TN	Annual Geometric Mean TP	Annual Geometric Mean TN
> 40 PCU	20 µg/L	0.05 mg/L	1.27 mg/L	0.16 mg/L	2.23 mg/L
≤ 40 PCU and > 20 mg/L CaCO ₃	20 µg/L	0.03 mg/L	1.05 mg/L	0.09 mg/L	1.91 mg/L
≤ 40 PCU and ≤ 20 mg/L CaCO ₃	6 µg/L	0.01 mg/L	0.51 mg/L	0.03 mg/L	0.93 mg/L

TABLE 6-32. SUMMARY OF WATER QUALITY IMPAIRMENT DETERMINATIONS FOR LAKE MIRROR BY YEAR. YEARS WITH INSUFFICIENT DATA FOR COMPARISON WITH NNC CRITERIA ARE NOTED BY “-”.

Year	chlorophyll-a (µg / liter)	TN (mg / liter)	TP (mg / liter)
2009	52.90	1.297	0.098
2010	43.84	1.158	0.104
2011	43.19	1.353	0.082
2012	43.29	2.297	0.092
2013	-	-	-
2014	40.03	1.171	0.085
2015	-	-	-
2016	-	-	-
Average percent reduction required (when needed)	55	23	67

In the years 2009 to 2012, and again in 2014, chlorophyll-a values were collected in sufficient quantity (and seasonality) that annual geometric means could be calculated. In each year for which there were sufficient water quality data, Lake Mirror was impaired for chlorophyll-a, TN and TP. During those years, values for chlorophyll-a and TP (in particular) far exceeded NNC criteria for low-color, alkaline lakes. Based on examples included in both PBS&J (2011) and Tomasko et al. (2013) the chlorophyll-a and TP reductions required are in excess of the range of reductions seen with implementing traditional lake management techniques such as stormwater retrofits.

While no relationship could be found between TN and chlorophyll-a, there was a statistically significant relationship between TP and chlorophyll-a (Figures 6-97 and 6-98, respectively).

As previously shown in PBS&J (2011) and Atkins and ESA (2014) concentrations of TN in excess of ca. 2.5 mg / liter likely indicate the influence of nitrogen-fixing cyanobacteria, as such values are in excess of the highest TN concentrations expected in most urban and agricultural stormwater runoff. However, most of the TN data from Lake Mirror are lower than 2.5 mg / liter, which suggest that the lake is truly limited by the availability of TP. As such, Lake Mirror’s phytoplankton levels appear to require reductions in the amount of TP in the lake’s water column.

A statistical correlation between annual average nutrient concentrations and annual rainfall was not found, indicating that external sources such as stormwater runoff are not likely dominant influences on in-lake water quality. Based upon these results, projects which focus on stormwater retrofits are

not good candidates toward restoring water quality in Lake Mirror. However, the maintenance and enhancement of native emergent and submerged aquatic vegetation is recommended.

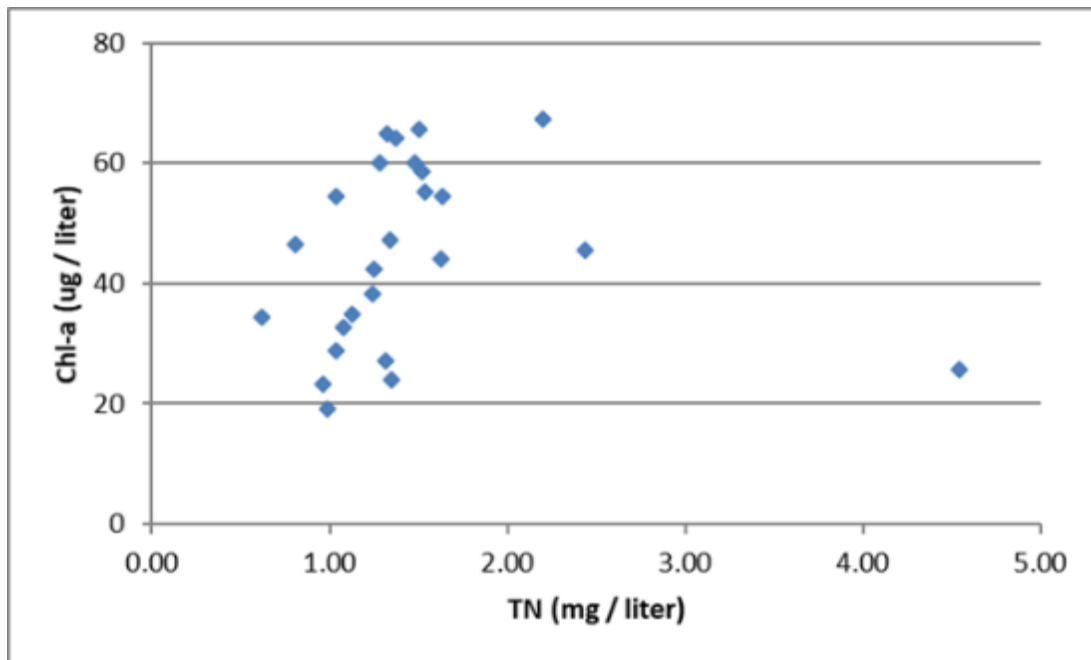


Figure 6-97. Relationship between TN and chlorophyll-a.

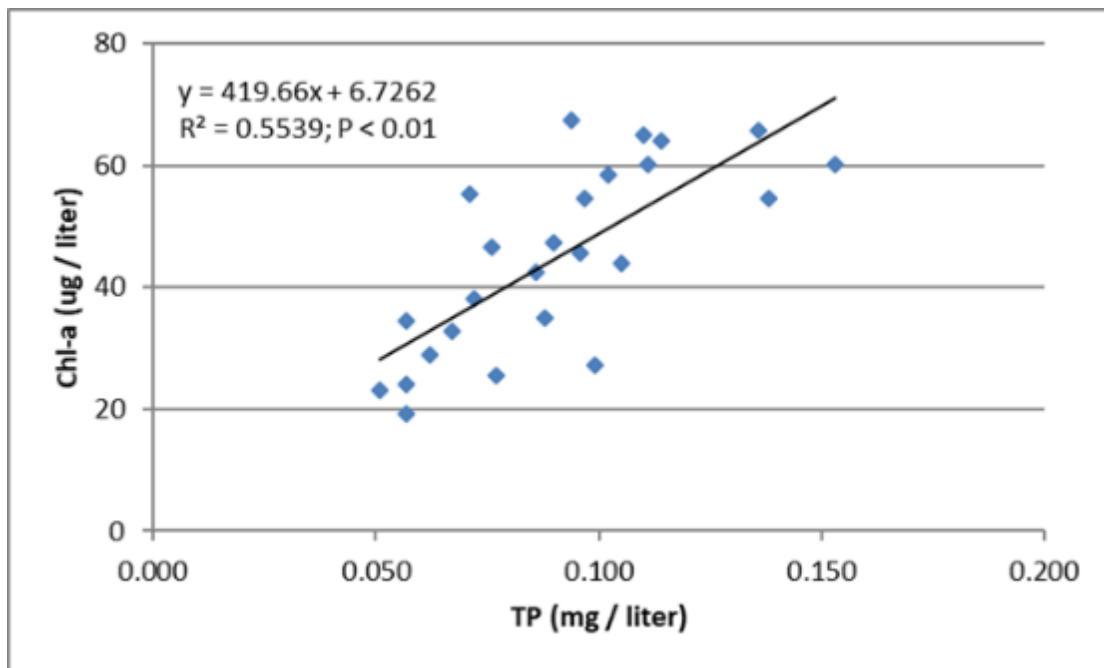


Figure 6-98. Relationship between TP and chlorophyll-a. Line is best fit equation of statistically significant ($p < 0.05$) relationship

Lake sediment resuspension was not identified as a likely source of internal nutrient loads to the overlying water column, as there was not an inverse relationship between TP concentrations and water levels, and no clear evidence of the influence of any past point source discharges to the lake. Sediment removal and/or sediment inactivation projects are thus not recommended, as there is no clear evidence of sediment resuspension as a major stressor to the lake. However, whole-lake circulation is recommended based on the lake size, and the past ability of such techniques to improve water quality in phosphorus-limited lakes.

An evaluation into the potential loss of wetland influences was performed through the analysis of the historical versus current lake extent. This analysis was inconclusive to determine if there has been a long-term change in lake water elevation. The geomorphology of the lake is such that Lake Mirror would be classified as a “ridge” lake, thus wetland influences on water quality are not likely as critical to assess. In fact, for Lake Mirror, any discussion of wetland – lake interactions is moot since absolutely no wetland fringe remains (it is completely surrounded by impervious ground cover and developed up to the water’s edge all the way around).

Although Lake Mirror clearly exhibits signs of nutrient enrichment, site-specific chlorophyll-a, TN, and TP targets have not been established and thus may be appropriate. collection and analysis of locally-derived paleo data is advisable if the City decides to pursue establishing site-specific criteria for Lake Mirror. Based on examples contained within both PBS&J (2011) and Tomasko et al. (2013) the TN and TP reductions required for Lake Mirror to meet NNC guidance are outside the reasonable obtainable range for lakes where whole-lake aeration has been applied, even if the technique actually proves to be able to improve water quality in the lake.

However, Lake Mirror is small enough to fit within the category of lakes where whole lake aeration has been suggested before as a feasible management action (PBS&J 2010). Aeration may be well worth examining, as part of a paired study with Lake Morton, to ascertain the feasibility of implementing such in City lakes of this type and size. If aeration can improve water quality in Lake Mirror, the chances of rehabilitating SAV and other aquatic macrophyte communities will likely improve. Lake Mirror is relatively sparsely vegetated and re-vegetation of the littoral zone should be a priority in this lake.

Water Quality Restoration Project Selection and Priorities

Based on Lake Mirror water quality and the surrounding watershed characteristics, four potential water quality restoration projects were identified using the City’s WQMP decision key. Projects to address water quality, nutrient and sediment loading, and reduced lake levels are proposed. A detailed discussion of the potential water quality restoration implications for each project can be found in Section 4.0.

Project 1: Artificial Circulation

Project 2: SAV Planting/Management or FTWs

Project 3: EAV Planting/Management

Project 4: Develop reasonable water quality targets through paleolimnology and coordination with FDEP

Project 1: Artificial Circulation

The project design is based on the assumption that the system configuration developed by SolarBee® for previous lake circulation projects is applicable to Lake Mirror. Therefore, each circulation pump is assumed to effectively circulate 16 to 20 acres. The surface area of Lake Mirror is 19 acres requiring the purchase and installation of one SB10000 v 18 machines. Prior to implementation of artificial circulation, a feasibility study to characterize the sediment quality, water column profiles and water depth within the lake.

Cost Estimate: \$100,000 (estimate based on cost provided by Solar Bee® for the purchase, delivery and installation of one unit). Based upon prior experience, the feasibility study could be completed for approximately \$50,000.

Project 2: SAV Planting/Management or FTWs

SAV Planting

A survey of existing SAV cover in Lake Mirror is recommended due to the lack of sufficient data to calculate percent lake cover. Based on the results of the SAV survey, conclusions regarding SAV planting can be determined. If SAV cover is less than 30 percent, lake conditions should be evaluated to assess if additional SAV is viable based on the soil condition, water clarity and water depth.

Based on the median Secchi depth (0.7 meter) from the POR (1988 to 2017), plants would not be planted in water depths greater than 0.9 meter (Water Atlas). The maximum planting effort for Lake Mirror cannot be calculated until digital bathymetry data are acquired.

Bathymetric Survey Cost Estimate: \$10,000

SAV Planting/Management Cost Estimate: A cost estimate will be generated upon receipt of the bathymetry data.

FTWs

If the feasibility study indicates that more than 30 percent of Lake Mirror has SAV cover, FTW may be considered. The installation of floating mats with appropriate aquatic vegetation would be expected to assimilate nutrients from the water column.

Project 3: EAV Planting

A survey of existing shoreline vegetation surrounding Lake Mirror is recommended due to the lack of sufficient data at this time. Based on the results of the shoreline survey, conclusions and recommendations regarding emergent aquatic or woody vegetation planting can be determined. If limited shoreline vegetation is present, shoreline conditions should be evaluated, preferably by City

staff, to assess if vegetation planting is viable based on the soil conditions, slope, water level and inundation frequency and wave disturbance.

EAV Planting/Management Cost Estimate: A cost estimate will be generated upon receipt of the shoreline survey data.

Project 4: Paleolimnology Study

A recurring issue is the need for site-specific water quality targets for each of the 11 lakes. A consideration, however, is the ability of FDEP to allow for target values of chlorophyll-a, TN, and TP that are higher than those contained within NNC (as outlined in FAC 62-302.531). If FDEP allows for the use of these proposed site specific alternative criteria under a BMAP scenario, a valid argument could also be made that all City lakes classified as low-color, alkaline, valley lakes should have the same target values (City lakes classified as ridge lakes may warrant additional paleo studies and subsequent water quality target derivations for ratification by the FDEP). This would not be an unreasonable request as FDEP has used paleo data in the past to set TMDL water quality targets for the Southern Chain of Lakes in Winter Haven (FDEP 2007). Locally-derived paleo data and corresponding TN, TP, and chlorophyll-a targets should ideally be determined for Lake Mirror and used as interim lake management goals, pending review and approval of more site specific targets by FDEP.

Cost estimate: \$30,000 to \$50,000 per lake including coordination with FDEP to develop site-specific water quality targets for chlorophyll-a and nutrients to be used in impairment determinations and/or TMDLs.

Lake Morton

Physical and chemical characteristics specific to Lake Morton are presented here in the context of relevant regulatory criteria and requirements.

Historical and Recent Conditions in Lake and Watershed

Lake Morton is a 41-acre lake located in the City within the eastern portion of Polk County, Florida (Figure 6-99). Maximum water depth is 22.0 feet, with an average water depth of 11.8 feet (City of Lakeland 2010). The lake is located within the Lakeland/Bone Valley Upland lake region of Florida, which according to Griffith et al. (1997), can be characterized with “high phosphorus, nitrogen, and chlorophyll-a values” and “alkaline, [with] some [lakes] receiving limestone-influenced groundwater.”

Lake Morton is located within the Peace River watershed and the immediate contributing watershed to the lake is 175 acres in size, resulting in a watershed to open water ratio of 4.3 (Table 6-33; Figure 6-99). Watershed to open water ratios can be used to compare the relative amount of influence that a lake experiences from its contributing watershed, such as stormwater runoff. Lake Morton is not influenced by inflows from any other lakes and its waters discharge to either Lake Hollingsworth and/or Lake Horney via an adjustable control structure and a downstream in-pipe

diversion dam (City of Lakeland 2010). Over the past three decades, Lake Morton water elevations have largely remained within the structure operating range, with the notable exception of a substantial reduction in water elevation that occurred in 2006 to 2007 (Figure 6-100). The operational water elevation range for Lake Morton is 176.60 to 177.80 feet NAVD. Within the Lake Morton watershed, there is a moderate elevation gradient NAVD (Figure 6-101). Lake Morton is located between 80 and 90-foot potentiometric surface elevations for the Floridan aquifer and south of the potentiometric peak (Figure 6-102). Additionally, the northern boundary of the intermediate aquifer system is just north of Lake Morton (Spelcher and Kroening 2007). Therefore, it is unlikely that there is direct connectivity between Lake Morton and either the intermediate or the Floridan aquifers.

As early as 1917, Sanborn maps identify numerous single family dwellings, a school, and Lake Morton Drive along the southeastern border of Lake Morton (Figures 6-103 and 6-104). A combination of residential and commercial development continued into the 1950's, with major development and improvements in place by 1968. As a result, the landscape features from 50 years ago are mostly similar to existing conditions (Figure 6-105). The extensive development within the watershed is reflected in the land use/land cover data provided by both USGS and SWFWMD (Table 6-34). Specifically, the SWFWMD land use data from 2011 classifies 134 acres (76%) as developed lands compared to 41 acres (24%) of undeveloped land (Figure 6-106).

There are 54 stormwater discharges in the Lake Morton watershed, including 36 minor outfalls, one retention/detention outlet, one lake/creek outlet, 15 end of pipe inputs, and one major outfall (Figure 6-107). The existing residential developments within the watershed utilize sanitary sewer for wastewater treatment provided by the City of Lakeland (2010) as there are no permitted OSTDS identified within the watershed (Figure 6-108). Based on a review of SWFWMD soil survey geographic data, soils within the watershed have a low runoff potential with high, moderate, and low infiltration rates and are classified either as hydrologic soil group A (77 acres) and B/D (15 acres), respectively (Figure 6-109). A large portion of soils in the watershed are classified as "Urban Land Complex" (83 acres) which denotes areas that are more than 85 percent covered by development and as such should be considered to be predominantly impermeable.

The majority of the shoreline vegetation has been modified as a result of residential and commercial encroachment, predominantly including landscaping activities. Sparse EAV is apparent on Google Earth imagery.

In 2002, Environmental Research & Design, Inc. (ERD) submitted a Water Quality Diagnostic Evaluation report to City. In that report, Lake Morton was described as eutrophic or hypereutrophic since at least the late 1980s, with poor water clarity and consistent algal blooms. Additionally, ERD (2002) identified untreated stormwater runoff discharges and numerous waterfowl as pollutant inputs. That report developed hydrologic and nutrient budgets for Lake Morton, including quantification of nutrient and pollutant inputs from stormwater runoff, waterfowl, groundwater seepage, bulk precipitation, and recycling from bottom sediments. The report recommended an in-lake alum treatment system to be operated on a continuous basis via a bottom-mounted aeration unit, as well as pointing out the impact to water quality of the large number of waterfowl.

In May 2005, BCI prepared a Joint Environmental Resource Permit/Federal Dredge and Fill Permit Application for City. According to the application, an average of 15 feet of uplands has been lost since the mid- 1980s, open water has encroached within 20 feet of City streets, and the shoreline was nearly a vertical escarpment, lacking in wetland vegetation. Recommended recovery and improvements to Lake Morton included shoreline recovery, stabilization, and management, re-paving nearby asphalt roads with brick, and adding and improving park amenities.

TABLE 6-33. PHYSICAL CHARACTERISTICS OF LAKE MORTON AND ADJACENT WATERSHED

Physical			
Location	City of Lakeland; Polk County	High infiltration soils (acres)	77
Relation to other lakes	Discharges to Lake Hollingsworth and/or Lake Horney	Developed land (acres)	134
Watershed area (acres)	175	Undeveloped land (acres)	41
Lake area (acres)	41	Mean water depth (ft)	3.9
Perimeter (feet)	4,529	Maximum water depth (ft)	14.2
Surface area: lake volume ratio	0.016	Volume (acre-feet)	2,433
Watershed to surface area ratio	4.3		

TABLE 6-34. CHANGES IN LAND USE WITHIN THE LAKE MORTON WATERSHED OVER TIME

Land Use	1970-1985*		1995		2011	
	Acres	Percent	Acres	Percent	Acres	Percent
Commercial and Services	86	69.4	79	64.3	75	60.4
Institutional			23	18.7	23	18.6
Open Land					4	3.3
Lakes	19	15.3	18	14.6	19	15.3
Residential	19	15.3	3	2.4	3	2.4

*Metadata for USGS land use data identifies data collection dates as a period between 1970 and 1985



Figure 6-99. Lake Morton location map

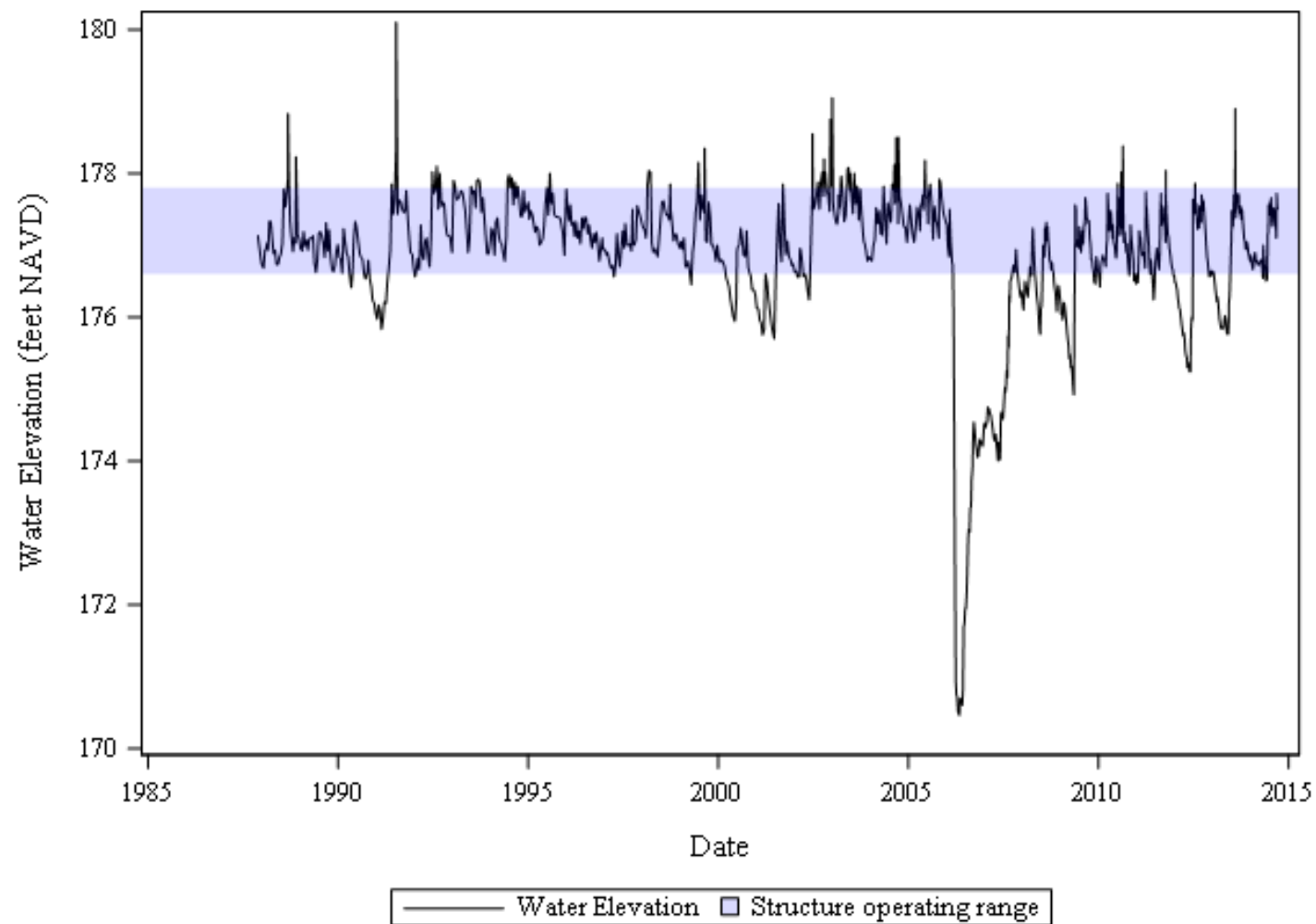


Figure 6-100. Period of record water elevation for Lake Morton



Figure 6-101. Lake Morton contour map

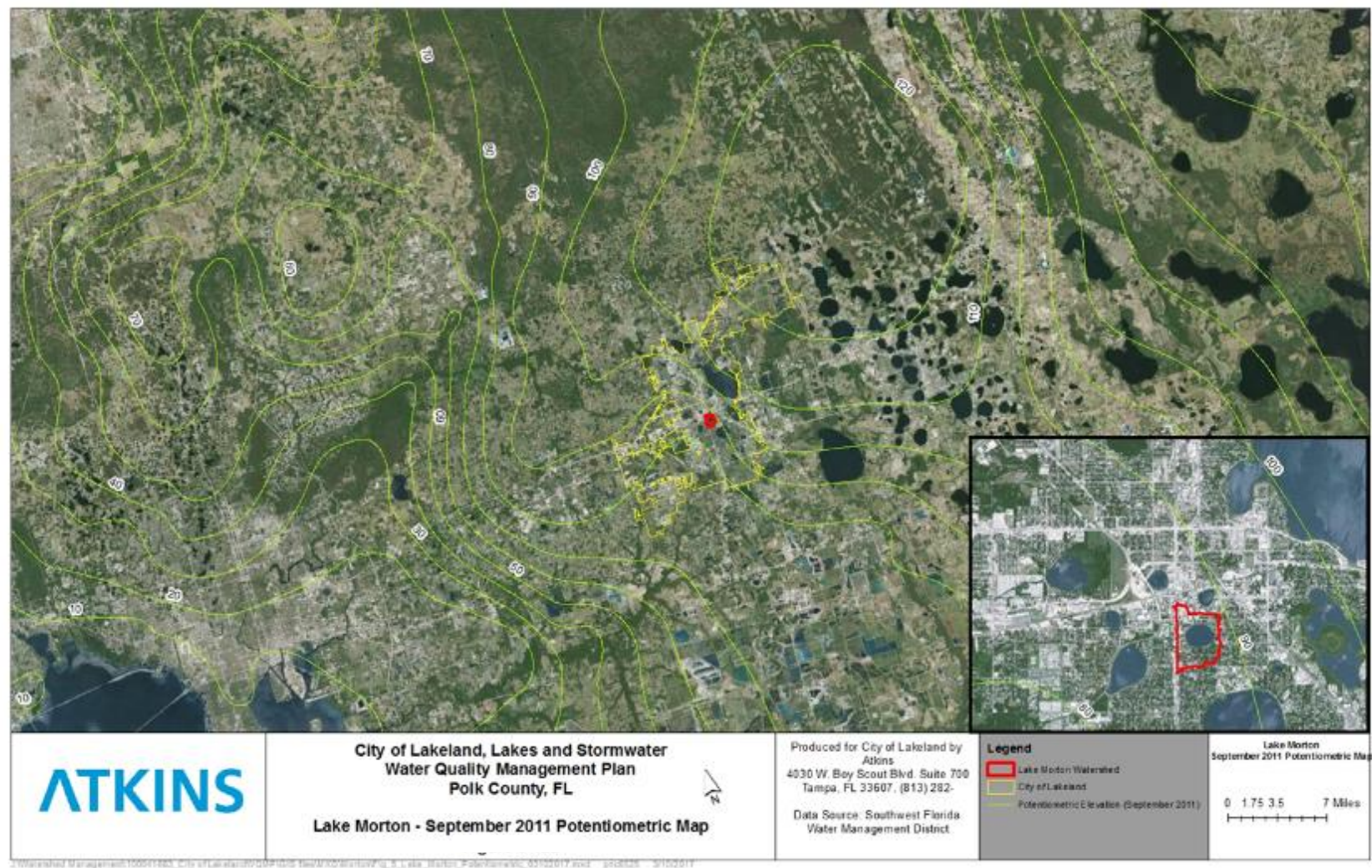


Figure 6-102. Lake Morton potentiometric map

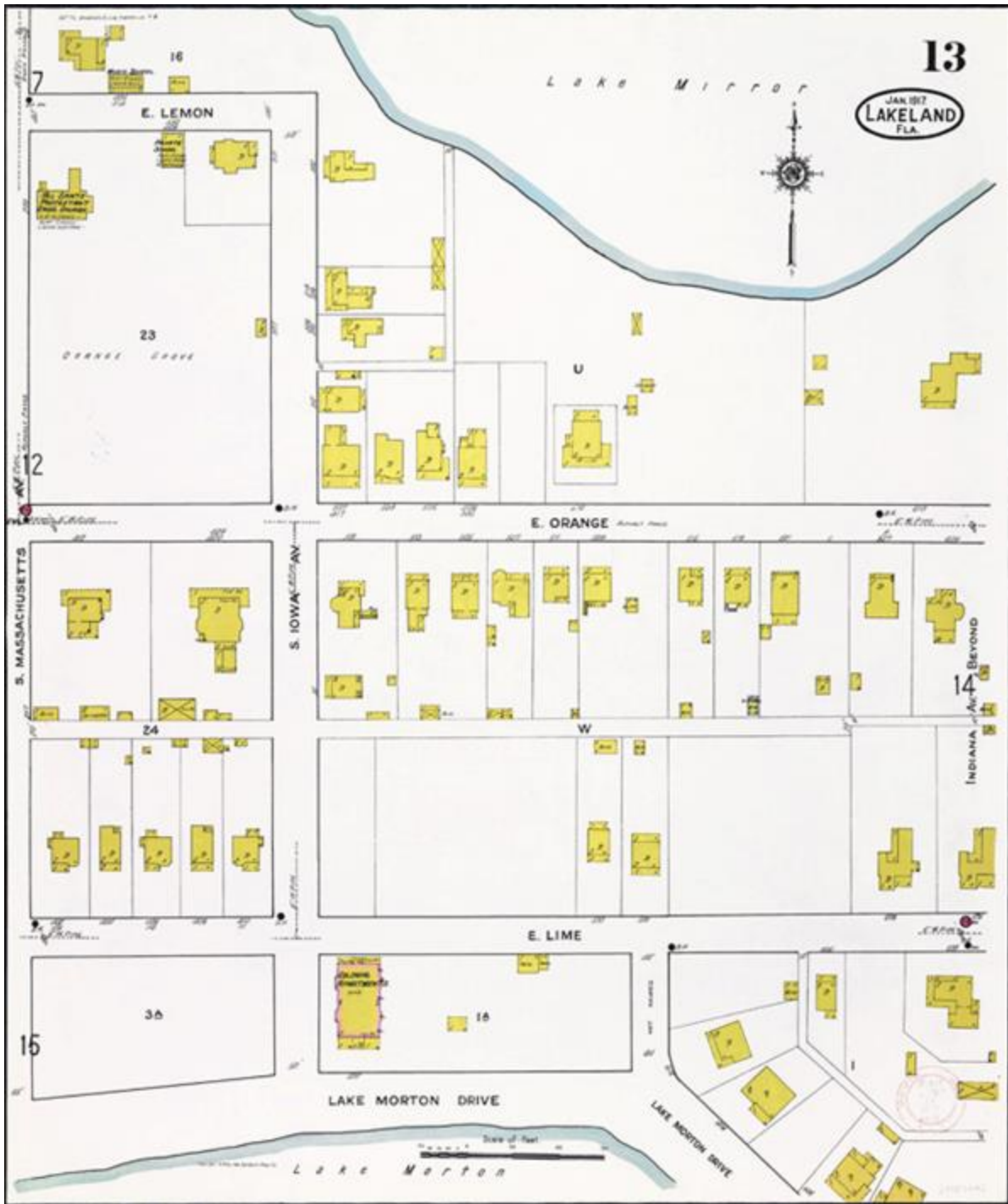


Figure 6-103. Northern portion of Lake Morton watershed 1917 Sanborn map

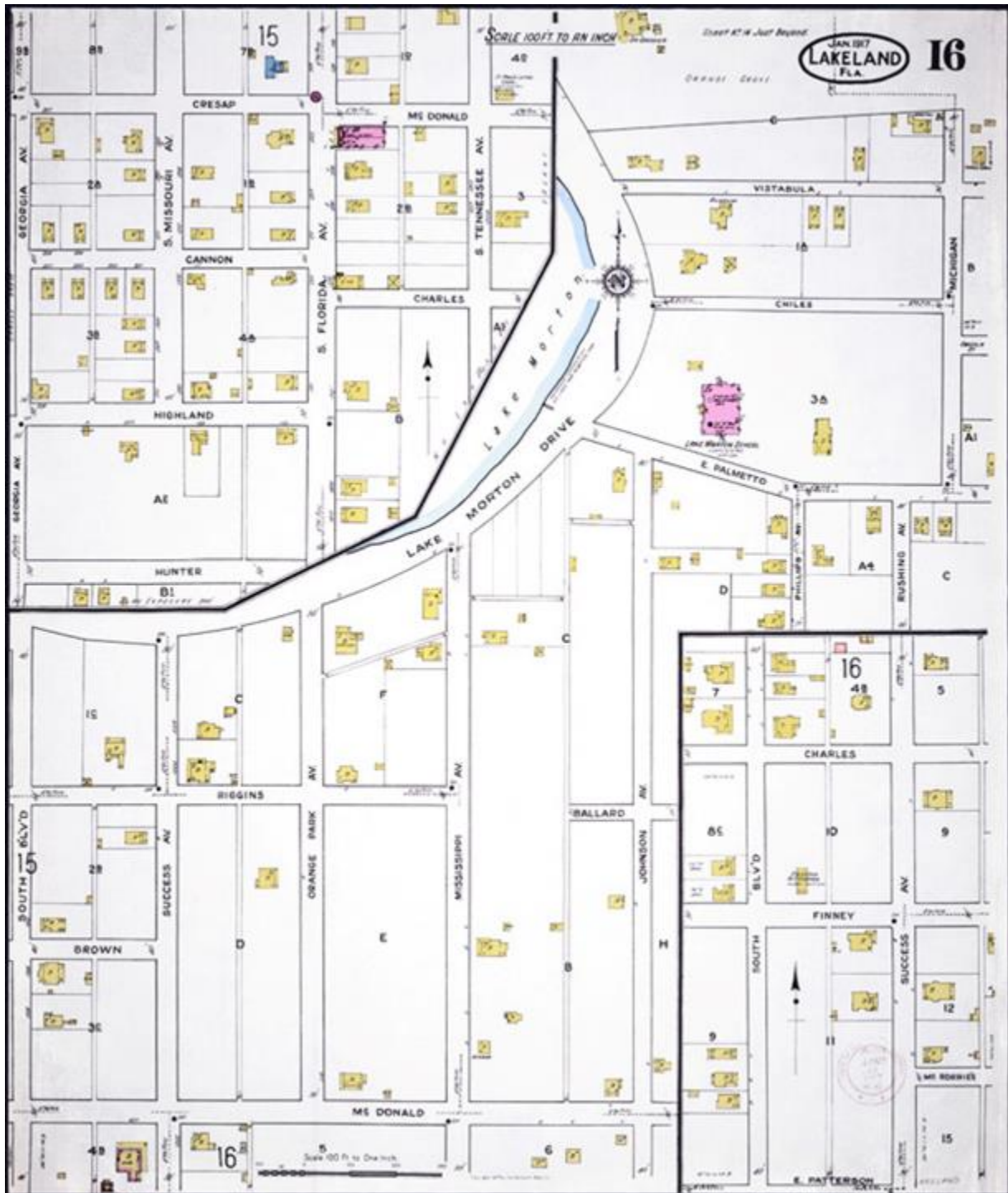


Figure 6-104. Southeastern portion of Lake Morton watershed 1917 Sanborn map



Figure 6-105. Lake Morton Historic aerial imagery. Left Photo: 1941. Right Photo: 1968

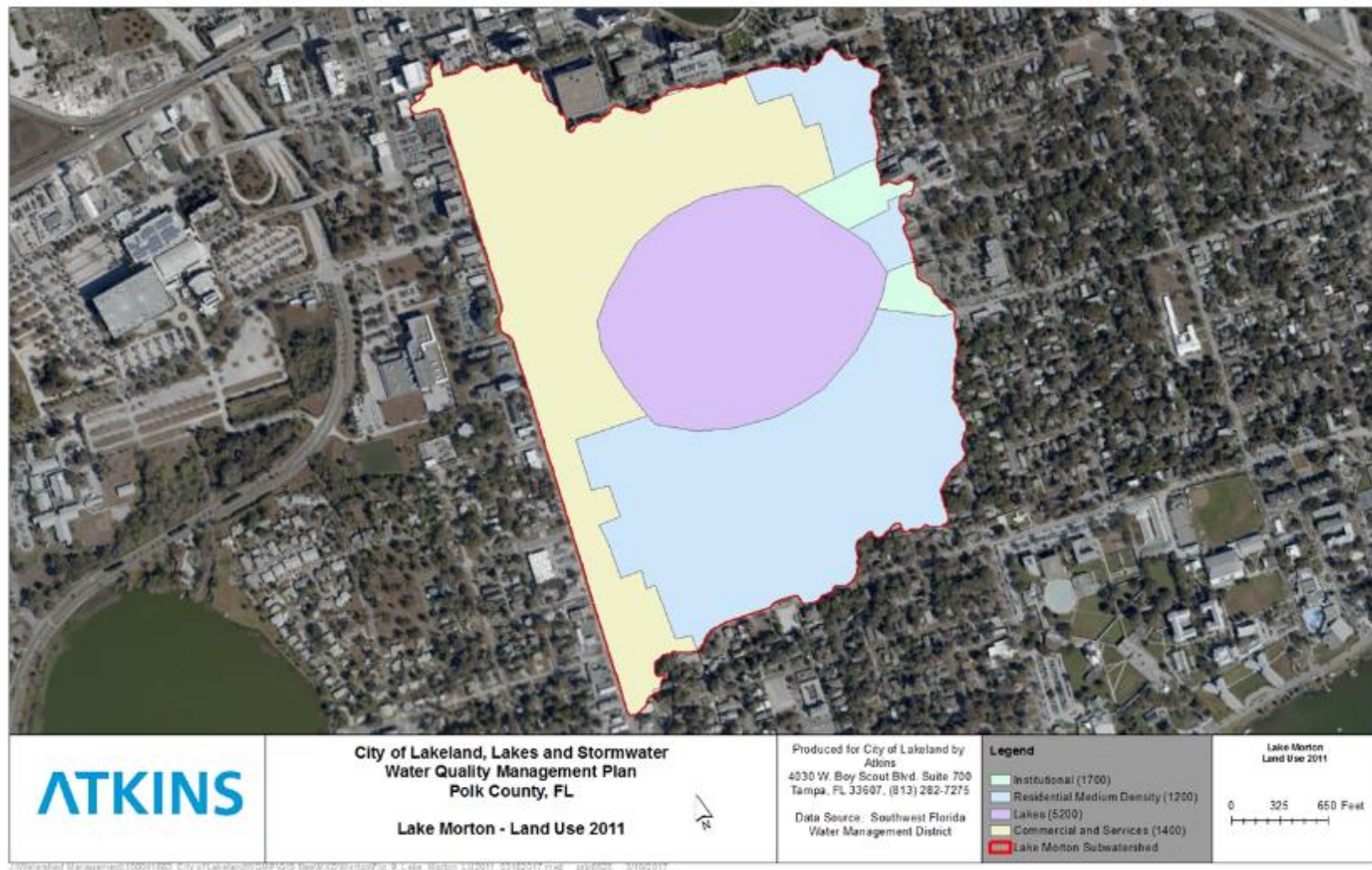


Figure 6-106. Lake Morton 2011 land use map



Figure 6-107. Lake Morton stormwater map

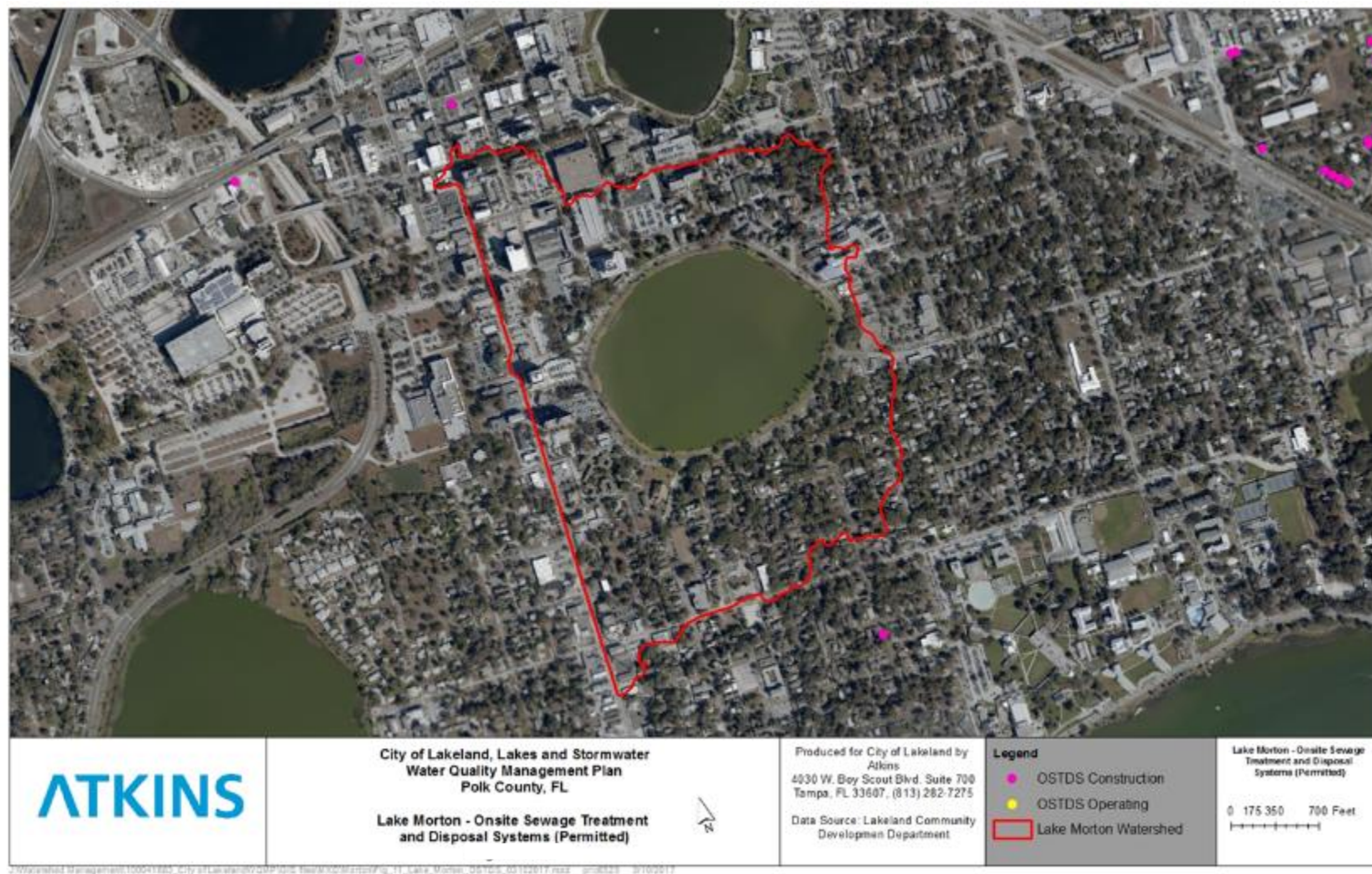


Figure 6-108. Lake Morton OSTDS map

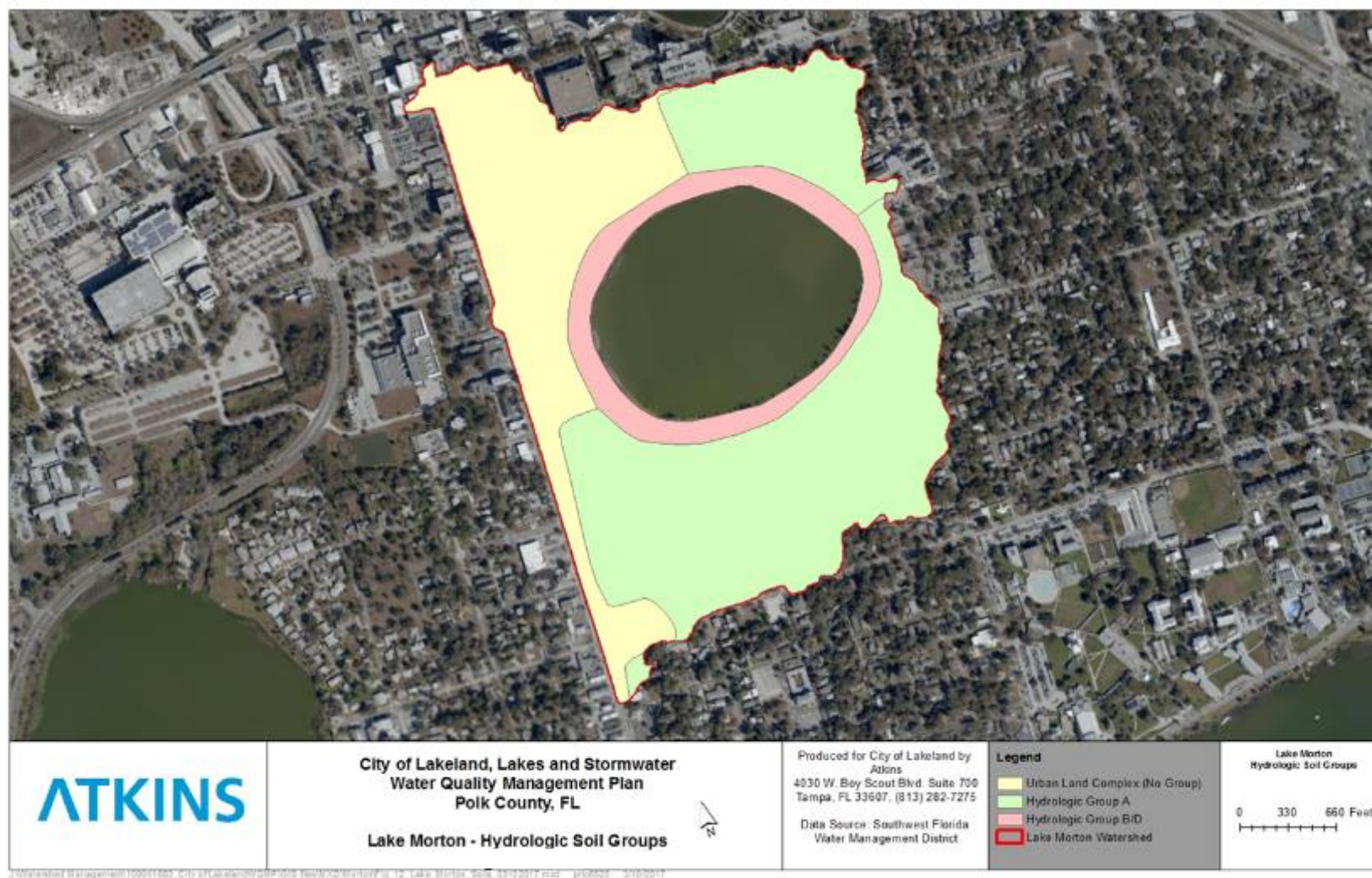


Figure 6-109. Lake Morton soils map

Water Quality

Previously, Lake Morton was listed as impaired for nutrients by the City (2010) even though the lake was not listed as impaired by FDEP at that time (page 47 in City of Lakeland 2010). A few years later, Lake Morton was listed as impaired for nutrients by FDEP (Atkins and ESA 2014). In FDEP's latest version of the Comprehensive Verified Impaired List (December 18, 2017) Lake Morton is not listed as impaired for nutrients. Lake Morton is a Group 3 waterbody as part of the Upper Peace River, the most recent impairment evaluation was performed for the verified period of January 1, 2008 to June 30, 2015 (Cycle 3) which applied NNC as the numeric criteria. The cycle 4 assessment period will occur in 2021 for the verified period of January 1, 2013 to June 30, 2020.

To minimize the impacts of different verified periods, this report characterizes water quality for each of the City's priority lakes during the same time period, 1/1/2009 to 6/30/2016. These dates correspond to the most recent Verified Period assessment used by FDEP during which water quality data are fully available for analysis for determining impairment status.

Water quality data were downloaded from FDEP, and used to determine the classification of Lake Morton. The lake was classified as a low-color, alkaline lake, based on a geometric mean value for color of 16 PCU and a geometric mean alkalinity value of 66 mg (as CaCO₃) / liter. Based on that classification, the water quality targets for TN and TP were then determined based on whether or not the annual geometric mean for a given year exceeds the threshold target of 20 µg chlorophyll-a / liter. The relevant water quality criteria for TN and TP for Lake Morton are highlighted in yellow in Table 6-35. Based on the criteria provided below, Lake Morton has the following exceedances (Table 6-36).

TABLE 6-35. WATER QUALITY CRITERIA FOR LAKE MORTON, WITH RELEVANT TARGETS FOR CHLOROPHYLL-A, TN AND TP HIGHLIGHTED IN YELLOW.

Long Term Geometric Mean Lake color and Alkalinity	Annual Geometric Mean chlorophyll-a	Minimum calculated numeric interpretation		Maximum calculated numeric interpretation	
		Annual Geometric Mean TP	Annual Geometric Mean TN	Annual Geometric Mean TP	Annual Geometric Mean TN
> 40 PCU	20 µg/L	0.05 mg/L	1.27 mg/L	0.16 mg/L	2.23 mg/L
≤ 40 PCU and > 20 mg/L CaCO ₃	20 µg/L	0.03 mg/L	1.05 mg/L	0.09 mg/L	1.91 mg/L
≤ 40 PCU and ≤ 20 mg/L CaCO ₃	6 µg/L	0.01 mg/L	0.51 mg/L	0.03 mg/L	0.93 mg/L

TABLE 6-36. SUMMARY OF WATER QUALITY IMPAIRMENT DETERMINATIONS FOR LAKE MORTON BY YEAR. YEARS WITH INSUFFICIENT DATA FOR COMPARISON WITH NNC CRITERIA ARE NOTED BY “-”.

Year	chlorophyll-a (µg / liter)	TN (mg / liter)	TP (mg / liter)
2009	53.56	1.538	0.083
2010	62.03	1.309	0.102
2011	64.48	1.881	0.094
2012	52.40	1.615	0.082
2013	-	-	-
2014	68.15	1.928	0.106
2015	-	-	-
2016	-	-	-
Average percent reduction required (when needed)	66	35	68

In the years 2009 to 2012, and again in 2014, chlorophyll-a values were collected in sufficient quantity (and seasonality) that annual geometric means could be calculated. In each year for which there were sufficient water quality data, Lake Morton was impaired for chlorophyll-a, TN and TP. During those years, values for chlorophyll-a and TP (in particular) far exceeded NNC criteria for low-color, alkaline lakes. Based on examples included in both PBS&J (2011) and Tomasko et al. (2013) the chlorophyll-a and TP reductions required are in excess of the range of reductions seen with implementing traditional lake management techniques such as stormwater retrofits.

Statistically significant relationships were found between TN and chlorophyll-a and also between TP and chlorophyll-a (Figures 6-110 and 6-111, respectively).

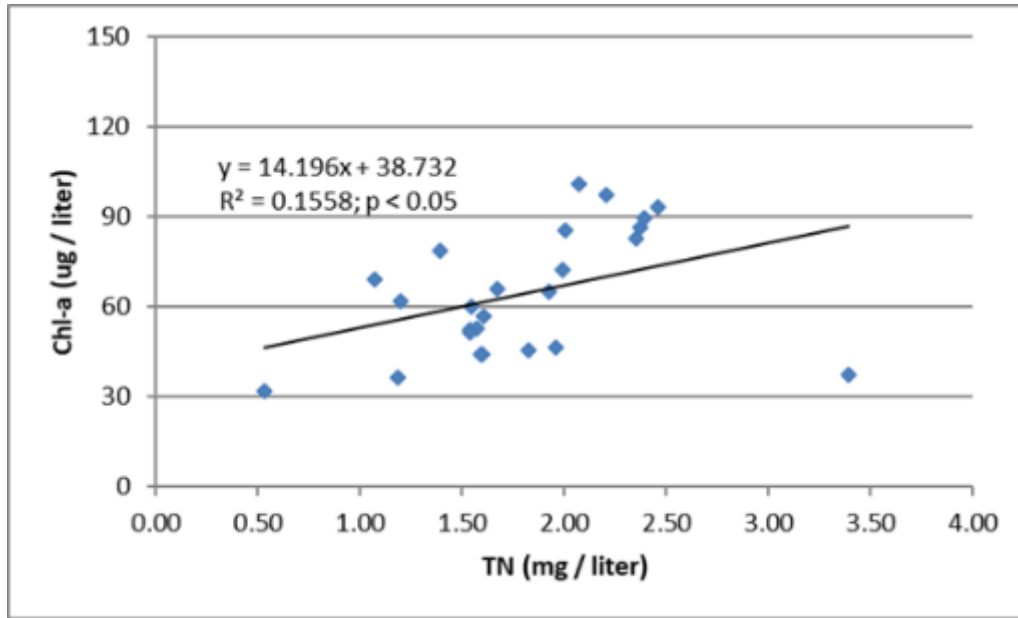


Figure 6-110. Relationship between TN and chlorophyll-a. Line is best fit equation of statistically significant ($p < 0.05$) relationship

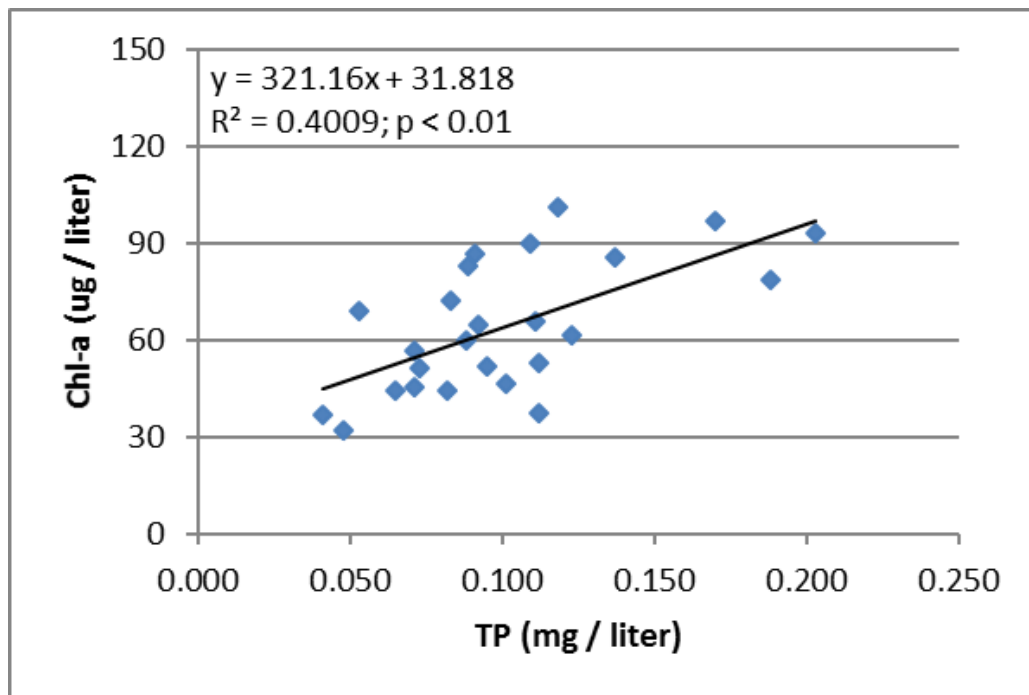


Figure 6-111. Relationship between TP and chlorophyll-a. Line is best fit equation of statistically significant ($p < 0.05$) relationship

As previously shown in PBS&J (2011) and Atkins and ESA (2014) concentrations of TN in excess of ca. 2.5 mg / liter likely indicate the influence of nitrogen-fixing cyanobacteria, as such values are in excess of the highest TN concentrations expected in most urban and agricultural stormwater runoff. However, most of the TN data from Lake Morton are lower than 2.5 mg / liter, which

suggest that the lake's TN values are not necessarily the result of nitrogen-fixing cyanobacteria. Consequently, it appears that algal growth in Lake Morton is limited by the availability of both TN and TP. As such, corrective actions to impact phytoplankton levels should be directed at both TN and TP as the data indicated nutrient co-limitation.

A statistical correlation between annual average nutrient concentrations and annual rainfall was not found indicating that external sources such as stormwater runoff are not likely the dominant influence on in-lake water quality. Based upon these results, projects which focus on stormwater retrofits are not good candidates toward restoring water quality in Lake Morton. However, the maintenance enhancement of native emergent and submerged aquatic vegetation is recommended.

Evidence of a prior or ongoing point source loads to the lake are unknown, and there are not any landscape features (historical or current) that would be expected to exceed "normal" urban landscape nutrient loads to the lake. However, the large amount of waterfowl along the lake's shoreline, and prior results from ERD (2002) suggest that sediments are a likely source of internal nutrient loads to the overlying water column. Sediment removal and/or sediment inactivation projects are not recommended at this point in time, as there is no direct evidence of sediment resuspension as the source of in-lake algal growth. However, whole-lake circulation is recommended based on the lake size, as well as prior studies that suggest that sediments could be a source of significant amounts of internal nutrient loading.

An evaluation into the potential loss of wetland influences was performed through the analysis of the historical versus current lake extent. This analysis was inconclusive to determine if there has been a long-term change in lake water elevation. The geomorphology of the lake is such that Lake Morton would be classified as a "ridge" lake, thus wetland influences on water quality are not as critical to assess. In fact, for Lake Morton, as with Lake Mirror, any discussion of wetland – lake interactions are moot since absolutely no wetland fringe remains (it is completely surrounded by landscaping sod and developed up to the water's edge all the way around).

Although Lake Morton clearly exhibits signs of nutrient enrichment, site-specific chlorophyll-a, TN, and TP targets have not been established and thus may be appropriate. collection and analysis of locally-derived paleo data is advisable if the City decides to pursue establishing site-specific criteria for Lake Morton. Based on examples contained within both PBS&J (2011) and Tomasko et al. (2013) the TN and TP reductions required for Lake Morton to meet NNC guidance are outside the expected obtainable range for lakes where whole-lake aeration has been applied.

However, Lake Morton is small enough to fit within the category of lakes where whole lake aeration has been suggested before as a feasible management action (PBS&J 2010). Aeration may be well worth examining, as part of a paired study with Lake Mirror, to ascertain the feasibility of implementing such in City lakes of this type and size. If aeration can improve clarity in Lake Morton, the chances of rehabilitating SAV and other aquatic macrophyte communities will drastically improve. Lake Morton is relatively sparsely vegetated and re-vegetation of the littoral zone should be a priority in this lake. Additionally, the City stocks Lake Morton with a wide variety of waterfowl thus fecal coliform, ammonia, and BOD problems are very likely to exist. Any effort

to aerate the water column would help moderate the water quality impacts of such a large quantity of waterfowl.

Water Quality Restoration Project Selection and Priorities

Based on Lake Morton water quality and the surrounding watershed characteristics, four potential water quality restoration projects were identified using the City's WQMP decision key. Projects to address water quality, nutrient and sediment loading, and reduced lake levels are proposed. A detailed discussion of the potential water quality restoration implications for each project can be found in Section 4.0.

Project 1: Artificial Circulation

Project 2: SAV Planting/Management or FTWs

Project 3: EAV Planting/Management

Project 4: Develop reasonable water quality targets through paleolimnology and coordination with FDEP

Project 1: Artificial Circulation

The project design is based on the assumption that the system configuration developed by SolarBee® for previous lake circulation projects is applicable to Lake Morton. Therefore, each circulation pump is assumed to effectively circulate 16 to 20 acres. The surface area of Lake Morton is 41 acres requiring the purchase and installation of two SB10000 v 18 machines. Prior to implementation of artificial circulation, a feasibility study to characterize the sediment quality, water column profiles and water depth within the lake.

Cost Estimate: \$120,000 (estimate based on cost provided by Solar Bee® for the purchase, delivery and installation of two units). Based upon prior experience, the feasibility study could be completed for approximately \$50,000.

Project 2: SAV Planting/Management or FTWs

SAV Planting

A survey of existing SAV cover in Lake Morton is recommended due to the lack of sufficient, recent data to calculate percent lake cover. Based on the results of the SAV survey, conclusions regarding SAV planting can be determined. If SAV cover is less than 30 percent, lake conditions should be evaluated to assess if additional SAV is viable based on the soil condition, water clarity and water depth.

Based on the median Secchi depth (0.5 meter) from the POR (1976 to 2017), plants would not be planted in water depths greater than 0.7 meter (Water Atlas). The maximum planting effort for Lake Morton cannot be calculated until digital bathymetry data are acquired.

Bathymetric Survey Cost Estimate: \$10,000

SAV Planting/Management Cost Estimate: A cost estimate will be generated upon receipt of the bathymetry data.

FTWs

If the feasibility study indicates that more than 30 percent of Lake Morton has SAV cover, FTW may be considered. The installation of floating mats with appropriate aquatic vegetation would be expected to assimilate nutrients from the water column.

Project 3: EAV Planting

A survey of existing shoreline vegetation surrounding Lake Morton is recommended due to the lack of sufficient data at this time. Based on the results of the shoreline survey, conclusions and recommendations regarding emergent aquatic or woody vegetation planting can be determined. If limited shoreline vegetation is present, shoreline conditions should be evaluated, preferably by City staff, to assess if vegetation planting is viable based on the soil conditions, slope, water level and inundation frequency and wave disturbance.

EAV Planting/Management Cost Estimate: A cost estimate will be generated upon receipt of the shoreline survey data.

Project 4: Paleolimnology Study

A recurring issue is the need for site-specific water quality targets for each of the 11 lakes. A consideration, however, is the ability of FDEP to allow for target values of chlorophyll-a, TN, and TP that are higher than those contained within NNC (as outlined in FAC 62-302.531). If FDEP allows for the use of these proposed site specific alternative criteria under a BMAP scenario, a valid argument could also be made that all City lakes classified as low-color, alkaline, valley lakes should have the same target values (City lakes classified as ridge lakes may warrant additional paleo studies and subsequent water quality target derivations for ratification by the FDEP). This would not be an unreasonable request as FDEP has used paleo data in the past to set TMDL water quality targets for the Southern Chain of Lakes in Winter Haven (FDEP 2007). Locally-derived paleo data and corresponding TN, TP, and chlorophyll-a targets should ideally be determined for Lake Morton and used as interim lake management goals, pending the review and approval of site-specific goals by FDEP.

Cost estimate: \$30,000 to \$50,000 per lake including coordination with FDEP to develop site-specific water quality targets for chlorophyll-a and nutrients to be used in impairment determinations and/or TMDLs.

Lake Parker

Physical and chemical characteristics specific to Lake Parker are presented here in the context of relevant regulatory criteria and requirements.

Historical and Recent Conditions in Lake and Watershed

Lake Parker is a 2,183-acre lake located in the City within the eastern portion of Polk County, Florida (Figure 6-112). The maximum water depth is 24.6 feet, with an average water depth of 5.2 feet (City of Lakeland 2010). The lake is located within the Lakeland/Bone Valley Upland lake region of Florida, which according to Griffith et al. (1997), can be characterized with “high phosphorus, nitrogen, and chlorophyll-a values” and “alkaline, [with] some [lakes] receiving limestone-influenced groundwater.” Due to the phosphate-rich geology in the Bone Valley formation, significant phosphate mining activities occurred along the north side of the lake which has impacted the soil structure and hydrology.

Lake Parker’s immediate contributing watershed is 5,381 acres in size, resulting in a watershed to open water ratio of 2.6 (Table 6-37; Figure 6-112). Watershed to open water ratios can be used to compare the relative amount of influence that a lake experiences from its contributing watershed, such as stormwater runoff. Lake Parker’s relatively low value suggests that internal processes could be more important to its water quality than would be the case for lakes with higher ratios.

Lake Parker is influenced by inflows from Lake Gibson (through Lake Crago), Lake Mirror, and Lake Bonny (City of Lakeland 2010). Lake Parker discharges into North Saddle Creek, which then flows into Lake Hancock. Over the past 20 years, the lake level appears to have mostly fluctuated within or above its structure operating range, with the exception of an extensive period of low flows in 2000 to 2002, and then again during 2007 to 2010 (Figure 6-113). The operational water elevation range for Lake Parker is 128.09 to 129.69 feet NAVD. Within the Lake Parker watershed, there is an elevation gradient ranging from 119 to 220 feet NAVD (Figure 6-114). Lake Parker is located between 80 and 120-foot potentiometric surface elevations for the Florida aquifer and southwest of the potentiometric peak, as of September 2011 (Figure 6-115). Additionally, the northern boundary of the intermediate aquifer system crosses Lake Parker (Spelcher and Kroening 2007). Therefore, it is unlikely that there is direct connectivity between Lake Parker and the Floridan aquifer.

Sanborn maps within the vicinity of Lake Parker identified single-family dwellings as far back as the 1910s (Figure 6-116). A combination of residential and commercial development continued into the 1950’s, with major development and improvements plateauing around 1968, such that the present land use patterns are broadly similar to those from the late 1960s (Figures 6-117 and 6-118). The extensive development within the watershed is reflected in the land use/land cover data provided by both USGS and SWFWMD (Table 6-38). Specifically, the SWFWMD land use data from 2011 classifies 4,930 acres (92%) as developed lands compared to 451 acres (8%) of undeveloped land (Figure 6-119).

There are 1,171 stormwater outlets in the Lake Parker watershed, including 67 minor outfalls, 85 retention/detention outlets, 78 storm discharges, 28 flumes, 895 end of pipe inputs, and 18 major outfalls (Figure 6-120). In regards to infrastructure, the majority of the existing residential developments within the watershed utilize sanitary sewer for wastewater treatment provided by the City of Lakeland (2010). There appear to be hundreds of septic tank systems in the watershed, as 310 OSTDS construction permits were identified within the watershed (Figure 6-121). Based on a review of SWFWMD soil survey geographic data, soils within the watershed have both low and high runoff potentials, based on the distribution of hydrologic soil group A (442 acres), B (447), B/D (1,175 acres), C (613 acres), and D (31 acres) respectively (Figure 6-122).

As reported by SWFWMD (2005), wetland and aquatic vegetation observed along the shoreline and within the lake basin include primrose willow (*Ludwigia sp.*), cattail (*Typha sp.*), giant bulrush (*Scirpus californicus*), Egyptian paspalidium (*Paspalidium geminatum*), para grass (*Brachiaria mutica*), pennywort (*Hydrocotyle umbellata*), spatterdock (*Nuphar luteum*), pickerelweed (*Pontederia cordata*), water milfoil (*Myriophyllum aquaticum*), red maple (*Acer rubrum*), Carolina willow (*Salix caroliniana*), wax myrtle (*Myrica cerifera*), and Brazilian pepper (*Schinus terebinthifolius*). Additionally, Lake Parker was noted for its lack of fringing cypress wetlands.

In December 1993, SWFWMD, the City, and Polk County prepared a Diagnostic Feasibility Study for Lake Parker due to the lake's inclusion within the Surface Water Improvement and Management (SWIM) program. The report described Lake Parker as a "large, shallow, hypereutrophic lake" with high algal productivity. TSI values were identified above 70. Additionally, the report recommended dredging the western embayment to remove accumulated muck, construction of treatment ponds and facilities to treat stormwater runoff from major storm drains, rehydration of the western wetland, ensure that new and redeveloped properties meet current stormwater treatment regulations, non-indigenous plant removal, and native vegetation enhancement. In April 2005, SWFWMD proposed Minimum Levels for Lake Parker, including a High Minimum Lake Level of 130.6 feet above NGVD or 2,167 acres and a Minimum Lake Level of 129.6 feet above NGVD or 2,123 acres (SWFWMD 2005).

In March 2006, EPA Region 4 issued a Nutrient TMDL Report for Lake Parker (EPA 2006d). According to the report, Lake Parker was verified as impaired by nutrients using the IWR and was included on the Verified List of impaired waters for the Lake Hancock Basin on June 17, 2005. During the verification period, chlorophyll-a, TN, and TP were identified at concentrations in exceedance of the state freshwater thresholds. Following issuance of the TMDL Report, a BMAP was to be developed to reduce the quantity of pollutants entering the lake.

TABLE 6-37. PHYSICAL CHARACTERISTICS OF LAKE PARKER AND ADJACENT WATERSHED

Physical			
Location	City of Lakeland; Polk County	High infiltration soils (acres)	442
Relation to other lakes	Discharges to Saddle Creek	Developed land (acres)	92
Watershed area (acres)	5,381	Undeveloped land (acres)	8
Lake area (acres)	2,183	Mean water depth (ft)	5.2
Perimeter (feet)	65,035	Maximum water depth (ft)	24.6
Surface area: lake volume ratio	0.13	Volume (acre-feet)	16,466
Watershed to surface area ratio	2.46		

TABLE 6-38. CHANGES IN LAND USE WITHIN THE LAKE PARKER WATERSHED OVER TIME

Land Use	1970-1985*		1995		2011	
	Acres	Percent	Acres	Percent	Acres	Percent
Residential	1,594	30.1	1,145	21.3	1,198	22.3
Commercial and Services	851	16.1	554	10.3	579	10.8
Industrial	62	1.2	88	1.6	58	1.1
Transportation, Communication, and Services	74	1.4				
Reclaimed Land					276	5.1
Intuitional					171	3.2
Recreational			528	9.8	206	3.8
Golf Course					65	1.2
Open Land			94	1.7	121	2.2
Other Urban or Built-up Land	105	1.9				
Cropland and Pasture	60	1.1	97	1.8	13	0.2
Row Crops					5	0.1
Evergreen Forest Land	35	0.7				
Tree Crops			28	0.5		
Other Open Lands			29	0.5	9	0.2
Shrub and Brushland			8	0.1		
Upland Hardwood Forests			21	0.4		
Hardwood Conifer Mixed			66	1.2	41	0.8
Tree Plantations					29	0.5
Streams and Waterways			6	0.1		

Land Use	1970-1985*		1995		2011	
	Acres	Percent	Acres	Percent	Acres	Percent
Lakes	2,098	39.6	4	0.1	4	0.1
Reservoirs	82	1.5	2,153	40.0	2,085	38.7
Stream and Lake Swamps			20	0.4	10	0.2
Forested Wetland	1	0.0	13	0.2	13	0.2
Freshwater Marsh			131	2.4	235	4.4
Emergent Aquatic Vegetation			18	0.3	13	0.2
Intermittent Ponds			1	0.0	5	0.1
Transportation			105	1.9	122	2.3
Communications			7	0.1	7	0.1
Utilities			149	2.8	9	0.2
Strip Mines, Quarries, and Gravel Pits	271	5.1				
Transitional Area	149	2.8				

*Metadata for USGS land use data identifies data collection dates as a period between 1970 and 1985

**Land use types differ between USGS and SWFWMD classification schemes. Please note that SWFWMD data does not include “transportation, communications, and services.

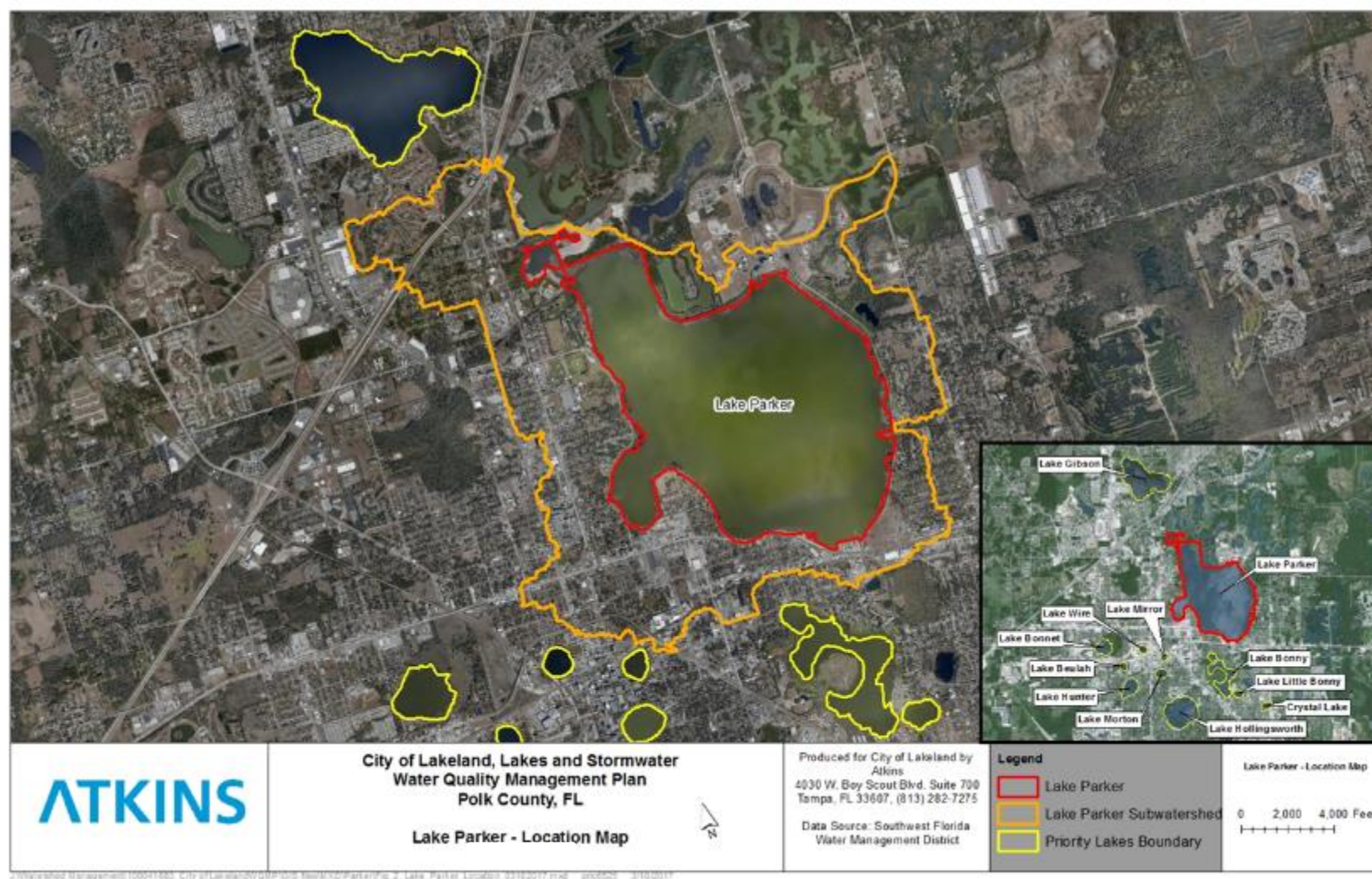


Figure 6-112. Lake Parker location map

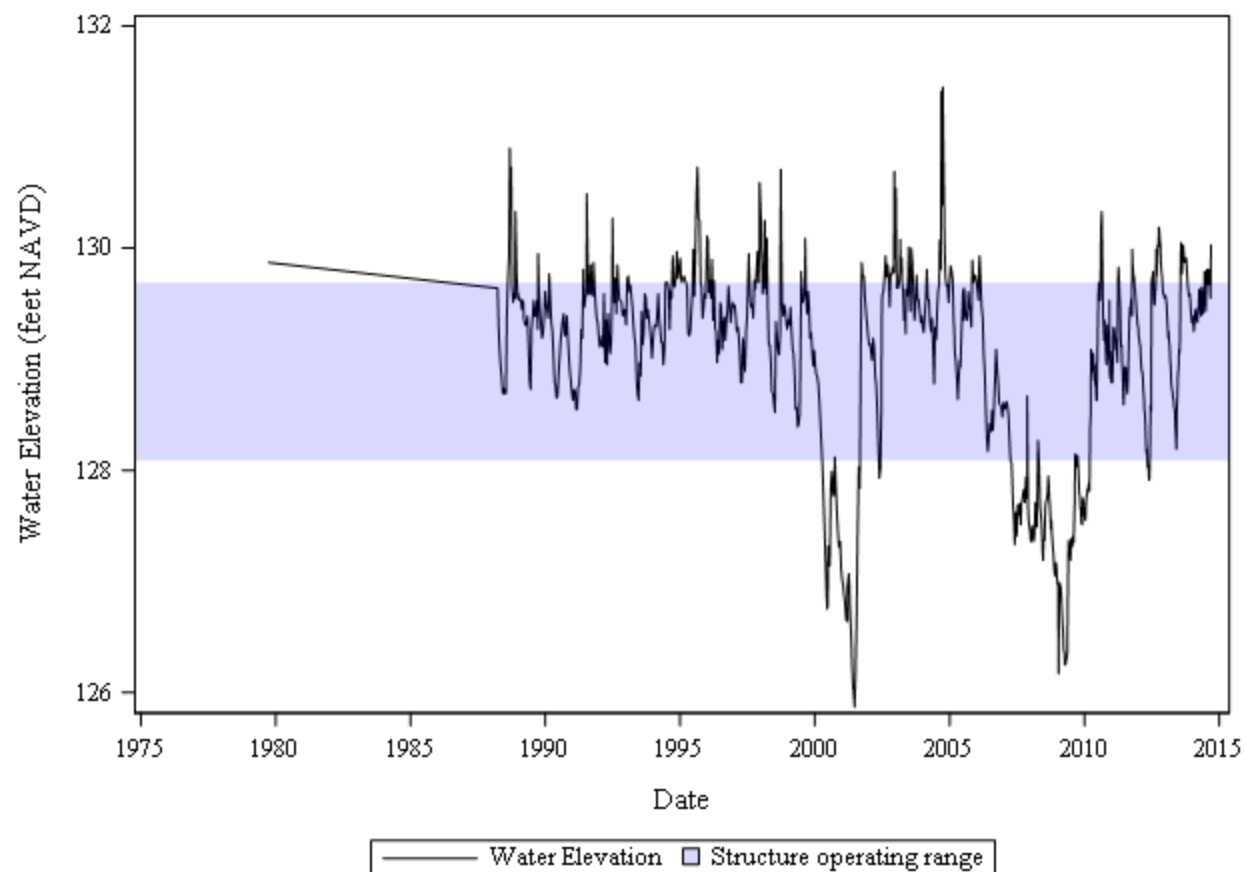


Figure 6-113. Period of record water elevation for Lake Parker



Figure 6-114. Lake Parker contour map

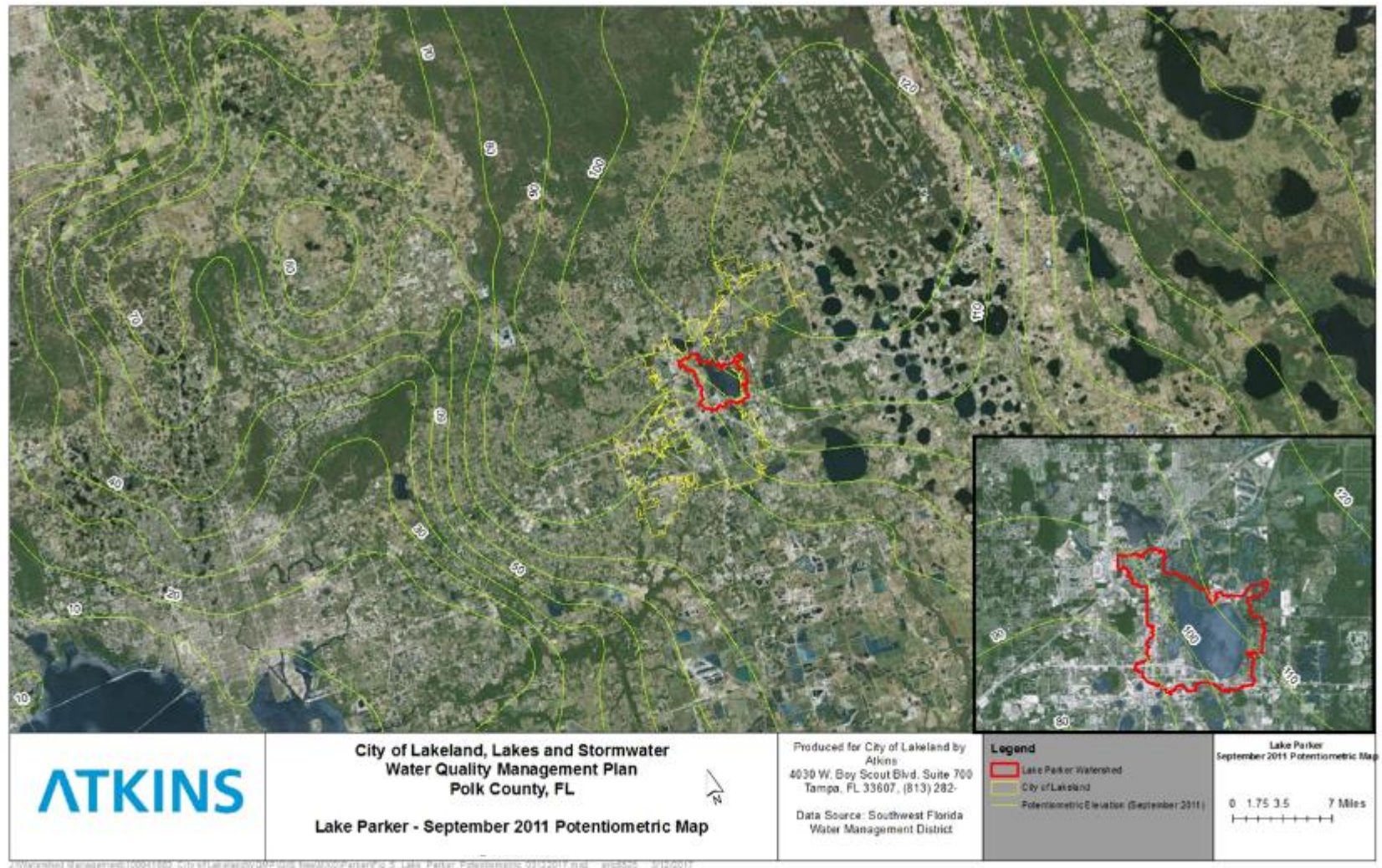


Figure 6-115. Lake Parker potentiometric map

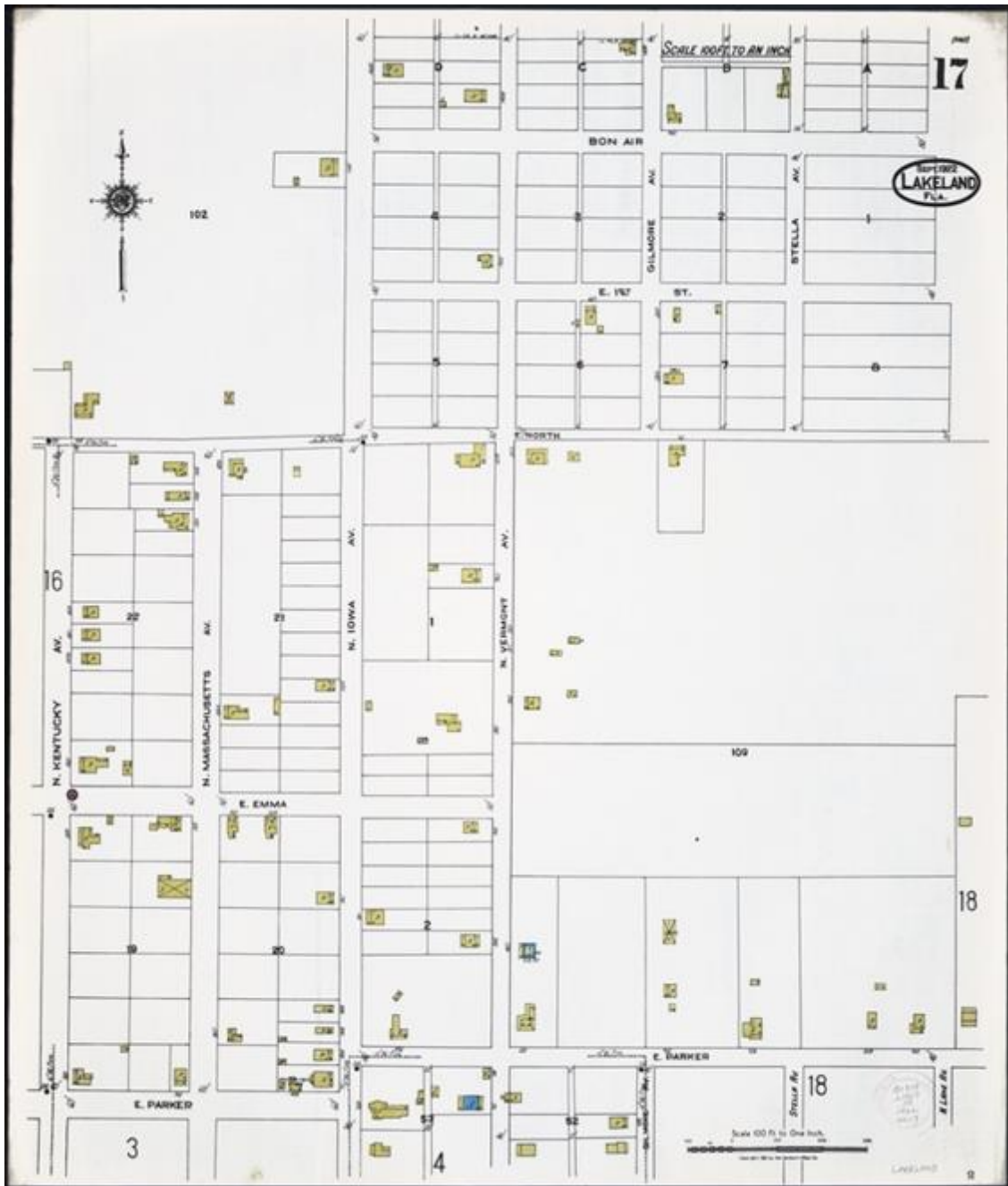


Figure 6-116. Lake Parker 1917 Sanborn map

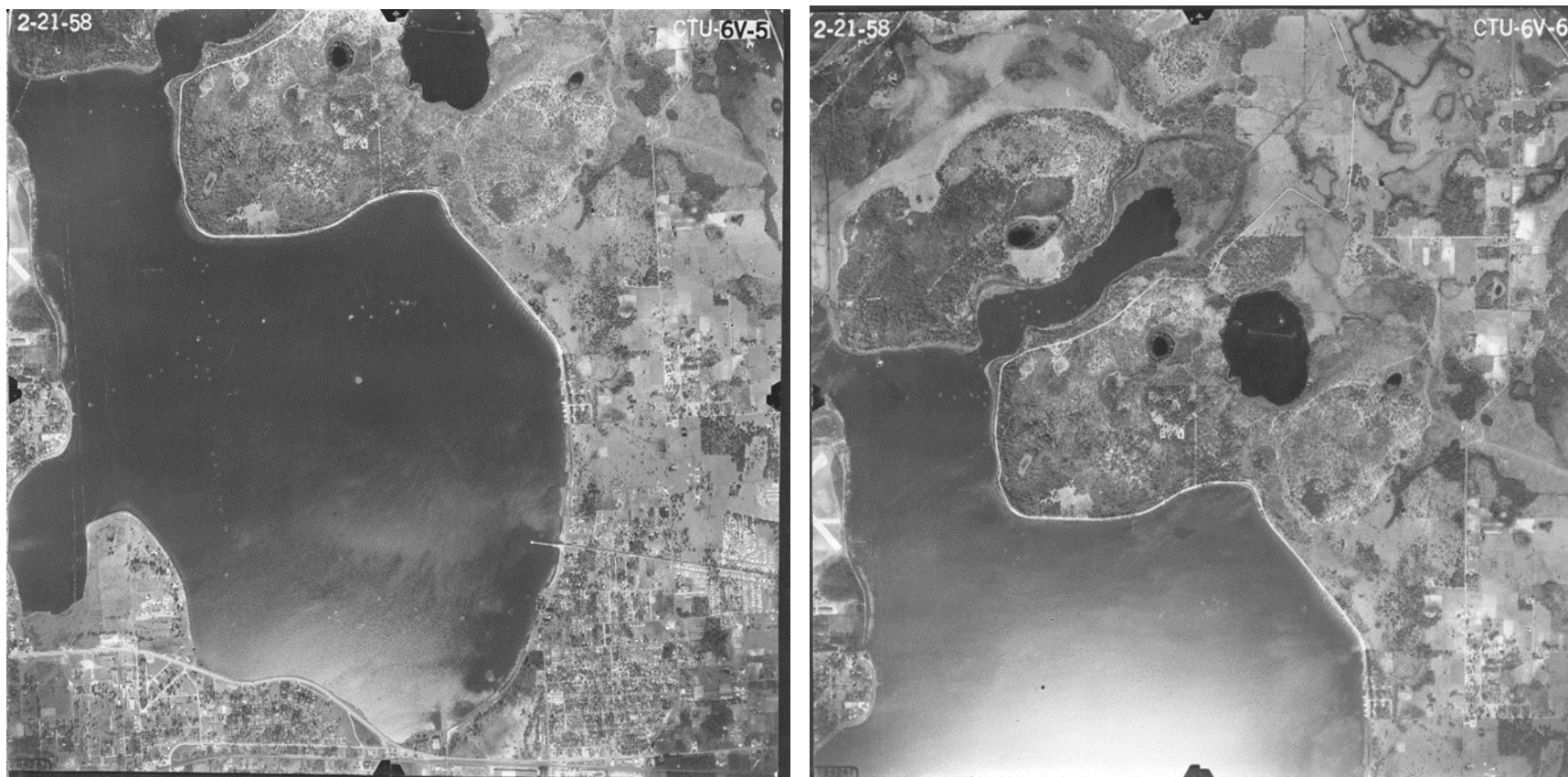


Figure 6-117. Lake Parker 1958 aerial imagery. Left photo: southeastern portion. Right image: northern portion.

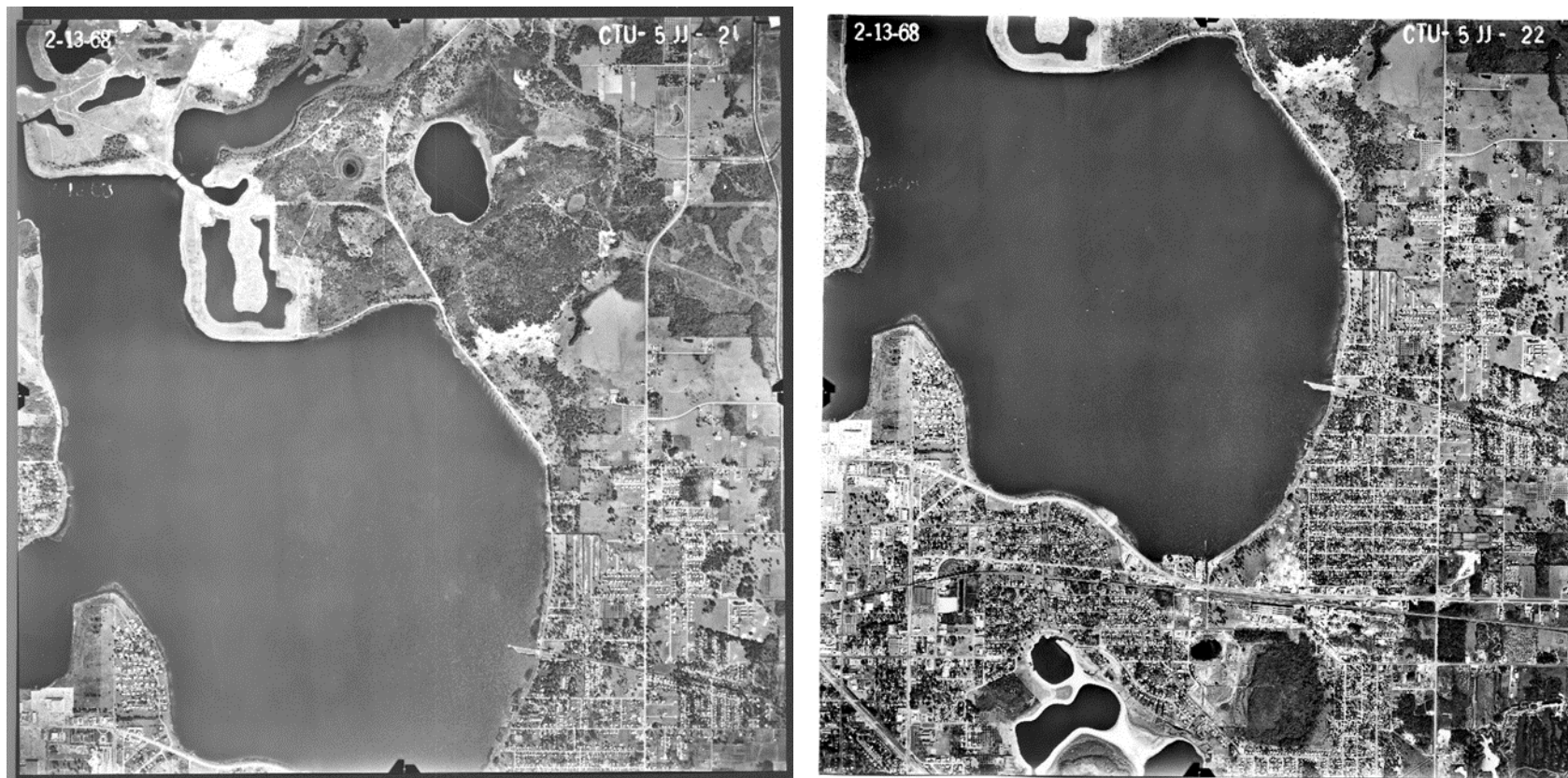


Figure 6-118. Lake Parker 1968 aerial imagery. Left Photo: northern portion. Right Photo: southern portion.

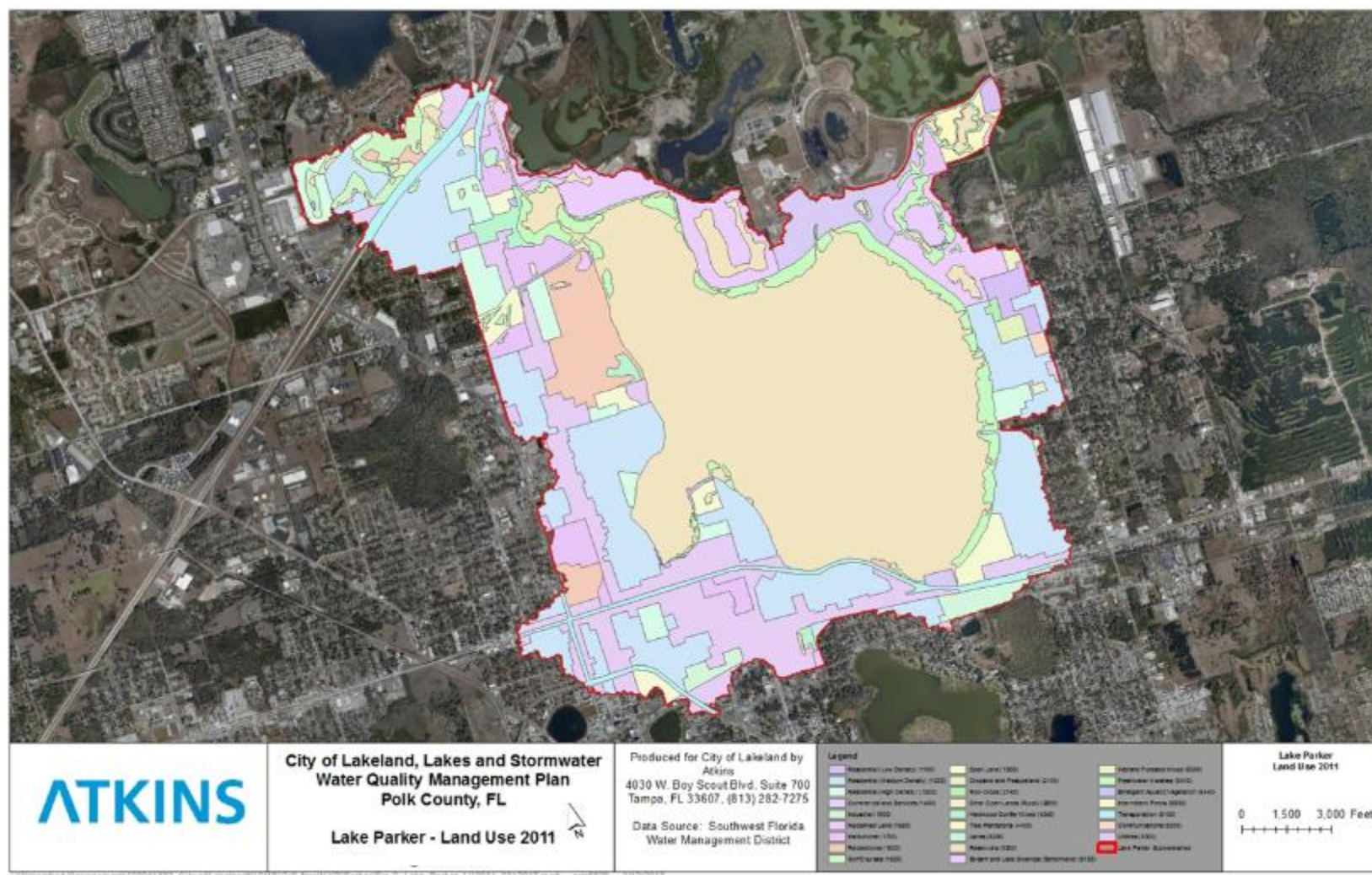
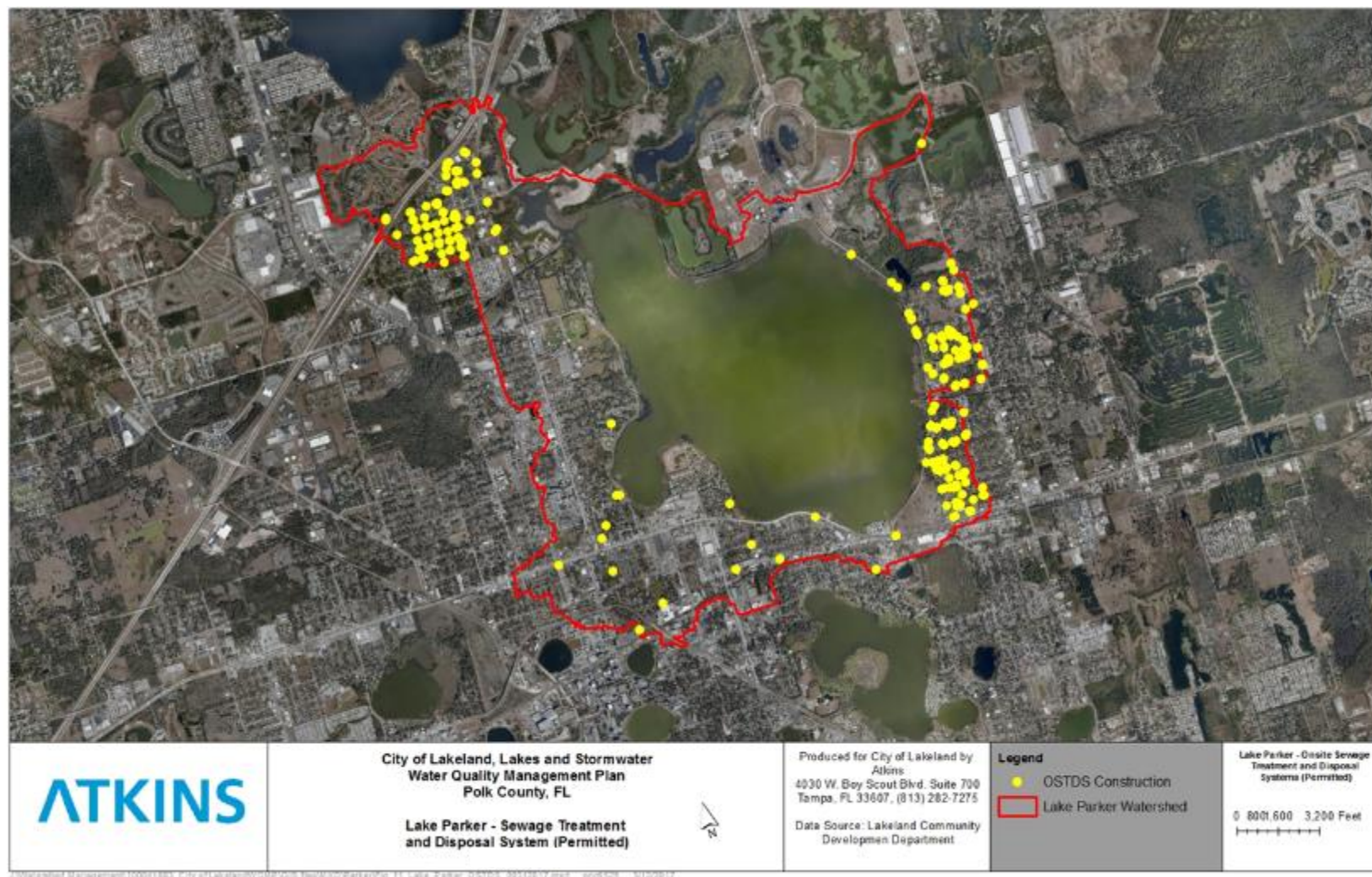


Figure 6-119. Lake Parker 2011 land use map



Figure 6-120. Lake Parker stormwater map



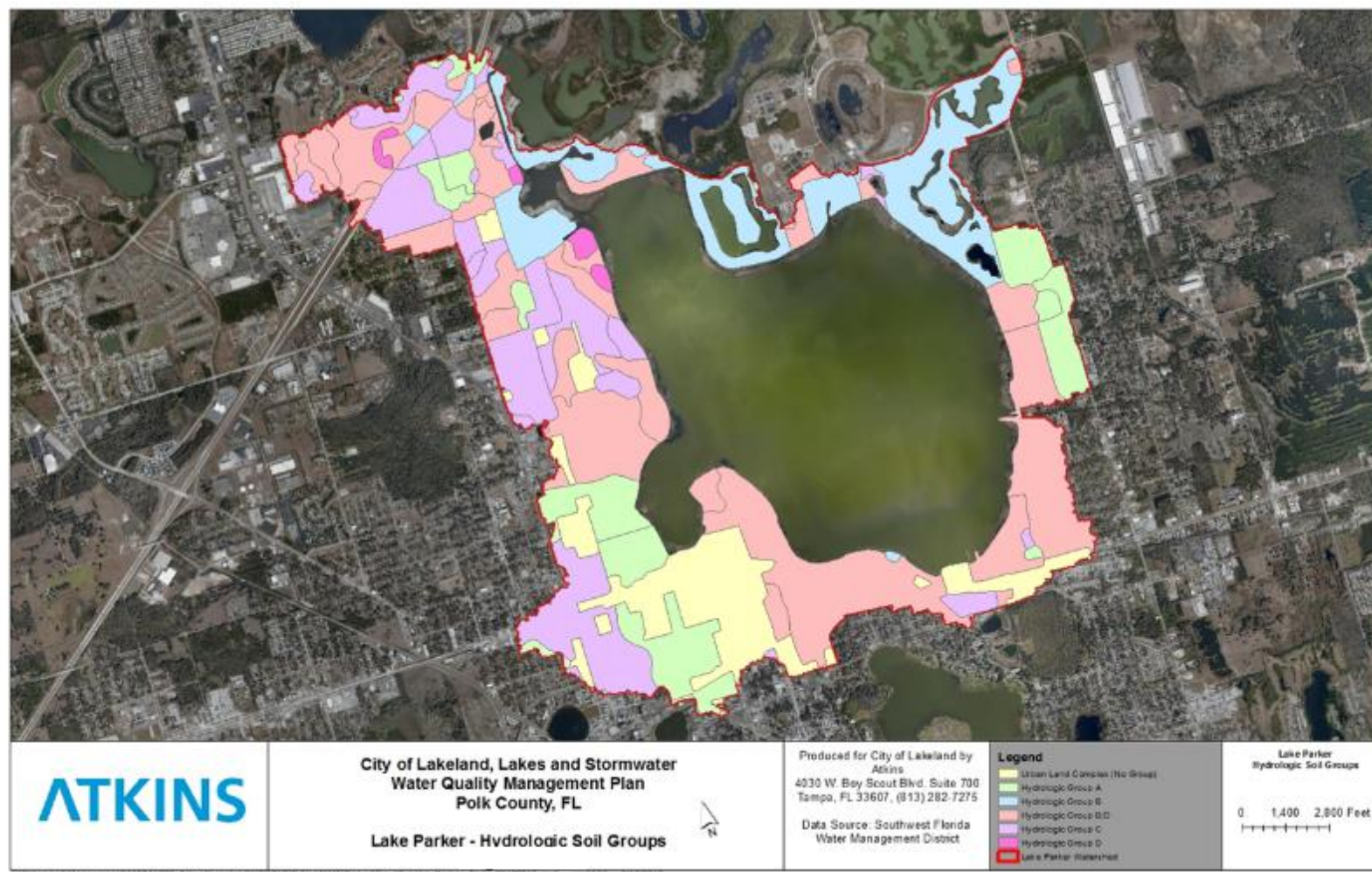


Figure 6-122. Lake Parker soils map

Water Quality

Lake Parker was listed as impaired for nutrients by FDEP (Atkins and ESA 2014) and has a TMDL for nutrients (EPA 2006d). In FDEP's most recent version of the Comprehensive Verified Impaired List (December 18, 2017) Lake Parker is no listed as impaired for nutrients, most likely because it has a TMDL meant to address nutrient concerns. The causative basis for TSI exceedance was listed as elevated levels of TN and TP. Lake Parker was previously classified as a clear, alkaline lake (Atkins and ESA 2014). Based on the clear, alkaline characterization, nutrient criteria were determined based on the use of a chlorophyll-a concentration of 20.0 µg/L. Lake Parker is a Group 3 waterbody as part of the Upper Peace River, the most recent impairment evaluation was performed for the verified period of January 1, 2008 to June 30, 2015 (Cycle 3) which applied NNC as the numeric criteria. The cycle 4 assessment period will occur in 2021 for the verified period of January 1, 2013 to June 30, 2020.

To minimize the impacts of different verified periods, this report characterizes water quality for each of the City's priority lakes during the same time period, 1/1/2009 to 6/30/2016. These dates correspond to the most recent Verified Period for which FDEP's water quality data are available for all the City's priority lakes.

Water quality data were downloaded from FDEP, and used to determine the classification status of Lake Parker. As was found previously, Lake Parker was classified as a low-color, alkaline lake, based on a geometric mean value for color of 25 PCU and a geometric mean alkalinity value of 68 mg (as CaCO₃) / liter. Based on that classification, the water quality targets for TN and TP were then determined based on whether or not the annual geometric mean for a given year exceeded the threshold chlorophyll-a value of 20 µg / liter. The relevant water quality criteria for TN and TP for Lake Hunter are highlighted in yellow in Table 6-39. Based on the below available criteria, Lake Hunter has the following exceedances (Table 6-40).

TABLE 6-39. WATER QUALITY CRITERIA FOR LAKE PARKER, WITH RELEVANT TARGETS FOR CHLOROPHYLL-A, TN AND TP HIGHLIGHTED IN YELLOW.

Long Term Geometric Mean Lake color and Alkalinity	Annual Geometric Mean chlorophyll-a	Minimum calculated numeric interpretation		Maximum calculated numeric interpretation	
		Annual Geometric Mean TP	Annual Geometric Mean TN	Annual Geometric Mean TP	Annual Geometric Mean TN
> 40 PCU	20 µg/L	0.05 mg/L	1.27 mg/L	0.16 mg/L	2.23 mg/L
≤ 40 PCU and > 20 mg/L CaCO ₃	20 µg/L	0.03 mg/L	1.05 mg/L	0.09 mg/L	1.91 mg/L
≤ 40 PCU and ≤ 20 mg/L CaCO ₃	6 µg/L	0.01 mg/L	0.51 mg/L	0.03 mg/L	0.93 mg/L

TABLE 6-40. SUMMARY OF WATER QUALITY IMPAIRMENT DETERMINATIONS FOR LAKE PARKER BY YEAR. YEARS WITH INSUFFICIENT DATA FOR COMPARISON WITH NNC CRITERIA ARE NOTED BY “-”.

Year	chlorophyll-a (µg / liter)	TN (mg / liter)	TP (mg / liter)
2009	54.79	3.02	0.056
2010	56.25	2.38	0.060
2011	93.26	3.52	0.070
2012	74.05	2.83	0.054
2013	62.40	2.37	0.051
2014	44.31	1.93	0.052
2015	54.88	1.89	0.049
2016	59.15	1.91	0.057
Average percent reduction required (when needed)	67	56	46

Lake Parker has water quality that far exceed NNC criteria for low-color, alkaline lakes. Based on case studies examined in PBS&J (2011) and Tomasko et al. (2013) the TN and especially the TP reductions required for Lake Hunter to meet NNC guidance are outside the range of reductions obtained by traditional lake management approaches, such as stormwater retrofits. Instead, more intensive project types are required, up to and including sediment inactivation or removal and hydrologic restoration.

Positive relationships were found between both TN and chlorophyll-a and TP and chlorophyll-a (Figures 6-123 and 6-124, respectively). The very high levels of TN shown in Figure 6-124 suggest the presence of nitrogen-fixing cyanobacteria, rather than external nitrogen loads with such high concentrations.

An evaluation of the TN data indicates that concentrations exceed 3.0 mg/L; therefore, nitrogen-fixing cyanobacteria are likely playing a role in nutrient cycling within the lake (Figure 6-124). As such, reductions in external loads of TN are not likely to significantly reduce TN concentrations within the lake. Therefore, TP was identified as the nutrient of concern, and reducing TP concentrations is the focus of proposed lake management activities.

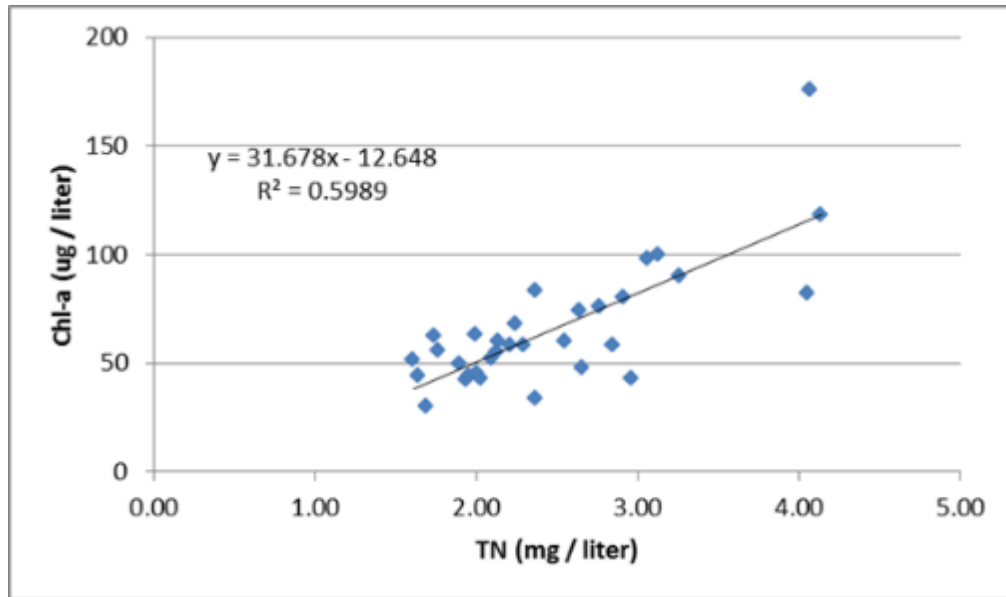


Figure 6-123. Relationship between TN and chlorophyll-a. Line is best fit equation of statistically significant ($p < 0.05$) relationship

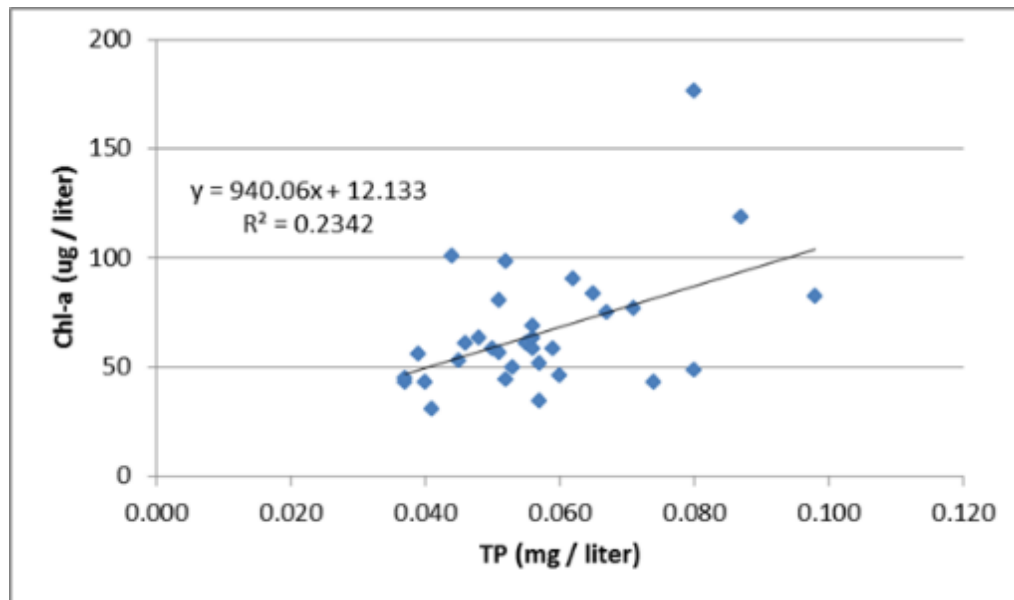


Figure 6-124. Relationship between TP and chlorophyll-a. Line is best fit equation of statistically significant ($p < 0.05$) relationship

A statistical correlation between annual average TP concentrations and annual rainfall was not found indicating that external sources such as stormwater runoff are not likely dominant influences on in-lake water quality. Based upon these results, projects which focus on stormwater retrofits would not be sufficient, by themselves, for restoring water quality in Lake Parker. However, the maintenance and enhancement of native emergent and submerged aquatic vegetation is recommended.

Evidence of a prior or ongoing point source loads to the lake are unknown which could have led to nutrient enriched sediments. Additionally, there are not any landscape features (historical or current) that would be expected to exceed “normal” urban landscape nutrient loads to the lake. Lake sediment resuspension was not identified as a likely source of internal nutrient loads to the overlying water column. Sediment removal and/or sediment inactivation projects are not recommended as there is no evidence of sediment resuspension as the dominant source of nutrient loads to the water column. Additionally, whole-lake circulation is not recommended based on the lake size.

However, an analysis of the historical versus current lake extent indicated that the lake has been lowered compared to its original configuration. Historical data suggest that the lake elevation has been lowered between 4 and 5 feet since the 1850s. As a result, the lake’s current elevation appears to be below the elevation of much of its historical wetland fringe. The 5-year average values for color in the report by the City of Lakeland (2010) indicate the lake is high-color while the report from Atkins and ESA (2014) shows the lake as being a low-color lake. This analysis also found the lake to be classified as a low-color, alkaline lake. However, Lake Parker’s color values averaged above 40 PCU in 2001, 2004, 2005, 2006, 2007 and 2008. The geomorphology of the lake is such that Lake Parker is classified as a “valley” lake. The finding that Lake Parker has been classified as low-color during certain periods and high-color during other periods may be due to changes in wetland – lake interactions.

Whether or not Lake Parker is designated as a high color lake or a low color alkaline lake does not change the chlorophyll-a target for the lake, which remains at 20 µg / liter for both lake types. However, the TP and TN targets are lower for low-color alkaline lakes than they are for high-color lakes, as higher levels of “color” act to moderate phytoplankton growth. The fact that the classification of Lake Parker can switch from low-color to high-color may be an indication that the lake’s wetland fringe, (particularly the large area west of North Florida Avenue and south of Griffin Road), may not be contributing the tannin loads otherwise expected if the wetland had not been ditched and/or if the water level in Lake Parker had not declined below its historical norm.

As discussed above, color levels within Lake Parker range between lower and higher than the 40 PCU threshold. The lake’s geomorphology suggests it is a valley lake as outlined in PBS&J (2008). Thus, hydrologic restoration should be considered for Lake Parker, especially since wetland fringes still remain and historical data suggest that the lake elevation has been lowered between 4 and 5 feet since the 1850s. There is evidence of a large drainage ditch cut through the middle of the extensive wetland located west of Lake Parker which likely reduces both the nutrient reduction capacity of the wetland and associated tannin exports to Lake Parker. Restoration of a more natural hydroperiod in this wetland could benefit lake water quality in two ways, by simultaneously reducing external TN and TP loading and increasing in-lake color.

Such a project could be brought about via implementing (with some modifications) existing project plans for that degraded wetland system, as outlined in the reports produced by CH2MHill (1994 and 2003).

In addition, a particularly unique feature of the Lake Parker watershed is the close proximity of the Tenoroc Fish Management Area (TFMA) lakes system. The mining pit lakes of the TFMA system might allow for a large-scale water quality restoration project designed to route lake water through these artificial waterways. This would provide a combination of water-column nutrient removal (perhaps through existing populations of Hydrilla and/or native SAV) and increased importation of tannins to the lake from pit lakes with more extensive wetland fringes. Preliminary discussions with staff from the Florida Fish and Wildlife Conservation Commission (FFWCC) indicate a willingness to work with the City on this conceptual plan. However, there is very little data on water quality and lake volumes in the TFMA lakes system according to FFWCC staff. This represents a large data gap that needs to be addressed prior to developing any concrete restoration plan inclusive of the TFMA.

Although Lake Parker clearly exhibits signs of nutrient enrichment, locally-derived chlorophyll-a, TN, and TP targets are recommended as a management tool. These targets have been partially provided by the paleo study conducted by Brenner et al. (1999). Additionally, in-lake wetland creation with hydrophilic hardwoods and herbaceous aquatic plants may, on a large scale, improve water quality in a number of ways, including increasing tannin levels and suppressing cyanobacteria growth.

Water Quality Restoration Project Selection and Priorities

Based on Lake Parker water quality and the surrounding watershed characteristics, four potential water quality restoration projects were identified using the City's WQMP decision key. Projects to address water quality, nutrient and sediment loading, and reduced lake levels are proposed. A detailed discussion of the potential water quality restoration implications for each project can be found in Section 4.0.

Project 1: SAV Planting/Management or FTWs

Project 2: EAV Planting/Management

Project 3: Re-establish Wetland Influence and Potential Flow-thru System in Teneroc Lakes

Project 4: Develop reasonable water quality targets through paleolimnology and coordination with FDEP

Project 1: SAV Planting/Management or FTWs

SAV Planting

A survey of existing SAV cover in Lake Parker is recommended due to the lack of sufficient, recent data to calculate percent lake cover. Based on the results of the SAV survey, conclusions regarding SAV planting can be determined. If SAV cover is less than 30 percent, lake conditions should be evaluated to assess if additional SAV is viable based on the soil condition, water clarity and water depth.

Based on the median Secchi depth (0.6 meter) from the POR (1975 to 2016), plants would not be planted in water depths greater than 0.8 meter (Water Atlas). The maximum planting effort for Lake Parker cannot be calculated until digital bathymetry data are acquired.

SAV Planting/Management Cost Estimate: A cost estimate will be generated upon receipt of the bathymetry data.

Bathymetric Survey Cost Estimate: \$10,000, however, given the size of Lake Parker, bathymetric survey costs may be significantly higher

FTWs

If the feasibility study indicates that more than 30 percent of Lake Parker has SAV cover, FTW may be considered. The installation of floating mats with appropriate aquatic vegetation would be expected to assimilate nutrients from the water column.

Project 2: EAV Planting

A survey of existing shoreline vegetation surrounding Lake Parker is recommended due to the lack of sufficient data at this time. Based on the results of the shoreline survey, conclusions and recommendations regarding emergent aquatic or woody vegetation planting can be determined. If limited shoreline vegetation is present, shoreline conditions should be evaluated, preferably by City staff, to assess if vegetation planting is viable based on the soil conditions, slope, water level and inundation frequency and wave disturbance.

EAV Planting/Management Cost Estimate: A cost estimate will be generated upon receipt of the shoreline survey data.

Project 3: Re-establish Wetland Influence and Potential Flow-thru System in Teneroc Lakes

The forested wetland system existing to the west of Lake Parker (Figure 6-125) is defined as a Stream and Lake Swamp (Bottomland) according to 2011 FLUCCS data and historically existed as a bayhead system. Bayheads are forested wetlands (swamps) that include a variety of dominant tree species. Generally, these are depression wetlands with a canopy and mucky, organic soils. Often this plant community is associated with a seepage bog and may represent a fire suppressed version of a typically open seepage bog in some areas.

The forested wetland system west of Lake Parker has been impacted due to the construction of a wide ditch that bisects the entire system in a NE to SW configuration. With the historical ditching and draining, the forested wetland lost its natural ability to support a functioning water environment. Current water level indicators are inconsistent with expected hydrologic conditions

for this wetland, and the existing vegetation shows very strong signs of hydrologic stress and exhibits an overall shift from an obligate and facultative-wet to facultative upland species



Figure 6-125. Proposed forested wetland rehydration project area for Lake Parker

The proposed conceptual restoration approach would entail the installation of ditch blocks within the primary ditch/channel (as well as any secondary tributary ditches) and spoil pile removal. This project approach is broadly consistent with the approach outlined in prior reports done on this same system (CH2MHill 1994 and 2003). Removing the influence of the ditches would restore the natural hydrology of the system and thereby enhancing the wetland by creating conditions conducive to further recruitment of appropriate obligate and facultative-wet vegetation species (Figure 6-126).

The restoration of this currently degraded wetland system would enhance wetland habitat, increase nutrient attenuation from incoming stormwater loads, and could, if properly designed, increase tannin loads to Lake Parker. In addition to ditch blocks, it is recommended that a control structure be installed that holds the water until a specific level of inundation is obtained and then provides a “pop-off” downstream to Lake Parker. The increased hydroperiod and residence time will allow for additional phosphorus adsorption and subsequent burial when waters subside during the dry season. An additional benefit, beyond enhanced nitrogen and phosphorus reductions, is the potential to increase tannic and humic acids from the restored forested wetlands, which appear to

be capable of reducing chlorophyll-a concentrations in lakes in Central Florida (i.e., Terrell et al. 2000, Tomasko et al. 2013).



Figure 6-126. Lake Parker Conceptual Wetland Restoration map

During preliminary field assessments conducted within the forested wetland west of Lake Parker, an area with the potential for contamination was identified - primarily due to the evidence of unregulated dumping of waste materials (debris) into the former wetland site, such as ceramic tiles, tires, and other miscellaneous commercial and household wastes (Figure 6-127). Based on knowledge of contamination impacts identified at sites with disposal of similar tiles, tires, and other materials, there is the potential for contamination to be present; therefore, an environmental assessment of the property would be warranted prior to initiation of any restoration projects.



Figure 6-127. Area of potential contamination within the forested wetland west of Lake Parker. Left Photo: Tile Remnants. Right Photo: Tire disposal

Contamination study cost estimate: Costs would include labor for developing the sampling plan, performing the field work and preparation of a letter report (with tables and figures) summarizing the findings of the sampling. Laboratory expenses and other direct expenses would be included in the cost.

Estimated Cost: \$7,500 to \$10,000 for Phase I (table top) environmental and constraints assessment, including identification of permitting issues. Phase II environmental assessment costs would be dependent upon the results of the Phase I, but for budgeting purposes assume \$50,000 - \$75,000. Phase III feasibility study of potential rehydration would be dependent upon Phase II results: \$150,000

A secondary restoration component for Lake Parker would involve the construction of a multi-point flow through system with the TFMA to the north of Lake Parker. East of the City, water from a large wetland system at the headwaters of Saddle Creek flowed south toward Lake Hancock, the largest lake in the Peace River basin. From the early 1950s through the late 1970s, three phosphate mines operated in this portion of the County – the Saddle Creek Mine (Agrico Mining Company), the Orange Park Mine (American Cyanamid Company), and the Tenoroc Mine (Borden, Inc.). Phosphate mining operations severely disrupted the natural drainage patterns in this region by eliminating the original wetlands and streams, then impounding water in settling areas and landlocked pits. In September 1982, Borden, Inc. donated 6,065 acres from its Tenoroc Mine to the State of Florida. The area, originally called the Tenoroc State Reserve and later renamed the Tenoroc Recreation Area, was managed until 1992 by the Division of Recreation and Parks of the Florida Department of Natural Resources (later the FDEP). The Florida Game and Fresh Water Fish Commission (now the FFWCC) began managing the area in 1992 and the tract was renamed the TFMA.

The proposed restoration conceptual plan would involve the construction of a flow-thru system in order to treat the hypereutrophic water of Lake Parker. Creating this hydrologic connection and providing an active pump system through an approximately 2,000-acre network of wetlands and pond features that would provide a mechanism for nutrient removal within the water column via anticipated nutrient reduction via the Hydrilla-dominated pond systems (where SAV of any kind has been found, it appears to be mostly Hydrilla).

Figure 6-128 gives a general overview of the potential restoration project for the Teneroc System and Lake Parker.



Figure 6-128. Proposed conceptual restoration plan for Lake Parker utilizing Lake Teneroc

An SAV survey, bathymetric survey, and water quality surveys are recommended for the pit lakes within the Lake Teneroc system due to the lack of sufficient data at this time. Based on the results of these surveys and filling of these data gaps, conclusions and recommendations regarding the feasibility of the proposed hydrologic connection can be made. Additionally, since this proposed restoration approach involves the connection of impaired waters within Lake Parker with Waters of the State within the TFMA, additional coordination with the FDEP will be required to determine the correct permitting mechanism. Based on preliminary research and discussions, it is thought that 62-330.451 General Permit to Counties, Municipalities, and other Agencies to Conduct Stormwater Retrofit Activities would be the appropriate permit mechanism. This general permit is granted to counties, municipalities, state agencies and water management districts to construct, operate and maintain stormwater retrofit activities as authorized below for improving existing surface water and stormwater systems. Further coordination with state regulatory agencies will be required to confirm satisfaction of the permit requirements and thresholds.

Estimated Cost: Baseline data collection for water quality, bathymetry, SAV survey \$70,000 to \$100,000. Feasibility study of flow-thru concept: \$200,000

Project 4: Paleolimnology Study

The paleolimnological study for Lake Bonny (Whitmore et al. 2016) is current enough that its findings should be discussed with FDEP to ensure that the State's agencies are aware of the

impractical nature of the existing NNC criteria for lakes such as Lake Parker, which appears to have been impacted by drainage ditches that have impacted the large wetland on the lake's northwestern border, thus reducing the wetland influence in such a way that the lake has likely become more susceptible to nutrient concentrations than it was historically. The complexity of the tannin-nutrient-phytoplankton relationships found for Lake Bonny are such that it was concluded that nutrient reduction alone, even if to pre-development concentrations, would not result in the lake also obtaining pre-development values for chlorophyll-a. The need for restoration of the lake's historical lake-wetland connectivity supports conclusions related to the need for such projects that was also reached for Lake Hancock (Tomasko et al. 2009).

Cost estimate: \$30,000 to \$50,000 per lake including coordination with FDEP to develop site-specific water quality targets for chlorophyll-a and nutrients to be used in impairment determinations and/or TMDLs.

Lake Wire

Physical and chemical characteristics specific to Lake Wire are presented here in the context of relevant regulatory criteria and requirements.

Historical and Recent Conditions in Lake and Watershed

It appears that no specific studies have been completed on nutrient-related issues with Lake Wire. However, FDEP has designated the lake as impaired based on lead concentrations (December 18, 2017).

Lake Wire is a 22-acre lake located in the City within the eastern portion of Polk County, Florida (Figure 6-129). Maximum water depth is 22 feet, with an average water depth of 10.8 feet (City of Lakeland 2010). The lake is located within the Lakeland/Bone Valley Upland lake region of Florida, which according to Griffith et al. (1997), can be characterized with “high phosphorus, nitrogen, and chlorophyll-a values” and “alkaline, [with] some [lakes] receiving limestone-influenced groundwater.”

Lake Wire is located within the Hillsborough River watershed, and the immediate contributing watershed to the lake is 155 acres in size, resulting in a watershed to open water ratio of 6.7 (Table 6-41; Figure 6-129). Watershed to open water ratios can be used to compare the relative amount of influence that a lake experiences from its contributing watershed, such as stormwater runoff.

Lake Wire is not influenced by any upstream lakes and it discharges water into Lake Hunter via an adjustable water control structure (City of Lakeland 2010). Lake Wire water elevations have remained predominantly within the structural operating range over the past 30 years. Water elevations were below the lower operating limit in 2006, but recovery was evident by 2009 (Figure 6-130). The operational water elevation range for Lake Wire is 193.19 to 195.19 feet NAVD. Within the Lake Wire watershed, there is a moderate elevation gradient ranging from 193 to 220 feet NAVD (Figure 6-131). Lake Wire is located between 80 and 90-foot potentiometric surface elevations of the Floridan aquifer, and southwest of the potentiometric peak (Figure 6-132).

Additionally, the northern boundary of the intermediate aquifer system is just north of Lake Wire (Spelcher and Kroening 2007). Therefore, it is unlikely that there is direct connectivity between Lake Wire and either the Floridan or intermediate aquifers.

By 1913, Sanborn maps identify numerous single family dwellings, an ice company, and a fruit packing business along the southwestern border of Lake Wire, and single family dwellings, a refinery, an oil company, and a supply warehouse along the eastern and south eastern borders (Figures 6-133 and 6-134). A combination of residential and commercial development continued into the 1950's, with major development and improvements plateauing by 1968. As such, the development patterns in the Lake Wire watershed in the late 1960s are very similar to existing development conditions (Figure 6-135). The extensive development within the watershed is reflected in the land use/land cover data provided by both USGS and SWFWMD (Table 6-42). Specifically, the SWFWMD land use data from 2011 classifies 106 acres (68%) as developed lands compared to 49 acres (32%) of undeveloped land (Figure 6-136).

There are 22 stormwater discharges in the Lake Wire watershed, including 14 minor outfalls, one retention/detention outlet, one lake-creek outlet, four end-of-pipe inputs, and two major outfalls (Figure 6-137). The majority of the existing residential developments within the watershed utilize sanitary sewer for wastewater treatment provided by the City of Lakeland (2010), as only three OSTDS construction permits were identified within the watershed (Figure 6-138). Based on a review of SWFWMD soil survey geographic data, soils within the watershed have a low runoff potential with high, moderate, and low infiltration rates and are classified either as hydrologic soil group A (25 acres), B (3 acres), or C (47 acres), respectively (Figure 6-139). A large portion of soils in the watershed are classified as "Urban Land Complex" (80 acres) which denotes areas that are more than 85 percent covered by development and as such should be considered to be predominantly impermeable.

As reported by City of Lakeland (2001) the Lake Wire shoreline is vegetated with cattails, primrose willow, paragrass, torpedo grass, and elephant ears. The City conducts periodic Hydrilla harvesting in an attempt to control the lake's Hydrilla infestation. Additionally, the City has stocked Lake Wire with sterilized grass carp for Hydrilla control. Additionally, the City has an ongoing invasive aquatic plant removal and shoreline revegetation program.

TABLE 6-41 PHYSICAL CHARACTERISTICS OF LAKE WIRE AND ADJACENT WATERSHED

Physical			
Location	City of Lakeland; Polk County	High infiltration soils (acres)	25
Relation to other lakes	Discharges to Lake Hunter	Developed land (acres)	106
Watershed area (acres)	155	Undeveloped land (acres)	49
Lake area (acres)	22	Mean water depth (ft)	10.8
Perimeter (feet)	3,776	Maximum water depth (ft)	22.0
Surface area: lake volume ratio	0.09	Volume (acre-feet)	245.9
Watershed to surface area ratio	6.7		

TABLE 6-42. CHANGES IN LAND USE WITHIN THE LAKE WIRE WATERSHED OVER TIME

Land Use	1970-1985*		1995		2011	
	Acres	Percent	Acres	Percent	Acres	Percent
Industrial			19	12.3		
Commercial and Services	84	54.2	29	18.8	25	16.1
Institutional			20	13.0	15	9.7
Open Land					25	16.2
Lakes	20	12.9	23	14.9	23	14.8
Reservoirs			1	0.6	1	0.6
Residential	51	32.9	52	33.8	43	27.8
Transportation, Communications, and Services**			10	6.6	23	14.8

*Metadata for USGS land use data identifies data collection dates as a period between 1970 and 1985

**Land use types differ between USGS and SWFWMD classification schemes. Please note that SWFWMD data does not include "transportation, communications, and services."



Figure 6-129. Lake Wire location map

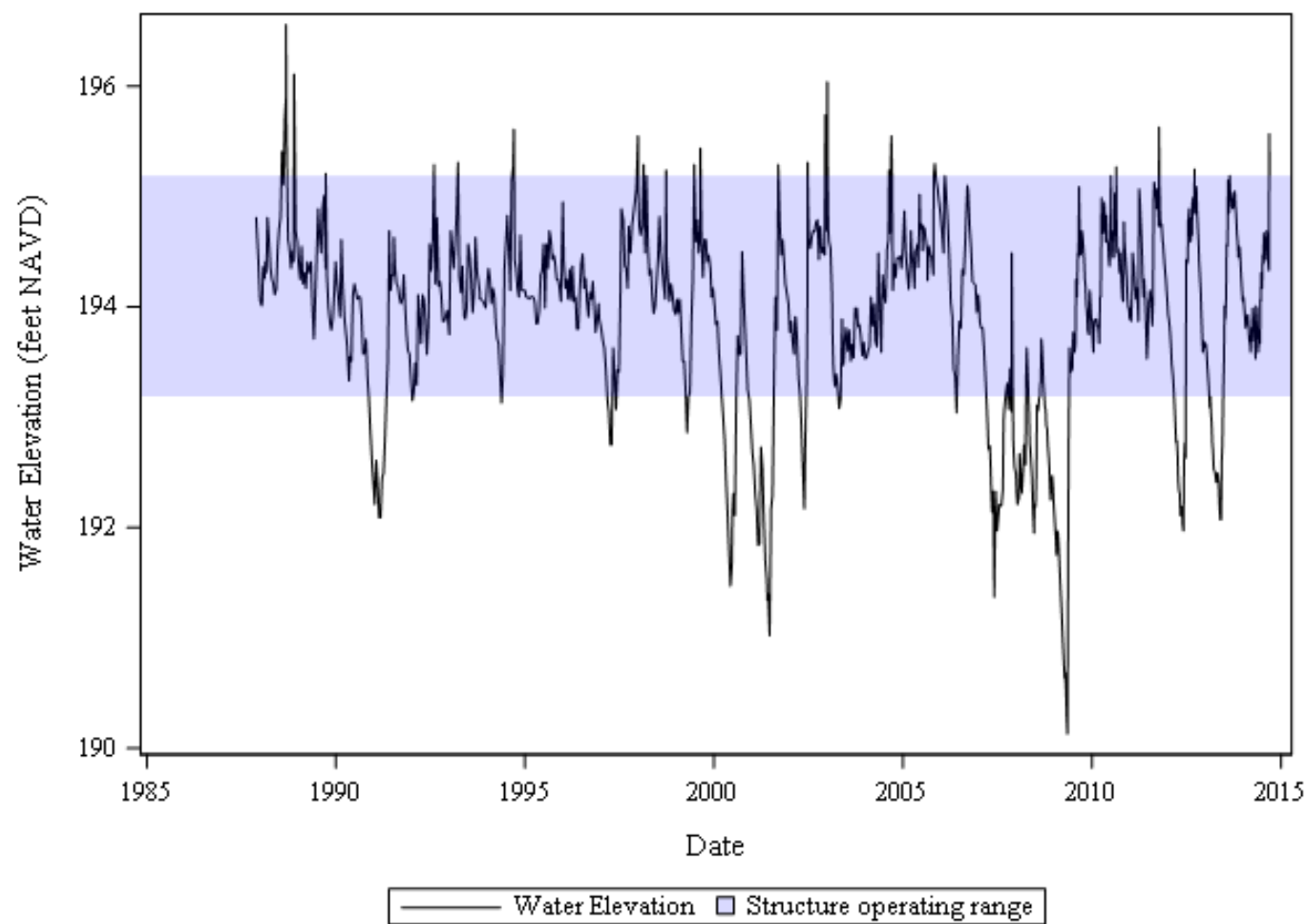


Figure 6-130. Period of record water elevation in Lake Wire

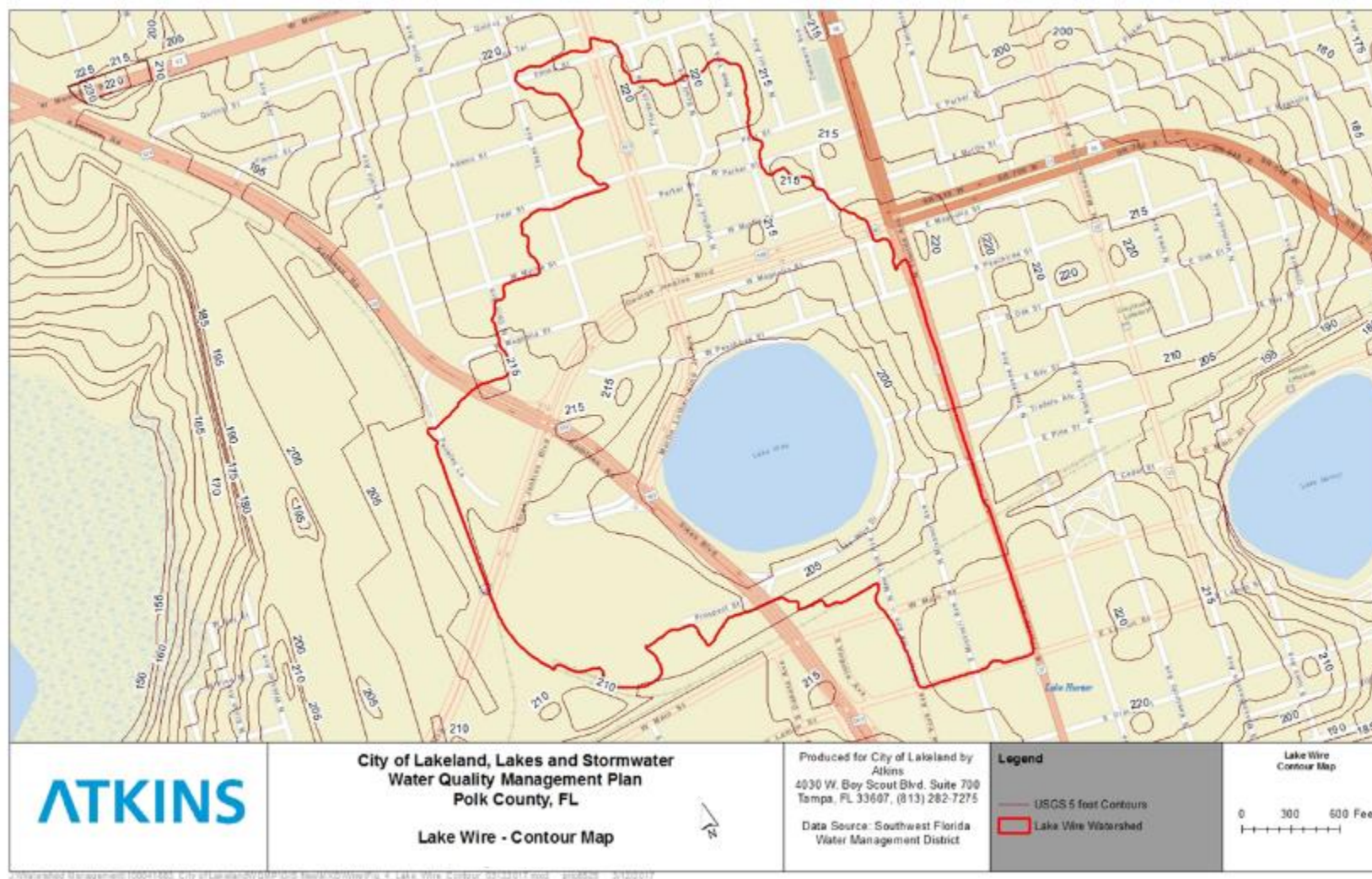


Figure 6-131. Lake Wire contour map

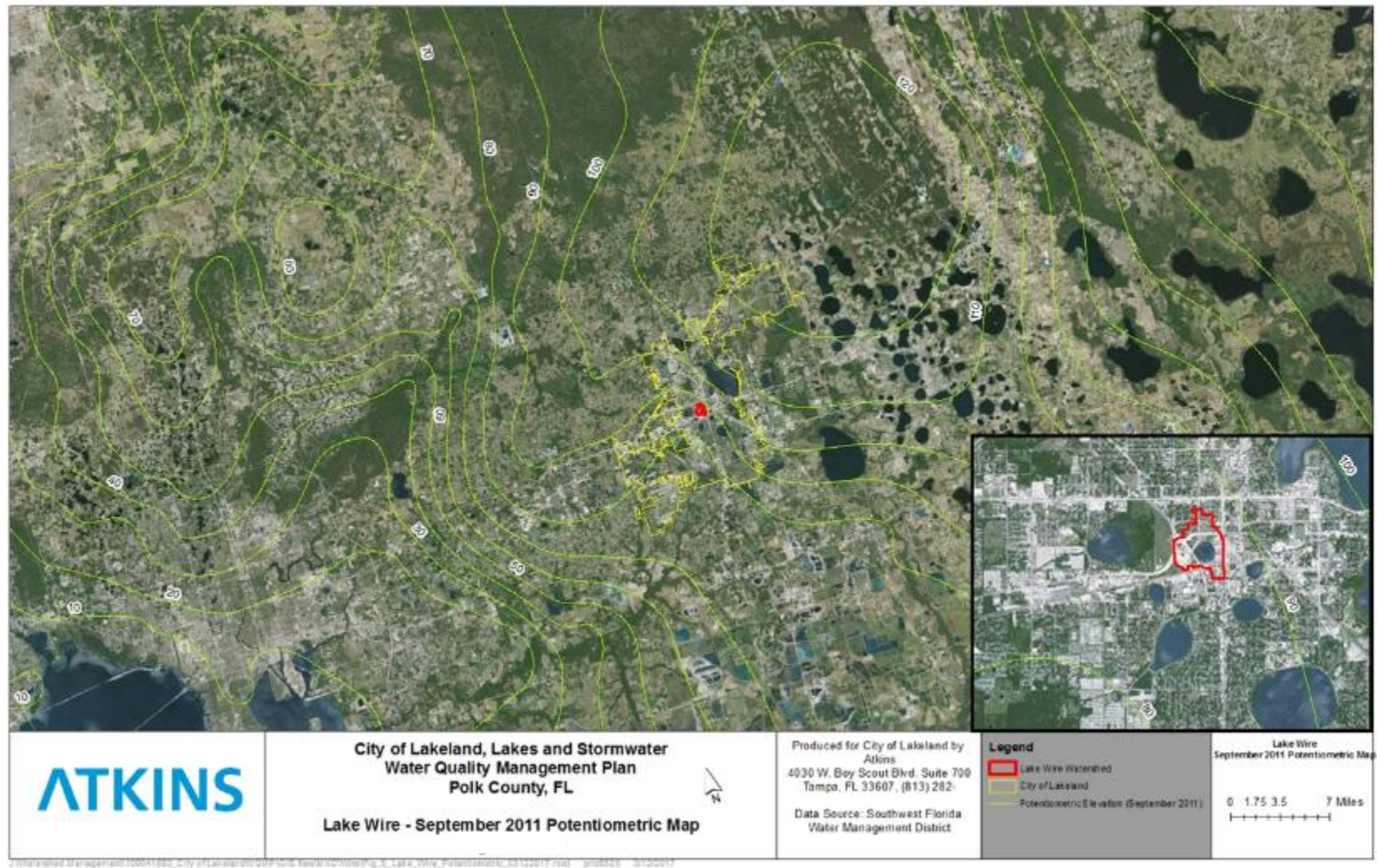


Figure 6-132. Lake Wire potentiometric map

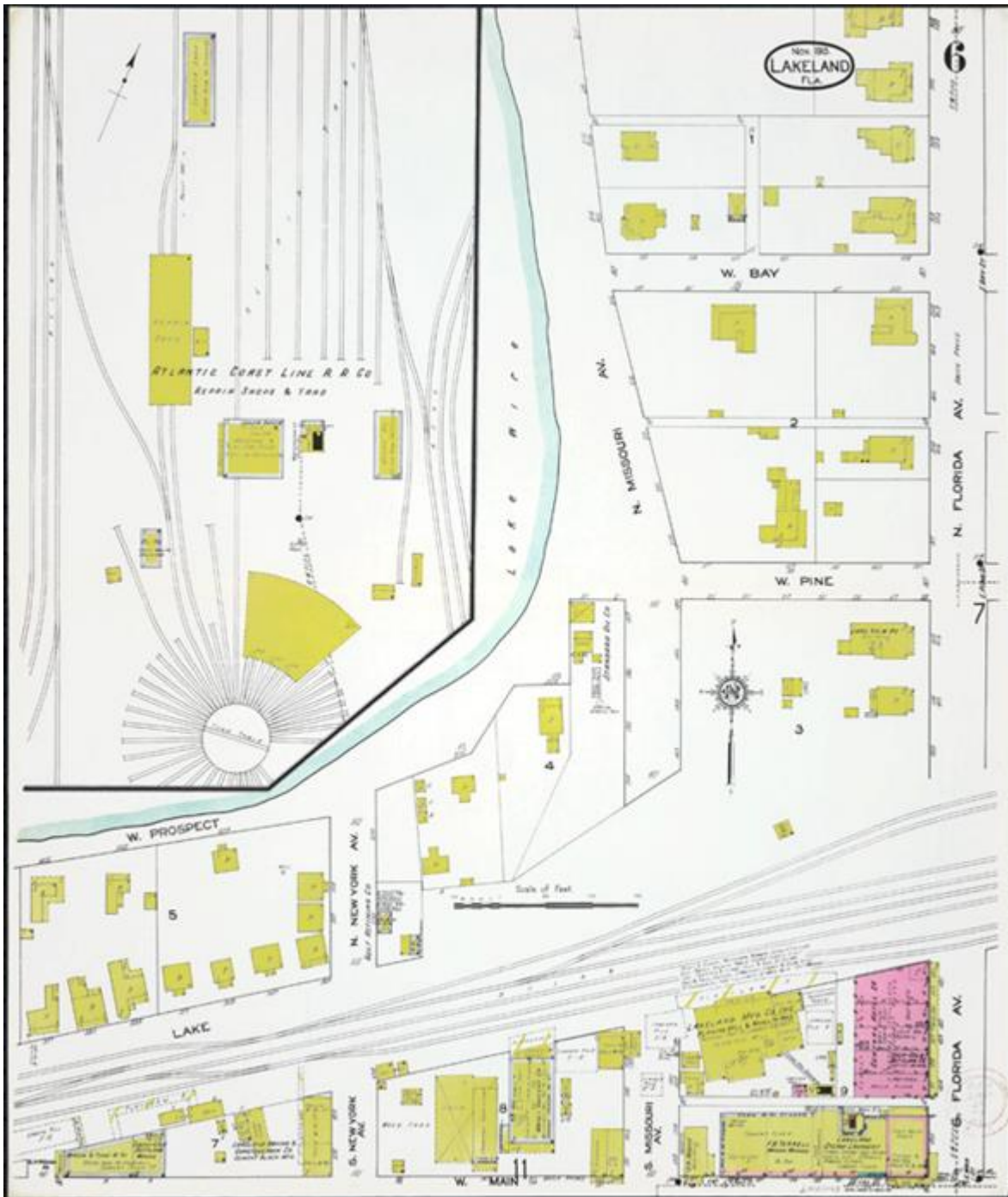


Figure 6-133. Eastern portion of the Lake Wire watershed 1913 Sanborn map

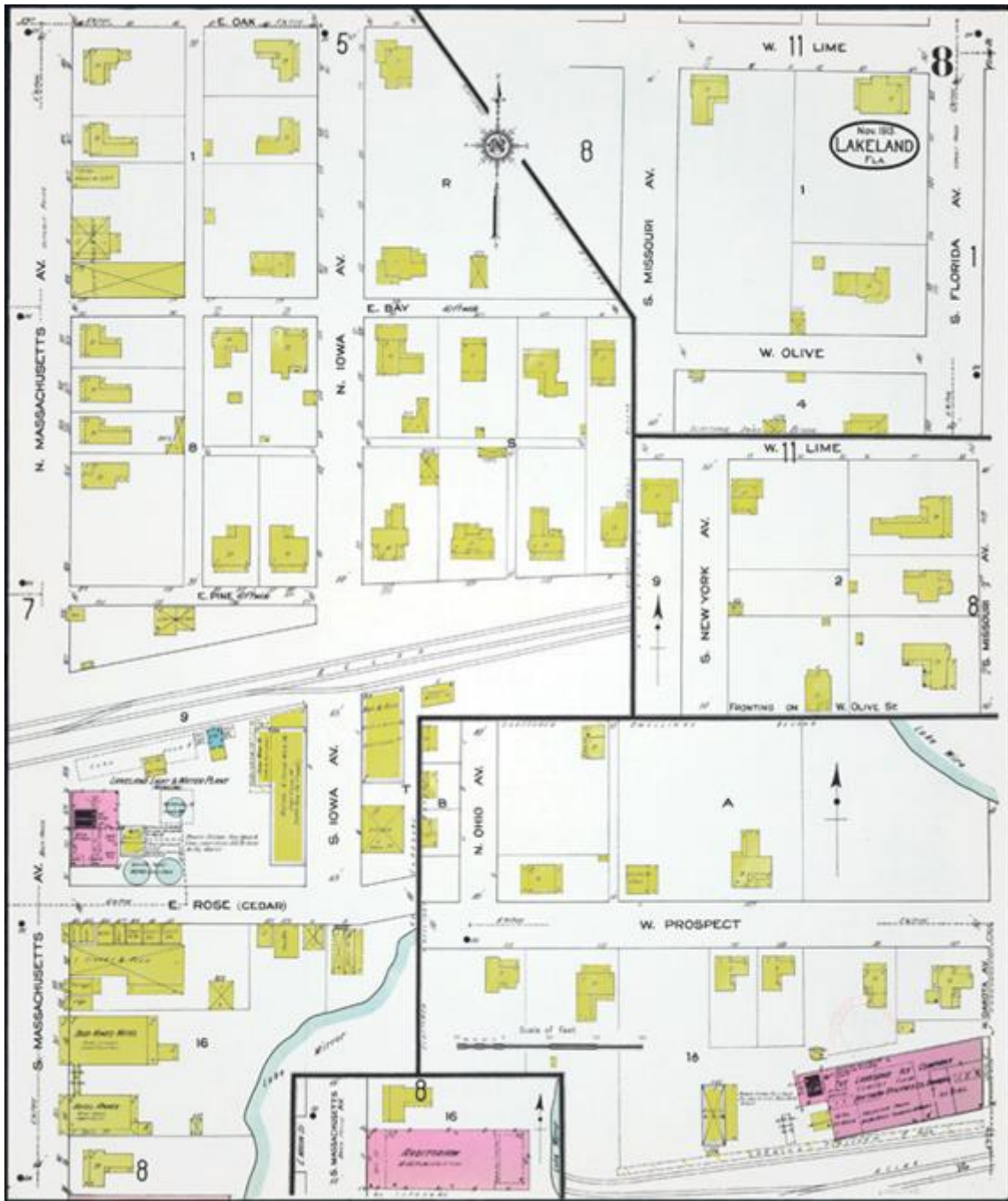


Figure 6-134. Southwestern portion of the Lake Wire watershed 1913 Sanborn map



Figure 6-135. Lake Wire Historic Aerial Imagery. Left Photo: 1958. Right Photo: 1968.

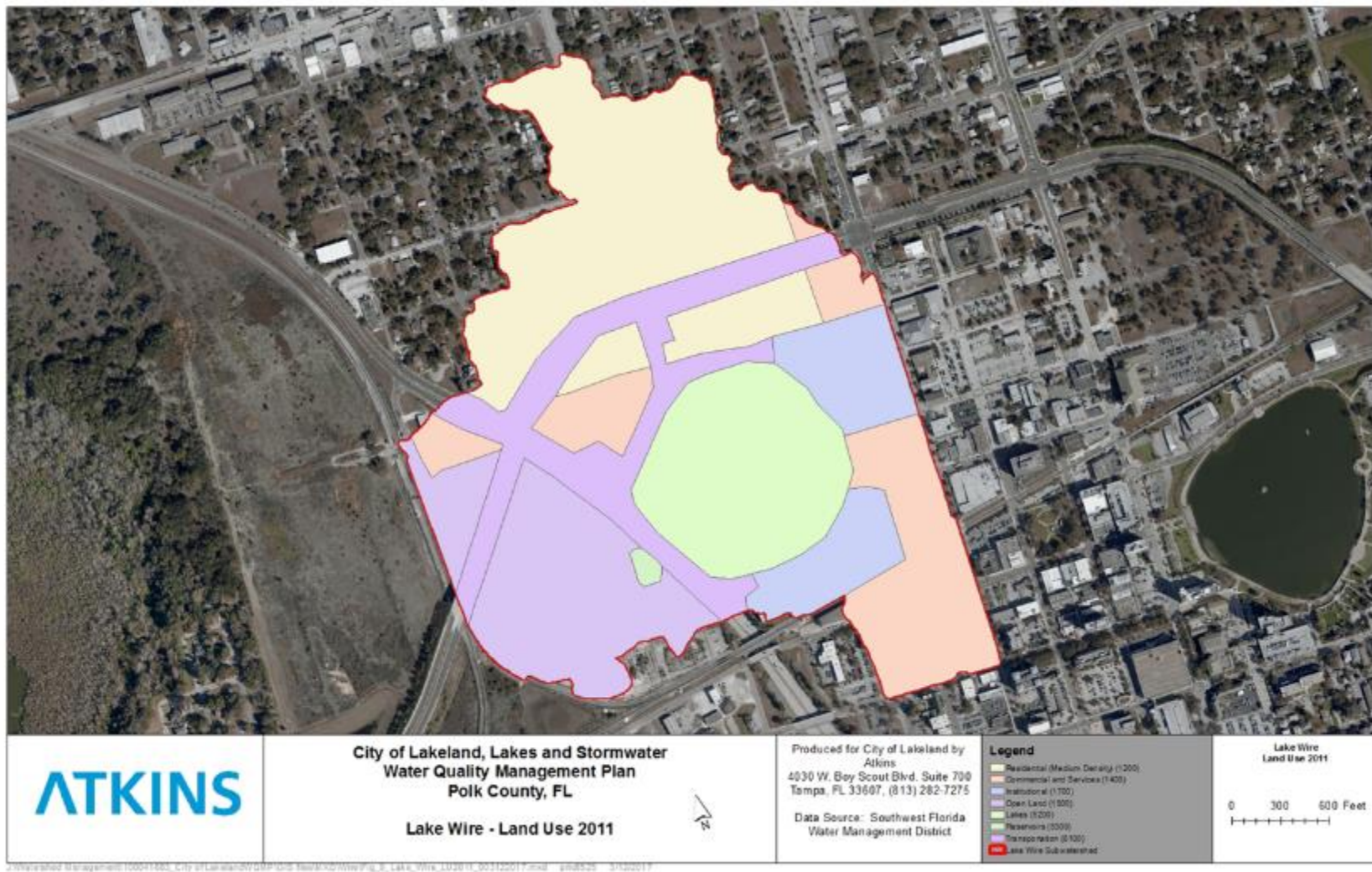


Figure 6-136. Lake Wire 2011 land use map



Figure 6-137. Lake Wire stormwater map



Figure 6-138. Lake Wire OSTDS map

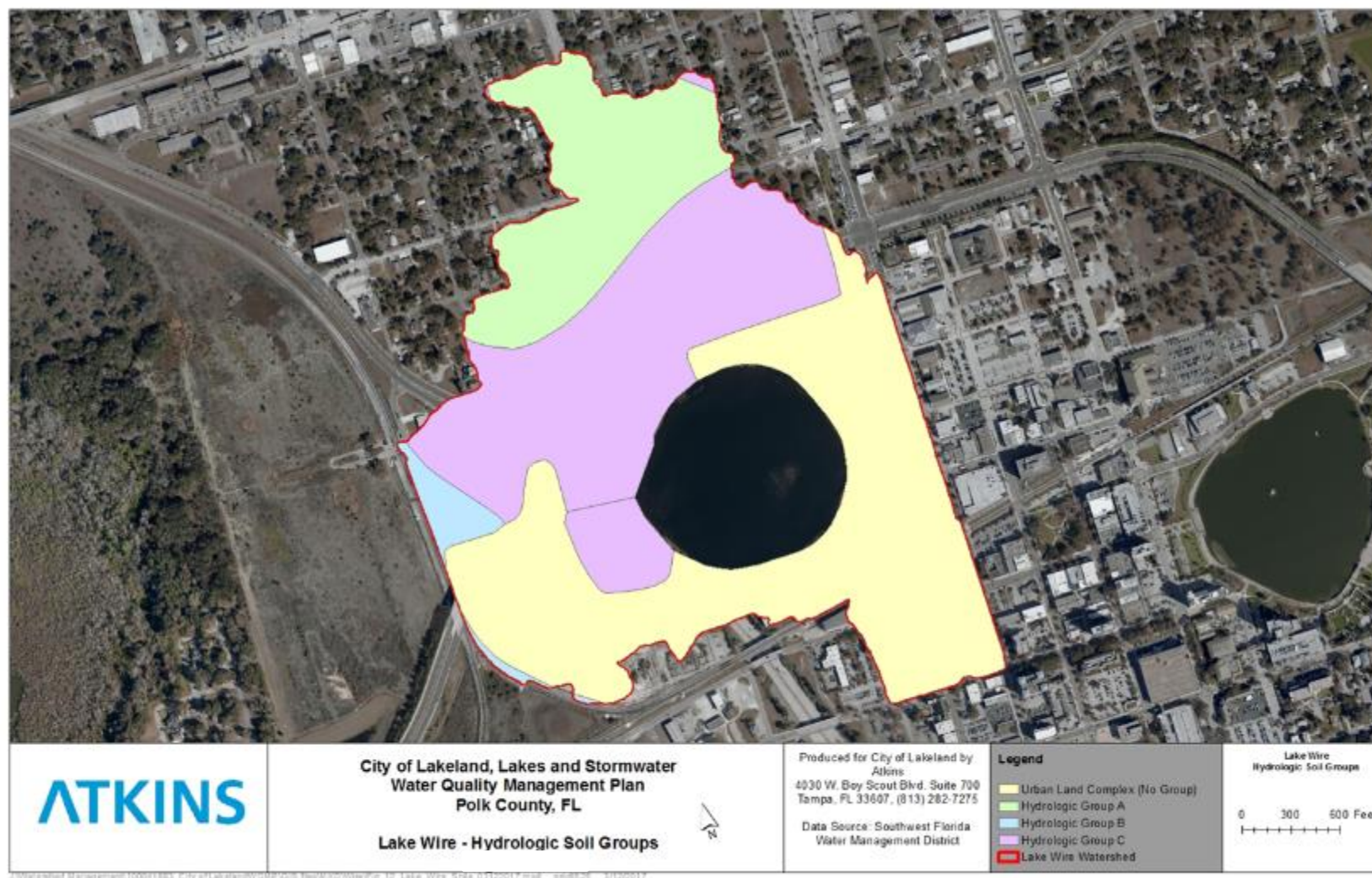


Figure 6-139. Lake Wire soils map

Water Quality

Previously, Lake Wire was listed as impaired for nutrients by the City even though the lake was not listed as impaired by FDEP (page 53 in City of Lakeland 2010). In FDEP's latest version of the Comprehensive Verified Impaired List (December 18, 2017) Lake Wire is listed as impaired for lead, but not nutrients. Lake Wire is a Group 2 waterbody as part of the Hillsborough River, the most recent impairment evaluation was performed for the verified period of January 1, 2007 to June 30, 2014 (Cycle 3) which applied NNC as the numeric criteria. The cycle 4 assessment period will occur in 2020 for the verified period of January 1, 2012 to June 30, 2019.

To minimize the impacts of different verified periods, this report characterizes water quality for each of the City's priority lakes during the same time period, 1/1/2009 to 6/30/2016. These dates correspond to the most recent Verified Period assessment used by FDEP during which water quality data are fully available for analysis for determining impairment status.

Water quality data were downloaded from FDEP, and used to determine the classification of Lake Wire. The lake was classified as a low-color, alkaline lake, based on a geometric mean value for color of 15 PCU and a geometric mean alkalinity value of 47 mg (as CaCO₃) / liter. Based on that classification, the water quality targets for TN and TP were then determined based on whether or not the annual geometric mean for a given year exceeds the threshold target of 20 µg chlorophyll-a / liter. The relevant water quality criteria for TN and TP for Lake Wire are highlighted in yellow in Table 6-43. Based on the above-listed criteria, Lake Wire has the following exceedances (Table 6-44).

TABLE 6-43. WATER QUALITY CRITERIA FOR LAKE WIRE, WITH RELEVANT TARGETS FOR CHLOROPHYLL-A, TN AND TP HIGHLIGHTED IN YELLOW.

Long Term Geometric Mean Lake color and Alkalinity	Annual Geometric Mean chlorophyll-a	Minimum calculated numeric interpretation		Maximum calculated numeric interpretation	
		Annual Geometric Mean TP	Annual Geometric Mean TN	Annual Geometric Mean TP	Annual Geometric Mean TN
> 40 PCU	20 µg/L	0.05 mg/L	1.27 mg/L	0.16 mg/L	2.23 mg/L
≤ 40 PCU and > 20 mg/L CaCO ₃	20 µg/L	0.03 mg/L	1.05 mg/L	0.09 mg/L	1.91 mg/L
≤ 40 PCU and ≤ 20 mg/L CaCO ₃	6 µg/L	0.01 mg/L	0.51 mg/L	0.03 mg/L	0.93 mg/L

TABLE 6-44. SUMMARY OF WATER QUALITY IMPAIRMENT DETERMINATIONS FOR LAKE WIRE BY YEAR. YEARS WITH INSUFFICIENT DATA FOR COMPARISON WITH NNC CRITERIA ARE NOTED BY “-”.

Year	chlorophyll-a (µg / liter)	TN (mg / liter)	TP (mg / liter)
2009	3.38	0.530	0.030
2010	4.20	0.368	0.028
2011	3.22	0.535	0.026
2012	5.00	1.075	0.026
2013	-	-	-
2014	3.67	0.539	0.031
2015	-	-	-
2016	-	-	-
Average percent reduction required (when needed)	None	None	None

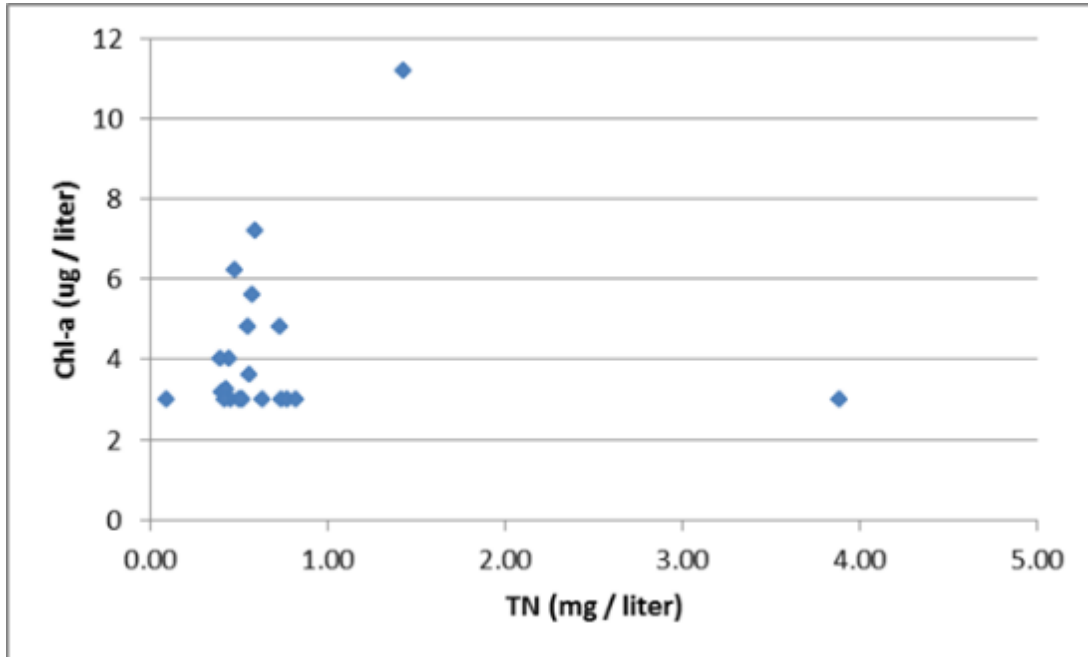
Based on NNC criteria, Lake Wire is not impaired for nutrients. As such, no reductions are required for TN or TP concentrations in the water column.

Additionally, there are no statistically significant relationships between either TN and chlorophyll-a or TP and chlorophyll-a (Figures 6-140 and 6-141, respectively).

Given the current water quality status and the lack of evidence of nutrient limitation of the limited algal biomass in Lake Wire, no water quality restoration projects are recommended at this time. However, an evaluation of internal and external nutrient loads was investigated to provide a preliminary list of projects should water quality begin to degrade.

A statistical correlation between annual average nutrient concentrations and annual rainfall was not found indicating that external sources such as stormwater runoff are not likely dominant influences on in-lake water quality. Based upon these results, projects which focus on stormwater retrofits are not good candidates for managing water quality in Lake Wire. However, the maintenance and enhancement of native emergent and submerged aquatic vegetation is recommended.

Lake sediment resuspension was not identified as a likely source of internal nutrient loads to the overlying water column, and therefore sediment removal and/or sediment inactivation projects are not recommended as there is no evidence of sediments as a likely problem for water quality in the lake. Should a nutrient-related water quality problem arise in the near future, whole-lake circulation is recommended based on the lake size.



An analysis of the historical versus current lake extent indicated that the lake has been lowered compared to its original configuration. The lake's geomorphology suggests it is a ridge lake, as outlined in PBS&J (2008), thus wetland influences on water quality are not as critical to assess. However, for Lake Wire, as with Lake Mirror and Lake Morton, the restoration of wetland – lake interactions are not likely, as there are no significant wetland fringes remaining along the lake shoreline.

Although Lake Wire appears to be a healthy lake, and it is not impaired using NNC guidelines, this is likely in large part related to the presence of substantial SAV biomass (i.e. Hydrilla). The Hydrilla almost certainly assimilates nutrients in the water column and suppresses the expression of chlorophyll-a. Moreover, Lake Wire currently receives periodic mechanical removal of Hydrilla supplemented by the more standard protocol of chemical eradication. Additionally, sterilized grass carp assist in managing Hydrilla. This provides two major benefits: a) Hydrilla is simply pruned and not eradicated thereby managing growth and simultaneously sustaining beneficial SAV biomass and b) physical removal of the SAV from the system results in physical removal of TN and TP loads. That being the case, it is prudent to suggest that the physical removal of Hydrilla should continue with only occasional supplemental control via chemical treatment. The annual load of TN and TP removed via Hydrilla harvesting should be quantified and reported as nutrient load reductions to the FDEP. Moreover, results can be used to justify development of SAV restoration projects in other City lakes where deemed feasible to do so.

Site-specific chlorophyll-a, TN, and TP targets have not been established and thus may be appropriate for Lake Wire. collection and analysis of locally-derived paleo data is advisable if the City decides to pursue establishing site-specific criteria.

Water Quality Restoration Project Selection and Priorities

Based on Lake Wire water quality and the surrounding watershed characteristics, two potential water quality restoration project was identified using the City's WQMP decision key. Proposed projects to enhance and "hold the line" on current water quality conditions. The projects are listed in order of priority, based on expected water quality improvements. A detailed discussion of the potential water quality restoration implications for each project can be found in Section 4.0.

Project 1: SAV Planting/Management or FTWs

Project 2: EAV Planting/Management

Project 1: SAV Planting/Management or FTWs

SAV Planting

A survey of existing SAV cover in Lake Wire is recommended due to the lack of sufficient, recent data to calculate percent lake cover. Based on the results of the SAV survey, conclusions regarding SAV planting can be determined. If SAV cover is less than 30 percent, lake conditions should be evaluated to assess if additional SAV is viable based on the soil condition, water clarity and water depth.

Based on the median Secchi depth (3.3 meter) from the POR (1988 to 2017), plants would not be planted in water depths greater than 3.5 meter (Water Atlas). The maximum planting effort for Lake Wire cannot be calculated until digital bathymetry data are acquired.

Bathymetric Survey Cost Estimate: \$10,000

SAV Planting/Management Cost Estimate: A cost estimate will be generated upon receipt of the bathymetry data.

FTWs

If the feasibility study indicates that more than 30 percent of Lake Wire has SAV cover, FTW may be considered. The installation of floating mats with appropriate aquatic vegetation would be expected to assimilate nutrients from the water column.

Project 2: EAV Planting

A survey of existing shoreline vegetation surrounding Lake Wire is recommended due to the lack of sufficient data at this time. Based on the results of the shoreline survey, conclusions and recommendations regarding emergent aquatic or woody vegetation planting can be determined. If limited shoreline vegetation is present, shoreline conditions should be evaluated, preferably by City staff, to assess if vegetation planting is viable based on the soil conditions, slope, water level and inundation frequency and wave disturbance.

EAV Planting/Management Cost Estimate: A cost estimate will be generated upon receipt of the shoreline survey data.

7. IDENTIFICATION OF DATA GAPS

The value of the WQMP for the City's priority lakes will depend on the scientific basis upon which various lake management actions are derived, and the WQMP would benefit from testing various potential water quality improvement projects at an early stage of the project development process. For example, preliminary work on an aquarium-scale study (Tomasko et al. 2016) has determined that the addition of bundles of cypress needles has been able to reduce algal biomass in hypereutrophic waters by more than 90 percent. While such results do not yet warrant the incorporation of such a lake management technique on a City-wide basis, the WQMP could benefit from results of a follow-up study at a larger, perhaps mesocosm scale. Similarly, past experiences have shown that whole-lake circulation can be a useful management tool for hypereutrophic lakes, although its direct applicability for larger lakes is less certain.

As well, paleolimnological sediment core data has been shown to provide evidence of the historical water quality conditions within a lake (e.g., Whitmore and Brenner 1995). The development of locally-appropriate water quality targets could be an important part of the WQMP, because regardless of whether or not TSI or NNC criteria are used for impairment determinations, the highest allowable chlorophyll-a concentration within lakes is 20 µg/L.

Data gaps fall into two main categories, those that are widespread to almost all 11 lakes, and those that might be specific to perhaps only one or more lakes. Widespread data gaps include the need for paleolimnological (paleo) data to support the establishment of reasonable water quality targets, the need to quantify the amount of SAV within lakes, and the need for detailed and up to date bathymetric data.

Paleo sediment core data has been shown to provide evidence of the historical water quality conditions within both Lake Hollingsworth and Lake Parker (Brenner et al. 1999). Paleo data does not exist for the remaining nine lakes. These paleo studies could be essential to ascertaining the appropriate management levels of TN, TP, and chlorophyll-a in each of the 11 lakes. Regardless of whether or not the TSI or NNC criteria is used for regulatory impairment and/or TMDL determinations, the highest allowable chlorophyll-a concentration within all 11 lakes is 20 µg/L. If the historical conditions of these lakes are such that a chlorophyll-a concentration of 20 µg/L is overly conservative, this would result in the City continuously "failing" established regulatory lake criteria well into the future.

Additional pervasive data gaps are a) the lack of detailed bathymetric data and b) detailed information related to the abundance of both desirable and nuisance SAV. What little available data there is regarding SAV communities, suggests that the abundance of SAV may be assimilating nutrients (TN and TP) rather than allowing it to freely stimulate phytoplankton blooms. For all 11 lakes, the relative abundance of SAV (or lack thereof) certainly influences overall water quality

and ecological health. Therefore, it would be well worth the effort of mapping the volume of lake occupied by the SAV community, for lakes where such information is not available, to gain a better understanding of the SAV – water quality relationships.

Data gaps specific to each of the 11 lakes are discussed in more detail in Appendix B, along with a general outline of how these data gaps might be filled, and approximate costs for filling the most critical data gaps.

Derivation and Use of Alternative Water Quality Targets

The paleolimnological study for Lake Bonny (Whitmore et al. 2016) is current enough that its findings should be discussed with FDEP to ensure that the State’s agencies are aware of the impractical nature of the existing NNC criteria for lakes such as Crystal and Bonny and Hunter, which appear to have been lowered below their historical elevation, as well as Gibson and Parker, where drainage ditches have been dug through large wetland features that border both those lakes. Both types of impacts likely reduced the lake-wetland hydrologic connections in such a way that these lakes have likely become more susceptible to nutrient concentrations than they were historically. The complexity of the tannin-nutrient-phytoplankton relationships found for Lake Bonny (Whitmore et al. 2016) are such that it was concluded that nutrient reduction alone, even if to pre-development concentrations, would not result in the lake also obtaining pre-development values for chlorophyll-a. The need for restoration of the lake’s historical lake-wetland connectivity supports conclusions related to the need for such projects that was also reached for Lake Hancock (Tomasko et al. 2009).

In Lake Hollingsworth, paleolimnological studies completed by Brenner et al. (1999) suggest that target values for chlorophyll-a should be 36.05 µg/L and TP and TN targets should be 0.047 mg/L and 0.79 mg/L respectively. If FDEP allows for the use of these proposed site specific alternative criteria under a BMAP scenario, a valid argument could also be made that all City lakes classified as low-color, alkaline, valley lakes should have the similar targets, although ridge lakes may warrant additional paleo studies and subsequent water quality target development. This would not be an unreasonable request as FDEP has used paleo data in the past to set TMDL water quality targets for the Southern Chain of Lakes in Winter Haven (FDEP 2007). Locally-derived paleo data and corresponding TN, TP, and chlorophyll-a targets should ideally be determined for each of the eleven City priority lakes and used as interim lake management goals.

Abundance and Influence of SAV on Water Quality

The abundance of SAV can be an important influence on water quality. Prior work has found that the amount of lake volume occupied by SAV can strongly influence phytoplankton biomass (e.g., Canfield et al. 1984, Moreno 2009). Lakes such as Lake Tarpon show a pattern wherein the acreage of Hydrilla chemically treated (and left to decay in situ) is positively correlated with chlorophyll-a concentration (Figure 7-1).

Combining these two paradigms, lake management actions should seek to maximize the abundance of native SAV species, while also being careful to not “flip” a lake into an algal-dominated system via chemically eradicating Hydrilla in situ. Lake Wire, for example, appears to be a lake where the abundance and careful maintenance of native SAV and Hydrilla might be responsible for the relatively low average chlorophyll-a concentration in any given year.

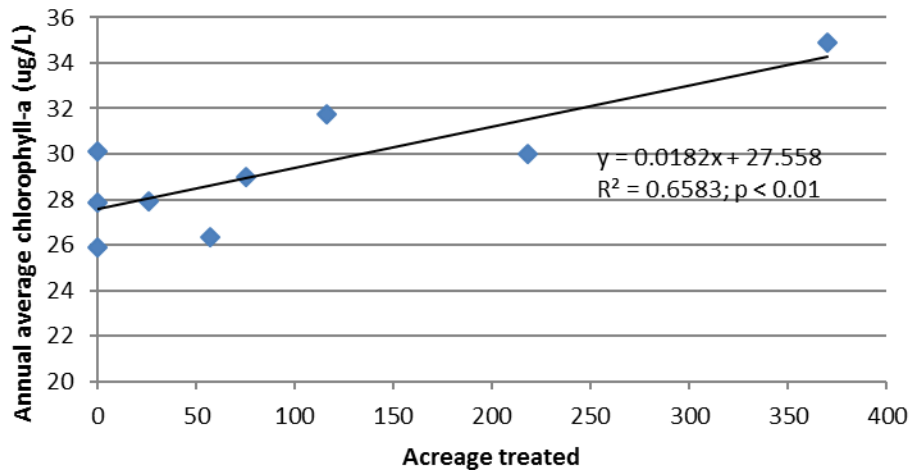


Figure 7-1. Annual Average chlorophyll-a Concentrations VS Acreage of Hydrilla Treated in the Same Year (Data from Lake Tarpon from 1993 to 2014).

Ideally, SAV abundance should be mapped and assessed in all eleven City priority lakes. At the very least, it is highly recommended to map SAV for the smaller lakes in the City (Mirror, Morton, Wire, and Beulah). The techniques used by Moreno (2010) should be replicated as the author found that quantifying the abundance of SAV in terms of the percent of the water column occupied was a good predictor of water quality. The techniques used by Moreno (2010) include the following: 1) simultaneous recording of “soft” and “hard” bottom returns generated through the use of a recording fathometer (e.g., Lowrance model LCX-28CHD) at 100 points per lake sampled and 2) direct observations for verification at 10 percent of the points sampled. Using such data, the percentage of lake volume occupied by SAV can be determined as follows:

$$\frac{\sum_{0}^{100} \left(\frac{\text{Lake depth} - \text{Depth of vegetation}}{\text{Lake depth}} \right)}{100} = \text{PVI}$$

Where:

- Lake depth = the hard return depth
- Depth of vegetation = the depth to the top of the vegetation at each site (soft return)
- PVI = Percent Volume Infested (or the volume of the lake occupied by SAV).

Should PVI be similarly important for Lakes Beulah, Mirror, Morton and Wire as was found by Moreno (2010) then target values for SAV could be developed based on empirically-derived relationships between PVI and water quality parameters. This could give rise to guidance related to the establishment of native SAV populations. If sufficient data exist from applicable Polk

County operations, it may be possible to find out if there is an inverse relationship within a given lake between Hydrilla eradication via chemical treatment and subsequent levels of chlorophyll-a. If such a pattern exists, then guidance criteria could be developed in terms of maximum acreages to be treated in such a manner.

Effects of Tannins and Tannin Sources on Cyanobacteria Populations

Water chemistry data in Lakes Bonnet, Bonny, Hollingsworth, Hunter, Little Lake Bonny and Parker suggest that TN concentrations are well above values that can be explained by stormwater runoff alone. That these lakes also have chlorophyll-a concentrations often in excess of 90 µg/L is suggestive of high rates of nitrogen-fixation by cyanobacteria, as has been documented in nearby Lake Hancock (Tomasko et al. 2009).

It is evident that the aforementioned six lakes have also been adversely impacted by lowered lake water elevations such that lake water elevations now fluctuate below the respective historical wetland fringe. The fact that large portions of their historical wetland fringes are now heavily developed exacerbates related water quality issues. Both processes are likely associated with reductions in the amount of tannins exported to these lakes. This has been previously shown to produce problematic water quality issues in the Winter Haven Chain of Lakes system (PBS&J 2008, 2011). For Florida, lakes with limited development along their shorelines, such as Cypress Lake in Osceola County, raising the lake water elevation is considered a valuable way to improve water quality (Atkins 2013). Unfortunately, it appears that intensive lakeside development precludes such an approach in most City lakes.

Rather than raising lake water elevations to restore historical lake – wetland interactions, the maintenance, re-creation, and/or restoration of wetland influences should be pursued. For example, the extensive wetland located west of Lake Parker is an ideal location for restoration, as it appears that a drainage ditch has reduced both the nutrient assimilative capacity of the wetland as well as the likely reduction in tannin exportation to the lake. Additionally, Lake Bonnet, Lake Bonny, Lake Gibson, and Lake Hunter have varying amounts of wetland remaining either immediately adjacent to the lakeshore or relatively nearby upstream in the watershed. These wetland areas should be preserved and, where feasible, their hydroperiods and vegetation quality be restored. Since Lake Gibson is not impaired for nutrients, the connected large wetland north of the lake may help the City determine the hydroperiod necessary for effective nutrient assimilation and tannin exportation.

For lakes where wetland influences have been lost and cannot be recovered via hydrologic restoration, water quality treatments through the use of barley straw and/or cypress leaf bundles could be tested for their ability to reduce cyanobacteria abundance as has been tested (at the aquarium scale) for Lake Hancock (Tomasko et al., 2016). Although the addition of cypress needles has been shown to be useful for reducing cyanobacteria populations, the study was limited to 10-gallon aquaria and it is not known at this time if results would scale up proportionally. To conduct this experiment at the level of a whole lake involves significant costs and the approach may not work as well on the level of a whole lake as it did in an aquarium.

In October of 2017, a preliminary mesocosm study was completed in Lake Hunter. The results from this study are included in the Appendices, with a summary of conclusions copied here:

The interpretation of results from the mesocosm study is complicated by two factors. First, the mesocosms appear to have “captured” water masses that differed at the beginning of the experiment. While levels of chlorophyll-a were similar across the four treatments, levels of TN and TP were higher in the controls and barley straw treatments on the initial sampling date. The reasons for this are unclear, as the mesocosm were randomly assigned, and no obvious differences were noted on the initial day of deployment. The second factor that needs to be accounted for is related to the mesocosm design. While the mesocosms looked appropriate on the day of deployment (see Figures 1 and 2) they did not prove to be capable of withstanding wind-induced wave action. As well, the mesocosms appear to have been deployed in waters that were too shallow, which reduced the volume of water in each mesocosm, and which resulted in the “buckling” of the mesocosm sides due to insufficient water depth.

Despite these complications, it does appear that there is some evidence of the value of the cypress leaves and pine straw treatments. In the controls, concentrations of TN and TP increased over the two weeks (although the increase was less than 5 percent for TN). In contrast, concentrations of TN decreased by at least 17 percent over that same time period for the cypress leaves and pine straw treatments. TP concentrations were similar over the two-week deployment for the barley straw, cypress leaves and pine straw treatments, while they had increased by more than 90 percent in the controls over the same time period.

This mesocosm study was not able to definitively determine whether or not promising results from aquarium studies (i.e., Tomasko et al. 2013) could be transferred to a whole-lake scale. The main issues with this mesocosm study appeared to be related to an inadequate design – the limno-corrals were too “flimsy” to withstand the wave action required for them to maintain their structural integrity. As such, the recommendation for a mesocosm study still stands, but with greater resources required to produce a potentially reproducible result.

Such an approach should be conducted in Lake Bonny for the following reasons: 1) water quality data suggest the lake is strongly influenced by cyanobacteria, 2) data exist that suggest Lake Bonny is now 3 to 4 feet lower than it was historically, and 3) deployment of and access to the limno-corrals to test the technique would be relatively easy. It is further recommended that such a study be conducted in a replicated manner, with three treatments (limnocorrals with cypress leaves), three controls (limno-corrals without cypress leaves) and three locations with neither cypress leaves nor cylinders. The experiment should be conducted twice; once at the end of the dry season (May) and again at the end of the wet season (September). Each experiment should last at least one month, and involve the collection of at least the following parameters:

- Secchi disk depth;
- chlorophyll-a;
- Phaeophytin;

- TN;
- TP;
- color;
- D.O.;
- pH; and
- BOD.

Results would be interpreted with the intent that findings would give guidance to the City as to whether or not deployments of bundles of cypress leaves should be considered as a lake management strategy for valley lakes that have lost their historical wetland influences and where water quality data suggest significant quantities of cyanobacteria.

However, the value of a project similar to that outlined above would be dependent upon several factors: 1) would the application of cypress leaves or barley straw or some similar material be permissible, or would such materials be classified as “pesticides” or “herbicides”, 2) would the costs of deployment of such a system on a whole-lake basis be cost-effective, and 3) would there be any potential adverse impacts to water quality associated with the decay of added organic compounds such as barley straw or cypress leaves?

Alternative considerations for increasing tannins and providing other important water quality and ecological benefits in applicable City lakes are 1) in-lake hydrophilic hardwood (e.g. cypress and bay trees) and herbaceous wetland creation projects and 2) where un-aided wetland flow-through by raising lake water elevations is not possible, constructing pumping stations to move lake water through the remaining lakeshore wetland areas.

Effect of Whole-Lake Aeration on Phytoplankton Populations

In the Winter Haven Chain of Lakes, whole-lake aeration was proposed as a water quality management action for lakes smaller than 75 acres. Lakes Beulah, Little Bonny, Mirror, Morton, and Wire are all less than 75 acres in size. In a review of literature conducted by Tomasko et al. (2013), it was found that whole-lake aeration reduced TP concentrations in lakes by an average of 52 percent with a range of 17 percent (Lake Persimmon, Florida) to 88 percent (Lake Hald, Denmark). In that study, it was found that Lake Huntsman (Virginia) experienced a significant reduction in TP concentrations in the 2 years after implementation of whole-lake aeration, although substantial variation reduced the confidence that the improvement would be sustained over time.

To test the value of whole-lake aeration, it is proposed that the City conduct a Before and After / Control and Impact (BACI) study with two small lakes. Water quality would be examined over time before and after the implementation of whole-lake aeration in one lake, while the other lake would serve as a control for the treatment effect. Due to their similar water quality and identical

TP reduction targets to meet NNC criteria, it is proposed that Lakes Mirror and Morton serve as the candidate lakes. Due to its smaller size, Lake Mirror is a stronger candidate for actual implementation of a whole-lake aeration system. Based on prior work conducted on behalf of the City of Winter Haven, it was found that a single solar-powered whole-lake aeration system (e.g., SolarBee© or equivalent) can be used for systems up to 20 acres in size. This would allow a single system to be tested in Lake Mirror (19 acres); if Lake Morton (41 acres) was used, 2 such aeration systems would be needed. Another option would be to deploy such a system in Little Lake Bonny (26 acres) and compare results of any trends over time to that of the much larger Lake Bonny (255 acres).

The list of parameters to be tested in both lakes includes at least the following:

- Secchi disk depth
- chlorophyll-a;
- Phaeophytin;
- TN;
- TP;
- color;
- D.O.;
- BOD;
- pH;
- Conductivity; and
- Turbidity.

Results of such a study would give guidance to the City as to whether or not deployments of solar-powered whole-lake aeration and circulation systems should be considered as a feasible lake management strategy for smaller eutrophic lakes.

8. CONCLUSIONS AND RECOMMENDATIONS

This WQMP provides a compilation of information relevant to managing water quality for the City's eleven priority lakes. Rather than developing a "one size fits all" approach, each lake was examined in detail to determine the factor(s) most responsible for any identified water quality concerns. To highlight the value of this approach, Lake Wire was found to no longer be impaired for water quality, when newly adopted water quality criteria were used.

In addition, only three of the eleven lakes are likely require expensive regional stormwater retrofits. For these three lakes (Beulah, Bonnet and Hunter) it may be more beneficial for stormwater to be treated through the use of raingarden-type projects, rather than the typical wet detention system. Raingarden projects act to capture stormwater runoff closer to the source, and they achieve greater reductions in nutrient loads per unit volume of water treated than wet detention ponds. Additionally, such projects can help to recharge the surficial aquifer, which can help maintain higher lake levels in the dry season.

For most of the priority lakes, internal processes are more likely responsible for problematic water quality, compared to external nutrient loads. This is particularly important for those lakes where sediments may be having a continuing adverse impact to water quality. Lakes Bonnet, Bonny, Crystal, and Hollingsworth are lakes where the removal of sediments or the isolation or sequestration of sediment nutrient pools would be needed to improve water quality. In the case of Lake Hollingsworth, prior sediment removal and sediment inactivation projects have improved water quality, but not to the point that water quality is no longer "impaired". However, FDEP's water quality criteria appear to be overly restrictive and unrealistic, at least for Lake Hollingsworth. The phosphorous and chlorophyll-a targets for Lake Hollingsworth, as listed in its TMDL (FDEP 2018) are so low that the lake would have been declared impaired for water quality as far back as the 1890s.

For five of the priority lakes, the impacts of "lost" wetland influences are likely a more important stressor on water quality than external nutrient loads. This lost influence was brought about via lowering of lake elevations, often by drainage systems that were constructed decades ago. Lakes Bonnet, Bonny, Crystal, Gibson and Parker, have experienced lowered lake levels or similar impacts from regional drainage features, which have reduced the amount of tannins or tannin-like compounds to these lakes. As lakes with intact wetland-lake interactions typically have higher tannin levels, and lakes with higher tannin levels are less likely to have problems with algal blooms, hydrologic restoration projects or other efforts to reintroduce tannin loads to these lakes are recommended. In the case of Lake Bonny, paleolimnological work supports the conclusion that historical lowering of the lake elevation was responsible for making the lake more susceptible to nutrient loads than it was prior to lake lowering.

Lake Parker is impacted by so many different stressors that water quality is not likely to improve unless a variety of lake management actions are implemented. These include hydrologic restoration of historical wetland fringes, as well as a potential large-scale project to use the Teneroc lake system as a sort of “polishing pond” to treat Lake Parker water, via a series of inter-connected pathways for water to routed through. As is the case for other lake management actions, the permitability of such an approach may not be fully known until further data is collected, analyzed and interpreted.

Finally, Lakes Beulah, Crystal, Mirror and Morton would likely benefit through the implementation of whole-lake circulation. The WQMP suggests that whole lake circulation be implemented in only one of these lakes as a feasibility study to test whether or not water quality improves in that lake, compared to the other three. Pending the review of those results, it could be that whole lake circulation is recommended for all four lakes.

In greater detail, the lake management guidance for each lake is outlined below. Preliminary cost estimates for more fully investigating the permitability of such projects listed in the section on lake by lake management actions (Chapter 6).

Lake Beulah

The lake is impaired for nutrients, with evidence that stormwater loads contribute to ongoing water quality problems. As such, stormwater loads should be reduced, with a focus on raingarden-type projects that are capable of reducing pollutant loads and recharging the surficial aquifer – to supplement dry season water levels. Additionally, Lake Beulah is small enough that artificial circulation would be expected to be able to improve water quality. A Before and After, Control and Impact (BACI) study on the benefits of whole-lake circulation should be undertaken to test the response to whole lake circulation, involving some combination of Lake Beulah, Crystal Lake, Lake Mirror and Lake Morton. There is no evidence that Lake Beulah would benefit from projects designed to increase the influence of wetland-related tannin loads to the lake.

Lake Bonnet

The lake is impaired for nutrients, with evidence that stormwater loads contribute to ongoing water quality problems. As such, stormwater loads should be reduced, with a focus on raingarden-type projects that are capable of reducing pollutant loads and recharging the surficial aquifer – to supplement dry season water levels. Additionally, Lake Bonnet would benefit from projects that could increase the influence of wetland-related tannin loads to the lake, as the lake appears to have been lowered to an elevation below that of its historical fringing wetlands. However, Lake Bonnet is too large for artificial circulation to be able to improve water quality. The bottom sediments in Lake Bonnet appear to be having an adverse impact on water quality, and further investigations are warranted to determine if sediment removal or sediment inactivation would be appropriate lake management strategies.

Lake Bonny

The lake is impaired for nutrients. However, while smaller projects may be appropriate in selected areas, there is no evidence of the need for large regional stormwater retrofit projects. Lake Bonny

would likely benefit from projects that could increase the influence of wetland-related tannin loads to the lake, as the lake appears to have been lowered to an elevation below that of its historical fringing wetlands. Lake Bonny is too large for artificial circulation to be able to improve water quality. The bottom sediments in Lake Bonny appear to be having an adverse impact on water quality, and further investigations are warranted to determine if sediment removal or sediment inactivation would be appropriate lake management strategies.

Crystal Lake

The lake is impaired for nutrients. However, while smaller projects may be appropriate in selected areas, there is no evidence of the need for large regional stormwater retrofit projects. Crystal Lake would likely benefit from projects that could increase the influence of wetland-related tannin loads to the lake, as the lake appears to have been lowered to an elevation below that of its historical fringing wetland. Additionally, Crystal Lake is small enough that artificial circulation would be expected to be able to improve water quality. The bottom sediments in Crystal Lake appear to be having an adverse impact on water quality, and further investigations are warranted to determine if sediment removal or sediment inactivation would be appropriate lake management strategies.

Lake Gibson

Lake Gibson is impaired for nutrients, using FDEP's newly adopted NNC criteria, but only for the last two years with sufficient data, not earlier years. Additionally, while smaller projects may be appropriate in selected areas, there is no evidence of the need for large regional stormwater retrofit projects. However, Lake Gibson would benefit from projects that could increase the influence of wetland-related tannin loads to the lake, particularly for a large wetland feature located north of the lake, which appears to have been compromised by a ditch running down through the middle. However, the lake is too large for artificial circulation to be able to improve water quality.

Lake Hollingsworth

While the lake is impaired for nutrients, paleolimnological studies have found that water quality in Lake Hollingsworth is better now than it was back in the 1960 to 1970s. The improvement in water quality is thought to be due to the historical loss of citrus groves as a dominant feature of the watershed. Also, and with potential implications to other lakes in the City, the paleolimnological work on Lake Hollingsworth shows that the water quality targets used by FDEP in its TMDL would have resulted in a finding of exceedance more than 100 years ago. While smaller scale and opportunistic projects may be appropriate in selected areas, there is no evidence of the need for large regional stormwater retrofit projects for Lake Hollingsworth. Lake Hollingsworth is too large for artificial circulation to be able to improve water quality. However, the bottom sediments in Lake Hollingsworth appear to be having an adverse impact on water quality, and further investigations are warranted to determine if additional sediment removal or sediment inactivation projects are still needed, or if the benefits from prior dredging and sediment inactivation projects are likely all that is likely to be reasonably expected to occur. There is no evidence that Lake Hollingsworth would benefit from projects designed to increase the influence of wetland-related tannin loads to the lake.

Lake Hunter

The lake is impaired for nutrients, with evidence that stormwater loads contribute to ongoing water quality problems. As such, stormwater loads should be reduced, with a focus on raingarden-type projects that are capable of reducing pollutant loads and recharging the surficial aquifer – to supplement dry season water levels. However, the lake is too large for artificial circulation to be able to improve water quality. There is also no evidence that Lake Hunter would benefit from projects designed to increase the influence of wetland-related tannin loads to the lake.

Lake Mirror

The lake is impaired for nutrients. However, while smaller projects may be appropriate in selected areas, there is no evidence of the need for large regional stormwater retrofit projects. Additionally, the lake is not likely to benefit from projects that could increase the influence of wetland-related tannin loads to the lake. However, Lake Mirror is small enough that artificial circulation would be expected to be able to improve water quality. A BACI study on the benefits of whole-lake circulation should be undertaken to test the response to whole lake circulation, involving some combination of Lake Beulah, Crystal Lake, Lake Mirror and Lake Morton.

Lake Morton

The lake is impaired for nutrients. However, while smaller projects may be appropriate in selected areas, there is no evidence of the need for large regional stormwater retrofit projects. Additionally, the lake is not likely to benefit from projects that could increase the influence of wetland-related tannin loads to the lake. However, Lake Morton is small enough that artificial circulation would be expected to be able to improve water quality. A BACI study on the benefits of whole-lake circulation should be undertaken to test the response to whole lake circulation, involving some combination of Lake Beulah, Crystal Lake, Lake Mirror and Lake Morton.

Lake Parker

The lake is impaired for nutrients. And while smaller projects may be appropriate in selected areas, there is no evidence of the need for large regional stormwater retrofit projects. However, Lake Parker would benefit from projects that could increase the influence of wetland-related tannin loads to the lake, particularly for a large wetland feature located west of the lake, which appears to have been compromised by a ditch running down through the middle. Lake Parker is too large for artificial circulation to be able to improve water quality. A unique feature of the Lake Parker watershed is the large Teneroc Lakes system, located on the lake's northern shoreline. While significant data gaps exist, it may be possible to create a flow-through water treatment system, if the Teneroc system lakes are found to have the appropriate characteristics of depth and water quality to allow for the extensive non-native Hydrilla beds in those lakes to act as "polishing ponds" for water pumped into the Teneroc lakes from Lake Parker, and then routed throughout the system before being discharged back into Lake Parker. While many permitting obstacles would be involved, there is the potential for such a system to be able to substantially improve water quality in Lake Parker.

Lake Wire

Lake Wire is not impaired for nutrients, using FDEP's newly adopted NNC criteria. Additionally, while smaller projects may be appropriate in selected areas, there is no evidence of the need for large regional stormwater retrofit projects.

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