LAKE CARLTON
HYDROLOGIC / NUTRIENT LOADING STUDY

To:	Orange County Government Lake County Water Authority
Date:	April 2018
From:	Amec Foster Wheeler Environment & Infrastructure, Inc.
Project #:	600218.9

LAKE CARLTON

HYDROLOGIC / NUTRIENT LOADING STUDY
WBID 2837B

Prepared for

ORANGE COUNTY GOVERNMENT
FLORIDA

With Cooperation from

LCWA
LAKE COUNTY WATER AUTHORITY

Prepared by

Amec Foster Wheeler Environment & Infrastructure, Inc.
2000 E. Edgewood Drive, Suite 215
Lakeland, FL 33803

Amec Foster Wheeler Project No. 600218.9

April 2018

EXECUTIVE SUMMARY

Lake Carlton, located in central Florida approximately 30 miles northwest of Orlando, is part of the Upper Ocklawaha River Basin (UORB). Lake Carlton is connected to Lake Beauclair and the rest of the Harris Chain-of-Lakes through a short navigable connection known as Carlton Cut. The water quality in Lake Carlton was verified as impaired by nutrients and added to the impaired waters list in August of 2002. The impaired waters list is maintained by the Florida Department of Environmental Protection (FDEP). In 2004, a total maximum daily load (TMDL) for total phosphorus of 195 pounds per year (lbs/yr) was adopted by Secretarial Order. Both lakes have the same total phosphorus (TP) Total Maximum Daily Load (TMDL) target concentration of 32 µg/L; however, the requite TP load reductions to each lake have been determined based on individual watershed characteristics. The 2015 Basin Management Action Plan (BMAP) Update indicates Lake Carlton is not expected to meet its TMDL target for TP; however, sufficient load reductions are indicated upstream for Lake Beauclair. This study aims to provide additional information beyond desktop modeling that can be used to determine the level of effort required to improve water quality within Lake Carlton and, ideally, achieve the TMDL.

Considerable evidence exists to suggest that significant hydrologic exchange is occurring between Lake Carlton and Lake Beauclair and TP concentration is decreasing in both lakes. Interestingly, mean TP concentration in Lake Carlton for the past twenty years has been 58% less than Lake Beauclair. Data for the same period indicates the TP concentration within both Lakes Beauclair and Carlton is approaching its TMDL target. Both lakes appear to exhibit a significant degree of hydrologic mixing and it is likely that continuing water quality improvements because of restoration activities upstream of Lake Beauclair will also be realized in Lake Carlton. However, because of significant variability in environmental conditions (e.g., rainfall), it is not clear how much additional TP concentration reduction will occur within Lake Carlton or when the TP concentration will achieve the 32 µg/L target.

There are relatively few stormwater outfalls discharging into Lake Carlton and structural projects to provide direct reduction of TP load are limited. Nine conceptual alternatives are evaluated in this study and include a no action alternative, public outreach, two stormwater retrofit projects, two sediment nutrient inactivation projects, one dredging project, one septic-to-sewer retrofit project, and enhancement of an existing BMP. Projects recommended for implementation include construction of a modular biofilter at the end of Earlwood Avenue, a basin-specific homeowner education program, sediment nutrient inactivation, and further evaluation of the septic-to-sewer conversion project. Based on the water quality model developed as a part of this study, the modular biofilter could achieve approximately 14% of the required TP concentration reduction, while the septic conversion alternative could achieve approximately 70% of the required concentration reduction. These projects could remove 74 pounds of TP or 26% of the necessary TP load reductions as detailed in the 2015 BMAP Update.

Summary of Alternatives

Alternative	Rank	$ per lb of TP Removed	Type of Reduction	Recommendation
Homeowner Education	1	416	Direct	Continued implementation of a basin-specific homeowner education program is recommended and is ongoing.
Modular Biofilter in Sub-Basin 2	2	1,786	Direct	Construction of a modular biofilter at the end of Earlwood Avenue is recommended for implementation and could achieve 14% of the required TP TMDL concentration reduction.
NuRF Enhancement	3	44	Indirect	Additional alum application utilizing potential excess capacity at the NuRF could easily be implemented, if necessary, based on water quality needs.
Sediment nutrient inactivation (alum)	4	104	Indirect	Targeted alum application is relatively inexpensive and could expedite water quality improvement in Lake Carlton.
Sediment nutrient inactivation (Phoslock™)	5	214	Indirect	Targeted Phoslock™ application is relatively inexpensive and could expedite water quality improvement in Lake Carlton.
Conversion of septic to central sewer	6	5,970	Direct	Septic loading is the largest source of controllable TP loading in the basin and removal could achieve 70% of the required TP TMDL concentration reductions. This is a required element of the BMAP update and should be investigated for implementation over the next ten years
Dredging	7	593	Indirect	Not recommended now due to the high anticipated expense, but this would be the best way to remove nutrient-rich sediment in Lake Carlton.
Exfiltration System in Sub-Basin 3	8	11,184	Direct	Not recommended now since the associated load reduction is minimal and would have the least impact on achievement of the TP TMDL target concentration.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES - CONTINUED

LIST OF FIGURES

LIST OF FIGURES - CONTINUED

LIST OF FIGURES - CONTINUED

LIST OF APPENDICES

LIST OF ACRONYMS AND ABBREVIATIONS

ac	acre
ac-ft	acre-feet
ADV	acoustic Doppler velocimeter
Amec Foster Wheeler	Amec Foster Wheeler E&I, Inc.
BMAP	Basin Management Action Plan
BMP	Best Management Practice
cfs	cubic feet per second
cm	centimeter
CN	curve number
DCIA	directly connected impervious area
EMC	event mean concentrations
FAC	Florida Administrative Code
FDACS	Florida Department of Agriculture and Consumer Services
FDEP	Florida Department of Environmental Protection
ft	feet
ft^2	square feet
ft^3	cubic feet
FYN	Florida Yards and Neighborhoods
GIS	Geographic Information System
HSG	Hydrologic Soil Groups
IFAS	Institute of Food and Agricultural Sciences
in	inches
kg	kilogram
LCWA	Lake County Water Authority
LOD	limit-of-detection
lb	pound
m	meter
m^2	square meter
MFW	Marsh Flow Way
mg/L	milligrams per liter
mg/kg	milligrams per kilogram
mg/m^2	milligrams per square meter
ml	milliliter
NAVD	North American Vertical Datum
NDCIA	non-directly connected impervious area
NEXRAD	Next Generation Radar
NO_2^-	nitrite
NO_3^-	nitrate
NTU	nephelometric turbidity units

LIST OF ACRONYMS AND ABBREVIATIONS - CONTINUED

NuRF	Nutrient Reduction Facility
OAWP	Office of Agricultural Water Policy
OCEPD	Orange County Environmental Protection Division
SCS	Soil Conservation Service
SLADV	side looking acoustic Doppler velocimeter
SJRWMD	St. Johns River Water Management District
STORET	Storage and Retrieval
TMDLs	Total Maximum Daily Loads
TN	total nitrogen
TP	total phosphorus
TSI	Trophic State Indices
TSS	total suspended solids
µg/L	micrograms per liter
UORB	Upper Ocklawaha River Basin
USDA	US Department of Agriculture
UnCF	unconsolidated flocculent
UF	University of Florida
USEPA	US Environmental Protection Agency
WAV	Watershed Action Volunteer
WLM	Water Level Model
WBID	Water body ID
yd^3	cubic yards
yr	year

1.0 INTRODUCTION

1.1 General Description

This report was prepared by Amec Foster Wheeler Environment & Infrastructure (Amec Foster Wheeler) for the Orange County Environmental Protection Division (Orange County) with cooperative funding provided by the Lake County Water Authority (LCWA). The purpose of this study was to develop site-specific hydrologic and nutrient budgets to assist with a comprehensive basin evaluation and management plan for Lake Carlton. Lake Carlton (WBID 2837B) is located immediately east of Lake Beauclair at the southern upstream end of the Harris Chain-of-Lakes within the Lake Harris Planning Basin portion of the Upper Ocklawaha River Basin (UORB) (**Figure 1-1**). Lake Carlton is a 390-acre lake located in central Florida about 20 miles northwest of Orlando (**Figure 1-2**). Approximately 250 acres (64 percent) of the lake are in Orange County while the remaining portion is within Lake County. This project is a cooperative effort between Orange County and the Lake County Water Authority (LCWA).

Tasks included determination of site-specific event mean concentrations (EMCs) for stormwater runoff, site-specific seepage loading, determination of hydrologic exchange between Lake Carlton and Lake Beauclair, and collection of sediment phosphorus speciation data from various locations in the lake. The new analyses and data have been used to provide recommendations for the management and protection of this lake to attain the adopted TMDL and to optimize the resources invested by both Orange County and the LCWA.

1.2 Impaired Waters Determination

Section 303(d) of the Clean Water Act requires surface waterbodies to be identified within each state that do not meet applicable water quality standards (FDEP, 2002). These waterbodies are defined as “impaired waters” and Total Maximum Daily Loads (TMDLs) must be established for these waters on a prioritized schedule. The TMDL process quantifies the amount of a pollutant that can be assimilated in a waterbody, identifies the sources of the pollutant, and recommends regulatory or other actions to be taken to achieve compliance with applicable water quality standards based on the relationship between pollution sources and in-stream water quality conditions. The Florida Department of Environmental Protection (FDEP) has established a series of guidelines to identify impaired waters which may require the establishment of TMDLs (FDEP 2006).

Lake Carlton was verified as impaired by nutrients, and was included on the verified list of impaired waters for the Upper Ocklawaha Basin that was adopted by Secretarial Order on August 28, 2002. The Total Phosphorus (TP) TMDL concentration was established at 32 µg/L with expectations of reducing the amount of chlorophyll-*a* to concentrations more consistent with unimpaired lakes (Magley, 2004). No other water quality targets [e.g., total nitrogen (TN) or chlorophyll-*a*] were established as part of the TMDL for Lake Carlton.

To meet the restoration targets specified in the TMDL report, Lake Carlton was included in the UORB Basin Management Action Plan (BMAP) adopted on August 14, 2007. The action plan was developed in partnership with cities, counties (including Orange County), the St. Johns River Water Management District (SJRWMD), LCWA, Florida Department of Transportation, Florida Department of Agriculture and Consumer Services, Florida Fish and Wildlife Conservation Commission and other local stakeholders. A BMAP update was completed in July 2014 and indicated that Lake Carlton was not likely to meet its overall load reduction requirements. The

FDEP released a draft UORB Supplemental Report on October 23, 2017 which is currently under review by the stakeholder group and includes this study as part of Orange County's planning effort to achieve the TMDL in Lake Carlton.

This report is intended to provide updated site-specific data for Lake Carlton along with discussion of various loading and water quality models to assist in the BMAP process and guide restoration efforts along with appropriate allocation of financial resources.

1.3 Basin Description

The Lake Carlton basin is a relatively complex hydrologic system including numerous upstream lakes connected either by culverts or open ditches. A flow diagram of the system is provided in **Figure 1-3**. Lakes Jem and Victoria discharge to Horseshoe Lake which is connected to Lake Carlton on the south end. Lake Ola is similar in size to Lake Carlton and is connected to Lake Carlton by an open ditch on the east side. Carlton Cut is a small navigable connection to Lake Beauclair from the north side of Lake Carlton. Topographic data indicate that water elevation Beauclair, Carlton, Horseshoe, Victoria, and Jem are all similar and water can exchange freely between these lakes (**Figure 3-1**). Lake Ola sits about eight feet higher than the other lakes in the system and flow is likely to occur only downstream to Lake Carlton.

The Lake Carlton Total Maximum Daily Load (TMDL) document indicates the total contributing area used to determine the loading estimates was 1,301.56 hectares or approximately 3,216 acres. No figure is provided in the TMDL document illustrating the total area used in the analysis, but this is likely the sum of both the Lake Carlton and Lake Ola basins.

Amec Foster Wheeler estimated a total Lake Carlton basin size of 3,098 acres inclusive of the 1,630-acre Lake Ola basin (**Figure 1-4**). The basin size was determined in ArcGIS using LiDAR data along with field reconnaissance. Several other smaller lakes are present within the Lake Carlton basin including Lake Jem, Lake Victoria, and Horseshoe Lake. Lake Victoria and Lake Jem discharge to Horseshoe Lake which discharges to Lake Carlton. These lakes provide considerable retention time and natural treatment for the Lake Carlton drainage basin. Lake Ola is a normally clear lake with excellent water quality based on data from the Orange County Water Atlas (http://www.orange.wateratlas.usf.edu/). Additional details regarding basin delineation are discussed in **Section 3**.

The Florida Department of Environmental Protection completed the UORB Basin Management Action Plan (BMAP) update in July 2014 and concluded that Lake Carlton is not expected to meet its TMDL goals using the current anticipated Best Management Plan (BMP) project list provided by the stakeholders. Lake Beauclair, however, is expected to meet its TMDL goals based on the upstream BMPs already implemented and others that are ongoing.

Lake Beauclair and Lake Carlton have identical TP TMDLs but their watersheds are vastly different. Lake Beauclair is located immediately downstream of Lake Apopka and historically received more than 90 percent of its TP load from the Apopka-Beauclair Canal (SJRWMD, 1995). Lake Carlton receives upstream inputs from several smaller and relatively clean lakes. Lakes Carlton and Beauclair are hydrologically connected through a navigable channel on the northern side of Lake Carlton adjacent to Orange County's Magnolia Park. The degree of hydrologic mixing between Lakes Carlton and Lake Beauclair has not been studied previously.

The TMDL and BMAP, derived using desktop methods, both consider Lake Carlton an upstream hydrologic and nutrient source to Lake Beauclair. While this may be true under net discharge conditions, Lake Beauclair and Lake Carlton are part of a so-call “super pond” consisting of about 50,000 acres of hydrologically intermingled surface water between the Burrell Lock and Dam north of Lake Eustis and the Apopka-Beauclair Lock and Dam south of Lake Beauclair (**Figure 1-5**). The super pond includes Lakes Carlton, Beauclair, Harris, Dora, Eustis, and several other smaller lakes.

During periods of little to no discharge, water elevation within the super pond should be nearly identical assuming calm weather conditions. However, water exchange between super pond lakes due to lake seiche (wind-driven water movement) and other mixing forces may play a significant role in influencing water quality conditions in lakes with comparatively small volumes. Seiche mixing may be particularly important for Lake Carlton due to its comparatively small size and position at the southern end of the super pond. The TMDL specifically recognizes the hydrologic exchange between Lake Beauclair and Lake Carlton as a potentially important piece of missing information. Furthermore, prior to our investigation, sources of seepage and internal recycling within Lake Carlton had not been assessed in the field.

This study was conducted to provide the following additional details regarding Lake Carlton to understand what, if any, additional action is required for the lake to achieve its TMDL:

1) Verify and ground truth the Lake Carlton basin
2) Estimate inputs from Lake Ola using GIS data
3) Estimate seepage loading using seepage meter data
4) Estimate stormwater runoff loading using GIS and autosampler data
5) Estimate the degree of mixing between Lake Beauclair and Lake Carlton using real-time flow data
6) Estimate soft sediment volume in Lake Carlton
7) Determine typical phosphorus speciation for the lake sediment

1.4 Work Efforts Performed by Amec Foster Wheeler

This report presents results of a hydrologic and nutrient loading evaluation along with conceptual project recommendations for Best Management Practices (BMPs) in the Lake Carlton drainage basin. Basin evaluations were developed for Lake Carlton to identify hydrologic contributions, pollutant loadings, and to provide a ranking of sub-basin areas with respect to annual mass and areal loadings. Hydrologic exchange between Lake Carlton and Lake Beauclair was evaluated to determine the effects and implications for expected water quality improvements within Lake Beauclair. Stormwater inputs to the lake were characterized during eight storm events using automated stormwater sampling equipment and compared to current literature-based runoff characterizations of the specific land use types within the basin. In addition, seepage inputs to the lake were characterized for water quantity and quality using six seepage meters placed along the perimeter of the lake and two additional seepage meters placed in deeper locations. Seepage meters were sampled six times during the study.

2.0 PHYSICAL AND CHEMICAL CHARACTERISTICS OF LAKE CARLTON

2.1 Physical Characteristics

Lake Carlton is located north of Lake Apopka within unincorporated Orange and Lake Counties (**Figure 2-1**). Based on water elevation data from 1960 to 2013 provided by Orange County, mean lake stage is 61.46 feet (ft) NAVD 88 and normal high-water elevation is 63.02 ft NAVD 88 (all elevations reported in NAVD 88 unless otherwise stated). As discussed above, water elevation in Lake Carlton is treated as a single waterbody and has an annual regulatory elevation range between 61.7 ft and 62.2 ft. Lake Carlton sits at the southern end of the super pond.

While net flow through the super pond occurs from south to north, direction of flow at any given time is largely dependent on the wind direction and subsequent lake seiche. In recent years, little discharge has been released from Lake Apopka and seiche is likely to have a pronounced effect within the super pond and particularly Lake Carlton due to its relatively small size and position in the system. Seiche is generally thought to be an internal lake dynamic and is not particularly well studied in Florida lakes. Part of this study is aimed at investigating the amount of mixing that occurs between Lake Beauclair and Lake Carlton.

Lake Carlton has a surface area of 390 acres and a single surface discharge into Lake Beauclair via a 100-ft long, 50-ft wide channel known as Carlton Cut on the west side. Significant inputs to the lake include discharge from Lake Ola on the east side and Horseshoe Lake on the south side. Horseshoe Lake receives discharge from Lakes Jem and Victoria. Lake Beauclair is surrounded by active and inactive citrus groves and has some low-density residential areas on the eastern shore. Historic aerials indicate that significant agricultural clearing had occurred prior to 1947 (**Figure 2-1**). Overall, very little impervious surface is present within the watershed.

2.2 Sediment Characteristics

Amec Foster Wheeler obtained bathymetric information in 2016 using over 500 manual soundings positioned across the lake on a 300-foot grid (**Figure 2-2**). Top of sediment was determined using a survey rod measuring the depth at first resistance. Average depth in the Amec Foster Wheeler survey was 12.2 ft with a maximum depth of 19 feet. Most of the lake bottom is uniform in depth, with steeply sloping shorelines. A few deeper holes are present along the south and west sides. Total lake volume at the time of survey (elevation 61.97 NAVD) is estimated to be 5,197 ac-ft.

At each survey point, the survey rod was pushed through the sediment to refusal and depth to hard bottom (or maximum penetration) was recorded. **Figure 2-3** illustrates sediment thickness which varies between zero near the shoreline to 10 feet in some areas in the lake center. Total sediment volume in Lake Carlton is approximately 2.57 million cubic yards (yd^3). This is proportionally similar to other lakes in the UORB based on information provided in Danek, et al., 1991. Danek et al. estimated that Lake Beauclair contained approximately 6.79 million yd^3 of sediment. Sediments within Lake Carlton are not currently impeding navigation and the lake is relatively deep compared to the southern end of Lake Beauclair.

Lake Carlton bathymetry was also obtained for the entire lake by the LCWA using sonar in 2013. LCWA data indicates mean depth of the lake at the time of survey was approximately 7.9 ft with a maximum depth of 13 ft (**Figure 2-4**). The two methodologies produced results differing in bottom elevation by as much as seven feet. Amec Foster Wheeler utilized the data obtained in 2016 for the purposes of this study.

This study represents the first-time sediments in Lake Carlton have been evaluated and, except for the 2013 bathymetric survey, no historic information regarding the sediments in Lake Carlton is known to exist. Nutrient flux was not measured directly and is outside the scope of this study but sediment phosphorus speciation was conducted to provide some insight into the potential for sediment nutrient contribution. Nutrient flux studies are recommended as part of future efforts if organic sediment removal or sediment nutrient inactivation alternatives are selected for further study.

Soft sediment was encountered over most of the lake below ten feet in depth. The soft sediment layer was present at all intact sediment core locations discussed in **Section 6**. The sediment was too soft near the center of the lake to allow placement of deep seepage meters discussed further in **Section 4.2.3**. Unconsolidated sediment was also observed in deeper portions of the lake during seepage meter installation. Physical observations during core collection indicated a significant layer of unconsolidated sediment in the top twelve inches of the cores. Unconsolidated flocculent sediments have densities very similar to water making them difficult to identify with sonar or to probe manually. Additional core sampling should be performed to provide better details regarding locations and thickness of unconsolidated flocculent sediment. This may explain some of the difference between the 2013 and 2016 bathymetry.

While the origin and quantity of the unconsolidated sediments in Lake Carlton is difficult to determine with certainty, it is significant to note that sediments transported from Lake Apopka resulted in accumulation of a 300-acre sediment delta in Lake Beauclair near the vicinity of Carlton Cut. Given the degree of historic sediment accumulation in Lake Beauclair and the potential hydrologic exchange between Lake Carlton and Lake Beauclair indicated in this study, it is possible that much of the unconsolidated sediment currently in Lake Carlton originated in Lake Apopka. While sediment characterization is not the focus of this report, additional sediment evaluation should be considered as part of future study efforts, particularly if dredging or sediment phosphorus inactivation alternatives are considered. The potential for additional sediment transport from Lake Beauclair has recently been minimized because the upper five feet of the nutrient enriched sediment deposit was removed during a lake enhancement dredging project completed by the LCWA in 2013. In addition, future sediment transport from Lake Apopka has also been minimized due to the SJRWMD's Marsh Flow Way (MFW) and the LCWA's Nutrient Reduction Facility (NuRF) described below.

The MFW began operation in 2003 and removes suspended particles and algae from Lake Apopka by recirculating lake water through an expansive system of wetland filtration cells. Cleaner water is either returned to Lake Apopka or travels downstream toward Lake Beauclair through the Apopka-Beauclair Canal depending on the lake level and discharge rate. Water flowing down the Apopka-Beauclair Canal is diverted to the NuRF adjacent to the Apopka-Beauclair Canal Lock and Dam structure (**Figure 1-4**). The NuRF began operation in 2009 as a cooperative effort between the LCWA and the FDEP. The NuRF provides both chemical treatment using liquid aluminum sulfate and mechanical settling to remove up to 90% of the TP and 99% of the total suspended solids (TSS) from Lake Apopka. Together, these projects were designed to achieve the 32 µg/L TP TMDL goals established for Lake Beauclair.

2.3 Water Quality Characteristics

2.3.1 Water Quality Trend Analysis Methodology

Amec Foster Wheeler obtained water quality data from the Orange County Water Atlas (http://www.orange.wateratlas.usf.edu/) to evaluate water quality trends for Lake Carlton. Numerous data sets provided by Orange County, Lake County, Lakewatch, St. Johns River Water Management District (SJRWMD), the Watershed Action Volunteer (WAV) program, and the FDEP were available dating back to 1970. However, data has only been collected consistently since 1997 and only data from 1997 through 2016 have been used for this analysis. Data sources are provided in **Table 2.1**. Relevant data from all available sources beginning in 1997 were pooled and analyzed using the Pivot Table function in Microsoft Excel®.

Concentration data for measured variables was modeled using the statistical analysis tools for Microsoft Excel® (total nitrogen and phosphorus, nitrate, nitrite, chlorophyll *a*, Secchi disk depth, and TSS). Geometric means were calculated for each year. Annual Trophic State Indices (TSI) were calculated according to Florida-specific procedures. TSI values are no longer relevant for impairment determinations but are nonetheless a useful limnological evaluation tool.

2.4 Results

2.4.1 Total Phosphorus

TP concentration has decreased significantly in Lake Carlton over the past 19 years ($R^2 = 0.29$, $p < 0.01$) (**Figure 2-5**). Average annual geometric mean TP concentration for all Lake Carlton samples in the 19-year monitoring period was 57 µg/L. The annual TP geometric mean was highest in 1999 at 87 µg/L and lowest in 2010 at 35 µg/L (**Figure 2-6**). Orthophosphate concentration is not a significant component of TP concentration within Lake Carlton because suspended algae are prevalent and assimilate it rapidly.

An analysis of the entire 19-year data set indicates that the January had the highest monthly median TP concentration and August had the lowest median TP concentration (**Figure 2-7**). TP concentration tended to fall within a lower and more narrow range during the summer months

In 2010, the geometric mean TP concentration in Lake Carlton was 35 ppb and nearly met the 32 µg/L TP TMDL. Lake Beauclair also exhibited a similar mean TP concentration during 2010. This historically low TP concentration followed the beginning of the LCWA's NuRF operation in 2009. No significant discharge from Lake Apopka has occurred since the first year of operation, and water quality in Lake Beauclair and Lake Carlton declined. Between 2010 and 2015, geometric mean TP concentration in Lake Carlton was 48 µg/L or 50 percent above the target concentration. As discussed previously, the LCWA completed a dredging project in 2013 to remove nutrient-rich flocculent sediments deposited in a large delta in Lake Beauclair near the connection with Lake Carlton. The sediment removal project appears to have had a significant impact on both Lake Beauclair and Lake Carlton and geometric mean annual TP concentration began to decline again in 2014. In 2015, the mean TP concertation in Lake Carlton was 39 µg/L, or 22 percent above the TMDL target.

2.4.2 Total Nitrogen

Total nitrogen (TN) concentration is calculated as the sum of total Kjeldahl nitrogen (TKN), and nitrite/nitrate (NO_2^-/NO_3^-) nitrogen fractions. TN concentration has decreased significantly in Lake

Beauclair over the past 19 years (R^2 = 0.08, p<0.01) (**Figure 2-8**). Average annual geometric mean total nitrogen (TN) concentration for all Lake Carlton samples in the 19-year monitoring period was 3,035 µg/L. The annual TN geometric mean concentration was highest in 2000 at 3,986 µg/L (**Figure 2-9**). Like TP, the lowest TN geometric mean concentration of 1,721 µg/L was detected in 2010.

Months with the highest median TN concentration were July and November while TN concentration was lowest in February and March (**Figure 2-10**). Monthly Median TN concentrations did not appear to follow a seasonal pattern.

2.4.3 TN:TP

In freshwater lakes, phosphorus is generally observed to be the macro-nutrient that limits primary production. However, in some lakes in Florida it has been demonstrated that nitrogen can be the limiting nutrient instead. In general, when the ratio of total nitrogen to total phosphorus (TN:TP) is less than 10, a lake is considered to be nitrogen limited, whereas when the TN:TP ratio is greater than 30 the lake is considered to be phosphorus limited. When the ratio falls between 10 and 30 the lake is considered to be balanced, or dependent upon both nutrients (Paulic *et al*., 1996). Mean annual TN:TP ratios were calculated for Lake Carlton for the period of record to evaluate nutrient limitation (**Figure 2-11**). Over the 19-year period of record, the mean annual TN:TP ratio was 73.5. Monthly median TN:TP ratios showed phosphorus limiting conditions in all months of the study period (**Figure 2-12**).

2.4.4 Nitrate and Nitrite

Inorganic nitrogen in the forms of nitrate and nitrite was evaluated for Lake Carlton beginning in 2000. Generally, nitrite was either undetectable or near detection limits throughout the monitoring period (**Figures 2-13** and **2-14**). Nitrate concentrations were also generally at or below the detection limits (**Figures 2-15** and **2-16**). However, relatively high nitrate concentrations were detected on three occasions in January 2000 (120 µg/L), March 2010 (275 µg/L), and February 2015 (91 µg/L).

2.4.5 Chlorophyll *a*

Chlorophyll *a* data was analyzed for Lake Carlton from 1999 to 2016 (**Figure 2-17**). The highest geometric mean annual chlorophyll *a* concentration occurred in 1999 (167 µg/L) and the lowest geometric mean annual chlorophyll *a* concentration occurred in 2010 (42 µg/L) (**Figure 2-18**). Similar to TP and TN, chlorophyll-*a* concentrations decreased significantly over the 17-year monitoring period (R^2 = 0.18; $p < 0.01$)

The months of April and October exhibited the highest monthly median chlorophyll *a* concentration over the monitoring period while the month with the lowest median concentration occurred during August **(Figure 2-19).** Median chlorophyll *a* for the months of February, March, June and July was comparable to August. The monthly medians generally support the expectation that chlorophyll *a* values will be highest during the dry season and lowest during the wet season.

2.4.6 Secchi Depth

The mean annual Secchi depth in Lake Carlton was lowest in 2001 [0.95 feet (ft)] and highest in 2015 (2.16 ft) (**Figure 2-20**). The highest single point Secchi depth measurement of 4.9 ft occurred in February 2015. No significant trend in Secchi depth is evident over the last 19 years ($p = 0.21$). The month with the lowest median Secchi depth over the 21-year period of record was June and the months producing the highest median Secchi depth were January and February (**Figure 2-21**). Overall, Secchi depth data was similar across all months.

2.4.7 Total Suspended Solids

Mean annual total suspended solids (TSS) concentration did not change significantly over the 17-year data period between 1999 and 2016 ($R^2 = 0.013$, $p = 0.14$) (**Figure 2-22**). The lowest mean annual TSS concentrations were 10.8 mg/L in 2015 and 11.8 mg/L in 2010. The highest mean TSS concentration of 25.5 mg/L occurred in 1999 (**Figure 2-22**).

The highest monthly median TSS concentration occurred in April and the lowest monthly median TSS concentration was in January (**Figure 2-23**). There did not appear to be a relationship between wet season and TSS concentrations for mean monthly values from the 17-year monitoring period.

2.4.8 Trophic State Index

Trophic State Index (TSI) was calculated according to a method developed for Florida (State)-specific procedures, outlined in the State's 1996 305 (b) report (FDEP, 1996) and formerly required by Rule 62-303.352 FAC. This was adapted from methodology originally developed by Carlson (1977). While no longer utilized for impairment determination, the Florida-specific TSI method was utilized in assessing the original impairment status of Lake Carlton remains a useful limnological tool. The Florida-specific TSI is based on a regression analysis of data from 313 Florida Lakes. Prior to implementation of Numeric Nutrient Criteria (NNC), TSI was utilized to establish nutrient limitations within lakes, and allowed alternate equations for calculating TSI based on the specific trophic characteristics of a given lake.

TSI data was evaluated for the period of record between 1997 and 2015. TSI trend analysis shows a significant ($R^2 = 0.30$; $p < 0.01$) downward trend indicating improvement (**Figure 2-24**). Significant and simultaneous improvements in Lake Beauclair water quality were also observed during the same time. A TSI of 0 - 59 is considered to indicate "good" water quality and a TSI greater than 70 is considered "poor" water quality (FDEP, 1996). The mean annual TSI for Lake Carlton was greater than 70 from 1997 to 2016, and is considered "poor" (**Figure 2-25**). However, following operation of the NuRF in 2008, TSI dropped to the lowest mean annual score for the period of record in 2010 and has averaged less than 70 during three of the last six years. Monthly median TSI is lowest in August and highest in April (**Figure 2-26**)

2.5 Hydrologic Exchange with Lake Beauclair

The potential for hydrologic exchange between Lake Carlton and Lake Beauclair was recognized in the Lake Carlton TMDL but has never been examined closely prior to this study. Because the connection between Lake Carlton and Lake Beauclair is relatively small and channelized, it provides a unique opportunity to collect side-looking acoustic Doppler velocimeter (SLADV) data. The SLADV was placed halfway between Lake Carlton and Lake Beauclair near the edge of the channel.

Amec Foster Wheeler and OCEPD staff installed a SonTek SLADV (Model SL1500) at the edge of the Carlton Cut vegetation line on August 15, 2016 (**Figure 2-27**). Prior to installation of the

SLADV, the channel was surveyed and appropriate channel geometry data was entered into the application software used to configure the SLADV (**Figure 2-28**). Cross-sectional area is calculated by the software using the channel morphometry entered by the user and water elevation data obtained from an on-board pressure transducer at the time of measurement. The SLADV calculates flow using the cross-sectional area and the average velocity returned by acoustic beams transmitted at several locations in the water column. Flow is recorded by the SLADV at a prescribed interval (generally 30 minutes). The SLADV can measure bi-directional flow which was critical for this application. The SLADV transmitted near real-time data to OCEPD's database via telemetry. Data was examined monthly. In January 2017, the SLADV experienced technical difficulties and no data was collected between January and March 2017. Data collection resumed on April 5, 2017 and is ongoing.

Discharge data collected during the initial period is provided in **Figure 2-29**. Data indicates flow between Lake Carlton and Lake Beauclair can change direction many times per day. This is consistent with the anticipated seiche effect discussed in **Section 2.1**. Maximum flow rates in and out of Lake Carlton during the initial data collection period occasionally reached 300 cfs or higher but these flows were not sustained for more than 30 minutes between sampling intervals. As expected, discharges from Lake Carlton to Lake Beauclair were coupled by a flow reversal from Lake Beauclair into Lake Carlton of a similar magnitude. During the data period evaluated for this study, weighted average positive flow out of Lake Carlton was measured to be 7.6 cfs while weighted negative flow into Lake Carlton was measured to be 11.6 cfs.

Interestingly, the SLADV data from the evaluated dataset indicates a net positive input of approximately 4 cfs to Lake Carlton from Lake Beauclair. One potential explanation for this could be that discharge interval out of Lake Carlton might be shorter than the interval for backward flow from Lake Beauclair to Lake Carlton. If the measurement interval is too long, it may over-represent the backward flow. However, following replacement of the SLADV, the collection frequency was increased two once every 15 minutes but a net backward flow from Lake Beauclair was still observed. Other possible reasons for the difference may be that the SLADV is not exactly perpendicular to flow or there could be signal interference from vegetation or other obstruction. At this time, it is not possible to calibrate the modeled hydrologic output from Lake Carlton using seiche exchange. However, the weighted average daily inflows and outflows should serve as a good indicator of the potential range of water exchange between the two lakes.

2.6 Discussion

All water quality data discussed above, except for Secchi depth and TSS which have no significant trend, indicate that conditions in Lake Carlton have improved significantly over the past 20 years and TP concentration is approaching the TMDL for the lake. Seiche mixing is expected to result in the average exchange of up to 22 ac-ft per day between the two lakes (**Figure 2-29**). On an annual basis, this is equivalent to 1.5 times the volume of Lake Beauclair. This suggests that the two lakes are relatively well mixed. As shown in **Figure 2-30**, Lake Carlton has maintained a consistently lower TP concentration than Lake Beauclair and both lakes exhibit a significant downward trend in TP. Both Lakes Beauclair and Carlton are approaching an intersection on target with the TMDL TP concentration of 32 µg/L.

Although not specifically addressed in this study, much of the UnCF sediment observed in Lake Carlton near the connection to Lake Beauclair may have been the result of hydrologic exchange with Lake Beauclair. More than one million cubic yards of similar organic material was removed from Lake Beauclair near the connection with Lake Carlton in 2013. In conjunction with the NuRF, the Lake Beauclair dredging project will likely reduce sediment transport from Lake Beauclair to Lake Carlton. However, material introduced to Lake Carlton from Lake Beauclair will likely remain in Lake Carlton because it is significantly deeper. Some evidence of this is evident in the phosphorus speciation analysis discussed in **Section 6.** Resuspension and internal recycling of this material may play a significant role in water quality conditions and should be investigated further.

Water quality data suggests significant overall improvements to Lake Carlton but the TMDL target for Lake Carlton has not yet been achieved and water quality impairments still exist. It is likely that recent lack of rainfall, low lake levels, and internal resuspension of unconsolidated flocculent (UnCF) sediments have been dominant factors in slowing water quality restoration in both Lake Beauclair and Lake Carlton. These conditions are also likely inhibiting the restoration of Lake Apopka (Amec Foster Wheeler, 2017). As water levels recover, cleaner water from restoration efforts upstream of Lake Beauclair will likely continue to have positive effects in Lake Beauclair and Lake Carlton.

Historic water quality and interaction with Lake Beauclair are clearly important considerations when evaluating the condition of Lake Carlton. However, the localized impacts from the Lake Carlton basin are also important. Drainage basin characteristics including the hydrologic and nutrient budgets for Lake Carlton are investigated in detail below.

3.0 DRAINAGE BASIN CHARACTERISTICS

The overall objective for this project was to develop a basin evaluation for Lake Carlton to estimate the hydrologic and nutrient inputs for the lake and to provide recommendations for the management and restoration of water quality to achieve its designated use as a Class III waterbody.

3.1 Basin Delineations

Amec Foster Wheeler developed basin and sub-basin delineations for Lake Carlton utilizing land contours, existing storm water drainage conveyance systems, and field observations. ESRI ArcView was used to generate contour maps displaying elevation changes with color gradients. Utilizing the contour maps and aerial background, the watershed boundaries were initially determined by location of maximum elevation points and topographic physical features (i.e. roadways, railroads, etc.).

The Lake Carlton TMDL reports a watershed area of 3,217 acres for Carlton, including Lake Ola and its contributing area. For consistency, Amec Foster Wheeler also included Lake Ola and determined an approximate Lake Carlton watershed area of 3,098 acres (**Figure 3-1**). The Lake Carlton basin boundary is defined by topographic ridges in the surrounding agricultural areas to the east, west, and south. The Lake Carlton basin is bounded on the north side by a narrow strip of land separating it from Lake Beauclair.

Sub-basins for the Lake Carlton contributing area were delineated using localized hydrologic features (**Figure 3-2**). Ten sub-basins where identified including one sub-basin each for Lakes Victoria, Jem, and Horseshoe on the southern side, two sub-basins along the western shoreline, two sub-basins along the eastern shoreline, one sub-basin on the northern shoreline, the area within Lake Carlton, and the lake Ola basin. The area within each sub-basin is provided in **Table 3-1**.

Sub-basin delineations, stormwater conveyances and stormwater outfall locations were field verified by Barnes, Ferland and Associates, Inc. personnel. Evaluation of the Lake Ola sub-basin was conducted using desktop methods. Outfall locations, existing drainage systems, and existing BMP treatment systems were located within each sub-basin (**Figure 3-3**). Copies of the field notes, pictures, and field waypoint locations are provided in **Appendix A**.

The Lake Carlton basin includes only about 381 acres upland runoff area connected directly to the lake or 12 percent of the overall basin size. The remainder of the contributing area is either surface water or land associated with sub-basins draining to Lakes Ola, Horseshoe, Victoria, or Jem. Relatively little drainage infrastructure is present in this basin and there are no known existing stormwater BMPs. However, numerous agricultural BMPs are present in the basin as shown in **Figure 3-4**. The Florida Department of Agriculture and Consumer Services (FDACS) Office of Agricultural Water Policy (OAWP) is responsible for administration of agricultural BMP enrollment which may provide load reduction credits consistent with improved agricultural practices. These load reductions are not measured directly and are not verified empirically. No agricultural drainage ditches were identified within the basin.

3.2 Land Use

Land use information for the Lake Carlton sub-basins was obtained from the SJRWMD 2009 Land Use and Land Cover (**Figure 3-5**). Characteristics of regional land uses were compiled in Geographic Information System (GIS) and categorized for further analysis. The landuse breakdown for Lake Carlton, Lake Ola and composite Lake Carlton /Ola contributing basins are summarized in **Table 3-2**, **Table 3-3** and **Table 3-4** in order of descending acreages. Aside from the lakes landuse (FLUCCS 5200) the predominant landuse within the Carlton contributing basin is citrus groves (23.58%) and residential low density (14.53%). The area contributing to Lake Ola appears more developed relative to Carlton where the predominant land use categories (not including lake) are: residential low density (22.2%) and residential medium density (14.28%). The predominant landuse categories for the combined Lake Carlton and Lake Ola basin (excluding lakes) are residential low density (18.57%) and citrus groves (15.76%).

3.3 Soil Characteristics

Information on soil types within the Lake Carlton drainage basins was obtained from the Natural Resources Conservation Service Soil Survey Geographic database for Orange County, Florida dated 2012. Soil information was extracted in the form of Hydrologic Soil Groups (HSG) which classifies soil types with respect to runoff-producing characteristics. Using this system, soils are classified into five (5) groups for evaluation and modeling purposes. The chief consideration in each of the soil group types is inherent capacity of bare soil to permit infiltration. A summary of the characteristics of each hydrologic soil group is presented below.

<u>Group A</u>: Soils having low runoff potential and high infiltration rates even when thoroughly saturated. They consist primarily of deep, well to excessively drained sands or gravels and have a high rate of water transmission.

<u>Group B</u>: Soils having moderate infiltration rates when thoroughly saturated and consist primarily of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

Group D: Soils having high runoff potential: These soils have low infiltration rates when thoroughly saturated and consist primarily of clay soils with high swelling potential, soils with a permanent high-water table, soils with a clay pan or clay layer at or near the surface and shallow soils over nearly impervious material. These soils have a very low rate of water transmission.

Dual Hydrologic Soil Groups (Group X/D): Soils located in areas where the water table is within 60 cm of the surface: In their saturated state, these soils still have a hydraulic conductivity that may be favorable for water transmission. If these soils can be adequately drained, they are assigned a dual hydrologic soil group (A/D, B/D, and C/D). The first letter applies to the drained condition and the second to the undrained condition.

Group W: Soils are categorized as wetland or hydric soils.

The HSG within the Lake Carlton and Lake Ola drainage basins is provided in **Figure 3-6** and a tabular summary of soil groups in **Table 3-5**. The soils within the basin are classified (in order of prevalence) as A, W, A/D, B/D, D, and B. The majority of the area is recorded as HSG A (56%).

4.0 WATER BUDGET

4.1 Hydrologic Characteristics

A water budget was developed for the watershed for the period from January 2001 through December 2010. The hydrologic budget includes inputs from direct precipitation, stormwater runoff, and groundwater seepage. Hydrologic losses include evaporation, groundwater recharge, and surface outflows. The water budget is used as an input for development of a nutrient budget and water quality model as well as estimation of hydraulic residence time within the lake. A discussion of identified hydrologic inputs and losses for Lake Carlton is provided in the following sections.

4.2 Hydrologic Inputs

4.2.1 Precipitation

Temporal and spatial daily precipitation data from January 1995 through December 2013 was derived from Next Generation Radar (NEXRAD) data (grid cell 119330). This service is deployed by the national weather service and uses radio signals to estimate spatial distribution of rainfall. Within Florida NEXRAD data are collected from seven primary radars, data are available on a 2km x 2km grid for every 15 minutes. The selected NEXRAD grid cell overlies most of Lake Carlton as well as a substantial portion of adjacent south contribution area. Daily rainfall was collected and aggregated for the 18-year period (1995-2013); this relatively long period of record may reflect weather variations from drought, normal, and significant storm event rainfall periods.

A total of 2,744 days with rain were recorded during this nineteen-year period, with a cumulative rainfall of 862 inches. **Figure 4-1** depicts the monthly rainfall from 1995- 2013. **Figure 4-2** depicts average monthly rainfall associated with this timeframe, while **Figure 4-3** depicts average annual rainfall associated with this timeframe. The annual average rainfall within this period of record is 45.38 inches.

As a quality control measure to verify the NEXRAD data collected, average yearly rainfall was obtained from the Orlando International Airport for the years 1953 to 2003. The annual average rainfall from this time-period was 49.04 inches per year, which is less than 5 inches difference from the annual average of 45.38 inches per year obtained from the analysis of the NEXRAD data.

Estimated monthly hydrologic inputs from direct precipitation into Lake Carlton were calculated by multiplying the measured monthly rainfall during the period from January 1995 through December 2013 by the lake surface area. A summary of estimated monthly hydrologic inputs from direct precipitation is presented in **Table 4-1**. During the nineteen-year monitoring period, direct precipitation contributed an annual average of 1,452 acre-ft to Lake Carlton. **Table 4-2** summarizes the direct precipitation into Lake Ola which has a surface area of approximately 439 acres.

4.2.2 <u>Stormwater Runoff</u>

Stormwater runoff is a significant component of the overall hydrologic budget for Lake Carlton. Each sub-basin was analyzed for annual runoff volume based on annual rainfall and local runoff characteristics. Local runoff characteristics are based on sub-basin area and the runoff CN, which is a function of land use and hydrologic soil group. The methodology is described in more detail below: Direct rainfall to Lake Carlton and Lake Ola are not included in the stormwater runoff total.

4.2.2.1 *Runoff Curve Number Calculation*

Information on hydrologic characteristics of the drainage sub-basin areas were developed for use in modeling inputs of stormwater runoff for the subject area. To accurately estimate runoff occurring within each of the sub-basins, basin specific hydrologic characteristics were calculated using the GIS land use and hydrologic soils data, as well as the digitized sub-basins for the watershed. Land use information from 2009 was provided by SJRWMD (**Figure 3-5**). Soils data from 2010 was also provided by NRCS Soil Survey Geographic Database for Orange County, FL, 2010 (**Figure 3-6**). Using the hydrologic characteristics collected from the soils data layer, as well as the land use classification, CNs were assigned using the Curve Number Lookup Table provided in Table 1-2 in **Appendix B**. This table was adapted from the "Urban Hydrology for Small Watersheds- TR-55 document (USDA 1986). Representative DCIA values were applied for the sub basin component landuse categories to accurately represent runoff conditions within the sub basin.

4.2.2.2 *Spreadsheet Runoff Model*

Estimation of annual surface water runoff requires a known amount of precipitation falling on the project area as well as the sub-basin runoff CN and DCIA. Sub-basin CNs were defined according to the methodology described in **Section 4.2.2.1**. Land use within the combined Carlton basin is summarized in **Table 3-5**. Hydrologic soil groups for the project area varied with A (55.73%), W (29.98%) and A/D (11.3%) group soils being predominant.

Surface water runoff modeling was conducted to estimate the annual stormwater runoff associated with each drainage sub basin. The surface water runoff modeling was accomplished using a Microsoft Excel spreadsheet named Pollutant Loadings Assessment (PLA) tool developed in-house by Amec Foster Wheeler that is based on design criteria that was developed by FDEP and the Water Management Districts during production of the draft guidance documents conceived during statewide stormwater regulation efforts. The model utilizes the modified U.S. Environmental Protection Agency's (EPA) Simple Method (Schueler, 1987). The Simple Method estimates stormwater runoff and pollutant loads as the product of annual runoff volume and pollutant concentrations. Specific discussion of applied pollutant load concentrations is presented in **Section 5**.

The Simple Method is a three-step calculation (Ohrel, 2000):

1. Runoff coefficient calculation, Rv:

   Rv = 0.05 + 0.009 * I

   Where:
   Rv = Mean runoff coefficient
   I = Percent of site imperviousness

2. Runoff volume (acre-feet per year) (ac-ft/yr) calculation:

   R = (P * Pj * Rv / 12) * A

   Where:
   R = Runoff volume (ac-ft/yr)
   P = Annual rainfall depth (inches)
   Pj = Fraction of rainfall events that produce runoff (normally equal to 0.9)
   A = Study area (acres)

3. Annual pollutant loads (pounds per year)

   L = 2.72 * R * C

   Where:
   L = Annual pollutant load (lb/year)
   C = Event mean concentration of the pollutant (mg/l)
   2.72 = Conversion factor (from mg/l to lb/ac-ft)

For this investigation, the Simple Method calculation of runoff volume was modified in accordance with the methodology developed by FDEP and the Water Management Districts when Florida was considering a statewide stormwater rule for calculating annual runoff as follows:

Q = 0.083*ciA

Where:
Q = Runoff Volume (ac-ft/yr)
c = Runoff coefficient determined based on Florida Meteorological Zones as classified in the draft Stormwater Quality Applicant's Handbook, March 2010.
i = Annual rainfall depth (in)
0.083 = Conversion factor (inches to feet)
A = Area (ac)

The runoff coefficient 'c' is determined based on the drainage sub basin non-directly connected impervious area curve number (NDCIA CN) and directly connected impervious area (DCIA) combination and the meteorological zone within which the project area falls (Zone 2). The March 2010 Draft Stormwater Quality Applicant's Handbook published the runoff coefficients for each NDCIA CN /DCIA combination and for each meteorological zone in Florida (DEP 2010). Among the five meteorological zones defined in Florida, both Lake County and Orange County are within

Zone 2; this is relevant because Lake Carlton lies within both Lake County and Orange County. Published runoff coefficients for Zone 2 are tabulated in **Table 1-1** of **Appendix B**. The NDCIA CN for the various land uses and soil types comprising the drainage basins were determined by using the lookup table provided in this report as **Table 1-2** of **Appendix B**.

The procedure described above allows for the determination of total runoff volumes generated from a given area. Additional hydrologic attenuation can be provided by stormwater BMPs, however, no BMPs were identified within the Lake Carlton basin as the area is primarily agricultural and low-density residential.

The development that has occurred within the Lake Beauclair basin is primarily on the eastern fringe of the lake. Most of the remaining land has been converted to agriculture with no existing structural BMPs and very few stormwater conveyance systems. Only two stormwater outfall pipes to Lake Carlton were identified during reconnaissance (**Figure 3-3**). Of these two, only one was selected for monitoring because the other is believed to simply provide drainage across a low portion of roadway. The only major conveyances in the basin include piped connections between Lake Victoria and Lake Jem to Horseshoe Lake. There were no identified direct stormwater outfalls discharging to any of these lakes. Stormwater runoff from sub-basins 4, 5, and 6 receives treatment from the receiving water in each sub-basin prior to discharging into Lake Carlton. The lakes are assumed to be at brim-full condition for modeling purposes and no volume attenuation is provided because the lake surfaces are normally connected.

As discussed previously, the basin has an active agricultural BMP enrollment program. Parcels enrolled in the program are shown in **Figure 3-4**. Load reduction from the program is discussed in **Section 5.**

4.2.2.3 *Lake Carlton Runoff Characterization*

Annual runoff calculations for the Lake Carlton Basin (inclusive of Lake Ola basin) suggest a relatively low amount of volume is contributed from stormwater runoff. Most of the soils within the combined Carlton and Ola basin are hydrologic group A soils (55.77%), which are typically well drained sandy soils. Estimates of hydrologic inputs to Lake Carlton from stormwater runoff were calculated for each identified sub-basin area based on the average NEXRAD rainfall from 1995-2013. **Table 4-3** summarizes the estimated sub-basin stormwater runoff. The sub-basin runoff estimates summarized in **Table 4-3** do not include the surface areas associated with Lake Carlton or Lake Ola. Direct rainfall contribution was discussed in **Section 4.2.1**.

The total estimated annual stormwater runoff volume for each sub-basin provided in **Table 4-3** is comparable to the annual direct precipitation to Lake Carlton (1,452 ac-ft) and Lake Ola (1,660 ac-ft). The majority of the stormwater runoff originates from Sub-basin 10 which includes Lake Ola and its watershed. Sub basin 10 is estimated to contribute about 53% of the total runoff to Lake Carlton through its connection with Lake Carlton. The runoff generated from Lake Ola and its watershed is the largest source of stormwater runoff to Lake Carlton followed by Sub-basin 4 which represents about 20%. Both sub-basins discharge to Lake Ola via an open channel. Runoff from sub-basins 5 and 6 also flows through the open channel connection between Lake Carlton and sub-basin 4, however, the contribution from these areas are considered separately.

4.2.3 Groundwater Seepage

A field investigation of groundwater seepage was conducted in Lake Carlton using eight seepage meters installed in the locations indicated in **Figure 4-4**. Six of the seepage meters were placed in approximately 4 ft of water and evenly spaced around the lake, in order, to assess potential contributions from the various land use types. Two additional seepage meters were placed in deeper areas with a suitable hard bottom in approximately ten feet of water depth.

Seepage meters provide a direct assessment of both water quantity and quality entering the lakes via groundwater influx, and provide a means of measuring groundwater-surface water interaction. Seepage meters measure groundwater flux by isolating a portion of the sediment-water interface with a chamber open at the base, so that groundwater flux can be assessed over time by measuring the change in volume of water in a bag attached to the top of the meter. The seepage meter was initially developed in 1977 (Lee, 1977) to provide a more accurate estimation of groundwater permeability into lakes and rivers. A diagram of a typical seepage meter installation is provided in **Figure 4-5**.

Seepage meters were constructed using 55-gallon stainless steel drums with a bottom diameter of 23 inches. Each drum isolated a 2.89 square ft portion of the sediment. A 0.75-inch threaded tubing connection was inserted into the top of the drum and sealed to ensure that it was watertight. A collection bag was connected to this threaded insert using 0.75 inner diameter reinforced polyethylene tubing. The open end of each collection bag was attached to a PVC ball valve that was directly connected to the tubing extending from the meter. Heavy duty black polyethylene bags were used for collection of water, each with an approximate volume of 35 gallons (132 liters).

Individual meters were installed in the sediments to a depth between 8-10 inches, with approximately 4-5 inches of water remaining in the top of each meter. The tubing attached to each meter was left open during installation to allow for equalization as the meter was pushed into the sediment. Each collection bag was pre-filled with a volume of 1,000 milliliters (ml) of distilled water. Pre-filling each bag prior to installation allowed for the measurement of a negative flux of water out of the meter, a condition which would represent recharge of surface water into the underlying aquifer. Ionic diffusion from the sediment is assumed to compensate for any dilution that would occur by the initial introduction of 1,000 ml of distilled water. All air within the collection bag was removed by partially submerging the bag with the ball valve above water. Once all the air was evacuated the ball valve was closed and submerged for connection to the tubing/meter. Once this connection was made the ball valve was opened, allowing for water exchange between the meter and collection bag. Meters were tilted slightly during installation so that the open end was partially elevated, allowing for the escape of any gasses collected in the container. A floating buoy was attached to each meter to mark its location.

A total of eight seepage meters were installed in the lake for assessment over a twelve-month period. Seepage meters were sampled every other month beginning June 30, 2016 and ending April 17, 2017. Prior to attaching the collection bag, seepage meters were allowed to equilibrate for one month. After the equilibration period, seepage meter bags were deployed at each location for approximately two months. Sample collection, measurement and analysis were performed after each collection period by closing the PVC ball valve and measuring the water using a 1 Liter graduated cylinder. Samples from each collection bag were placed into sample bottles and submitted to SRL for analysis of total nitrogen (total Kjeldahl nitrogen + nitrate/nitrite), total phosphorus, pH, alkalinity, and specific conductivity. A summary of laboratory reports for Lake Carlton seepage samples is provided in **Appendix C**.

Seepage data was used to assess both the hydrologic and nutrient mass contribution of shallow groundwater flux to Lake Carlton. For the hydrologic contribution, it was assumed that the shallow groundwater flux into Lake Carlton occurred in depths less than 10 ft. This is slightly deeper than typical seepage contributions as reported in a 1988 paper by Edward Deevey titled *"Estimation of Downward Leakage in Florida Lakes"*, which stated that the limit to which seepage was detected in lakes occurred within 30 m (98 ft) of the lake shoreline. Extremely soft organic material on the lake bottom prevented placement of seepage meters deeper than ten feet (**Figure 2-2**). Total seepage contribution to Lake Carlton was estimated using average flow rates for each meter and dividing the net collected seepage volume (final volume minus initial volume) by the cross-sectional area of each meter (2.89 ft^2) for each sample collection event. Then, because the seepage meters were evenly distributed along the perimeter of the lake, flow rates for the eight meters were averaged and multiplied by the total area of the lake that had a depth of 10 feet or less (62.8 acres).

Total annual seepage contribution to Lake Carlton was estimated to be 34.55 ac-ft. Seepage was not estimated in Lake Ola and assumed to be zero.

4.3 Hydrologic Losses

4.3.1 Evaporation

Hydrologic loss through evaporation occurring at the surface of each lake was not directly measured in this study. Amec Foster Wheeler utilized a pan evaporation rate of 47.33 in/ year based on a study conducted on the Butler Chain of Lakes (ERD, 2007). The Keene's Point Monitoring station used in the study was located approximately 11 miles from Lake Carlton and provided an entire year of daily pan evaporation data. This evaporation rate is similar to long-term evaporation rates previously measured in Central Florida (i.e., Litchter *et al,* 1976). Total evaporative loss from Lake Carlton is expected to be 1,566 ac-ft. Total evaporative loss from Lake Ola is expected to be 1,731 ac-ft.

4.3.2 Groundwater Recharge

No loss from groundwater recharge is expected in Lake Carlton because the potentiometric surface of the underlying Floridan aquifer generally sits above the bottom of the lake (Boniol and Stokes, 2014). This is further evidenced by positive seepage inputs measured at seepage meters placed in deeper sections of the lake.

4.3.3 Surface Outflow

Surface outflow, or discharge, is assumed to be the difference between total hydrologic inputs and evaporation. Based on the hydrologic model, net surface outflow from Lake Carlton is approximately 1,413 ac-ft/yr. Mean seiche flow of 8 to 12 cfs between Lakes Carlton and Beauclair contributes significantly to the total volume exchanged and mixing occurring between Lake Beauclair and Lake Carlton. However, unlike external hydrologic inputs such as stormwater runoff, tributary inflows, and rainfall; seiche exchange should have no net hydrologic impact because it is an internal phenomenon.

4.4 Hydrologic Budget

Hydrologic inputs to Lake Carlton include direct precipitation, stormwater runoff, tributary inflow (from Lake Ola) and groundwater seepage (**Figure 4-6**). Because of its size, the Lake Ola hydrologic budget is estimated separately in **Tables 4-4** and **4-5**. Inputs from Lakes Jem, Horseshoe, and Victoria and their associated sub-basins are counted as direct stormwater runoff. Approximately half of the hydrologic inputs to Lake Carlton enter via direct precipitation (49%), with smaller contributions from runoff (29%) and tributary inflow (21%). Seepage inputs represent approximately one percent of the overall hydrologic budget. Hydrologic outputs from Lake Carlton include evaporation and surface outflow (**Figure 4-7**). Evaporative losses account for approximately 1,566 ac-ft per year (53%).with discharge totaling 1,402 ac-ft (47%).

4.4.1 Water Residence Time

Annual hydrologic residence time was estimated for Lake Carlton by dividing the volumetric capacity (5,197 ac-ft as estimated in GIS from bathymetric contours) of the lake by the modeled surface outflow calculated in **Section 4.4**. Based on this calculation, Lake Carlton has a residence time of 3.7 years. This is similar to the hydrologic residence times of other lakes within the Harris Chain-of-Lakes (Fulton, 1995) and seiche exchange with Lake Beauclair has no net impact.

5.0 NUTRIENT BUDGET

5.1 Nutrient Inputs

A nutrient budget was developed for Lake Carlton utilizing the hydrologic budget discussed in **Section 4.2.2**. The nutrient budget included inputs from direct precipitation, atmospheric loading, stormwater runoff, tributaries, septic systems, and shallow groundwater seepage. Stormwater runoff loading was estimated using a combination of both literature-based and site-specific data. A discussion of identified nutrient loads for the lake is provided in the following sections.

5.1.1 Precipitation and Dry Deposition

Precipitation and dry deposition loadings were not determined directly as a part of this study. The values used in the TMDL have been utilized for determination of the nutrient budget. During the 1991-2000 evaluation period, Mean TP load from precipitation and dry deposition was 50 lbs/yr and 68 lbs/yr, respectively. Mean TN load from precipitation and dry deposition was 1,771 lbs/yr and 505 lbs/yr, respectively. The corresponding TN concentration in the direct annual rainfall volume would be approximately 434 µg/L and the TP concentration would be 12 µg/L.

5.1.2 Runoff

Surface runoff volume used in developing the nutrient budget for the lake was obtained from the hydrologic budget previously described in **Section 4**. Inputs from surface runoff were estimated from the hydrologic model described in **Section 4.2.2.3**.

5.1.2.1 *Literature Based EMCs*

For the spreadsheet loading model (previously discussed in **Section 4.2.2.2**), event mean concentrations (EMC) for specific land uses were applied to the volumes of surface runoff coming from the watershed to estimate total annual mass pollutant loading. For contributing sub basins that do not discharge to water quality monitored outfall locations, literature-based EMC values (summarized in **Table 1-3** within **Appendix B**) in conjunction with estimated stormwater runoff were utilized to estimate representative pollutant loading. **Table 1-3** of **Appendix B** lists the event mean concentrations (EMC) used to estimate pollutant loads for non-monitored contribution areas. EMCs were developed using land use specific pollutant concentrations obtained from past monitoring activities conducted throughout the State of Florida, and were derived from several sources as noted in the documentation. EMCs were developed for total nitrogen (TN), total phosphorous (TP), and total suspended solids (TSS). Contributing areas within the footprint of the monitoring outfall were assigned pollutant concentrations based on the average stormwater pollutant concentrations identified in the monitoring effort.

Figure 3-4 depicts agricultural areas currently enrolled in the FDEP's agricultural BMP program. These areas were assigned a ten percent TN, TP, and TSS loading reduction which is reflected in the EMC's for each sub-basin.

5.1.2.2 *Stormwater Sampling*

Site-specific water quality characterization of stormwater runoff can be utilized to refine the loading model and is especially important in areas where literature-based EMCs may not be sufficient. Three locations were selected for deployment of auto-sampling equipment and subsequent monitoring based on anticipated potential for greatest hydrologic and nutrient contribution to Lake Carlton (**Figure 5-1**).

Beginning in May 2016, Amec Foster Wheeler installed OCEPD autosampler units and flow modules. One autosampler was placed at the only significant stormwater outfall to Lake Carlton which is in Sub-basin 2 at the end of Earlwood Avenue (**Figure 5-2**). The suction strainer was placed at the bottom of a grate inlet which discharges through a 24-inch concrete pipe. The acoustic Doppler velocimeter (ADV) was mounted inside the 24-inch pipe immediately downstream of the suction strainer.

The remaining two autosamplers were placed at discharges from upstream lakes including Lake Ola (**Figure 5-3**) and Horseshoe Lake (**Figure 5-4**). The Lake Ola autosampler was placed several hundred feet downstream of the Lake Ola outfall within the right-of-way and adjacent to a large grate inlet. Both the ADV and suction strainer were mounted on a steel rod at the end of the 48-inch culvert crossing under Dora Drive. The ADV and suction strainer were elevated approximately 4 inches above the sediment in the pipe. During the monitoring period, approximately 100 feet of the downstream ditch was excavated to match the invert elevation of the 48-inch culvert. Standing water was always observed within the pipe and ditch although there was no discernable flow and no base flow was recorded by the ADV.

The Horseshoe Lake autosampler was placed near the confluence with Lake Carlton and the ADV was mounted to a steel pipe approximately five feet from the shoreline and away from direct contact with aquatic vegetation. Submersed aquatic vegetation was present at this location although shading from tree canopy prevented the vegetation from growing densely. Flow at this location was observed to routinely change direction and appears to be influenced by seiche from Lake Carlton and the super pond.

Installation was completed on June 15, 2016 and the first collection event occurred on August 15, 2016. The remaining samples were collected at each of the monitoring sites until May 2017. Stormwater samplers were programmed to begin sampling after a rainfall event exceeded 0.25 inches within a 2-hour period with no antecedent rainfall for at least 72 hours. Once triggered, samplers sequentially filled up to 12 sample containers. Flow-weighted samples were collected using a pacing interval that provided sufficient sample volume.

Eight stormwater samples were collected from each location including four during the dry season and four during the wet season. The complete laboratory reports for stormwater runoff collected at the three autosampler locations is provided in **Appendix D**. Rain totals and collection dates are shown in **Figure 5-5**. Summary data for each station are shown in **Table 5-1**. The Earlwood station had the highest mean TN and TP concentrations as well as the highest concentrations of dissolved nitrogen and phosphorus fractions. Discharge at the Earlwood sampling location was generally only present for a short duration following a rain event and the station normally filled only the first few sample bottles. This is consistent with the relatively small contributing area and is likely to be characteristic of the location even during wet conditions. It should be noted that stormwater sampling during this study spanned an unusually dry period which should be considered carefully when utilizing the data.

Discharge from Lake Ola was not observed to contribute significant flows to Lake Carlton during the study period. Although the autosampler was successfully triggered for most of the rainfall events, discharge at the Lake Ola sampling location was consistently near the low end of the ADV detection limits following rain events and was occasionally undetectable. Grab samples were collected when insufficient flow was detected to trigger the autosampler. The EMC measured at Lake Ola likely significantly over-represents the tributary contribution to Lake Beauclair. Long-term water quality data is available for Lake Ola on the Orange County Water Atlas. Therefore, Lake Ola's long-term mean concentrations for TN and TP were used for determination of the site-specific EMC at this location instead.

These data were utilized to develop the loading model discussed in **Section 5.2**. Site-specific EMCs were incorporated for all Sub-basins 4, 5, 6, and 10 and a portion of Sub-basin 2 (**Table 5-2**). Measured water quality data are also utilized in conjunction with modeled data to provide load reduction scenarios for the BMP alternatives presented in **Section 6**.

5.1.3 Internal Loading from Seepage

Internal loading from shallow groundwater contribution around the perimeter of the lake was estimated using the seepage meter data discussed in **Section 4.2.3**. Seepage contributions to total nitrogen and total phosphorus loadings to Lake Carlton were calculated using the total annual hydrologic contribution from shallow groundwater seepage was combined with mean concentration of the nutrients found in the seepage samples. **Table 5-3** summarizes the results of the seepage loadings, while a full listing of seepage laboratory results and analysis can be found in **Appendix C**.

5.2 Surface Runoff Loading Estimates Model

A pollutant loading model was developed for the Lake Carlton watershed based on regional land use and soils information as well as the site-specific EMC data obtained from direct stormwater sampling. Modeled loading of nitrogen, phosphorus, and suspended solids was combined with modeled runoff to develop annual nutrient budgets for the lake. The results of the nutrient budget and pollutant loading model were used to make specific recommendations for BMPs within the watershed. An estimate of anticipated water quality improvements with implemented BMP recommendations was also performed.
The constituent loading estimates analyzed in the model included TN, TP, and TSS. No structural BMPs were identified in the basin but non-structural BMPs such as agricultural enrollment is considered. Lakes Ola, Horseshoe, Victoria, and Jem act as natural BMPs and the nutrient attenuation provided by these systems are accounted for in the site-specific EMC. Loading from

Sub-basins 4, 5, and 6 was estimated using the mean TN, TP and TSS concentrations at the Horseshoe Lake sampling location. The Horseshoe Lake outfall captures all the upstream sedimentation impacts occurring within Lakes Victoria, Jem, and Horseshoe.

Loading from Sub-basin 10 (Lake Ola) was initially estimated using flow-weighted sampling data discussed in **Section 5.1.2.2**. However, Lake Ola elevation was relatively low for the duration of the study and only minimum flow was observed following storm events. Samples collected at the Lake Ola autosampler location were likely overrepresented by localized stormwater runoff from the adjacent citrus groves or from the grated inlet along Dora Drive upstream of the autosampler. Under normal conditions, Lake Ola should discharge approximately 610 ac-ft per year. Because there are relatively few inputs between Lake Ola and Lake Beauclair, discharge water quality from Lake Ola should be similar to that of open water within the lake. Therefore, Orange County's long-term TN and TP data for Lake Ola (available on the Water Atlas) were used as the EMC for Sub-basin 10 runoff.

Modeled TSS data from Sub-basin 10 was assigned a 99% reduction due to sedimentation that occurs naturally in Lake Ola. Lake Ola is normally a clear lake with turbidity less than 5 NTU.

5.2.1 Surface Runoff Loading to Lake Carlton

Total nutrient loading attributable to surface runoff into Lake Carlton is estimated from the modeled data to be 179 lb/year TP, and 4,229 lb/year TN (**Table 5-4**). Sediment load was estimated to be 22,503 lb/year TSS. Although Sub-basins 5 and 6 discharge through Sub-basin 4, loadings are listed separately in **Table 5-4** for discussion and ranking purposes. Runoff loading from sub-basin 10 was calculated using 89% of the modeled volume to balance with Lake Ola discharge shown in **Table 4-5**.

TP is the primary nutrient of concern and the only parameter utilized for determining achievement of the TMDL. Sub-basins 4, 2, and 3 were estimated to contribute the highest TP loads to Lake Carlton with contributions of 40.0, 37.8, and 32.5 lb/year respectively. Stormwater conveyance systems exist in small portions of Sub-basins 2 and 3 introduce untreated stormwater to Lake Carlton, but the remaining surface loading is assumed to occur from overland flow. Sub-basins 2 and 3 are dominated by sandy soils, agricultural land uses at the higher elevations, and low density residential land use immediately around the lake. Runoff from Sub-basin 5 discharges to Lake Jem and then to Horseshoe Lake in Sub-basin 4. Runoff from Sub-basin 6 discharges to Lake Victoria prior to flowing into Horseshoe Lake. Sub-basins 1, 8, and 7 are all narrow sections of land along the western side of Lake Carlton with no stormwater conveyance systems and minor loading contributions

TN loading was modeled for discussion purposes. Sub-basins with the highest TN loads were 4, 10, and 6 with contributions of 1,289.1, 1,197.5, and 555.8 lb/year, respectively.

5.2.2 Pollutant Loading from Septic Tanks

Due to the lack of sanitary sewer infrastructure available to serve the majority of properties within the Lake Carlton basin, homes and facilities surrounding the lake are primarily served by septic tanks (**Figure 5-6**). Little has changed since 2003 with regard to new development in the basin so the same seepage loading estimates determined as part of the Lake Carlton TMDL have been utilized to develop the nutrient budget. Seepage from septic systems is estimated to contribute 67 lb TP/yr and 1,188 lb TN /yr.

5.2.3 Summary of Annual Pollutant Load from Orange and Lake Counties

Amec Foster Wheeler estimated the pollutant load contribution to Lake Carlton from both Orange and Lake Counties. Sub-basins 1, 3, and 4 were the only areas that included a portion of Lake County. The Orange and Lake County loading for these three basins is shown in **Table 5-5**.

5.2.4 Summary of Annual Pollutant Loads by Source

To assess relative pollutant load contributions to Lake Carlton, all previously described pollutant load sources have been summarized and are included in **Table 5-6**. The highest total phosphorus load is associated with surface runoff, and represents 39% of the total phosphorus load to Lake Carlton. Direct rainfall, atmospheric deposition, seepage and septic each contributed between 12 and 16% of the TP load. Tributary loading contributed the least TP or 4%.

Runoff contributed 34% of TN and was the greatest source of TN loading to Lake Carlton. Direct rainfall, tributary input, seepage, and septic each contributed between 13 and 19%. Atmospheric deposition contributed the least TN at 6%.

TSS contribution was not calculated for precipitation, seepage or failed septic and is not expected to be significant. Runoff contributed 98% of the total anticipated TSS load.

The loading estimates determined in this study were like those calculated in the Lake Carlton TMDL. Total TP loading was within 11% of the TMDL estimate and Total TN loading was within 1% of the TMDL estimate. Most of the difference in TP loading is likely explained using site-specific EMCs in this study.

5.2.5 Seiche Impacts on Water Quality

As shown in **Figure 2-29**, SLDV data indicated mean flow out of Lake Carlton was 8 cfs while mean flow into Lake Carlton was 12 cfs. These values should offset each other, but for various reasons explained above, they do not. Although the net hydrologic impact from seiche is expected to be zero, the volume exchanged between the two lakes is an order of magnitude greater than the stormwater and tributary loading to Lake Carlton. This has a profound impact on the water quality in Lake Carlton.

The water quality impacts of seiche exchange are particularly apparent in TP data for Lake Carlton and Lake Beauclair as shown in **Figure 2-30.** Over the past twenty years, TP concentration in Lake Carlton has remained consistently lower and has exhibited a declining trend similar to Lake Beauclair although very little has changed in Lake Carlton basin. In fact, mean TP concentration declined by approximately 50% over the evaluation period. The impact of seiche mixing from Lake Beauclair is further evidenced following operation of the NuRF in 2009 when TP concentration in both Lakes Carlton and Beauclair decreased and were nearly equal to the TP TMDL.

Based on the evidence obtained in this study for significant mixing between the two lakes and the correlation between TP concentration in Lakes Beauclair and Carlton, it is likely that achievement of the TP TMDL in Lake Beauclair will also allow achievement of the TP TMDL in Lake Carlton.

5.3 Nutrient Reduction Model

The TMDL developed for Lake Carlton assumes that it is a phosphorus-limited ecosystem and improvements in other water quality parameters are expected as the TP concentration decreases.

Therefore, a phosphorus-specific and relatively simple water quality model was developed for the existing TP concentration within the lake. The methodology to set up the model for existing conditions is described below. The model is then utilized in **Section 7.0** to predict the anticipated change in Lake Carlton TP concentration in response to water quality (load reduction) improvement alternatives.

Predictive TP concentration modeling was conducted for Lake Carlton using the Bathtub Eutrophication Model (Walker, 2004). The Bathtub Eutrophication Model was developed by the United States Army Corps of Engineers utilizing a variety of methods; several which are specific to Florida lakes. Amec Foster Wheeler set up the model by incorporating the hydrologic inputs summarized in **Section 4.0** and the nutrient inputs summarized in **Table 5-6**. The model was then calibrated using the 2016 mean TP concentration provided in **Section 2.0**.

The TP concentration predicted by the Bathtub Eutrophication Model was 36 µg/L using the second-order decay function. The actual mean TP concentration during 2016 was 39 µg/L, and was within 8% of the uncalibrated model estimate. The model was calibrated to the 2016 mean TP concentration using a factor of 0.75 which is within the recommended range of 0.5 to 2 as described in the Bathtub User's Manual. Internal loading was not included as a source of TP in the model because the TP concentration was predicted reasonably well without it.

6.0 SEDIMENT CHARACTERIZATION

The role of internal sediment recycling is not well studied in Lake Carlton. Internal recycling was not estimated during development of the TMDL nor was it considered as a component of the loading model. However, because of its significant hydrologic interaction with Lake Beauclair, Lake Carlton may be experiencing internal nutrient recycling associated with nutrient-rich sediments deposited during seiche events.

Bathymetric analysis and preliminary sediment characterization revealed primarily organic substrates within Lake Carlton. Sandy substrates were present in the lake, but only extend out a few hundred feet in some locations. Six sediment cores were collected as a part of this study to characterize the various species of phosphorus throughout the lake (**Figure 6-1**). Intact sediment cores were collected using a piston tube sampler. The upper 10 cm of each core was collected, sealed in an evacuated air-tight bag and transported on ice to DB Environmental, Inc. for analysis.

In addition to percent moisture, the following parameters were analyzed for each core as part of the modified Chang and Jackson extraction analysis:

(1) Saloid-bound and exchangeable Ca
(2) Aluminum phosphate
(3) Iron phosphate
(4) Reductant phosphate
(5) Calcium phosphate
(6) Total phosphorus

Moisture percentage indicates more consolidated sediments at locations C2, C3, and C5. Locations C1, C4, and C6 are higher in moisture content and every other analyzed phosphorus species. This would support the hypothesis that UnCF material is being transported by seiche flow from Lake Beauclair. **Table 5-4** provides the phosphorus speciation data for each sediment core. Gradient maps for moisture percentage and the various phosphorus species are presented in **Figures 6-2** through **6-9**, while full laboratory reports are included in **Appendix E**.

Sediment chemistry data are provided in **Table 6-1**. Sediment TP concentrations ranged between 677 mg/kg and 2830 mg/kg with the highest concentrations found at locations C1, C4, and C6. Saloid phosphorus was an order of magnitude higher at location C1 than the other locations which were all similar. Saloid phosphorus is loosely bound within the sediments and is easily released. Reductant soluble phosphorus, or phosphorus that may be released during anoxic conditions, ranged from 75.8 mg/kg to 393 mg/kg. Iron-bound phosphorus not released during the reductant soluble phosphorus extraction was present in concentrations ranging from 16.3 to 45.1 mg/kg. These three parameters are considered part of the mobile P fraction which is available for biological uptake under typical low dissolved oxygen conditions found at or near the water/sediment interface.

Aluminum-bound phosphorus was present in higher concentrations relative to iron-bound and ranged from 140 mg/kg to 476 mg/kg. Higher concentrations of Al-bound P were found at locations C1, C4, and C6 also suggesting that these sediments may have been transported from Lake Beauclair after Al enrichment due to NuRF outputs. Calcium-bound phosphorus ranged from 48.1 mg/kg to 294 mg/kg. The remaining balance of total phosphorus within the sediment is considered unextractable and is presumed to be incorporated into compounds other than those identified in the analyses. Unextractable phosphorus is normally considered biologically unavailable under steady-state conditions.

Sediment phosphorus speciation data is useful for determining the potential magnitude of phosphorus loading from internal sources, and serves primarily as a means of designing sediment-phosphorus inactivation projects. While there is no direct load associated with phosphorus speciation, the data are useful for determining the available phosphorus pool found in the sediments. Generally, only the top several inches are subject to resuspension but given the characteristics of UnCF sediment, this may be thicker in Lake Carlton.

Sediment flux studies may provide additional information regarding the magnitude of internal loading of the organic sediments in Lake Carlton. Flux study data would provide additional information regarding the potential release of the various P species which were comparatively high at C1, C4, and C6.

7.0 WATER QUALITY IMPROVEMENT ALTERNATIVES

Water quality in Lake Carlton has been steadily improving for the past twenty years and is expected to continue to improve as benefits from Lake Apopka and Lake Beauclair restoration projects are realized. Potential structural stormwater BMP Improvements within the Lake Carlton watershed are limited because there are few existing stormwater collection systems. Improvements to Lake Carlton may be enhanced through several structural, in-lake, and non-structural means as discussed below. Regardless of additional BMP implementation, water quality conditions in Lake Carlton are likely to continue to improve and approach the TP TMDL target as they have in Lake Beauclair.

Both structural and non-structural alternatives were identified for Lake Carlton and are discussed below. Estimated costs for each alternative are also presented along with total loads removed in order to include cost per pound of pollutant removed. Anticipated water quality benefits have been assessed using the previously described pollutant load modeling techniques. Where possible, costs include professional design (engineering and surveying) costs or permitting costs but are subject to vary depending on the state of the existing infrastructure (i.e. if substantial conflicts arise, pipes need replacement, design/installation of non-standard control structures, curbing/pavement replacement, etc.).

7.1 Structural Alternatives

7.1.1 Alternative 1 – Modular Biofilter

Alternative 1 is recommended to improve water quality entering Lake Carlton via Sub-basin 2 (**Figure 7-1**). Sub-basin 2 is comprised primarily of low density residential and agricultural landuse. Sandy soils and lack of widespread stormwater collection systems reduce the overall discharge from the basin. However, the nutrient concentrations and mass loadings indicate some benefit may be achieved with additional stormwater treatment in this sub-basin. Sub-basin 2 currently contributes 3,380 lb TSS, 339 lb TN, and 38 lb TP to Lake Carlton per year.

7.1.1.1 *Description*

Alternative 1 consists of installing a modular biofilter within the right-of-way at the end of Earlwood Avenue. Suitable area appears to be available based on information from the Orange County Property Appraiser website. Modular biofilters have been used successfully by Orange County previously and are particularly suited for end of pipe applications where limited land is available.

7.1.1.2 *Efficiency*

The upflow and modular wetland filtration technologies proposed for **Alternative 1** are novel compared to typical BMP alternatives, such as wet and dry detention facilities. Therefore, operational data is not as abundant as the more common BMPs. However, Orange County has recently completed an operational study for a modular biofilter treating an outfall to Bay Lake in the Wekiva Basin (Geosyntec, 2017). Data from the study indicates that modular biofilters with Bold & Gold™ media are capable of significant nutrient reduction. Amec Foster Wheeler assumed a reduction of up to 57% for TP, 48% for TN, and 83% for TSS.

In its existing condition, the grate inlet at the end of Earlwood Avenue in Sub-basin 2 receives discharge from Earlwood Avenue, adjoining properties, and a residential area to the east. If treated with a Bold and Gold ™ upflow filtration system, potential annual mass load reductions to Lake Carlton are 624 lb TSS, 37 lb TN, and 7 lb TP. Flow not treated by the BMP is expected to be discharged directly to Lake Carlton. TP loading through the existing stormwater system is estimated to contribute approximately one third of the TP loading from Sub-basin 2 while the remaining portion is contributed through overland flow.

Based on Bathtub model predictions using literature based EMCs, the cumulative water quality result of implementing **Alternative 1** would result in a 3% decrease in water column TP concentration within Lake Carlton. Assuming no mixing benefits from Lake Beauclair, the resulting TP concentration of 38 µg/L would not achieve the TMDL target concentration of 32 µg/L, but would provide approximately 14% of the necessary reduction.

7.1.1.3 *Costing*

Alternative 1 involves installation of new structures within Orange County's right-of-way and requires no land acquisition. Costs associated with the implementation of **Alternative 1** consist of a filter box, construction cost, filter media costs, and routine maintenance. Costs are based on information provided by Orange County for a recent modular biofilter construction project involving an outfall on Bay Lake in Orange County. Costs estimates assume one 10' x 15' box.

The total present worth cost (including design, construction, operation and maintenance) for this alternative assuming a 20-year life span is approximately $250,000, which translates to approximately $12,500 in annualized cost. Based on the previously stated efficiencies and load reduction for a filter media application, this alternative would cost approximately $1,786/lb TP, $338/lb TN, and $20/lb TSS removed. **Table 7-1** provides an itemized list of implementation costs, while **Table 7-8** provides a comparison of the costs associated with this alternative to the other alternatives for Lake Carlton.

7.1.2 Alternative 2 - Exfiltration

Alternative 2 proposes installation of an exfiltration system prior to the grated inlet structure on Grove Lane leading directly to Lake Carlton (**Figure 7-2**). This structure drains only a small portion of Sub-basin 3 consisting approximately 28 acres of agricultural (citrus) and low density residential land use. Sub-basin 3 currently contributes 3,533 lb TSS, 286 lb TN, and 33 lb TP to Lake Carlton per year. **Alternative 2** focuses on reducing the total volume of surface runoff contributed by Sub-basin 3.

7.1.2.1 *Description*

The proposed BMP would consist of a subsurface retention system incorporating conduit such as perforated pipe surrounded by natural or artificial aggregate which would temporarily store and allow runoff to percolate into the surrounding soil. Exfiltration systems promote more efficient infiltration of surface runoff to shallow groundwater tables by detaining stormwater and evenly distributing it through the base of the trench. Exfiltration system work best in well drained soils which are present area proposed for BMP placement. The elevation of the ground surface at the proposed BMP area is about 15 feet above lake level so it should be well suited for an exfiltration system.

7.1.2.2 *Efficiency*

The efficiency of exfiltration trenches is based on the treatment volume of the design, or the volume of stormwater runoff that can be retained and percolated into the ground. The treatment volume of the system proposed for Lake Carlton Drive / Grove Lane assumes that an exfiltration trench will be constructed parallel to Lake Carlton Drive on the northwest side for a length of approximately 280 linear feet. Trench design assumes minimum standards, which consist of the following:

- Minimum perforated or slotted pipe diameter of 18 inches;
- Minimum aggregate reservoir trench width of 3 ft;
- Minimum aggregate reservoir trench depth of 3 ft; and
- Aggregate void space of 35%.

Using the above criteria, the cross-sectional void area of the proposed exfiltration design is 3.7 ft^2, resulting in an available retention volume of 1,025 ft^3. Applied to the 13.8-acre basin, this is equivalent to 0.02 inches of runoff retention. Pollutant removal efficiencies were obtained using the methodology outlined in the Draft Stormwater Quality Handbook (FDEP, 2010), which provides performance efficiencies for dry retention runoff volumes as a function of curve number and directly connected impervious area (DCIA). Using an area weighted average to determine the basin-wide non DCIA curve number of 33 (**Table 1-1 of Appendix B**) and a DCIA value of 10% (USDA, 1986), a mean annual mass removal efficiency of 95.98 % is obtained. Based on the basin hydrology a storm event with 0.3 inches of rainfall would produce 1,004 ft^3 runoff volume; this volume would be completely treated with the proposed exfiltration system. Furthermore, based on historical rainfall data (from Lisbon, FL) summarized in **Appendix F** the 0.3" event corresponds with approximately 20% of the annual cumulative rainfall.

Treatment of 20% of the total rainfall for the portion of sub-basin 3 intercepted by the exfiltration system would result in an annual load reduction of 5.3 lbs TN and 0.38 lbs TP. Based on Bathtub model predictions, the cumulative water quality impact to TP within Lake Carlton from the implementation of **Alternative 2** would be negligible.

7.1.2.3 *Costing*

Alternative 2 is proposed to be constructed along the north side of Lake Carlton Drive south of Grove Lane. The costs utilized in this analysis assume the project can be constructed entirely within the County right-of-way. Construction costs were based on the treatment volume provided by the design parameters described in **Section 7.1.2.2**, as well as all associated material and installation costs. These costs pertained to all excavation, piping, installation and sidewalk/pavement repair associated with installation of the trenches.

The total present worth cost (including operation and maintenance) for this alternative assuming a 20-year life span is approximately $85,000, which translates to approximately $4,250 in annualized cost. This alternative would cost approximately $11,184 per lb TP, and $801 per pound TN. **Table 7-2** provides an itemized list of implementation costs, while **Table 7-8** provides a comparison of the costs associated with this alternative to the other alternatives for Lake Carlton.

7.1.3 Alternative 3 – Septic Conversion

7.1.3.1 *Description*

Alternative 3 consists of conversion of the existing onsite sewage treatment and disposal systems (OSTDS) within the Lake Carlton basin to sewer. OSTDS conversion within the next ten years is a required element of the most recent draft BMAP update for the UORB.

7.1.3.2 *Efficiency*

Conversion of OSTDS to sewer is intended to remove the localized sources of groundwater loading of nitrogen and phosphorus to a surface water through seepage. The actual loading from these sources is difficult to determine compared to surface water inputs such as outfall pipes. However, since the source is normally removed from the basin, it is considered 100% efficient although the groundwater impacts may remain for quite some time. Based on the Bathtub model predictions, impacts to water quality from septic load reduction could reduce the TP concentration from 39 µg/L to 34 µg/L, and could achieve approximately 70% of the required reduction.

7.1.3.3 *Costing*

The cost of septic system conversion is generally high compared to other typical BMP alternatives. However, there are limited sources of concentrated nutrients within the Lake Carlton basin, so relatively few load reduction options exist.

Cost for two ongoing south Florida-based septic conversion projects ranges between $9,600 and $19,594 per parcel (Amec Foster Wheeler, 2016). Total parcels served for the completed septic conversion projects ranges between 1,500 and 7,400 and total project cost is between $14.4 and $145 million. Given the limited number of homes surrounding Lake Carlton and the lack of nearby sewer systems, the cost per parcel would likely be significantly higher. Assuming 368 parcels would need to be converted at the higher cost range (due to small project scale, large lot size, and long distance from sewer main), total cost to construct would be approximately $7.3 million with an additional $700,000 in design and permitting cost. It is assumed that a utility fee would be charged for routine maintenance which is not included in the total cost.

Total potential load reduction to Lake Carlton over twenty years is estimated to be 1,340 pounds, or $5,970 per pound of TP removed. Potential load reduction possible from septic removal is relatively high compared to Alternatives 1 and 2. However, implementation would address the greatest controllable source of TP load within the basin. **Table 7-3** provides estimated implementation costs, while **Table 7-8** provides a comparison of the costs associated with this alternative and the other alternatives for Lake Carlton.

7.2 In-Lake Alternatives

7.2.1 Alternative 4 - Enhanced NuRF Operation

7.2.1.1 *Description*

The NuRF is currently managed to assist with the achievement of Lake Beauclair’ s downstream TP TMDL target of 32 µg/L. As water quality continues to improve upstream of the NuRF, it is conceivable that less treatment may be needed by the NuRF to maintain the TMDL in Lake Beauclair. In the unlikely scenario where Lake Beauclair maintains a lower TP concentration than Lake Carlton, the additional treatment capacity at the NuRF could be utilized to reduce the TP concentration in Lake Beauclair to the point where the appropriate TP concentration in Lake Carlton could be achieved through mixing. This alternative requires that sufficient discharge is occurring from Lake Apopka to allow operation of the NuRF. The cost for this alternative would be determined by the chemical expense and facility operation necessary to achieve the additional reduction.

7.2.1.2 *Efficiency*

The efficiency of alum treatment to reduce TP loading is normally relatively efficient compared to other BMP alternatives such as stormwater ponds. TP removal by the NuRF had been reported to be around $300 per pound of TP removed.

7.2.1.3 *Costing*

The cost of additional alum application would depend on flow rate and the TP concentration in the NuRF discharge required to achieve the 32 µg/L TP TMDL target in Lake Carlton. Mean design flow through the NuRF was estimated to be approximately 50 cfs. Mean annual alum consumption is expected to be approximately 250,000 gallons. Assuming alum cost of $0.80 per gallon, the total cost of alum applied annually at the NuRF is $200,000. If 10% more TP mass load reduction were needed in Lake Beauclair to achieve the Lake Carlton TP, this would require approximately $20,000 annually for the purchase of additional alum, or $400,000 over 20 years. Assuming a load reduction of 5,000 pounds of TP attributed to the NuRF annually, the potential additional reduction could be 450 pounds of TP reduction per year or 9,000 pounds of TP reduction over 20 years. **Table 7-4** provides an itemized list of implementation costs, while **Table 7-8** provides a comparison of the costs associated with this alternative to the other alternatives for Lake Carlton.

7.2.2 Alternative 5 – Sediment Nutrient Inactivation

7.2.2.1 *Description*

Sediment nutrient inactivation may be a suitable option for expediting and enhancing water quality improvement within Lake Carlton. Phosphorus speciation analysis indicates the presence of significant sources of phosphorus in some areas of the lake bottom that may interact with the water column during resuspension. These areas of relatively high TP concentration are located near the connection with Lake Beauclair and may have been transported to Lake Carlton from Lake Beauclair. Inactivation of potentially bioavailable phosphorus by chemical application using liquid aluminum sulfate (alum) has been a successful means of improving water quality for many lakes in Orange County and elsewhere. The NuRF utilizes aluminum sulfate for removal of phosphorus in the water column, but some of the alum flocculent travels downstream where it may provide additional sediment nutrient inactivation benefit. Other chemical inactivation methods are also available including Phoslock™. Phoslock™ is a proprietary product utilizing lanthanum to selectively bind free phosphate ions. Phoslock™ is not a flocculent like alum but selectively binds with phosphate to prevent biological uptake. Phoslock™ application is the preferred method in Lake Carlton because it does not reduce pH, has no precautionary environmental concerns, and aluminum sulfate is already used extensively at the NuRF. However, both methods are discussed below because alum has a history of successful use in Florida lakes.

7.2.2.2 *Efficiency*

Sediment nutrient inactivation is highly efficient assuming the chemical settles completely within the target area. Aluminum sulfate is highly effective at inactivating bioavailable sediment phosphorus although it forms a flocculent in the water column and aluminum reacts with many other ions which can reduce the number of aluminum binding sites available for phosphate. This is generally overcome by applying sufficient aluminum mass to achieve an Al:P ratio of at least 10:1. Phoslock™ is designed to disperse within the water column and settle to the bottom over the course of several days. In Lake Carlton, this would be relatively challenging because only a portion of the lake is recommended for sediment inactivation and considerable mixing occurs between Lake Carlton and Lake Beauclair near the application location. Application during calm winds would alleviate some of the mixing concerns. Special Phoslock™ mixes could also be prepared that allow for more rapid settling of the product within the target areas. The lanthanum mass applied would be available for phosphate inactivation at a 1:1 ratio.

Both alum and Phoslock™ alternatives address a portion of the in-lake loading which is not considered in the TMDL loading model or the nutrient model developed for this study. However, reducing internal loading may accelerate water quality improvements.

7.2.2.3 *Costing*

Sediment inactivation cost can be estimated for aluminum sulfate application by first determining the total amount of Al mass required to inactivate the available P present within the sediment area selected for inactivation. For the purposes of this analysis, the northeast quadrant, or 25% of the lake surface (bottom) was evaluated for treatment. Total treatment area is 98 acres. Assuming an available P concentration of 414 mg/kg in the top 10 cm of sediment, the estimated phosphorus mass to be treated is approximately 4.23 g P / m^2. The aluminum mass required to inactivate this phosphorus mass in terms of lake volume over the treatment area would be approximately 11.56 g Al / m^3. Total estimated aluminum sulfate application to treat the targeted 25% of Lake Carlton sediment area would be 83,000 gallons. Alum cost for a partial lake treatment would be approximately $83,000 with application cost of approximately $60,000 and a total project cost of $160,000 including project design (**Table 7-5A**). Jar testing will be required to determine if buffering is necessary which may require additional cost. Furthermore, it is recommended that additional sediment analysis be conducted within the lake to determine if the overlying water column may be interacting with more than the top 10 cm of sediment or if additional lake areas should be treated.

Estimated Phoslock™ product and application cost were provided by SePro based on the phosphorus speciation data from this study. Total cost for sediment inactivation using Phoslock™ would be approximately $310,000 (**Table 7-5B**). Additional Phoslock™ application methods are available which could be used to deliver a more targeted approach for the areas with higher concentrations of bioavailable phosphorus.

7.2.3 Alternative 6 – Dredging

Dredging can be an effective means of reducing internal load by removing nutrient-rich organic sediments which may contribute to recycling of nutrients. Approximately 2.57 million yd^3 of soft sediment is present within Lake Carlton based on bathymetric data developed as a part of this study. The exact origin of the sediment is unknown but the phosphorus speciation data suggests that at least a portion of it may have been transported in seiche flow from Lake Beauclair.

Hydraulic dredging was recently conducted in Lake Beauclair to remove a large nutrient-rich sediment deposit causing navigational impairment at the end of the Apopka-Beauclair Canal. This project appears to have resulted in beneficial water quality impacts in both Lakes Beauclair and Carlton. The sediment in Lake Carlton is deep enough that it does not cause navigational problems and removal is evaluated primarily on impacts to water quality and habitat improvement.

7.2.3.1 *Description*

Sediment removal of this scale requires the use of hydraulic dredging equipment and pumps to transport material from one location to another. Hydraulic dredging was utilized effectively for the Lake Beauclair Aquatic Enhancement project and the spoil material was used for beneficial restoration purposes in the Lake Apopka North Shore. This resulted in a highly efficient sediment removal rate as it did not require dewatering.

The most significant challenge associated with dredging projects is typically the selection of a disposal area. If the material needs to be dewatered in a confined material management area (CMMA) and trucked to the ultimate disposal area, this adds considerable cost.

7.2.3.2 *Efficiency*

Dredging projects such as the Lake Beauclair Aquatic Enhancement project near the Lake Apopka North Shore have a significant cost advantage over other typical dredging projects since there are certain areas within the 20,000 acres of former farmland that benefit from placement of organic material. Although the material must be pumped several miles, there is no need to operate costly dewatering facilities or move the material to a final disposal location once it has been dewatered.

The center of Lake Carlton is approximately one mile from the outer dredge boundary of the Lake Beauclair Aquatic Enhancement project. It would be possible to design a similar dredge project for Lake Carlton where the organic sediments are placed within the Lake Apopka North Shore. The original disposal area, known as the F and G Cells, previously utilized for the Lake Beauclair Aquatic Enhancement project is currently being utilized for other Lake Apopka sediment removal projects. These areas may not be available for Lake Carlton, but they are utilized here for the purposes of cost estimating.

Like the sediment nutrient inactivation alternatives, dredging addresses a portion of in-lake loading which is not considered in the TMDL loading model or the nutrient model developed for this study. Reducing internal loading by dredging may accelerate water quality improvements.

7.2.3.3 *Costing*

Dredge projects can vary widely in the cost per cubic yard of material removed. Depending on the project scale and dewatering needs, the cost can range between $10 and $100 per cubic yard. The dredge project in Lake Beauclair removed slightly over one million cubic yards of material and cost approximately $11 million or $11 per cubic yard including all construction project expenses (Ron Mincey personal communication). Engineering, permitting, and project management added approximately $2 million to the project total.

Total soft sediment volume in Lake Carlton is estimated to be 2.57 million cubic yards. It is not likely financially feasible to remove all this material. Using the phosphorus speciation data produced in this study, it is assumed that approximately 25% of the sediment, or 640,000 cubic yards was transported from Lake Beauclair and is higher in nutrient content than the native Lake Carlton sediment. It is assumed that all soft sediment within the affected quadrant would be removed. If this alternative is pursued, the exact locations and target bottom elevations for selective dredging should be defined through additional core sampling and sediment characterization.
Total cost for removal of 25% of the total soft sediment in Lake Carlton is expected to range between $15 and $20 per cubic yard or between $9.6 million and $12.8 million plus an estimated $1.2 million design and permitting cost. **Table 7-6** provides an itemized list of implementation costs, while **Table 7-8** provides a comparison of the costs associated with this alternative to the other alternatives for Lake Carlton.

7.3 Non-Structural Alternatives

7.3.1 Alternative 7 – Homeowner Education

OCEPD is actively participating in homeowner education throughout the county and should work to focus specifically on the Lake Carlton basin. Community outreach and education are vital components of any stormwater management plan, as the originating source for a great deal of these pollutants are residents, agricultural operators, lawn maintenance companies, and other individuals who may lack understanding or knowledge of the potentially deleterious impact their actions or habits have on local waterbodies. The primary remedy is to implement a well-conceived public education program that persuades citizens that they have a valuable role in the maintenance of the water quality within their community, and teaches practices to minimize or eliminate the sources of pollution. The program should be creative, convey a consistent message, and be sustainable over a period of time. In addition, the education program may be supplemented with an incentive program to encourage and facilitate community members in implementing site specific solutions to non-point source pollution and water quality problems.

Orange County recently implemented Ordinance No. 2017-14 which supersedes the prior fertilizer ordinance and places additional restrictions on the application of fertilizer throughout the County (http://www.orangecountyfl.net/Portals/0/Library/Environment/docs/Revised%20Fertilizer%20Management%20Ordinance%202017-14.pdf). The focus is mainly on reducing nitrogen loading in response to the 2016 Springs and Aquifer Protection Act, but the ordinance also prohibits the application of fertilizers containing phosphorus on residential property unless a phosphorus deficiency is proven. Still, many homeowners are not aware of the ordinance and the information is not widely available from retail suppliers. Furthermore, much of the area within the Lake Carlton basin is agricultural and exempt from the new ordinance. Therefore, the managers of the agricultural areas should be directed to the agricultural BMP enrollment program.

In addition to the measures prescribed in the ordinance, a wide range of BMPs are available as guidelines for homeowners and others involved in turf grass maintenance. Exemplary BMP information is available from:

The Florida Yards & Neighborhoods (FYN) program, an educational outreach program of UF/IFAS Extension (http://hort.ufl.edu/fyn/); the FYN Handbook (FYN, 2003); and FDEP's Non-Point Source Management website and specifically the Florida Green Industries: BMPs for Protection of Water Resources in Florida developed jointly by the Florida Green Industries, FDEP, FDACS, DCA, water management districts, and UF (Florida Green Industries, 2002) http://www.dep.state.fl.us/water/nonpoint/pubs.htm.

Information for professional lawn care service providers is also available from diverse sources including industry associations such as the Florida Turfgrass Association (http://www.ftga.org/index.html).

The primary sources of guidance used by most residential fertilizer users are package labels; advice by family, friends and neighbors; and information from retail sources of the product (see Israel and Knox, 2001). More effective public education programs should be implemented to increase citizens' understanding of the FYN Program, residential turfgrass BMPs, and their importance to Florida's environment. A potential funding source for enhanced community awareness programs could include a dedicated tax on fertilizer sales. Completion of UF/IFAS certified training could be a criterion for exempting the fertilizer purchaser from the fertilizer tax.

Both rain sensors and soil moisture sensors, if used properly, can facilitate irrigation management, conserve water, and prevent excessive chemical leaching by overriding automatic operation of a sprinkler system. Furthermore, Florida is the only state in the nation with an overall rain sensor statute. Beginning in 1991, this statute applies to all new automatic sprinkler systems: "Any person who purchases and installs an automatic lawn sprinkler system after May 1, 1991, shall install, and must maintain and operate a rain sensor device or switch that will override the irrigation cycle of the sprinkler system when adequate rainfall has occurred" (Florida Statute 373.662). This requirement was intended to conserve water. However, avoiding overwatering clearly will have additional benefits in preventing nutrient runoff and leaching to groundwater. Consequently, enhancements of the state and/or County's approach to encouraging sensor-controlled irrigation may be warranted. One potential enhancement could be the provision of funds for operation of a program to install and maintain sensor-controlled irrigation systems. For example, water supply utilities could administer a program to install and maintain sensor-controlled irrigation systems, targeting large users of irrigation water, regardless of the applicability of the rain sensor statute to that user. Based on industry experience with such systems, providing for routine maintenance would be an important part of such a program.

An estimate of the potential benefit of more widespread adoption of residential turf grass BMPs was developed in a similar study performed by Amec Foster Wheeler (previously MACTEC, 2007) for the SJRWMD. Specifically, it was assumed that use of turf grass BMPs would eliminate specific practices (excess watering, excess fertilization, and/or exclusive use of "fast-release" fertilizer formulations) that were studied by Morton, et al. (1988) and Snyder, et al. (1984). MACTEC (2007) concluded that effective implementation of turf grass BMPs could achieve a 33% reduction in groundwater loadings of TN from residential land uses. Although not specifically addressed by MACTEC (2007), their methodology suggests a similar reduction in stormwater loadings of TN.

7.3.1.1 *Efficiency*

Homeowner education is achieved through mass advertising using primarily television commercials and signage. The cost for these broad-reaching public awareness campaigns is distributed over the entire county and is minimal in any one basin. However, success of these advertising campaigns is difficult to measure on a large scale, and a more targeted approach for this specific basin is recommended. The effort to identify and work with homeowners immediately adjacent to Lakes Carlton and Ola should be focused on minimizing fertilizer application, particularly near the shoreline; importance of maintaining riparian vegetation; and proper septic system maintenance.

7.3.1.2 *Costing*

Orange County is in the process of continuing a comprehensive public outreach program. As part of the new draft BMAP update for the Upper Ocklawaha River Basin, Orange and Lake Counties have been credited with 5 pounds and 1 pound of TP reduction, respectively, or a total of 6% overall loading to the basin. The actual cost is assumed to be approximately $2,500 per year and can easily be incorporated into the lake management plan provided sufficient staffing resources are available. **Table 7-7** provides an itemized list of implementation costs, while **Table 7-8** provides a comparison of the costs associated with this alternative to the other alternatives for Lake Carlton.

7.3.2 Alternative 8 – No-Action (Natural Attenuation) Alternative

7.3.2.1 *Description*

The no action alternative would allow the ongoing restoration activities in Lake Apopka and the NuRF, as well as benefits from dredging in Lake Beauclair, to continue to benefit and presumably improve Lake Beauclair. As discussed previously, these restoration activities are expected to meet the TP TMDL goal for Lake Beauclair. Historic water quality data demonstrates that TP concentration in Lake Carlton is consistently lower than TP concentration in Lake Beauclair and both are approaching their TMDL goals. This may be in large part due to restoration projects upstream of Lake Beauclair and the degree of hydrologic exchange between the two lakes.

7.3.2.2 *Efficiency*

The no-action alternative does not have an associated efficiency.

7.3.2.3 *Costing*

The no-action alternative has no cost.

7.4 Summary of Alternatives

A summary of all evaluated alternatives, including potential TP reductions over 20 years and cost per pound of nutrient removed, is included in **Table 7-8**. Alternatives were ranked based on the cost per pound of reduction and the impact on TMDL loading to Lake Carlton. In-lake alternatives will not receive load reduction credit under the current TMDL, but may improve water quality. Credits for homeowner education have already been credited to Orange and Lake Counties as part of countywide efforts, but should be developed to focus specifically in the Lake Carlton basin.

The modular biofilter discussed as **Alternative 1** would provide a reasonable amount of load reduction in an area where stormwater runoff has a relatively high nutrient concentration. This type of pipe-end treatment is typically what is expected for types of load reduction projects required to achieve the TMDL. While the exfiltration system discussed in **Alternative 2** removes pollutants, the treated area is comparatively small and is not expected to have the same effectiveness as the modular biofilter.

In-lake restoration methods may expedite the restoration of Lake Carlton. However, internal loading or hydrologic exchange with Lake Beauclair were not considered when the TMDL was developed for Lake Carlton. Therefore, it is not likely that load reduction credits will be available for these types of projects.

Water quality data clearly indicates that significant improvements have occurred in Lake Carlton over the past 20 years even though very little has changed in the contributing basins considered by the TMDL. Concurrent improvements in Lake Beauclair have been attributed to upstream restoration projects. Improvements in both lakes suggests that these improvements upstream of Lake Beauclair also positively impact Lake Carlton. Therefore, efforts such as operation of the NuRF which address water quality in Lake Beauclair should also beneficially impact Lake Carlton.

Implementation of **Alternatives 1** (modular biofilter) and **3** (septic conversion) would result in approximately 84% of the required concentration reduction as estimated by the Bathtub nutrient model developed as part of this study. The estimated 77 pounds of annual TP load reduction achieved by these two alternatives would satisfy approximately 26% of the necessary load reduction as indicated in the Ocklawaha River Basin Management Action Plan 2015 Annual Progress Report.

8.0 CONCLUSIONS

Seven alternatives have been evaluated for Lake Carlton including construction of a modular biofilter, basin-specific homeowner education, enhanced NuRF management, sediment nutrient inactivation, dredging, and exfiltration. The no-action alternative was also evaluated.

Water quality trends indicate that Lake Carlton is approaching achievement of the TP TMDL without changes or new BMP implementation within the Lake Carlton basin. Water quality improvements are likely due to interaction with Lake Beauclair which has also been experiencing significant water quality improvements. Lake Beauclair is expected to meet its TP TMDL goal due to ongoing upstream load reductions. The interaction between Lakes Beauclair and Carlton was not evaluated as part of the Lake Carlton TMDL, but it appears to have a significant and positive effect based on the findings of this study. Based on the current trend of TP concentration within both Lakes Carlton and Beauclair, achievement of the 32 µg/L annual mean is possible in both lakes within the next several years and could potentially be attained without further action.

Despite the current trend in Lake Carlton's TP concentration, it is not clear if mean TP concentration will consistently achieve and remain below the 32 µg/L target soon. It is also unclear if achieving the TP TMDL target will be sufficient to improve other water quality parameters such as Secchi depth and chlorophyll-*a*. Therefore, Amec Foster Wheeler recommends that OCEPD and LCWA focus near-term efforts on implementation of Alternatives 1 and 7. Potential TP load reduction could be as high as 7 lb/year for the modular biofilter at a cost of approximately $1,786 per pound of TP removed. The nutrient model developed for this study indicates the modular biofilter could achieve as much as 14% of the required TP concentration reduction. The modular biofilter option would provide comparatively good removal efficiency for a pipe-end BMP and it is the least expensive structural alternative in terms of TP removed per dollar. The cost per pound of TP removed is within the range of completed BMP projects.

Public outreach and homeowner education is a low cost and relatively low effort alternative that may help to reduce nutrient loading in the basin. Both Orange and Lake Counties have already received credit for this effort in the BMAP update, however, a more targeted basin-specific approach should be prepared to focus on the Lake Carlton basin.

Septic systems are estimated to contribute approximately 15% of the total phosphorus load to Lake Carlton. Because few stormwater outfalls exist within the basin, conversion of septic to sewer would remove the largest sources of controllable TP load to Lake Carlton. The draft Upper Ocklawaha BMAP Supplement includes septic conversion as a requirement prior to 2027. This alternative ranks relatively low compared to other alternatives because of its anticipated high cost per pound of phosphorus removed; however, it provides the greatest overall mass removal from an external source. Furthermore, the nutrient model developed as part of this study indicates that approximately 70% of the required TP concentration could be achieved. It is recommended that OCEPD proceed with exploring this alternative in more detail.

In-lake loading and resuspension from nutrient-rich unconsolidated flocculent sediment may play a significant role in the historic water quality problems in Lake Carlton. Lake Carlton sediment chemistry data indicates elevated bioavailable phosphorus concentration which has potential for release over a portion of the lake bottom closest to Lake Beauclair. Sediment nutrient inactivation may expedite water quality improvements within the lake although load reduction credits would not likely be granted because it is an in-lake project. Additional assessment of sediment nutrient flux is recommended prior to implementation of a sediment nutrient inactivation project. Dredging may be beneficial for the lake but it is also an in-lake restoration activity, costly, and could require significant effort to permit.

Limited options exist for additional structural BMPs within the Lake Carlton basin. This is primarily because the area is dominated by rural agricultural and low density residential land uses with sandy soils. Little impervious surface is present within the basin and only a few small outfalls are required at the ends of the roads adjacent to the lake. Three of the ten sub-basins already have significant natural treatment, and runoff generated from the largest sub-basin is primarily discharge from a clean lake with normally low TP concentration. Runoff from the other basins is primarily from overland flow spread out over a wide area.

OCEPD and LCWA should evaluate the water quality within Lake Carlton and Lake Beauclair closely over the next five years to determine whether the current trend in TP concentration is sustained and whether the TMDL is likely to be achieved. Concurrently, it is recommended that OCEPD proceed with implementation of **Alternatives 1** (modular biofilter) and **7** (homeowner education). Water quality improvement in Lake Carlton may be accelerated by implementation of **Alternatives 5A** or **5B** (sediment nutrient inactivation). Additionally, the NuRF may be utilized to provide additional benefits to Lake Carlton although this would likely only be necessary if Lake Beauclair achieves its target TMDL and Lake Carlton does not. Finally, conversion of septic systems within the Lake Carlton basin may provide significant water quality benefits and this alternative should be investigated in further detail.

9.0 REFERENCES

Amec Foster Wheeler, 2016. Lake Butler Sub-Basin 10 Hydrologic / Nutrient Loading Study. Prepared for Orange County Environmental Protection. May 2016.

Amec Foster Wheeler. 2017. Assessment of Permitting and Expanded Dredging Area Options, Task 4-3. Prepared for St. Johns River Water Management District. September 2017

Boniol, D. and J.A. Stokes. 2014. Upper Floridan Aquifer Potentiometric Surface Maps in the St. Johns River Water Management District, Florida, May and September. SJRWMD Publication SJ2014.FS.

Carlson, R.E. 1977. A trophic state index for lakes. *Limnology and Oceanography*. 22:361-369.

Danek, L., T. Barnard, and M. Tomlinson. 1991. Bathymetric and Sediment Thickness Analysis of Seven Lakes in the Upper Ocklawaha River Basin. SJRWMD Special Publication SJ91-SP14.

Deevey, E.S. 1988. Estimation of Downward Leakage in Florida Lakes. *The American Society of Limnology and Oceanography. Limnol Oceanogr 33 (6 part 1) page 1308 – 1320. 1988.*

Environmental Research and Design, Inc. (ERD). 2007. Butler Chain-of-Lakes Hydrologic/Nutrient Budgets and Management Plan. Prepared for Orange County Environmental Protection Division. January 2007.

FDEP. 1996. 305(B) Main Report: 1996 Water-Quality Assessment for the State of Florida. (http://www.seminole.wateratlas.usf.edu/upload/documents/1996_305b.pdf), Accessed April 14, 2010

FDEP. 2002. Rule 62-303: Identification of Impaired Surface Waters. (http://www.dep.state. fl.us/ legal/Rules/shared/62-303/62-303.pdf), Accessed April 11, 2010

FDEP. 2006. Total Maximum Daily Loads (TMDL) Protocol Version 6.0 Task Assignment 003.03/05-003.

FDEP. 2010. Environmental Resource Permit Stormwater Quality Applicant's Handbook. March 2010 Draft.

Fulton, R. 1995. External Nutrient Budget and Trophic State Modeling for Lakes in the Upper Ocklawaha River Basin. SJRWMD Publication SJ95-6.

Geosyntec Consultants, 2017. Bay Lake Stormwater Retrofit. Prepared for Orange County Environmental Protection. August 2017.

Israel, G. D. and G. W. Knox. 2001. Reaching diverse homeowner audiences with environmental landscape programs: Comparing lawn service users and nonusers. AEC363. Gainesville: University of Florida Institute of Food and Agricultural Sciences. http://edis.ifas.u-fl.edu/wc044

Lee DR. 1977. A device for measuring seepage flux in lakes and estuaries. Limnology and Oceanography 22(1):140-147.

Littler, W. F, 1976. *Hydrologic relations between lakes and aquifers in a recharge area near Orlando, Florida.* USGS Water Resources Investigation 76-65. August 1976

MACTEC, 2007. Phase I Report Wekiva River Basin Nitrate Sourcing Study. Prepared for SSJRWMD and FDEP. March 2007.

Magley, W. 2004. Total Maximum Daily Load for Total Phosphorus for Lake Carlton. Lake County, Florida. Florida Department of Environmental Protection. March 3, 2004.

Mincey, R. 2017. Personal communication. Jahna Dredging, Inc.

Morton, T. G., A. J. Gold, and W. M. Sullivan. 1988. “Influence of Overwatering and Fertilization on Nitrogen Losses from Home Lawns.” Journal of Environmental Quality. Vol. 17, No. 1, pp 124-130.

Natural Resources Conservation Service (NRCS). 2012. *Soil Survey Geographic Database for Orange County, FL. 2012.*

Orange County Property Appraiser. 2017. http://www.ocpafl.org/. Accessed October 2017.

Ohrel, R. 2000. Simple and Complex Stormwater Pollutant Load Models Compared. In *The Practice of Watershed Protection*, editors Thomas R. Schueler and Heather K. Holland, published by the Center for Watershed Protection, Ellicott City, MD.

Schueler, T. R.: 1987, Controlling urban runoff: A practical manual for planning and designing urban BMPs, Washington Metropolitan Water Resources Planning Board, July. Google Scholar

St. Johns River Water Management District (SJRWMD) 2009 Land Use and Land Cover

Snyder, G. H., B. J. Augustin, and J. M. Davidson. 1984. “Moisture Sensor-Controlled Irrigation for Reducing N Leaching in Bermudagrass Turf.” Agronomy Journal, Vol 76, pp. 964-969.

United States Department of Agriculture (USDA). 1986. *Urban hydrology for small watersheds*. Technical Release 55 (TR-55) (Second Edition ed.). Natural Resources Conservation Service, Conservation Engineering Division. ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf.

United States Environmental Protection Agency (USEPA). 2011. National Menu of Stormwater Best Management Practices. http://cfpub1.epa.gov/npdes/stormwater/menuofbmps/index.cfm.

Walker, W. W. 2004. BATHTUB – Version 6.1. Developed for USAE Waterways Experiment Station, Vicksburg, MS. April 2004.

Water Atlas. 2017. Orange County Water Atlas. Available at: http://www.orange.wateratlas.usf.edu/

TABLES

Table 3-1
Sub-basin Area

Basin Name	Area (acres)
1	26.03
2	129.06
3	142.79
4	341.18
5	77.05
6	278.94
7	64.81
8	18.01
9	390.32
Lake Carlton Direct Subtotal	**1,468.18**
Lake Ola (10)	1,629.59
Combined Total	**3,097.77**

Table 3-2
Landuse for Lake Carlton Contribution Basins

FLUCCS: Landuse Description	Area (acres)	%
5200: LAKES	499.07	33.99
2210: CITRUS GROVES	346.13	23.58
1100: RESIDENTIAL, LOW DENSITY - LESS THAN 2 DWELLING UNITS/ACRE	213.37	14.53
2150: FIELD CROPS	109.76	7.48
2430: ORNAMENTALS	57.43	3.91
6300: WETLAND FORESTED MIXED	52.78	3.59
2120: UNIMPROVED PASTURES	28.89	1.97
2140: ROW CROPS	26.65	1.81
2110: IMPROVED PASTURES (MONOCULT, PLANTED FORAGE CROPS)	22.25	1.52
4340: UPLAND MIXED CONIFEROUS/HARDWOOD	19.77	1.35
6460: MIXED SCRUB-SHRUB WETLAND	16.25	1.11
1800: RECREATIONAL	15.10	1.03
1180: RESIDENTIAL, RURAL - ONE UNIT ON 2 OR MORE ACRES	14.08	0.96
2510: HORSE FARMS	11.34	0.77
2400: NURSERIES AND VINEYARDS	10.78	0.73
3100: HERBACEOUS UPLAND NONFORESTED	10.49	0.71
6430: WET PRAIRIES	4.32	0.29
1700: INSTITUTIONAL	4.19	0.29
4410: PINE PLANTATION	2.82	0.19
1850: PARKS AND ZOOS	1.27	0.09
6410: FRESHWATER MARSHES	0.92	0.06
1200: RESIDENTIAL, MEDIUM DENSITY - 2-5 DWELLING UNITS/ACRE	0.37	0.03
6440: EMERGENT AQUATIC VEGETATION	0.18	0.01
Total	**1,468.19**	**100**

Table 3-3
Landuse for Lake Ola Contribution Basins

FLUCCS: Landuse Description	Area (acres)	%
5200: LAKES	427.23	26.22
1100: RESIDENTIAL, LOW DENSITY - LESS THAN 2 DWELLING UNITS/ACRE	361.81	22.20
1200: RESIDENTIAL, MEDIUM DENSITY - 2-5 DWELLING UNITS/ACRE	232.67	14.28
2210: CITRUS GROVES	142.21	8.73
4410: PINE PLANTATION	130.17	7.99
4340: UPLAND MIXED CONIFEROUS/HARDWOOD	89.63	5.50
6300: WETLAND FORESTED MIXED	40.98	2.51
2150: FIELD CROPS	33.47	2.05
2430: ORNAMENTALS	26.33	1.62
2110: IMPROVED PASTURES (MONOCULT, PLANTED FORAGE CROPS)	24.64	1.51
1190: LOW DENSITY UNDER CONSTRUCTION	24.05	1.48
2120: UNIMPROVED PASTURES	18.10	1.11
6410: FRESHWATER MARSHES	17.74	1.09
8140: ROADS AND HIGHWAYS (DIVIDED 4-LANES WITH MEDIANS)	15.83	0.97
3100: HERBACEOUS UPLAND NONFORESTED	13.80	0.85
3300: MIXED UPLAND NONFORESTED	12.72	0.78
5300: RESERVOIRS - PITS, RETENTION PONDS, DAMS	5.48	0.34
3200: SHRUB AND BRUSHLAND (WAX MYRTLE OR SAW PALMETTO, OCCASIONALLY SCRUB OAK)	4.90	0.30
1700: INSTITUTIONAL	2.45	0.15
2240: ABANDONED TREE CROPS	1.95	0.12
6460: MIXED SCRUB-SHRUB WETLAND	1.24	0.08
6170: MIXED WETLAND HARDWOODS	0.94	0.06
8370: SURFACE WATER COLLECTION BASINS	0.91	0.06
6440: EMERGENT AQUATIC VEGETATION	0.32	0.02
Total	**1,629.59**	**100**

Table 3-4
Landuse for Lake Carlton and Lake Ola Contribution Basins

FLUCCS: Landuse Description	Area (acres)	%
5200: LAKES	926.30	29.90
1100: RESIDENTIAL, LOW DENSITY - LESS THAN 2 DWELLING UNITS/ACRE	575.18	18.57
2210: CITRUS GROVES	488.34	15.76
1200: RESIDENTIAL, MEDIUM DENSITY - 2-5 DWELLING UNITS/ACRE	233.04	7.52
2150: FIELD CROPS	143.23	4.62
4410: PINE PLANTATION	132.99	4.29
4340: UPLAND MIXED CONIFEROUS/HARDWOOD	109.39	3.53
6300: WETLAND FORESTED MIXED	93.76	3.03
2430: ORNAMENTALS	83.76	2.70
2120: UNIMPROVED PASTURES	46.99	1.52
2110: IMPROVED PASTURES (MONOCULT, PLANTED FORAGE CROPS)	46.90	1.51
2140: ROW CROPS	26.65	0.86
3100: HERBACEOUS UPLAND NONFORESTED	24.30	0.78
1190: LOW DENSITY UNDER CONSTRUCTION	24.05	0.78
6410: FRESHWATER MARSHES	18.66	0.60
6460: MIXED SCRUB-SHRUB WETLAND	17.50	0.56
8140: ROADS AND HIGHWAYS (DIVIDED 4-LANES WITH MEDIANS)	15.83	0.51
1800: RECREATIONAL	15.10	0.49
1180: RESIDENTIAL, RURAL - ONE UNIT ON 2 OR MORE ACRES	14.08	0.45
3300: MIXED UPLAND NONFORESTED	12.72	0.41
2510: HORSE FARMS	11.34	0.37
2400: NURSERIES AND VINEYARDS	10.78	0.35
1700: INSTITUTIONAL	6.63	0.21
5300: RESERVOIRS - PITS, RETENTION PONDS, DAMS	5.48	0.18
3200: SHRUB AND BRUSHLAND (WAX MYRTLE OR SAW PALMETTO, OCCASIONALLY SCRUB OAK)	4.90	0.16
6430: WET PRAIRIES	4.32	0.14
2240: ABANDONED TREE CROPS	1.95	0.06
1850: PARKS AND ZOOS	1.27	0.04
6170: MIXED WETLAND HARDWOODS	0.94	0.03
8370: SURFACE WATER COLLECTION BASINS	0.91	0.03
6440: EMERGENT AQUATIC VEGETATION	0.50	0.02
Total	**3,097.78**	**100**

Table 3-5
Soils Summary for Lake Carlton Basin

Hydrologic Soil Group	Area (acres)	%
A	1,726.41	55.73
W	928.59	29.98
A/D	350.14	11.30
B/D	49.61	1.60
D	41.10	1.33
B	1.93	0.06
Total	**3,097.78**	**100**

Table 4-1
Estimated Monthly Inputs from Direct Precipitation to Lake Carlton (1995 – 2013)

Month	Average Monthly Rainfall (inches)	Average Monthly Contribution to Lake (ac-ft)
Jan	2.19	70.04
Feb	2.24	71.57
Mar	3.43	109.90
Apr	1.87	59.79
May	2.98	95.35
Jun	6.72	215.09
Jul	6.69	213.98
Aug	7.32	234.32
Sep	5.31	170.02
Oct	2.87	91.79
Nov	1.28	41.08
Dec	2.48	79.34
Annual	**45.38**	**1452.28**

Table 4-2
Estimated Monthly Inputs from Direct Precipitation to Lake Ola (1995 – 2013)

Month	Average Monthly Rainfall (inches)	Average Monthly Contribution to Lake (ac-ft)
Jan	2.19	80.08
Feb	2.24	81.82
Mar	3.43	125.65
Apr	1.87	68.35
May	2.98	109.01
Jun	6.72	245.89
Jul	6.69	244.63
Aug	7.32	267.88
Sep	5.31	194.37
Oct	2.87	104.94
Nov	1.28	46.97
Dec	2.48	90.70
Annual	**45.38**	**1660.29**

Table 4-3
Estimated Sub-Basin Stormwater Runoff

Sub-Basin	Annual Basin Runoff (ac-ft)	% Contribution
1	32.69	2.6
2	55.71	4.5
3	57.11	4.6
4	259.39	20.8
5	36.89	3.0
6	111.76	9.0
7	24.97	2.0
8	11.43	0.9
9	26.60	2.1
10	629.00	50.5
Total	**1,245.55**	**100**

Note: 10 is the contribution basin for Lake Ola

Table 4-4
Hydrologic Inputs to Lake Ola

Hydrologic Input	ac-ft/yr	% Input
Direct Precipitation	1,660	70.3
Stormwater Runoff	700	29.7
Groundwater Seepage	0	0.0
Total	**2,360**	**100.0**

Table 4-5
Hydrologic Losses from Lake Ola

Hydrologic Output	ac-ft/yr	% Output
Evaporation	1,731	73.3
Discharge	629	26.7
Groundwater Recharge	0	0.0
Total	**2,360**	**100.0**

Table 4-6
Hydrologic Inputs to Lake Carlton

Hydrologic Input	ac-ft/yr	% Input
Direct Precipitation	1,452	48.7
Stormwater Runoff	863	29.0
Tributary Inflow	629	21.1
Groundwater Seepage	35	1.2
Total	**2,979**	**100.0**

Table 4-7
Hydrologic Loses from Lake Carlton

Hydrologic Output	ac-ft/yr	% Output
Evaporation	1,566	52.6
Discharge	1,413	47.4
Groundwater Recharge	0	0.0
Total	**2,979**	**100.0**

Table 5-1
Mean Autosampler Water Quality Data

Station	TAN (µg/L)	$NO_2 + NO_3$ (µg/L)	TKN (µg/L)	TN (µg/L)	OP (µg/L)	TP (µg/L)	TSS (µg/L)	Specific Conductance (µS/cm)	pH	Total Alkalinity as CaCO3 (µg/L)	Turbidity (NTU)
Earlwood	350	1,250	2,750	3,990	550	0.63	3,613	848.50	7.07	2,750	7.25
Horseshoe	80	30	1,880	1,890	10	50	1,125	426.25	7.21	5,125	8.14
Ola	230	470	2,210	2,670	70	270	2,756	243.75	7.03	3,175	19.28

Table 5-2
Composite EMCs by Sub-Basin

Sub-basin	Basin Composite TN EMC (µg/L)	Basin Composite TP EMC (µg/L)	Basin Composite TSS EMC (mg/L)
1	1,230	120	14.00
2	2240	250	22.31
3	1840	210	22.76
4	1830	60	10.71
5	1830	60	10.71
6	1830	60	10.71
7	1840	170	21.57
8	1200	70	9.52
9	1470	100	9.46
10	700	10	0.24

Note: Blue shading indicates EMCs were derived using site-specific data

Table 5-3
Lake Carlton Seepage Data

Collection Date	Mean NH_4^+ (µg/L)	Mean NO_x (µg/L)	Mean TKN (µg/L)	Mean TN (µg/L)	Mean OP (µg/L)	Mean TP (µg/L)	Mean Specific Conductance (µS/cm)	Mean pH	Mean Seepage Flow rate (l/m^2-day)	Mean TN Seepage Load (mg/m^2-day)	Mean TP Seepage Load (mg/m^2-day)
6/30/2016	740	20	4,810	4,810	80	290	259.75	7.15	0.14	0.60	0.03
8/29/2016	3,040	20	6,730	6,730	20	370	337.14	7.10	0.28	2.24	0.11
11/2/2016	11,520	870	16,620	16,950	200	510	438.33	7.37	0.26	3.84	0.09
12/21/2016	11,060	830	14,470	15,300	200	860	383.33	7.14	0.41	7.84	0.34
2/20/2017	5,700	1,300	9,450	10,670	100	490	378.33	6.77	0.35	4.94	0.21
4/21/2017	5,800	200	8,420	8,620	50	340	358.00	7.21	1.66	13.65	0.69

Table 5-4
Pollutant Loading by Sub-Basin

Sub-Basin	Estimated Existing Annual TN Load (lb)	% of Load	Estimated Existing Annual TP Load (lb)	% of Load	Estimated Existing Annual TSS Load (lb)	% of Load
1	109.24	2.6	10.22	5.7	1244.14	5.5
2	338.88	8.0	37.80	21.1	3379.75	15.0
3	286.48	6.8	32.56	18.2	3535.29	15.7
4	1289.10	30.5	39.98	22.3	7553.33	33.6
5	183.44	4.3	5.69	3.2	1074.85	4.8
6	555.80	13.1	17.24	9.6	3256.66	14.5
7	124.86	3.0	11.28	6.3	1464.78	6.5
8	37.27	0.9	2.11	1.2	295.99	1.3
9	106.67	2.5	7.02	3.9	295.99	1.3
10	1197.48	28.3	15.40	8.6	402.06	1.8
Total	**4229.22**	**100.00**	**179.31**	**100.00**	**22502.84**	**100.0**

Table 5-5
Orange and Lake County Loading Contributions to Sub-Basins 1, 3, and 4

Sub-Basin	County	TP (lb/yr)	TN (lb/yr)	TSS (lb/yr)
1	Lake	0.9	11.7	104.1
	Orange	9.31	97.51	1140.1
3	Lake	0.6	6.1	78.6
	Orange	31.9	280.4	3456.7
4	Lake	17.7	713.6	4209.4
	Orange	22.3	575.5	3343.9

Table 5-6
Lake Carlton Nutrient Budget

Inputs	TP (lb/yr)	%	TN (lb/yr)	%	TSS (lb/yr)	%
Direct rainfall	50	12	1,771	20	0	0
Atmospheric deposition	68	16	505	6	0	0
Surface Runoff	164	39	3,032	34	22,101	98
Tributary Input	15	4	1,197	13	402	2
Septic	67	16	1,190	13	0	0
Seepage	55	13	1,262	14	0	0
Total	**419**	**100**	**8,957**	**100**	**22,503**	**100**

Table 6-1
Lake Carlton Sediment Phosphorus Speciation Data

Sample Site	% Moisture	Bulk Density	Total Phosphorus (mg/kg dry)	Saloid-Bound Phosphorus (mg/kg dry)	Aluminum-Bound Phosphorus (mg/kg dry)	Iron-Bound Phosphorus (mg/kg dry)	Reductant Soluble Phosphorus (mg/kg dry)	Calcium Bound Phosphorus (mg/kg dry)
C1	96.57	0.036	2060	74.0	424	45.1	314	102
C2	93.98	0.064	972	7.4	195	16.3	117	161
C3	92.55	0.079	1390	8.6	224	31.9	96.2	59.9
C4	96.72	0.036	2830	8.0	329	41.5	322	117
C5	92.23	0.086	677	5.4	140	17.2	75.8	48.1
C6	97.51	0.026	1580	6.4	476	38.1	393	294
Mean	94.93	0.055	1585	18.3	220	31.7	298	130.3

Table 7-1. Alternative 1 Modular Biofilter Cost Analysis

Cost Parameter	Cost
Design and Permitting	$30,000
Construction	$100,000
Total Cost to Construct	**$130,000**
Annual O& M	$6,000
Total 20-yr Cost	**$250,000**

Table 7-2. Alternative 2 Exfiltration Cost Analysis

Cost Parameter	Cost
Design and Permitting	$10,000
Construction	$45,000
Total Cost to Construct	**$55,000**
Annual O& M	$1,500
Total 20-yr Cost	**$85,000**

Table 7-3. Alternative 3 Septic Conversion

Cost Parameter	Cost[1]
Design and Permitting	$700,000
Construction	$7,300,000
Total Cost to Construct	**$8,000,000**

[1]Assumes upper range of construction cost and cost of O&M to be included in a utility fee

Table 7-4. Alternative 4 Enhanced NuRF Operation

Cost Parameter	Cost[1]
Additional Alum Cost (annual)	$20,000
Total 20-yr Cost	**$400,000**

[1]Cost of chemical only

Table 7-5A. Alternative 5 Sediment Nutrient Inactivation (Alum Option)

Cost Parameter	Cost
Design	$17,000
Chemical and Application	$143,000
Total Cost to Construct	**$160,000**

Table 7-5B. Alternative 5 Sediment Nutrient Inactivation (Phoslock™ Option)

Cost Parameter	Cost
Design	$20,000
Chemical and Application	$310,000
Total Cost to Construct	**$330,000**

Table 7-6. Alternative 6 Dredging

Cost Parameter	Cost[1]
Design and Permitting	$1,200,000
Construction	$12,800,000
Total Cost to Construct	**$14,000,000**

[1]Assumes upper range of cost

Table 7-7. Alternative 7 Homeowner Education

Cost Parameter	Cost
Marketing Material	$500
Staff Time	$2,000
Total 20-yr Cost	**$50,000**

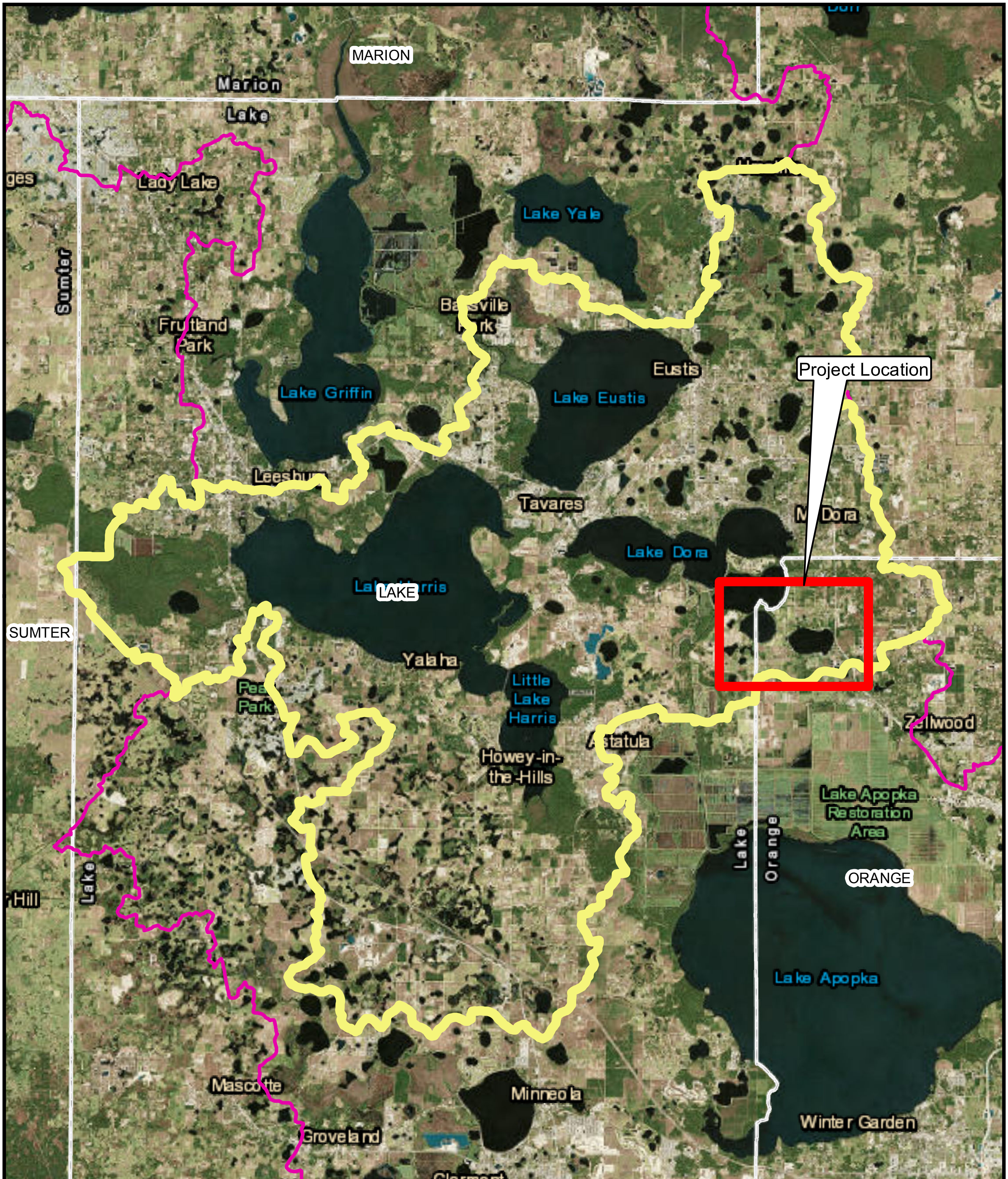
Table 7-8. Alternative Summary for 20-Year Project Life Cycle

Alternative	Estimated Cost	Pounds of TP removed (or inactivated)	Cost per Pound of TP Removed (or inactivated)	Rank
1 – Modular Biofilter	$250,000	140	$1,786	2
2 – Exfiltration	$85,000	7.6	$11,184	8
3 - Septic Conversion	$8,000,000	1,340	$5,970	6
4 – Enhanced NuRF Operation	$400,000	9,000	$44	3
5A – Sediment Nutrient Inactivation (alum)	$160,000	1,540	$104	4
5B – Sediment Nutrient Inactivation (Phoslock™)	$330,000	1,540	$214	5
6 - Dredging	$14,000,000	23,574[A]	$593	7
7 – Homeowner Education	$50,000	120[B]	$416	1

[A] Includes TP mass in top 10 cm of sediment only

[B] Load reduction already credited in BMAP

FIGURES



Notes:

1- Project No.: 600218x9

2- Data Source - SJRWMD

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 8/17/16
Revised: SF
Checked By:

Explanation of Features

N

Lake Harris Planning Basin

Ocklawaha River Basin

County Boundary

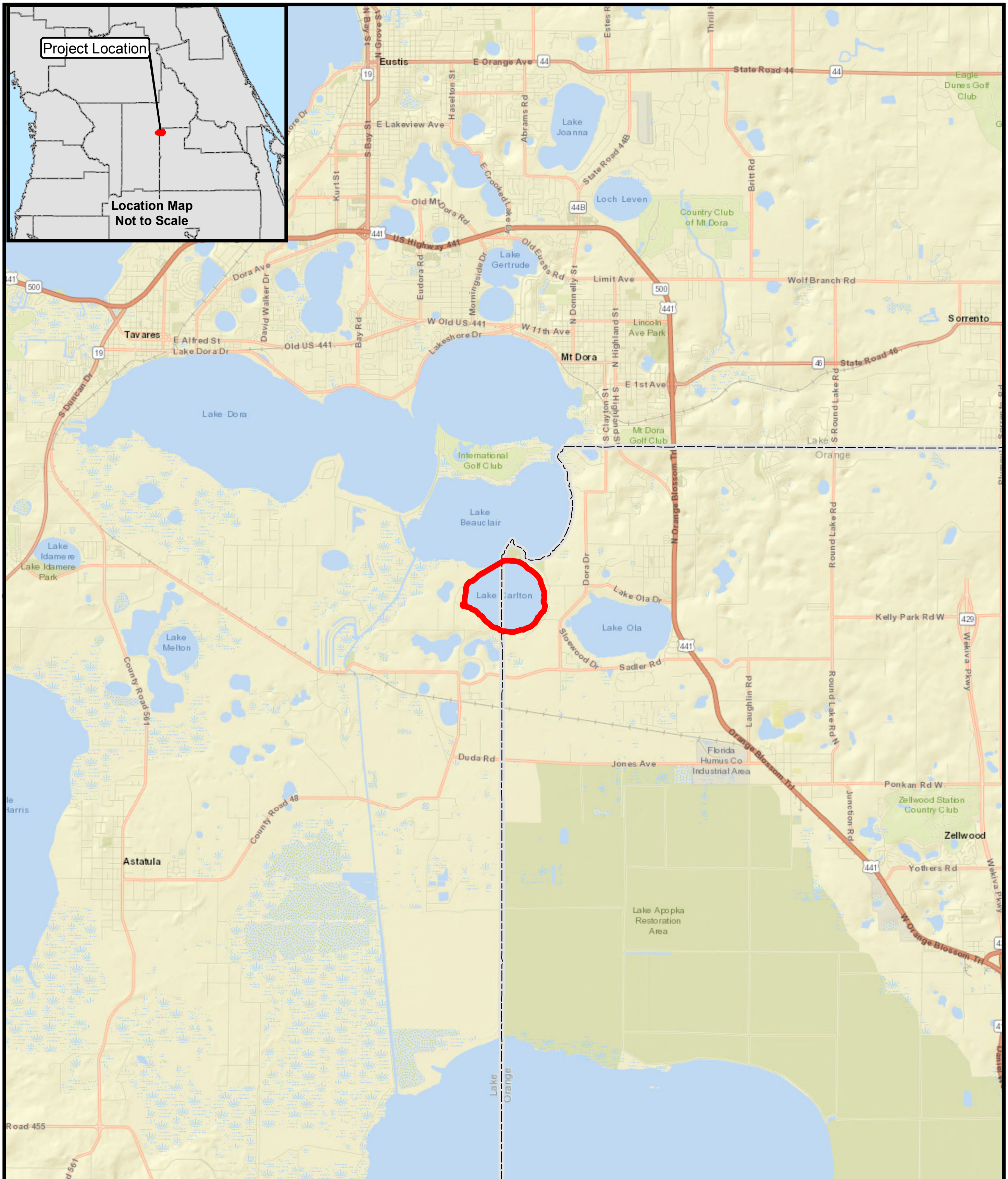
0 2
Miles

amec foster wheeler

Amec Foster Wheeler
Environment & Infrastructure, Inc.
2000 E. Edgewood Drive Ste #215
Lakeland, FL 33803
CA-5392
(863) 667-2345

Figure 1-1
Harris Planning Basin
Project Location
Orange/Lake Counties
Florida

Path: V:\600218x9 Lake Carlton\MXDs\New MXDs\Fig1.1_HarrisPlanningBasinMapv2.mxd



Notes:

1- Project No.: 600218x9

2- Data Source - SJRWMD

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 8/17/16
Revised: SF
Checked By:

Explanation of Features

Lake Carlton

County Boundary

0 1
Miles

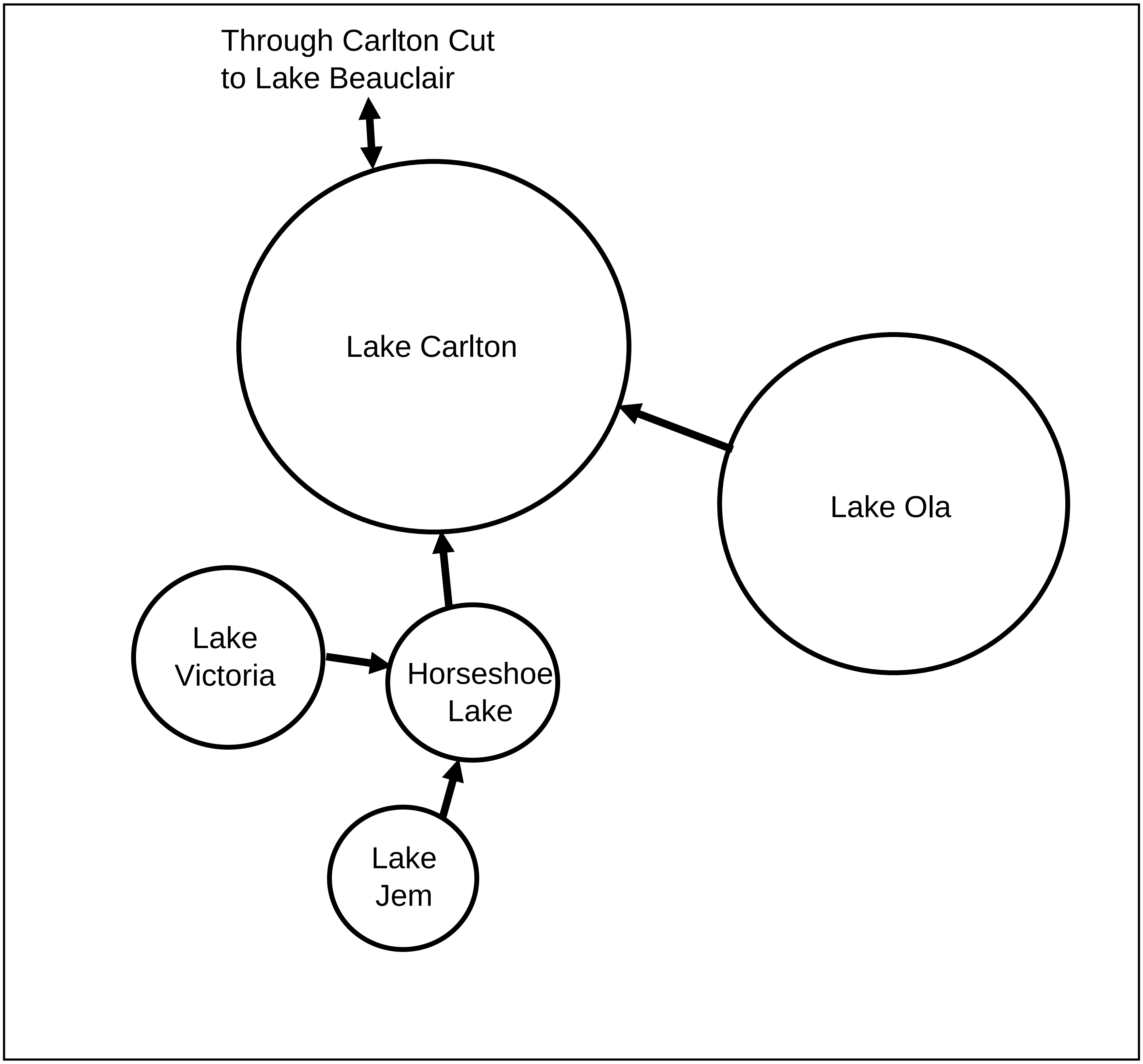
amec foster wheeler

Amec Foster Wheeler
Environment & Infrastructure, Inc.
2000 E. Edgewood Drive Ste #215
Lakeland, FL 33803
CA-5392
(863) 667-2345

Figure 1-2
Location Map
Lake Carlton
Orange/Lake Counties
Florida

Path: V:\600218x9 Lake Carlton\MXDs\New MXDs\Fig1.2_Location Mapv2.mxd

Figure 1-3. Lake Carlton Basin Flow Diagram



Notes:

1- Project No.: 600218x9

2- Data Source - SJRWMD, ESRI 2017 NAIP Imagery, AmecFW

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 8/22/16
Revised: SF
Checked By: AB

Explanation of Features

N

- Lake Carlton Basin
- Lake Ola Basin
- County Boundary

0 1,000
Feet

amec foster wheeler

Amec Foster Wheeler Environment & Infrastructure, Inc.
2000 E. Edgewood Drive Ste #215
Lakeland, FL 33803
CA-5392
(863) 667-2345

Figure 1-4
Lake Carlton Basin Map
Orange/Lake Counties Florida

Path: V:\600218x9 Lake Carlton\MXDs\New MXDs\Fig1-3_Lake Carlton Basin.mxd

Figure 1-5

SJRWMD Dam Structures in the Upper Ocklawaha
(source: SJRWMD)

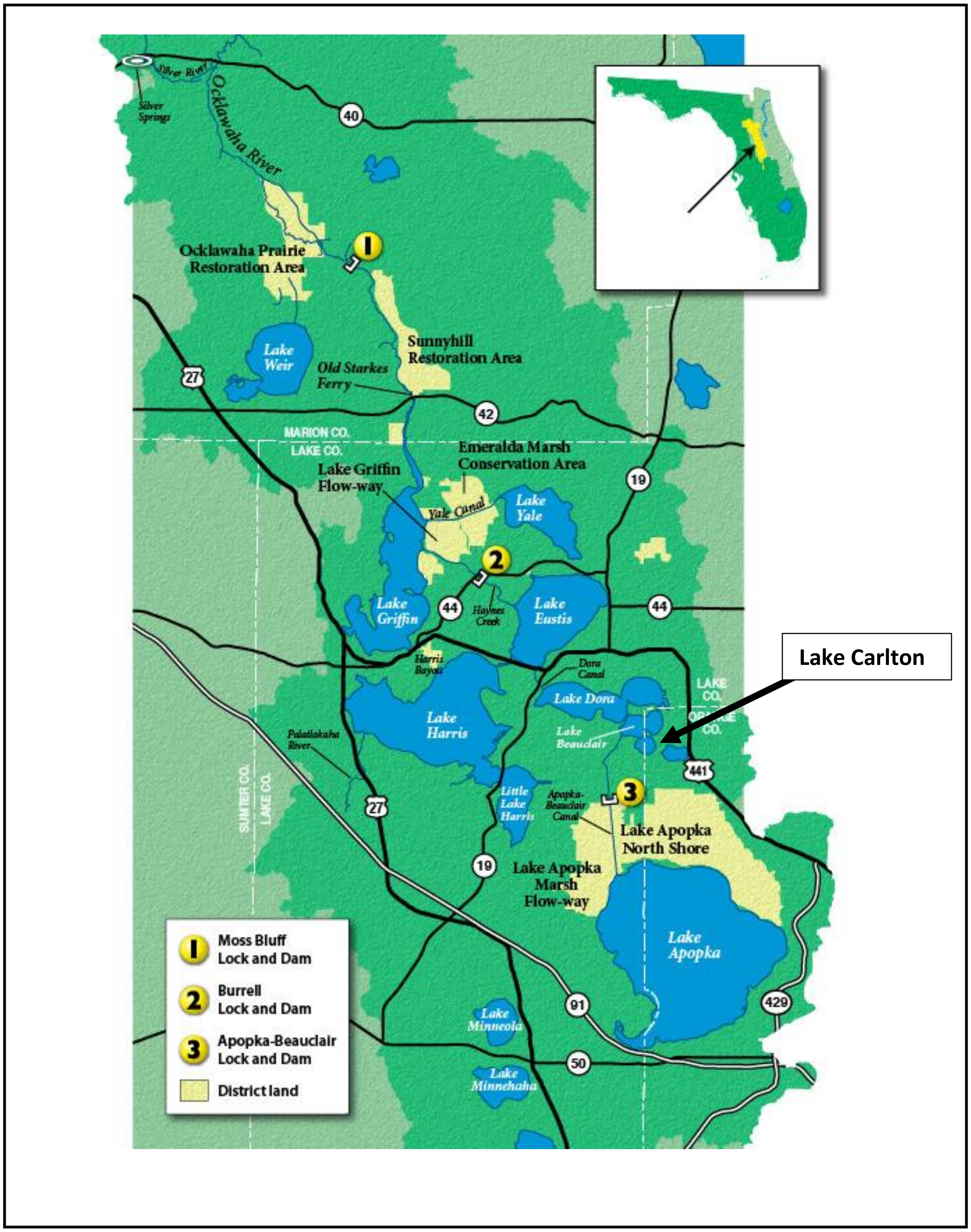
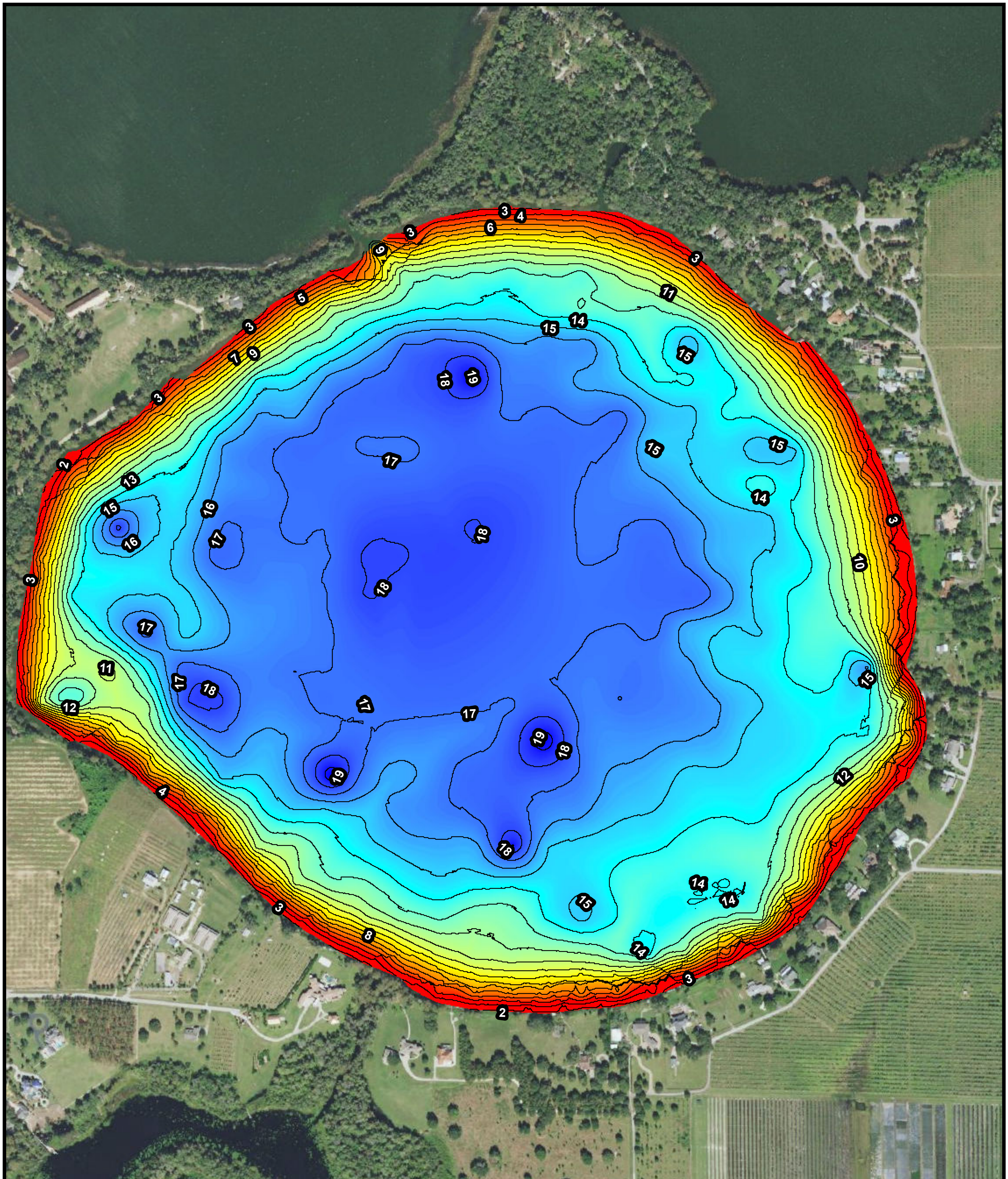


Figure 2-1. 1947 and 2017 aerial photographs of Lake Carlton and Lake Ola



Notes:

1- Project No.: 600218x9

2- Data Source - SJRWMD, ESRI 2017 NAIP Imagery, AmecFW

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 08/30/2017
Revised: AB
Checked By: LL

Explanation of Features

N

Bathymetric Depth Contours

Water Depth DEM (feet)

Deep : 19

Shallow: 2

Surveyed water level: 61.97

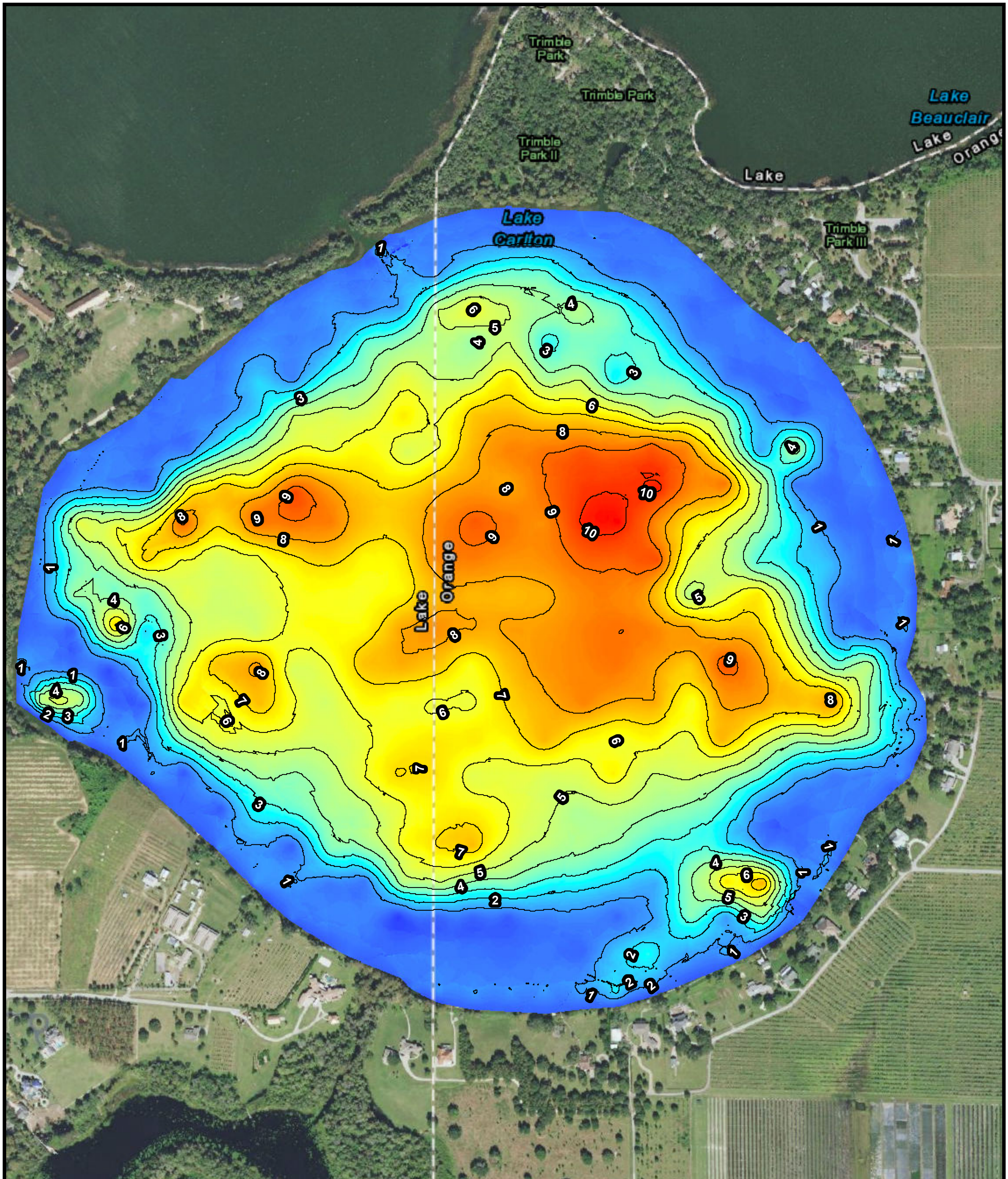
0 600
Feet

amec foster wheeler

Amec Foster Wheeler
Environment & Infrastructure, Inc.
2000 E. Edgewood Drive Ste #215
Lakeland, FL 33803
CA-5392
(863) 667-2345

Figure 2-2
Bathymetric Map
Lake Carlton
Orange/Lake Counties
Florida

Path: V:\600218x9 Lake Carlton\MXDs\New MXDs\Fig2-2_Lake Carlton bathy.mxd



Notes:

1- Project No.: 600218x9

2- Data Source - SJRWMD, ESRI 2017 NAIP Imagery, AmecFW

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 10/27/2016
Revised: AB
Checked By: LL

Explanation of Features

N

Sediment Thickness

—— Sediment Thickness Contour (ft)

DEM (feet)

High : 10.33

Low : 0

0 600
Feet

amec foster wheeler

Amec Foster Wheeler
Environment & Infrastructure, Inc.
2000 E. Edgewood Drive Ste #215
Lakeland, FL 33803
CA-5392
(863) 667-2345

Figure 2-3
Sediment Thickness
Lake Carlton
Orange/Lake Counties
Florida

Path: V:\600218x9 Lake Carlton\MXDs\New MXDs\Fig2-3_Lake Carlton sed_thickness.mxd

Figure 2-4. Lake Carlton Bathymetry 2013 (LCWA)

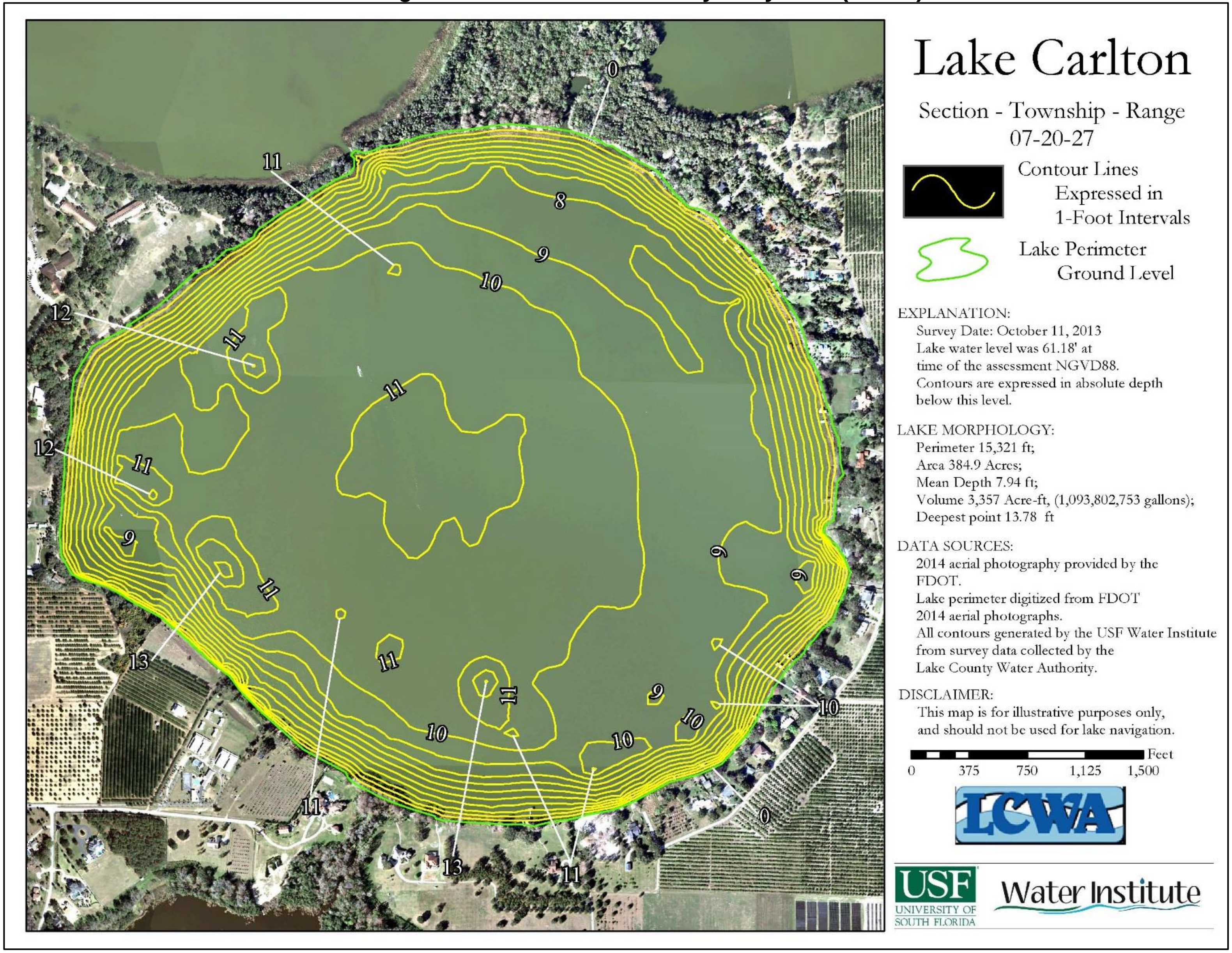


Figure 2-5. TP Concentration in Lake Carlton Surface Water (1997-2016)

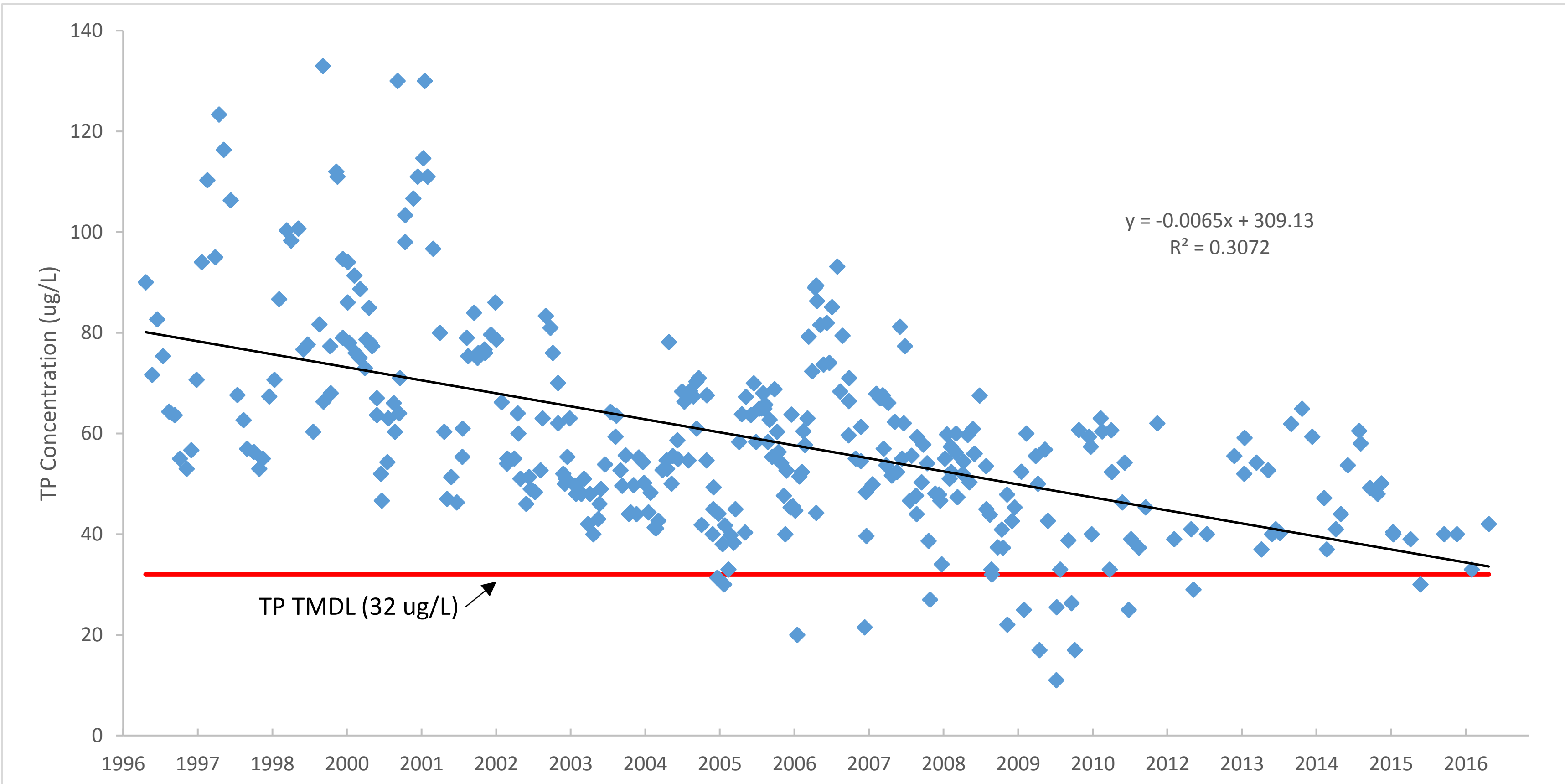


Figure 2-6. Annual Geometric Mean TP Concentration in Lake Carlton Surface Water (1997-2016)

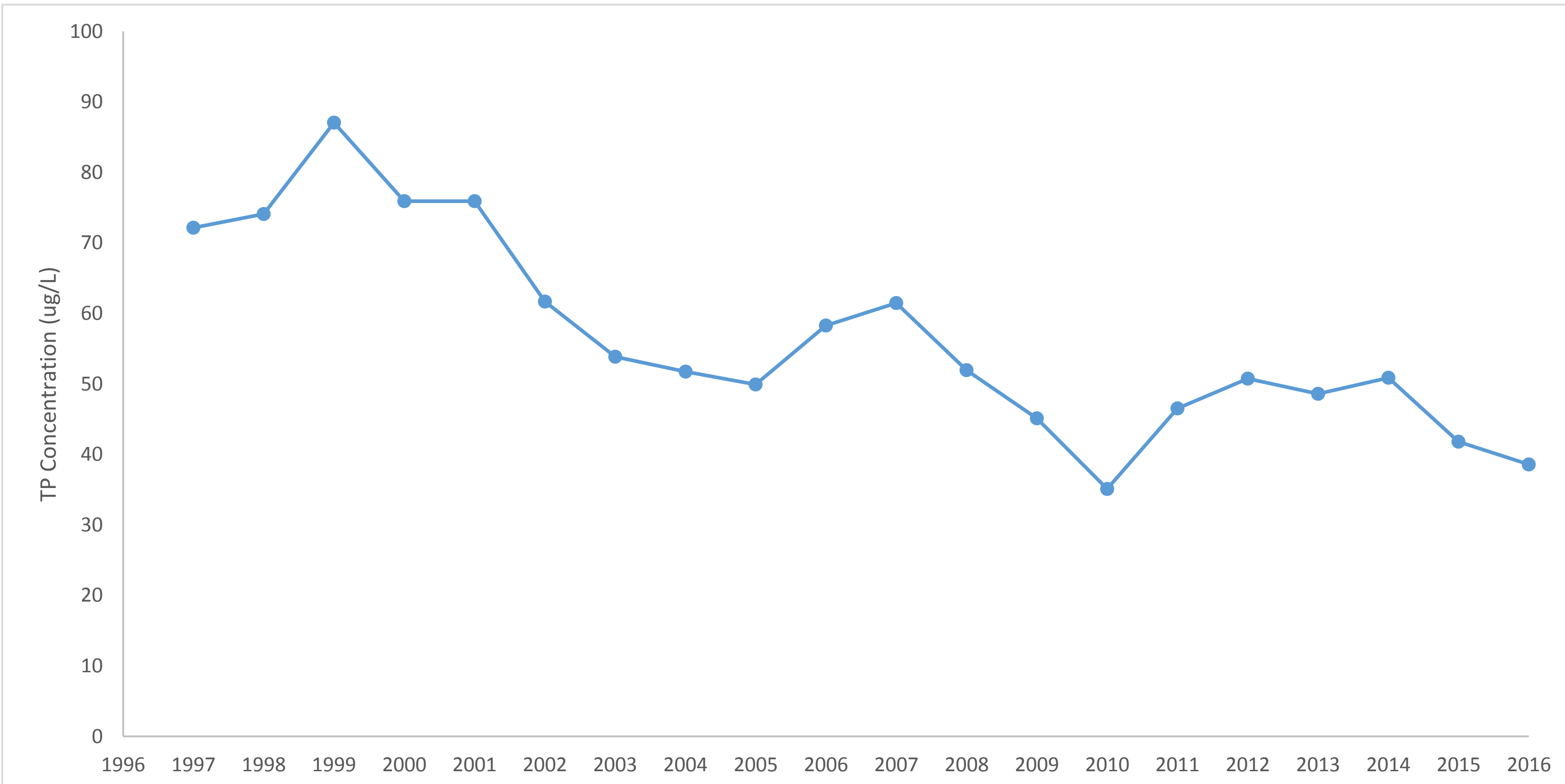
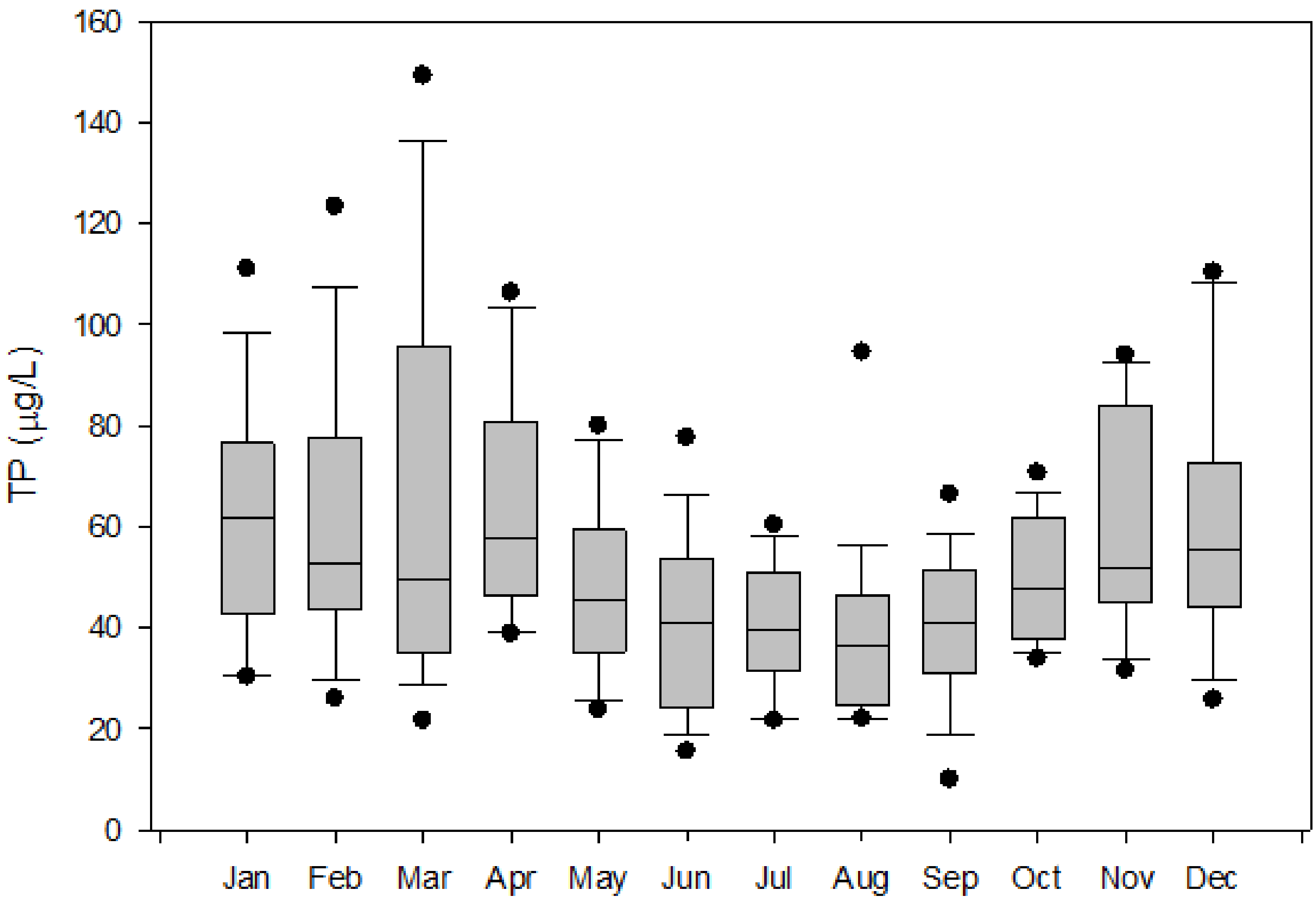


Figure 2-7. Box and Whisker Plot for Monthly TP Concentration in Lake Carlton Surface Water (1997-2016)



Note - Middle line represents median, and boundary of box indicates 25th and 75th percentile. Whiskers indicate 10th and 90th percentiles. Filled in circles represent 5th and 95th percentiles.

Figure 2-8. TN Concentration in Lake Carlton Surface Water (1997-2016)

Figure 2-9. Annual Geometric Mean TN Concentration in Lake Carlton Surface Water (1997-2016)

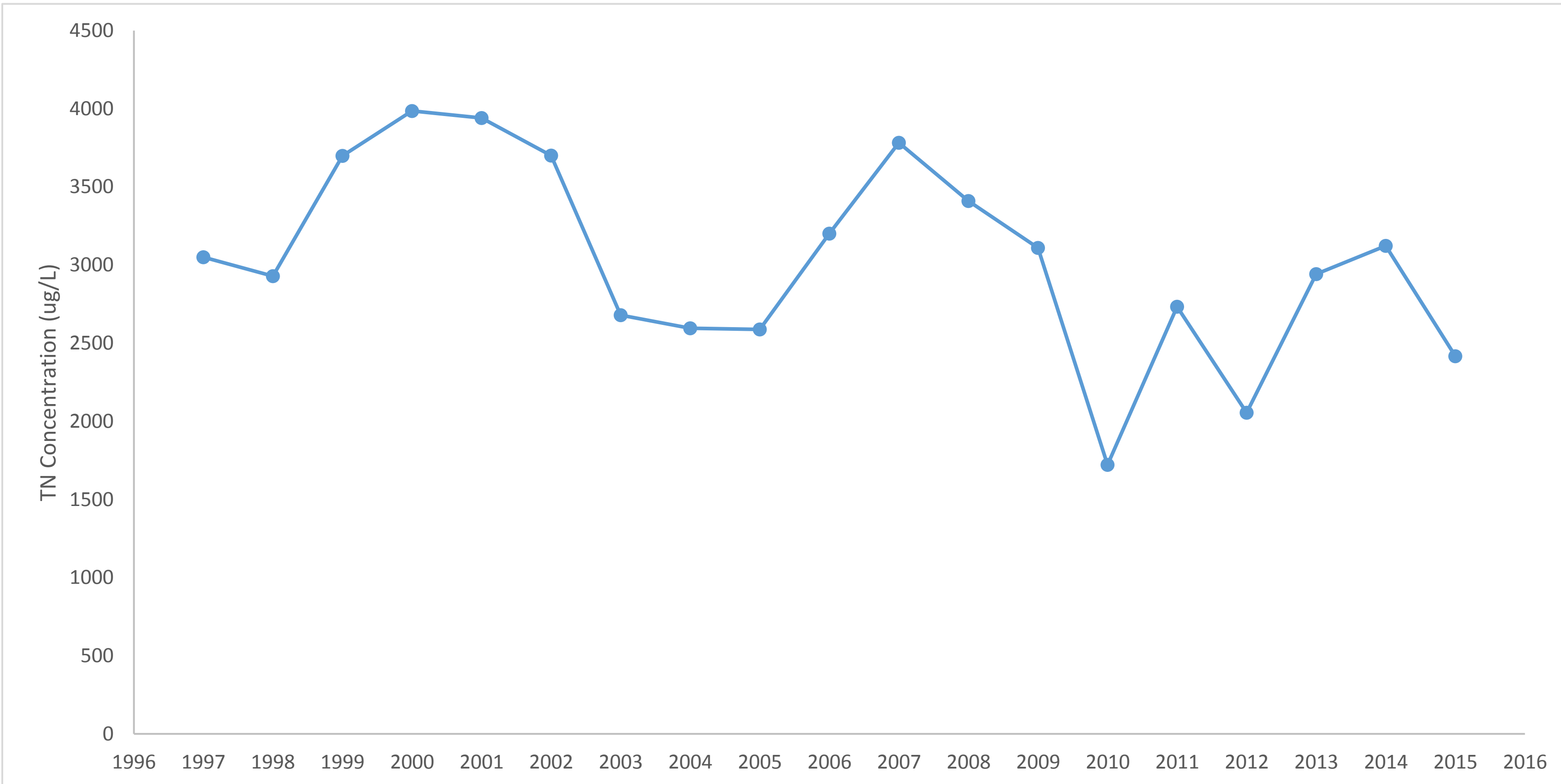
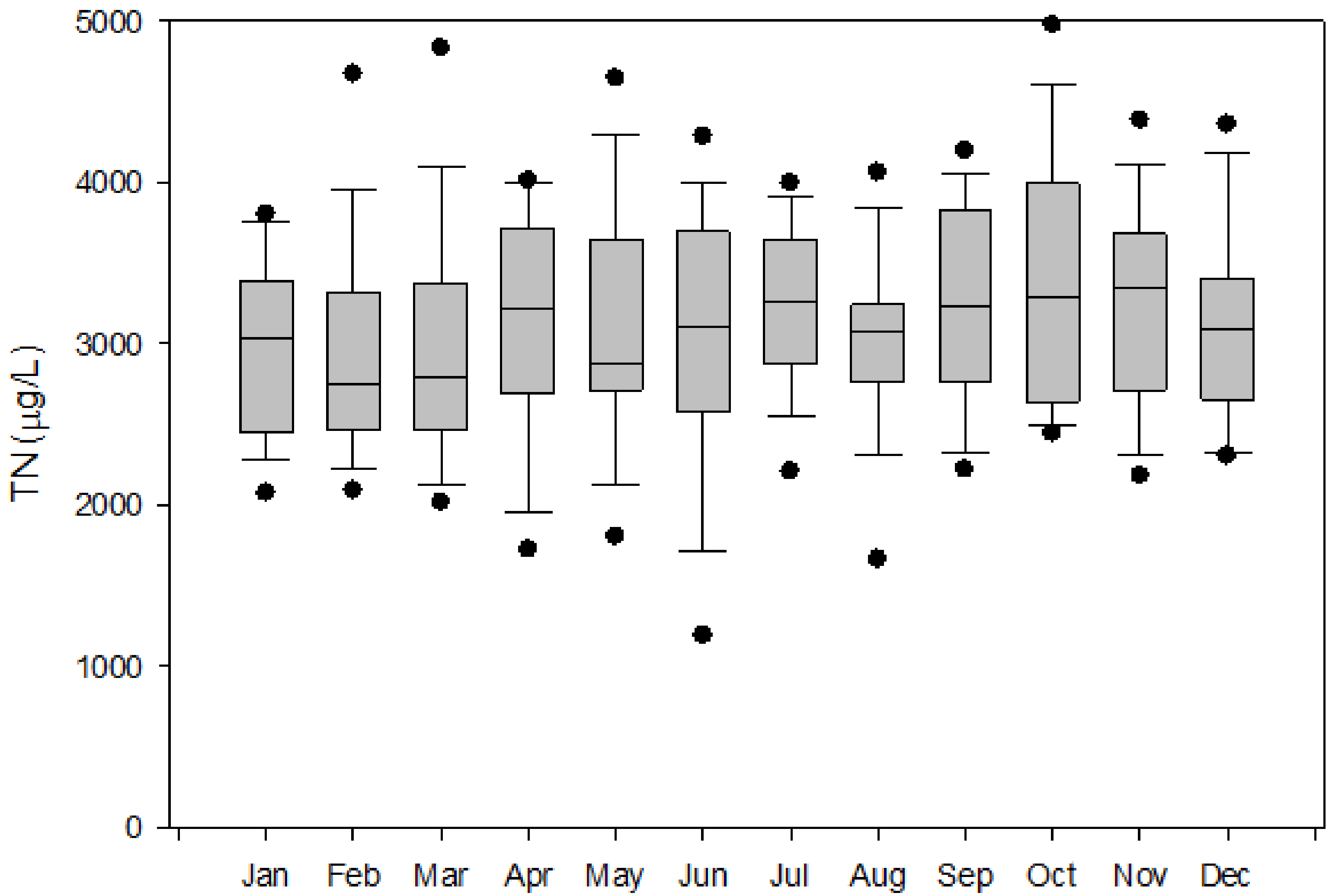


Figure 2-10. Box and Whisker Plot for Monthly TN Concentration in Lake Carlton Surface Water (1997-2016)



Note - Middle line represents median, and boundary of box indicates 25th and 75th percentile.
Whiskers indicate 10th and 90th percentiles. Filled in circles represent 5th and 95th percentiles.

Figure 2-11. TN:TP Ratio in Lake Carlton Surface Water (1997-2016)

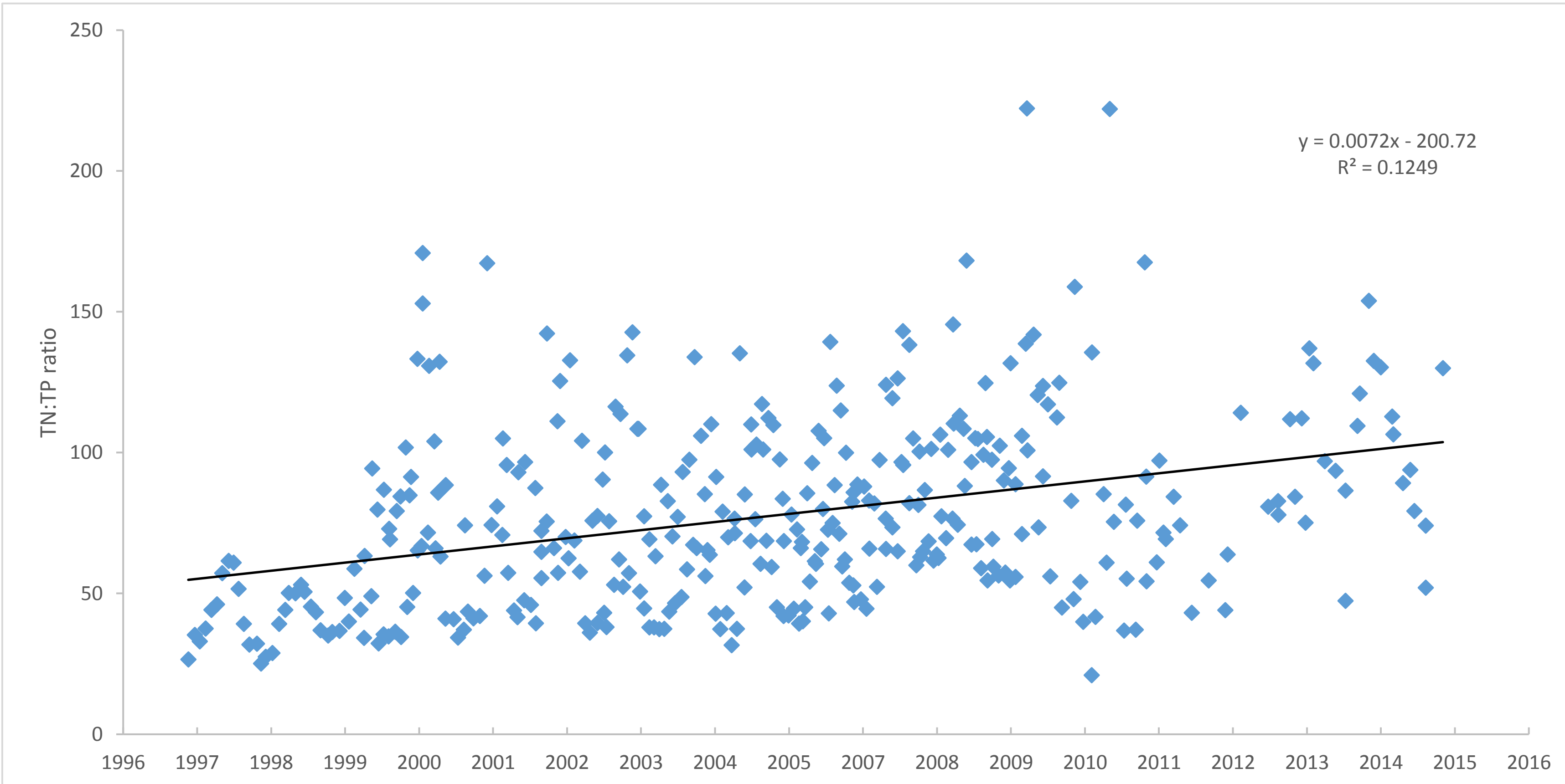
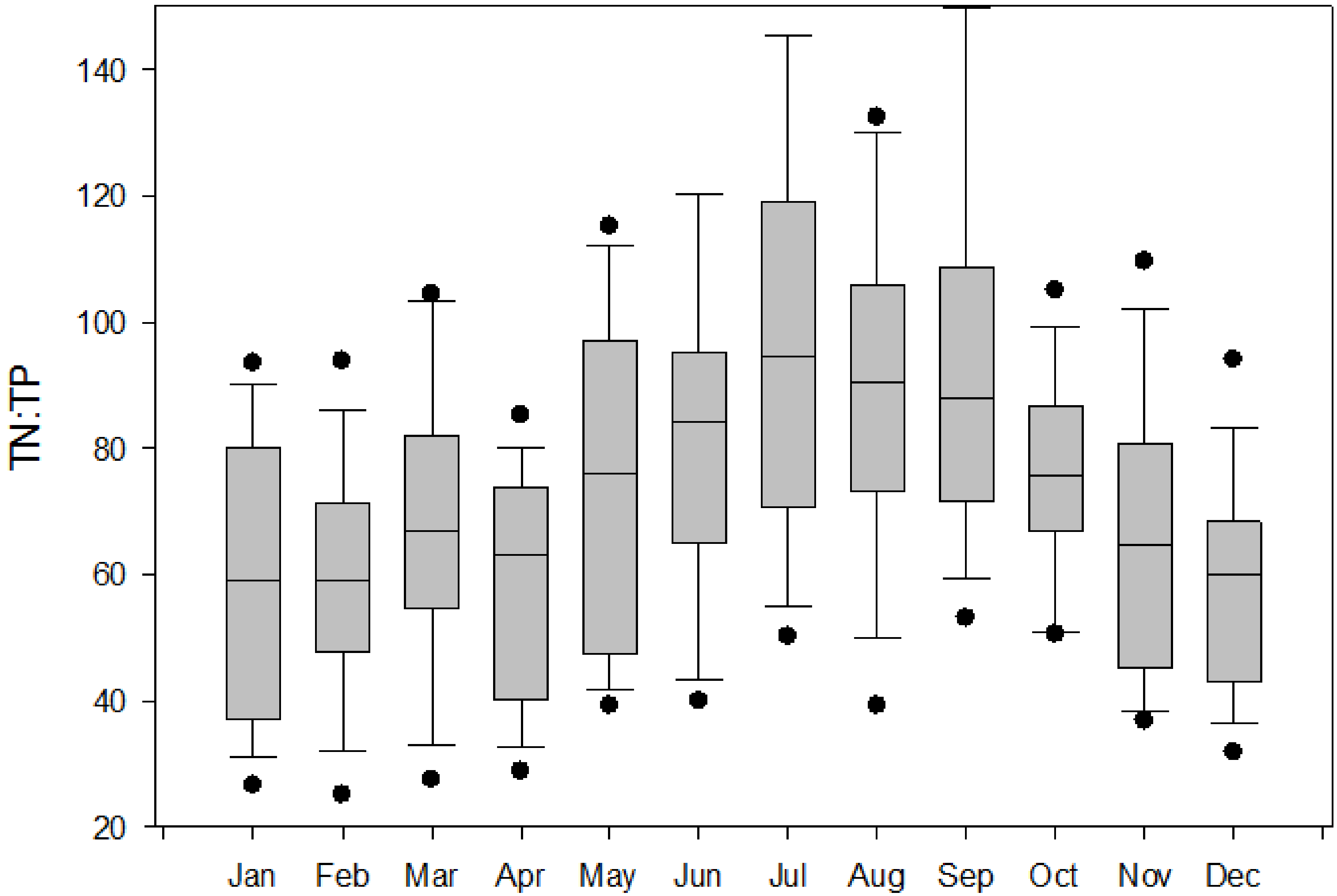


Figure 2-12. Box and Whisker Plot for Monthly TN:TP Ratio in Lake Carlton Surface Water (1997–2016)



Note - Middle line represents median, and boundary of box indicates 25th and 75th percentile. Whiskers indicate 10th and 90th percentiles. Filled in circles represent 5th and 95th percentiles.

Figure 2-13. Nitrite Concentration in Lake Carlton Surface Water (2000-2016)

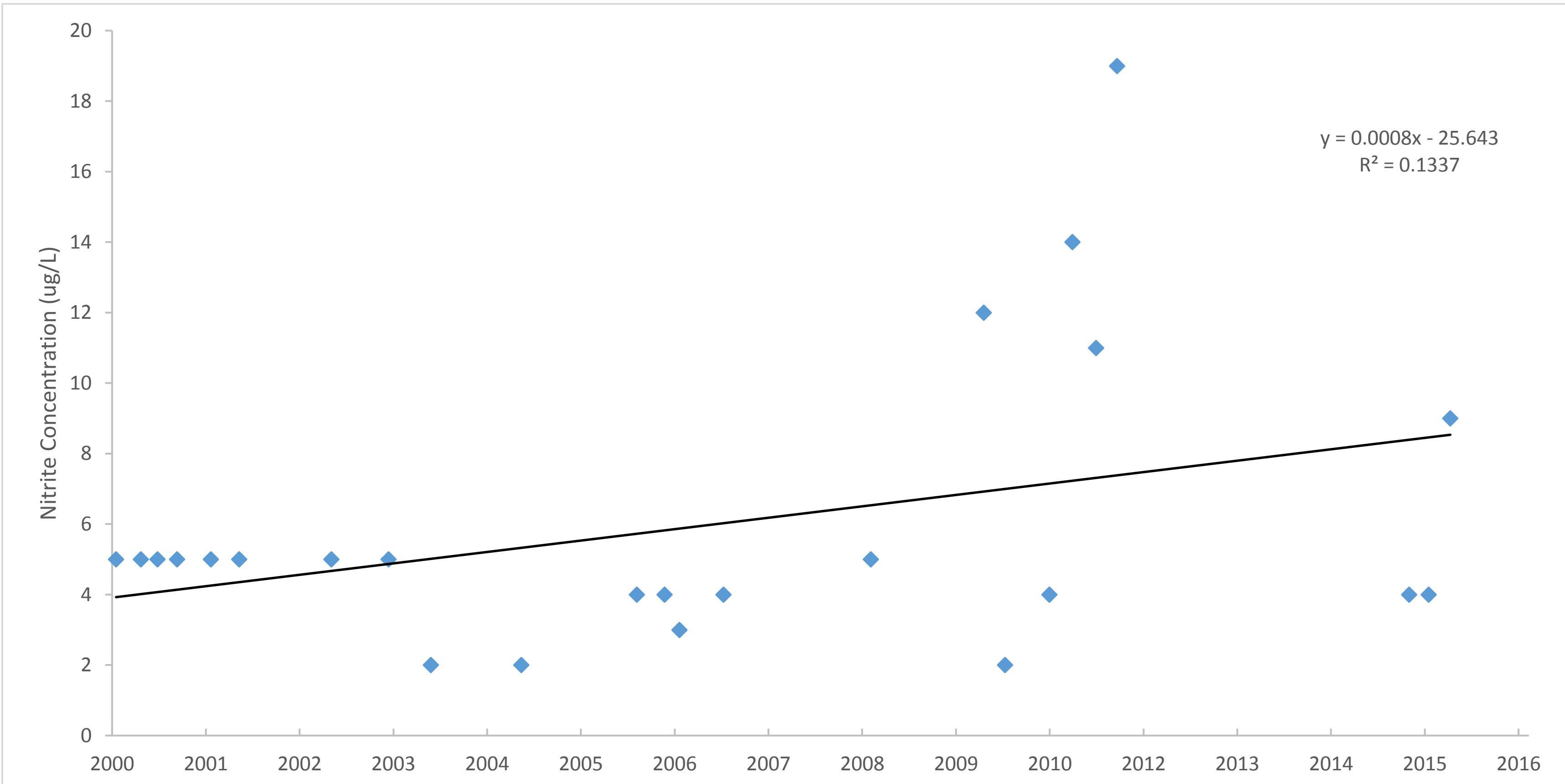
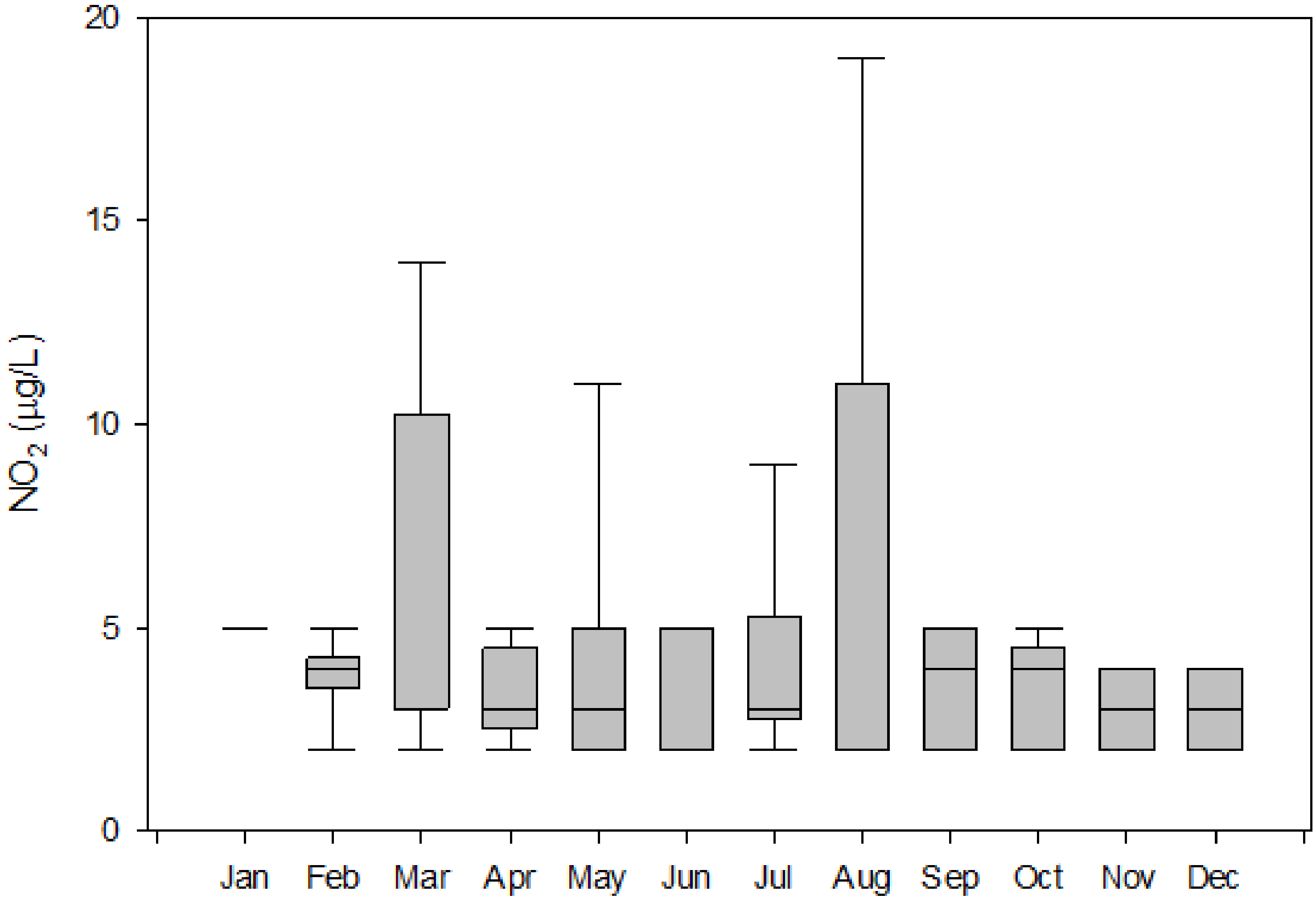


Figure 2-14. Box and Whisker Plot for Monthly Nitrite Concentration in Lake Carlton Surface Water (2000-2016)



Note - Middle line represents median, and boundary of box indicates 25th and 75th percentile. Whiskers indicate 10th and 90th percentiles. Filled in circles represent 5th and 95th percentiles.

Figure 2-15. Nitrate Concentration in Lake Carlton Surface Water (2000-2016)

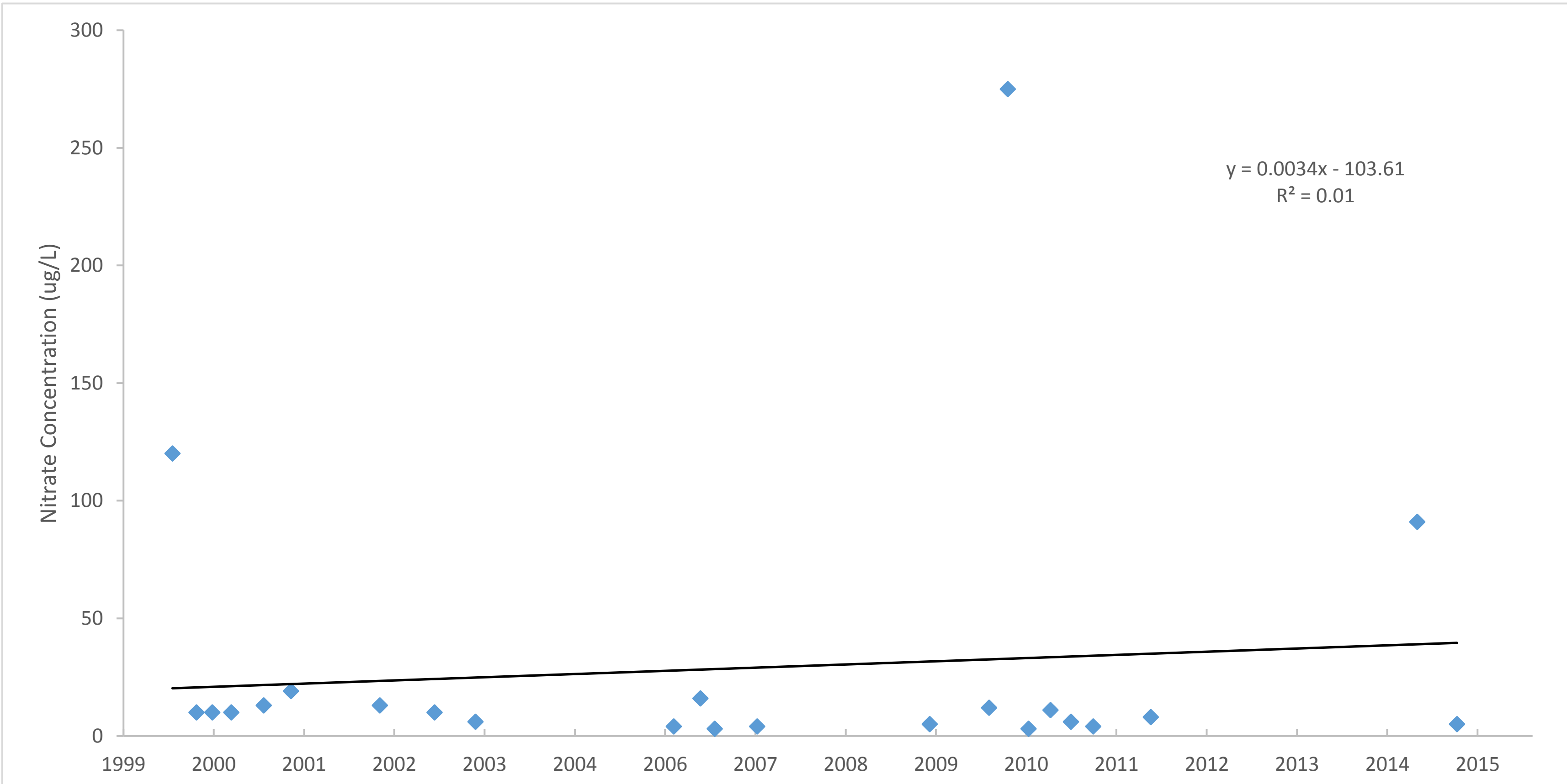
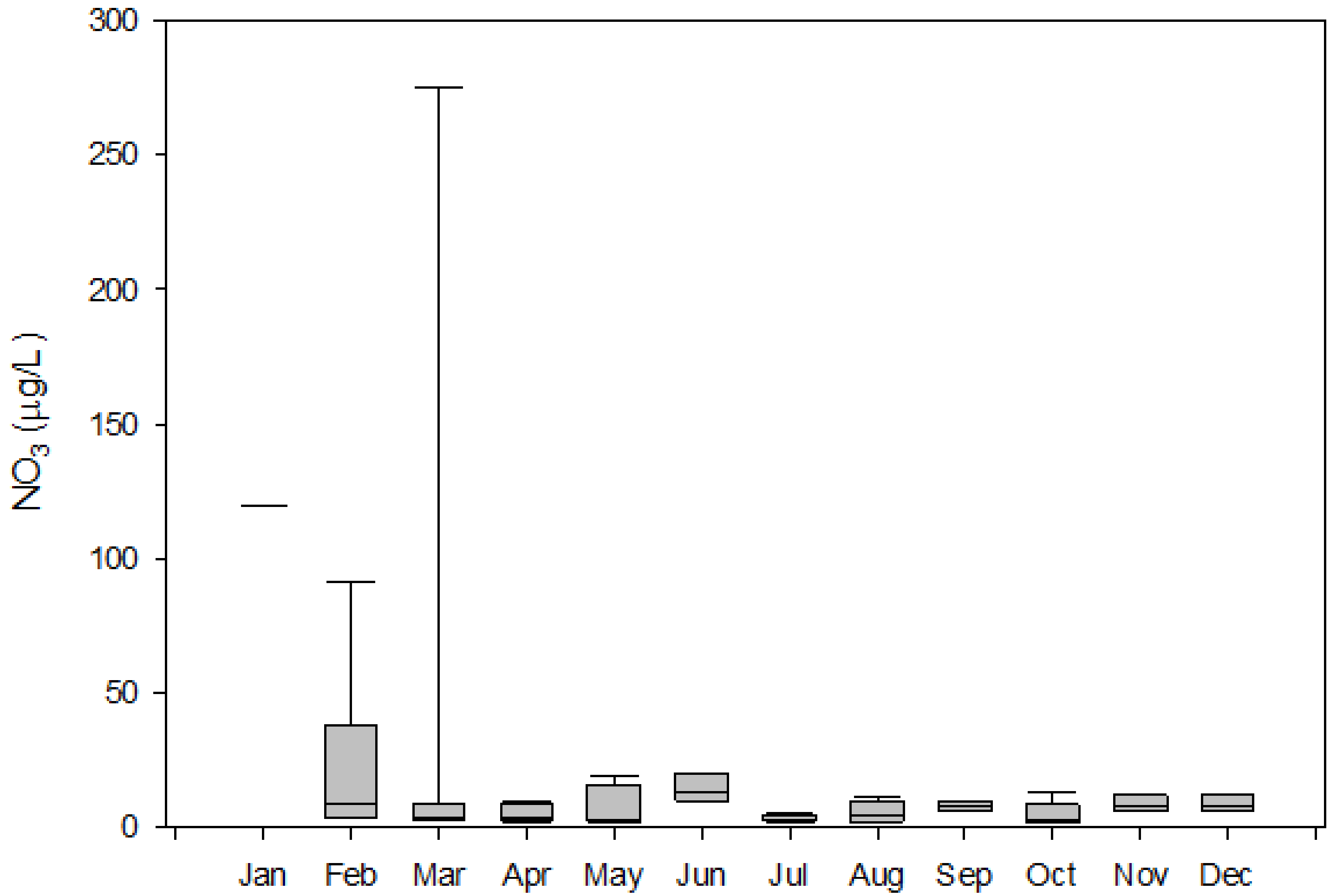


Figure 2-16. Box and Whisker Plot for Monthly Nitrate Concentration in Lake Carlton Surface Water (1997-2016)



Note - Middle line represents median, and boundary of box indicates 25th and 75th percentile. Whiskers indicate 10th and 90th percentiles. Filled in circles represent 5th and 95th percentiles.

Figure 2-17. Chlorophyll-a Concentration in Lake Carlton Surface Water (1999-2016)

Figure 2-18. Geometric Mean Chlorophyll-a Concentration in Lake Carton Surface Water (1999-2016)

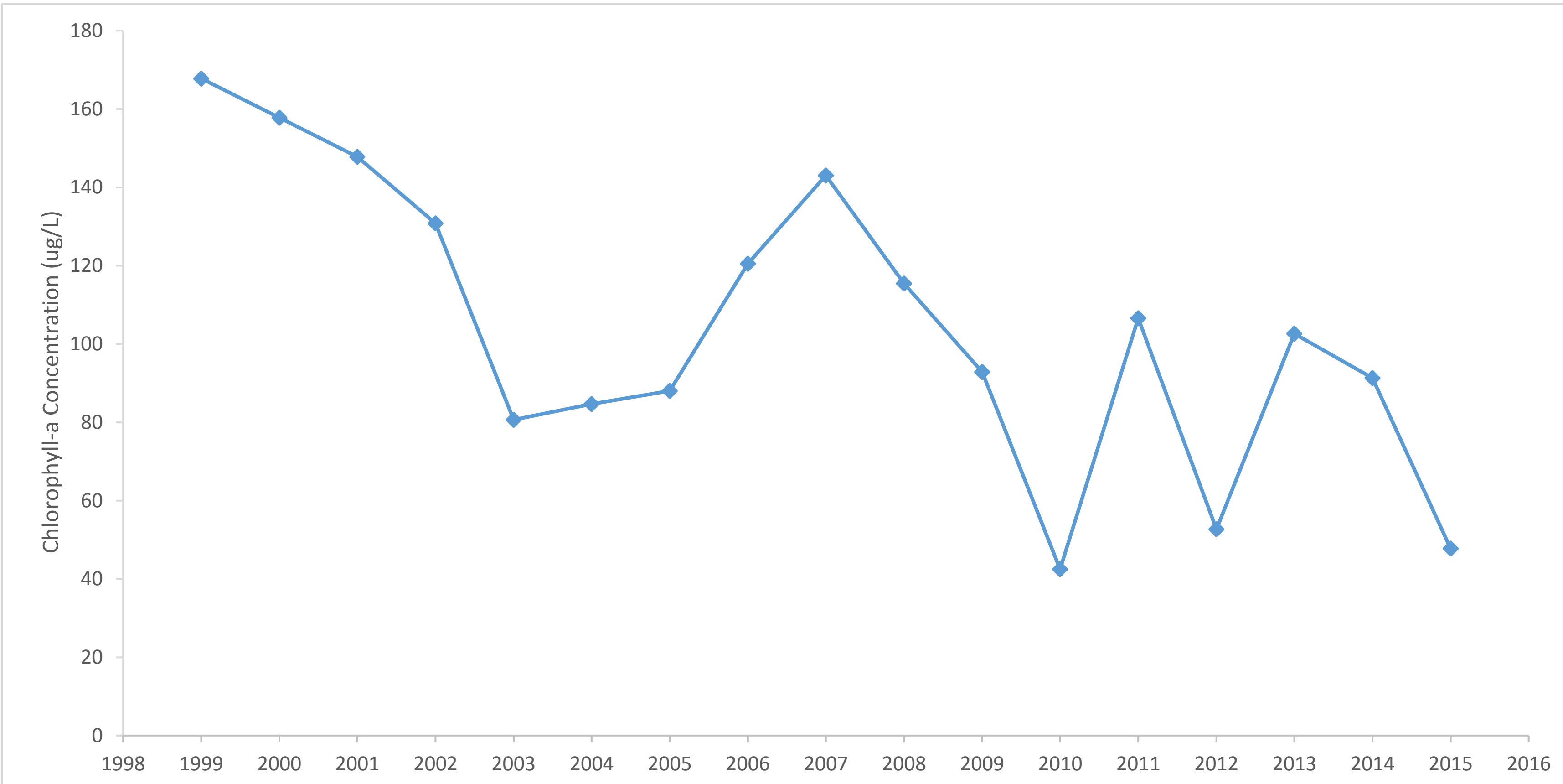
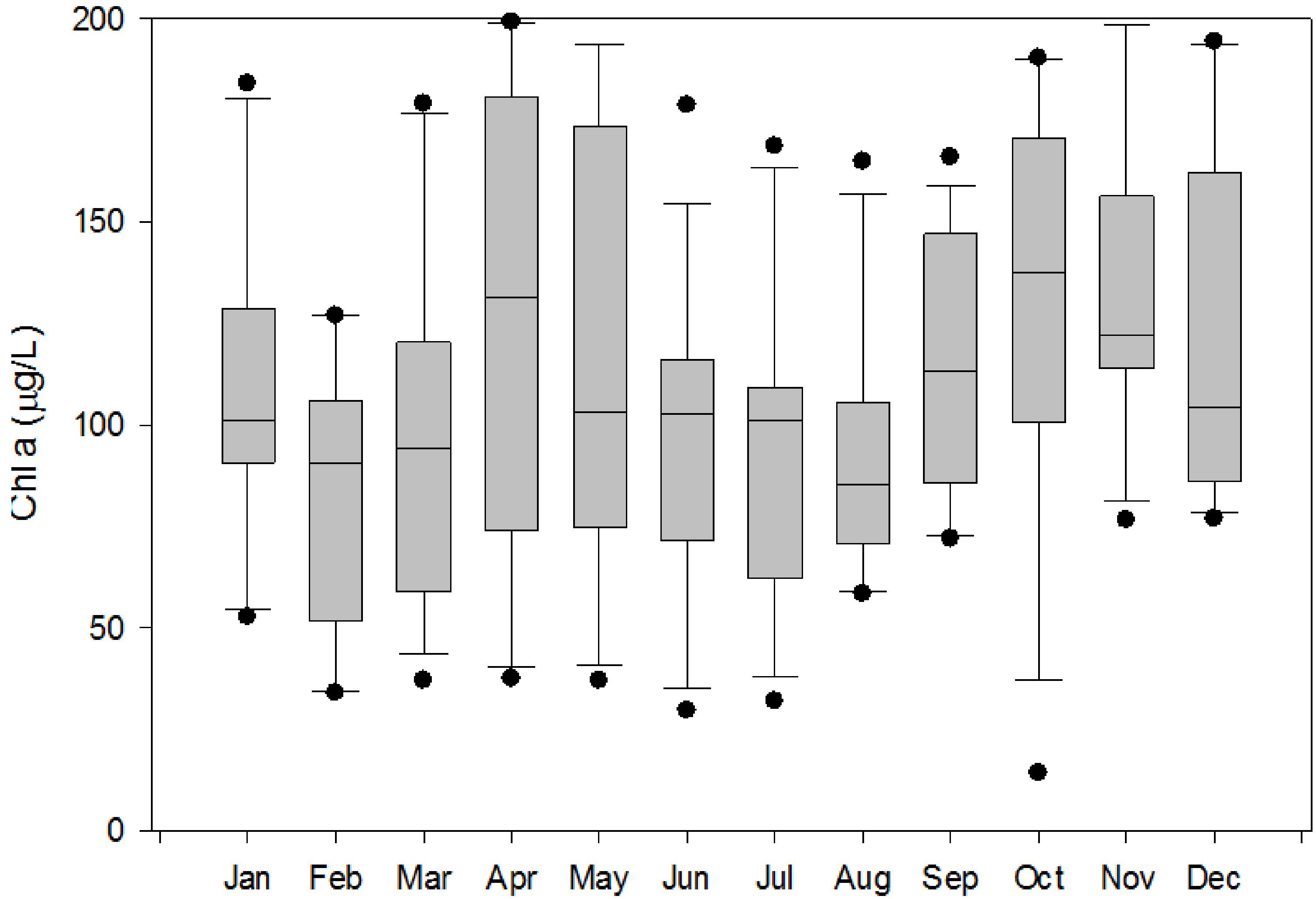


Figure 2-19. Box and Whisker Plot for Monthly Chlorophyll-a Concentration in Lake Carlton Surface Water (1999-2016)



Note - Middle line represents median, and boundary of box indicates 25th and 75th percentile. Whiskers indicate 10th and 90th percentiles. Filled in circles represent 5th and 95th percentiles.

Figure 2-20. Secchi Depth in Lake Carlton Surface Water (1997-2016)

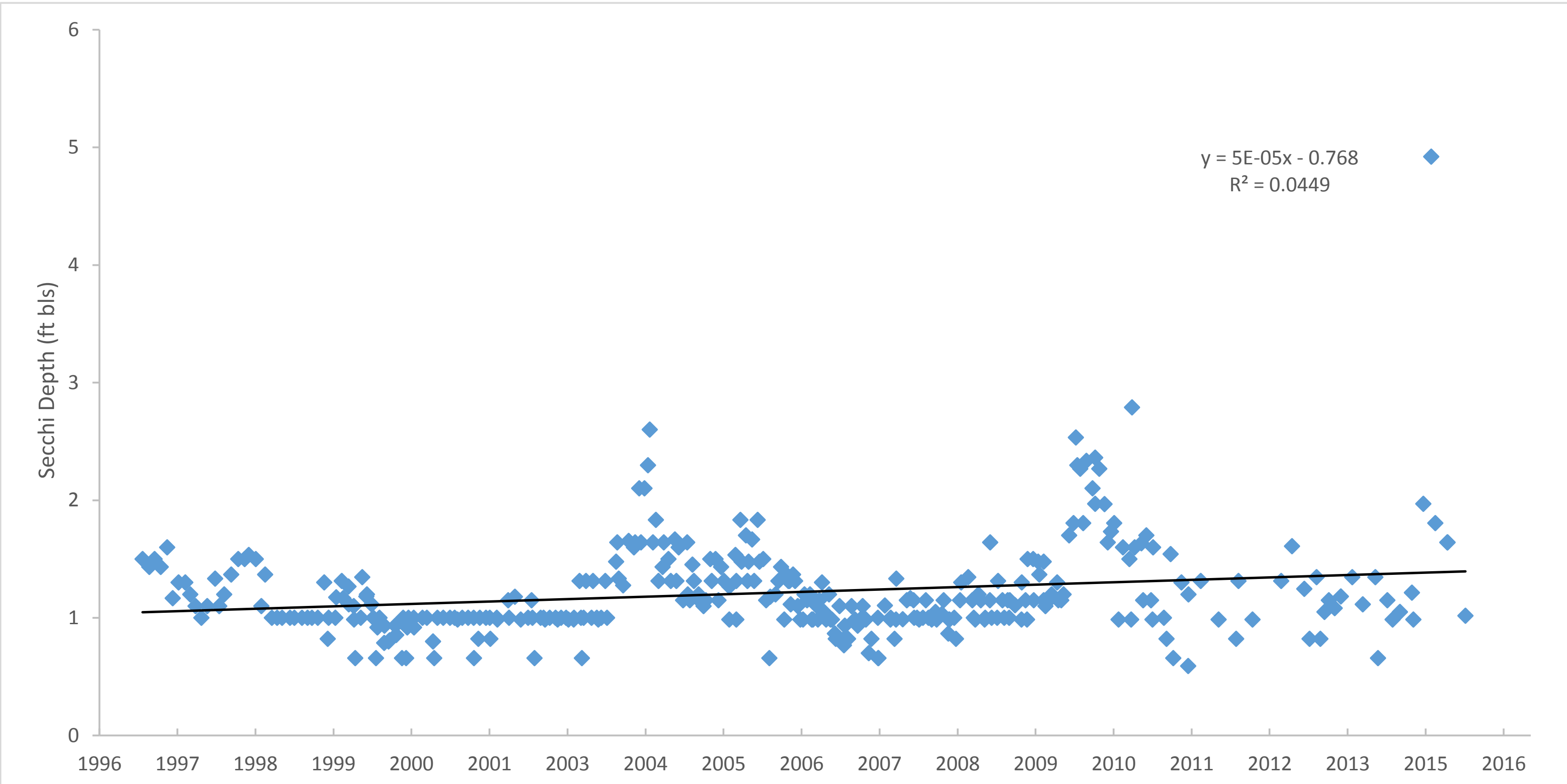
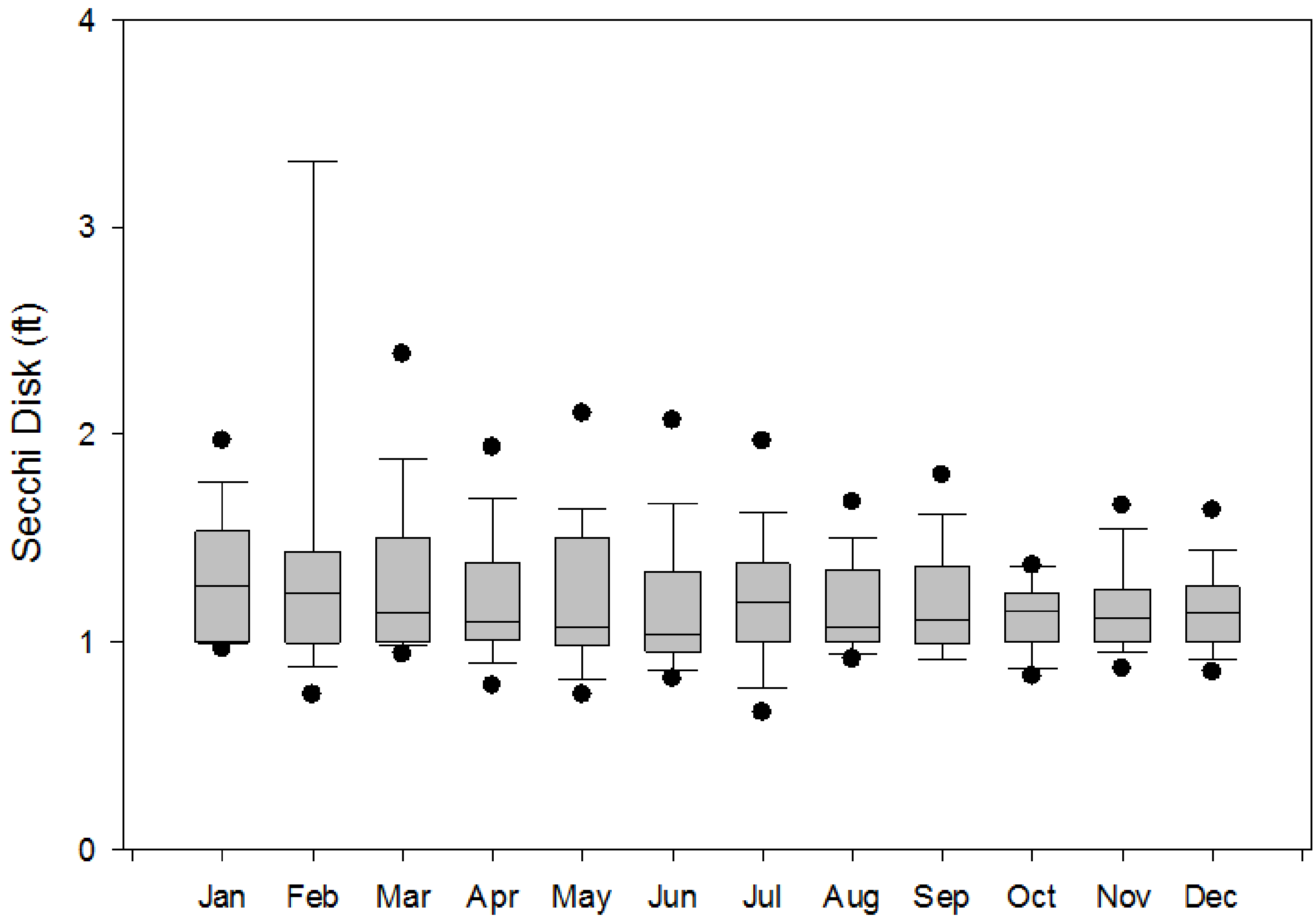


Figure 2-21. Box and Whisker Plot for Monthly Secchi Depth in Lake Carlton Surface Water (1997-2016)



Note - Middle line represents median, and boundary of box indicates 25th and 75th percentile. Whiskers indicate 10th and 90th percentiles. Filled in circles represent 5th and 95th percentiles.

Figure 2-22. TSS Concentration in Lake Carlton Surface water (1999-2016)

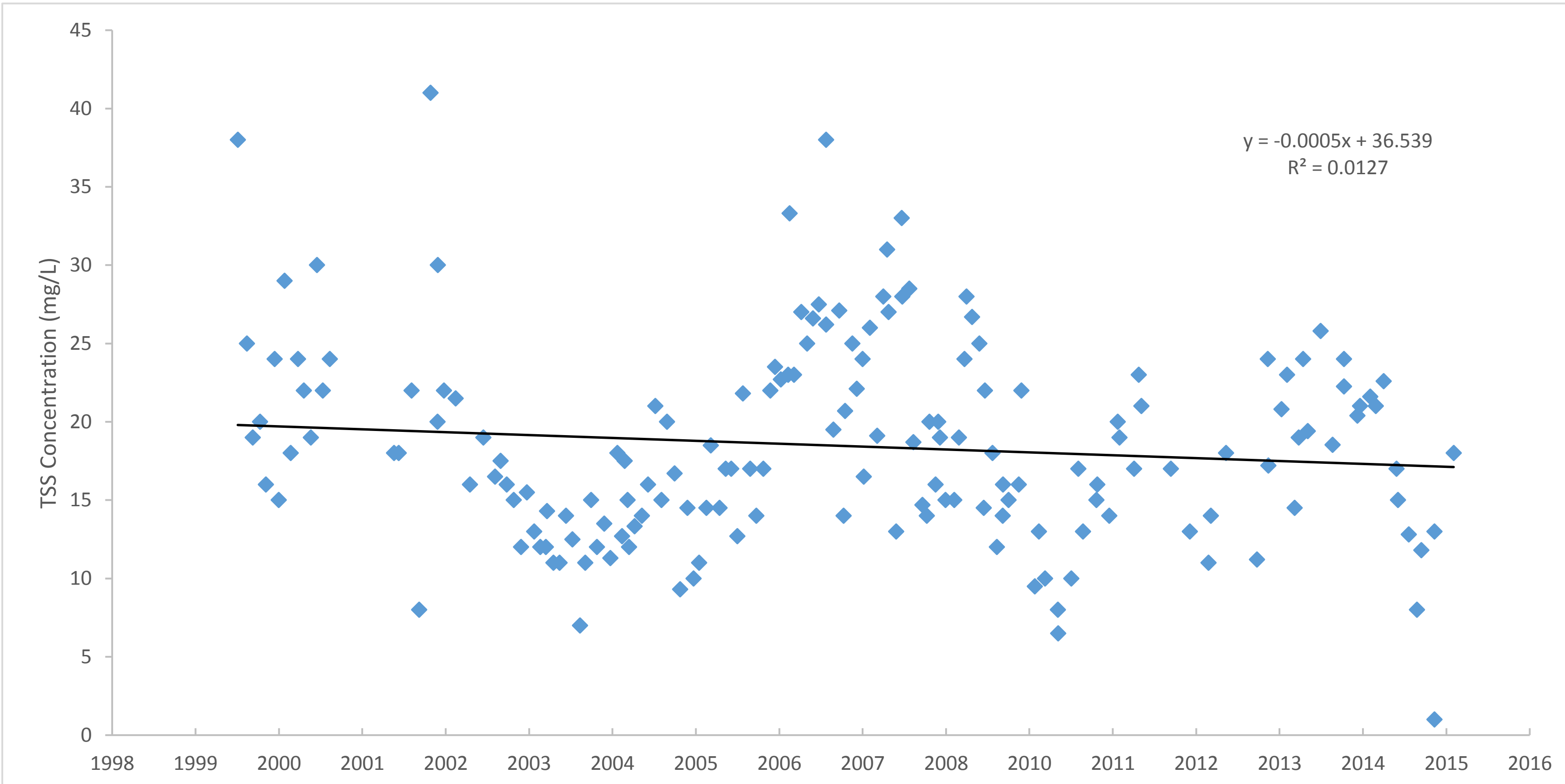
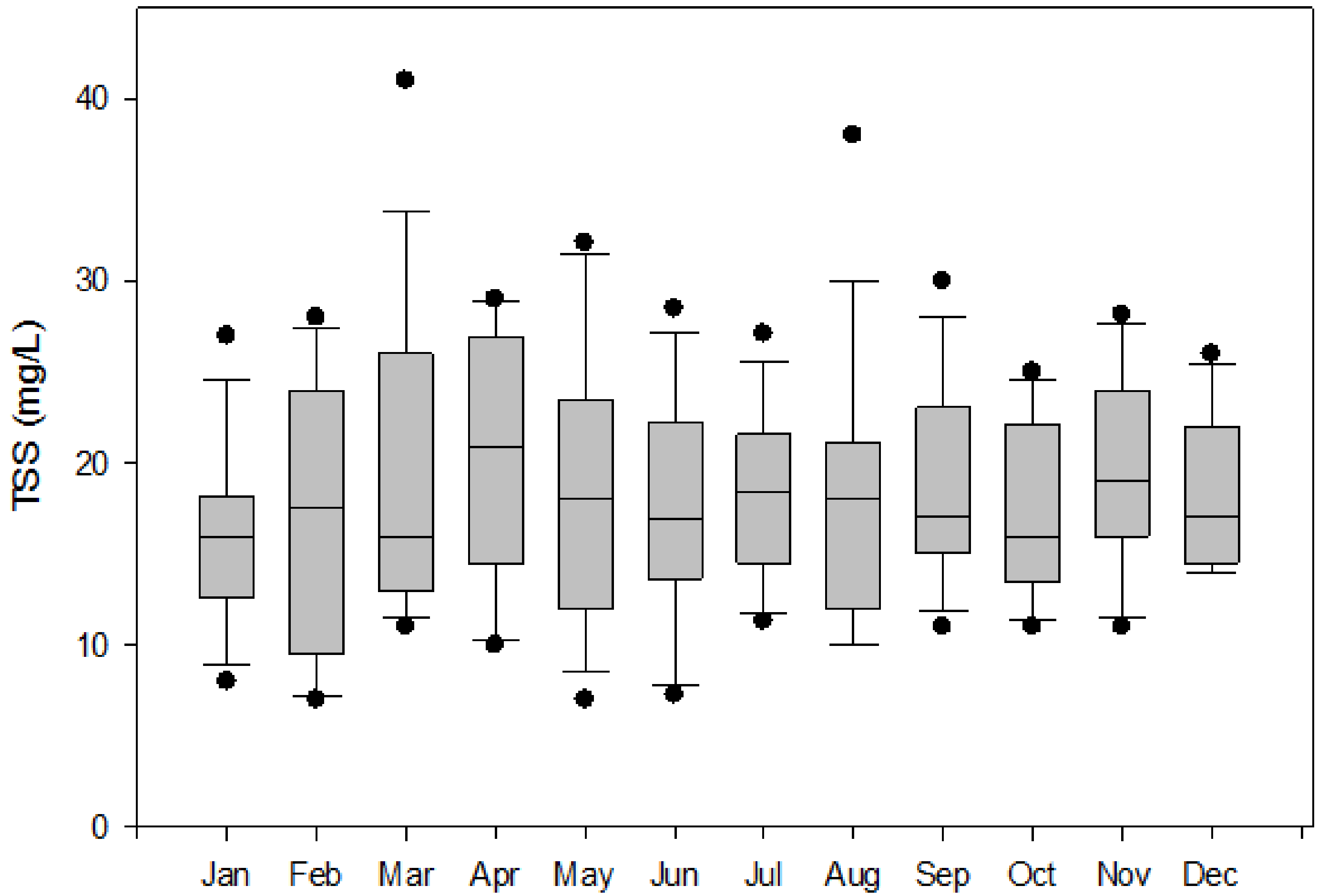


Figure 2-23. Box and Whisker Plot for Monthly TSS Concentration in Lake Carlton Surface Water (1999-2016)



Note - Middle line represents median, and boundary of box indicates 25th and 75th percentile. Whiskers indicate 10th and 90th percentiles. Filled in circles represent 5th and 95th percentiles.

Figure 2-24. TSI for Lake Carlton Surface Water (1997-2016)

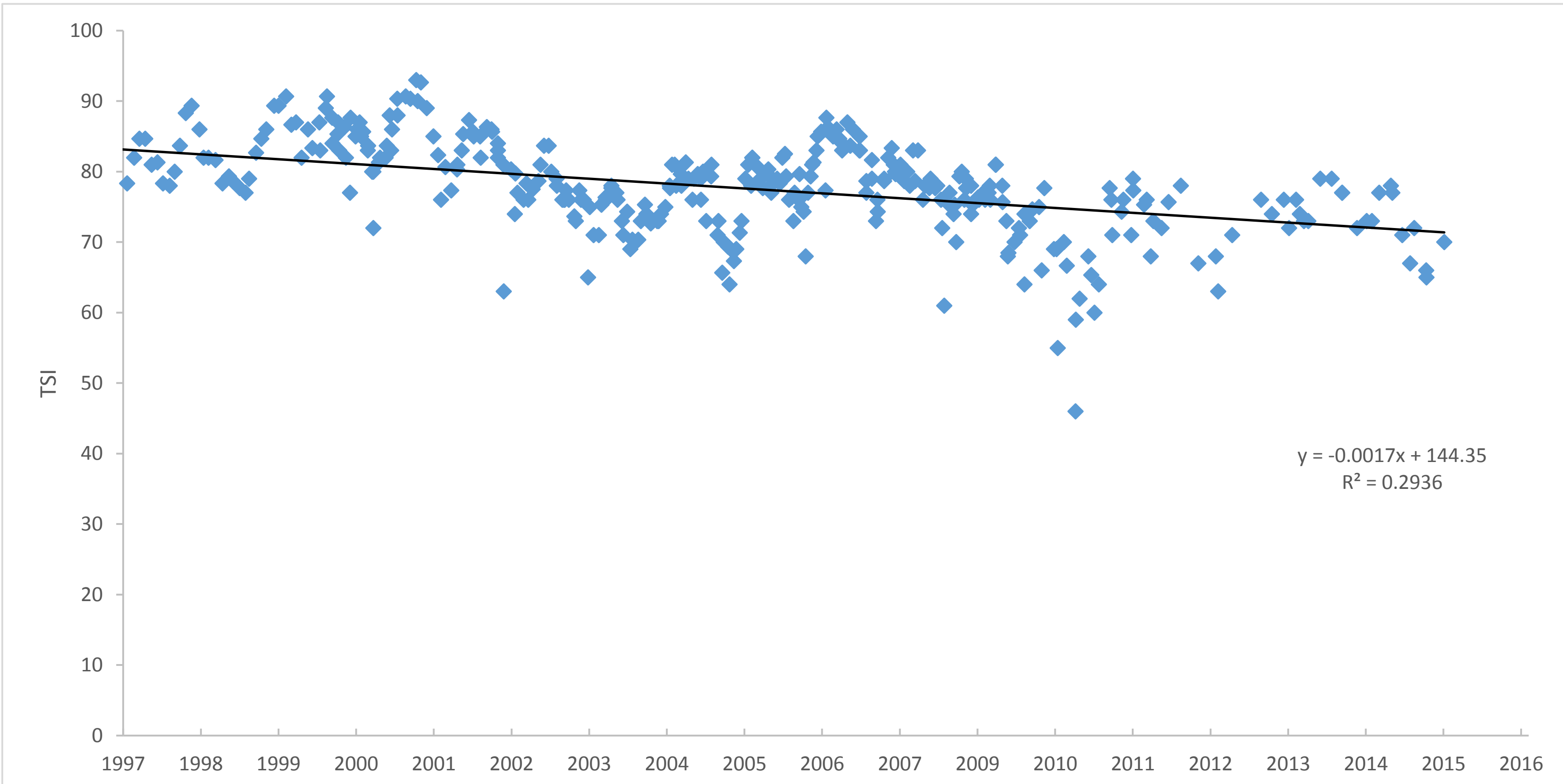


Figure 2-25. Mean Annual TSI for Lake Carlton Surface Water (1997-2016)

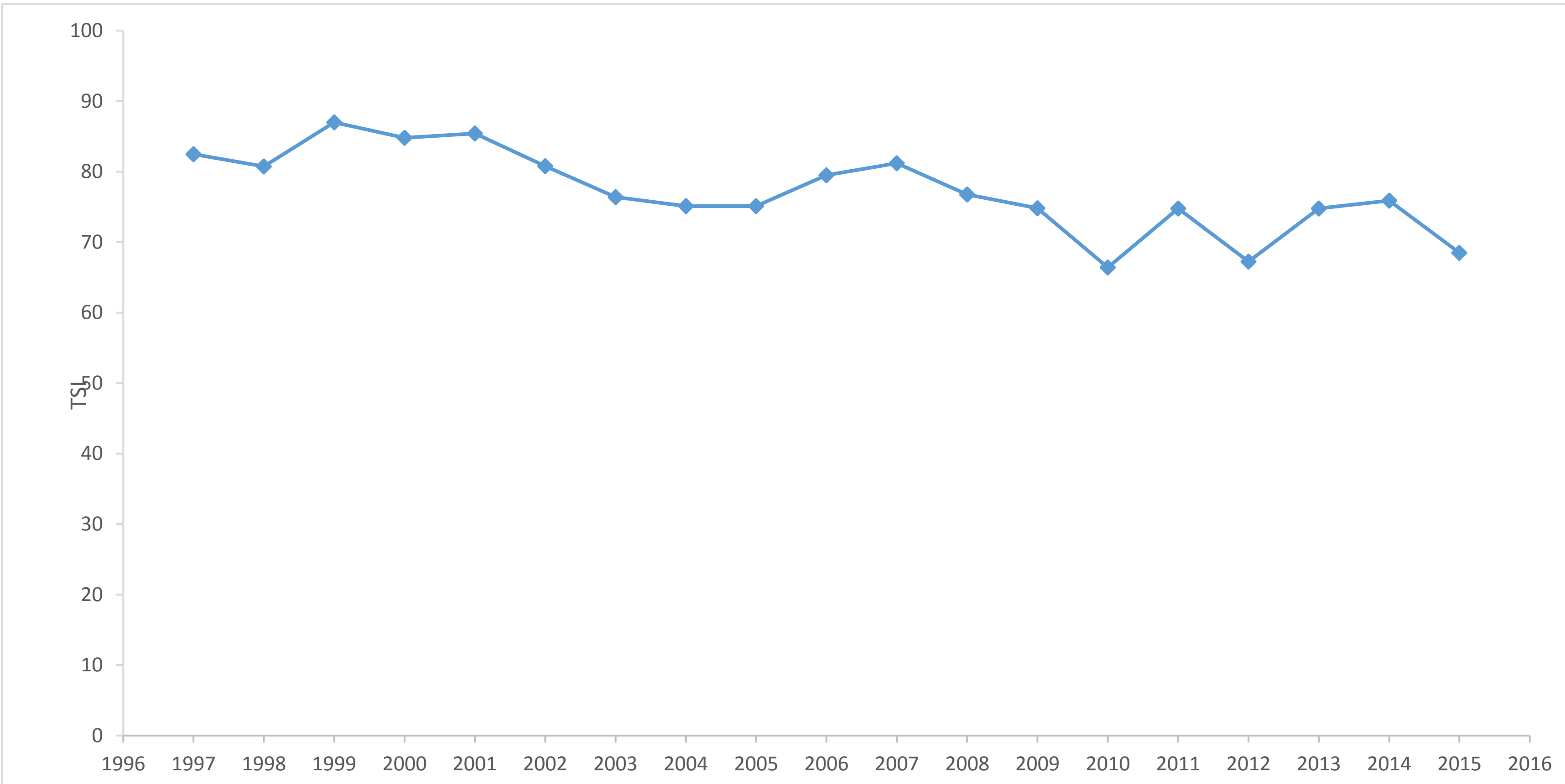
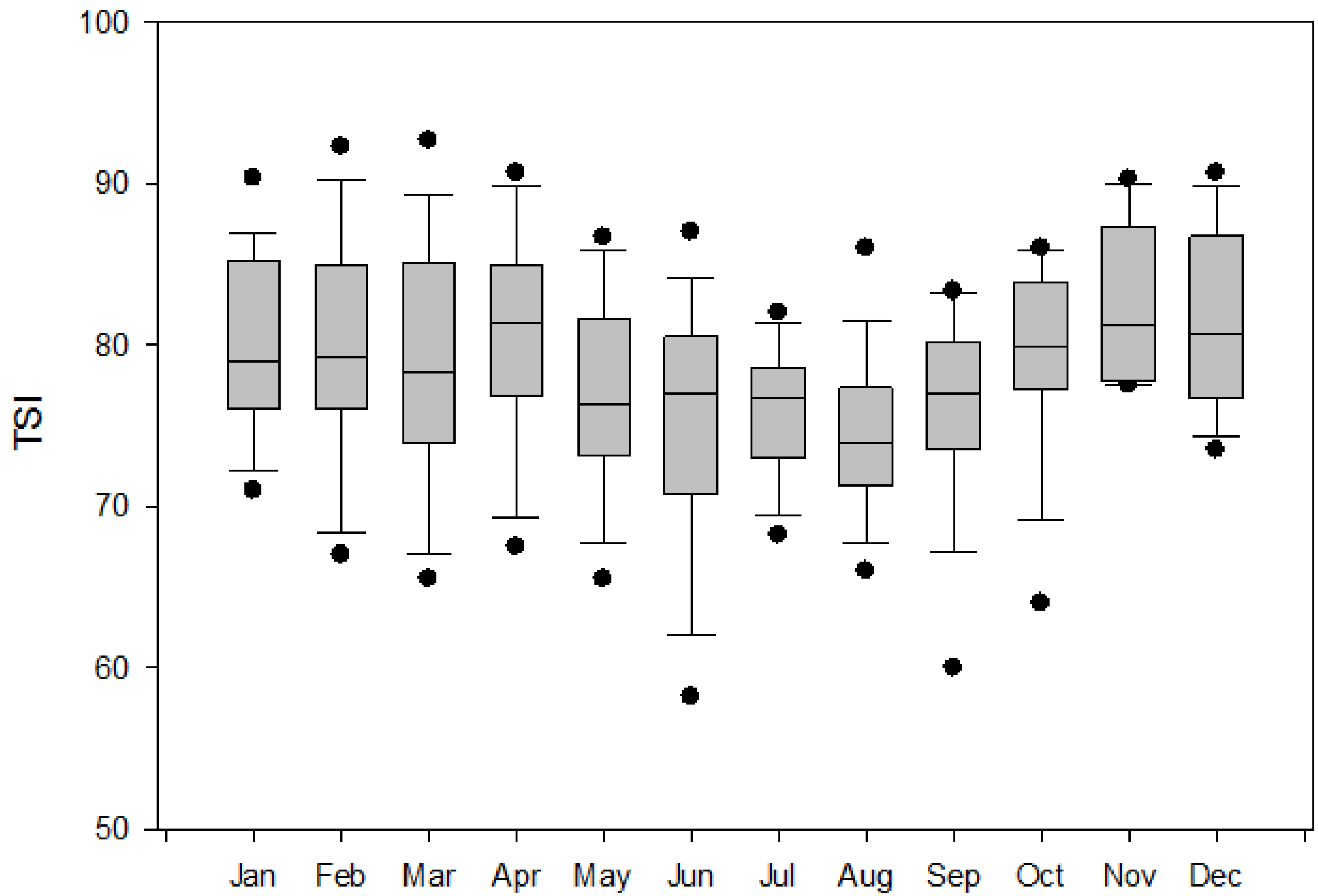
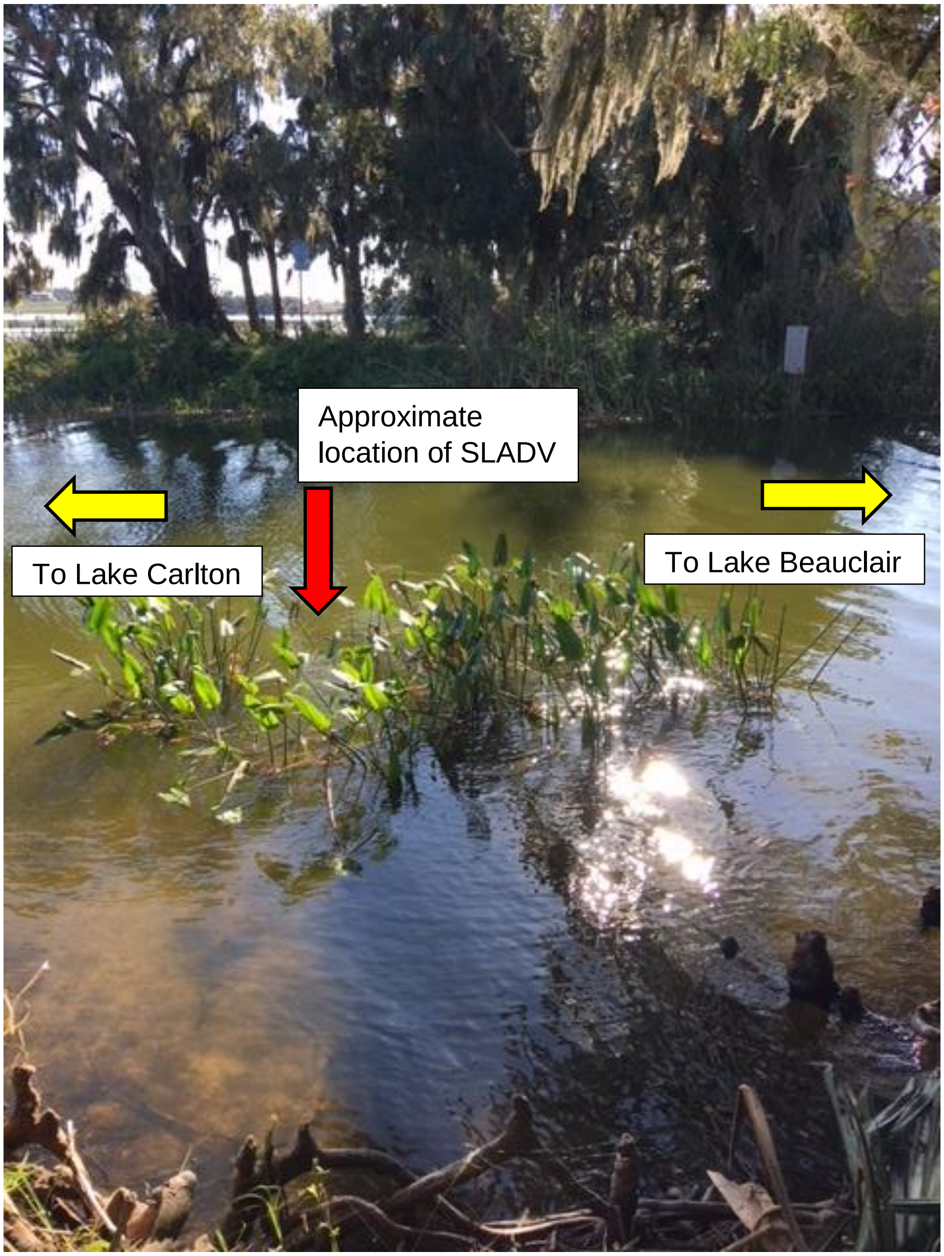


Figure 2-26. Box and Whisker Plot for Monthly TSI for Lake Carlton Surface Water (1997-2016)

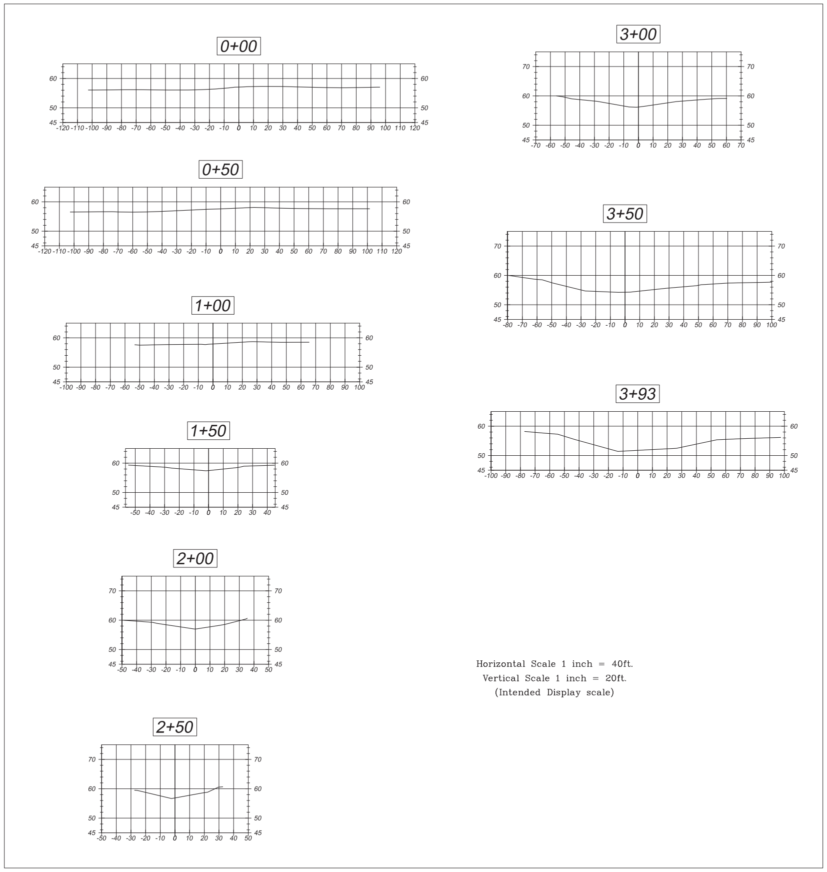


Note - Middle line represents median, and boundary of box indicates 25th and 75th percentile. Whiskers indicate 10th and 90th percentiles. Filled in circles represent 5th and 95th percentiles.

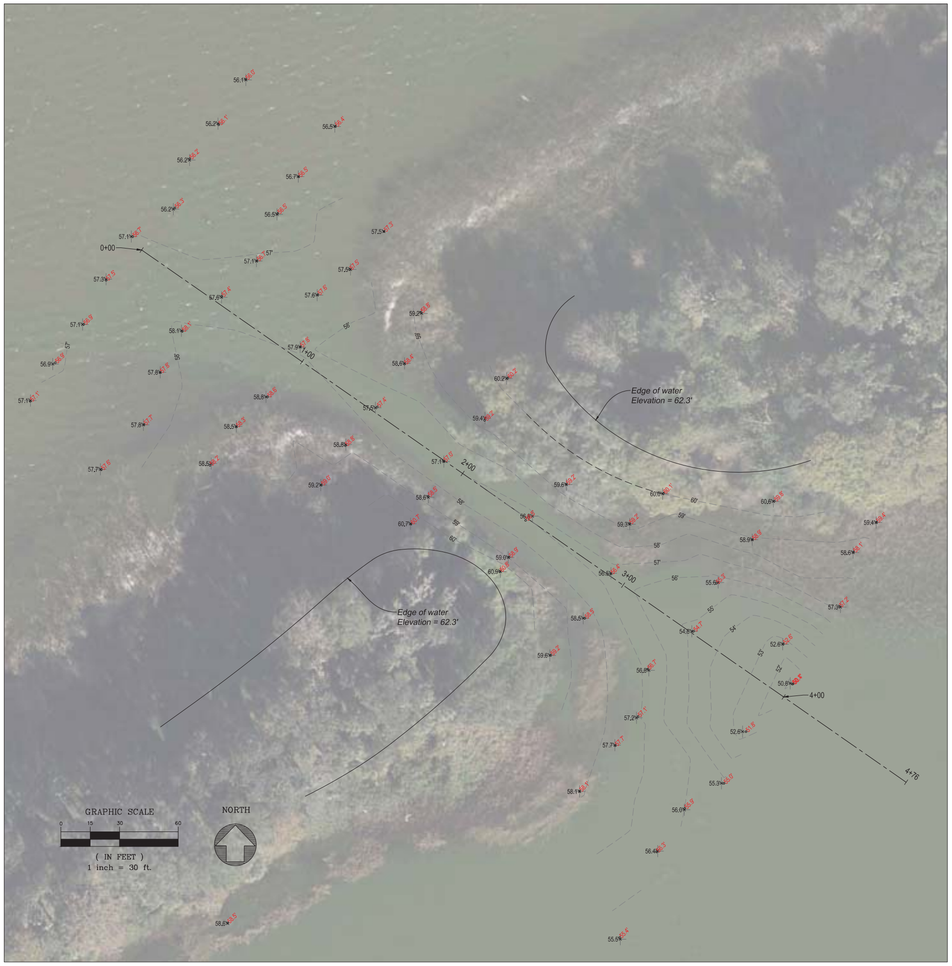
Figure 2-27. Location of Side Looking Acoustic Doppler Velocimeter at Carlton Cut Adjacent to Trimble Park



Carlton Cut Cross-Sections



Horizontal Scale 1 inch = 40ft.
Vertical Scale 1 inch = 20ft.
(Intended Display scale)



REVISIONS

DRAWN	CHECKED	DATE

DRAWN: ADW CHECKED: RMJ DWG. DATE: 3/22/2016 SCALE:
FIELD PERSON(S): M. FOLLIS & V. PABON
FIELD DATE(S): 3-15-16 thru ....
FIELD BOOK(S): 1311
PAGE(S): 28-....
DATA COLLECTOR FILE(S): 18X9FA

Figure 2-28
Carlton Cut Cross-Sections
LAKE COUNTY & ORANGE COUNTY
SECTION 7 TOWNSHIP 20 SOUTH RANGE 27 EAST
& SECTION 12 TOWNSHIP 20 SOUTH RANGE 26 EAST

Prepared by:

Amec Foster Wheeler
Environment & Infrastructure, Inc.
75 East Amelia Street, Suite 200
Orlando, Fl 32801 USA
Phone: (407) 522-7570
Fax: (407) 522-7576
Certificate of Authorization Number LB-0007932

CADD FILE NO.

DRAWING NO.
----
1 SHEET OF 1

Figure 2-29. TP Concentration for Lakes Beauclair and Carlton (1996 – 2015)

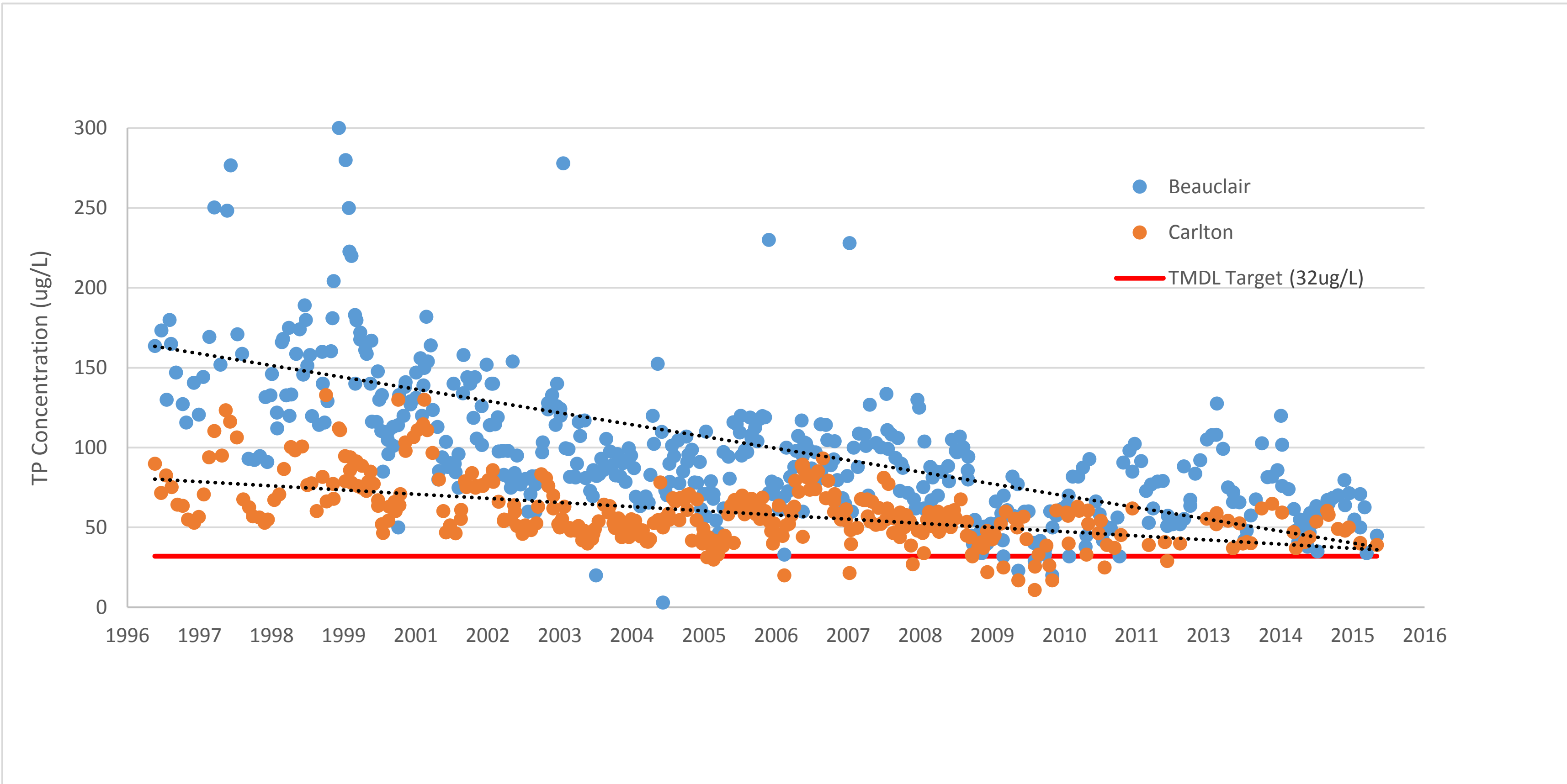
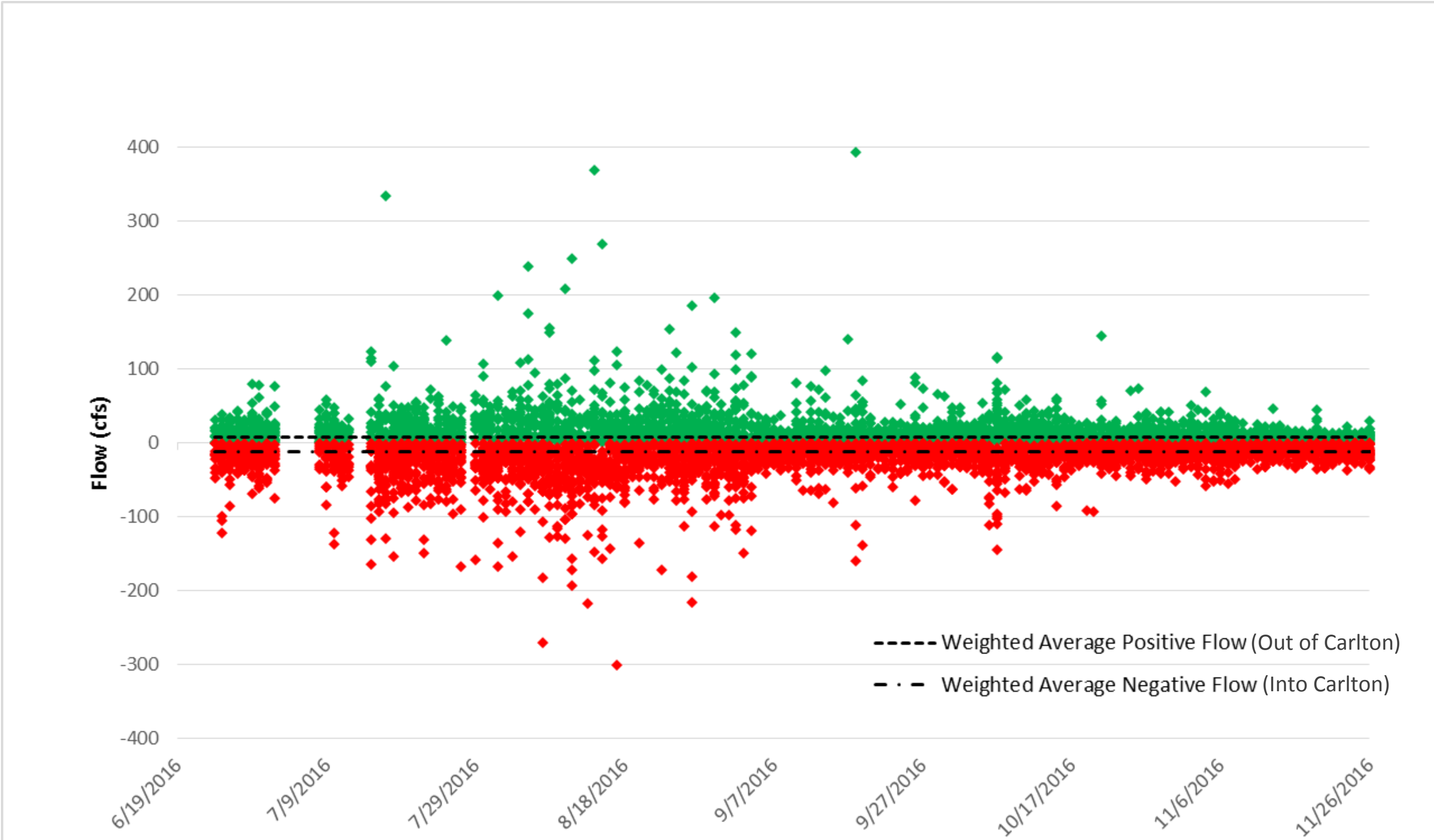
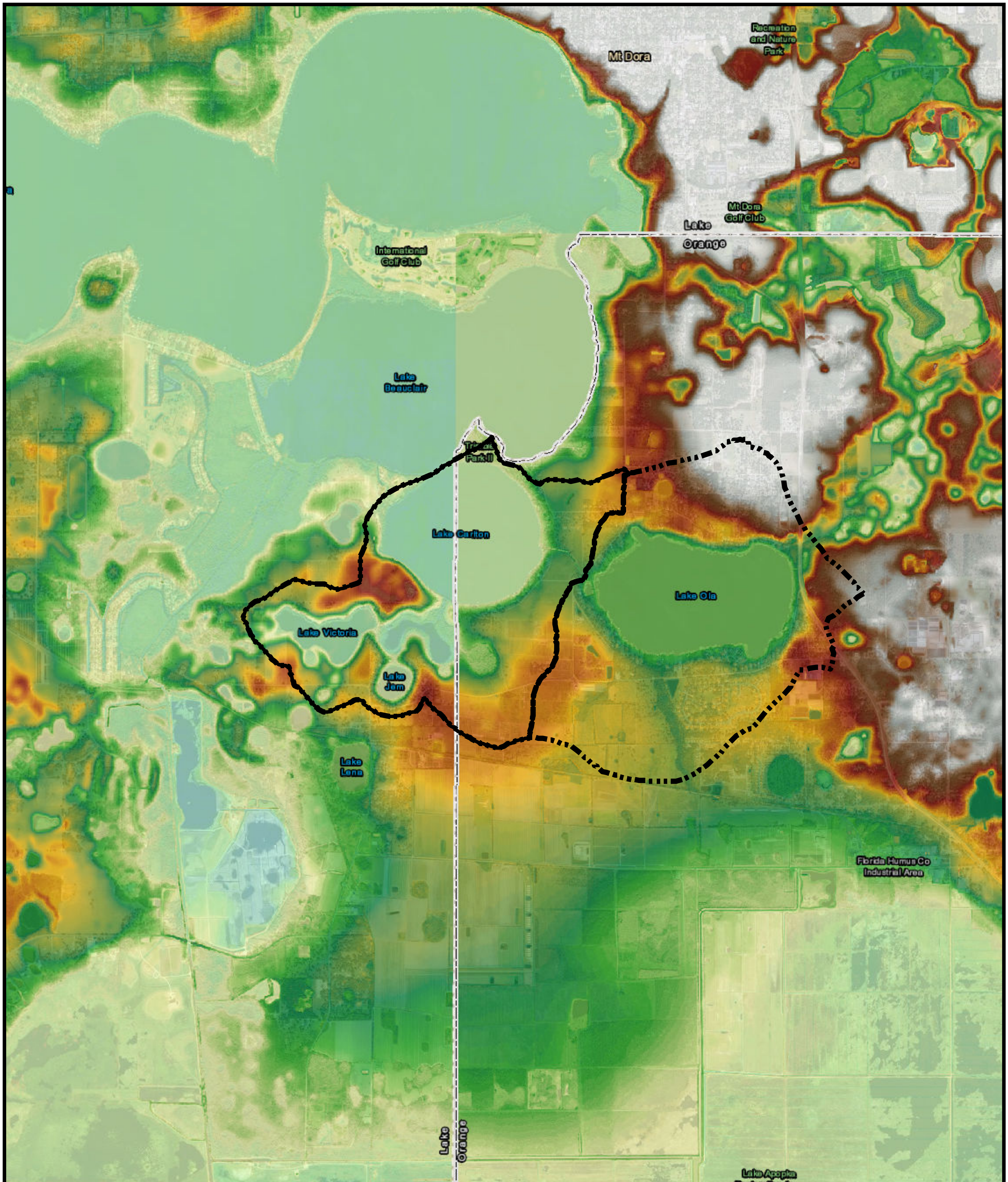


Figure 2-30. Flow at Connection Between Lake Carlton and Lake Beauclair





Notes:

1- Project No.: 600218x9

2- Data Source - SJRWMD, ESRI 2017 NAIP Imagery, AmecFW LiDAR - NAVD 88 feet

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 8/22/16
Revised: AB
Checked By: LL

Explanation of Features

N

NAME

Lake Carlton Basin

Lake Ola Basin

County Boundary

DEM

Elevation (Feet)

High : 180.399

Low : 57.0713

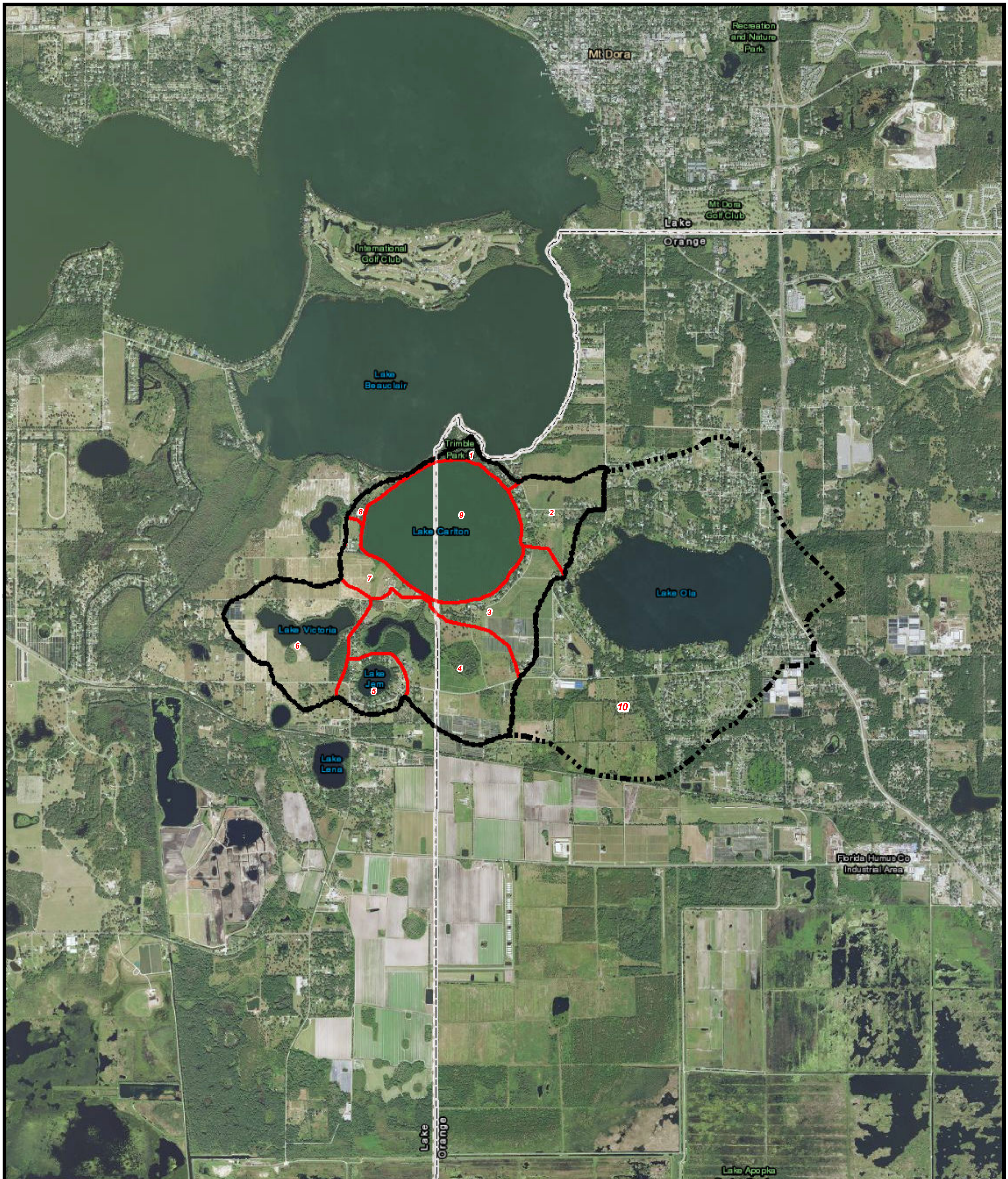
Feet

amec foster wheeler

Amec Foster Wheeler
Environment & Infrastructure, Inc.
2000 E. Edgewood Drive Ste #215
Lakeland, FL 33803
CA-5392
(863) 667-2345

Figure 3-1
Basin Map with
Digital Elevation Model (DEM)
Lake Carlton
Orange/Lake Counties
Florida

Path: V:\600218x9 Lake Carlton\MXDs\New MXDs\Fig3-1BasinandTopo.mxd



Notes:

1- Project No.: 600218x9

2- Data Source - SJRWMD, ESRI 2017 NAIP Imagery, AmecFW

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 8/22/16
Revised: SF
Checked By: AB

Explanation of Features

N

Lake Carlton Basin

Lake Ola Basin

Sub-basin Boundaries

County Boundary

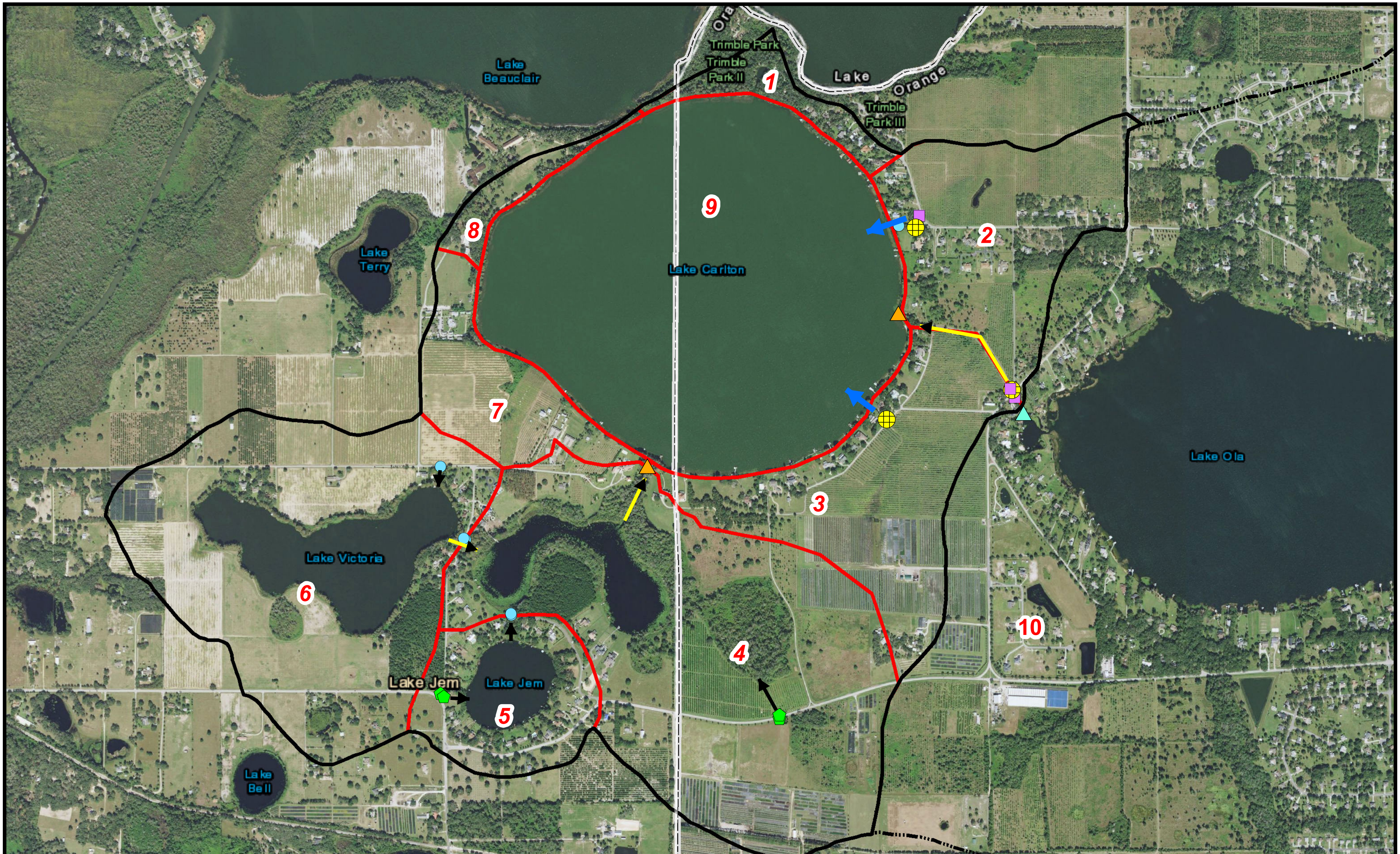
0 1,000
Feet

amec foster wheeler

Amec Foster Wheeler
Environment & Infrastructure, Inc.
2000 E. Edgewood Drive Ste #215
Lakeland, FL 33803
CA-5392
(863) 667-2345

Figure 3-2
Sub-Basin Map
Lake Carlton
Orange/Lake Counties
Florida

Path: V:\600218x9 Lake Carlton\MXDs\New MXDs\Fig3-2_Lake Carlton SubBasin.mxd



Notes:
1- Project No.: 600218x9
2- Data Source - SJRWMD, ESRI 2017 NAIP Imagery, AmecFW
3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 8/22/16
Revised: AB
Checked By:

Explanation of Features

- Lake Carlton Basin
- Lake Ola Basin
- County Boundary
- 1 Revised Sub-basin Boundary
- Lake Outflow
- Pipe Outflow
- Outfall to Lake
- Culvert
- Grated Drop Inlet
- Headwall
- Channel Connection
- Mitered End Section
- Outfall

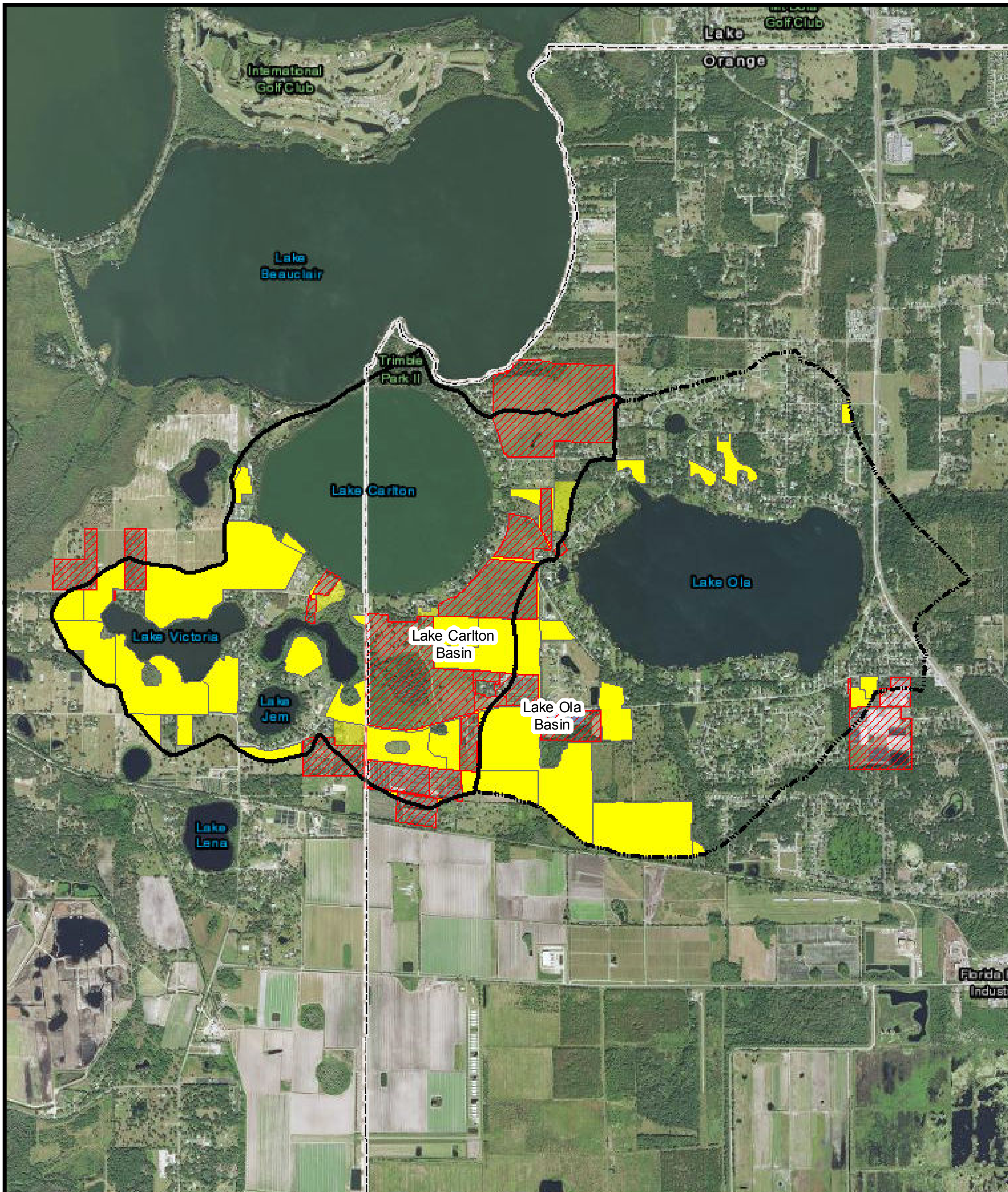
N

0 1,500 Feet

amec foster wheeler
Amec Foster Wheeler
Environment & Infrastructure, Inc.
2000 E. Edgewood Drive Ste #215
Lakeland, FL 33803
CA-5392
(863) 667-2345

Figure 3-3
Stormwater Structures and Drainage Map
Lake Carlton
Orange/Lake Counties
Florida

File Path: V:\600218x9 Lake Carlton\MXDs\New MXDs\Fig3-3_Lake Carlton Storm and Drain.mxd



Notes:

1- Project No.: 600218x9

2- Data Source -
SJRWMD 2014 LU
2017 NAIP Imagery

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 9/26/16
Revised: 4/12/2018 AB
Checked By: LS

Explanation of Features

- OAWP BMP enrollment
- Un-enrolled Agriculture
- County Boundary
- Lake Carlton Basin
- Lake Ola Basin

N

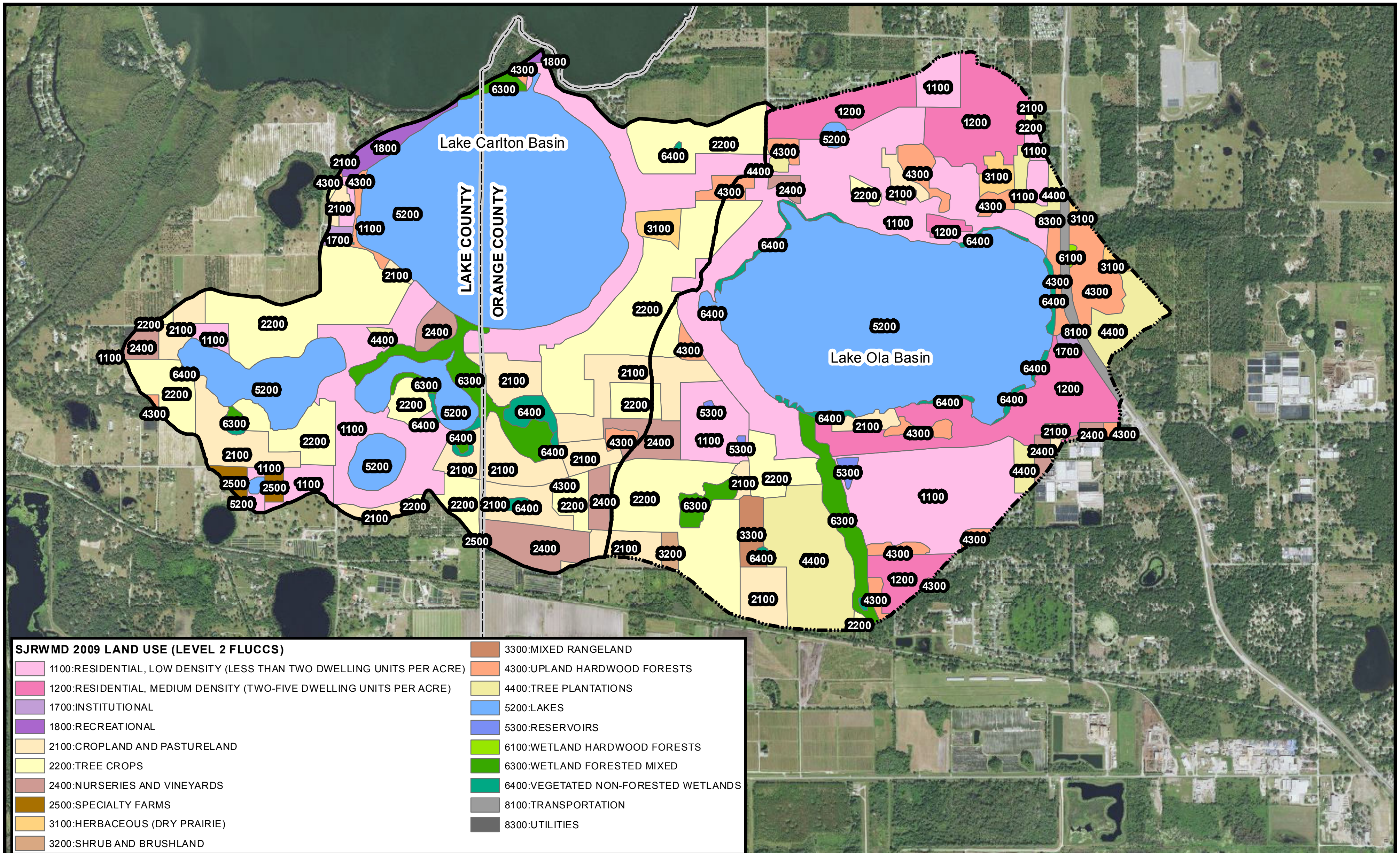
0 2,500
Feet

amec foster wheeler

Amec Foster Wheeler
Environment & Infrastructure, Inc.
2000 E. Edgewood Drive Ste #215
Lakeland, FL 33803
CA-5392
(863) 667-2345

Figure 3-4
Agricultural BMP enrollment
Lake Carlton
Orange/Lake Counties
Florida

Path: V:\600218x9 Lake Carlton\MXDs\New MXDs\Fig3 4_Agricultural BMP enrollment.mxd



Notes:
1- Project No.: 600218x9
2- Data Source - SJRWMD, ESRI 2017 NAIP Imagery, AmecFW
3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 8/22/16
Revised: AB
Checked By : LL

Explanation of Features

N

County Boundary
Lake Carlton Basin
Lake Ola Basin

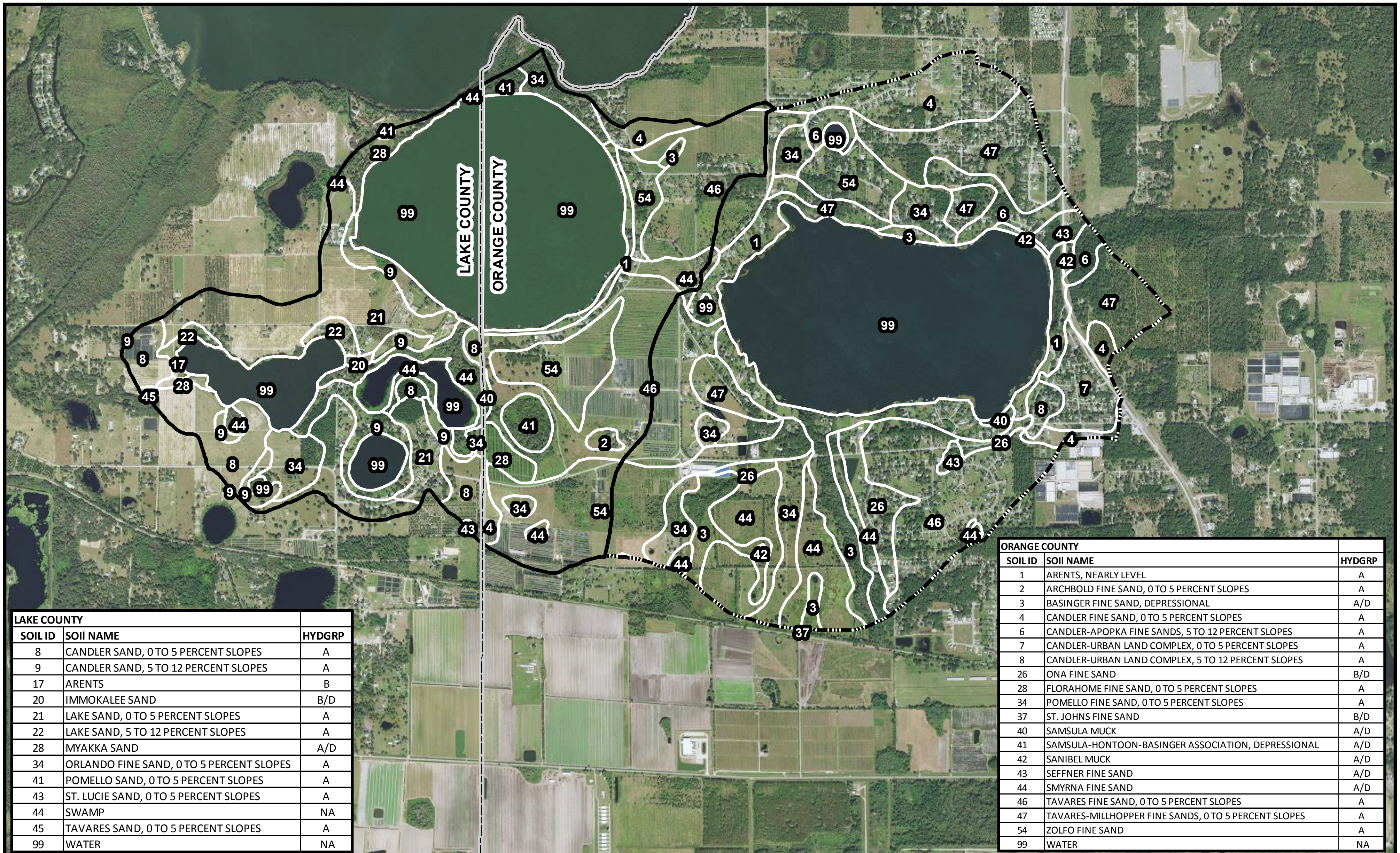
0 2,500
Feet

amec foster wheeler

Amec Foster Wheeler
Environment & Infrastructure, Inc.
2000 E. Edgewood Drive Ste #215
Lakeland, FL 33803
CA-5392
(863) 667-2345

Figure 3-5
Land Use Map
Lake Carlton
Orange/Lake Counties
Florida

File Path: V:\600218x9 Lake Carlton\MXDs\New MXDs\Fig3-5_Lake Carlton_LU_LS.mxd



LAKE COUNTY		
SOIL ID	SOIl NAME	HYDGRP
8	CANDLER SAND, 0 TO 5 PERCENT SLOPES	A
9	CANDLER SAND, 5 TO 12 PERCENT SLOPES	A
17	ARENTS	B
20	IMMOKALEE SAND	B/D
21	LAKE SAND, 0 TO 5 PERCENT SLOPES	A
22	LAKE SAND, 5 TO 12 PERCENT SLOPES	A
28	MYAKKA SAND	A/D
34	ORLANDO FINE SAND, 0 TO 5 PERCENT SLOPES	A
41	POMELLO SAND, 0 TO 5 PERCENT SLOPES	A
43	ST. LUCIE SAND, 0 TO 5 PERCENT SLOPES	A
44	SWAMP	NA
45	TAVARES SAND, 0 TO 5 PERCENT SLOPES	A
99	WATER	NA

ORANGE COUNTY		
SOIL ID	SOIl NAME	HYDGRP
1	ARENTS, NEARLY LEVEL	A
2	ARCHBOLD FINE SAND, 0 TO 5 PERCENT SLOPES	A
3	BASINGER FINE SAND, DEPRESSIONAL	A/D
4	CANDLER FINE SAND, 0 TO 5 PERCENT SLOPES	A
6	CANDLER-APOPKA FINE SANDS, 5 TO 12 PERCENT SLOPES	A
7	CANDLER-URBAN LAND COMPLEX, 0 TO 5 PERCENT SLOPES	A
8	CANDLER-URBAN LAND COMPLEX, 5 TO 12 PERCENT SLOPES	A
26	ONA FINE SAND	B/D
28	FLORAHOME FINE SAND, 0 TO 5 PERCENT SLOPES	A
34	POMELLO FINE SAND, 0 TO 5 PERCENT SLOPES	A
37	ST. JOHNS FINE SAND	B/D
40	SAMSULA MUCK	A/D
41	SAMSULA-HONTOON-BASINGER ASSOCIATION, DEPRESSIONAL	A/D
42	SANIBEL MUCK	A/D
43	SEFFNER FINE SAND	A/D
44	SMYRNA FINE SAND	A/D
46	TAVARES FINE SAND, 0 TO 5 PERCENT SLOPES	A
47	TAVARES-MILLHOPPER FINE SANDS, 0 TO 5 PERCENT SLOPES	A
54	ZOLFO FINE SAND	A
99	WATER	NA

Notes:

1- Project No.: 600218x9

2- Data Source - SJRWMD, ESRI 2017 NAIP Imagery, AmecFW NRCS

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 03/15/18
Revised: AB
Checked By : LL

Explanation of Features

N

Lake Carlton Basin

Lake Ola Basin

County Boundary

0 2,500
Feet

amec foster wheeler

Amec Foster Wheeler
Environment & Infrastructure, Inc.
2000 E. Edgewood Drive Ste #215
Lakeland, FL 33803
CA-5392
(863) 667-2345

Figure 3-6
Soils Map
Lake Carlton
Orange/Lake Counties
Florida

File Path: V:\600218x9 Lake Carlton\MXDs\New MXDs\Fig3-6_Lake Carlton Soils_LS.mxd

Figure 4-1. Monthly Rainfall for Lake Carlton (1995 - 2013)

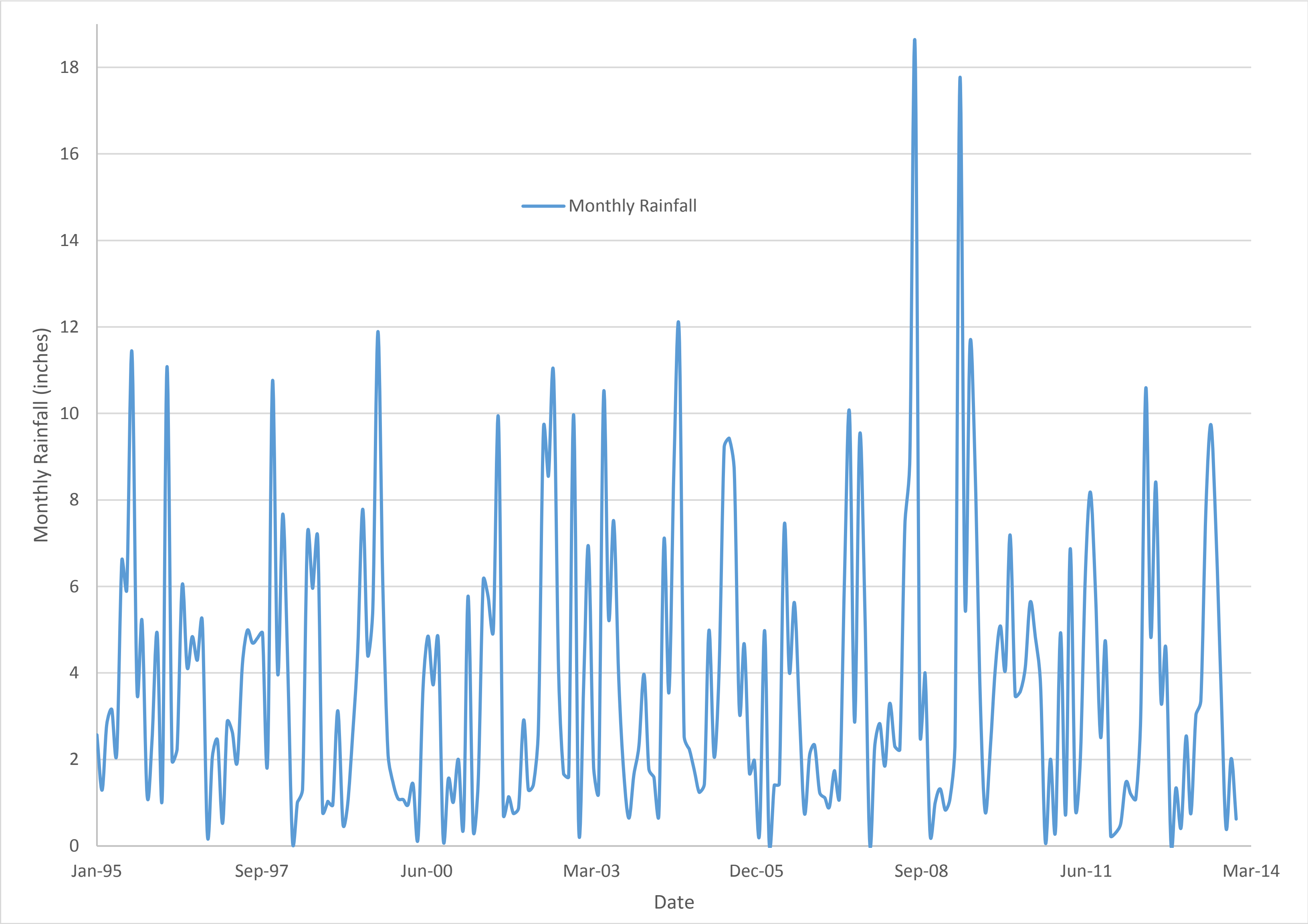
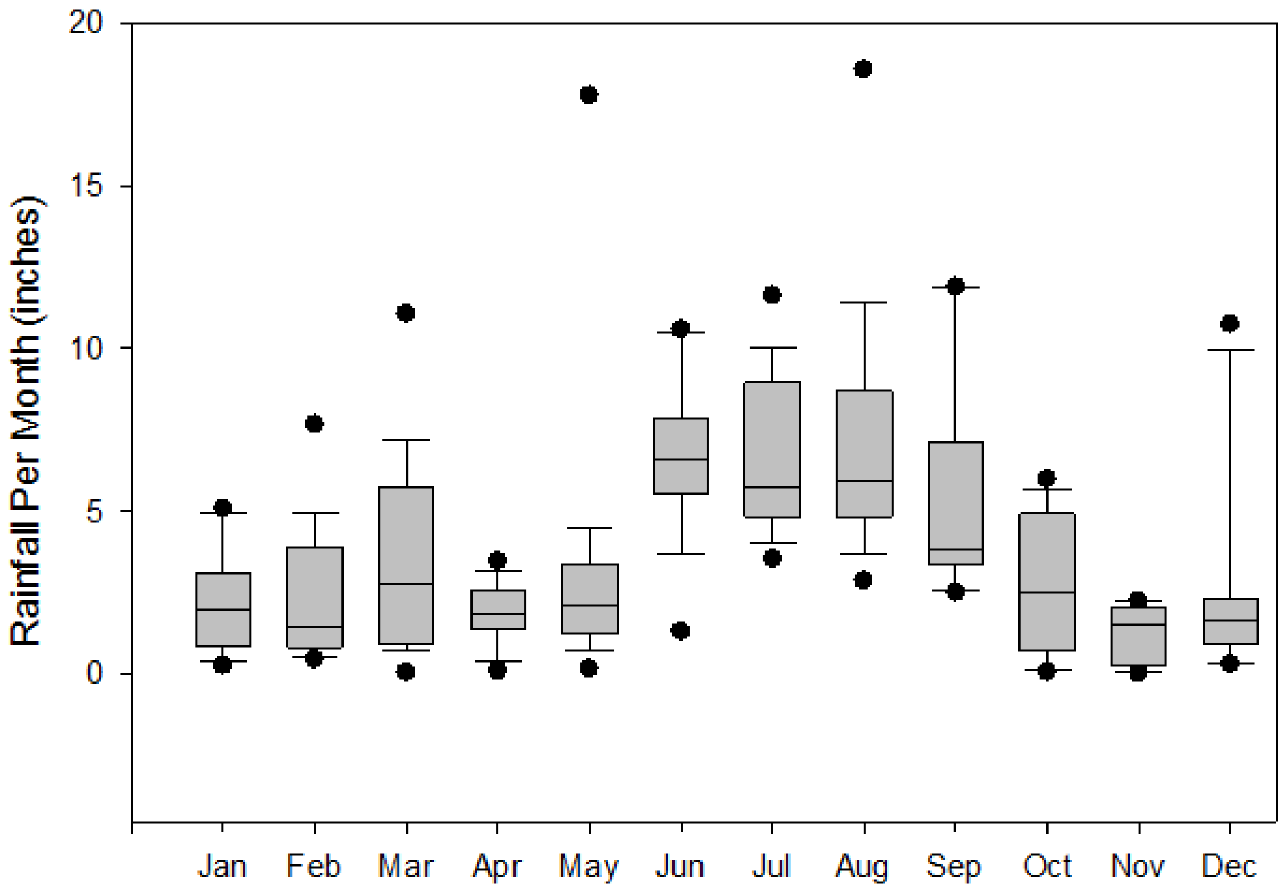
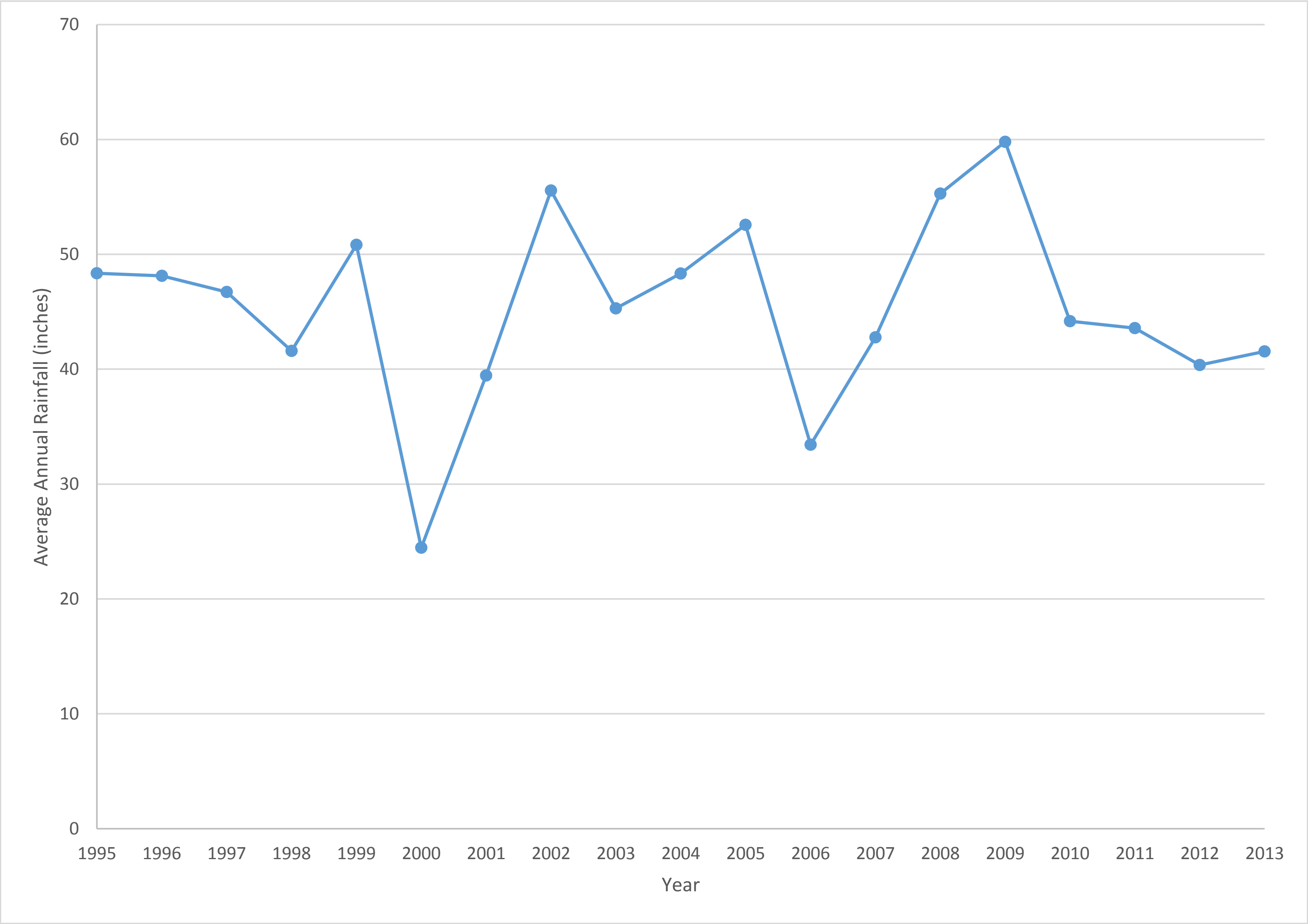


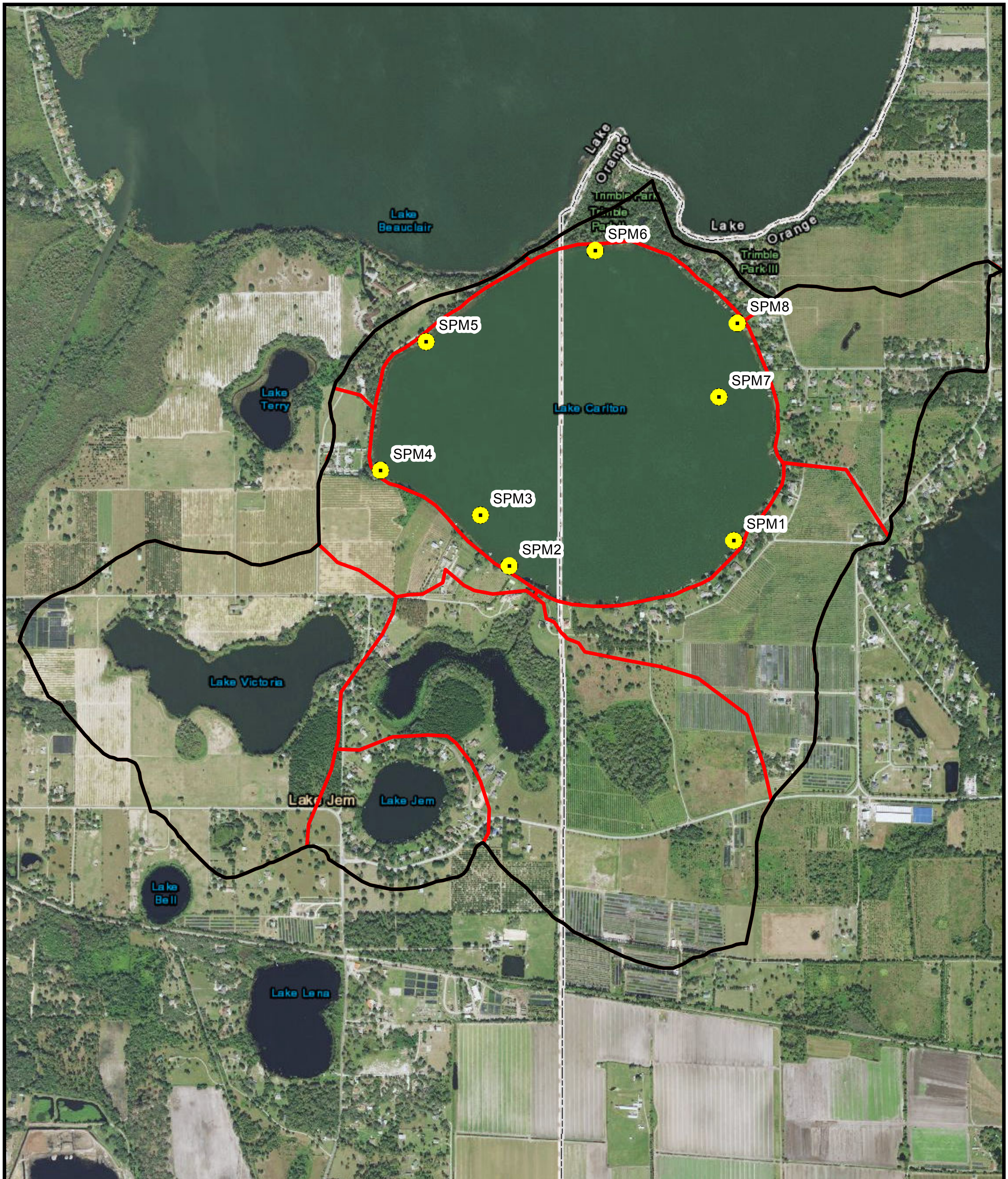
Figure 4-2. Box and Whisker Plot for Monthly Lake Carlton Rainfall (1995 - 2013)



Note - Middle line represents median, and boundary of box indicates 25th and 75th percentile. Whiskers indicate 10th and 90th percentiles. Filled in circles represent 5th and 95th percentiles.

Figure 4-3 Mean Annual Rainfall for Lake Carlton (1995 - 2013)





Notes:
1- Project No.: 600218x9
2- Data Source - SJRWMD, ESRI 2017 NAIP Imagery, AmecFW
3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 03/16/18
Revised: SF
Checked By: AB

Explanation of Features

N

- Seepage Meters
- Lake Carlton Basin
- Revised Sub-basin Boundary
- County Boundary

0 1,000
Feet

amec foster wheeler

Amec Foster Wheeler
Environment & Infrastructure, Inc.
2000 E. Edgewood Drive Ste #215
Lakeland, FL 33803
CA-5392
(863) 667-2345

Figure 4-4
Seepage Meter Locations
Lake Carlton
Orange/Lake Counties
Florida

Path: V:\600218x9 Lake Carlton\MXDs\New MXDs\Fig4-4_Lake Carlton_seepage.mxd

Figure 4-5. Typical Seepage Meter Installation

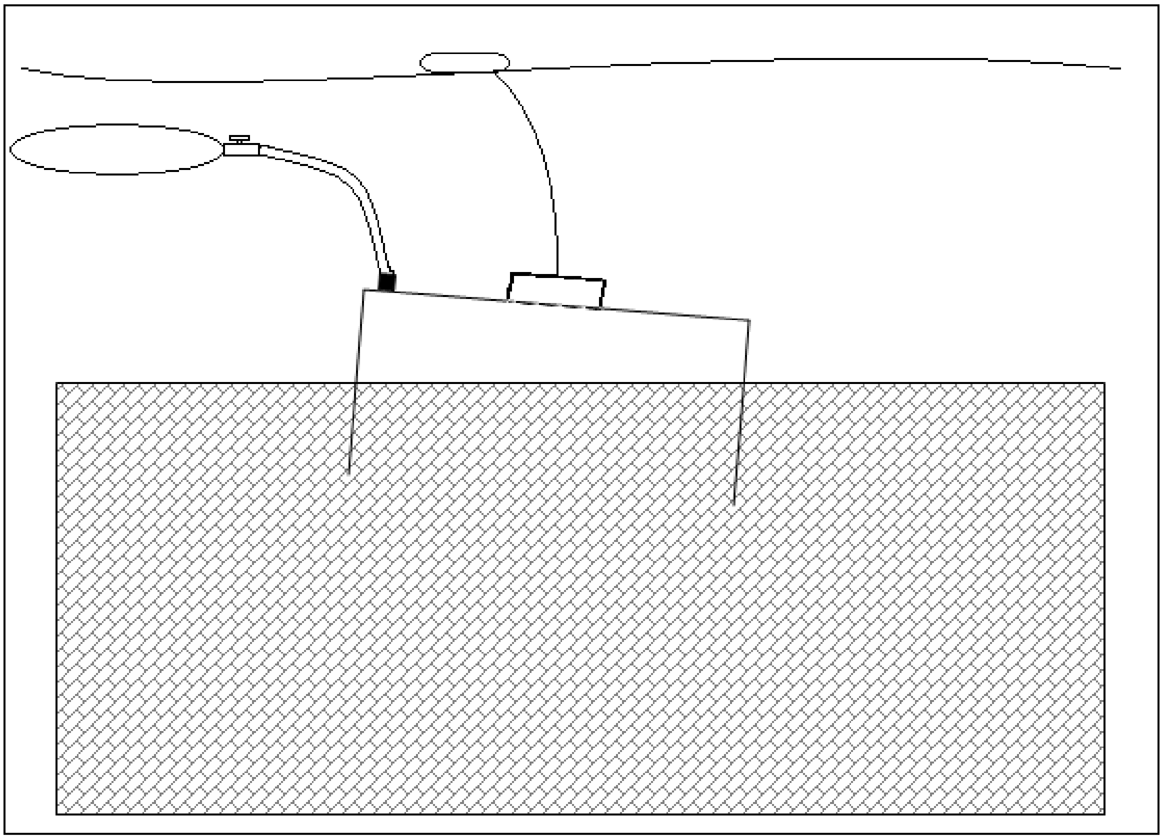


Figure 4-6. Lake Carlton Hydrologic Inputs

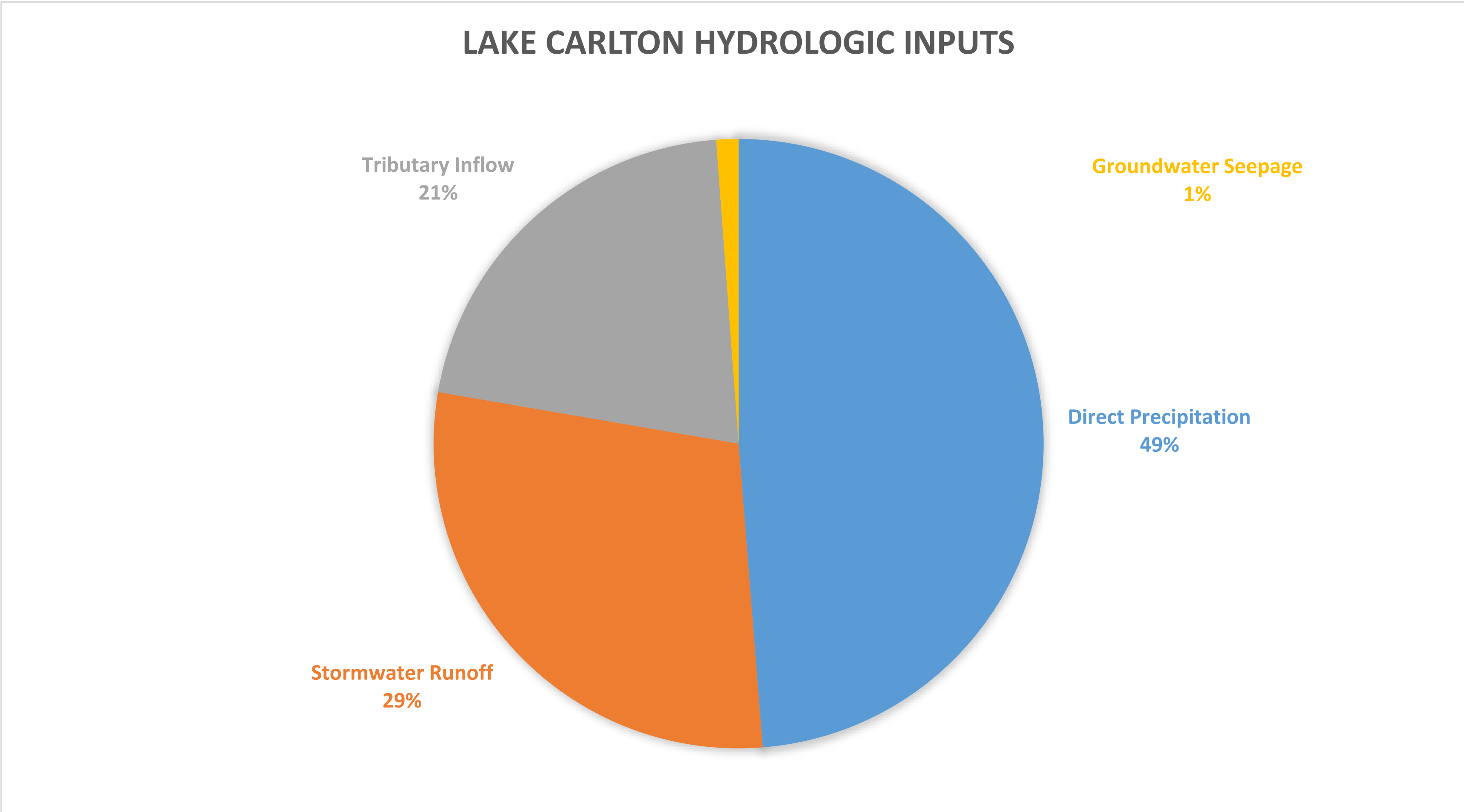
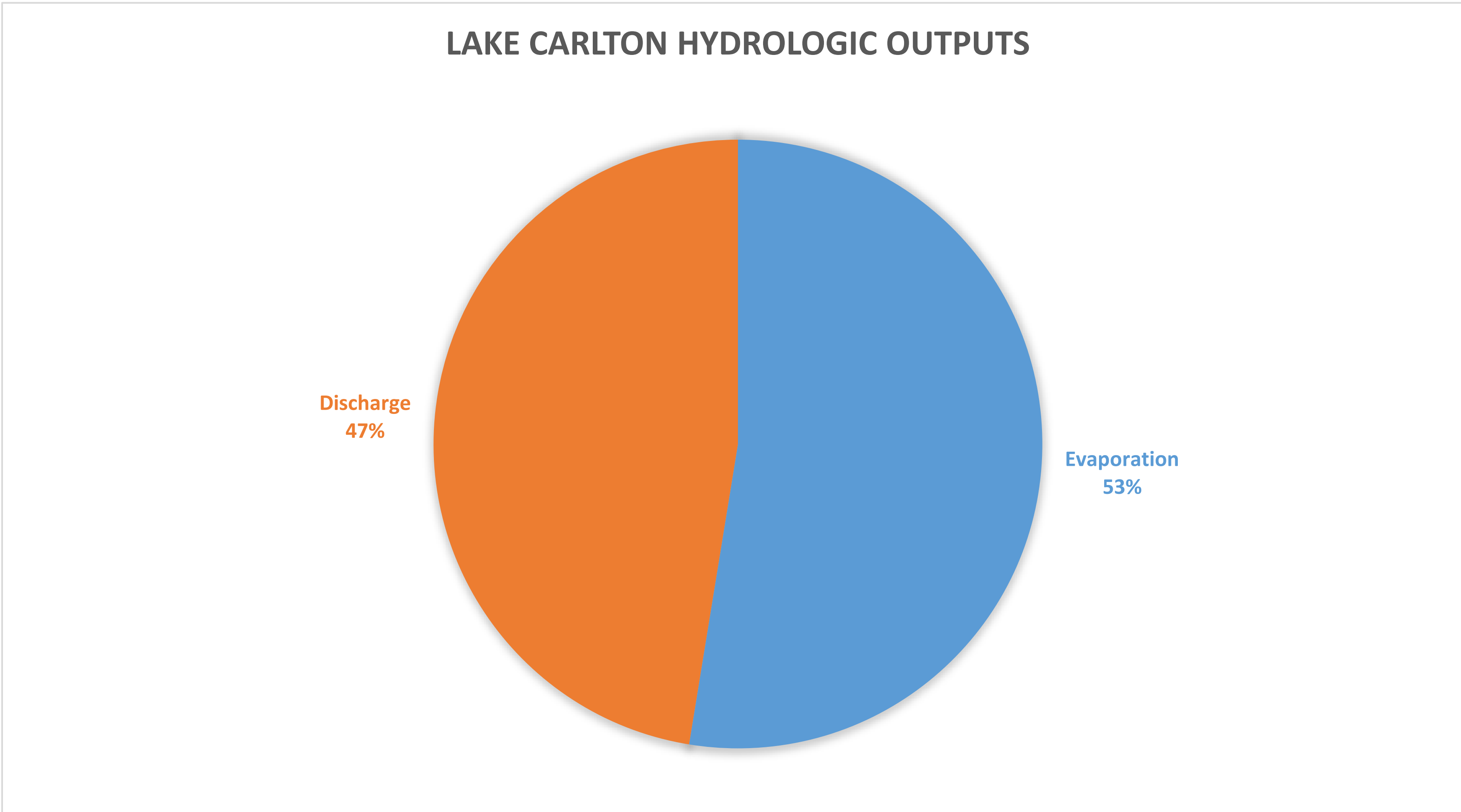
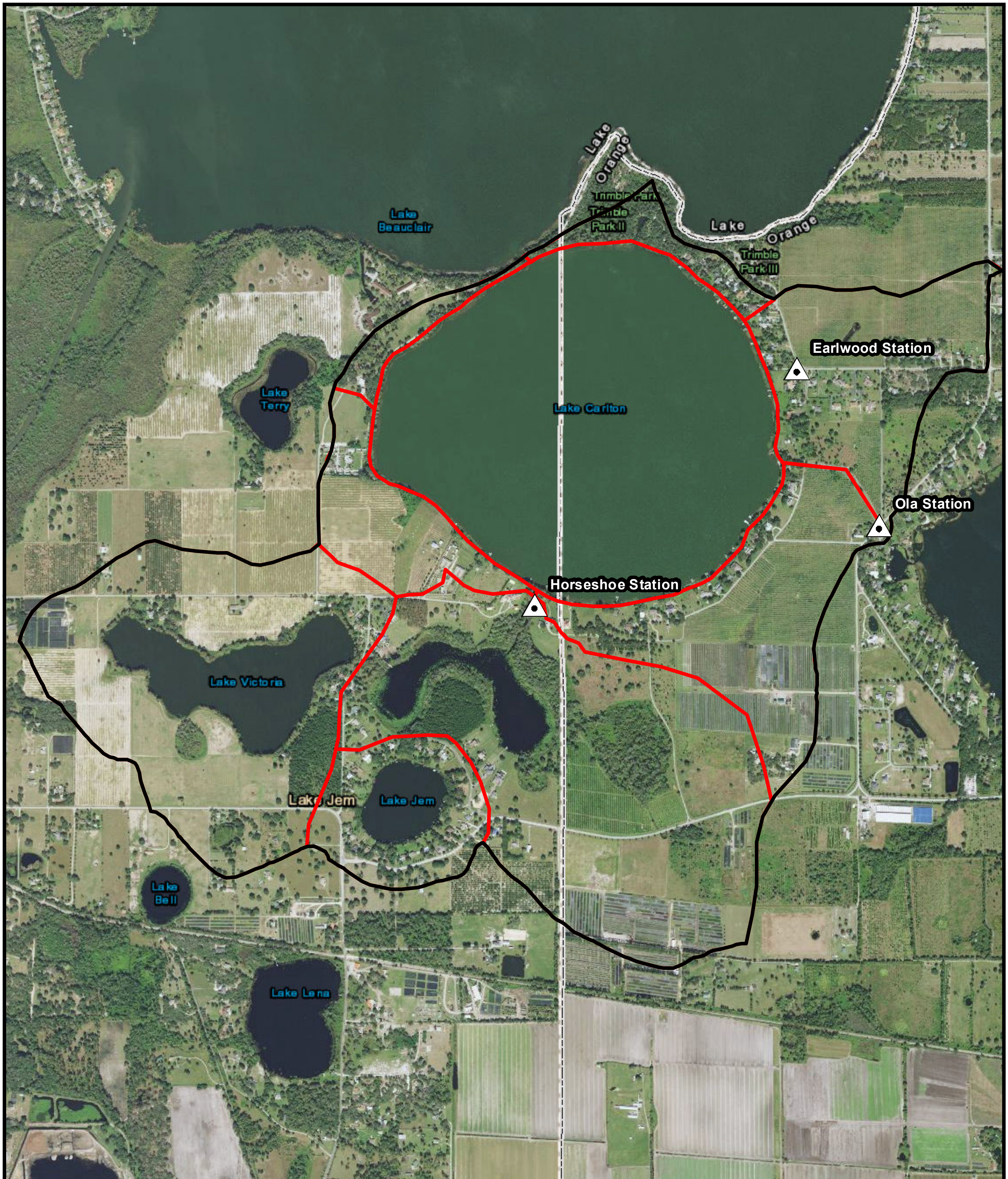


Figure 4-7. Lake Carlton Hydrologic Outputs





Notes:

1- Project No.: 600218x9

2- Data Source - SJRWMD, ESRI 2017 NAIP Imagery, AmecFW

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 03/16/2018
Revised: SF
Checked By: AB

Explanation of Features

N

Stormwater Autosampler

Lake Carlton Basin

Revised Sub-basin Boundary

County Boundary

0 1,000
Feet

amec foster wheeler

Amec Foster Wheeler
Environment & Infrastructure, Inc.
2000 E. Edgewood Drive Ste #215
Lakeland, FL 33803
CA-5392
(863) 667-2345

Figure 5-1
Autosampler Locations
Lake Carlton
Orange/Lake Counties
Florida

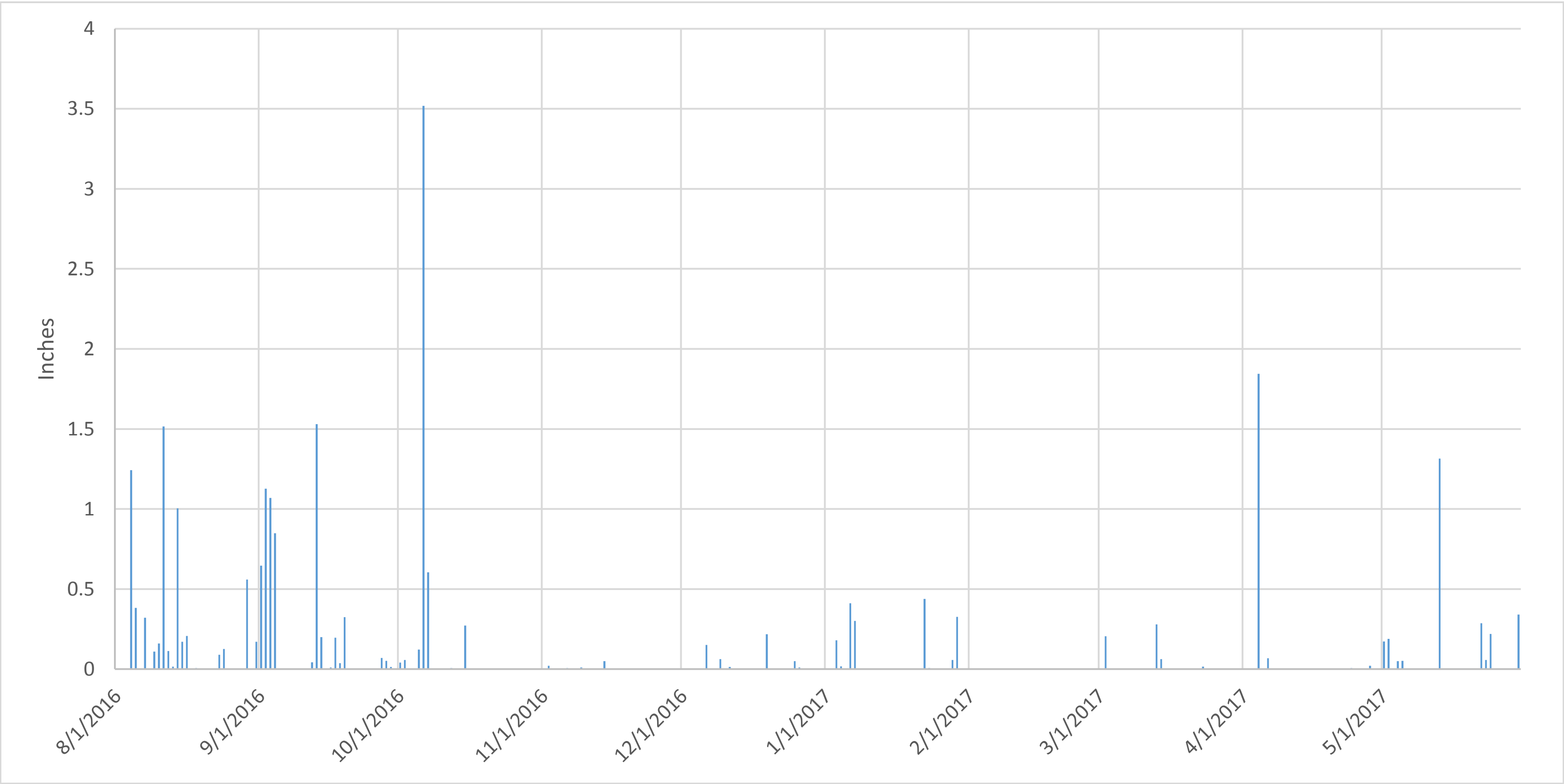
Path: V:\600218x9 Lake Carlton\MXDs\New MXDs\Fig5-1_Lake Carlton_stormwaterstations.mxd

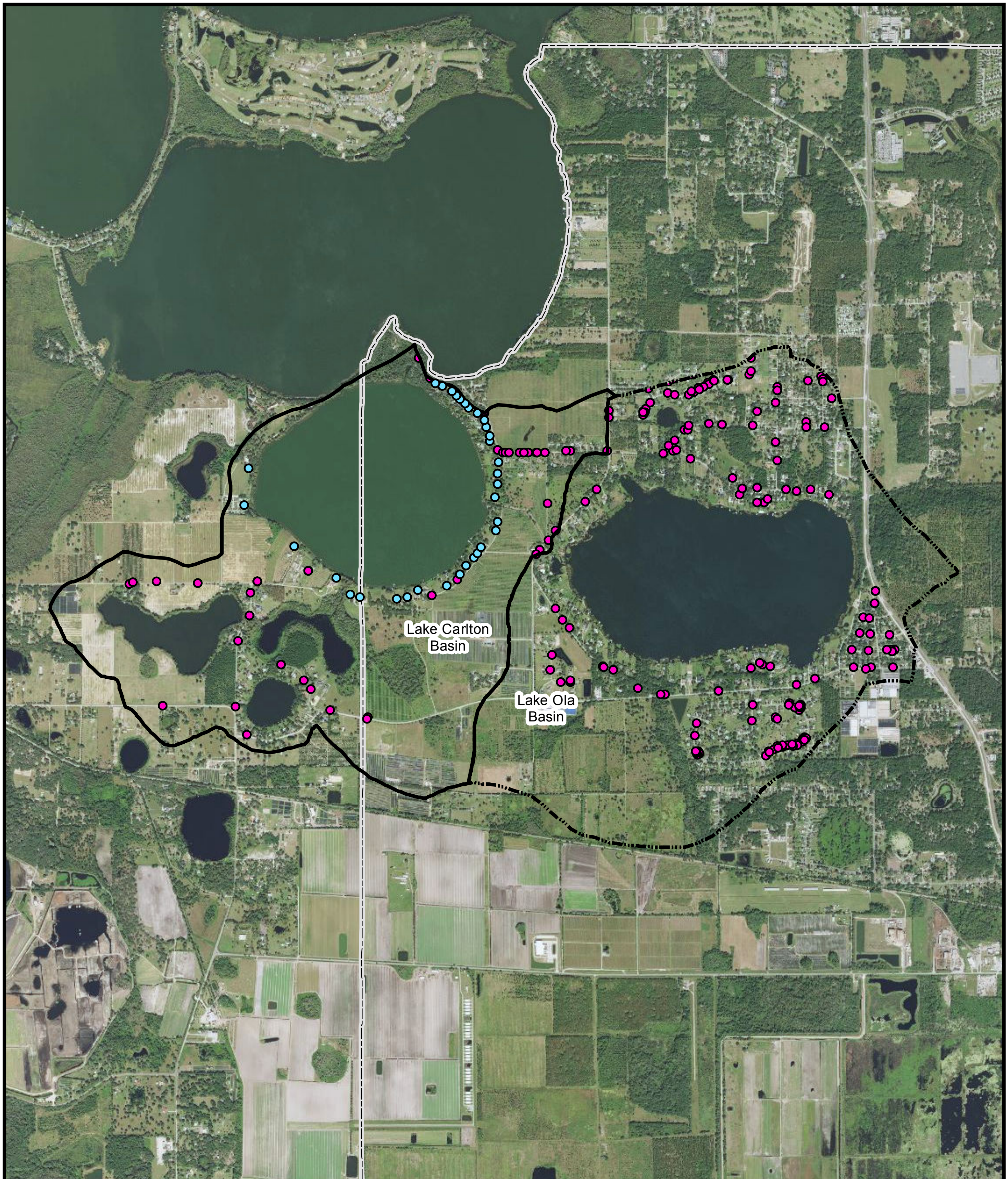
Figure 5-2. Earlwood Avenue Outfall sampling location.

Figure 5-3. Lake Ola Discharge Sampling Location

Figure 5-4. Horseshoe Lake Discharge Sampling Location

Figure 5-5. Daily Rainfall During Sampling Period Rainfall for Lake Carlton Basin





Notes:

1- Project No.: 600218x9

2- Data Source - SJRWMD
2017 NAIP Imagery
FDOH Septic (2013)

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 03/15/18
Revised: AB
Checked By:

Explanation of Features

N

- Assumed Septic Tanks
- Septic Locations
- Lake Carlton Basin
- Lake Ola Basin
- County Boundary

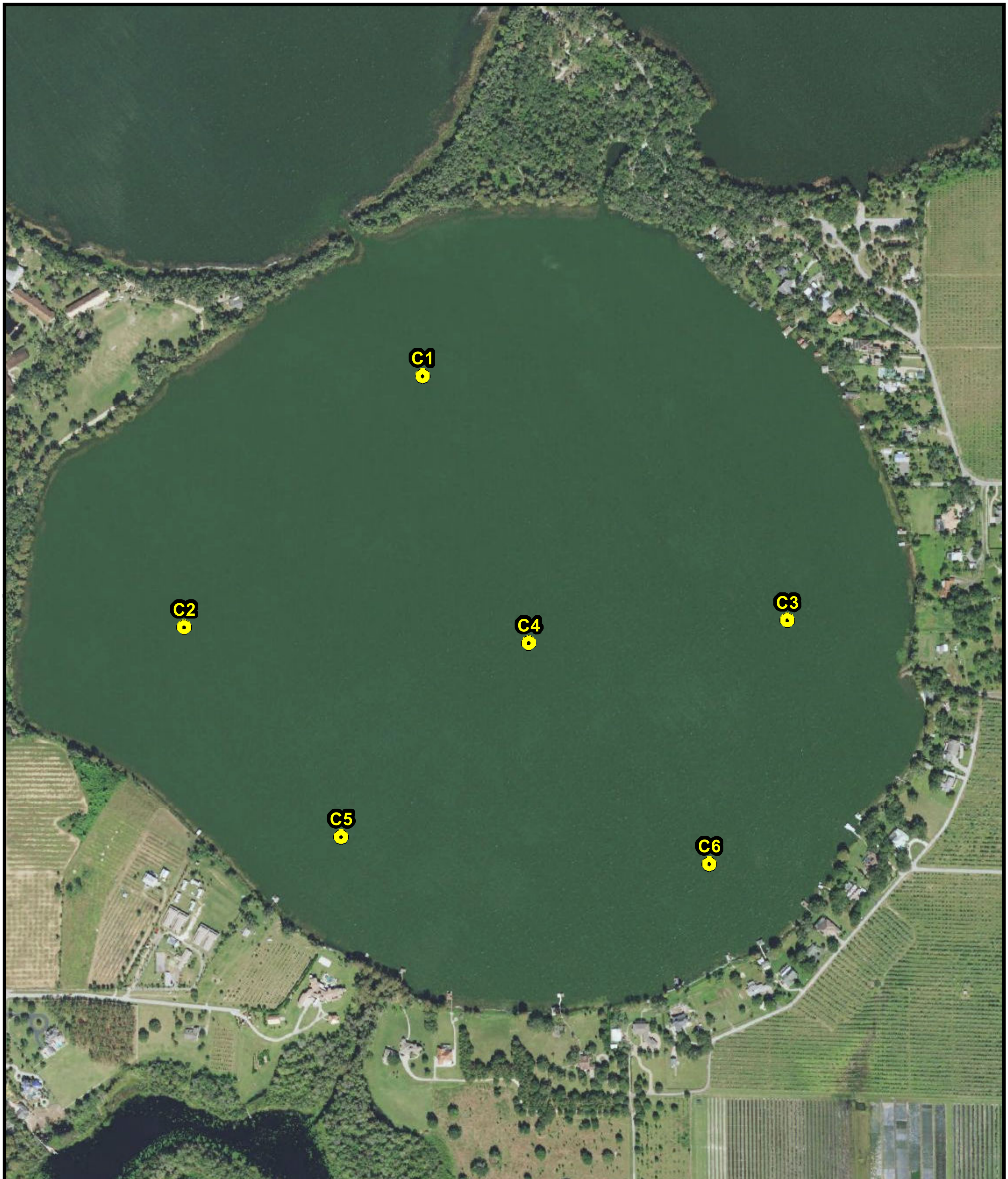
0 2,500
Feet

amec foster wheeler

Amec Foster Wheeler
Environment & Infrastructure, Inc.
2000 E. Edgewood Drive Ste #215
Lakeland, FL 33803
CA-5392
(863) 667-2345

Figure 5-6
Septic Location Map
Lake Carlton
Orange/Lake Counties
Florida

Path: V:\600218x9 Lake Carlton\MXDs\New MXDs\Fig5-6_SepticMap.mxd



Notes:

1- Project No.: 600218x9

2- Data Source - SJRWMD, ESRI 2017 NAIP Imagery, AmecFW

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 08/30/2017
Revised: AB
Checked By: LL

Explanation of Features

N

Sediment Core Locations

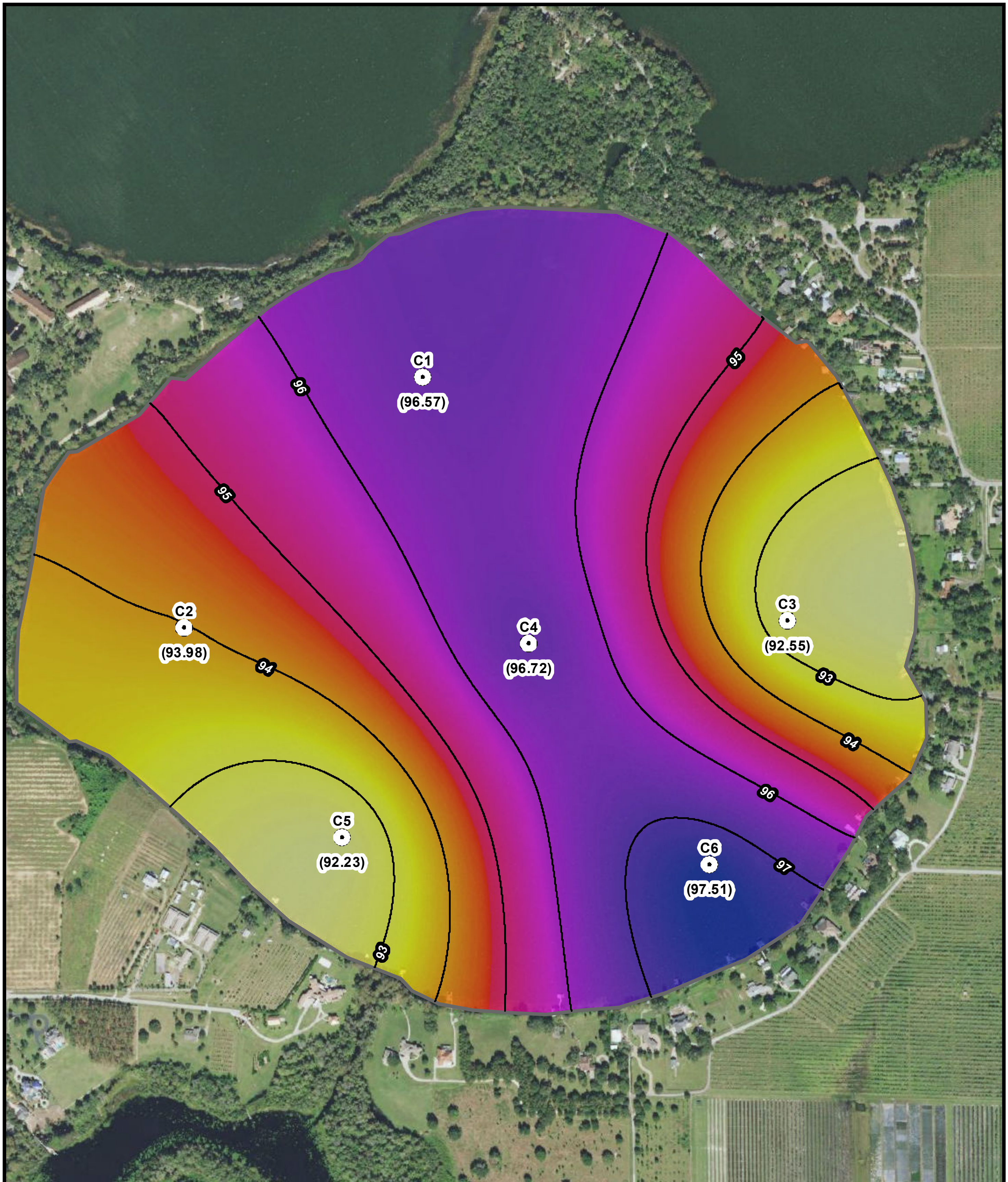
0 600
Feet

amec foster wheeler

Amec Foster Wheeler
Environment & Infrastructure, Inc.
2000 E. Edgewood Drive Ste #215
Lakeland, FL 33803
CA-5392
(863) 667-2345

Figure 6-1
Sediment Core Locations
Lake Carlton
Orange/Lake Counties
Florida

Path: V:\600218x9 Lake Carlton\MXDs\New MXDs\Fig6-1_Lake Carlton Core Locations.mxd



Notes:

1- Project No.: 600218x9

2- Data Source - AmecFW 2017 NAIP Imagery

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 08/30/2017
Revised: AB
Checked By: LL

Explanation of Features

N

Sample Locations

Percent Moisture Contours

Lake Carlton

% Moisture

High : 97.5

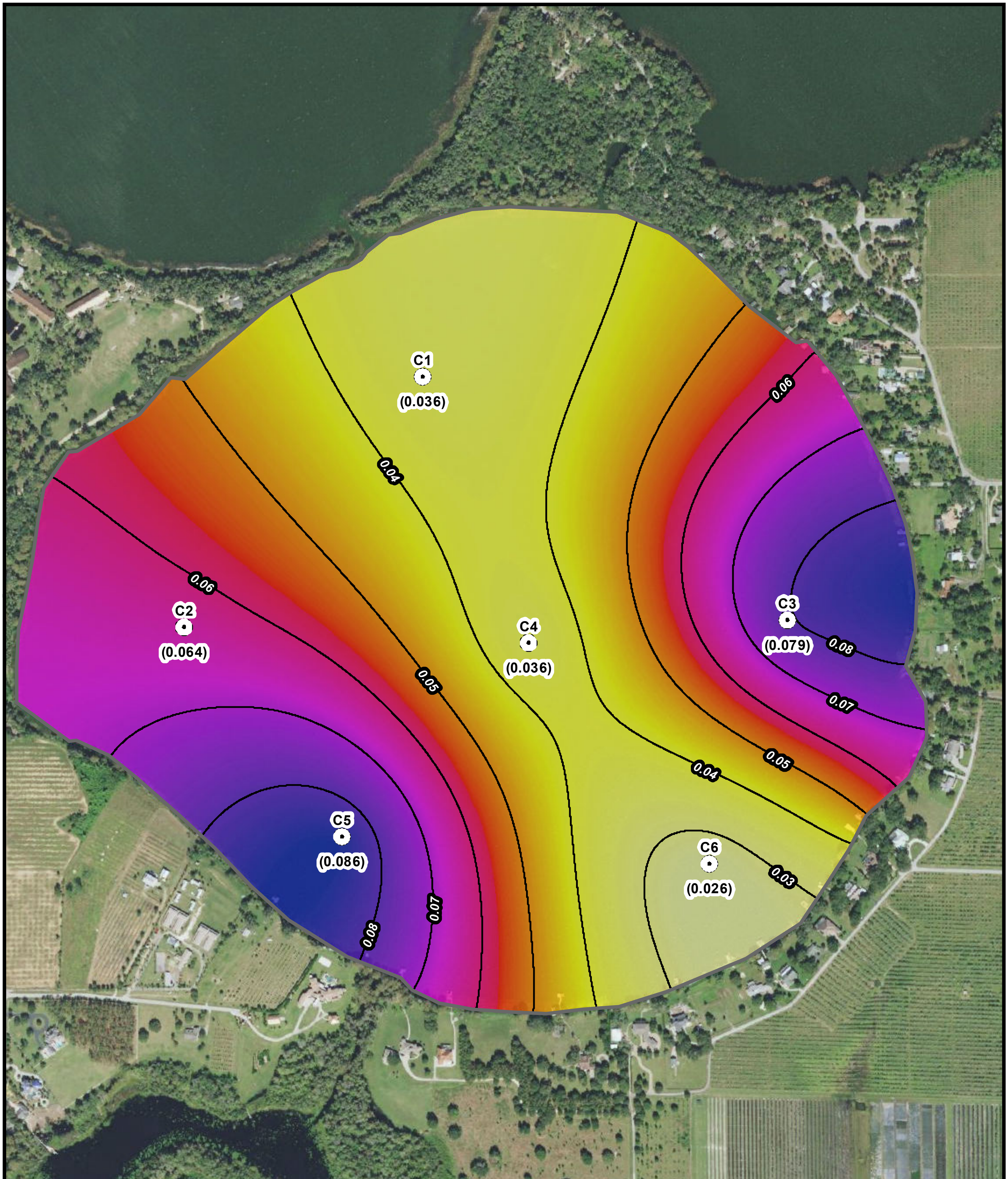
Low : 92.2

0 600
Feet

Amec Foster Wheeler
Environment & Infrastructure, Inc.
2000 E. Edgewood Drive Ste #215
Lakeland, FL 33803
CA-5392
(863) 667-2345

Figure 6-2
Percent Moisture
Lake Carlton
Orange/Lake Counties
Florida

Path: V:\600218x9 Lake Carlton\MXDs\New MXDs\Fig6-2_Perc_Moisture.mxd



Notes:

1- Project No.: 600218x9

2- Data Source - AmecFW 2017 NAIP Imagery

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 08/30/2017
Revised: AB
Checked By: LL

Explanation of Features

N

Sample Locations

Lake Carlton

Bulk Density Contours

Bulk Density %

High : 0.086

Low : 0.026

0 600

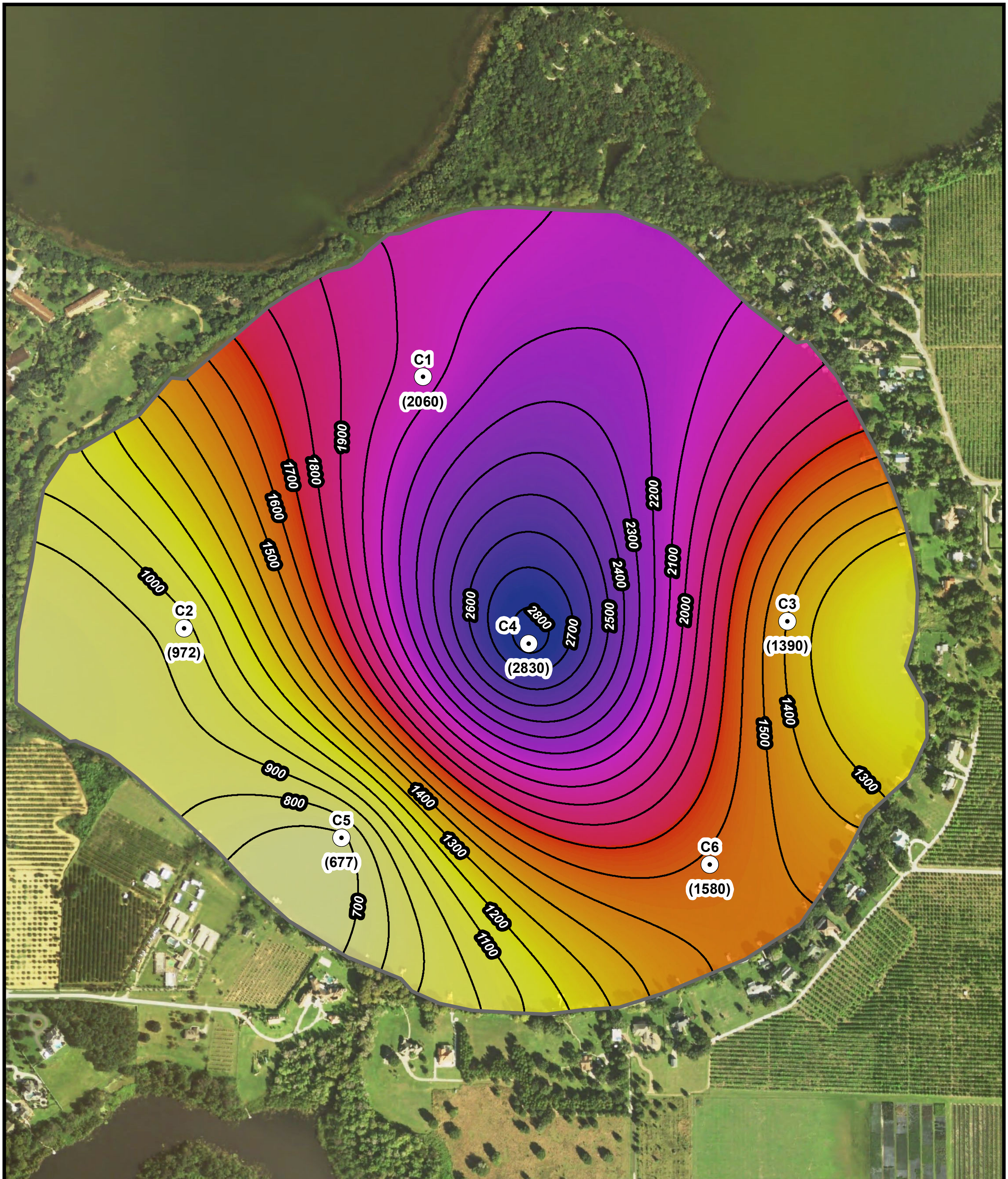
Feet

amec foster wheeler

Amec Foster Wheeler
Environment & Infrastructure, Inc.
2000 E. Edgewood Drive Ste #215
Lakeland, FL 33803
CA-5392
(863) 667-2345

Figure 6-3
Bulk Density (Percent)
Lake Carlton
Orange/Lake Counties
Florida

Path: V:\600218x9 Lake Carlton\MXDs\New MXDs\Fig6-3_Bulk_Density.mxd



Notes:

1- Project No.: 600218x9

2- Data Source - AmecFW 2015 NAIP Imagery

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 08/30/2017
Revised: AB
Checked By: LL

Explanation of Features

N

Sample Locations

Lake Carlton

Total Phosphorous Contours

Total Phosphorous

High : 2830

Low : 677

0 600

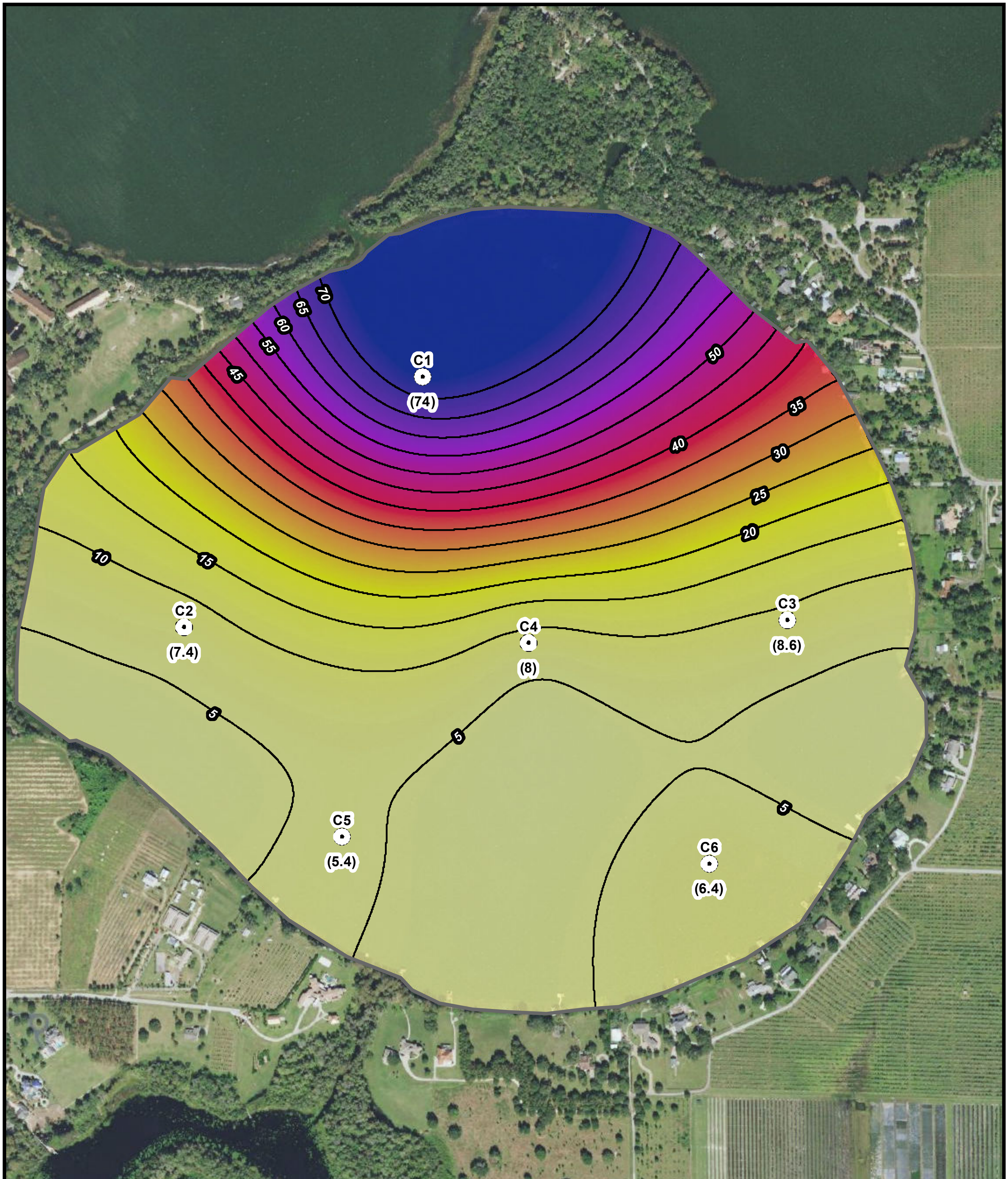
Feet

amec foster wheeler

Amec Foster Wheeler
Environment & Infrastructure, Inc.
2000 E. Edgewood Drive Ste #215
Lakeland, FL 33803
CA-5392
(863) 667-2345

Figure 6-4
Total Phosphorus
(mg/kg dry)
Lake Carlton
Orange/Lake Counties
Florida

Path: V:\600218x9 Lake Carlton\MXDs\New MXDs\FigX_Total_P.mxd



Notes:

1- Project No.: 600218x9

2- Data Source - AmecFW 2017 NAIP Imagery

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 08/30/2017
Revised: AB
Checked By: LL

Explanation of Features

N

Sample Locations

Saloid Bound P Contours

Lake Carlton

Saloid Bound P

High : 74

Low : 5.4

0 600

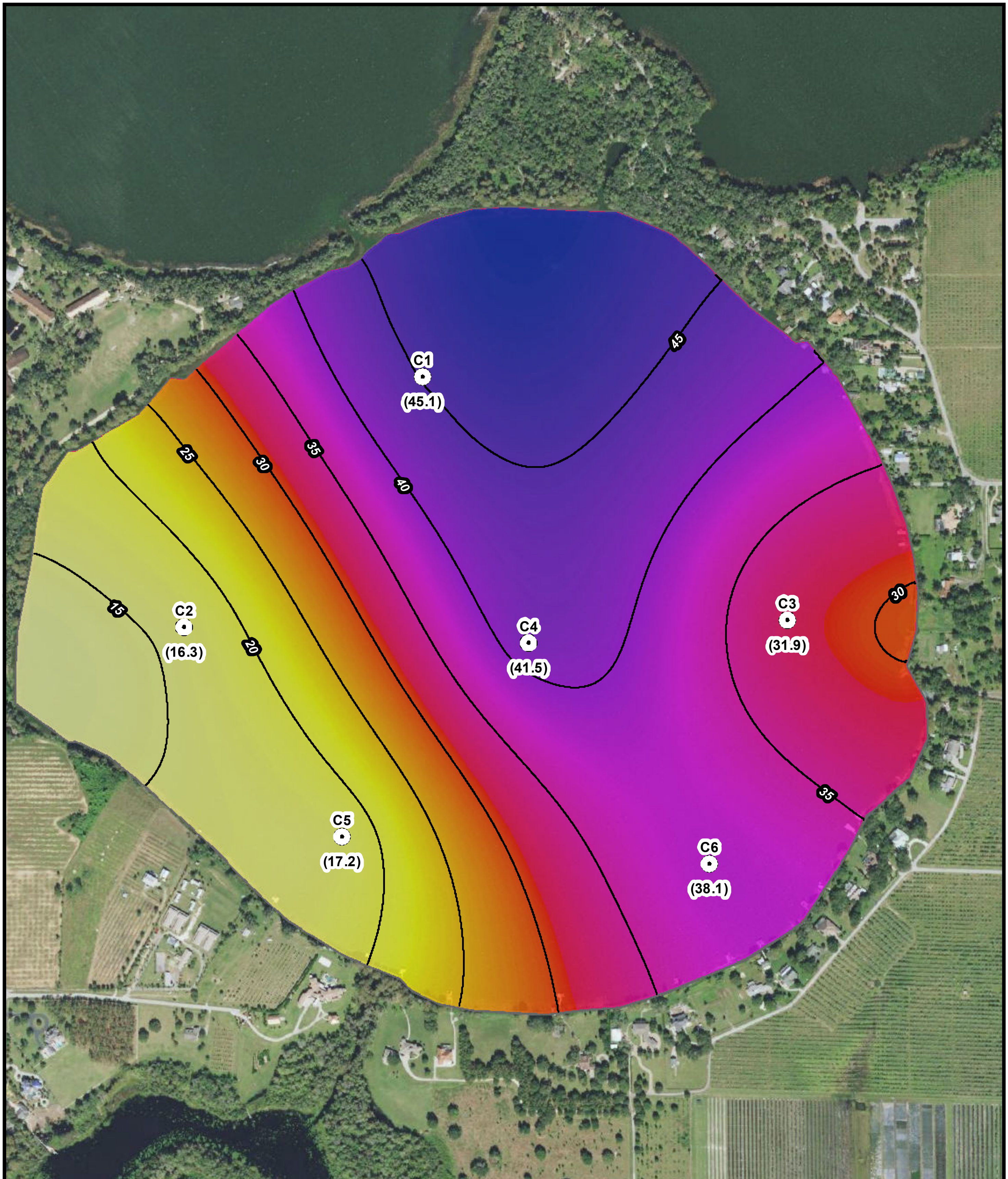
Feet

amec foster wheeler

Amec Foster Wheeler
Environment & Infrastructure, Inc.
2000 E. Edgewood Drive Ste #215
Lakeland, FL 33803
CA-5392
(863) 667-2345

Figure 6-5
Saloid Bound P
(mg/kg dry)
Lake Carlton
Orange/Lake Counties
Florida

Path: V:\600218x9 Lake Carlton\MXDs\New MXDs\Fig6-5_Saloid.mxd



Notes:

1- Project No.: 600218x9

2- Data Source - AmecFW 2017 NAIP Imagery

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 08/30/2017
Revised: AB
Checked By: LL

Explanation of Features

N

Sample Locations

Aluminium Phosphate

Lake Carlton

Iron Phosphate

High : 45.1

Low : 16.3

0 600

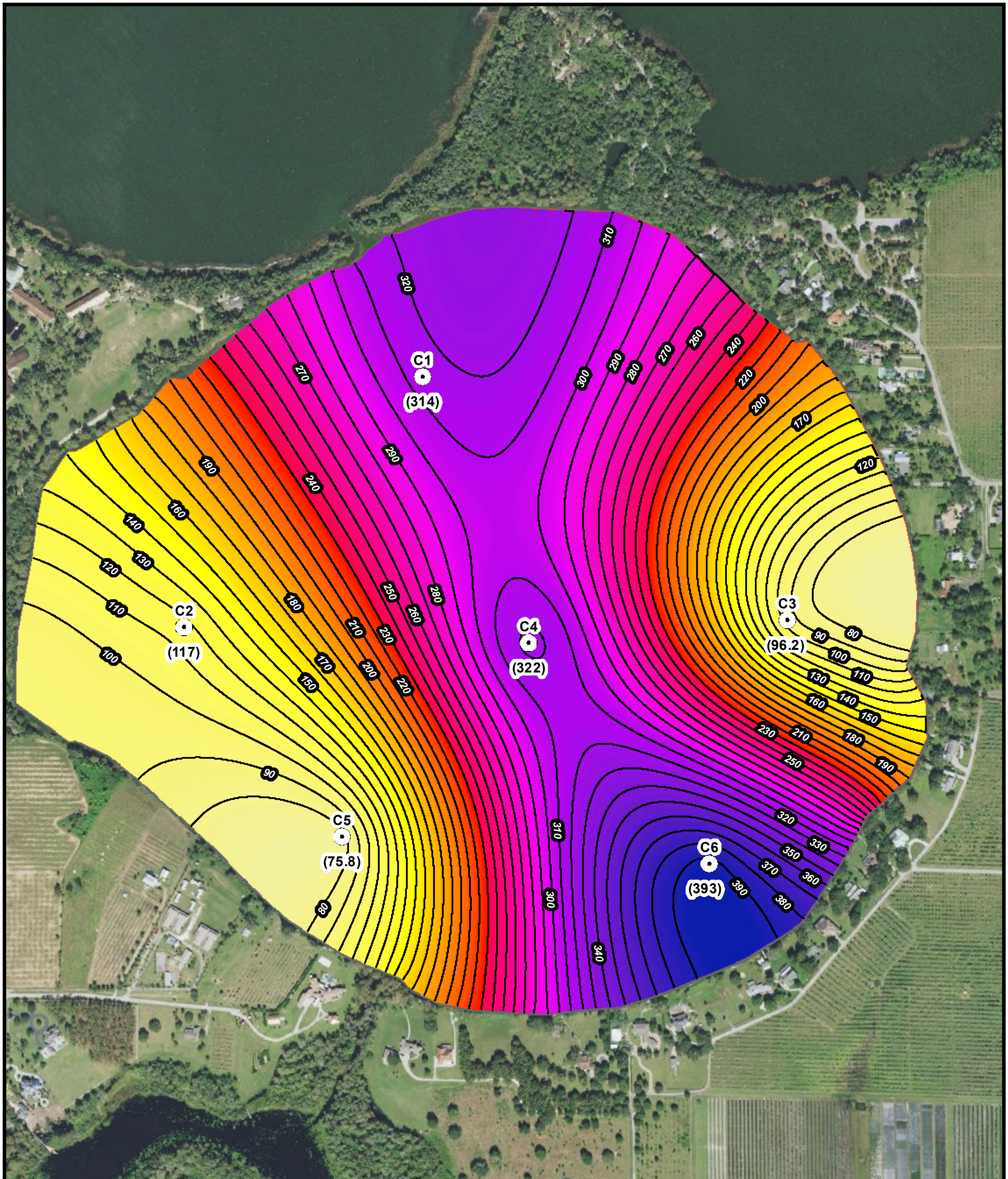
Feet

amec foster wheeler

Amec Foster Wheeler
Environment & Infrastructure, Inc.
2000 E. Edgewood Drive Ste #215
Lakeland, FL 33803
CA-5392
(863) 667-2345

Figure 6-6
Iron Phosphate
(mg/kg dry)
Lake Carlton
Orange/Lake Counties
Florida

Path: V:\600218x9 Lake Carlton\MXDs\New MXDs\Fig6-6_Fe_Phos.mxd



Notes:

1- Project No.: 600218x9

2- Data Source - AmecFW 2017 NAIP Imagery

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 08/30/2017
Revised: AB
Checked By: LL

Explanation of Features

N

Sample Locations

Reductant Soluble Phosphate Contours

Lake Carlton

Reductant Soluble Phosphate

High : 393

Low : 75.8

0 600

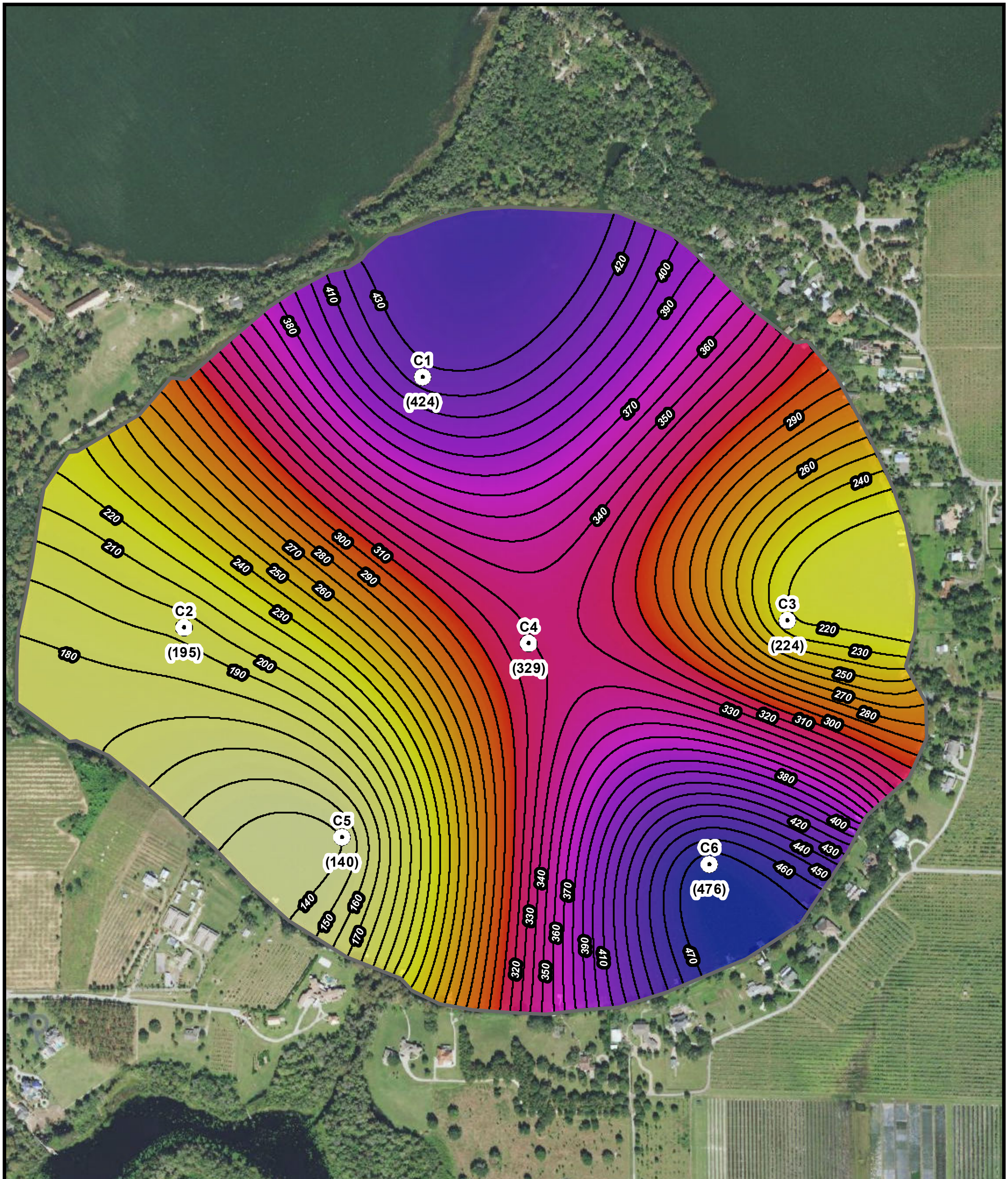
Feet

amec foster wheeler

Amec Foster Wheeler
Environment & Infrastructure, Inc.
2000 E. Edgewood Drive Ste #215
Lakeland, FL 33803
CA-5392
(863) 667-2345

Figure 6-7
Reductant Soluble Phosphate (mg/kg dry)
Lake Carlton
Orange/Lake Counties
Florida

Path: V:\600218x9 Lake Carlton\MXDs\New MXDs\Fig6-7_red_sol_phos.mxd



Notes:

1- Project No.: 600218x9

2- Data Source - AmecFW 2017 NAIP Imagery

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 08/30/2017
Revised: AB
Checked By: LL

Explanation of Features

N

Sample Locations

Lake Carlton

Aluminium Phosphate Contours

Aluminium Phosphate

High : 476

Low : 140

0 600

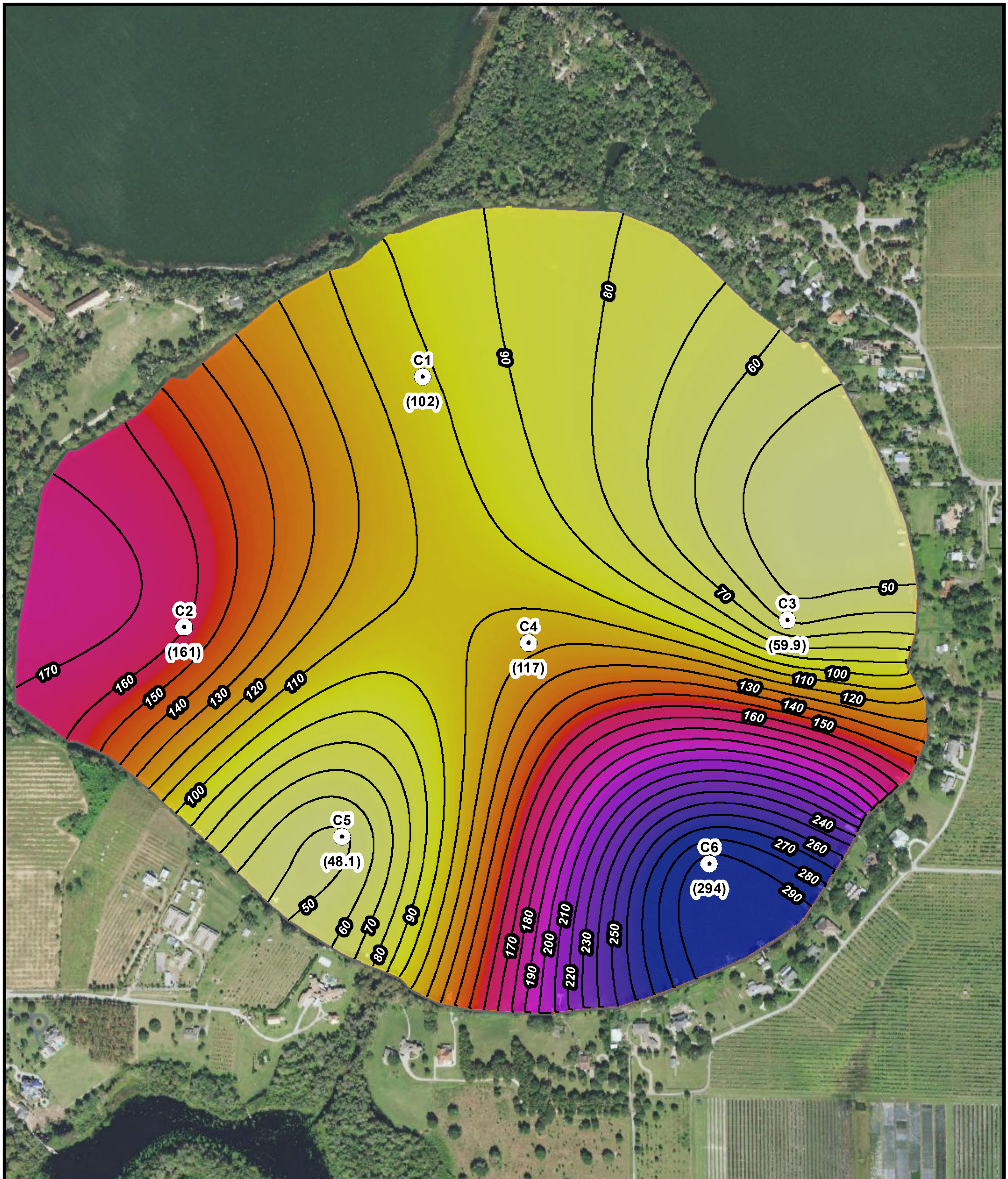
Feet

amec foster wheeler

Amec Foster Wheeler
Environment & Infrastructure, Inc.
2000 E. Edgewood Drive Ste #215
Lakeland, FL 33803
CA-5392
(863) 667-2345

Figure 6-8
Aluminum Phosphate (mg/kg dry)
Lake Carlton
Orange/Lake Counties
Florida

Path: V:\600218x9 Lake Carlton\MXDs\New MXDs\Fig6-8_Al_Phos.mxd



Notes:

1- Project No.: 600218x9

2- Data Source - AmecFW 2017 NAIP Imagery

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 08/30/2017
Revised: AB
Checked By: LL

Explanation of Features

N

Sample Locations

Calcium Phosphate Contours

Lake Carlton

Calcium Phosphate

High : 294

Low : 48.1

0 600

Feet

amec foster wheeler

Amec Foster Wheeler
Environment & Infrastructure, Inc.
2000 E. Edgewood Drive Ste #215
Lakeland, FL 33803
CA-5392
(863) 667-2345

Figure 6-9
Calcium Phosphate (mg/kg dry)
Lake Carlton
Orange/Lake Counties
Florida

Notes:

1- Project No.: 600218x9

2- Data Source - SJRWMD, ESRI 2017 NAIP Imagery, AmecFW

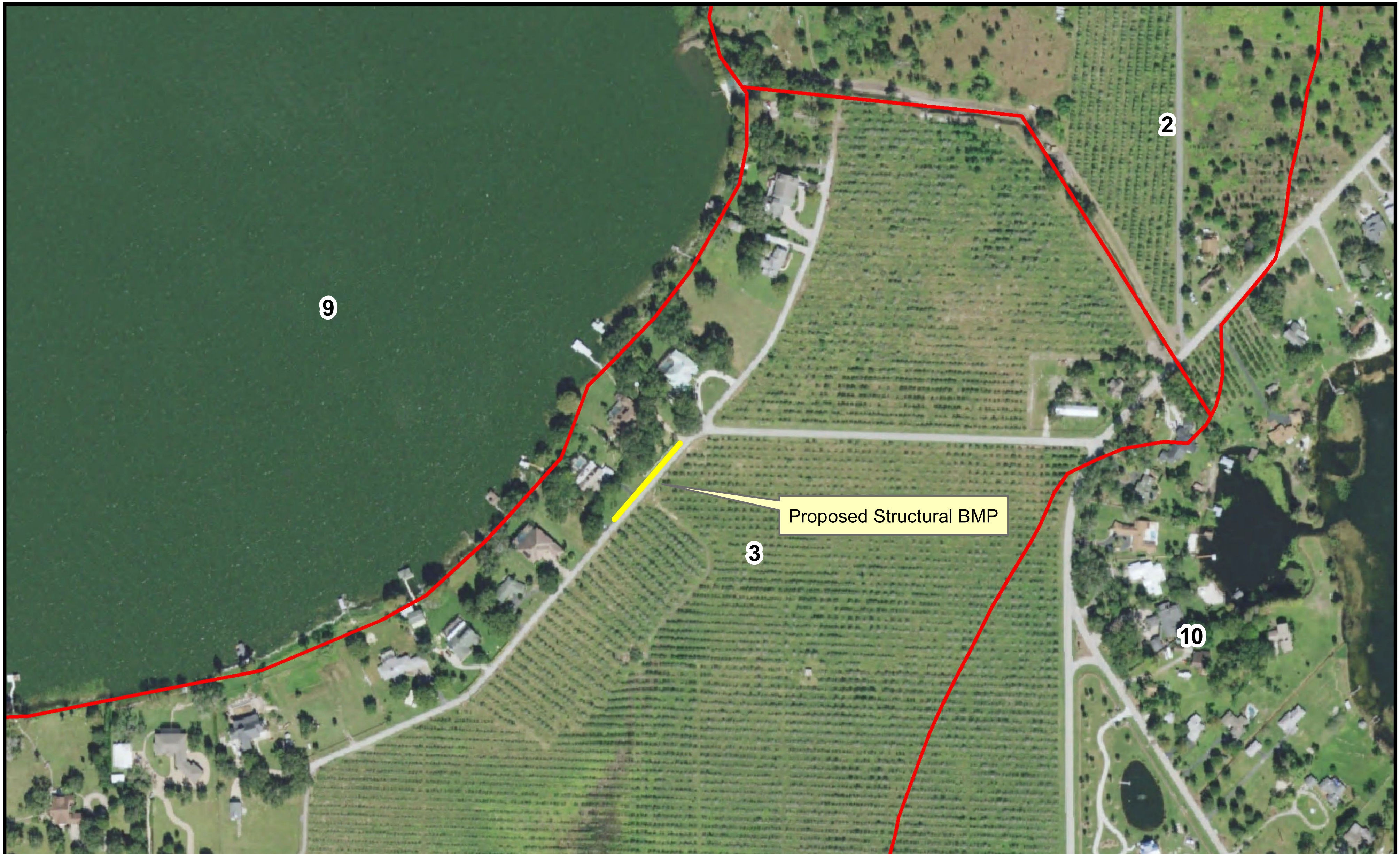
3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 8/22/16
Revised: AB
Checked By:

amec foster wheeler
Amec Foster Wheeler
Environment & Infrastructure, Inc.
2000 E. Edgewood Drive Ste #215
Lakeland, FL 33803
CA-5392
(863) 667-2345

Figure 7-1
Alternative 3
Modular Biofilter
Lake Carlton
Orange/Lake Counties
Florida

File Path: V:\600218x9 Lake Carlton\MXDs\New MXDs\Fig7-1_Lake Carlton BasinAlt3.mxd



Notes:

1- Project No.: 600218x9

2- Data Source - SJRWMD, ESRI 2017 NAIP Imagery, AmecFW

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 8/22/16
Revised: AB
Checked By:

Explanation of Features

N

Exfiltration BMP

Revised Sub-basin Boundary

0 500
Feet

amec foster wheeler

Amec Foster Wheeler
Environment & Infrastructure, Inc.
2000 E. Edgewood Drive Ste #215
Lakeland, FL 33803
CA-5392
(863) 667-2345

Figure 7-2
Alternative 4
Exfiltration
Lake Carlton
Orange/Lake Counties
Florida

File Path: V:\600218x9 Lake Carlton\MXDs\New MXDs\Fig7-2_Lake Carlton BasinAlt4.mxd

Amec Foster Wheeler
2000 E. Edgewood Drive
Suite 215
Lakeland, Florida 33803
863.667.2345