An Evaluation of Nutrient Sources and Potential Nutrient Reduction Projects for Santa Fe Lake

September 30, 2021

DB Environmental

Alachua County Environmental Protection Department
Work Order 002D-20-171

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1 Executive Summary

Despite its designation as an Outstanding Florida Water, degradation of water quality within Santa Fe Lake has been observed in recent years (LAKEWATCH 2020). To address likely causes as well as potential solutions, Alachua County Environmental Protection Department (ACEPD) has initiated, "An Evaluation of Nutrient Sources and Potential Nutrient Reduction Projects for Santa Fe Lake". The objective of this effort is to provide information necessary to develop projects which will reduce external loads of total nitrogen (TN) and total phosphorus (TP) to Santa Fe Lake. Such information is critical to assessing the potential for reversing the eutrophication that appears to be occurring in this lake. Santa Fe Lake is not considered impaired by Florida Department of Environmental Protection (FDEP) or United States Environmental Protection Agency (EPA). Hence, without the development of a total maximum daily load (TMDL) or basin management action plan (BMAP), a thorough assessment of the nutrient sources within the watershed has previously not been completed.

Water quality data for the Santa Fe Lake system is available from as far back as the 1950s and 1960s, though monitoring frequency was sparse prior to 1985 when LAKEWATCH began intensive monthly monitoring. The infrequent sampling and higher detection limits for nutrients limit the utility of the earlier data. In general, the available data indicate that since 1985, water quality in the Santa Fe Lake system has been declining. Increased nutrient levels (TP and TN) apparently have supported greater phytoplankton growth (increased chlorophyll *a* concentrations) and poorer water clarity (measured as Secchi depth) which could be from increased algae concentrations and/or color, both reducing light penetration into the water column. Temporal water quality patterns in the Santa Fe Lake system have been influenced by natural perturbations that exert both short-term and long-term controls on water chemistry in the lake system, often producing cumulative effects. These perturbations include significant droughts, extreme rainfall events, including from tropical cyclones and the catastrophic forest fire in the Santa Fe Swamp. Following these events significant increases in TN and TP were observed in the water quality of Santa Fe Lake. Since 2010, the TN and TP concentrations have been decreasing but have not returned to historic levels.

Some anthropogenic stressors in the lake drainage area, such as residential land development and the number of onsite sewage treatment and disposal systems (OSTDS) or septic systems, have increased during the period of record, but the effect on lake water quality is difficult to define. The lake receives direct stormwater runoff from the developed parcels on the lake shore and surrounding communities. However, the quality and quantity of this stormwater runoff is generally not well documented and is expected to be highly variable among contributing drainages depending on land use. These stormwater inputs have not been adequately inventoried or investigated. As part of the current effort, a study plan was developed to identify locations within the lake that exhibit elevated nutrient concentrations and identify stormwater input locations as well as the associated contributing areas. Identifying the location, quality and magnitude of these stormwater inputs is the first step to identifying the appropriate project to reduce nutrient loading to Santa Fe Lake.

OSTDS are a common and widespread source of nutrients to shallow groundwater and receiving water bodies interacting with that groundwater. The number of septic systems in the vicinity of the Santa Fe Lake system has clearly increased from an estimated 243 total shoreline residences in the mid-1960s to recent estimates of 760 parcels with known or likely septic systems within 200 m of the shoreline. The effect of these nutrient loads on lake water quality has not been estimated, nor are estimates of loads from other nutrient sources available for comparison. A qualitative assessment of the impact from septic systems surrounding Santa Fe Lake will be conducted as part of this study.

While natural events have influenced water quality in the lake, opportunities to reduce nutrient inputs from controllable sources have been identified and must be addressed to protect the water quality and beneficial uses of the Santa Fe Lake system.

2 Background

The Santa Fe Lake system is located in northeast Alachua County and is the headwaters of the Santa Fe River (Figure 1) (Hunn and Slack 1983). The system is approximately 5,217 acres (2,111 hectares) and consist of three basins, Little Santa Fe Lake, Santa Fe Lake, and Melrose Bay (Figure 2). The Santa Fe Lake system lies above the Pleistocene clays of the Hawthorn Group formation, creating a confining layer above the Floridan aquifer (Pirkle and Brooks 1959; Scott 1988). There are no major streams or tributaries to the lake and levels are primarily controlled by rainfall within the relatively small and primarily closed drainage basin. The size and extent of the surface water drainage basin contributing to Santa Fe Lake has not been accurately defined and variations in the estimated size depend on how much of the Santa Fe Swamp is included and whether adjacent waterbodies are included. During extremely high water levels the lake does discharge to the Santa Fe River. The Santa Fe Swamp, located north of Little Santa Fe Lake, can also be a source of water to the lake, depending on rainfall and water levels. There are constructed hydrologic connections to other adjacent waterbodies, including Lake Alto and Black Lake. Rainfall within the watershed slowly runs off the land surface or seeps into the lake to offset losses from evaporation, transpiration, groundwater recharge, and withdrawals. All of these conditions result in more stable water levels than in lakes to the east in the Trail Ridge region.

In this sand hill lakes region, the Hawthorn Group formation contains sinkholes and solution features, and many nearby lakes are hydrologically connected to the Floridan aquifer. For example, Lake Geneva, which is just 1.5 miles to the east (Figure 2), is 40 ft lower in elevation than Santa Fe Lake (Clark et al. 1964) and responds to changes in the potentiometric surface of the Floridan aquifer. Due to these solution features, the Trail Ridge region is considered a high recharge area for the Floridan aquifer by the SJRWMD (Figure 3). Although hydrologic connections through the Hawthorn Group do exist in this area, recharge rates may be lower than shown in the recharge maps (Figure 3). The SRWMD considers the area surrounding Santa Fe Lake to have medium to low recharge rates to the Floridan aquifer. Recharge rates to the Floridan aquifer are partially controlled by the degree of aquifer confinement. Alachua County adopted the Floridan aquifer system "Degree of Confinement" map (Figure 4) in the County's Comprehensive Plan as a surrogate to aquifer recharge maps prepared by the SJRWMD (Boniol and Mouyard 2016) and SRWMD (https://www.mysuwanneeriver.com/319/Data-Directory) (Figure 3). This map shows the area around the lake to be confined which the County considers synonymous with low recharge rates to the Floridan aquifer near Santa Fe Lake (Figure 4).

Early limnological studies by Shannon and Brezonik (1972) classified Santa Fe Lake as a softwater, clear lake, Little Santa Fe Lake as an acid, colored lake and both lakes had low nutrients and were considered oligotrophic. Later work confirmed that the Santa Fe Lake was slightly acidic, colored, and had low nutrients and chlorophyll (Canfield 1981). These studies concluded that the trophic status of the lake was primarily driven by geology and morphology and not from cultural eutrophication. Brezonik and Shannon (1971) completed a nutrient budget for the lake and estimated that 21% of the P and 22% of the N supply to Santa Fe Lake was from cultural sources. These included urban runoff, pasture, fertilized areas, and septic systems. Based on the interpretation of aerial photographs and topographic maps from the mid-1960s, there were an estimated 243 residences on the shoreline of the lake and another 115 within the watershed (Brezonik and Shannon 1971). By 2014, there were more than 700 residential parcels on the lake serviced by OSTDS (Canfield et al. 2016). According to the FDOH inventory, there are an estimated 760 septic systems within 200 m of the lake (Ursin 2016).

Discussion of land use changes, and their potential link to the recently increasing trends in nutrients and chlorophyll *a* in the Santa Fe Lake system, is provided in subsequent sections of this report. Regardless of the extent of anthropogenic nutrient loading to the lake, sources such as stormwater inputs, OSTDS, and fertilizer use can be mitigated, unlike nutrient loads from rainfall and atmospheric deposition. In this report, we identify some known sources and potential nutrient reduction technologies to address them. In addition, a plan for identifying other sources within the watershed is provided. A hydrologic and nutrient budget for the lake has not been completed in recent years and would help explain some of the trends in water levels and water quality observed in the data. This effort is beyond the scope of this report, however the data necessary to complete the budgets are identified as well as gaps in the data and methods to attain the required data. This would include an evaluation of net groundwater contributions to and from the lake.

3 Outstanding Florida Waters

Santa Fe Lake was designated an Outstanding Florida Waters on August 16, 1984. The Environmental Regulation Commission designated the Santa Fe River System as a Special Water due to the exceptional recreational and ecological significance and that the environmental, social, and economic benefits of the designation outweigh the environmental, social, and economic costs (62-302.700(9)(i), F.A.C.). In the context of this designation, the Santa Fe River System consists of the Santa Fe River, Santa Fe Lake, Little Santa Fe Lake, Santa Fe Swamp, Olustee Creek, and the Ichetucknee River below S.R. 27, but excludes all other tributaries.

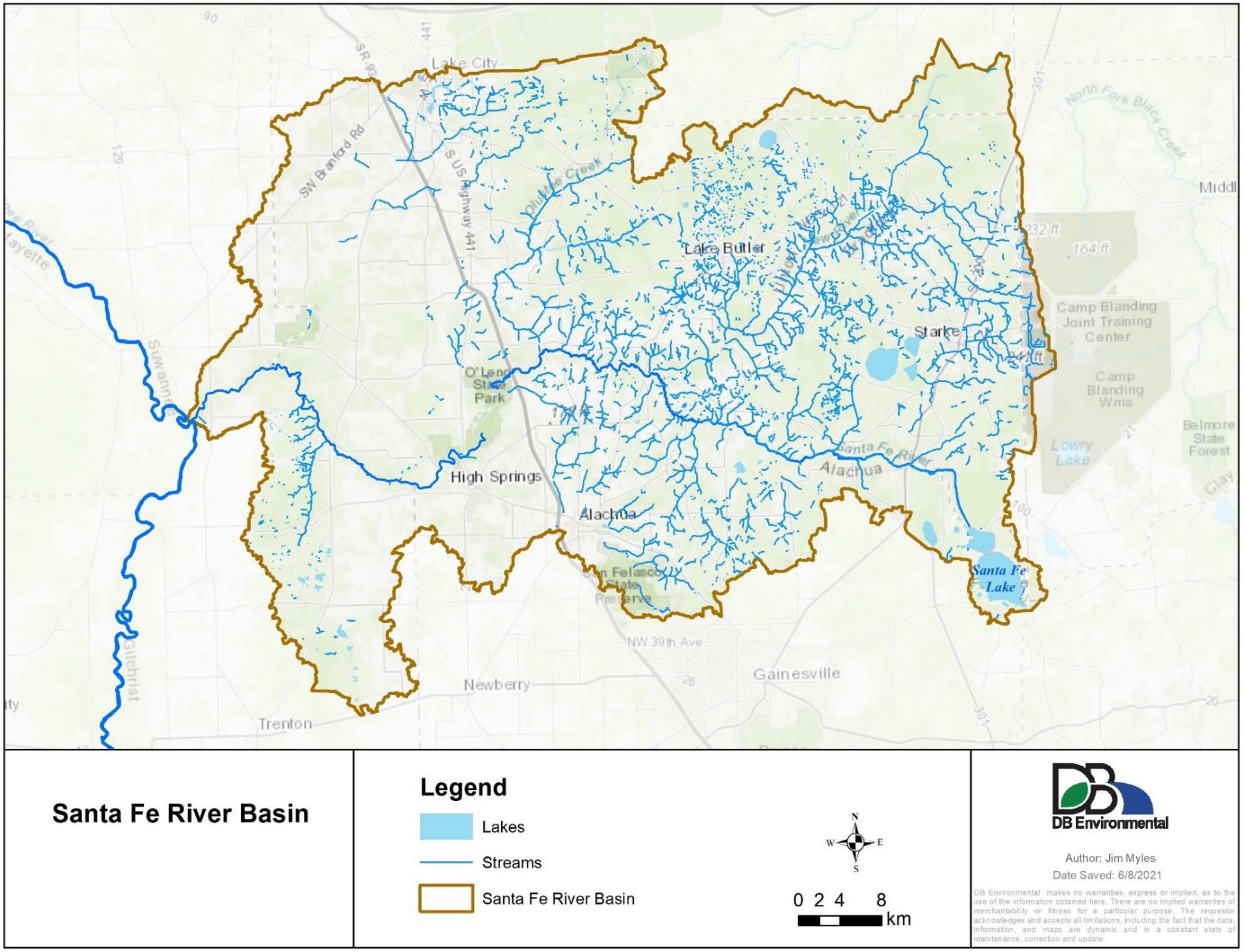

Figure 1. Santa Fe River basin.

Figure 2. Santa Fe Lake and surrounding water bodies.

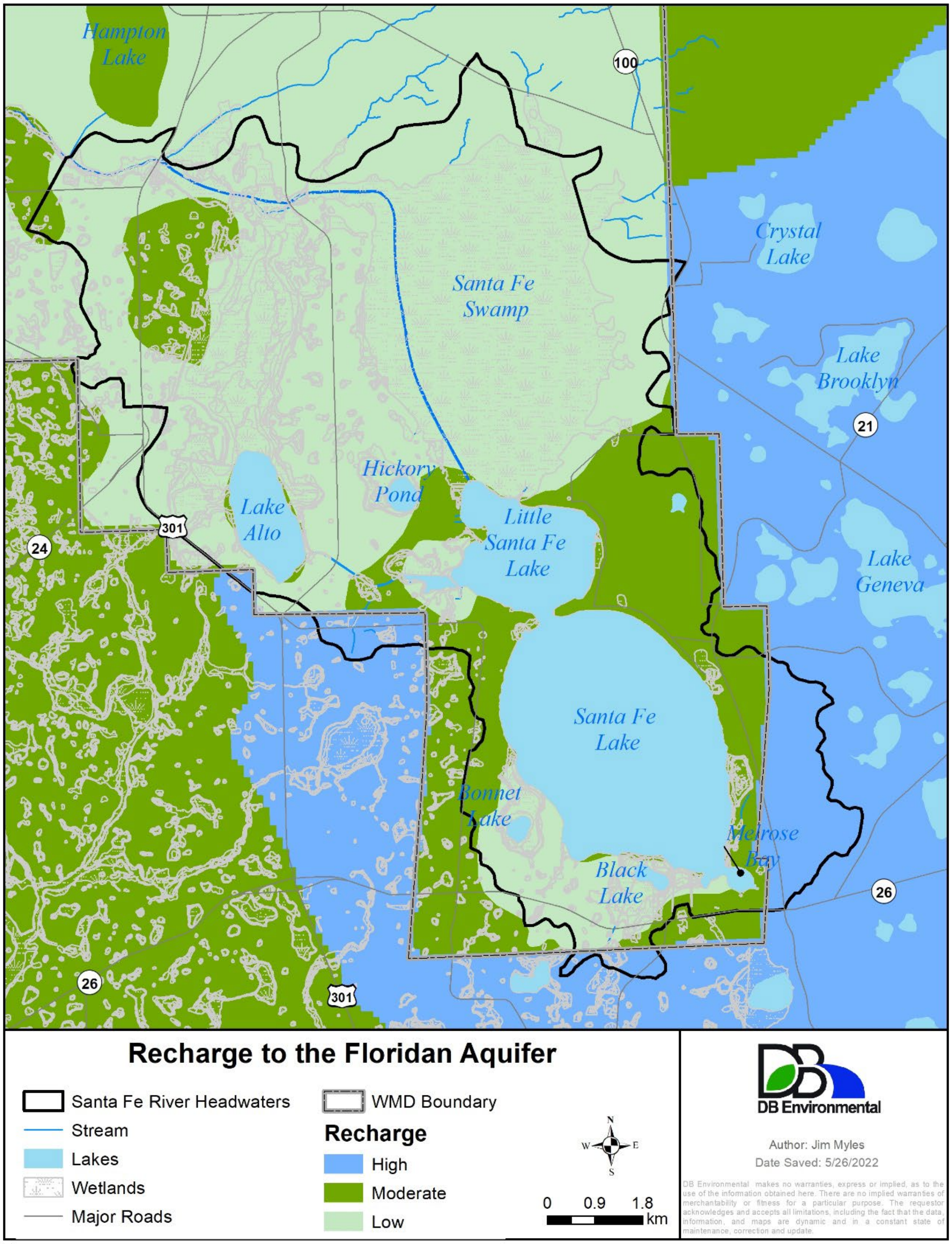

Figure 3. Recharge to the Upper Floridan aquifer near Santa Fe Lake. Data sources include the Upper Floridan Aquifer Groundwater Recharge (Boniol and Mouyard 2016) for the SJRWMD and the Recharge to the Floridan aquifer for the SRWMD (https://www.mysuwanneeriver.com/319/Data-Directory). (Recharge Areas; High >10in/yr, Moderate 5 to 10 in/yr and Low 1 to 5 in/yr)

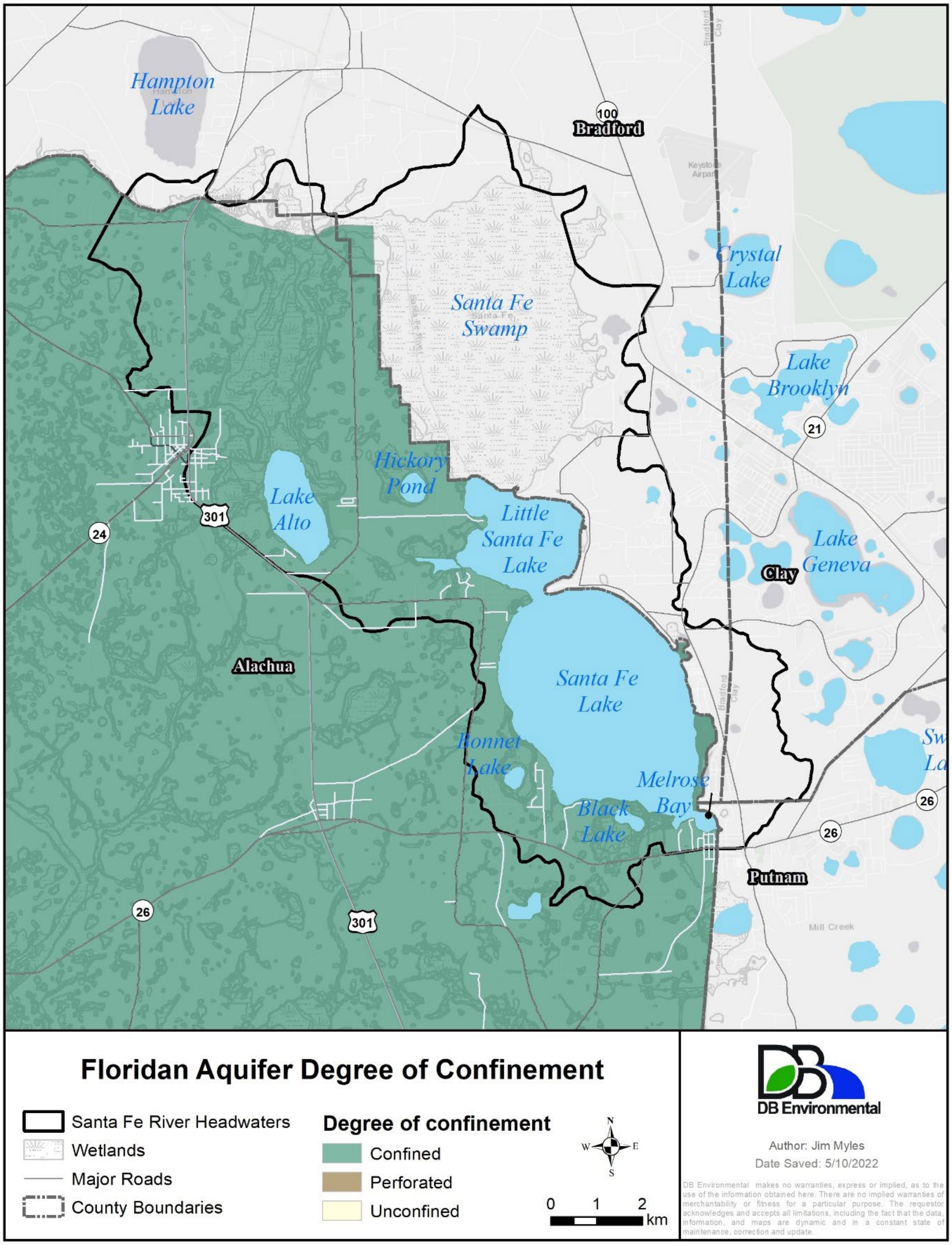

Figure 4. Degree of confinement of the Floridan aquifer within Alachua County. The perforated and unconfined areas are west and south of the area shown on the map. Source ACEPD.

4 Numeric Interpretation of Narrative Nutrient Criteria

4.1 Lakes

The applicable numeric interpretations of the narrative nutrient criterion (NNC) for lakes are provided in Table 1 (62-302.530(47)(b), F.A.C.). The numeric nutrient criteria differ depending on lake color and alkalinity. Lake color and alkalinity are the long-term geometric mean for the period of record and must have a minimum of ten data points over at least three years with at least one data point in each year. To calculate an annual geometric mean for chlorophyll *a*, TN, and TP, there must be four temporally independent samples per year with one sample collected between May 1 and September 30 and one during the other months of the year. Samples must be taken at least one week apart to be considered temporally independent.

Table 1. Numeric interpretation of narrative nutrient criteria for lakes (62-302.531(2)(b), F.A.C.)

		Minimum calculated numeric interpretation		Maximum calculated numeric interpretation	
Long Term Geometric Mean Lake Color and Alkalinity	Annual Geometric Mean Chlorophyll *a*	Annual Geometric Mean Total Phosphorus	Annual Geometric Mean Total Nitrogen	Annual Geometric Mean Total Phosphorus	Annual Geometric Mean Total Nitrogen
≥ 40 Platinum Cobalt Units	20 µg/L	0.05 mg/L	1.27 mg/L	0.16 mg/L[1]	2.23 mg/L
≤ 40 Platinum Cobalt Units and ≥ 20 mg/L $CaCO_3$	20 µg/L	0.03 mg/L	1.05 mg/L	0.09 mg/L	1.91 mg/L
≤ 40 Platinum Cobalt Units and ≤ 20 mg/L $CaCO_3$	6 µg/L	0.01 mg/L	0.51 mg/L	0.03 mg/L	0.93 mg/L

[1] For lakes with color ≥ 40 PCU in the West Central Nutrient Watershed Region, the maximum TP limit shall be the 0.49 mg/L TP streams threshold for the region.

If there is insufficient data to calculate the annual geometric mean for chlorophyll *a* or the annual geometric mean chlorophyll *a* exceeds the values in Table 1, then the applicable numeric interpretations for TN and TP are the minimum values. The applicable numeric interpretations for TN, TP, and chlorophyll *a* cannot be exceeded more than once in any consecutive three-year period.

The Santa Fe Lake Water Body Identification Number (WBID) (3605G) is part of the Group 1 basins and was assessed by FDEP in Cycle 4 which was completed in 2019. According to the assessment, which includes all data collected within the WBID, the lake did not exceed the NNC for chlorophyll *a*. FDEP has recently changed to a biennial assessment of all waterbodies throughout the state. FDEP completed the 2020-2022 biennial assessment and released a draft list of impaired waterbodies on September 7, 2021. The evaluation was completed using data from the

FDEP Impaired Waters Rule (IWR) Run 60 database which was compiled on July 7, 2020. Santa Fe Lake was not included on the verified list or the study list of impaired waters. In the assessment done by FDEP, all data collected within the WBID are considered, as opposed to the earlier studies and those done recently by LAKEWATCH, where Little Santa Fe Lake, Santa Fe Lake, and Melrose Bay are evaluated separately. These lakes have been evaluated separately by some researchers due to differences in color within the lake water column. Contribution of tannic and fulvic acids (dissolved organic matter) from Santa Fe Swamp to Little Santa Fe Lake increase the color in that lake. Color from dissolved organic matter can attenuate light and influence the response of phytoplankton (and chlorophyll) to available nutrients. For this reason, color affects the application and interpretation of the NNC.

Based on the IWR Run 61 database, the long-term geometric mean color for the Santa Fe Lake WBID is greater than 40 PCU (49 PCU) and alkalinity is low at 3 mg/L making this a colored, soft water lake (Figure 5). The thresholds used to interpret the NNC of lakes with color greater than 40 PCU, sets the maximum annual geometric mean for chlorophyll *a* at 20 µg/L, 0.16 mg/L for TP, and 2.23 mg/L for TN (FDEP 2013) (Table 1). According to IWR Run 61 (5/27/2021) Santa Fe Lake does not exceed the NNC for chlorophyll *a* (20 µg/L) during the planning period (1/1/2008 - 12/31/2017) (Figure 5) or the verified period (1/1/2013 - 6/30/2020) (Figure 6). Neither the minimum or maximum criterion for TP (0.05 and 0.16 mg/L) or TN (1.27 and 2.23 mg/L) were exceeded in any year during the evaluation period (Figures 5 and 6).

4.2 Applicability of Chlorophyll *a* Methods

Except for data used to establish historical chlorophyll *a* levels, chlorophyll *a* data assessed for determining impairment must account for pheophytin interferences by using methods outlined in "Applicability of Chlorophyll *a* Methods" (DEP-SAS-002/10). There are four approved methods which are published by the EPA or, by the American Public Health Association (APHA) in "Standard Methods for the Examination of Water and Wastewater". For the period of record, there are 4156 samples analyzed for chlorophyll *a* and 843 of the more recent samples (since 2004) are corrected for pheophytin.

4.3 Streams

The reference stream-based nutrient thresholds in peninsular Florida are 0.12 mg/L for TP and 1.54 mg/L for TN (FDEP 2013). Nutrient thresholds are used to interpret the numeric nutrient criteria (NNC) in combination with biological information. The NNC is achieved in a stream segment if an imbalance in flora or fauna is not observed, and the nutrient thresholds (expressed as annual geometric means) are not exceeded more than once in a three-year period, or the mean stream condition index (SCI) is above 40. While there are not any perennial streams flowing into the lake there are a few ephemeral streams that have been sampled by ACEPD in the past. These results are discussed in Section 7.1.1.

WBID: 3605G

Waterbody Name: SANTA FE LAKE

Waterbody Type: LAKE **Waterbody Class:** 3F

Cycle: 4 **Group:** 1 **Group Name:** Suwannee

export all pp NNC data

Show data summary for: ◉ *planning period* 01/01/2008 - 12/31/2017 ○ *verified period* 01/01/2013 - 06/30/2020

Chlorophyll-a (CHLAC)

Min Criterion: 20 *Max Criterion:* 20 µg/L AGM

year	samples	weeks	seasons	geo mean
2008	1	1	1	
2009	6	3	2	
2010	24	8	2	7.7
2011	10	5	2	6.0
2012	4	2	1	
2013	187	22	2	8.5
2014	158	19	2	6.4
2015	139	15	2	6.4
2016	139	16	2	5.4
2017	20	6	2	6.0

 # decimals ○ 0 ◉ 1

Total Nitrogen (TN)

Min Criterion: 1.27 *Max Criterion:* 2.23 mg/L AGM

year	samples	weeks	seasons	geo mean
2008	83	8	2	0.78
2009	120	14	2	0.80
2010	99	17	2	0.80
2011	89	17	2	0.66
2012	128	15	2	0.70
2013	200	24	2	0.76
2014	158	19	2	0.71
2015	139	15	2	0.69
2016	139	16	2	0.65
2017	31	6	2	0.65

 # decimals ◉ 2 ○ 3

Total Phosphorus (TP)

Min Criterion: 0.05 *Max Criterion:* 0.16 mg/L AGM

year	samples	weeks	seasons	geo mean
2008	83	8	2	0.030
2009	120	14	2	0.029
2010	99	17	2	0.021
2011	88	16	2	0.015
2012	129	16	2	0.020
2013	201	24	2	0.022
2014	158	19	2	0.017
2015	139	15	2	0.016
2016	137	16	2	0.016
2017	32	7	2	0.016

 # decimals ○ 2 ◉ 3

Applicable Lake Assessment Type:* 1 - *Color > 40 PCU

export lake classification raw data

	Color	Alkalinity	Sp. Conductance
geomean	49	3	72
#years	23	36	43
#samp	92	214	328

Figure 5. Water quality and impairment of the Santa Fe Lake system (WBID3605G) was assessed using the IWR Run 61 (5/27/2021) database during the planning period of January 2008 to December 2017.

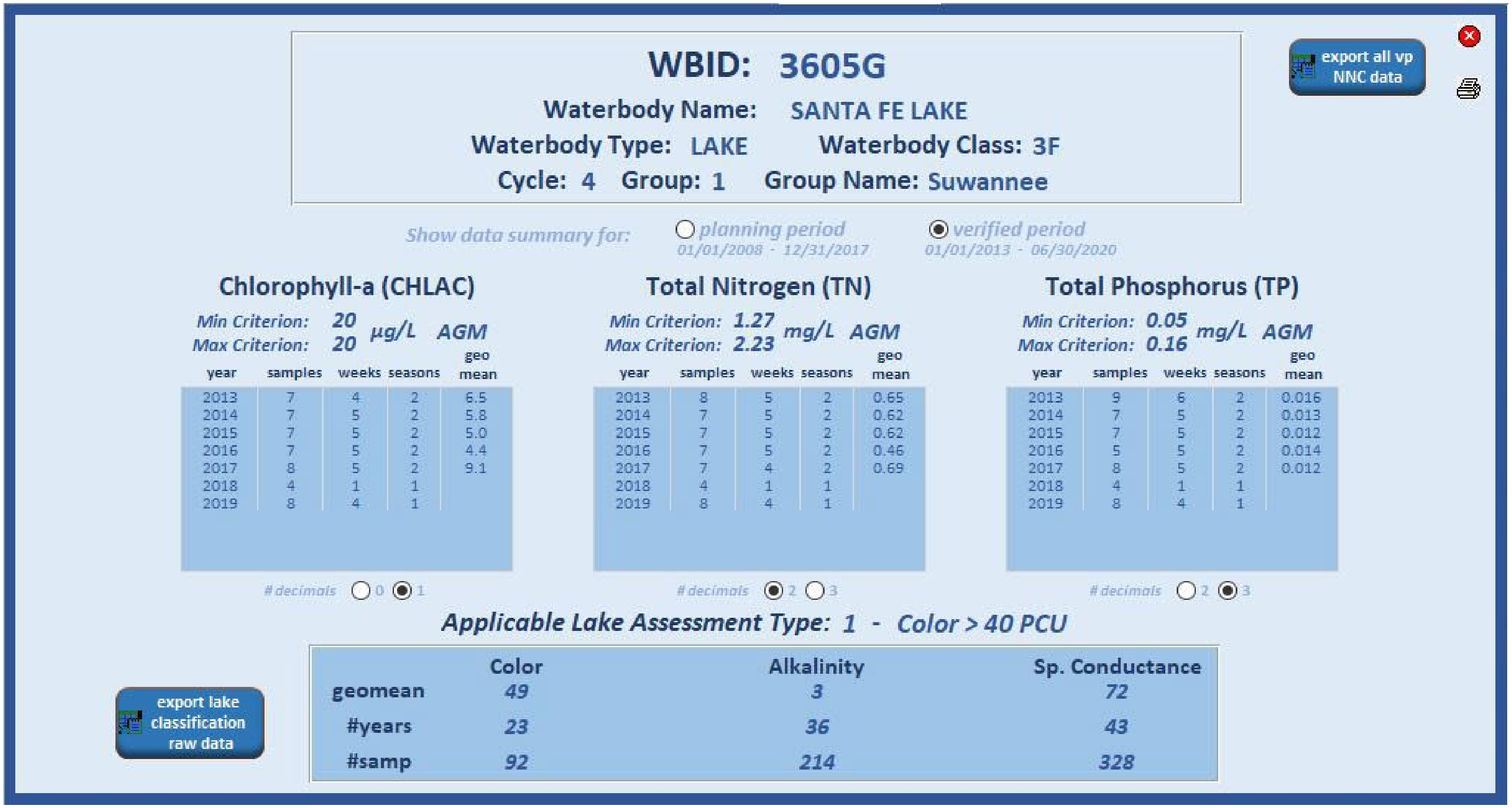

Figure 6. Water quality and impairment of the Santa Fe Lake system (WBID3605G) was assessed using the IWR Run 61 (5/27/2021) database during the verified period of January 2013 to June 2020.

5 Historical Water Quality, Hydrologic and Biological Data

5.1 Available data and data quality

The Watershed Assessment Section of FDEP utilizes the best available information and data to identify waterbodies (WBIDs) that are not meeting the applicable water quality standards and designated uses based on the Impaired Waters Rule (IWR) Chapters 62-302 and 62-303, Florida Administrative Code (F.A.C.). Water quality and biological data were extracted from the STORET, WIN, United States Geological Survey (USGS), and SBIO databases on March 11, 2021, and compiled into the IWR Run 61 database, which is used by FDEP to assess water quality and impairment of waterbodies. This database was used by DBE to assess of the water quality in the Santa Fe Lake system.

In this database, there are 109 sampling stations with 30,458 records spanning from 1957 to 2020. These stations are distributed throughout the lake (Figure 7) and include long term monitoring stations sampled by Suwannee River Water Management District (SRWMD) and Florida LAKEWATCH. Data were also provided by FDEP, USGS, and ACEPD. LAKEWATCH has reported data through September 2020 and SRWMD has not reported data since July 2019. SRWMD is no longer sampling the lake on a regular basis. Since August 9, 2017, only two samples have been collected (July 23, 2019, and July 13, 2021). The additional analytes collected by SRWMD are necessary in understanding the forms of N and P in the lake. Without these samples valuable information is being lost. These data were utilized to evaluate the color of the lake and trends in nutrients (TP and TN) and chlorophyll *a*.

Color is an important parameter used in classifying lakes for evaluation of the criteria in the NNC. The color data reported in the IWR Run 61 database was collected sporadically and over varying time periods by all 5 agencies (Figure 8). There are 179 color measurements made between 1957 and 2020 throughout Santa Fe Lake, Little Santa Fe Lake, Melrose Bay, and the Painter Canal. The geometric mean color over the period of record is 48 PCU, making the Santa Fe Lake system a colored waterbody. However, according to LAKEWATCH (2020), the long-term geometric mean color in Santa Fe Lake (excluding Little Santa Fe Lake and Melrose Bay) is less than 40 PCU (33 PCU), which significantly reduces the chlorophyll *a* NNC threshold to 6 µg/L. It was also reported in the Alachua County Lake Report (LAKEWATCH 2020) that Little Santa Fe Lake is colored with a geometric mean color of 77 PCU. This report is based on data collected by LAKEWATCH and does not evaluate data collected by other agencies. To determine if the discrepancy in the color of the Santa Fe Lake basin by LAKEWATCH and FDEP was an artifact of including samples from Little Santa Fe Lake in the calculation, data from the IWR Run 61 database was evaluated.

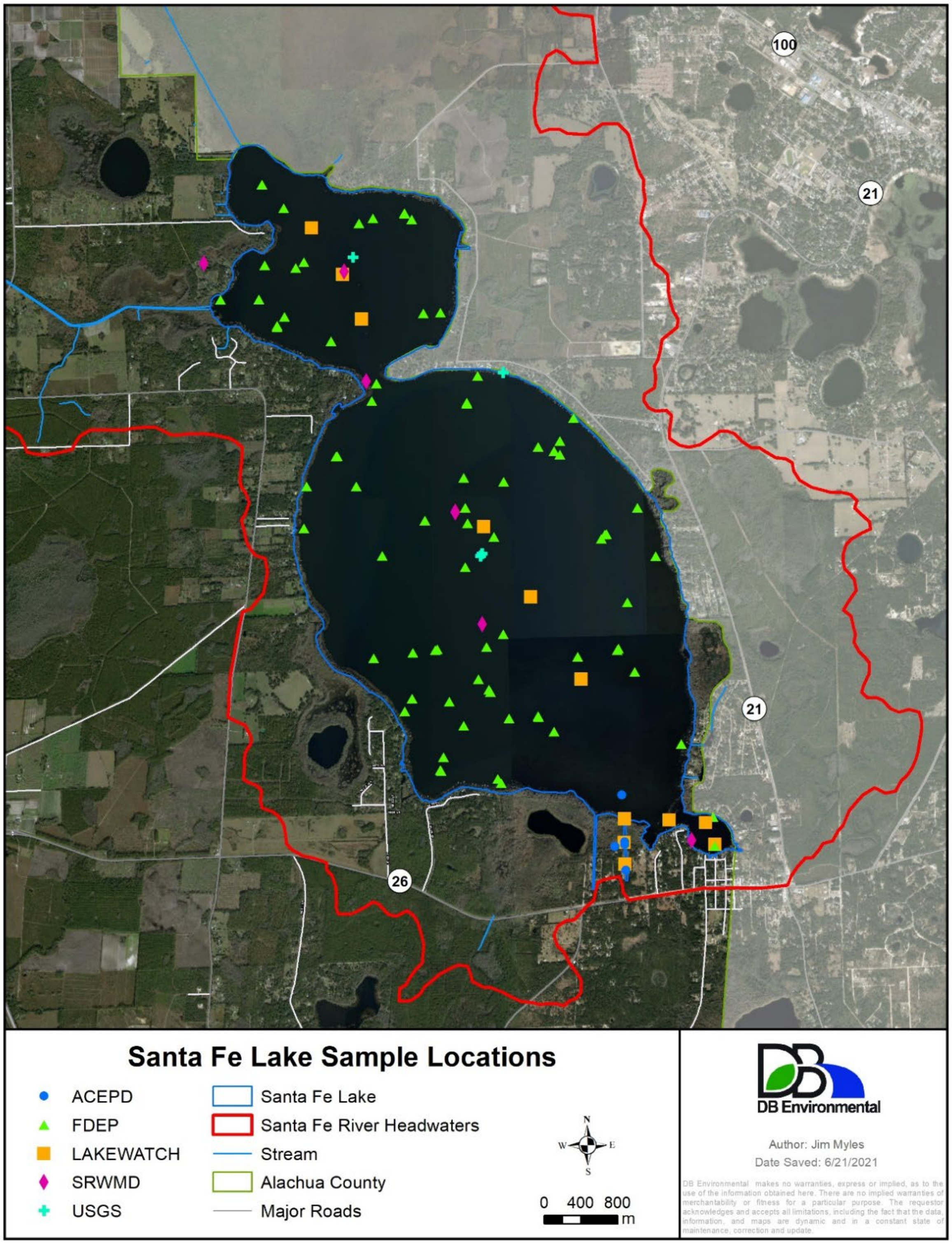

Figure 7. Santa Fe Lake sample locations.

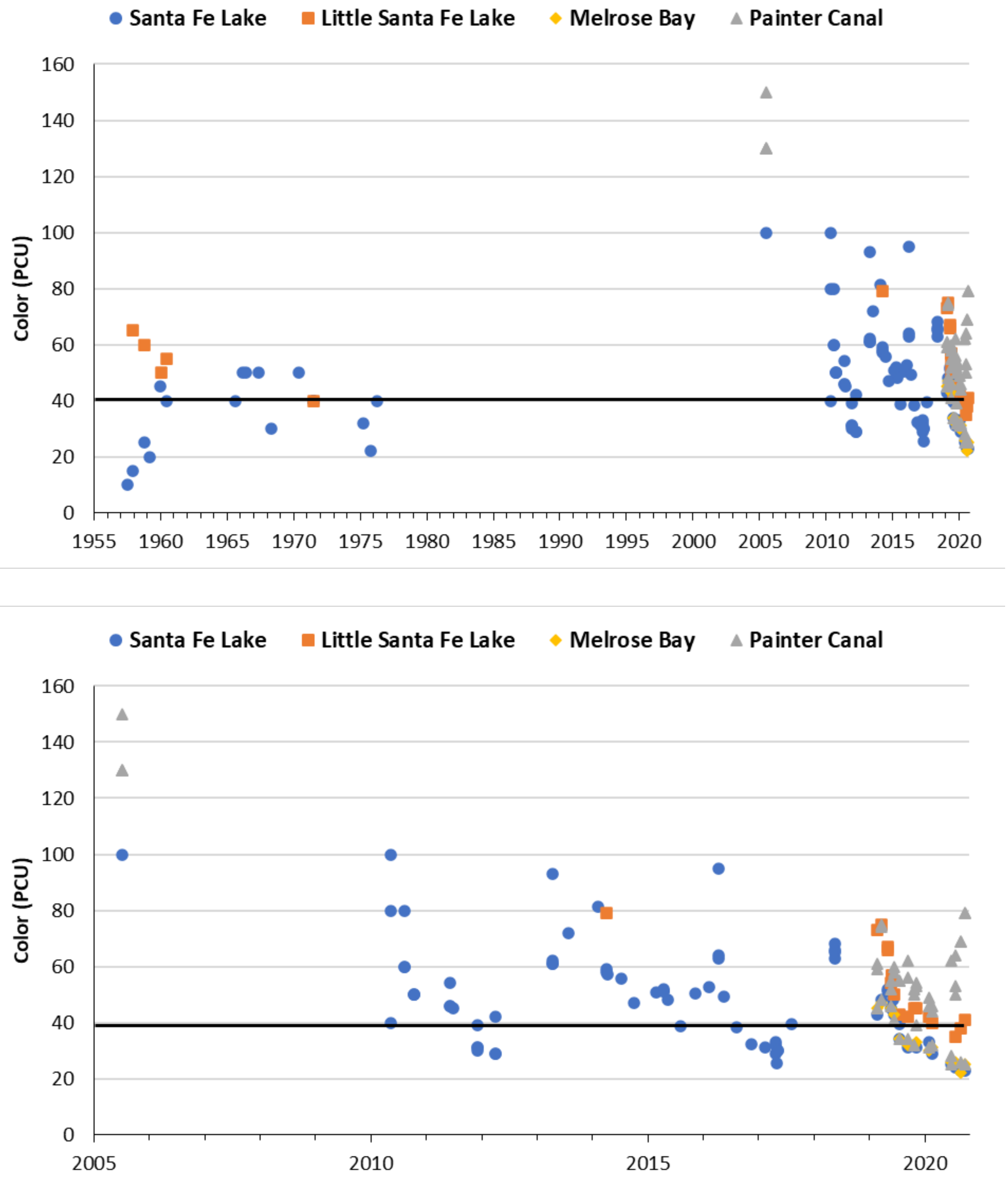

Figure 8. Color (PCU) measurements in Santa Fe Lake and Little Santa Fe Lake over the period of record (top panel) and during the contemporary monitoring period, since 2005 (bottom panel). Lakes are considered colored if the geometric mean color over the period of record is greater than 40 PCU (bold line).

After parsing out the data by station location, the geometric mean color in Santa Fe Lake is 43 PCU for the period of record (Figure 8). Prior to 1977, the geometric mean color was 33 PCU (clear), which agrees with earlier studies (Shannon and Brezonik 1972) and after 2005 the geometric mean is 46 PCU (colored) (Figure 8). Despite only using color samples collected from within the main lake, the data indicate the lake is considered colored according to FDEP methods. However, recent data show that Santa Fe Lake and Melrose Bay have color measurements below 40 PCU, while Little Santa Fe Lake and the Painter Canal have consistently higher color (Figure 9). The data provided by agencies other than LAKEWATCH affected the calculation of the long-term geometric mean and likely accounts for the discrepancy in the reported lake color.

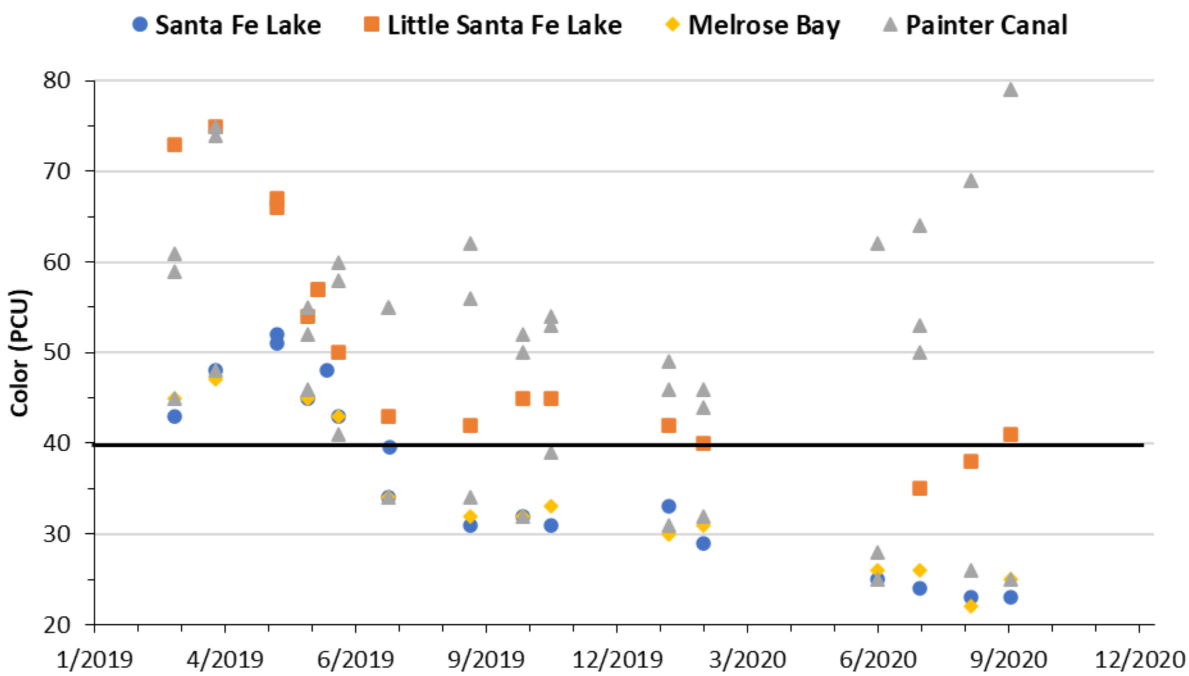

Figure 9. Color (PCU) measurements in Santa Fe Lake, Little Santa Fe Lake, Melrose Bay, and Painter Canal since 2019.

The geometric mean color for Little Santa Fe Lake is 56 PCU, Melrose Bay is 38 PCU, and Painter Canal is 58 PCU. The highest color recorded in Santa Fe Lake was in July 2005, in a sample collected by ACEPD during the Painter Canal investigation. During this time period, the lake was highly colored due to extreme rainfall the previous year associated with hurricanes Frances and Jeanne. The 29 inches of rainfall in August and September 2004, quickly raised water levels 2.7 ft and inputs of dissolved organic matter (DOM) from the surrounding swamps increased color in the lake. This is an interesting conundrum, of whether Santa Fe Lake should be classified as a colored or clear lake and whether it is best to consider the 3 main basins separately, even though FDEP apparently does not. Color and other water chemistry changed significantly in response to hurricanes and wildfire (Canfield et al. 2016, see Section 5.3.4, below), so long-term geometric means may not be appropriate for interpreting conditions on these lakes. In addition, the inclusion of all data within the WBID for the determination of the lakes color, could affect the evaluation of the lake's nutrient status by FDEP.

Another potential issue observed with the data was that between 1989 and 1992 SRWMD consistently reported TP values of either 50 or 100 µg/L. Prior to October 1991 it appears the MDL was 50 µg/L and the PQL was 100 µg/L, which is above the NNC maximum threshold of 90 µg/L (Table 1). Only 7 of the 52 samples were not qualified with I, M, and K, all of which indicate that the concentration was lower than could be reliably quantified by the analyzing laboratory (Table 2). SRWMD data also includes samples collected from just above the sediments of the lake. These concentrations do not agree with samples collected by LAKEWATCH over the same period of time when the mean TP concentration was 11 µg/L. An example is on June 17, 1990, LAKEWATCH collected 3 samples from Santa Fe Lake with a mean concentration of 10.3 µg/L and on the next day SRWMD reports TP concentrations of 100 and 600 µg/L.

There are duplicate results in the FDEP database for these analyses where they were entered with sample depth in feet and again in meters. These data, from this older time period, are not used when comparing the NNC to annual geometric means to determine impairment. However, including these results does affects the trend analysis by artificially raising the annual geometric mean concentrations. It is highly doubtful that these are accurate results and should be removed from the databases. Discussions with SRWMD and FDEP would be required to determine the best course of action on how to address these data issues.

Table 2. Qualifier codes and definitions for data submitted by SRWMD.

Qualifier Code	Definition
I	The reported value is greater than or equal to the laboratory method detection limit but less than the laboratory practical quantitation limit.
M	When reporting chemical analyses: presence of material is verified but not quantified; the actual value is less than the value given. The reported value shall be the laboratory practical quantitation limit. This code shall be used if the level is too low to permit accurate quantification, but the estimated concentration is greater than or equal to the method detection limit.
K	Off-scale low. Actual value is known to be less than the value given. This code shall not be used for microbiological tests or for biochemical oxygen demand. This code shall not be used for field-testing measurements where quantitative bracketing is required. This code shall be used if: 1. The value is less than the lowest calibration standard and the calibration curve is known to be non-linear; or 2. The value is known to be less than the reported value based on sample size, dilution. This code shall not be used to report values that are less than the laboratory practical quantitation limit or laboratory method detection limit.

5.2 Hydrologic Data and Relationship to Water Quality

Over the period of record, the mean water level in Santa Fe Lake is 138.9 ft (NAVD88) and the lake has fluctuated from approximately 135 ft to 141.5. The extreme low water levels in June 2002 and May 2012 followed droughts. The highest water levels occurred in January 1998 (Figure 10). June 2017 was the wettest in the history for Gainesville, FL, according to the Florida Climate Center (Stefanova et al. 2017). Between May and July 2017, water levels in the lake increased 3 ft after the area received 33 inches of rain during the same time period (Figure 11).

Water quality parameters were compared to water levels to determine if lake stage has an influence on water quality. There did not appear to be a relationship between lake stage and TP, TN, or chlorophyll *a*, when all data are included (data not shown). However, color does appear to increase with higher stages (Figure 12) when the lake is hydrologically connected to Santa Fe Swamp and other wetlands surrounding the lake.

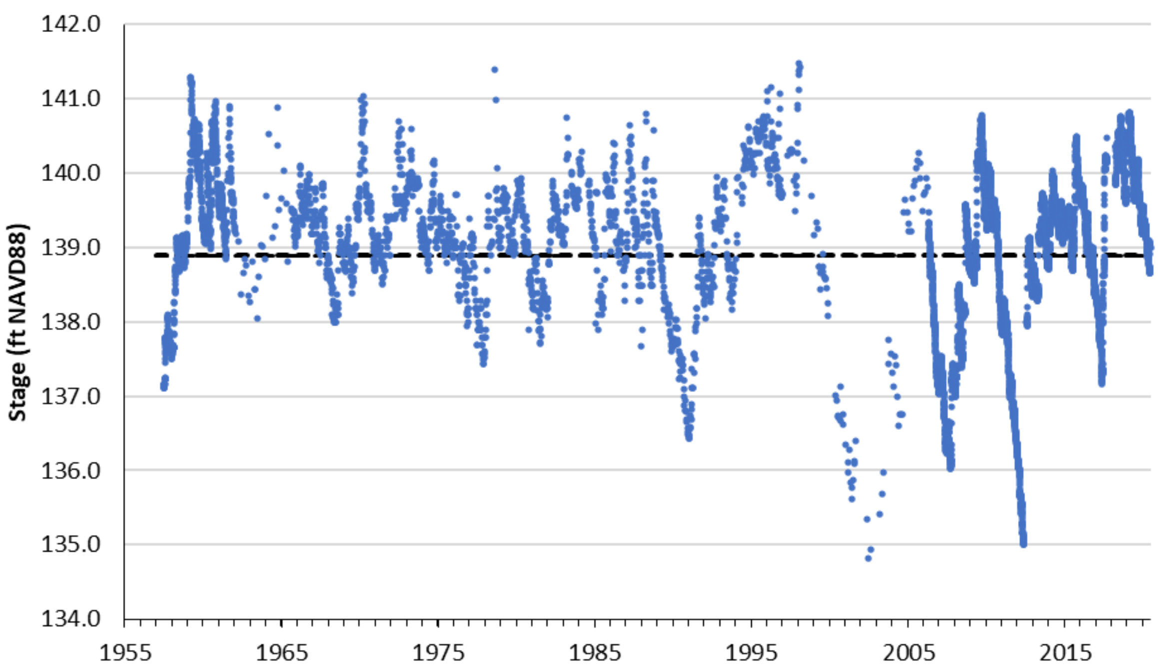

Figure 10. Water levels (ft NAVD88) in Santa Fe Lake over the period of record (1957 to 2021). Data downloaded from SRWMD (July 2021).

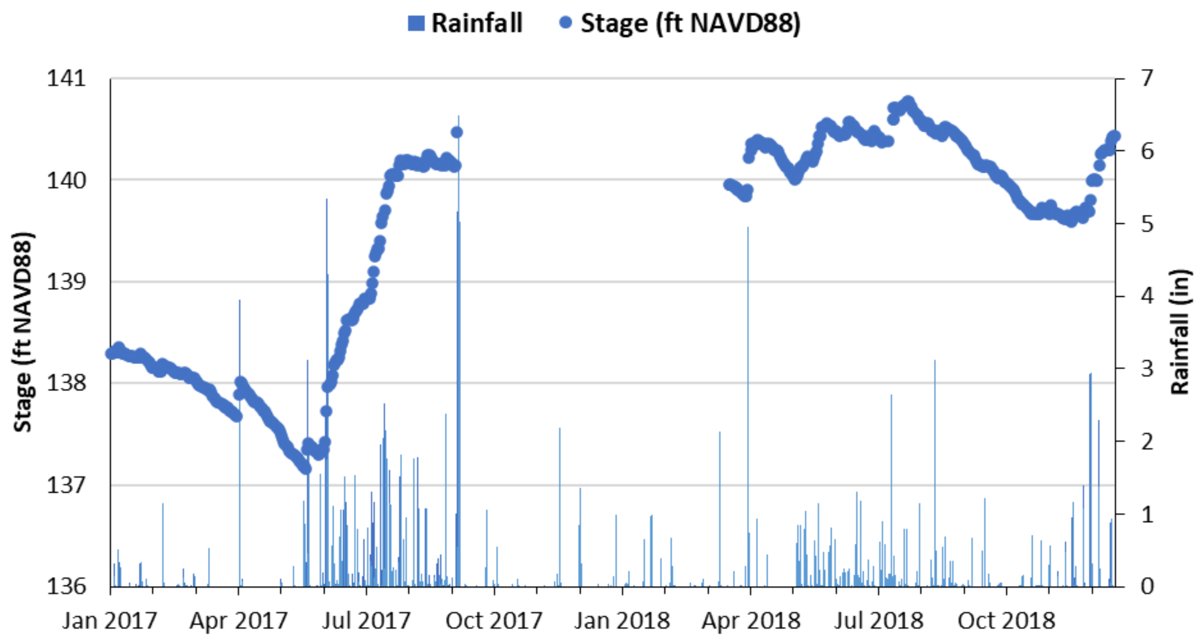

Figure 11. Record rainfall and response of stage in Santa Fe Lake from January 2017 to January 2019. Rainfall is from SRWMD station 02320601 Santa Fe Lake near Earleton and supplemented with data from SJRWMD station 00260033 Alachua County Fairgrounds at Gainesville for missing records (September 11, 2017, to November 14, 2018).

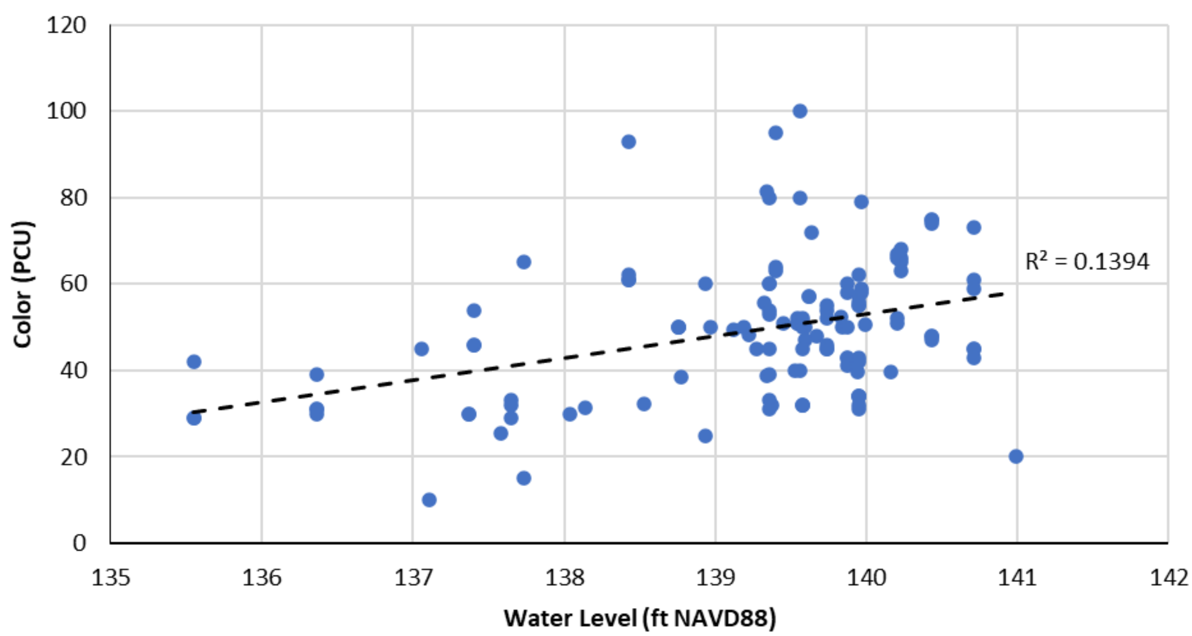

Figure 12. Cross plot of color and water level (ft NAVD88) in Santa Fe Lake for the period of 1965 to 2019. Each point represents an individual sample date.

5.3 Trends in lake water quality

5.3.1 1986 – 2019 LAKEWATCH Assessment

The Alachua County Lake Report (LAKEWATCH 2020) documents that between 1986 and 2019, the Santa Fe Lake system has been increasing in nutrients (Figure 13) and chlorophyll *a* resulting in decreasing water clarity (Figure 14). These trends were observed when annual average values were examined separately for each of the three lakes in the Santa Fe Lake system.

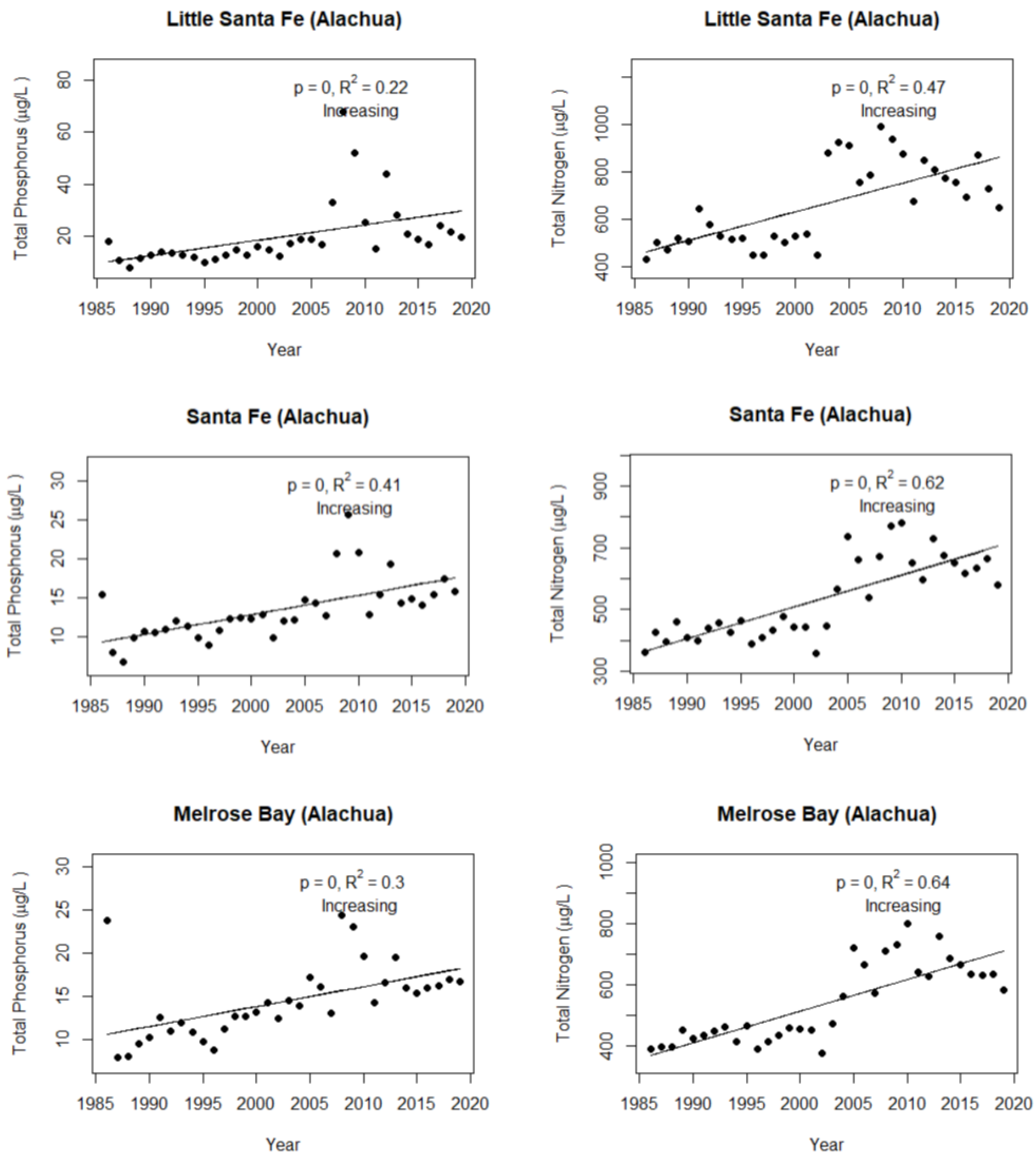

Figure 13. Annual average total phosphorus and total nitrogen concentrations in the Santa Fe Lake system. (measured and reported by LAKEWATCH 2020)

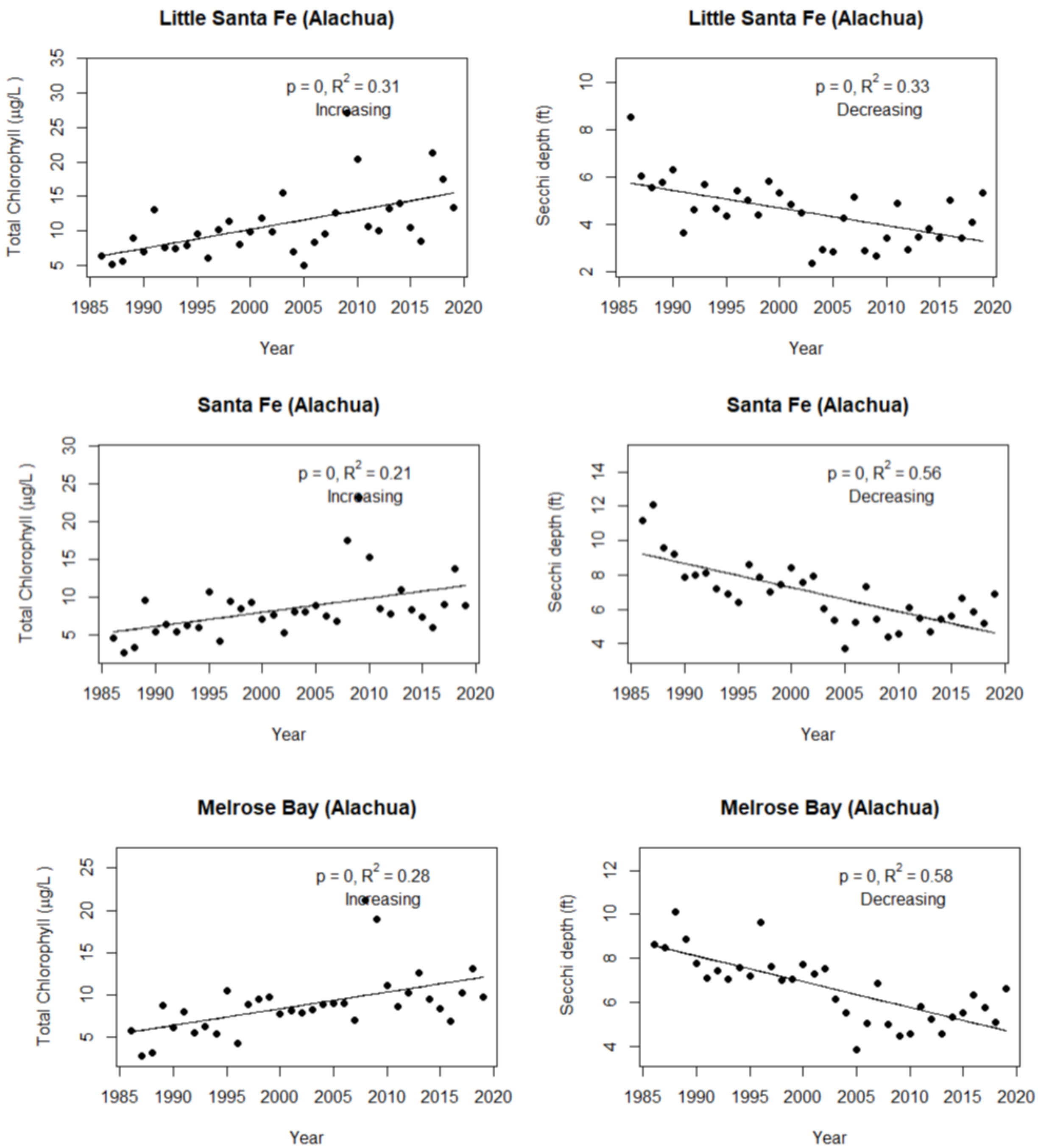

Figure 14. Annual average chlorophyll *a* concentration and Secchi depth in the Santa Fe Lake system. (measured and reported by LAKEWATCH 2020)

5.3.2 Full Period of Record 1967-2020

The trends in nutrients and chlorophyll *a* described in LAKEWATCH (2020) are not apparent when plotting the raw data used by FDEP (IWR Run 61 database) to determine whether the lake is impaired (Figures 15 through 17). For example, no increasing trend is observed in TP concentration over time when the full period of record is considered (Figure 15). These data were contributed over many years, by different agencies, at different stations (Figure 7) and with different objectives. To understand the discrepancy between these data sources, we examined the datasets that comprise the IWR Run 61 database.

Prior to 1990, there were a number of extremely high TP (Figure 15) and TN (Figure 16) concentrations reported and since then, there have been periods of elevated nutrients. One notable source of the high variability in water chemistry observed during recent years in the Santa Fe Lake system is the Dairy Road Fire, a major wildfire in the Santa Fe Swamp during late 2007 (Ruiz-Bernard 2012). This will be discussed in detail in Section 5.3.3, followed by a discussion of other climatic factors that influence long-term trends in lake water quality (Section 5.3.4). These factors must be considered when interpreting results from sampling efforts over an extended time frame, especially by multiple agencies.

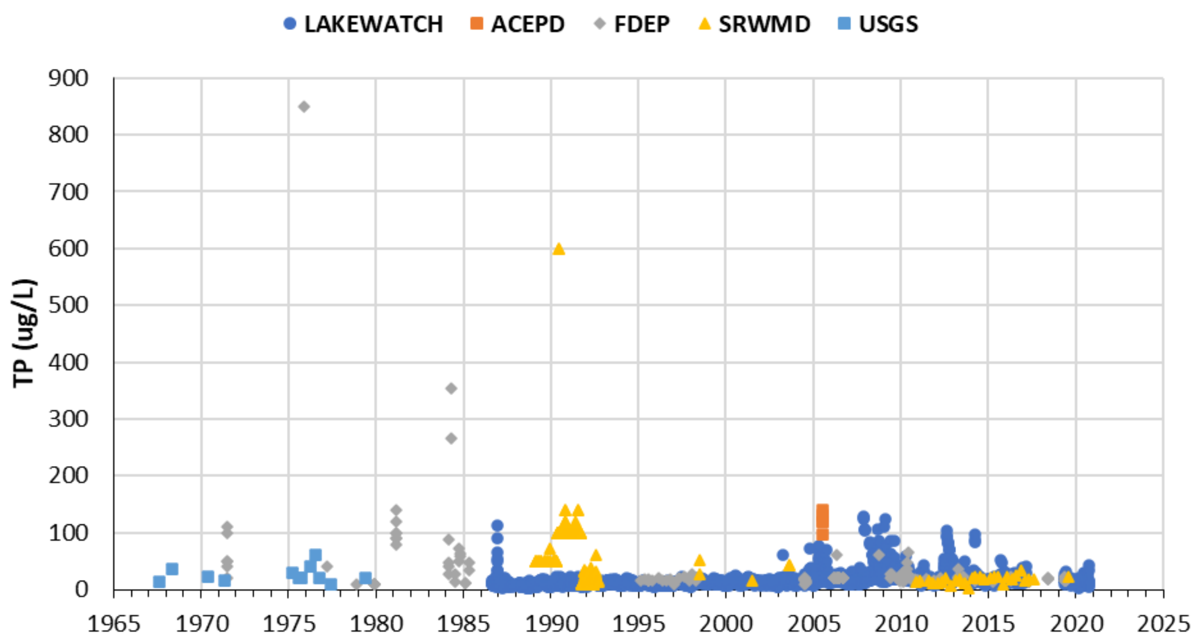

Figure 15. Total phosphorus (TP) concentrations measured in Santa Fe Lake for the period of record in IWR Run 61 database (August 1967 to September 2020) differentiated by the agencies collecting the data.

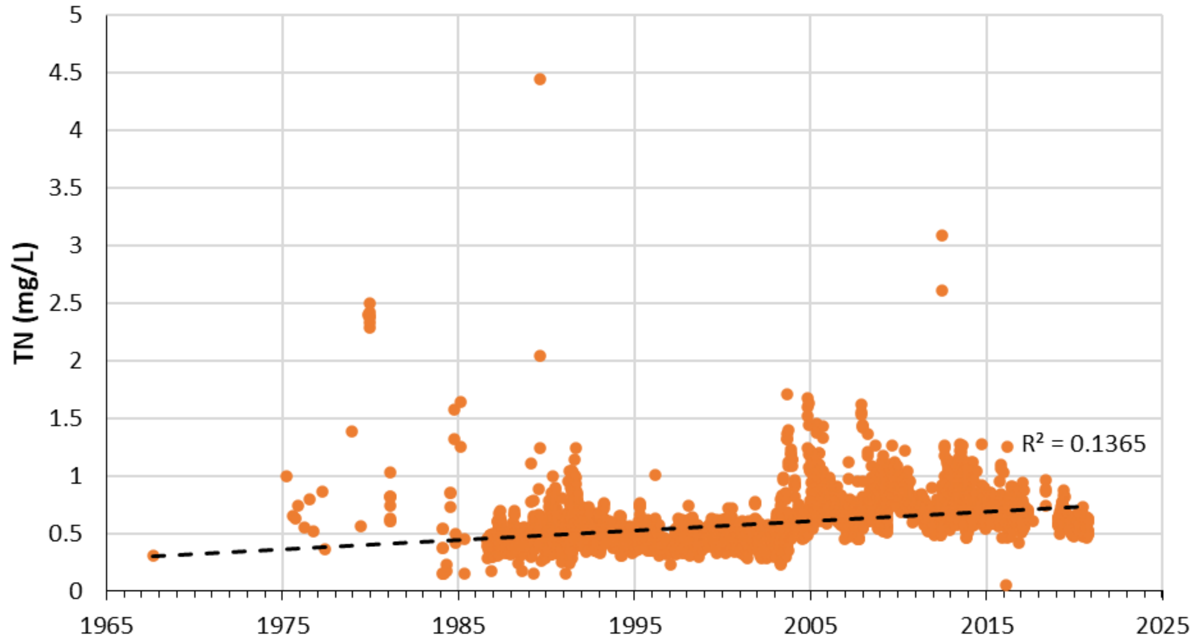

Figure 16. Total nitrogen (TN) concentrations measured in Santa Fe Lake for the period of record in IWR Run 61 database (August 1967 to January 2020).

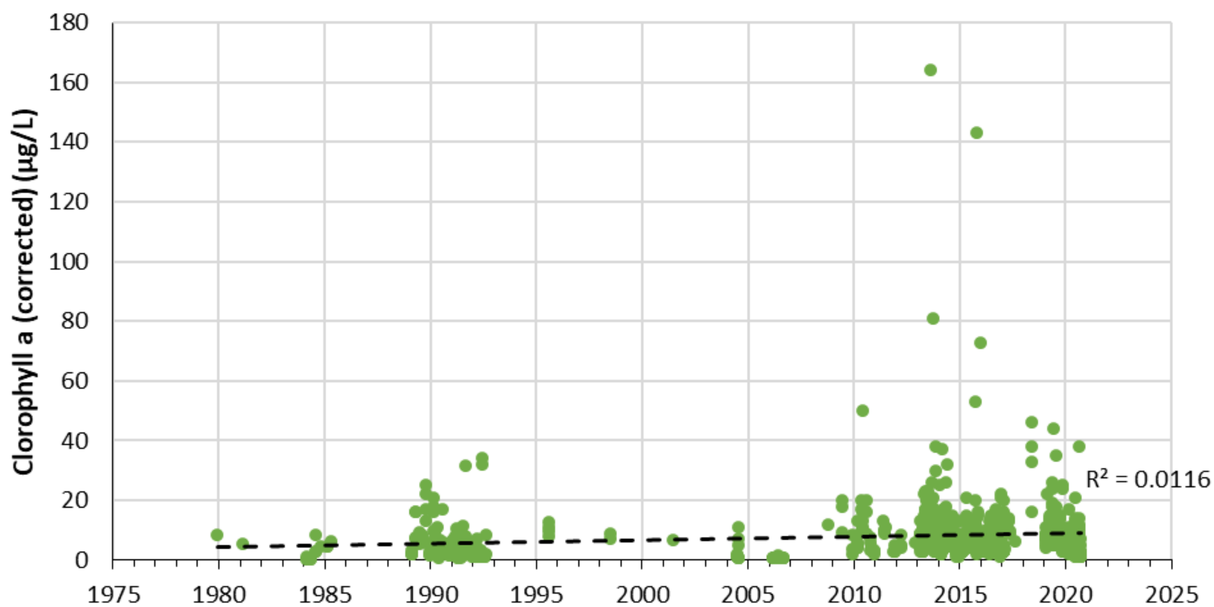

Figure 17. Chlorophyll *a* (corrected for pheophytin) concentrations measured in the Santa Fe Lake system for the period of record in IWR Run 61 database (December 1979 to September 2020).

5.3.2.1 Phosphorus

There was a total of 4,023 samples analyzed for TP between August 1967 and September 2020 (Figure 15). During a number of years, there were not enough samples collected, or they did not meet the temporal requirements necessary, to calculate the annual geometric mean under 62-302.531 F.A.C. Numeric Interpretations of Narrative Nutrient Criteria. The qualified and suspect data (discussed in Section 5.1) were removed from the dataset, leaving 3,813 TP records (Figure 18). When these data were used to calculate the annual geometric mean concentration for the Santa Fe Lake system, an increasing trend in TP is observed (Figure 19). The TP concentrations prior to the drought conditions that led to record low levels in June of 2002 may have been increasing but the correlation coefficient is low (Figure 20). There was a significant increase in TP between 2002 and 2008. Since 2008, the TP concentrations have been steadily decreasing (Figure 20).

5.3.2.2 Nitrogen

There was a total of 4,069 samples analyzed for TN between August 1967 and September 2020 (Figure 16). After removing data for years when too few samples were collected, or they did not meet temporal requirements, the annual geometric mean concentration for the Santa Fe Lake system was calculated (Figure 21). From 1984 until the record low water levels in 2002 the TN concentrations did not show a trend (Figure 22). Between 2002 and 2008, TN concentrations significantly increased and since 2009, the TN concentrations have been steadily decreasing (Figure 22).

There does appear to be a relationship between TN and color (Figure 23), both of which increased after 2004 hurricanes. The color in water is attributable to dissolved organic matter that is high in N, so the relationship is not unexpected. Due to the limited color data, TN may serve as a surrogate when comparing other parameters. An outlier was observed in this relationship for a sample (LSF010C1) collected on February 9, 2016 when TN was reported at 0.06 mg/L. This is the Total Kjeldahl Nitrogen (TKN) value, reported by SRWMD, which does not include the 0.032 mg/L NOx. This value is suspect since color was reported at 52 PCU and this reported organic nitrogen concentration is an order of magnitude lower than any other reported by SRWMD.

5.3.2.3 Water Clarity (Secchi Depth)

Water clarity is not only important to recreational use of lakes but is an important factor controlling how nutrients impact ecological processes, including excessive growth by nuisance algae. Perhaps the most common measure of water clarity is Secchi depth, or the depth at which a Secchi disk is no longer visible. There have been 3,910 Secchi depth measurements made in the Santa Fe Lake system since 1967. Prior to 1979 only one or two measurements were reported each year and therefore the geometric mean for those years were not calculated, as well as in 2018 when only 4 measurements were made, all on the same day (May 22, 2018). The annual geometric mean Secchi depth has been decreasing, meaning water clarity or visible light penetration has been decreasing (Figure 24). This trend was determined to be statistically significant ($p\text{-value} < 0.0002$). Whether the reduced water clarity is due to algal abundance or increases in color is not clear from the available data. Comparing Secchi depth to TN, color, and chlorophyll *a*, suggests that color (and TN as a surrogate) is limiting water clarity (**Figure 25**). However, chlorophyll *a* also has an impacts on transparency (**Figure 25**).

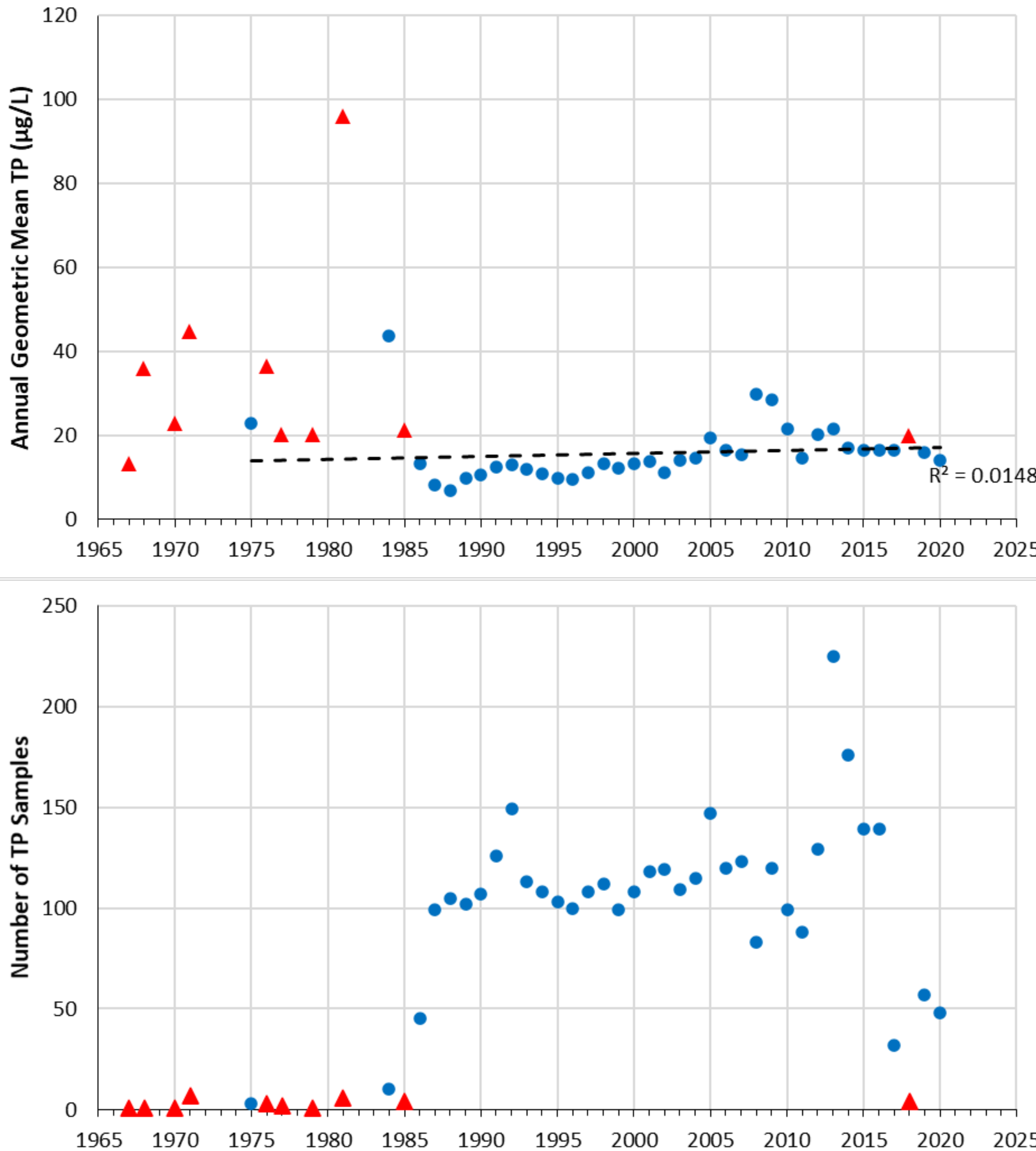

Figure 18. Annual geometric mean TP (µg/L) concentration measured in the Santa Fe Lake system for the period of record in IWR Run 61 database (top panel) and the number of samples collected each year (bottom panel). Data designated with a red triangle do not meet the minimum data requirements in 62-302.531 F.A.C. Numeric Interpretations of Narrative Nutrient Criteria and are not included in the trend analysis.

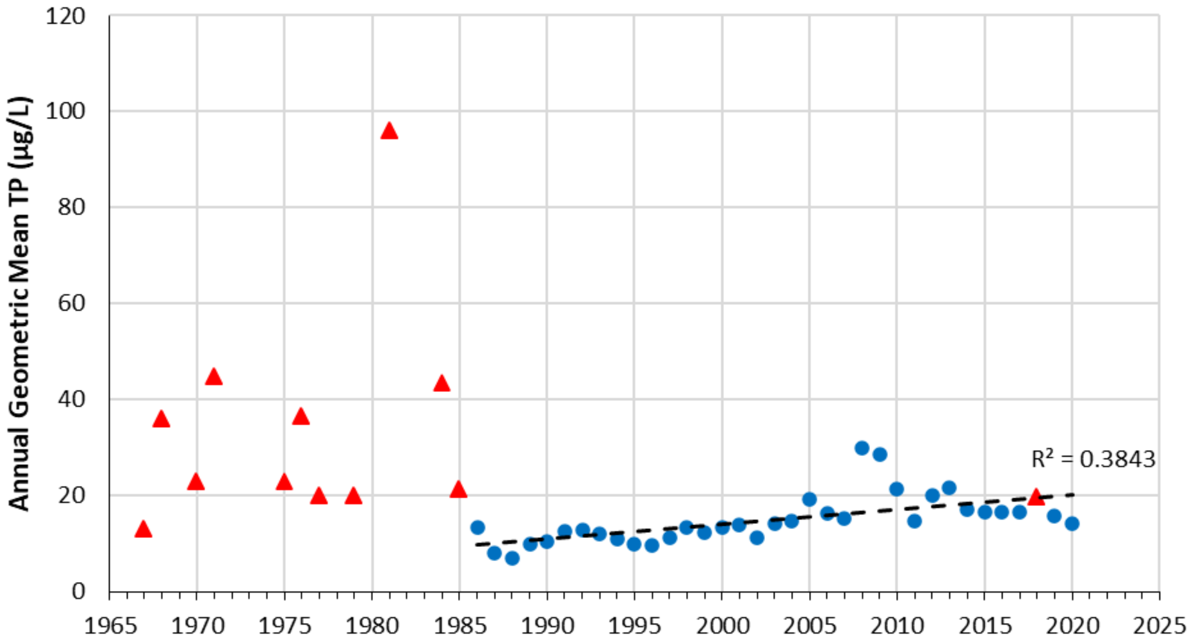

Figure 19. Annual geometric mean total phosphorus (TP) concentration in the Santa Fe Lake system using the data meeting quality requirements in 62-302.531 F.A.C. Numeric Interpretations of Narrative Nutrient Criteria. This represents only the data collected since 1986, when LAKEWATCH began monitoring the lake.

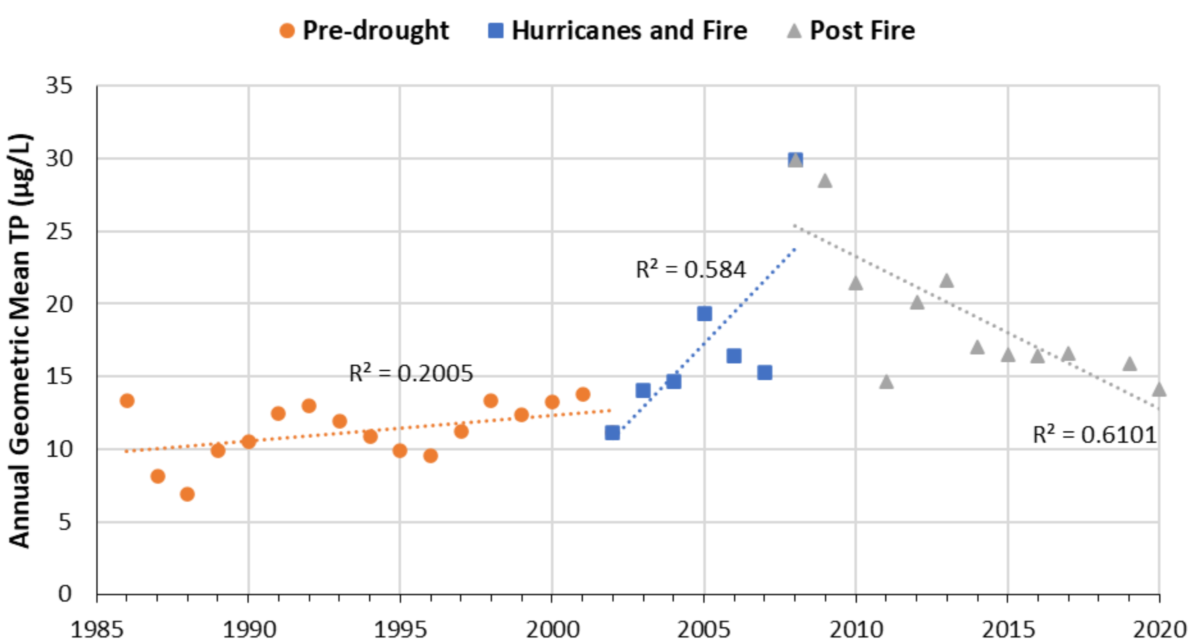

Figure 20. Annual geometric mean total phosphorus (TP) concentration in the Santa Fe Lake prior to and after the Dairy Road Fire of 2007. This represents only the data collected since 1986 when LAKEWATCH began monitoring the lake.

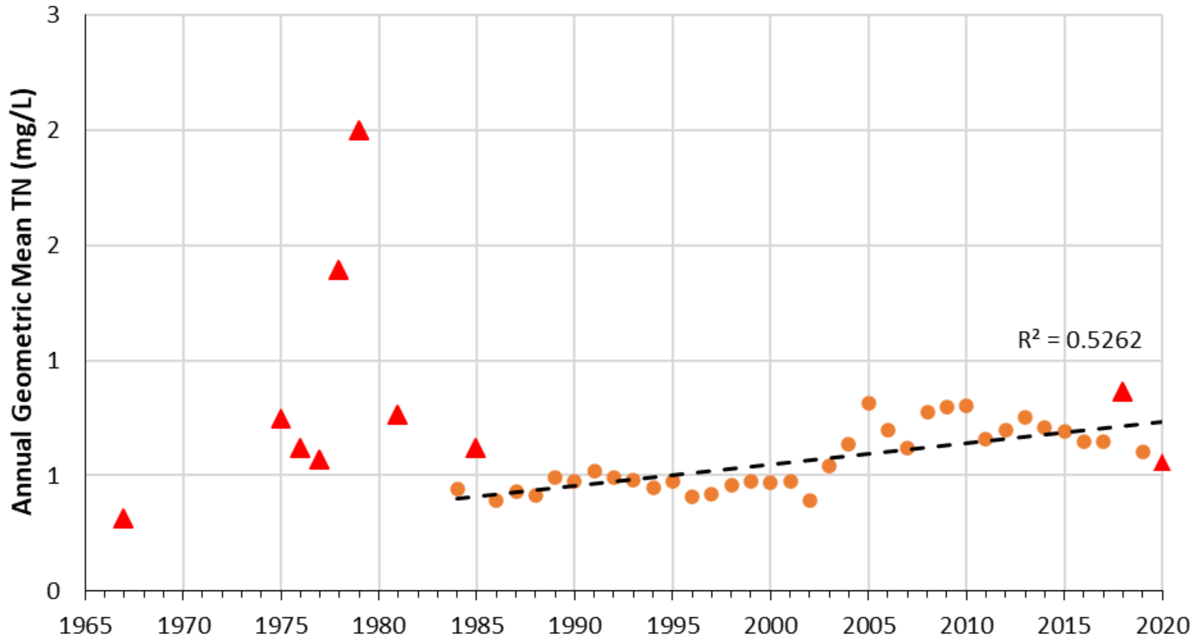

Figure 21. Annual geometric mean TN (mg/L) concentration measured in the Santa Fe Lake system for the period of record in IWR Run 61 database. Data designated with a red triangle do not meet the minimum data requirements in 62-302.531 F.A.C. Numeric Interpretations of Narrative Nutrient Criteria and are not included in the trend analysis.

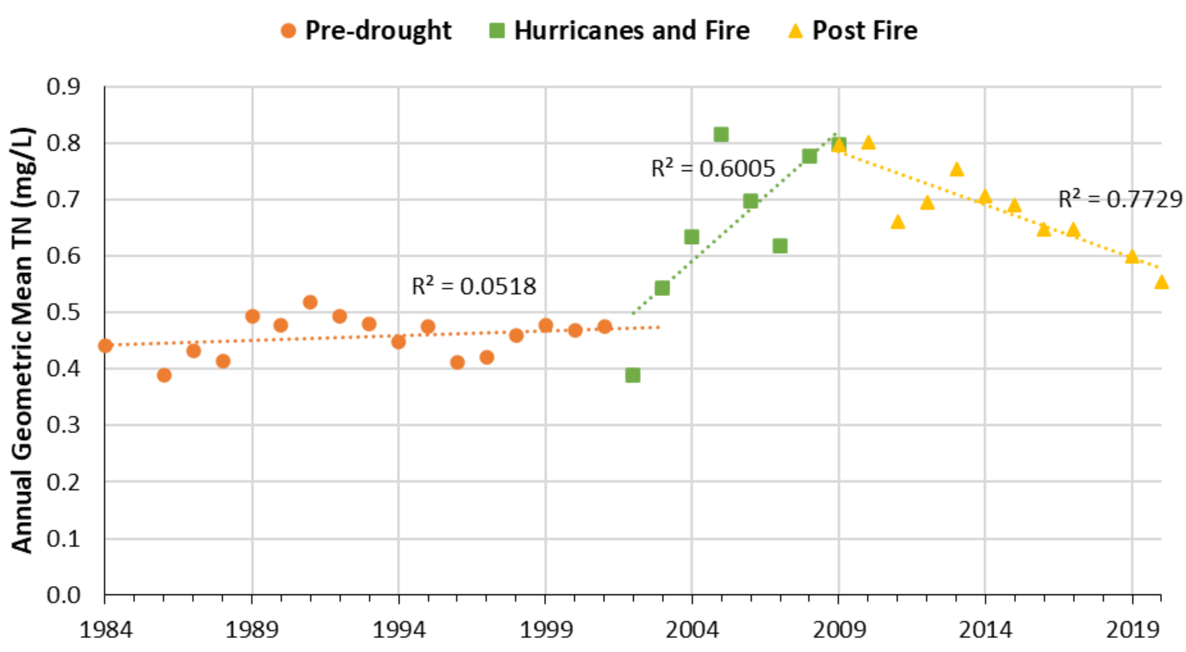

Figure 22. Annual geometric mean TN (mg/L) concentration measured in the Santa Fe Lake system for the period of record in IWR Run 61 database.

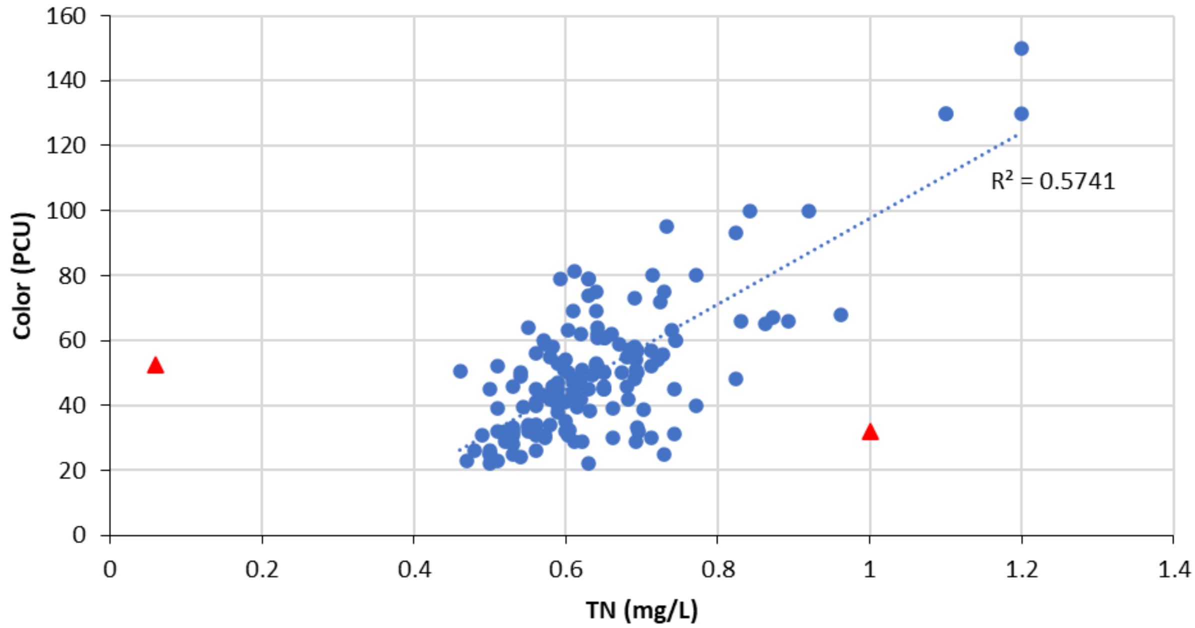

Figure 23. The relationship between total nitrogen (TN) and color in Santa Fe Lake WBID 3605G. Red triangles represent outliers or suspect data which were not used in the trend analysis.

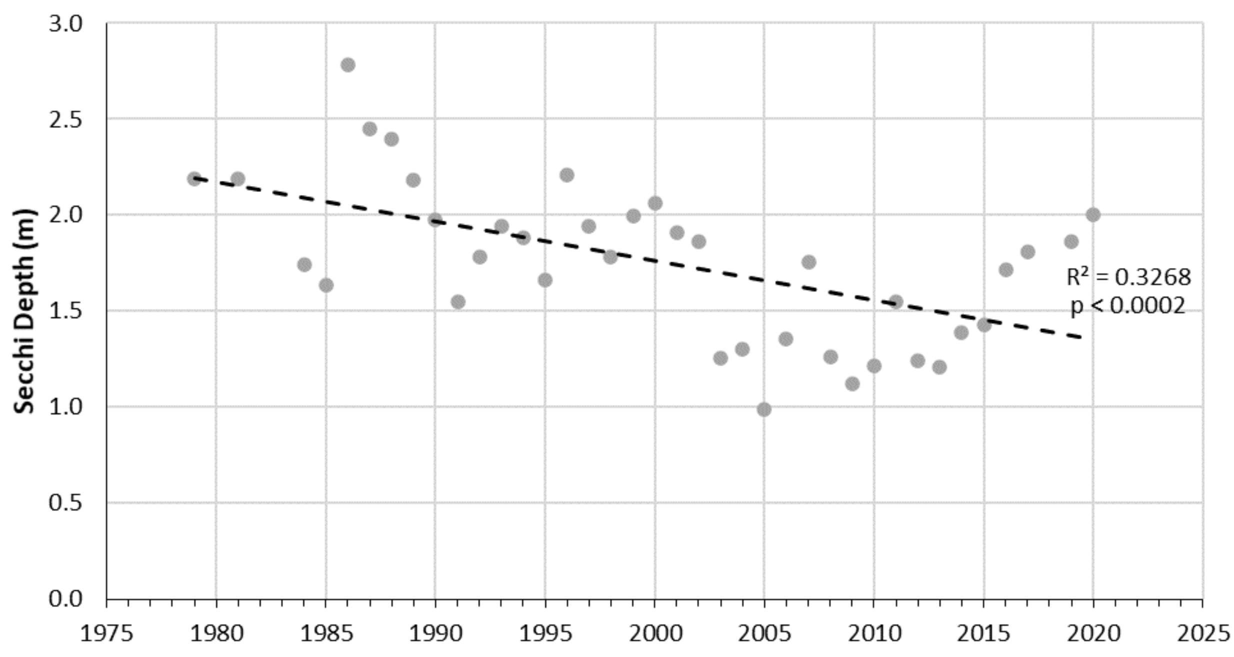

Figure 24. Annual geometric mean Secchi depth (m) measurements in the Santa Fe Lake system for the period of record in IWR Run 61 database.

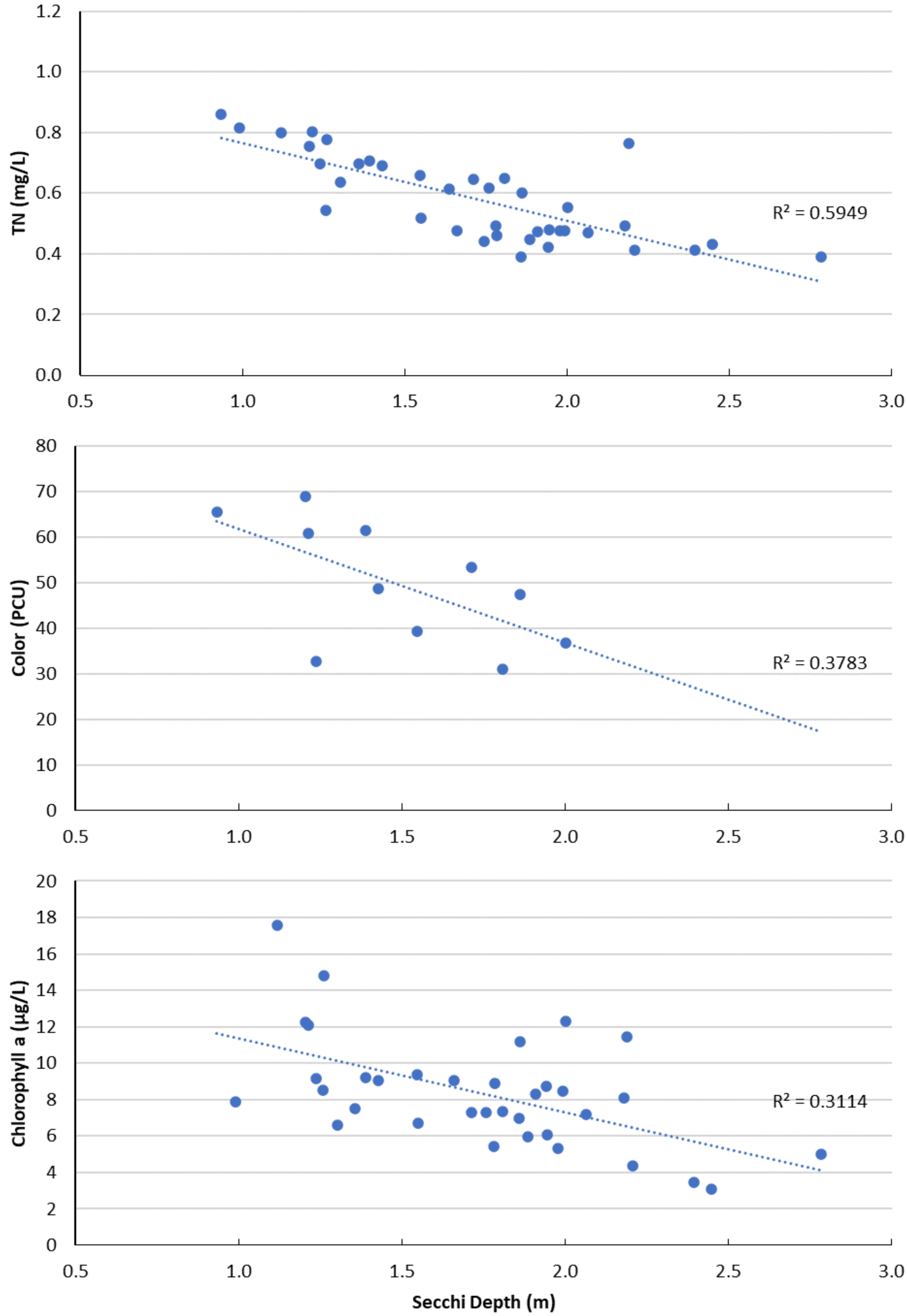

Figure 25. Relationships between annual geometric mean values for Secchi depth to total nitrogen (TN), color, and chlorophyll *a*.

5.3.2.4 Chlorophyll a

There was a total of 1,113 samples analyzed for chlorophyll *a*, corrected for pheophytin, between December 1979 and September 2020 (Figure 17). These data were used to calculate the annual geometric mean concentration for the Santa Fe Lake system (Figure 26). During a number of years, there were not enough samples collected, or they did not meet the temporal requirements necessary, to calculate the annual geometric mean under 62-302.531 F.A.C. Numeric Interpretations of Narrative Nutrient Criteria. After removing those data, there appears to be an increasing trend in chlorophyll *a* concentrations (Figure 26). These agree with the annual report produced by LAKEWATCH (2020) (Figure 14). In the IWR Run 61 database, there were 3,787 records for chlorophyll *a* that were uncorrected for pheophytin, over the same period of record. Annual geometric means were similarly calculated chlorophyll *a*, uncorrected for pheophytin, and a similar trend was observed (Figure 27).

Like TP and TN, the chlorophyll data record may be best interpreted by considering major, non-anthropogenic events that influence time trends. Prior to the Dairy Road Fire in 2007 (discussed below in Section 5.3.3), the chlorophyll *a* concentrations had been gradually increasing since 1986 (Figure 28). The record low water levels in June of 2002 (135 ft NAVD88) (Figure 10) and the tropical systems in 2004 did not appear to impact the chlorophyll *a* concentrations (Figure 28). However, there was a significant increase after the fire in 2007, where concentrations peaked in 2009 (Figure 28). Between 2008 and 2017, the chlorophyll *a* concentrations were declining and approaching the pre-fire concentrations (Figure 28). Since 2017, however, there has been an increase in chlorophyll *a* concentrations. This turning point was coincident with the record rainfall in that year (Figure 11).

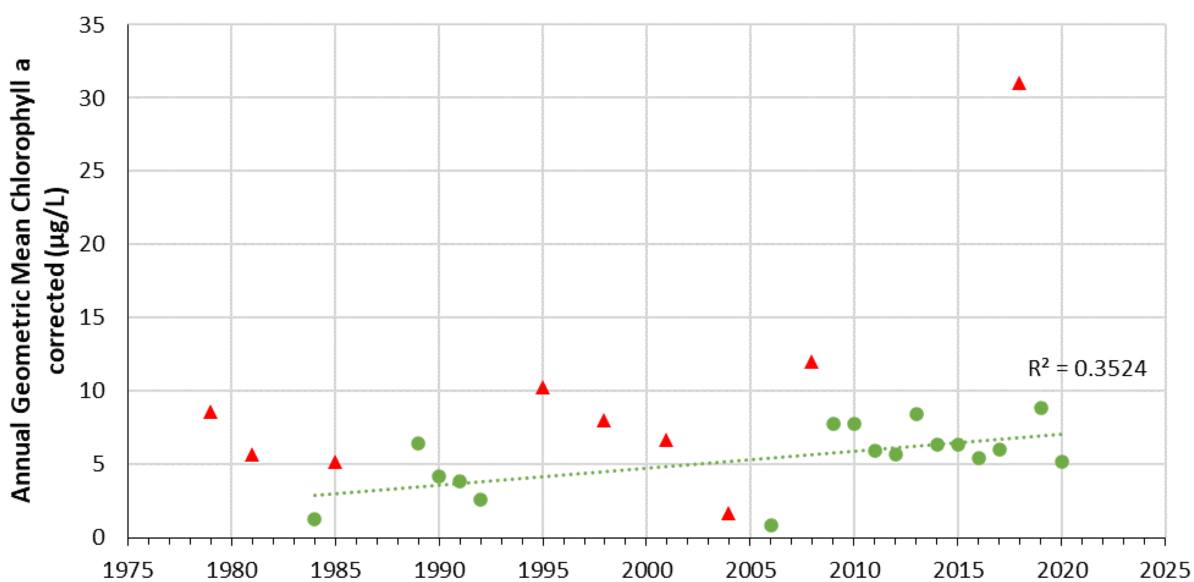

Figure 26. Annual geometric mean chlorophyll *a* corrected for pheophytin concentrations measured in the Santa Fe Lake system for the period of record in IWR Run 61 database (December 1979 to September 2020). Data designated with a red triangle do not meet the minimum data requirements in 62-302.531 F.A.C. Numeric Interpretations of Narrative Nutrient Criteria and are not included in the trend analysis.

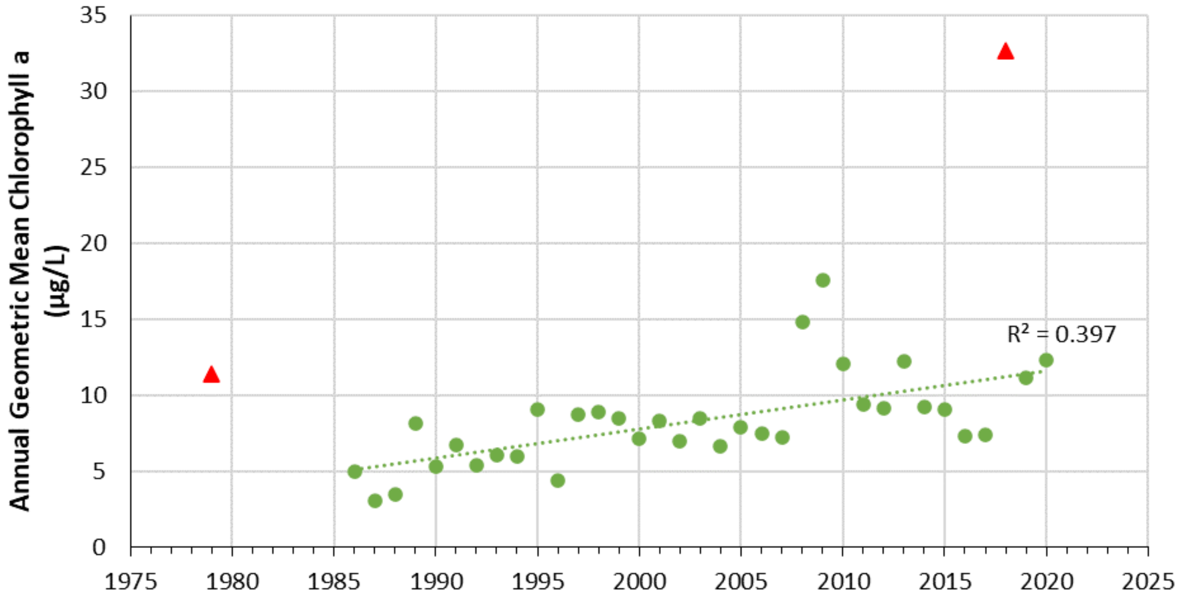

Figure 27. Annual geometric mean chlorophyll *a* (uncorrected for pheophytin) concentrations measured in the Santa Fe Lake system for the period of record in IWR Run 61 database (December 1979 to September 2020). Data designated with a red triangle do not meet the minimum data requirements in 62-302.531 F.A.C. Numeric Interpretations of Narrative Nutrient Criteria and are not included in the trend analysis.

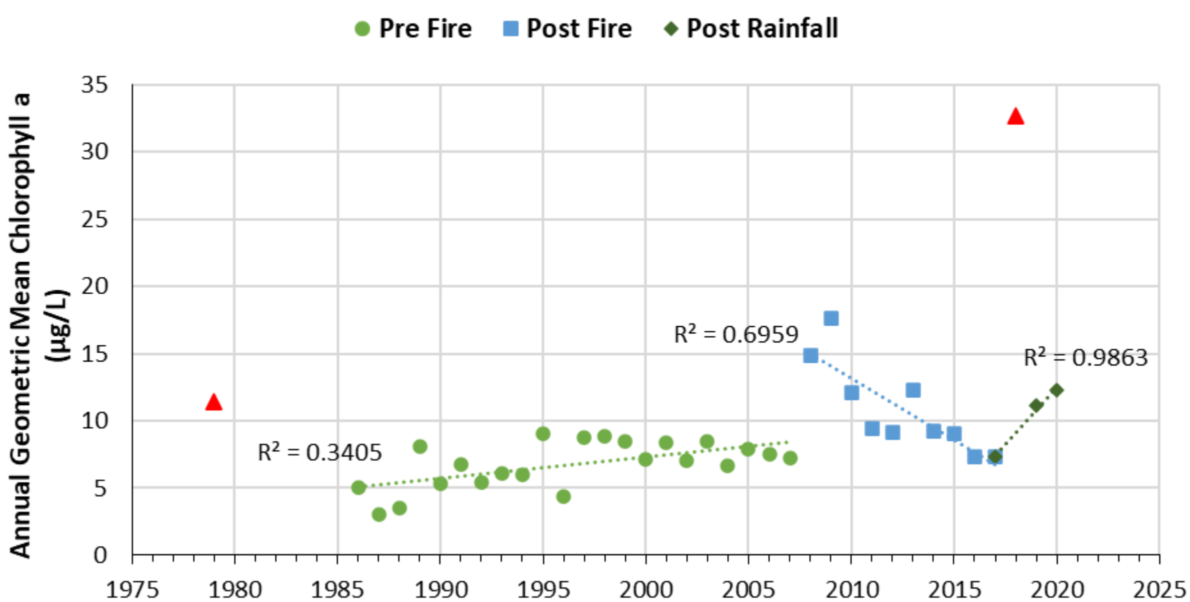

Figure 28. Annual geometric mean chlorophyll *a* concentrations, prior to and after the Dairy Road Fire in 2007, measured in the Santa Fe Lake system for the period of record in IWR Run 61 database (December 1979 to September 2020). Data designated with a red triangle do not meet the minimum data requirements in 62-302.531F.A.C. Numeric Interpretations of Narrative Nutrient Criteria and are not included in the trend analysis.

5.3.3 Impact of 2007 Fire in Santa Fe Swamp

Ruiz-Bernard (2012) evaluated impacts of a wildfire in the Santa Fe Swamp on water chemistry in the main Santa Fe Lake basin, Little Santa Fe Lake, and Melrose Bay. Known as the 2007 Dairy Road Fire, this fire was considered to be catastrophic, due to the areal extent (5100 ha, or 12,600 acres) and the long duration and intensity of the burn, which resulted in extensive loss of peat (i.e., a "muck fire"). Water quality in all three lake basins deteriorated rapidly after the onset of the burn, with only partial recovery observed during a 3-year post-burn monitoring period. Post-burn (November 2007 – November 2010) levels of TN, TP, chlorophyll *a* and color were highest in Little Santa Fe Lake, followed in order of magnitude by Santa Fe Lake and Melrose Bay, reflecting a general decrease in water quality impacts with distance from the burned wetland area (Table 3). Mean TP, TN, and color values during this period were significantly higher in Little Santa Fe Lake, but only slightly higher in Santa Fe Lake than in Melrose Bay, while a relatively small stepwise decrease in chlorophyll *a* was observed among the three basins (Ruiz-Bernard 2012) (Table 3).

Based on this study, Ruiz-Bernard (2012) concluded that single, non-anthropogenic catastrophic events such as the 2007 Santa Fe Swamp fire may have a significant short or longer-term influence on lake water chemistry, and even trophic state, at a magnitude similar or greater than anthropogenic influences.

Table 3. Average water quality and clarity of Little Santa Fe Lake, Santa Fe Lake and Melrose Bay prior to the Dairy Road Fire (August 1986 to October 2007) and after the fire (November 2007 through November 2010).

	Mean Values				
	TP (µg/L)	**TN (µg/L)**	**Chlorophyll *a* (µg/L)**	**Color (PCU)**	**Secchi Depth (m)**
Little Santa Fe Lake (pre-burn)	13	582	8.8	76	1.5
Little Santa Fe Lake (post-burn)	51	970	20	152	0.9
Santa Fe Lake (pre-burn)	11.2	461	6.9	32	2.3
Santa Fe Lake (post-burn)	23	739	18	63	1.5
Melrose Bay (pre-burn)	12.3	467	7.3	32	2.3
Melrose Bay (post-burn)	21	732	17	63	1.5

5.3.4 Influence of Regional and Long-term (decadal) Climate Patterns - Assessment of 1986-2013 LAKEWATCH data

Due in part to concerns voiced by local residents over the persistence of high levels of lake TP following the 2007-2008 increase, a study was initiated by the Fisheries and Aquatic Sciences center at the University of Florida to investigate suspected anthropogenic causes of eutrophication in the Santa Fe Lake system. In addition, the potential influence of cyclical regional and global climatic events on water chemistry in Santa Fe Lake and other peninsular Florida lakes was investigated (Canfield et al. 2016).

Based on Florida LAKEWATCH data collected in the Santa Fe Lake system from 1986 through 2013 (Canfield et al. 2016), the annual geometric mean concentrations for TP (Figure 13), TN 1986 through 2013 (Canfield et al. 2016), the annual geometric mean concentrations for TP (Figure 13) and chlorophyll *a* (Figure 14) increased significantly over time, while Secchi depth decreased significantly (Figure 14). The same trends were shown for minimum geometric average monthly values, suggesting that baseline levels for these trophic state variables were changing over time. Although nutrient concentrations were significantly higher and Secchi depth was significantly lower in Little Santa Fe Lake than in Santa Fe Lake and Melrose Bay during this period, each basin exhibited increasing nutrient concentrations and decreasing Secchi depth. Similar trends in nutrients, chlorophyll *a*, and Secchi depth, as well as increasing specific conductance (based on limited measurements by LAKEWATCH) were reported for nearby Lake Alto and Lake Hampton (two lakes located in the Santa Fe River watershed). The changes in specific conductance (SC) were determined not to be due solely to dilution or concentration within the lake (and associate changes in lake water level/volume) but were significantly correlated to changes in groundwater level. This suggests that increases in lake water SC could be a result of higher ratios of groundwater (higher SC) input to surface water input to these lakes.

Based on data from LAKEWATCH during the 1986-2013 monitoring period, TP, TN, chlorophyll *a,* and Secchi depth were significantly correlated with each other. None of these variables were significantly correlated with annual precipitation of El Niño/La Niña events, and TN and Secchi depth were only weakly correlated with reported Atlantic Multidecadal Oscillations (AMO). However, all of the variables were significantly negatively correlated to adjusted cumulative rainfall deviation (ACRD), for which annual surplus and deficit deviations from the long-term precipitation average are successively added year by year to provide a cumulative precipitation series. The ACRD zero value represents the site's long-term precipitation average, allowing identification of periods of positive and negative long-term precipitation. The negative correlations indicate that nutrient concentrations were lower in the Santa Fe Lake system during periods of increased rainfall (Canfield et al. 2016).

In the absence of detailed water and nutrient budgets for the Santa Fe Lake system, the authors concluded that currently available information is insufficient to determine if the increase in TP, TN and chlorophyll *a* concentrations and decrease in Secchi depth has been caused by cultural eutrophication. They also offer reasons to suggest otherwise. For example, they point out that the increase in lake residential units do not represent concentrated urban development, and that most of the surrounding watershed has remained rural forested lands, with fertilized croplands making up <1% of the watershed. Further, they stated that the most concentrated area of development, the town of Melrose (on Melrose Bay) has existed for an extended period of time, yet nutrient and chlorophyll *a* concentrations and Secchi depth are not significantly different from the primary Santa Fe Lake basin.

Numerous random, non-anthropogenic events were discussed as factors that likely have exerted both short-term and long-term influence on water chemistry in the lake system, often producing cumulative effects. These include the 2007 wildfire that devastated the Santa Fe swamp (Ruiz-Bernard 2012), but also recurring periods of flood and drought. Multiple El Niño and La Niña weather events are thought to have influenced lake hydrology and water quality. For example, a sharp increase in TN occurred from 2002 through 2005 in the Santa Fe Lake system, which is believed to be the cumulative result of drought during La Niña years in 1999-2001 followed by increased rainfall during 2002 and 2003, and the rain and wind from three hurricanes in 2004. Conversely, TN did not decrease to pre-1999 levels when below average rainfall occurred from 2006-2011. The authors point out that multiple and interacting environmental stressors complicate prediction of ecosystem response, and the duration of events and recovery times can be highly variable.

5.4 Canal Water Quality

At times, the data demonstrate relatively high nutrient and chlorophyll *a* concentrations (Figures 15 through 17). After looking into the location of the some of these higher concentrations it became evident that many of these samples were collected from a canal on the south side of the lake (Figure 29). Unpermitted dredging to deepen this canal (Painter Canal) occurred in the winter of 2000 to 2001. In response to the high turbidity levels observed from the dredging activities, ACEPD completed a monitoring effort from February to September 2001. During this period of elevated turbidity, extremely high concentrations of TP were observed in the canal (Figure 30). Increased TN and chlorophyll concentrations in 2001 were not observed (Figures 31 and 32), suggesting a discreet source of P to the water column, that had not become accompanied by N or stimulated phytoplankton and chlorophyll *a* concentrations.

The turbidity in this canal is evident in the aerial imagery from 2001 (Figure 40 on page 60). In a follow up study by ACEPD, which took place between 2005 and 2006, water quality in three canals were sampled and compared to the open water portion of Santa Fe Lake (ACEPD 2006). Significantly higher concentrations of TP and TN were found in the canals. Sediments from these canals also had significantly higher TP content and water extractable phosphorus (WEP), when compared to a sample from the lake (ACEPD 2006). It was determined that land use surrounding canals on Santa Fe Lake was likely having a negative impact on water quality within the canals.

LAKEWATCH has continued to sample one of these canals (Painter Canal) and those data have been uploaded to the FDEP databases and are considered in determining impairment. These data are also reported in the annual lake report (LAKEWATCH 2020). These canal data seem to indicate that water quality and clarity in the canal tends to be improving in the years since the dredging disturbance in 2001 (Figures 33 and 34). The station at the mouth of the canal did show an increasing trend in TN (Figure 33), similar to Santa Fe Lake and Melrose Bay (Figure 13). Trends in temporal data are considered significant when the p-value is less than 0.05. The p-value represents a probability of the error in rejecting the null hypothesis that there is no change over time and values are the result of random fluctuations (Figures 33 and 34).

After compiling the data sets, a comparison of the water quality in the lake versus the canals was completed. The mean TP concentration measured in the canals (30 μg/L), over the same period

(2001 to 2020), was significantly higher ($P < 0.00005$) than the lake (18 μg/L). This suggests that the canals around the lake may be sources of nutrients to the lake when water exchange occurs. Water exchange could occur from surface water inputs to the canal, wind driven currents and boat traffic. However, the actual amount of water exchange between the canals and lake are unknown. Nutrients from adjacent lands enter these canals through several transport mechanisms, including direct discharge of stormwater runoff and infiltration to groundwater (leaching of fertilizer and septic effluent to groundwater) into the canals. Data from these canals on sediment quality, stormwater inputs and groundwater contributions were not readily available, but could be collected and evaluated further in the next phase of this project.

The argument could be made that this data is not representative of the lake's water quality and should not be considered when determining the impairment of Santa Fe Lake. Additional investigation to determine if there are rules on what type of data should be loaded to STORET or WIN could be completed but were beyond the scope of this data review. Additional data analysis to determine if the inclusion of the canal data affects the trends or annual geometric mean concentrations may be warranted.

Figure 29. Sampling locations in the Painter Canal on the south side of Santa Fe Lake.

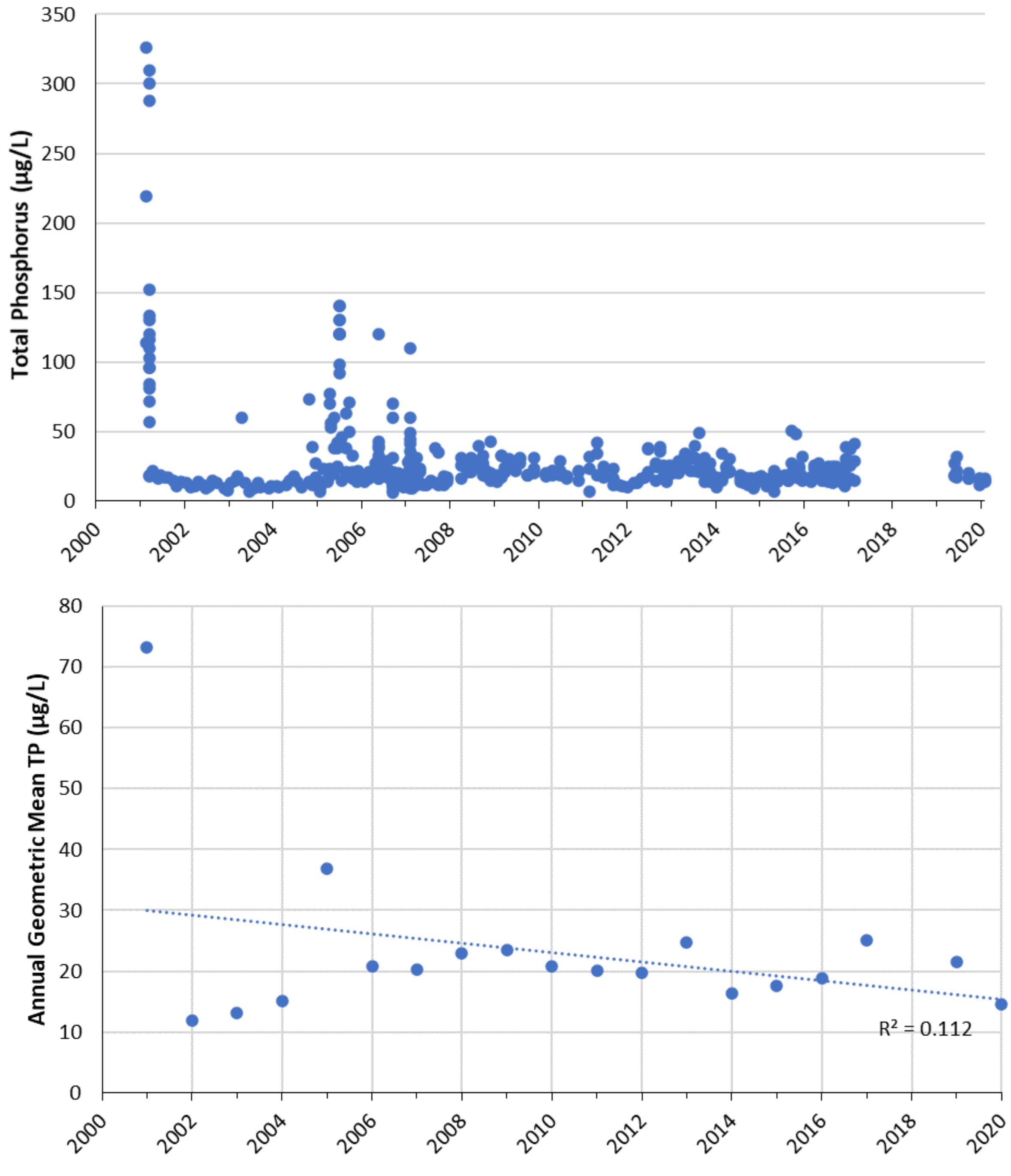

Figure 30. Total phosphorus in water samples collected in canals on Santa Fe Lake (data from LAKEWATCH and ACEPD).

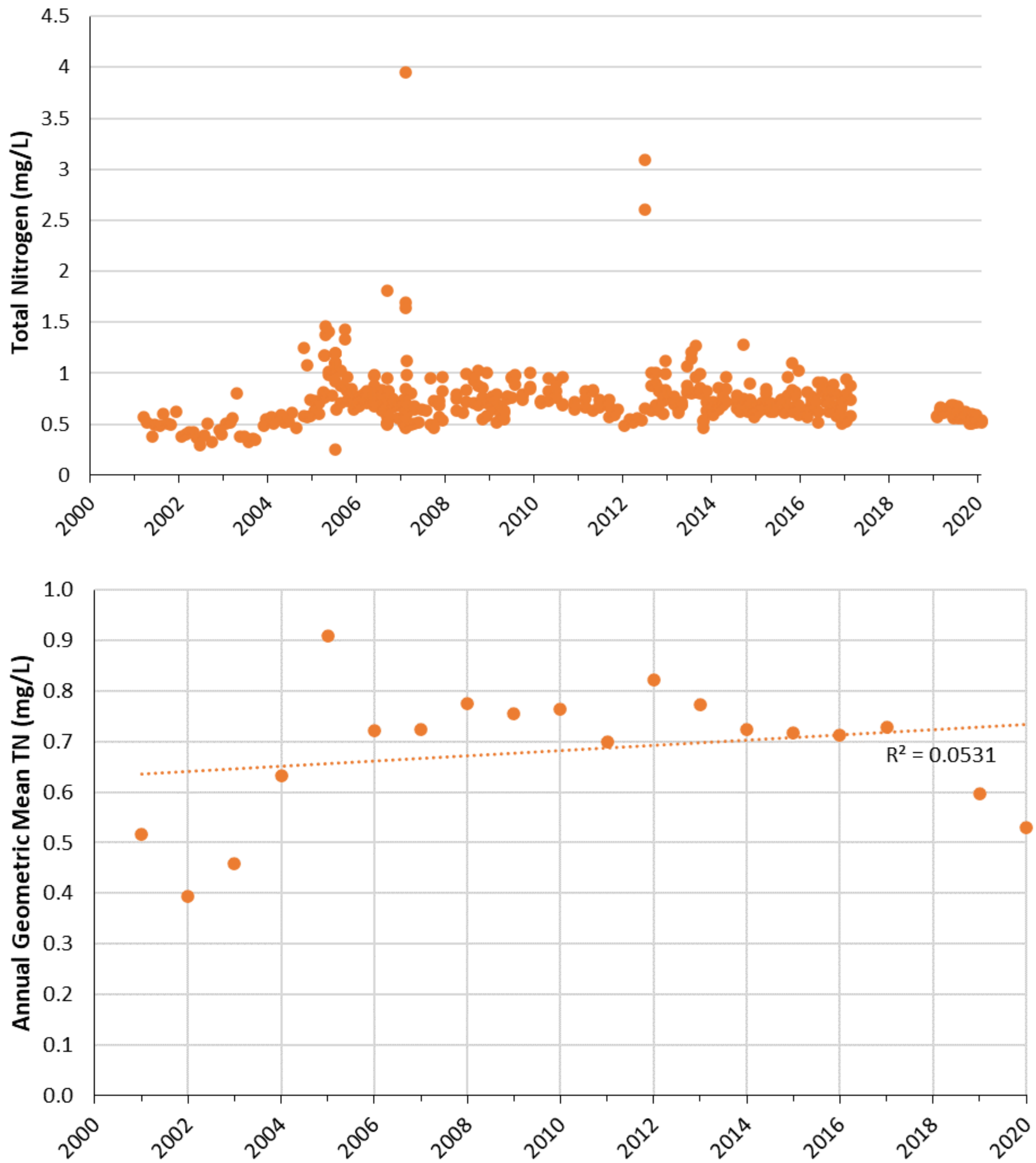

Figure 31. TN concentrations in the canal on the south side of the lake.

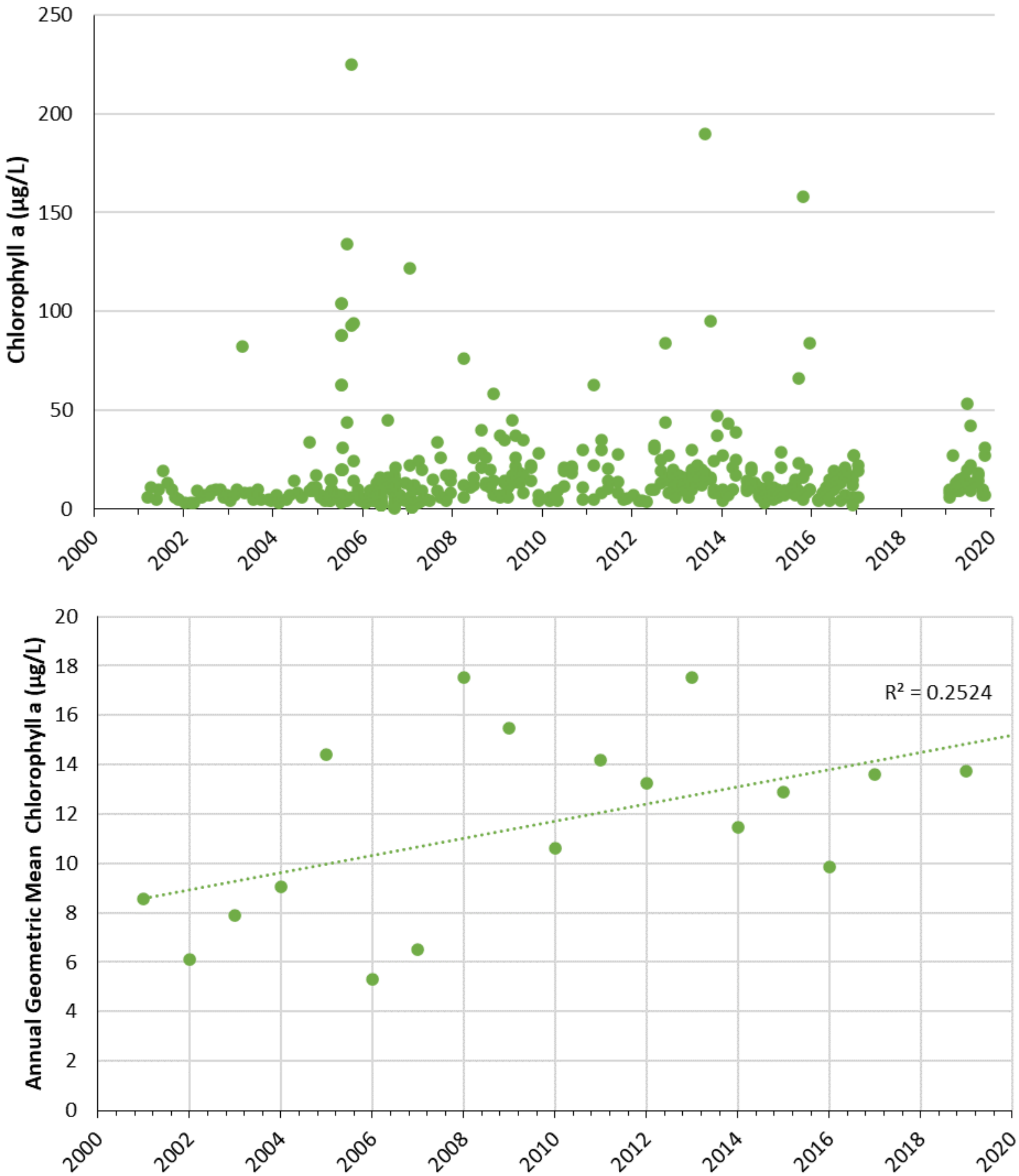

Figure 32. Chlorophyll *a* concentrations in the canal on the south side of the lake.

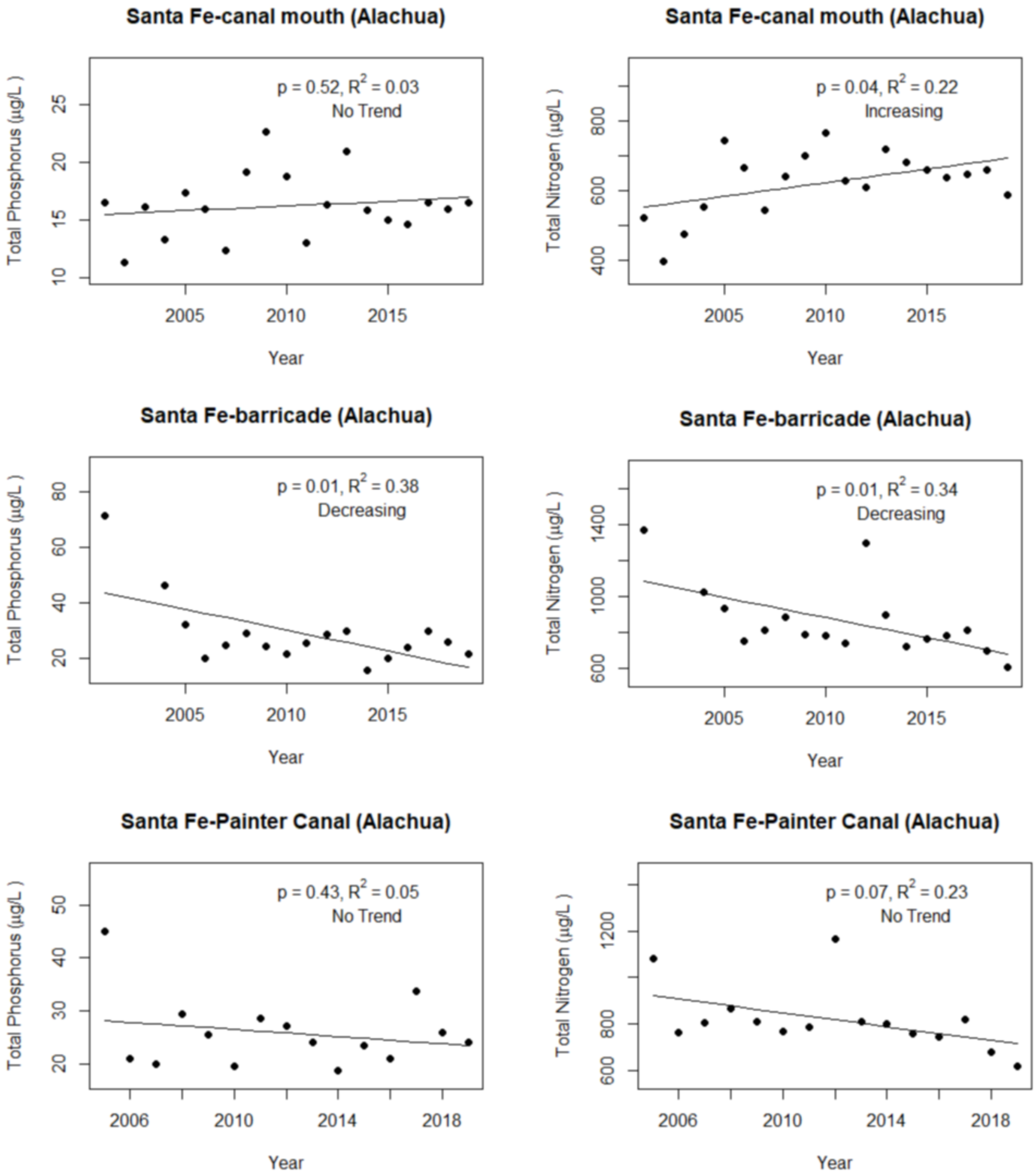

Figure 33. Annual average total phosphorus and total nitrogen concentrations in the canal on south end of Santa Fe Lake (measured and reported by LAKEWATCH 2020). See Figure 29 for sampling locations.

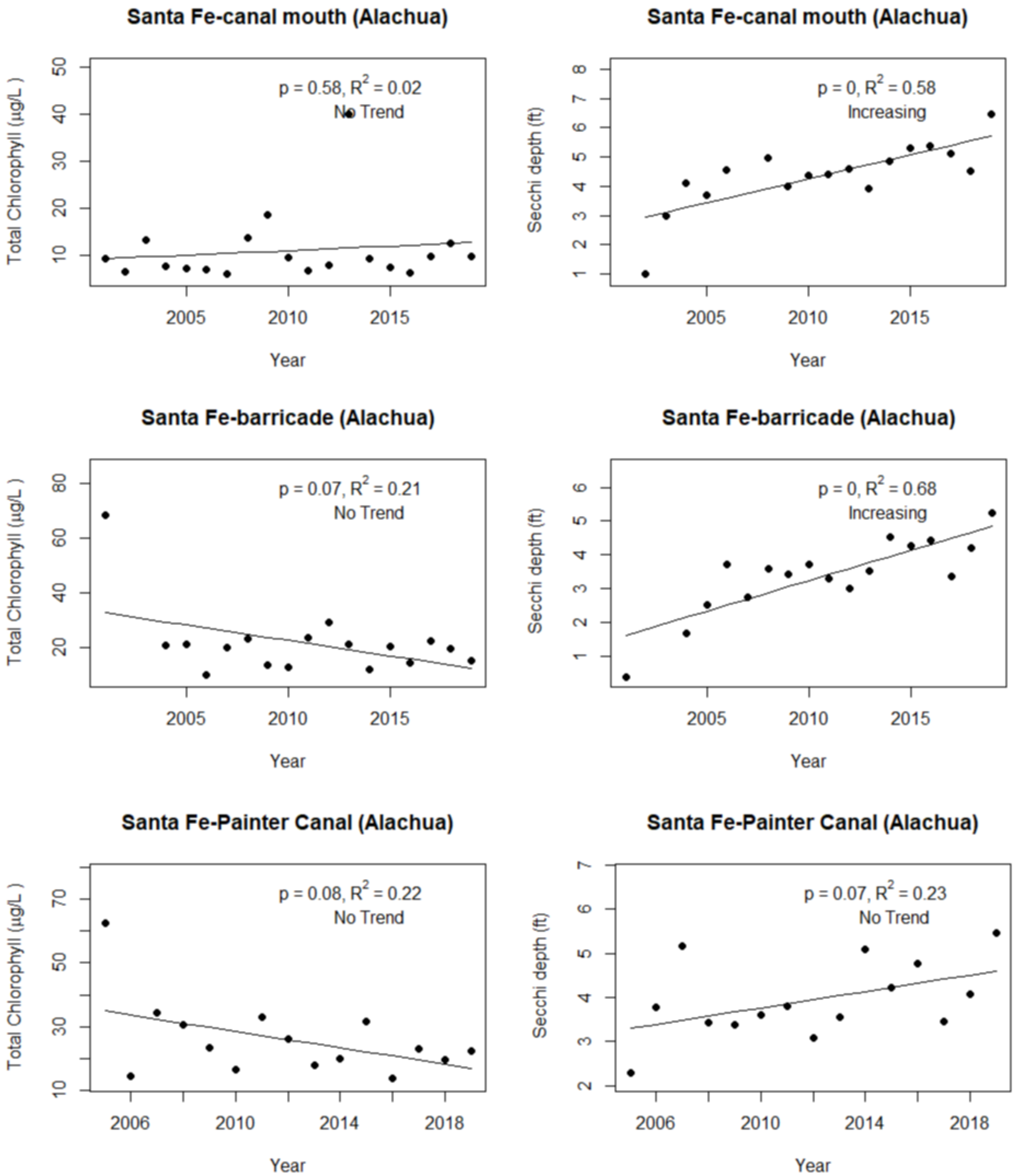

Figure 34. Annual average chlorophyll *a* concentration and Secchi depth in the canal on south end of Santa Fe Lake (measured and reported by LAKEWATCH 2020). See Figure 29 for sampling locations.

5.5 Sediment Nutrients

Sediment quality data was downloaded from FDEP through the Watershed Information Network (WIN) Advanced View and Extraction System (WAVES) system. This dataset had 891 records from 16 samples collected since 2017. Upon request, additional data was provided by the Watershed Monitoring Section of FDEP. This included 2,610 records from 76 samples collected throughout the Santa Fe Lake system from July 2004 to May 2021. There were 129 different analytes reported, which included nutrients (TP and TKN), metals, pesticides, herbicides, and polycyclic aromatic hydrocarbons (PAHs).

There were 66 samples with analytical results for TP (Figure 35) and TKN (Figure 36) content of sediments throughout the lake. Fourteen of those samples were collected from within Little Santa Fe Lake, 51 from Santa Fe Lake and one from Melrose Bay. The TP content varied considerably from 19 to 1,800 mg/kg. These TP concentrations are generally lower than sediments collected from phytoplankton dominated hyper-eutrophic lakes of Central and North Florida, which range from 820 to 4,270 mg/kg (Kenney et al. 2002). Sediment cores collected from Orange Lake showed an increase in the contribution of phytoplankton to the organic content of sediments as a result of anthropogenic P loading. The transition in the primary producer community from a macrophyte dominated system to phytoplankton dominance was identified in the sediment cores (Kenney et al. 2002). Those sediments accrued during macrophyte dominance had mean TP concentrations of 480 mg/kg while those that accumulated after the shift to phytoplankton dominance had mean TP concentrations of 820 mg/kg.

There was also a considerable range in the TKN content of these sediment samples (0.01 to 3.6%). Typical of lake sediments the TKN content was correlated with the amount of organic matter in the sediments (Figure 37). The sediment with the highest organic N content (TKN) was collected in May of 2019 from the northwest corner of Little Santa Fe Lake closest to the Santa Fe Swamp (Figure 36). This amount of organic nitrogen is higher than would be expected based on the amount of organic carbon in the sediments (Figure 37) and may be an indicator of organic nitrogen entering the lake from the swamp.

There were detections of several metals and mercury in the sediments of Santa Fe Lake. However, only a few samples had metabolites of DDT and other pesticides as well as PAHs related to coal tar (wood preservative and asphalt additive) detected in the sediments (Z2-LL-11011 and Z2-LL-11015). One sample was collected from near the center of the lake at one of the deepest locations and the other is approximately 600 meters off the western shore near Earleton, FL. Almost all of the other pesticides, herbicides, and PAHs were not detected in the other sediment samples. These data were recently received from FDEP, and further analysis is warranted.

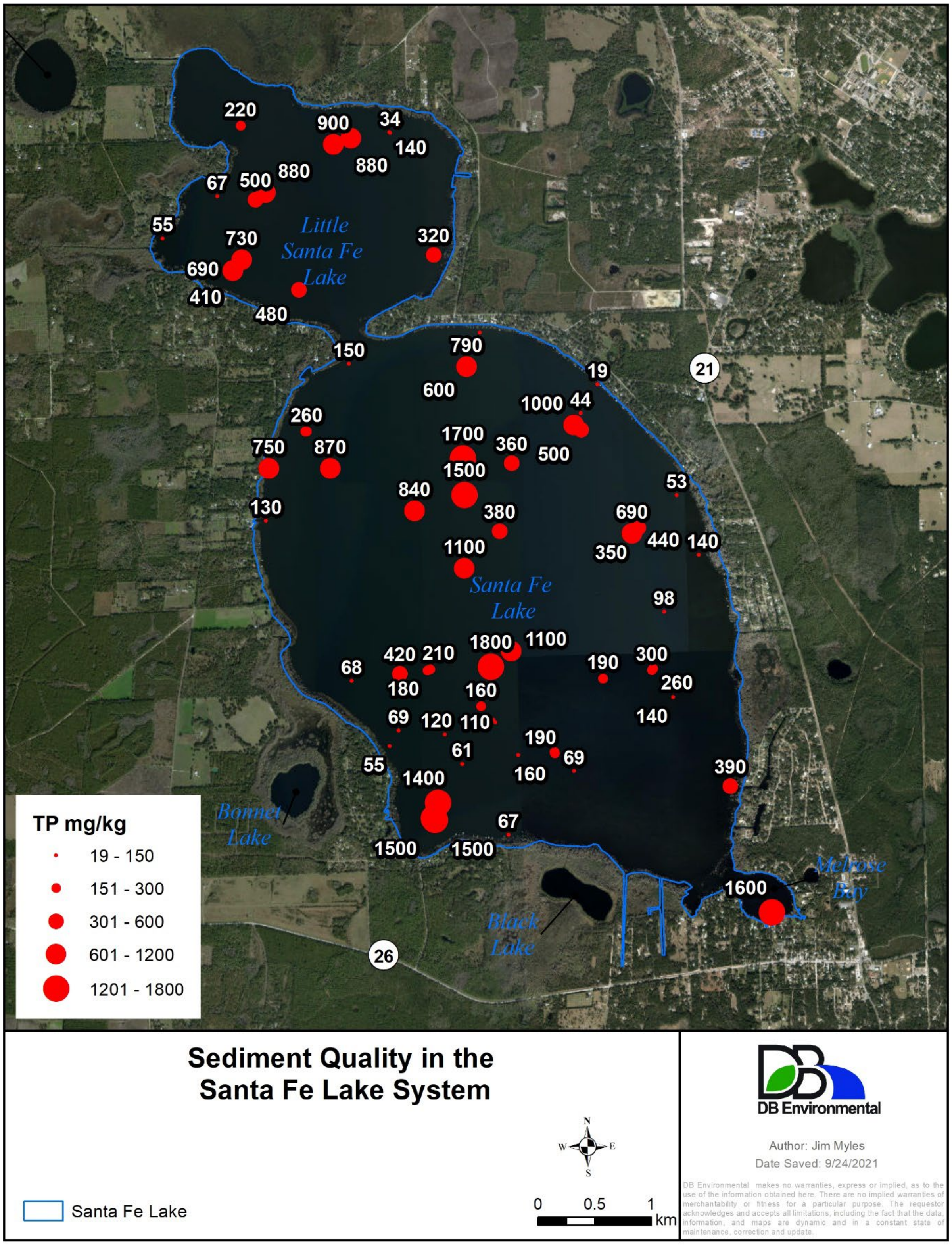

Figure 35. Total phosphorus (TP) concentration of sediments collected from the Santa Fe Lake system between 2005 and 2020. Source: FDEP.

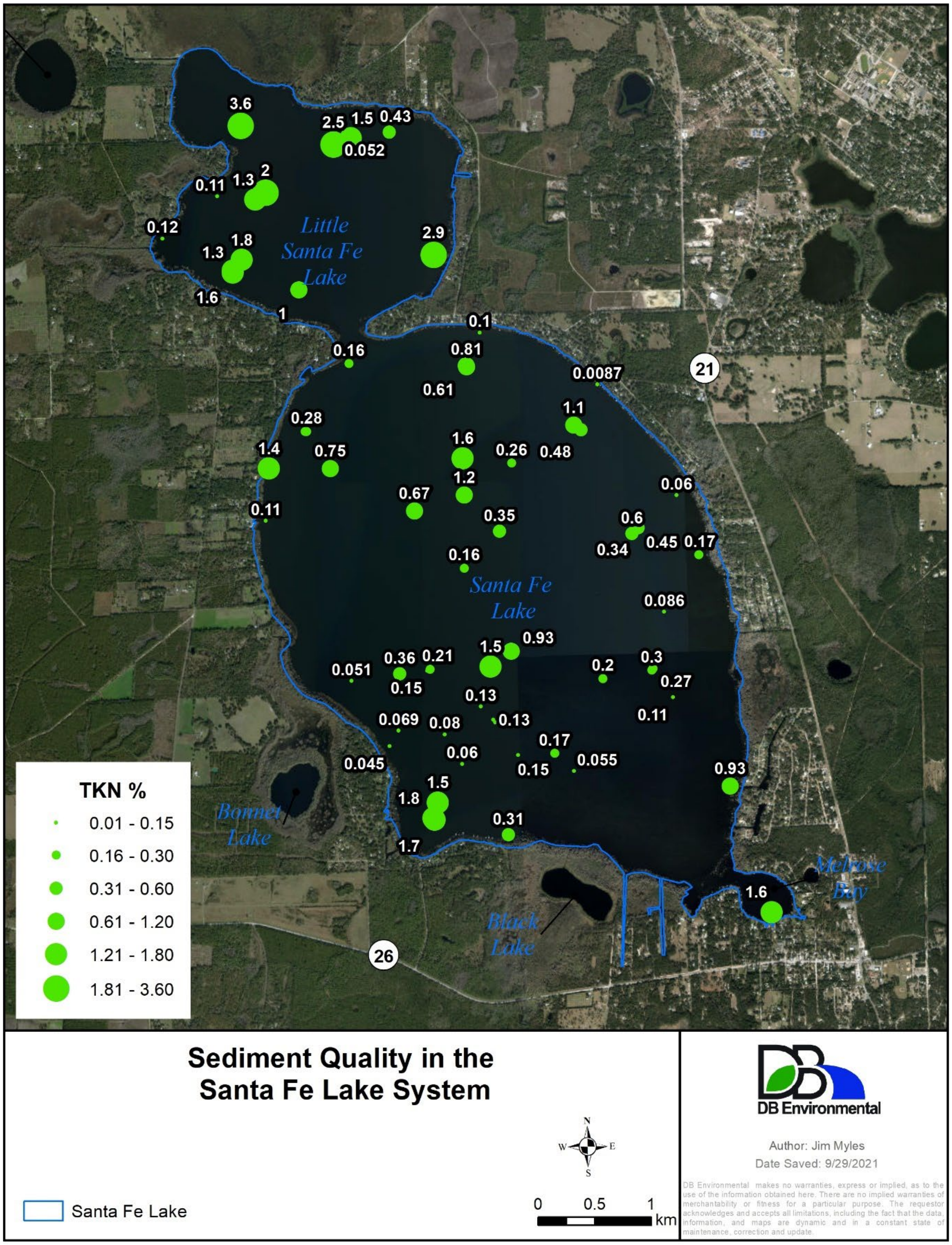

Figure 36. Total Kjeldahl Nitrogen (TKN) concentration of sediments collected from the Santa Fe Lake system between 2005 and 2020. Source: FDEP.

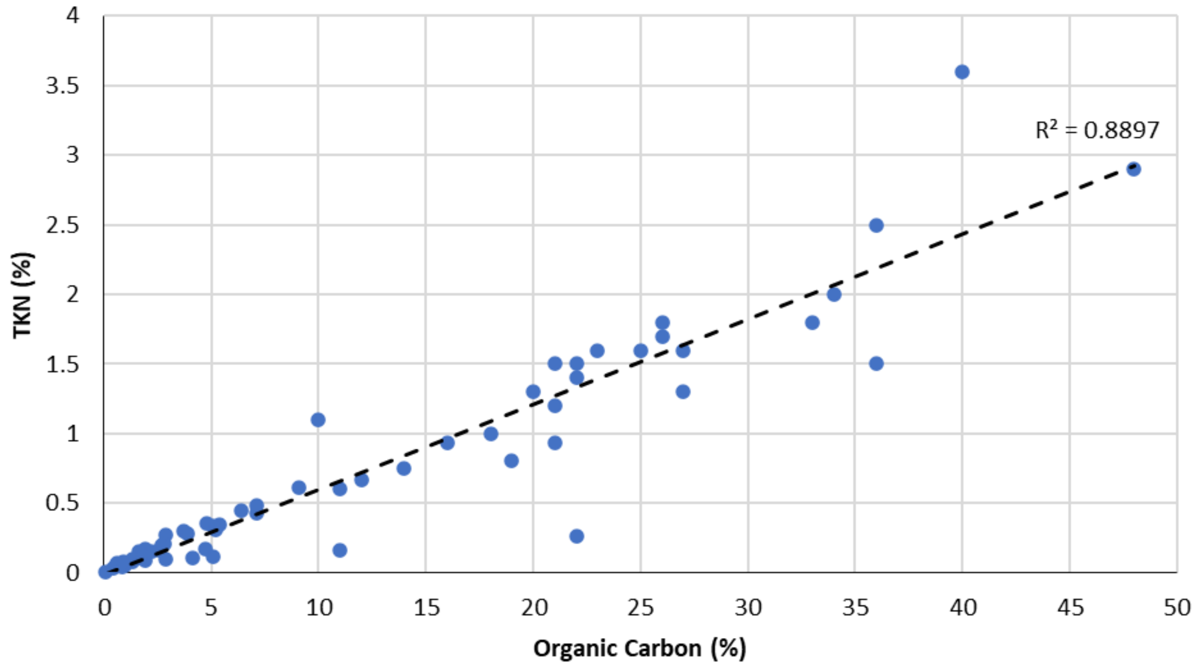

Figure 37. Correlation between organic carbon content and TKN content.

5.6 Water and Nutrient Budget

5.6.1 Water Budget

A lake water budget is calculated by measuring or estimating all gains and losses and the corresponding change in lake volume over the same period (Equation 1). Until recently, a water budget for Santa Fe Lake had not been completed. In November of 2021 a water budget was completed (ECT 2021a) to support the establishment of Minimum Flows and Levels (MFLs) for Santa Fe Lake and Lake Alto (ECT 2021b). The Storm Water Management Model (SWMM) was used to simulate the hydrologic cycle such as rainfall, evapotranspiration, surface water inflow and outflows and to some degree the groundwater interactions as they relate to measured and modeled lake stages.

Equation 1. Typical lake water budget.

$$\Delta V = P - E + S_i - S_o + G_i - G_o$$

ΔV= change in lake volume
P = direct precipitation
E = evaporation
S_i = surface water inflow
S_o = surface water outflow
G_i = groundwater inflow
G_o = groundwater outflow

Prior to this effort information necessary to calculate the volume of the lake had not been developed, including a digital elevation model showing the bathymetry of the lake. In addition, the surface water inflows to and outflows from the lake were unknown since they had not been gauged or surveyed. This modeling effort delineated the watershed for both lakes (Santa Fe and

Alto) and their sub-basins and modeled the runoff from those basins to the lake. Due to the complex hydrology of these lakes, especially the interaction with the Floridan aquifer and surface water connections to surrounding waterbodies, several assumptions were made, and parameters adjusted during the calibration of the model. The model calibration period utilized lake stages from 2006 through 2015, a period which included several major hydrologic events including both droughts and intense rainfall from tropical storms. A long-term simulation was completed from 1960 to 2015 to assess lake levels under current, predicted and no groundwater pumping scenarios. Based on this model, additional groundwater withdrawals could lower the Floridan aquifer by 8 to 20 feet below the modeled no-pumping potentiometric surface before the MFL would no longer be met for Santa Fe Lake. The recommended minimum levels (NAVD88) for Santa Fe Lake are 140.06 ft (minimum frequent high), 137.89 ft (minimum average), and 136.52 ft (minimum frequent high) (ECT 2021b).

This modeling effort and report provided a water budget for the Lake Alto and Santa Fe Lake watershed, which included both waterbodies together in one watershed (Table 4) (ECT 2021a). Model results concluded that the primary source of water to the lakes is from rainfall and surface water runoff (66%) while the largest losses are from evaporation (64%) (Table 4). However, the model estimated a substantial proportion of the budget was from groundwater inputs to the lakes from the Floridan aquifer (34%) and losses from the lakes, recharging the Floridan aquifer (23%) (Table 4). The model results suggest a net input (11%) from the Floridan aquifer to the lake system, making the evaluation of groundwater quality an important component of a nutrient budget. Based on these model results only 13% of the water left the basin through surface water runoff to the Santa Fe River (Table 4). These model outputs need to be evaluated to determine if the water budget for Santa Fe Lake can be extracted.

Table 4. Water budget results in the Santa Fe Lake and Lake Alto watershed from the SWMM calibration and simulation period of 2006 to 2015. (ECT 2021a)

Inputs	Volume (acre-ft)	Volume (Million Gal)	Average Depth (in/yr)	Percent
Initial Storage	107,133	34,911	3.43	
Surface Runoff	397,088	129,397	12.71	66%
Groundwater Inflow	205,716	67,036	6.59	34%
Losses				
Evaporation	386,742	126,026	12.38	64%
To Downstream Ditch	76,750	25,009	2.46	13%
To Upper Floridan aquifer	139,594	45,487	4.47	23%
Final Storage	106,851	34,822	3	
Storage Change	282	89	0	

The SWMM did not directly model groundwater contributions from the surficial aquifer to Santa Fe Lake. While these contributions may not have a significant impact on lake stage and volume, they may transport nutrients from activities on the land surface to the lake and may be a considerable portion of the nutrient budget. While some information on the local surficial aquifer levels is available, it needs to be evaluated in relation to lake levels to determine gradients and flow directions. There are 5 surficial aquifer wells near the northeast shoreline of Santa Fe Lake in Bradford County that have monthly water levels from May 1994 to October 1999 (ECT 2021b). The SRWMD has also been monitoring the surficial aquifer in the Santa Fe Swamp since 2012. However, there are no monitoring wells in Alachua County near the lake. Additional wells would need to be installed around the lake to determine the water levels and flow potential in the surficial aquifer. These wells could also be used to determine the quality of the surficial aquifer and the extent of nutrient plumes down gradient of septic system drain fields.

5.6.2 Nutrient Budget

A nutrient budget has not been completed in over 50 years. Since that time, development in the watershed has increased along with the number of septic systems, likely resulting in increased nutrient loading to the lake. A partial nutrient loading budget was completed by Brezonik and Shannon (1971) based on data from the 1960’s, including expected nutrient loading rates from different land use types, septic systems and rainfall (Table 5). Fertilized areas were calculated from average fertilizer composition and application rates, assuming only 10% of nitrogen and 1% of the applied phosphorus was exported to the lake. Septic loading was estimated from a daily effluent volume of 475 liters with a total N concentration of 35 mg/l and total P of 8 mg/L. Septic systems were then divided into two groups, those immediately adjacent to the lake and those further away. Systems on the lake were assumed to contribute 25% of the N and 10% of the P load to the lake while those further away contributed 10% of the N and 1% of the P. At the time it was estimated that there were 243 septic systems on the lake, since then there has been 213% increase to 760 septic systems within 200 m of the lake. In the watershed there were an estimated 358 septic systems in the 1960’s. Based on recent data there may be as many as 1,538 septic systems in the watershed, a 330% increase.

The land use data, nutrient loading rates and an estimated volume (1,674 ha, mean depth of 5.5 m) of the lake was used to calculate the nutrient loading to the Santa Fe Lake system (Table 6). Based on this data Brezonik and Shannon (1971) estimated that 21% of the nutrient contribution to Santa Fe Lake was from anthropogenic activities, while rainfall to the lake accounted for 37% of the N and 54% of the P. The majority (54%) of the N loading to the lake was estimated to be from forested areas. These estimates were for Santa Fe Lake only and did not include Little Santa Fe Lake (Brezonik and Shannon 1971).

Utilizing these nutrient loading rates, land use data and the number of septic systems provided in this report (Brezonik and Shannon 1971), a nutrient budget was calculated for the Santa Fe Lake and Little Santa Fe Lake in the mid 1960’s (Table 7). Based on this data, anthropogenic activities accounted for 24% of the N load while rainfall and runoff from forested areas accounted for the other 76% (Table 7). The majority of the P load came from rainfall (54%) and runoff from forested areas (25%). It was estimated that 19% of the P load to the Santa Fe Lake system was from anthropogenic activities (Table 7).

Comparing data between this study, and recent land use and nutrient loading information is made difficult by the different reported sizes of the watershed contributing to the Santa Fe Lake system. Brezonik and Shannon (1971) estimated the watershed for Santa Fe Lake and Little Santa Fe Lake to be 20,373 acres. The Santa Fe Headwaters watershed, which is smallest basin delineated within the NHD encompasses 32,042 acres. However, Canfield et al. (2016) and Franklin et al. (1995) estimated the size of the watershed contributing to the Santa Fe Lake system to be only 12,378 and 13,376 acres, respectively. Due to low topographic relief and the alteration of flow paths from roadways and drainage features, the accurate delineation of watersheds was difficult. Other discrepancies arise from how much of the Santa Fe Swamp is included and whether Lake Alto is included in the watershed or not. For this reason, the accurate delineation of the watershed is essential to estimating nutrient loads from land use activities, OSTDS and other sources.

Table 5. Estimated N and P loading rates for various land uses, wastewater and rainfall (Brezonik and Shannon 1971).

Source	Reference	N	P	Units
Domestic Sewage	Vollenweider 1968	3940	795	g/person/year
Fertilized Area				
Citrus Farms		2.24	0.018	g/m^2/year
Muck Farms		0.11	0.135	g/m^2/year
Pastured Area	Millar 1955	0.85	0.018	g/m^2/year
Unproductive Cleared Area	Brink 1964	0.18	0.006	g/m^2/year
Forested Area	Sylvester 1961	0.24	0.008	g/m^2/year
Urban Area	Weibel 1969	0.88	0.11	g/m^2/year
Rainfall	Brezonik et al. 1969	0.58	0.044	g/m^2/year
Septic Tanks	Soil Conservation Society of America Minnesota Chapter 1969			
Immediate		2420	138	g/year
Remote		970	13.8	g/year

Table 6. Nitrogen and phosphorus loading rates for the Santa Fe Lake system (Brezonik and Shannon 1971).

Lake	N (g/m^3/yr)	P (g/m^3/yr)	Mean Depth	N (g/m^2/yr)	P (g/m^2/yr)
Santa Fe	0.28	0.015	5.5	1.54	0.0825
Little Santa Fe	0.32	0.014	4.8	1.536	0.0672

Table 7. Estimated nitrogen and phosphorus budget for the Santa Fe Lake system based on land use in the mid 1960's and loading rates provided by Brezonik and Shannon (1971).

Land Use 1965-1968	Santa Fe Lake system (ac)	lbs N/acre /year	lbs P/acre /year	lbs N /year	lbs P /year	% N Loading	% P Loading
Forested Area	13,013	2.141	0.071	27,863	929	38.2	24.9
Urban Area	472	7.851	0.981	3,706	463	5.1	12.4
Fertilized Cropland	301	19.985	0.161	6,020	48	8.2	1.3
Pastured Area	778	7.584	0.161	5,903	125	8.1	3.3
Unproductive Cleared Area	518	1.606	0.054	833	28	1.1	0.7
Rainfall on the lake	5,291	5.175	0.393	27,377	2,077	37.5	55.6
Septic Tanks	**Number**	**lbs N/year**	**lbs P/year**				
Immediate Cultural Units	209	5.335	0.304	1,115	64	1.5	1.7
Remote Cultural Units	91	2.138	0.030	195	3	0.3	0.1
Total				73,010	3,736	100	100

5.7 Atmospheric Deposition

Atmospheric deposition, including wet deposition (rainfall) and dry deposition to the surface of a large lake can be a significant percentage of the nutrient budget and therefore important to estimate. To estimate the load, the open water area of the lake must be determined. Several sources were reviewed including the lake boundary provided by FDEP (WBID 3605G) which measured 5,217 acres and the bathymetry provided by FWC which shows the lake to be 5,185 acres (Figure 38). Both boundaries are very similar in location to the 138 foot contour (NAVD88) (Figure 38) which was recently determined to be the minimum average level of the lake (ECT 2021b). To estimate atmospheric deposition to Santa Fe Lake the open water portion of the lake was considered to be 5,217 acres. Several published estimates of atmospheric deposition in Florida were reviewed along with data from two local monitoring stations, one in Bradford County and another in Alachua County.

The National Atmospheric Deposition Program (NADP) National Trends Network (NTN) monitors precipitation at a network of sites across the country. The NADP Bradford Forest (FL03) site, located in Bradford County about 28 km north-northwest from Santa Fe Lake, has been monitoring rainfall since 1978. During the determination of the TMDL for Lochloosa Lake the precipitation-weighted mean annual concentrations for ammonium (NH_4) and nitrate (NO_3) were used to estimate atmospheric deposition to Lochloosa Lake (Magley 2017). The same methodology was used to estimate the load of $NH_4 + NO_3$ to Santa Fe Lake. The data from the NADP Bradford Forest (FL03) site was downloaded, and concentrations were converted to mg N/L for both NH_4 and NO_3 (Table 8). Concentrations reported by this program (NADP/NTN) are in mg of the ion (NH_4 and NO_3) per liter (personal communication, C. G. Danielson, 4/22/2022), unlike the standard methods used by laboratories analyzing surface water samples which report concentrations in mg of N/L. The mean concentration of $NH_4 + NO_3$ as N in rainfall was 0.235 mg

N/L over the period of record (1978-2016). Using this concentration and the long-term (1900-2021) average annual rainfall for Gainesville, FL of 50.87 inches (https://climatecenter.fsu.edu/products-services/data/precipitation/gainesville) over the area of Santa Fe Lake (5,217 acres) the estimated annual load of NH_4 + NO_3 as N is 14,129 lbs/year.

The NADP/NTN program also provides deposition totals which are the product of the precipitation-weighted mean and the total precipitation for the summary period. The mean deposition rate of NH_4 + NO_3 was 2.843 kg N/ha over the period of record (1978-2016) at the NADP Bradford Forest (FL03) site. The estimated load based on this wet deposition rate was 13,233 lbs/year. These estimates only include the NH_4 and NO_3 ions in wet deposition and exclude the organic nitrogen component of TKN, which can be substantial (41%; Table 9). Dry deposition rates are not available from this station and therefore total atmospheric loads to Santa Fe Lake cannot be estimated from this source alone.

According to Magley (2017) the SJRWMD provided a summary of wet and dry deposition measurements in the Lake Apopka Basin which were used in development of TMDLs for several lakes in the Ocklawaha Basin. Wet and dry deposition measurements from April 1991 to January 2013 were averaged. The mean wet deposition concentrations were 0.612 mg TN/L and 0.021 mg TP/L and the mean dry deposition rates were 9.724 lbs TN/acre/year and 0.214 lbs TP/acre/year (Magley 2017). Using these figures and assuming a lake surface area of 5,217 acres and a long-term average annual rainfall of 50.87 inches, precipitation would contribute approximately 36,806 lbs of TN and 1,263 lbs TP annually. These rainfall concentrations are considerably higher than those observed at the Bradford Forest site, resulting in much higher estimated loads to Santa Fe Lake from rainfall. Based on these deposition rates, dry deposition would contribute another 50,730 lbs TN and 1,116 lbs TP to Santa Fe Lake bringing the total estimated annual load from atmospheric deposition to 87,536 lbs of TN/year and 2,379 lbs of TP/year (Table 10).

Fulton and Smith (2008) used annual median TP concentrations in rainfall and dry deposition for calculations of direct atmospheric deposition to lakes in the Upper Ocklawaha River Basin. Median concentrations for rainfall were 0.011 (0.005–0.031) mg TP/L and 20 (5–81) mg TP/m^2/year for dry deposition (Fulton and Smith 2008). Based on these estimated deposition rates, the estimated annual load from atmospheric deposition to Santa Fe Lake is 1,592 lbs TP/year (Table 10).

Grimshaw and Dolske (2002) provided statewide mean estimates for the atmospheric deposition of ions in weekly composited rain samples collected from September 1992 through October 1993 at NADP/NTN sampling stations in Florida. Over that period, the mean rate of wet atmospheric P deposition across the state, and the mean rainfall P concentration, were 25 µg P/m^2/week and 1.3 µg P/L, respectively. The mean dry deposition of NH_4 as N was 0.961 mg/m^2/week and the mean NO_3 as N rate was 8.016 mg/m^2/week. The mean rainfall concentration of NH_4 as N was 108 µg/L and NO_3 as N was 856 µg/L (Grimshaw and Dolske 2002). Based on these atmospheric deposition rates the estimated annual load to Santa Fe Lake is 79,703 lbs of TN/year and 139 lbs of TP/year (Table 10). These estimated statewide deposition rates of TP are considerably lower than other sources reviewed.

The South Florida Water Management District (SFWMD) utilized average nitrogen and phosphorus concentrations of 0.54 mg/L and 0.0159 mg/L to estimate wet deposition for the Lake Okeechobee Watershed (The HDR Team 2010). Based on these concentrations, average annual rainfall, and the area of Santa Fe Lake, the estimated load from rainfall is 32,476 lbs of TN/year and 956 lbs of TP/year (Table 10).

Poor et al (2013) estimated atmospheric deposition of TN directly over water in Tampa Bay to be 8.1 kg/ha (7.2 lbs/acre). Applying this loading rate to the surface of Santa Fe Lake results in an estimated annual load of 37,562 lbs of TN (Table 10).

A wet and dry deposition monitoring station was located in the Lochloosa Lake watershed from May 2000 to July 2003. Sample results were provided by the SJRWMD and wet and dry deposition rates were calculated for TN and TP. Several samples were removed from the analysis due to contamination or quality issues noted in the data qualifiers. From this data set the average monthly wet and dry deposition rates were calculated (Tables 11 and 12). The average monthly rainfall concentration was 0.423 mg/L and 0.0137 mg/L for TN and TP respectively. These concentrations are within the range of other measurements and estimated annual loads from rainfall to Santa Fe Lake are 25,429 lbs of TN and 822 lbs of TP (Table 10). However, the dry deposition rates are much lower than other measurements and estimates, particularly for TN. The N loading rate of 1.93 lbs/acre/year produced an estimated load of 10,094 lbs, the lowest of the estimated TN loads to Santa Fe Lake based on the reviewed literature and data (Table 10). The mean rate of TP dry deposition was determined to be 0.225 lbs/acre/year resulting in an estimated annual load of 1,173 lbs of TP to Santa Fe Lake (Table 10).

Based on these sources the average estimate of annual loads to Santa Fe Lake from direct rainfall is 30,008 (13,233 to 57,976) pounds of N per year and 645 (78 to 1,263) pounds of P per year. This estimate of N loading to the lake from rainfall is similar to the estimate by Brezonik and Shannon (1971) which was 27,377 pounds of N per year. However, the P loading is much lower than the 2,077 pounds of P per year estimated by Brezonik and Shannon (1971). The average estimate of dry deposition to the Santa Fe Lake system is 30,028 (10,094 to 50,730) pounds of N per year 820 (61 to 1,173) pounds of P per year, making the average estimate of total load from atmospheric deposition to Santa Fe Lake, 60,036 pounds of N per year and 1,465 pounds of P per year.

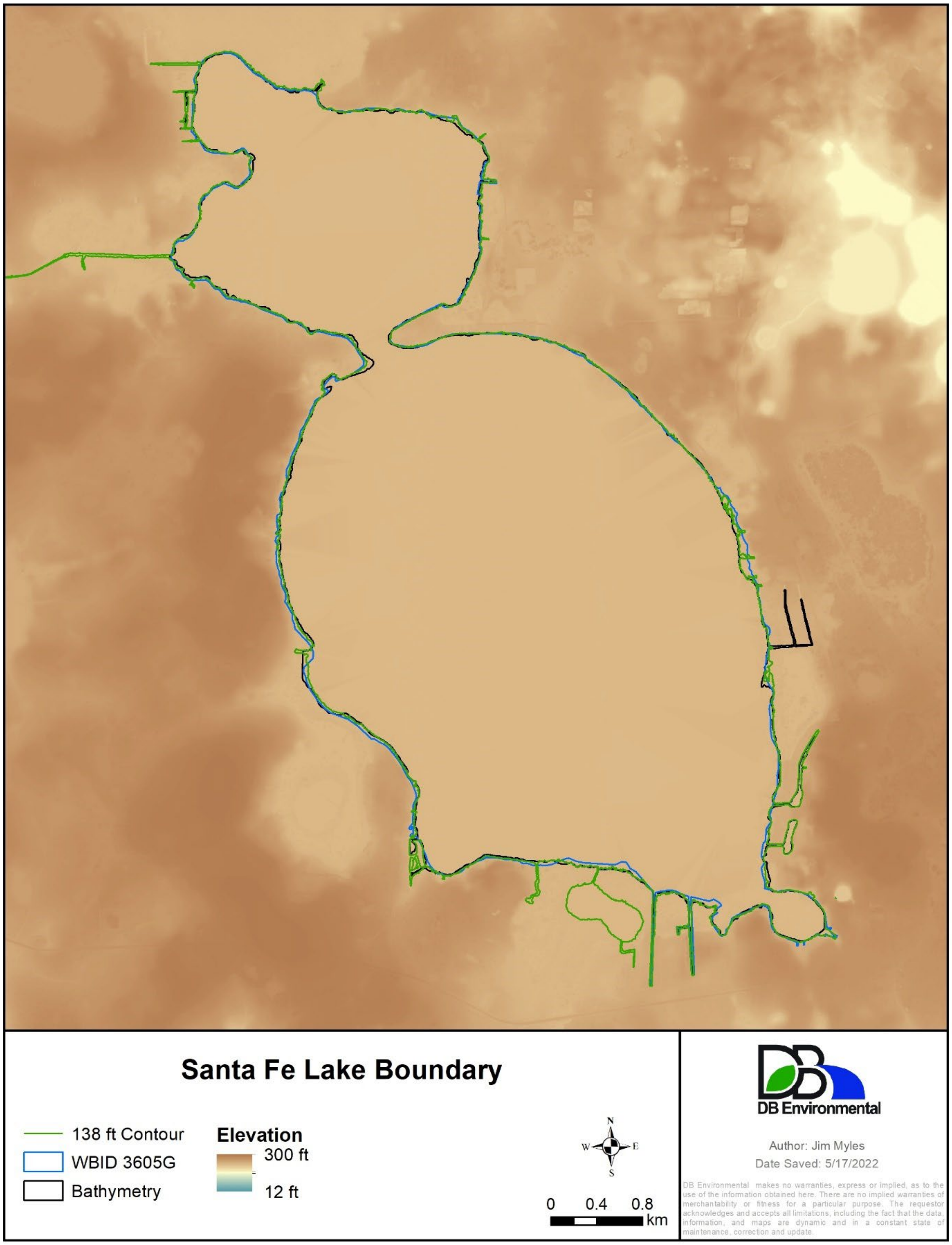

Figure 38. Boundaries delineating the open water portion of Santa Fe Lake.

Table 8. Summary of annual precipitation-weighted mean wet deposition concentrations of ammonium and nitrate in rainfall at the NADP/NTN Bradford Forest station.

Site ID	Year	NH_4 (mg N/L)[1]	NO_3 (mg N/L)[1]	$NH_4 + NO_3$ (mg N/L)
FL03	1978	0.026	0.098	0.124
FL03	1979	0.047	0.106	0.153
FL03	1980	0.093	0.153	0.246
FL03	1981	0.151	0.186	0.338
FL03	1982	0.078	0.150	0.229
FL03	1983	0.078	0.146	0.224
FL03	1984	0.107	0.179	0.287
FL03	1985	0.054	0.165	0.219
FL03	1986	0.058	0.209	0.267
FL03	1987	0.081	0.146	0.228
FL03	1988	0.040	0.131	0.171
FL03	1989	0.205	0.187	0.392
FL03	1990	0.126	0.201	0.327
FL03	1991	0.065	0.158	0.224
FL03	1992	0.074	0.164	0.238
FL03	1993	0.088	0.201	0.290
FL03	1994	0.064	0.166	0.229
FL03	1995	0.105	0.152	0.257
FL03	1996	0.067	0.149	0.216
FL03	1997	0.055	0.123	0.178
FL03	1998	0.140	0.197	0.337
FL03	1999	0.088	0.165	0.252
FL03	2000	0.089	0.189	0.279
FL03	2001	0.092	0.193	0.284
FL03	2002	0.092	0.203	0.295
FL03	2003	0.078	0.171	0.248
FL03	2004	0.063	0.132	0.195
FL03	2005	0.070	0.141	0.211
FL03	2006	0.075	0.130	0.205
FL03	2007	0.066	0.134	0.200
FL03	2008	0.046	0.131	0.177
FL03	2009	0.085	0.122	0.206
FL03	2010	0.069	0.127	0.196
FL03	2011	0.150	0.145	0.295
FL03	2012	0.055	0.093	0.148
FL03	2013	0.080	0.122	0.202
FL03	2014	0.078	0.128	0.206
FL03	2015	0.083	0.137	0.220
FL03	2016	0.075	0.094	0.169
Average		**0.083**	**0.152**	**0.235**

[1] Precipitation weighted mean concentrations

Table 9. Summary of wet and dry deposition rates from SJRWMD monitoring sites in the Apopka Basin.

Parameter	Wet Deposition (number of samples)	Wet Deposition (mg/L)	Dry Deposition (number of samples)	Dry Deposition (lbs/ac/yr)
NH_3 + NH_4 Total	746	0.199	212	0.234
NOXT or NOXD	807	0.261	370	0.437
TKN	845	0.339	386	8.913
TN	775	0.612	362	9.724
TP	845	0.021	386	0.214

Table 10. Wet and Dry deposition rates from various sources and data sets along with estimated annual load to Santa Fe Lake from atmospheric deposition.

N Concentration in Rainfall	**mg N/L**	**kg N/ha**	**lbs/year**
Mean TN (Apopka Basin Magley 2017)	0.612		36,806
Mean TN (Lochloosa Station)	0.423		25,429
Mean TN (The HDR Team 2010)	0.540		32,476
Mean NO3 + NH4 as N (NADP Bradford Site)	0.235		14,129
Mean NO3 + NH4 as N DEP (NADP Bradford Site)		2.536	13,233
Mean NO3 + NH4 as N Statewide (Grimshaw and Dolske 2002)	0.964		57,976
Dry Deposition of N	**lbs/ac/yr**		**lbs/year**
Mean TN (Apopka Basin Magley 2017)	9.724		50,730
Mean TN (Lochloosa Station)	1.93		10,094
Mean NO3 + NH4 as N Statewide (Grimshaw and Dolske 2002)	4.165		21,727
TN Direct over water (Poor et al. 2013)	7.2		37,562
TN Load to Santa Fe Lake			**lbs/year**
Mean TN (Apopka Basin Magley 2017)			87,536
Mean TN (Lochloosa Station)			35,523
Mean NO3 + NH4 as N Statewide (Grimshaw and Dolske 2002)			79,703
P Concentration in Rainfall	**mg P/L**		**lbs/year**
Mean TP (Apopka Basin Magley 2017)	0.0210		1,263
Mean TP (Lochloosa Station)	0.0137		822
Median TP (Fulton and Smith 2008)	0.0110		662
Mean TP (The HDR Team 2010)	0.0159		956
Mean TP Statewide (Grimshaw and Dolske 2002)	0.0013		78
Bradford Site NADP (Grimshaw and Dolske 2002)	0.0015		90
Dry Deposition of P	**lbs/ac/yr**		**lbs/year**
Mean TP (Apopka Basin Magley 2017)	0.214		1,116
Mean TP Statewide (Grimshaw and Dolske 2002)	0.012		61
Mean TP (Lochloosa Station)	0.225		1,173
Median TP (Fulton and Smith 2008)	0.178		931
TP Load to Santa Fe Lake			**lbs/year**
Mean TP (Apopka Basin Magley 2017)			2,379
Mean TP (Lochloosa Station)			1,995
Median TP (Fulton and Smith 2008)			1,592
Mean TP Statewide (Grimshaw and Dolske 2002)			139

Table 11. Mean monthly concentration of TN and TP in rainfall collected at the SJRWMD monitoring station located southeast of Lochloosa Lake.

Year	Month	TN (mg N/L)	TP (mg P/L)
2000	Jun	0.160	0.013
2000	Jul	0.711	0.006
2000	Aug	0.589	0.009
2000	Sep	0.348	0.005
2000	Oct	0.383	0.013
2000	Nov	0.593	0.159
2000	Dec	0.707	0.031
2001	Jan	0.375	0.009
2001	Feb	0.333	0.001
2001	Mar	0.414	0.012
2001	Apr	0.243	0.002
2001	May	0.630	0.005
2001	Jun	0.542	0.006
2001	Jul	0.492	0.003
2001	Aug	0.227	0.009
2001	Sep	0.189	0.027
2001	Oct	0.713	0.041
2001	Dec	0.346	0.005
2002	Jan	0.508	0.005
2002	Feb	0.302	0.003
2002	Mar	0.302	0.010
2002	Apr	0.654	0.010
2002	May	1.346	0.032
2002	Jun	0.759	0.010
2002	Jul	0.145	0.000
2002	Sep	0.219	0.000
2002	Oct	0.295	0.016
2002	Nov	0.210	0.000
2002	Dec	0.178	0.003
2003	Jan	0.163	0.006
2003	Feb	0.256	0.005
2003	Mar	0.401	0.005
2003	Apr	0.529	0.011
2003	May	0.282	0.007
2003	Jul	0.258	0.001
Mean		0.423	0.014

Table 12. Monthly dry deposition rates of TN and TP (lbs/acre/month) collected at the SJRWMD monitoring station located southeast of Lochloosa Lake.

Year	Month	TN (lbs/ac/mo)	TP (lbs/ac/mo)
2000	Jun	0.08	0.009
2000	Jul	0.08	0.004
2000	Aug	0.22	0.011
2000	Sep	0.38	0.013
2000	Oct	0.08	0.005
2000	Dec	0.11	0.008
2001	Jan	0.07	0.004
2001	Feb	0.08	0.004
2001	Mar	0.13	0.009
2001	May	0.08	0.006
2001	Jun	0.31	0.030
2001	Jul	0.10	0.004
2001	Aug		
2001	Sep	0.07	0.005
2001	Oct	0.08	0.005
2001	Nov	0.00	0.000
2001	Dec	0.07	0.003
2002	Jan	0.07	0.004
2002	Mar	0.33	0.032
2002	Apr	0.16	0.020
2002	May	0.07	0.005
2002	Jun		
2002	Jul	0.26	0.025
2002	Sep	0.24	0.116
2002	Oct	0.15	0.015
2002	Nov	0.10	0.005
2002	Dec	0.06	0.002
2003	Jan	0.09	0.004
2003	Feb	0.06	0.004
2003	Mar	0.15	0.016
2003	Apr	0.19	0.034
2003	May	1.06	0.172
2003	Jul	0.07	0.006
Monthly Mean		0.16	0.019
Annual Loading Rate		1.93	0.225

N Concentration in Rainfall	mg N/L	kg N/ha	lbs/year
Mean TN (Apopka Basin Magley 2017)	0.612		36,806
Mean TN (Lochloosa Station)	0.423		25,429
Mean TN (The HDR Team 2010)	0.540		32,476
Mean NO3 + NH4 as N (NADP Bradford Site)	0.235		14,129
Mean NO3 + NH4 as N DEP (NADP Bradford Site)		2.536	13,233
Mean NO3 + NH4 as N Statewide (Grimshaw and Dolske 2002)	0.964		57,976
Dry Deposition of N	**lbs/ac/yr**		**lbs/year**
Mean TN (Apopka Basin Magley 2017)	9.724		50,730
Mean TN (Lochloosa Station)	1.93		10,094
Mean NO3 + NH4 as N Statewide (Grimshaw and Dolske 2002)	4.165		21,727
TN Direct over water (Poor et al. 2013)	7.2		37,562
TN Load to Santa Fe Lake			**lbs/year**
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Mean TN (Lochloosa Station)			35,523
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Median TP (Fulton and Smith 2008)	0.0110		662
Mean TP (The HDR Team 2010)	0.0159		956
Mean TP Statewide (Grimshaw and Dolske 2002)	0.0013		78
Bradford Site NADP (Grimshaw and Dolske 2002)	0.0015		90
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Mean TP (Apopka Basin Magley 2017)	0.214		1,116
Mean TP Statewide (Grimshaw and Dolske 2002)	0.012		61
Mean TP (Lochloosa Station)	0.225		1,173
Median TP (Fulton and Smith 2008)	0.178		931
TP Load to Santa Fe Lake			**lbs/year**
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Mean TP (Lochloosa Station)			1,995
Median TP (Fulton and Smith 2008)			1,592
Mean TP Statewide (Grimshaw and Dolske 2002)			139

6 Land use changes in the watershed

As discussed earlier in this report, changes in land use in the Santa Fe Lake watershed may be responsible for some fraction of the recent increases in lake water nutrients and chlorophyll *a* and decrease in water clarity (Secchi depth). Residential development has increased during the last half of the twentieth century and into the current century, but the timing and extent of this development is not well documented due to incomplete records and differences in methodology used to define land use. Based on the interpretation of aerial photographs and topographic maps from the mid-1960s, there were an estimated 243 residences on the shoreline of the lake and another 115 within the watershed (Brezonik and Shannon 1971). By 2014 there were more than 700 residential parcels on the lake serviced by OSTDS (Canfield et al. 2016). In Section 7.1.2.1 of this report it is estimated there are 760 known or likely OSTDS within 200 m of the lake shore or canals. Additional quantitative information for this watershed was not readily available for this report but acquiring a more complete record of land development changes will be a priority for the next phase of the study.

A semi-quantitative approach for detecting changes in land use and development in the lake vicinity can be provided by examination of existing aerial photography. The time series of aerial photographs in Figures 39 through 41 illustrates changes occurring in the Santa Fe Lake vicinity during the period 1938 – 2020. These images reflect the lack of development around the lake prior to the mid-twentieth century, with the notable exception of the town of Melrose, located on Melrose Bay, which has a considerably longer history. Between 1938 and 1957, canals were being dug on the east and south sides of the lake (Figure 39). By 1968 additional canals had been excavated on the east, south, and southwest shores of the lake, and the number of residences had increased along the northeast and southwest shorelines (Figure 39). By 1979, it appears that most of the canals existing on the lake today had been excavated, and residential areas on the east and southwest shores of the lake were filling in (Figure 39).

Residential density appears to have progressively increased in most of the existing developed areas around Santa Fe Lake during the 1980s and 1990s, and noticeable development on Little Santa Fe Lake appeared during this time (Figure 40). Since the early 2000s, the most extensive new residential development appears to have been on the east side of Santa Fe Lake (west of SR 21) and along or inland from the southern and eastern shorelines of Little Santa Fe Lake (Figures 40 and 41). These changes in residential development are also shown in the time series of land use maps in Figure 42. However, it is evident that residential development was significantly underestimated in the land use map for 1988. The 1979 aerial imagery shows residential development surrounding new canals on the southeast side and the west side of the lake. Those residential areas are not captured in the 1988 land use maps. Dependence on this map for determining changes in residential development in the lake watershed from the mid-1980s to present may lead to erroneous conclusions regarding the rate of increase of development during this 40-year period.

There are three counties that border Santa Fe Lake, with varying lengths of shoreline and densities of development. Alachua County encompasses approximately 9.3 miles of shoreline, primarily on the west and south side of the lake. Based on the FDOH inventory of OSTDS (Ursin 2016), there are approximately 237 developed parcels within Alachua County that are either waterfront or on a canal. Bradford County encompasses most of the eastern shoreline with 7.6 miles and approximately 337 developed parcels on the lake or a canal. Putnam County has a small area along

Melrose Bay, with 0.7 miles of shoreline and 19 developed lots. These shoreline measurements do not include the perimeter of each canal.

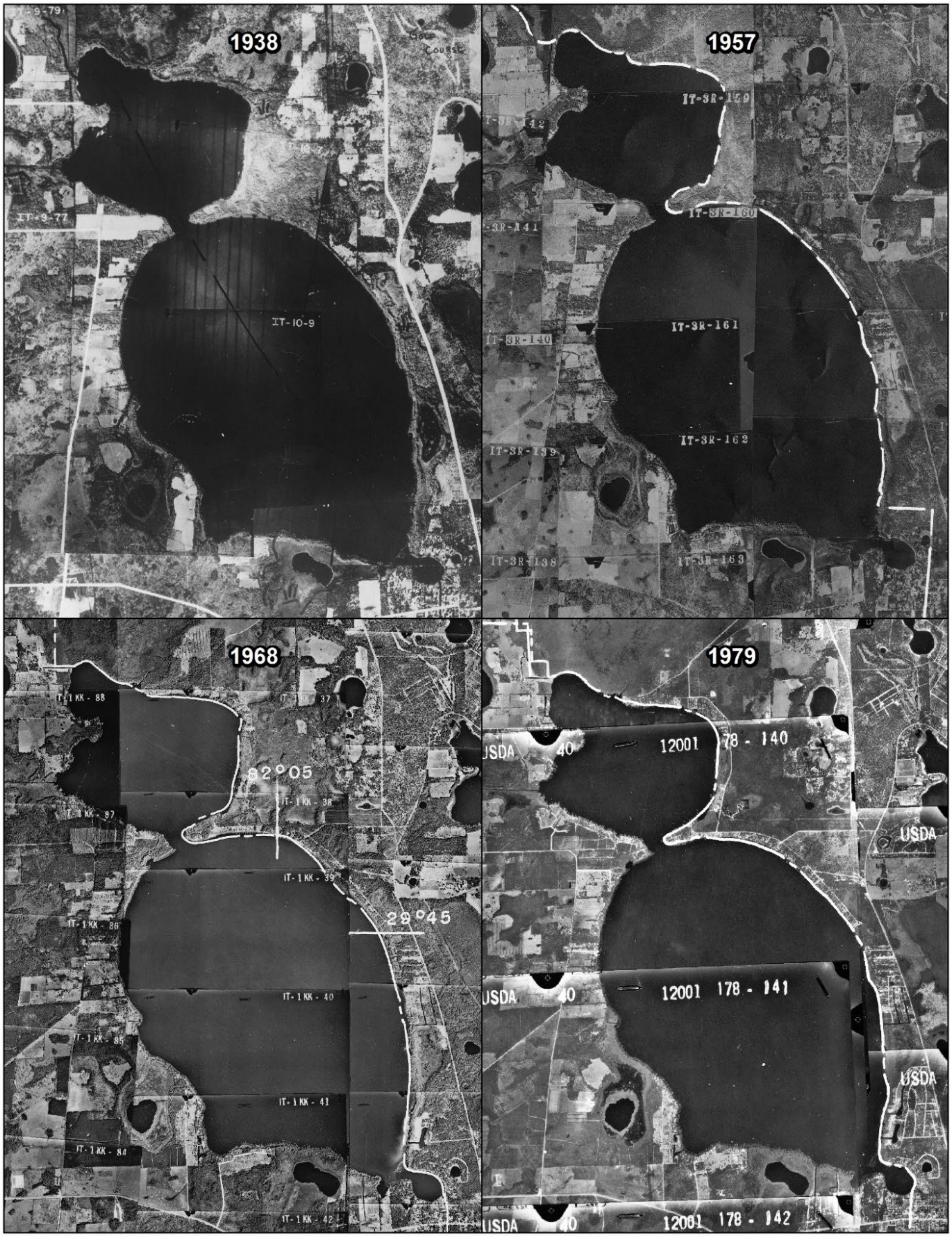

Figure 39. Aerial images of the Santa Fe Lake system from 1938, 1957, 1968, and 1979.

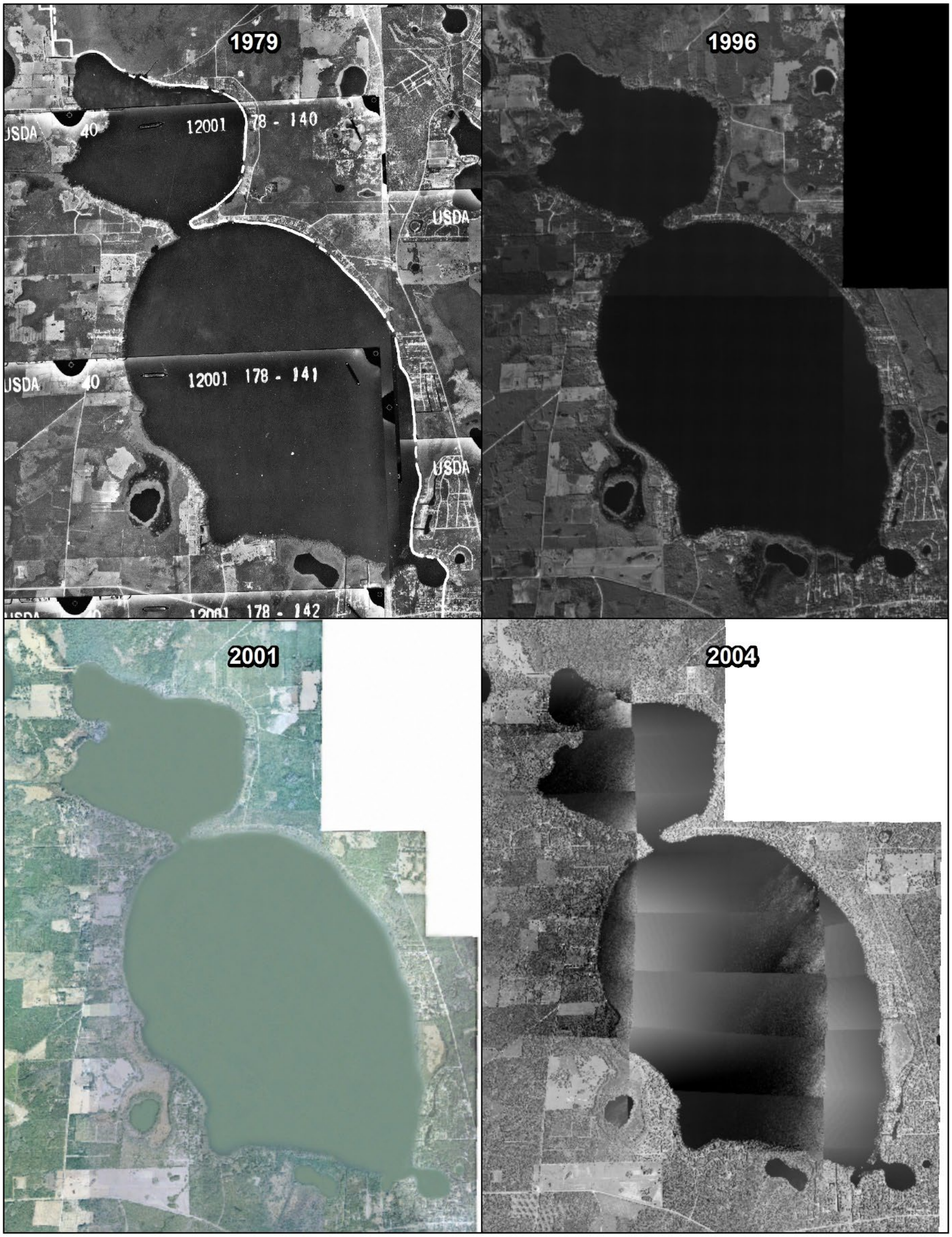

Figure 40. Aerial images of the Santa Fe Lake system from 1979, 1996, 2001, and 2004.

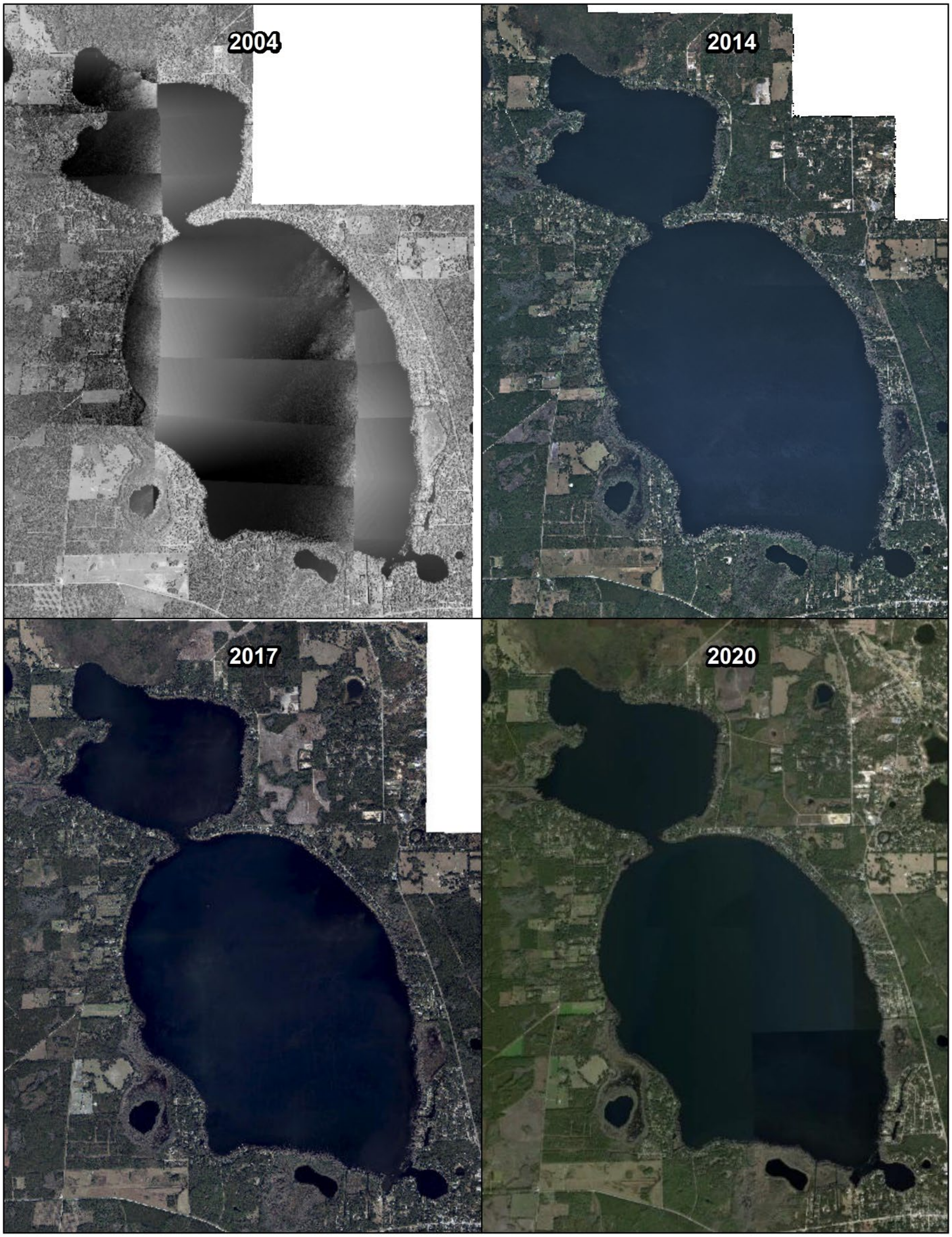

Figure 41. Aerial images of the Santa Fe Lake system from 2004, 2014, 2017, and 2020.

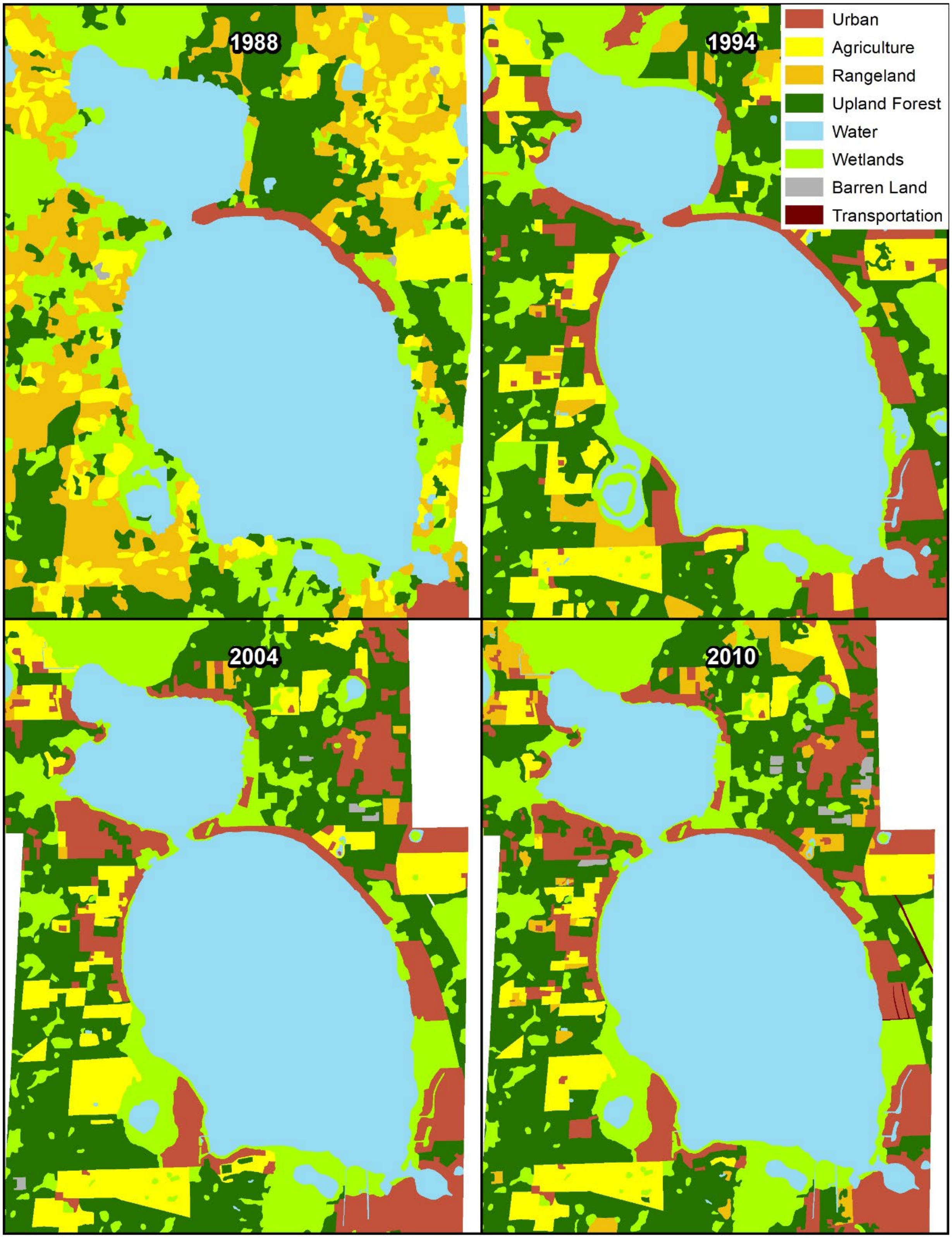

Figure 42. Land use and land cover for the Santa Fe Lake system from 1988, 1994, 2004, and 2010.

6.1 Conservation Lands

Significant portions of the watershed are currently under conservation either through acquisition or easements. According to the Florida Natural Areas Inventory (FNAI) and recent acquisitions by Alachua County Forever, there are 8,731 acres of managed lands within the Santa Fe River Headwaters (Figure 43). Most of the lands lie within the Santa Fe Swamp Conservation Area owned by the SRWMD. (Figure 43) The Alachua County Forever program administered by ACEPD has purchased environmentally sensitive lands south of Santa Fe Lake and on the western shore of Little Santa Fe Lake (Figure 43).

6.2 Bioassessment Data

6.2.1 LDI and LVI data from FDEP

Florida DEP (FDEP) conducts various types of bioassessments for aquatic communities to characterize community structure (i.e., diversity, pollution tolerance). To determine the biological health of a waterbody, FDEP has developed or adopted multi-metric indices to quantify the overall adverse changes caused by human activities, compared to minimally disturbed conditions. Common bioassessments used for evaluation of Florida lakes are the Land Development Intensity (LDI) index and Lake Vegetation Index (LVI).

The LDI is an objective measure of how human disturbance affects biological, chemical, and physical processes of aquatic systems. It is based on land use and land cover, and can be applied using available land use/land cover, aerial photography and/or field surveys (Brown and Vivas 2005). The LDI index is calculated as percent area within the catchment of a particular type of land use multiplied by the coefficient of energy use associated with that land use, summed over all land use types found in the catchment. Coefficient values used to calculate the LDI range from 1 to 10, where 1 represents natural open water and higher values representing incrementally greater intensity of human land use. For lakes and isolated wetlands, FDEP typically uses a LDI calculated for the 100 m buffer around the waterbody. LDI values less than two can be considered minimally disturbed.

Data obtained from FDEP reflect LDI index values determined for Santa Fe Lake during multiple events from July 2004 through August 2015, and a single event in July 2004 for Little Santa Fe Lake (Figure 44). During this period, LDI values for Santa Fe Lake were essentially constant, deviating only slightly from a mean value of 4.5, while the single LDI value determined for Little Santa Fe Lake in 2004 was slightly lower, at 4.0. Based solely on these LDI index calculations, the overall intensity of human land use within the lake's perimeter buffer zone would be considered relatively moderate, with no significant change during the 2004-2015 time period.

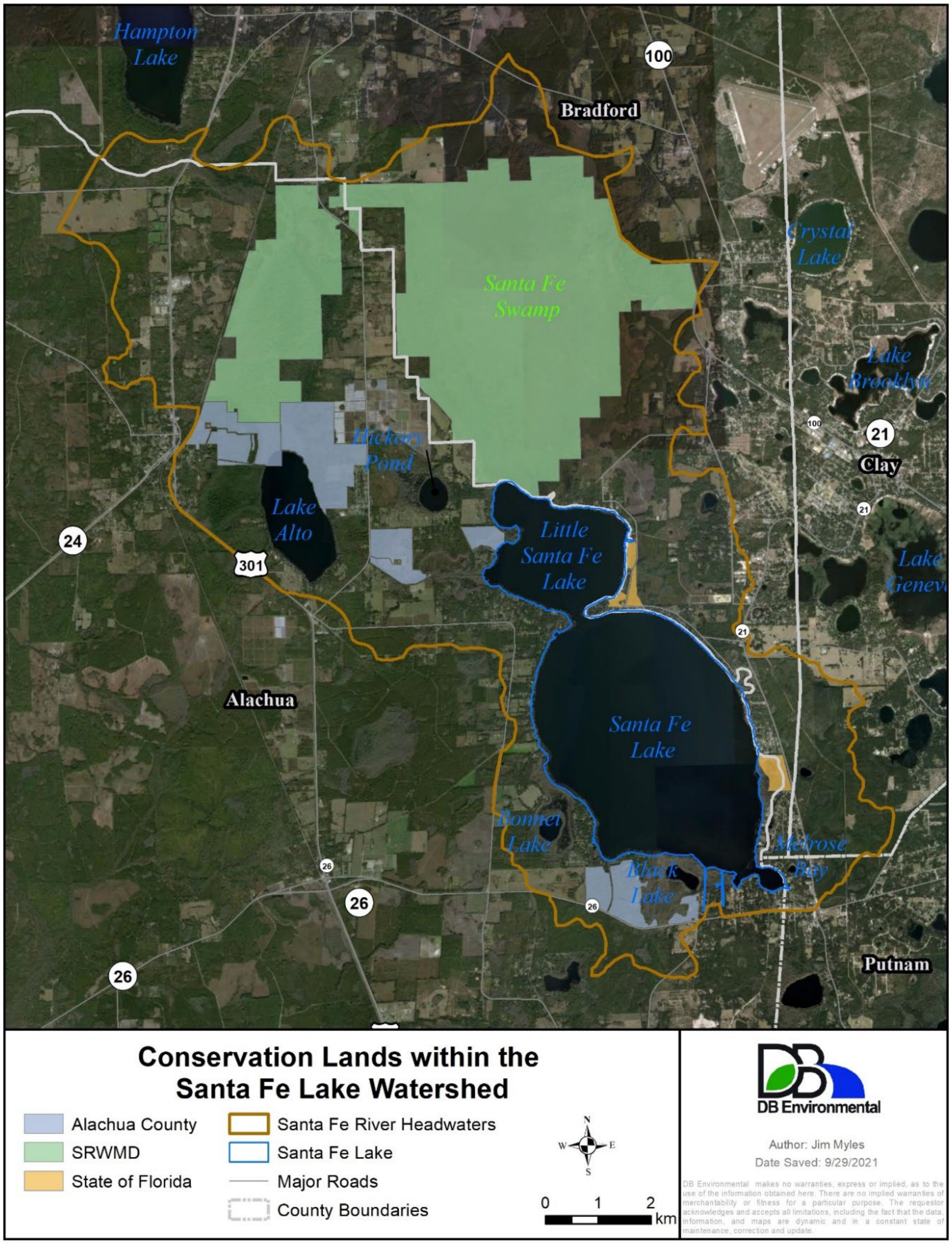

Figure 43. Conservation lands within the Santa Fe Lake watershed.

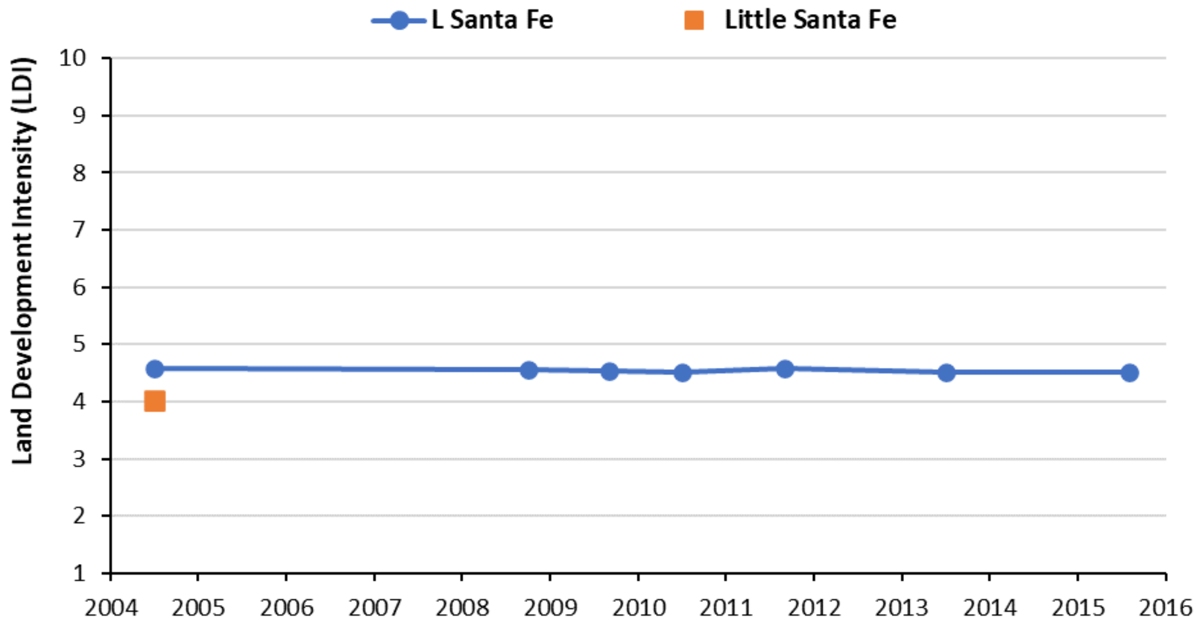

Figure 44. Land Development Intensity (LDI) index values over time for Santa Fe Lake (2004-2015), and for Little Santa Fe Lake (2004 only).

The Lake Vegetation Index (LVI) was developed by FDEP as a tool for assessing the biological conditions of Florida lakes, rivers and streams (Fore et al. 2007). FDEP currently uses the LVI, which is based on a lake's macrophyte community structure, as the primary method to assess biological health in Florida lakes. Field data related to species presence is used to calculate four biological metrics which have been shown to respond to human disturbance: 1) percent native taxa, 2) percent invasive taxa (Category 1 by Florida Exotic Pest Plant Council), 3) percent sensitive taxa and 4) coefficient of conservatism (Cof C) of dominant/co-dominant taxa. For example, these four LVI metrics are each highly correlated with human disturbance gradient (HDG), water quality index, habitat index, and the LDI index.

The LVI is scaled from 0 to 100, where decreasing values correspond to increasing anthropogenic disturbance. FDEP categorizes LVI values in the 78-100 range as "exceptional" (Category 1), while values in the 38-77 range reflect "healthy" conditions (Category 2), and LVI values below 38 indicate "impaired" conditions (Category 3).

Data for LVI assessments of Santa Fe Lake (main basin) were found for multiple dates between October 2008 and May 2019 (Figure 45). A single data point was available for Little Santa Fe Lake, for May 2019. LVI values for Santa Fe Lake averaged 58.5 during this 10+ year period and ranged from 53 to 71. LVI declined slightly from 2008 through 2011 and were consistently within the range of 50-60 through mid-2017. However, during the most recent survey (May 2019), LVI increased to 71, which was slightly higher that the LVI of 68 determined concurrently for Little Santa Fe Lake. LVI values for the lake remained within the Category 2 range ("healthy") during the entire period of record, although the LVI for May 2019 lies in the upper end of that range. It is not yet clear whether the incremental increase in LVI from 53 to 71 in Santa Fe Lake between

August 2015 and May 2019 is indicative of an increasing trend or shorter-term (e.g., seasonal) variability, since this nearly 4-year period is characterized by only 3 measurement events.

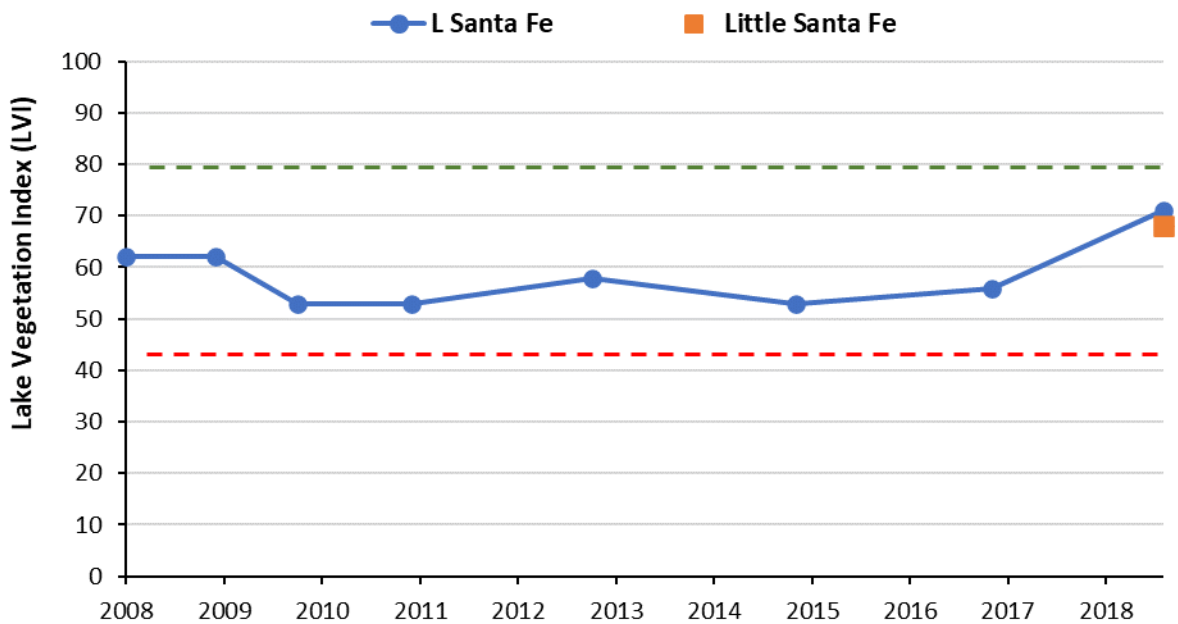

Figure 45. Lake Vegetation Index (LVI) values over time for Santa Fe Lake (2008-2015), and for Little Santa Fe Lake (2019 only). Dashed lines delineate LVI Categories 1 ("exceptional", LVI = 78–100), 2 ("healthy", LVI = 38–77) and 3 ("impaired", LVI = 0–37).

6.2.2 Algal Bloom Investigations

FDEP and ACEPD have responded to citizen reports of algal blooms in the Santa Fe Lake system. On May 29, 2014, ACEPD collected samples from Little Santa Fe Lake in response to an observed algal bloom (Figure 46). The dominant species of algae or cyanobacteria (blue-green algae) were not identified; however, the samples were analyzed for the cyanotoxins cylindrospermopsin and anatoxin-a which are produced by cyanobacteria blooms. Neither toxin was detected in the sample collected from Little Santa Fe Lake. The chlorophyll *a* concentration was 19 µg/L, which is considerably higher than the mean concentration of 8 µg/L and indicative of an algae bloom.

FDEP has responded to several reports of algal blooms including one in May of 2018. Samples were collected from the north shore of Santa Fe Lake on May 24, 2018. The dominant taxa were *Dolichospermum cf. zinserlingii* and neither cyanotoxin were detected. In the spring of 2022, FDEP has collected 2 samples from Melrose Bay in response to reports of an algal bloom. The dominant taxa in the samples collected on March 17, 2022, were *Cylindrospermopsis raciborskii* and *Dolichospermum sp.* On April 6, 2022, the dominant taxa were *Cylindrospermopsis raciborskii* and *Aphanizomenon flos-aquae.* Cyanotoxins were not detected in either sample from Melrose Bay.

Figure 46. Algal bloom in Little Santa Fe Lake on May 29, 2014.

6.2.3 Invasive exotic plant survey

Encroachment of invasive exotic plants in lake shoreline and wetland areas has major implications related to water quality in the lake and downstream aquatic systems. For example, proliferation of exotic vegetation in the extensive wetland fringe of the Santa Fe Lake system could alter vegetation and faunal communities to an extent that results in reduced capacity of the wetlands to serve as a buffer between the lake and upland areas and to provide long-term storage of nutrients from both natural and anthropogenic sources.

To address these concerns, a survey was conducted during 2002 by Current Problems Inc. for Alachua County EPD to document presence and abundance of invasive exotic plant species on waterfront properties of Santa Fe Lake, within the County boundaries (Olson 2003). Individual parcels were surveyed from the shoreline to approximately 75 feet upland of the lake's ordinary high-water line. The survey was performed by groups of volunteer citizens, many of them being residents of Santa Fe Lake neighborhoods.

A list of 10 target species was developed for the survey, based on known presence in the area and potential for colonizing cleared and developed land near the lake shore. The list consisted of the following species: air potato (*Dioscorea bulbifera*), camphor (*Cinnamomum camphora*), Chinese tallow (*Sapium sebiferum*), coral ardisia (*Ardisia crenata*), Japanese climbing fern (*Lygodium japonicum*), sesbania or Spanish gold (*Sesbania punicea*), torpedo grass (*Panicum repens*), Spiderwort (*Tradescantia fluminensis*), wedelia (*Wedelia trilobata*), and wild taro (*Colocasia esculenta*). Elephant ear (*Xanthosoma sagittifolium*), another invasive exotic, was included with wild taro on the survey list because of difficulties in distinguishing between the two species in the field. In addition to identifying target species, the surveyors also documented each parcel's natural features, including landscape type, tree canopy coverage, shoreline vegetation, and beach zone type. Landscape type was categorized as either natural, minimally disturbed, or manicured/mowed lawn.

A total of 320 parcels out of the targeted 354 parcels (all within Alachua County) were surveyed. Results of the survey indicated that the most commonly occurring of the targeted species were wild taro and Chinese tallow (found in 23.1% and 20.6% of the parcels, respectively). These were followed by camphor (16.9%), air potato and coral ardisia (8.4% for each), sesbania (6.6%) spiderwort (5.0%), wedelia (4.1%), Japanese climbing fern (3.8%), and torpedo grass (3.4%). Wild taro occurred at highest densities, classified as "infestation", on 16.6% of the parcels, while Chinese tallow and coral ardisia infestations were found in 5.6% and 5.0% of the parcels, respectively.

One or more of the targeted invasive species were found on approximately one-half of the parcels surveyed. The greatest concentrations of parcels with exotic invasive plants occurred in three main areas: Earleton (northwest), Melrose shoreline, and the far north end of the lake, with significant numbers also found along the southwest corner of the lake (Figure 47). High densities, or "hot spots", of individual species included Chinese tallow along the Little Santa Fe Lake shoreline, sesbania on the western shore of Santa Fe Lake (Earleton), and wild taro in the southwest and southeast Santa Fe Lake and other sites along the western shores of both the main basin and Little Santa Fe Lake. In addition, there was evidence that torpedo grass was actively spreading during the survey period (a period of low water), and new stands of cattails, cogon grass, and tropical soda apple were observed during that time.

In general, the survey results indicated that the presence and spread of invasive exotic plant species may be related to landscape type, or management. It was suggested that, ironically, increased occurrence of exotic vegetation was observed on disturbed parcels, compared to "manicured" (e.g., mowed) parcels, and also on manicured parcels with a vegetated shoreline buffer vs. mowed grass to water's edge. This was apparently an artifact of the suppression of invasive plants achieved by regular mowing. However, as pointed out by the author, there remains the likelihood of the spread of these invasive species from manicured parcels to adjacent, and even distant, sites. With all of these factors taken into account, the survey results would support the conclusion that completely undisturbed parcels of land are most resistant to invasion and colonization by invasive exotic plant species.

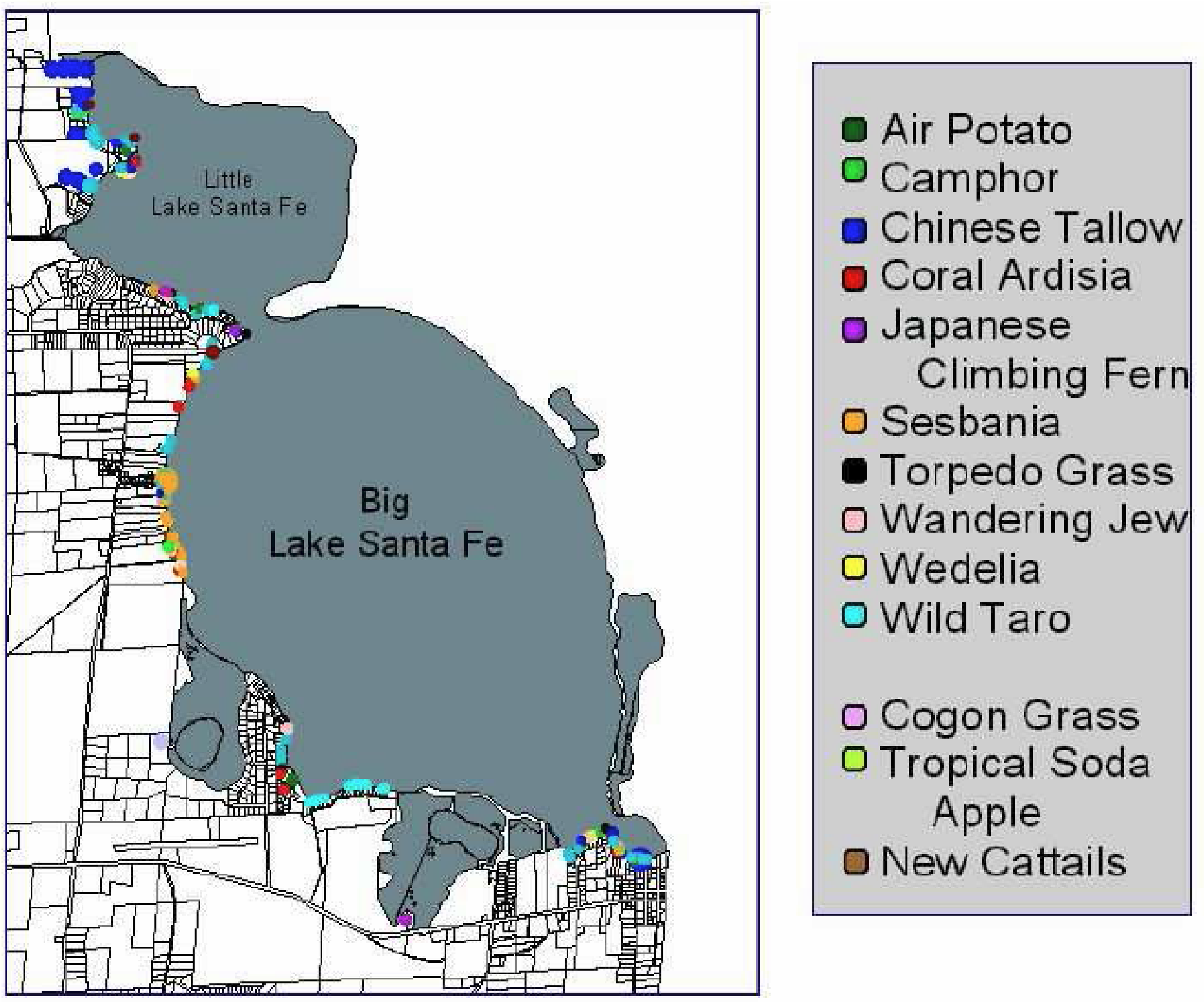

Figure 47. Invasive plant infestations of Santa Fe Lake, based on the 2002 survey of parcels within Alachua County only (source: Olson 2003).

7 Identifying Nutrient Sources in Watersheds

7.1 Identified Sources

Brezonik and Shannon (1971) completed a nutrient budget for the lake and estimated that 21 % of the P and 22% of the N supply to Santa Fe Lake was from cultural sources. These included urban runoff, pasture, fertilized areas, and septic systems. Based on the interpretation of aerial photographs and topographic maps from the mid-1960s there were an estimated 243 residences on the shoreline of the lake and another 115 within the watershed (Brezonik and Shannon 1971). By 2014 there were more than 700 residential parcels on the lake serviced by OSTDS (Canfield et al. 2016). Increased development increases stormwater runoff from impervious and pervious areas, the number of OSTDS on the lake shore and fertilizer use and irrigation. All of these are known sources to the lake.

7.1.1 Stormwater discharges

The stormwater geodatabase provided by Alachua County Public Works Department does not include stormwater infrastructure in the City of Melrose, the neighborhoods surrounding the lake and does not show any outfalls to the lake. However, a few stormwater inputs were already known, and a few were identified during this review of available data. Identification of individual stormwater discharges should be a task for the next phase of this study. Assuming a comprehensive list can be developed, the outfalls would also need to be prioritized according to discharge volume or pollutant load. Initial ranking could be done based on a qualitative assessment of outfall and its contributing area. A quantitative assessment would require high resolution stormwater modeling or monitoring to estimate nutrient loads to the lake.

7.1.1.1 NE 100th Avenue in Earleton, FL

While reviewing the stormwater geodatabase, a collector pipe was observed near the corner of CR 1469 and NE 100th Avenue (Figure 48). Based on the topography and imagery available through Google Street view it appears stormwater runoff from NE 100th Avenue (C.R. NE 28-D) and the residences is flowing east toward Santa Fe Lake (Figures 49 and 50). At the end of the road there is a small parcel where it appears the concrete swale discharges. Additional investigations would need to be completed to determine if runoff is directly entering the lake and if there are opportunities for nutrient reduction projects. This parcel is privately owned and would need to be accounted for when ranking potential projects. Possible solutions include partnership with the landowners to implement a stormwater improvement project. Other options would include acquisition or lease from the owner (Parcel ID - 18478-000-000, Prop Id – 100208, Owner - BIVINS & BIVINS & DAVIS &GREEN, Acres - 0.1) (Figure 51). Further investigations are necessary to determine if this parcel could be utilized for a stormwater treatment swale, pond or bioretention garden.

7.1.1.2 Stormwater Runoff from SR 26 and NE 221st Street

Stormwater runoff from the parcels at the northwest corner of SR 26 and NE 221st Street has been a known issue since January 2007. At the time, the property was being converted from pasture and hay production into turf grass production. Complaints of stormwater runoff from bare soil on the farm, which flowed into a canal on Santa Fe Lake at NE 69th Lane, were received by ACEPD at that time. Water samples were collected from the canal and two culverts crossing NE 221st Street after rain events in January 2007, October 2007, and January 2013. These culverts and the open channel that discharges to the canal are not included in the stormwater geodatabase (Figure 52). The two samples collected from the culverts in October 2007 exceeded the NNC threshold for TN in streams (1.54 mg/L) (Figure 53). However, every sample collected exceeded the NNC threshold of 0.12 mg/L for TP, including a sample in October 2007 which was 30 times the standard (Figure 54). The P was primarily in the soluble form which is readily available to algae and also one of the least costly forms of P to remove.

These culverts and the canal also receive runoff from the roadways including SR 26, NE 221st Street and NE 69th Lane. Sampling should be conducted at these locations to determine if runoff from the current land uses is still elevating nutrients in this stream and ultimately the lake. Through the Alachua County Forever program, the County has acquired the parcel between these culverts and the canal on Santa Fe Lake (18796-002-000). The County now has the opportunity to capture and treat runoff from the roadways prior to it entering the lake.

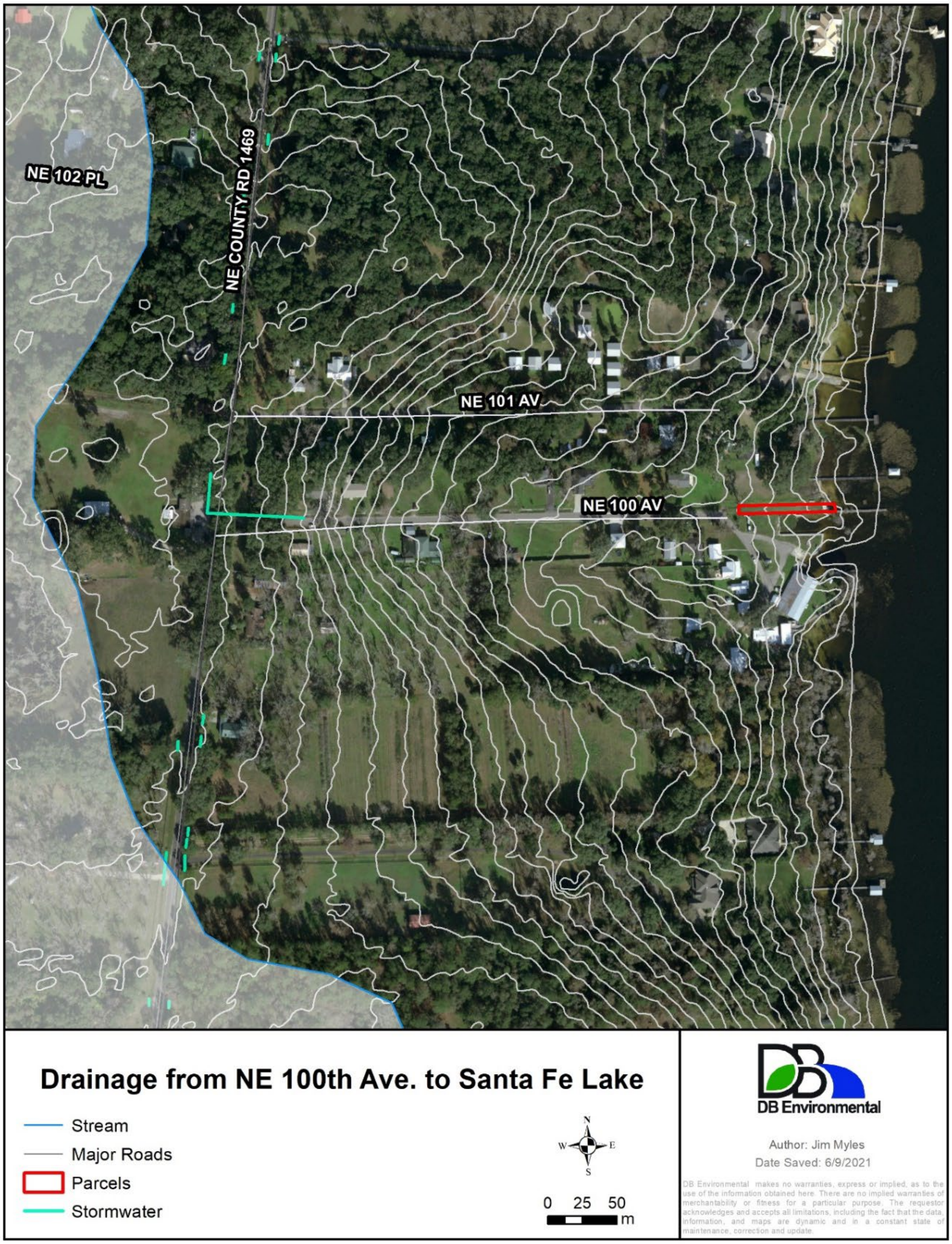

Figure 48. Drainage from NE 100th Avenue into Santa Fe Lake.

Figure 49. Google street view facing east from the end of NE 100th Avenue, Earleton, FL.

Figure 50. Google street view facing west from the end of NE 100th Avenue, Earleton, FL.

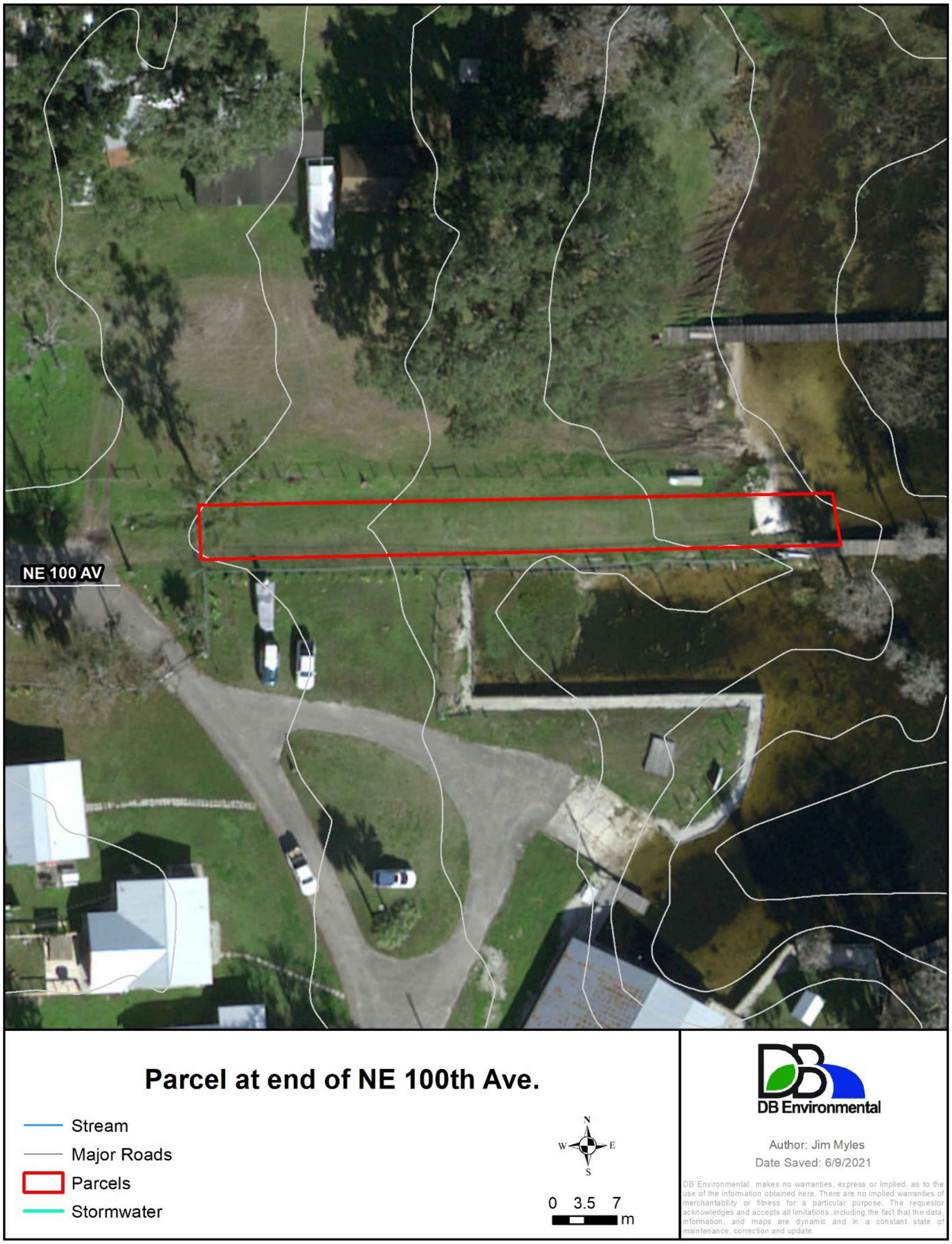

Figure 51. Potential parcel for nutrient reduction project.

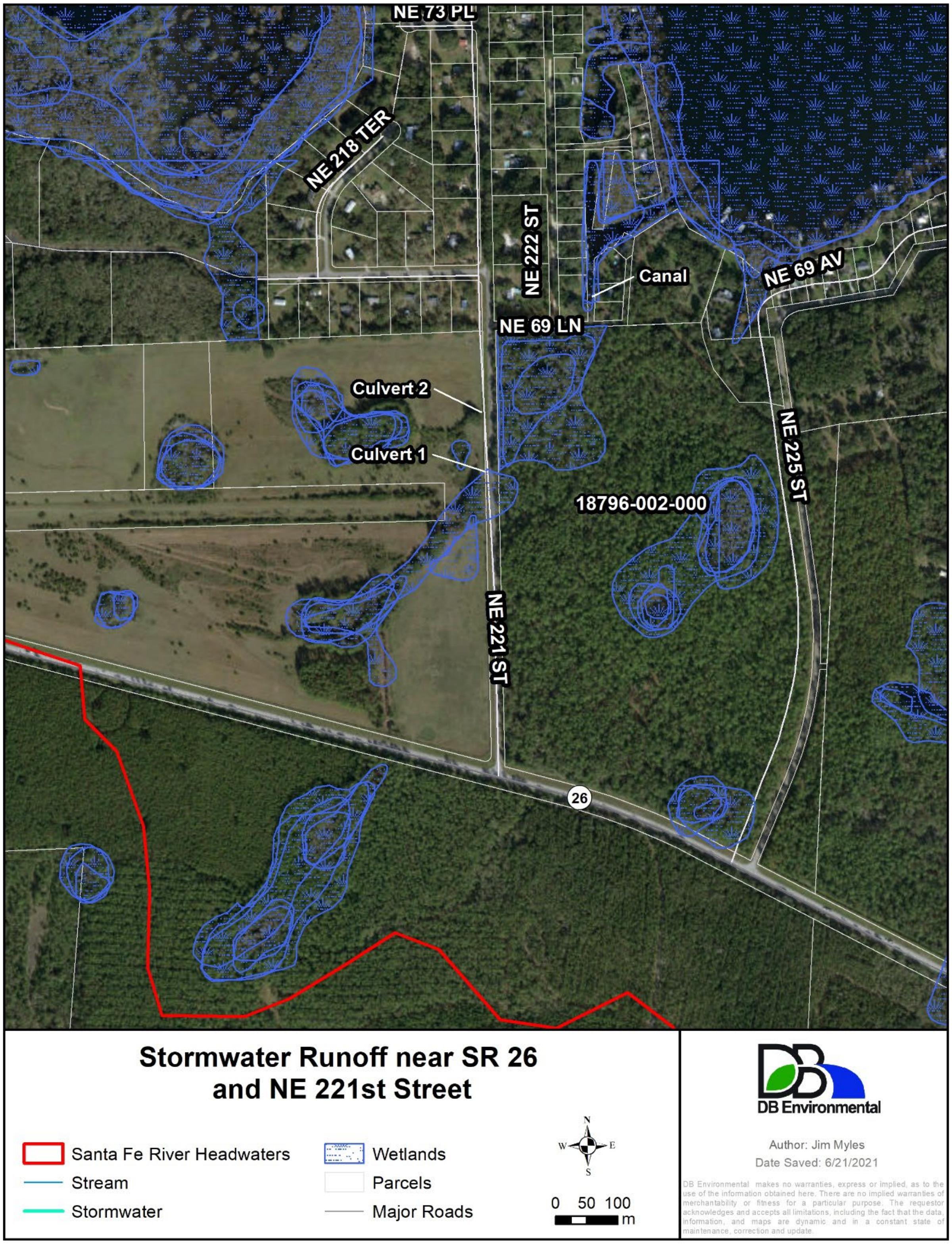

Figure 52. Stormwater runoff near SR 26 and NE 221st Street.

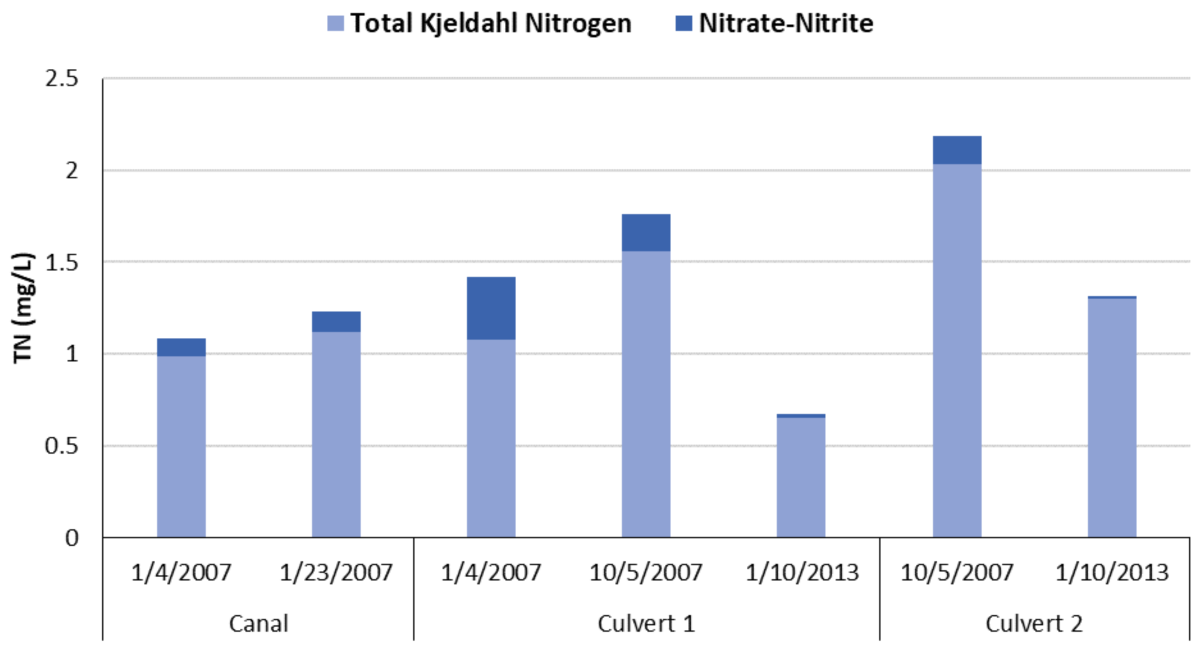

Figure 53. Total nitrogen (TN) concentration (mg/L) of samples collected from culverts crossing NE 221st Street and the canal on Santa Fe Lake receiving the runoff.

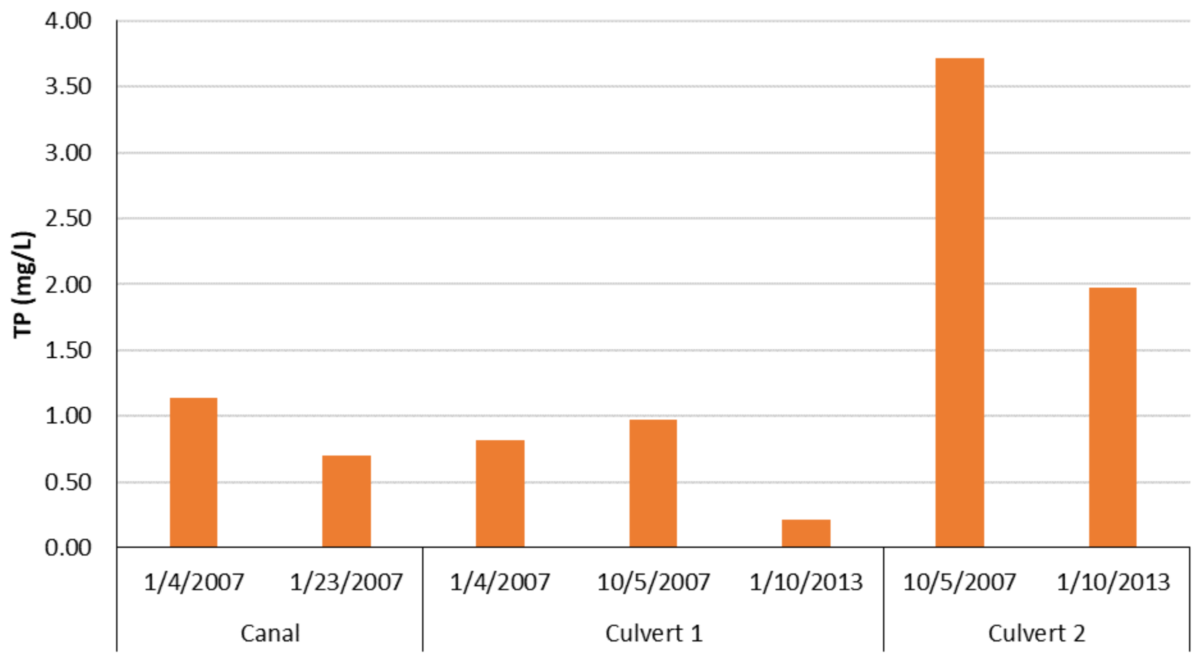

Figure 54. Total Phosphorus (TP) concentration (mg/L) of samples collected from culverts crossing NE 221st Street and the canal on Santa Fe Lake receiving the runoff.

7.1.1.3 Trout Street boat ramp in Melrose Bay

The neighborhood surrounding Trout Street and the boat ramp located on Melrose Bay contribute untreated stormwater runoff to the lake (Figure 55) through a stormwater collection system and road runoff that discharges near the boat ramp (Figure 56). This collection system appears to drain several blocks of residential properties between SR 26 and the boat ramp (Figure 55). While curb inlets, drop inlets, and concrete swales are evident in Google Street View (Figure 57) this stormwater infrastructure is not captured in the geodatabase provided by Alachua County Public Works (Figure 55). There are also drop inlets along SR 26 and the fate of that stormwater is unknown.

Field reconnaissance and surveys of the stormwater infrastructure in this neighborhood will be necessary to determine the outfall locations in Melrose Bay and the contributing areas for the collection system. Once completed areas from stormwater treatment technologies can be identified based on the flows, pollutant loads, and land available for implementation.

Figure 55. Stormwater runoff from Trout Street to Melrose Bay near the boat ramp.

Figure 56. Trout Street boat ramp on Melrose Bay. Image is from Google Street View.

Figure 57. Stormwater drainage on Trout Street in Melrose, FL. Image is from Google Street View.

7.1.2 Septic Systems and Wastewater

Septic systems, also known as Onsite Sewage Treatment and Disposal Systems (OSTDS), provide a cost-effective treatment option for low density development in areas without centralized sewage systems. These systems often service individual homes or other small facilities with minimal wastewater flows, but collectively can have an impact on nearby waterbodies under some circumstances, especially lake-front development. These systems are permitted through the Department of Health and provide a basic protection against health and pollution concerns related to the disposal of human waste. However, OSTDS typically are less effective than centralized systems at removing nutrients from wastewater flows. There is not a centralized wastewater collection system servicing homes or businesses in the Santa Fe Lake watershed. There are two small (>7,500 gpd capacity) wastewater treatment facilities (WWTF) in Melrose, FL serving the Melrose Community School and the Sandhill Apartment Complex, however these are in the Etonia Creek watershed, southeast of the intersection of SR 26 and SR 21. There is a public water supply located in the same general areas that service homes and businesses in Melrose, FL. The extent of the public water supply system is currently unknown.

The contribution of septic systems to nutrient loading of nearby aquatic systems depends on several factors, including the density of septic systems within an area, the characteristics of the soils into which septic systems are installed, and the proximity to the water body. Other considerations include the proper functioning of the installed equipment, and whether systems include advanced treatment options that are currently available, but usually at a significantly higher cost.

Typical "conventional" septic installations consist of a septic tank for solids separation, followed by a leach field that allows percolation of the wastewater into an unsaturated soil profile of at least 2 feet. In a properly functioning leach field, nitrification occurs in the aerobic vadose zone, where nitrifying bacteria in the soil convert ammonia to nitrate and nitrite. Reductions in nitrogen can occur in the anerobic saturated zone of the surficial aquifer through the process of denitrification. The degree of denitrification and loss of N to the atmosphere is a function of the amount of organic carbon available in the soil matrix and the movement of shallow groundwater. Phosphorus is often removed through soil sorption mechanisms, though the effectiveness of this removal mechanism can depend on local soil characteristics. Estimates of the nutrient concentration in OSTDS leach fields vary considerably as a result, which leads to large uncertainties about the contribution of hundreds or thousands of septic systems located within a given watershed.

As nutrients accumulate in the groundwater, some septic systems create plumes of nutrient enriched shallow groundwater that can contribute to nearby aquatic systems. Septic systems can generate NO_3-N concentrations at the water table from 25 to 80 mg/L in some situations (Table 13; McCray et al. 2005). Between 10 and 50% of septic tank effluent TN may be removed during flow through unsaturated soil before reaching groundwater (Hazen and Sawyer 2009). In older septic systems, P plumes can develop in groundwater with time even though the systems may be working properly (Robertson et al. 1998; Zurawsky et al. 2004). The most commonly recommended means of reducing P transport to surface water is to increase the distance from the drain field to water bodies, thus increasing the chances for P adsorption to soil surfaces (Lusk et al. 2011). Another study of nitrate-N fate and transport in the Indian River Lagoon Basin of east-central Florida found that nitrate levels under septic systems were significantly elevated over background levels, but that by 15 meters down gradient of the septic system, nitrate levels were at or near background levels (Anderson 1988). These studies support establishing setbacks from waterbodies to reduce the potential transport for N and P to adjacent water bodies.

Table 13. Estimates of total phosphorus (TP) and total nitrogen (TN) concentrations (in mg/L) in septic tank effluent from various studies.

Reference	Mean TP	Range TP	Mean TN	Range TN
TMDL references Lusk et al. 2011; Toor et al. 2011	10		57	
Toor et al. 2011; Lowe et al. 2009			57.5[1]	33-178
Lusk et al. 2011; Lowe et al. 2009	10[1]	3-40		
Lowe et al. 2009, (All locations) n=61	10.3	0.2-33.4	64	27-119
Lowe et al. 2009, (Florida) n=24	10.1	0.2-21.6	61	38-86
Lowe et al. 2009, (Literature Review)[2]	1.09	0.03-10.3	58	26-124
McCray et al. 2005				25-80[1]
FDEP 2006, OCB Loading				30-50

[1]Median value in septic tank effluent
[2] n = 38 for TP and n = 40 for TN

7.1.2.1 Septic tank inventory in the Santa Fe Lake watershed

The number of septic systems in the Santa Fe Lake watershed was estimated from available records with the Florida Department of Health (FDOH). This information, combined with estimates of septic tank effluent nutrient concentrations and typical water use rates, were used to approximate the potential nutrient load from septic systems in the watershed. The statewide inventory effort by FDOH (Ursin 2016) estimated there are approximately 1,538 septic tanks in the Santa Fe River Headwaters watershed (Figure 58), with an estimated 760 septic systems located within a 200-meter buffer of the lake and associated canals (Figure 59). The 200-m zone of influence was used in Lochloosa Lake TMDL (Magley 2017) and earlier work on lakes in the Upper Ocklawaha River Basin (Fulton 1995) and is based on even earlier empirical modeling work (Reckhow et al. 1980; Reckhow and Chapra 1983). There are three counties bordering the shoreline of Santa Fe Lake having systems within 200 m of the lake or a canal. There are an estimated 360 of these systems in Alachua County, 368 in Bradford County and 32 in Putnam County.

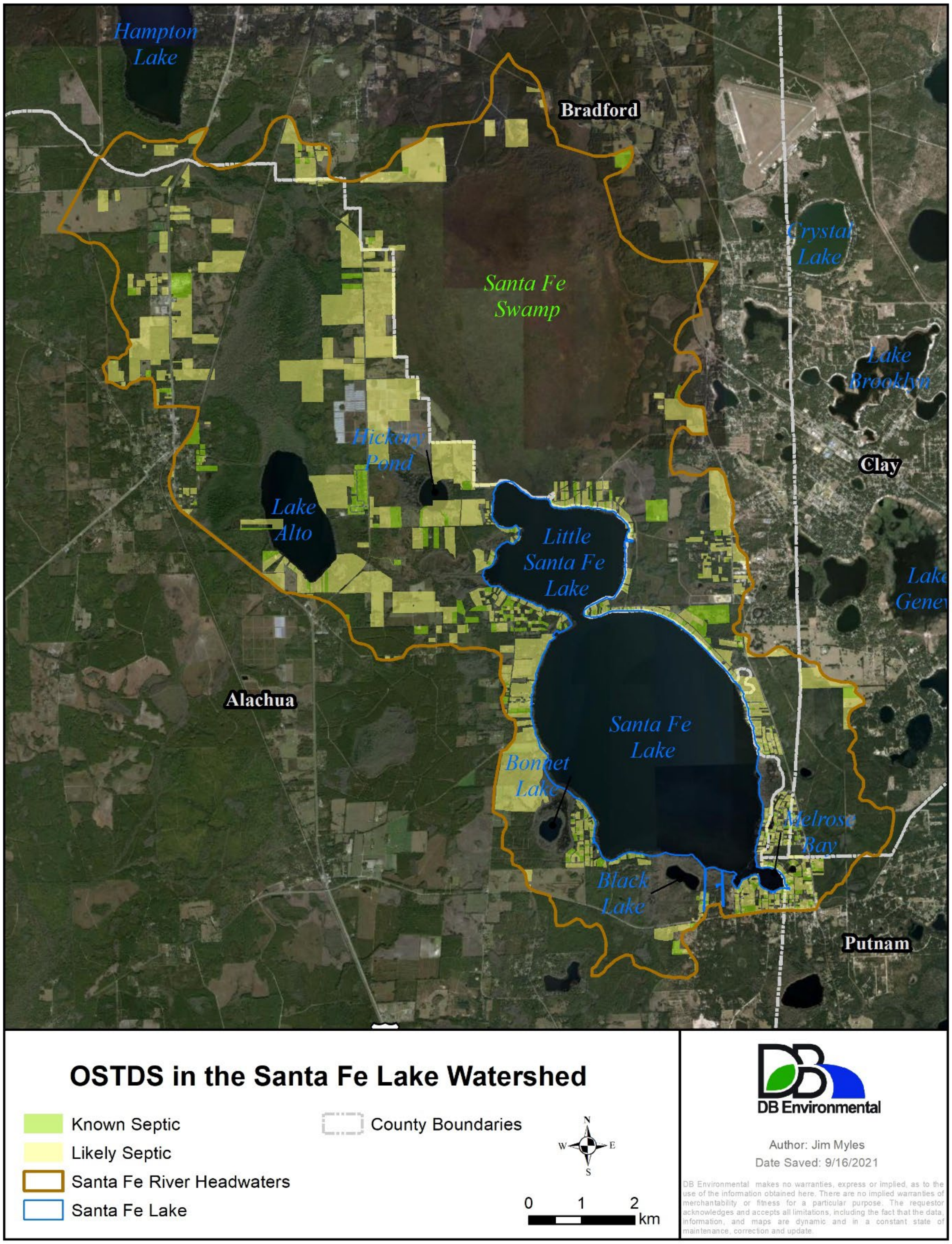

Figure 58. OSTDS in the Santa Fe Lake watershed.

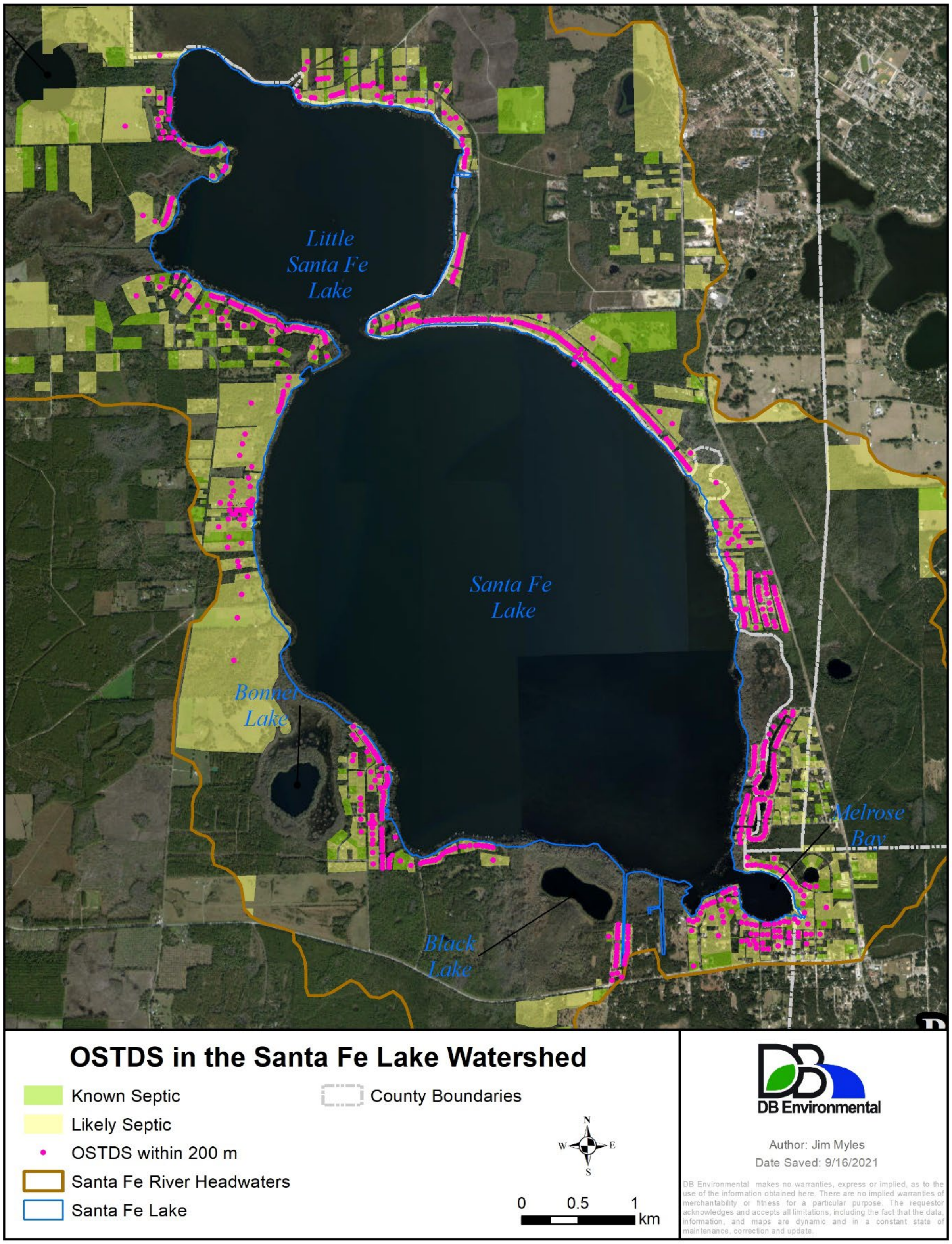

Figure 59. There are an estimated 760 OSTDS within 200 meters of Santa Fe Lake.

7.1.2.2 Estimate of nutrient loads from OSTDS

7.1.2.2.1 Nitrogen Loads

Using an estimate of 190 gallons/day/household (Taylor et al. 2020), septic tank effluent TN concentration of 57 mg/L (Toor et al. 2011), and soil retention factor of 0.45 for TN (Fulton 1995) potential annual groundwater loads of TN were calculated for the estimated 760 septic systems within a 200-m buffer of Santa Fe Lake. This first-order approximation yields a load to groundwater of 13,789 pounds of TN per year (Table 14). Several factors, including soil types, the age of the system, vegetation, and proximity to a receiving water, will each influence the cumulative total (and attenuation of) loads from these systems which are transported to the lake.

Table 14. Estimated TN loads to groundwater from OSTDS within 200 m of Santa Fe Lake and associated canals.

Within 200 m of Santa Fe Lake	Number of Households on Septic	Gallons per Day Per Household	TN in Drain Field mg/L	Annual TN Load (lbs/yr)
Alachua	360	190	57	6,532
Bradford	368	190	57	6,677
Putnam	32	190	57	581
Total				13,789

An earlier estimate of septic loads to lakes in the Orange Creek Basin was conducted by FDEP (FDEP 2006). This estimate was also based on the number of septic systems within 200 m of a drainage feature as contributing to the waterbody. It also considered 5% of those systems as failing and contributing 100% of the load to the waterbody, whereas the functioning systems applied soil retention factor of 45% for TN (Fulton 1995). This report provided estimates of TN loads at two effluent concentrations of 30 and 50 mg/L TN. Utilizing this method the estimated TN load to Santa Fe Lake from the 760 septic systems within 200 m of the lake shore and canals, ranged from 7,918 to 13,196 pounds of TN per year (Table 15). The previous estimate is at the upper end of the range of loads using this methodology.

Table 15. Estimated TN loading to Santa Fe Lake from OSTDS within 200 m of lake and associated canals, using methods developed by FDEP (FDEP 2006).

	Number of Households on Septic	Gallons per Day Per Household	TN in Drainfield mg/L	TN in Drainfield mg/L	Annual TN Load at 30 mg/L (lbs/yr)	Annual TN Load at 50 mg/L (lbs/yr)
Within 200 m of Santa Fe Lake	760	190	30	50	7,258	12,096
Number of Failing Septic Systems	35	190	30	50	660	1,100
Total					7,918	13,196

In the Santa Fe River BMAP the TN load from OSTDS to the Floridan aquifer was estimated using methods developed for the Nutrient Source Inventory and Loading Tool (NSILT) (FDEP 2018). The calculation was based on a per capita contribution of 9.012 lb-N/yr and the average number of people per household, which was weighted to account for the portions of the population that were away from the house for school and work. In the Alachua County portion of the springshed this reduced the average number of people per household from 2.46 to 2.01 (2010 US Census). The load of N to the Floridan aquifer is attenuated by biological and chemical processes of the N cycle which is accounted for through the application of an attenuation factor (0.5). Recharge to the Floridan aquifer, and therefore nitrate transport, is accounted for by applying attenuation factors for the recharge area in which the OSTDS is located (0.9 for High, 0.5 for Medium and 0.1 for Low). This methodology is not directly applicable since the concern is loading to the surficial aquifer and then Santa Fe Lake and not the Floridan aquifer. However, assuming the nitrate that would reach the Floridan aquifer could also reach the lake an estimate of loading can be calculated. Using the per capita contribution (9.012 lb-N/yr), the average household size for each county (2020 US Census) and a medium recharge rate, a potential N load from OSTDS within 200 m of the lake can be calculated for comparison purposes. Using this method approximately 8,756 lbs N/yr would be loaded to the Floridan aquifer from OSTDS surrounding Santa Fe Lake (Table 16).

Table 16. Estimated TN loading to the Floridan aquifer from OSTDS within 200 m of Santa Fe Lake, using methods developed by FDEP for the NSILT (FDEP 2018).

Within 200 m of Santa Fe Lake	Number of Households on Septic	Number of People Per Household (2020 census)	lbs-N/yr/person	Annual TN Load (lbs/yr)
Alachua	360	2.55	9.012	4,137
Bradford	368	2.57	9.012	4,262
Putnam	32	2.48	9.012	358
Total				8,756

The average of these four estimates of nitrogen loading to Santa Fe Lake is 10,915 lbs N/year. This estimate is considerably higher than the load estimated by Brezonik and Shannon (1971) for 243 systems on the lake that contributed an estimated 1,115 lbs N/year (Section 5.6.2).

Analytical tools have been developed to estimate N loading from OSTDS to adjacent waterbodies. ArcNLET is one such tool that uses hydraulic conductivity and soil porosity properties from publicly available soil survey data to predict the spatial effects of OSTDS discharges on nutrient distribution within the shallow groundwater (Wang et al. 2013). The ArcNLET model is not intended for planning level estimates, instead it is intended to be used when OSTDS projects are being implemented, so that calibrations with pre and post project data can be completed (FDEP Septic Calculator). Such analyses are beyond the scope of this literature and data review.

7.1.2.2.2 Phosphorus Loads

The attenuation of P in the drain field, soils and groundwater zone is highly variable and affected by multiple environmental factors including the mineral composition of soils, organic matter content and composition, influence of pH on the availability of Al and Fe cations, and the presence of biofilms. The attenuation of P, through mineralization by bacteria, and the adsorption and precipitation occurring in the soils and aquifer, significantly reduces the transport of P to adjacent waterbodies. In general, acidic, non-calcareous soils that are rich in clay and silt are much less vulnerable to P migration than permeable sandy soils that are pH neutral and calcareous (Lusk et al. 2011). Due to the variability in soils surrounding the lake, age of the systems, separation from the water table and distance from the lake, generalized attenuation rates cannot be determined. A study of P load reduction goals for lakes in the Upper Ocklawaha River Basin estimated P loading to the lakes from OSTDS (Fulton and Smith 2008). Total phosphorus loading from septic tank effluents was estimated using a per capita TP release of 1.48 kg/year (3.26 lbs/year), and 90% soil phosphorus retention (Fulton and Smith 2008). The estimated P load from OSTDS within 200 m of the lake is 633 lbs P/year (Table 17). This is significantly lower than the load estimated by Brezonik and Shannon (1971) for 243 systems on the lake that contributed an estimated 64 lbs P/year (Section 5.6.2).

Table 17. Estimated TP loading from OSTDS within 200 m of Santa Fe Lake, using per capita P loading from septic tank effluents and soil P retention rates provided by Fulton and Smith, (2008).

Within 200 m of Santa Fe Lake	Number of Households on Septic	Number of People Per Household (2020 census)	lbs-P/yr/person	Annual TP Load (lbs/yr)
Alachua	360	2.55	3.26	299
Bradford	368	2.57	3.26	308
Putnam	32	2.48	3.26	26
Total				633

7.1.2.3 Estimate of septic contributions from permitted facilities

At the request of the County, an estimate of the potential nutrient loadings from the septic system serving the County's Santa Fe Park was conducted. The county park and boat ramp are located on the southern shore of the lake. The Park and restroom facilities are supplied with water from a transient non-community public water supply which is regulated by FDEP and required to meter and report water use. The water use records were obtained from the FDEP OCULUS database and assembled to estimate the annual water use and subsequent hydraulic load to the septic system. Outdoor water use from this system is minimal; there does not appear to be any irrigation or boat washing conducted at the park. Based on communications with the Florida Department of Health (FDOH) in Alachua County, the permitted wastewater flow for the Santa Fe Park is 400 gpd.

The TP and TN concentrations used to approximate septic tank effluents were 10 and 57 mg/L, respectively. This approximation is within the range of concentrations reported in several other studies (Table 13). We used the range of concentration values from Florida studies reviewed by Lowe et al. (2009) to also calculate a "low" and "high" estimate of potential loading rates from each septic system. Using both the measured water use and the permitted water use rates, and the range of effluent concentrations, both P and N loads were estimated for this OSTDS (Table 18).

Table 18. Potential loadings from the County Park at Santa Fe Lake, using measured water use and the permitted flow rate, at three different concentrations for the septic tank effluent.

		Mean Water Use 2008 to 2013	**Permitted Flow Rate (400 gpd)**
Annual Water Volume (gal)		24,217	146,000
(gal/day)		66	400
TP Concentration Range (mg/L)		TP (lbs/y)	TP (lbs/y)
Low	0.2	0	0
Mean	10.0	2	12
High	21.6	4	26
TN Concentration Range (mg/L)		TN (lbs/y)	TN (lbs/y)
Low	38.0	8	46
Mean	57.0	12	69
High	86.0	17	105

8 Synopsis

8.1 Santa Fe Lake Water Quality

Water quality data for the Santa Fe Lake system is available from monitoring agencies such as USGS and FDEP as far back as the 1950s and 1960s, though monitoring intensity (samples per year) was sparse prior to 1985 when LAKEWATCH began intensive monthly monitoring. The infrequent sampling and higher detection limits for TP limit the utility of the earlier data. Average values and precise temporal trends differ somewhat among datasets and data handling approaches of different agencies. In general, the available data indicate that within the intensively monitored interval since 1985, water quality in the Santa Fe Lake system is declining. Increased nutrient levels (TP and TN) apparently have supported greater phytoplankton growth (increased chlorophyll *a* concentrations) and poorer water clarity (measured as Secchi depth) which could be from increased algae concentrations and/or color, both reducing light penetration into the water column. Numerous stochastic, non-anthropogenic events have exerted both short-term and long-term influence on water chemistry in the lake system, often producing cumulative effects.

In general, temporal water quality patterns in the Santa Fe Lake system have been dominated by the effects of natural perturbations. For example, TN concentrations were relatively stable until 2003, when TN concentrations increased by about 50% between 2003 and 2005 in the Santa Fe system. Following a 1998-2002 drought, high rainfall in 2002 and 2003, and several tropical cyclones in 2004 transported significant loads of colored water including organic nitrogen from the swamps and watershed to the lake. TN concentrations remained elevated after the Dairy Road Fire in 2007 and remained high through 2010. Since 2010, the TN concentrations have been steadily decreasing. Similarly, among years meeting the minimum requirements for NNC assessment, annual average TP concentrations significantly increased following the high rainfall in 2002 and 2003, and tropical cyclones in 2004. Following the Dairy Road Fire and subsequent rainfall in 2007 the TP concentrations increased by 50% in 2008. Since 2008, the TP concentrations have been decreasing but have not returned to historic levels. Water clarity also declined dramatically between 2003 and 2005, and since that time has remained generally low (compared to 1985-2003) but interannually variable and may be due to increased color.

Some anthropogenic stressors in the lake drainage area, such as residential land development and the number of OSTDS (septic systems), have increased during the period of record, but the effect on lake water quality is difficult to define. One investigation concluded, "An impact of land-use changes on water quality at [Santa Fe Lake System] cannot be totally dismissed, but the circumstantial evidence leads to the need to consider that forces other than cultural eutrophication may be exerting a greater impact on water quality at [Santa Fe Lake System]" (Canfield et al. 2016). Nonetheless, some opportunities to reduce nutrient inputs to the lake from the watershed have been identified.

8.2 Watershed nutrient sources

OSTDS are a common and widespread source of nutrients to shallow groundwater, and thus, potentially, to receiving water bodies interacting with that groundwater. The number of septic systems in the vicinity of the Santa Fe Lake system has clearly increased. By the mid-2010s, there were approximately 760 septic systems serving shoreline residences, compared to an estimated 243 total shoreline residences in the mid-1960s. Recent estimates calculated nutrient loads to of approximately 10,915 lbs N/year and 633 lbs P/year from OSTDS within 200 m of the Santa Fe Lake system (Section 7.1.2.2). The effect of these nutrient loads on lake water quality has not been estimated, nor are estimates of loads from other controllable nutrient sources available for comparison. Nonetheless, the septic systems surrounding Santa Fe Lake clearly merit further investigation regarding their contribution to lake water quality, and as a potential opportunity to reduce nutrient loading to the lake.

The lake also receives direct stormwater runoff from surrounding parcels and communities. One example exists of high TN and TP concentrations in stormwater runoff from agricultural lands and road runoff. However, the quality of stormwater runoff from parcels around the lake is generally not well documented and is expected to be highly variable among contributing drainages depending on land use and cover. Many of these point inputs have not been adequately inventoried. With further investigation, there could be opportunities to reduce nutrient loading to Santa Fe Lake through stormwater management and treatment.

9 Detailed Study Plan

The objectives of this study plan for Santa Fe Lake are to identify locations within the lake that exhibit elevated nutrient concentrations during the dry season (Task 1) and wet season (Task 2) and identify stormwater input locations to the lake (Task 3). These inputs are not clearly defined along the developed portion of the lakeshore, and the drainage basin for the lake will be updated as part of this effort (Task 4).

9.1 Task 1 – Dry Season Spatial Survey of Surface Water Quality in Santa Fe Lake

For this task, a spatial survey of water quality in Santa Fe Lake will be performed. The objective of this sampling event is to identify regions within the lake that exhibit elevated nutrient concentrations. Sampling is planned for the dry season of 2022 which extends from November to May in this region of Florida (Rao et al. 1990). Typically, during the dry season groundwater contributions to lakes represent a greater proportion of the water budget. Therefore, the potential for detecting nutrient impacts from groundwater seepage to the lake is higher. Samples will be focused along the developed shoreline and canals of the lake (Figure 60). It is in these near shore environments where elevated nutrients have been detected in other studies (DBE 2021), indicating nutrient loads to the lake.

At each sampling location the water depth and Secchi depth (a measure of water transparency) will be recorded, and a surface water grab sample will be collected for analyses of the following parameters: TP, soluble reactive phosphorus (SRP), total soluble phosphorus (TSP), total Kjeldahl nitrogen (TKN), nitrate plus nitrite (NOx), ammonia nitrogen (NH4-N), chlorophyll *a*, and True Color. Field parameters including temperature, pH, dissolved oxygen, specific conductance, and turbidity will be measured at the time of sampling. A depth profile of field parameters will be measured to determine if the lake is stratified. Water quality sampling will be performed at approximately 40 stations and will follow the appropriate FDEP Standard Operating Procedures (FDEP 2017).

Septic tanks represent a potential source of nutrients to Santa Fe Lake, yet few empirical data are available demonstrating a direct impact on water quality. In addition to the spatial sampling event described above, a subset of samples (10) will be analyzed for wastewater tracers including, chloride, sulfates, boron, potassium, sodium, E coli, and sucralose (ACEPD 2014). The surface water nutrient and wastewater tracer concentrations from these samples will be compared to the results from samples collected near the center of the lake.

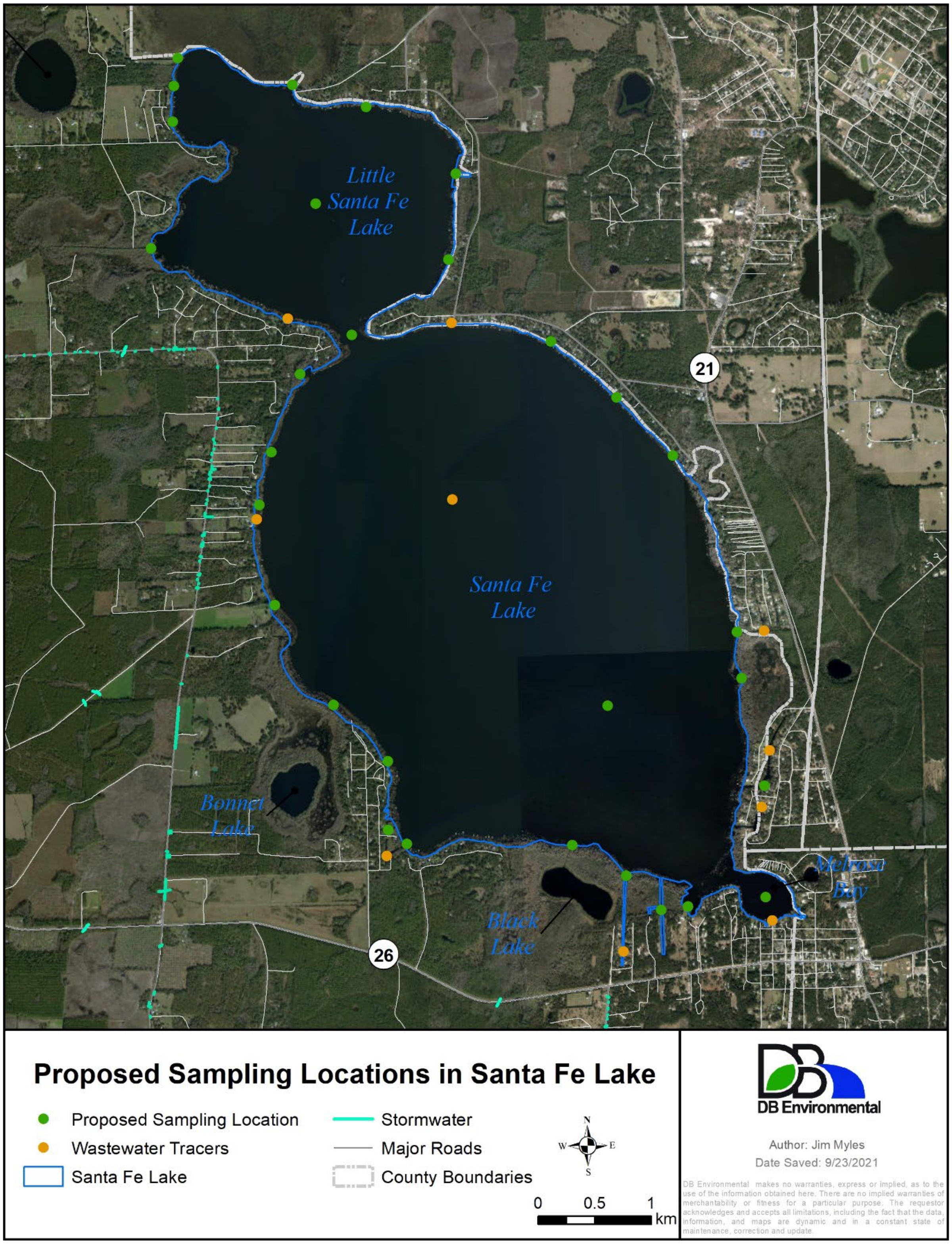

Figure 60. Proposed sampling locations in Santa Fe Lake.

9.2 Task 2 – Wet Season Spatial Survey of Surface Water Quality in Santa Fe Lake

For this task, a spatial survey of water quality in Santa Fe Lake will be performed during the wet season of 2022, which extends from June to October in this region of Florida (Rao et al. 1990). Santa Fe Lake hydrology is primarily controlled by local rainfall, so runoff from the watershed is typically highest during the wet season and immediately after storm events. Samples will be collected from the same locations that were visited during the dry season (Figure 60) and analyzed for the same set of parameters (Table 19). The objective is to identify areas with elevated nutrient concentrations that indicate impacts from surface water inputs and localized runoff. Hotspots within the lake and associated canals could indicate non-point sources and potential focus areas for mitigation strategies.

9.3 Task 3 – Identify and Sample Stormwater Inputs to Santa Fe Lake

In this task, direct stormwater discharges to the lake will be identified. This effort will be limited to the Alachua County portion of the lake shoreline. A reconnaissance of the shoreline and canals will be conducted to locate any discharge points. Once identified, the contributing area of each outfall will be investigated. The location of the associated stormwater infrastructure will be recorded along with a general description. This information will be used to update the Alachua County stormwater geodatabase.

Three direct stormwater inputs have already been identified (Section 7.1). The stormwater infrastructure upstream of these outfalls has not been captured in the geodatabase. Recording the contributing area and stormwater infrastructure in these locations will be the focus of the initial field investigations. With this information, stormwater flows from these areas can be estimated. However, the nutrient contributions to the lake are unknown. During two storm events, grab samples for water quality analysis will be collected, along with flow measurements where feasible and estimated elsewhere. Samples will be analyzed for the N and P species listed in Table 19. Based on location and magnitude of these stormwater inputs nutrient reduction opportunities can be identified.

9.4 Task 4 – Define Drainage Basin for Santa Fe Lake

In this Task, the surface water drainage basin for Santa Fe Lake will be delineated using available data including light detection and ranging (LiDAR) derived digital elevation model (DEM), topography layers and existing basin boundaries. A combination of manual interpretation and modeled contributing areas will be employed to complete the delineation. Once the surface water drainage basin is delineated, the number of septic systems in the drainage basin can be more accurately estimated. In addition, the proportions of land use and land cover within the watershed can be determined and nutrient loads estimated.

In addition, the lake stage data will be reviewed and compared to the DEM to determine the wetted perimeter of the lake under various lake stage conditions and resulting hydrologic connections to the surrounding waterbodies. This may include an analysis of how often hydraulic connections occur to Lake Alto, Black Lake, Bonnet Lake and Santa Fe Swamp.

9.5 Field Sampling Protocols

Sample collection, field-testing procedures, and field quality control requirements for this project will follow the procedures and requirements found in DEP-SOP-001/01 (FDEP 2017). Sample handling and preservation procedures for the requested parameters will be performed as outlined in DEP-SOP-001/01. Field blanks (for surface water samples) and field duplicates (for water and sediment/soil samples) will be collected at a frequency of 5% for the project.

9.6 Analytical Methods

The analytical methods and method detection limits to be used during this study are provided in Table 19 below.

Table 19. Surface water and soil chemical parameters to be analyzed for this project along with their associated analytical methods and method detection limits (MDL).

Analyte	Method	MDL
Total Phosphorus (TP)	SM 4500-P F	3 µg/L
Total Soluble Phosphorus (TSP)	SM 4500-P F	3 µg/L
Soluble Reactive Phosphorus (SRP)	SM 4500-P F or DBE SOP OPO4	2 µg/L
Total Kjeldahl Nitrogen (TKN)	EPA 351.2	0.037 mg/L
Nitrate-N + Nitrite-N (NOx-N)	SM 4500NO3 H-2011	0.016 mg/L
Ammonia-N (NH_3-N)	SM 4500-NH3 H (18th ed.)	0.020 mg/L
Chlorophyll a	SM 10200 H-2011	0.50 mg/m^3
Alkalinity	SM 2320 B	2 mg/L
True Color	SM 2120 B	5 PCU
Chloride	EPA 300.0	0.29 mg/L
Sulfate	SM 4110 B	0.2 mg/L
Dissolved Ca	SM 3111 B	0.20 mg/L
Boron	EPA 6020B	0.98 µg/L
Sucralose	LC-MS-MS	20 ng/L
E. Coli	SM 9223 B / Quanti-tray	1 MPN/100 mL
Potassium	6010D	250 µg/L
Sodium	6010D	100 µg/L

9.7 QA/QC Management

Relevant samples, including field testing and field quality control (QC) samples, will be collected in accordance with DEP-SOP-001/01 (FDEP 2017). Project-specific quality assurance and quality control (QA/QC) protocols specified in this Study Plan will be followed. Applicable sections of DEP-SOP-001/01 include, but are not limited to, field sample collection procedures, decontamination procedures, field testing, and quality control requirements. Samples will be analyzed according to the provisions within the analytical laboratory's QA/QC documents (ENCO

2015; DBE 2020). These documents are periodically updated, and therefore, the most recent version of the QA/QC documents details the specific laboratory analyses' data quality objectives for this project at the time of sample analysis. Data are verified and qualified, if necessary, in accordance with the respective chemical analytical laboratories' QA/QC documents.

DB Environmental (DBE) will perform data verification, including checking the following QC checks as part of their routine data validation: reversal checks (for example, verify that TP>SRP), sensitivity checks, matrix interference checks, precision checks, and accuracy checks for applicable chemical analytes. Criteria and recommended corrective actions will be those stated in the chemical analytical laboratories' QA/QC documents or agreed upon with the Project Manager. DBE will also review the field QA/QC results according to DEP-SOP-001/01 (2017). All raw data and findings will be available for County review. A final QA'd data report for the project will be provided with the final project report.

9.8 Documentation and Records Management

Field notes and copies of all records relative to the chain of custody and chemical analytical data will be maintained by DBE. Both current and historical method and operating procedures will be maintained so that at any given time the conditions that were applied to a sampling event can be evaluated. Records will be maintained by DBE for five years after the end of this study, in a manner that will protect the physical condition and integrity of the records. Corrections of data or records will follow the chemical analytical laboratories' QA/QC documents.

9.9 Data Analysis

Statistical testing will consist of testing hypotheses by appropriate selection of what is considered the background condition (or null hypothesis), and then applying the appropriate statistical tests (parametric vs. non-parametric). For this project, statistical analyses of selected data sets will be reserved for final results at the end of the study.

9.9.1 Establishing Background Conditions and Testing Hypotheses

Even though the data collection and analysis methods may be unbiased, the sample data are subject to random and systematic errors at different stages of acquisition, from field collection to sample analysis. Selecting the correct baseline condition (null hypothesis: H_o) therefore will be important. Potential random and systematic errors will be managed through field replication, sampling design (where and when to sample), lab duplicates, and setting an appropriate probability threshold for Type I errors in hypothesis testing. For this study, $\alpha = 0.05$ will be used as the probability criteria for false rejection (i.e., rejecting the null hypothesis when it is really true) while being aware of the possibility of Type II errors (β; not rejecting the data when it is false), and thereby recognizing the importance of the power ($1-\beta$) of the statistical test being applied.

9.9.2 Statistical Analyses

The data analysis plan includes statistical testing for a variety of comparisons including, but not limited to, comparisons across sites, along with the identification of the relevant field parameters or analytes contributing to the differences. The principal statistical test to be employed to evaluate differences in water chemistry between open water and canal samples will be the matched-pairs t-test. When normality assumptions for a matched-pairs t-test are not met, the Wilcoxon signed-rank test will be applied. In addition, bivariate analyses (i.e., Pearson's product-moment correlation) may be applied to relate water chemistry observations to physicochemical and other parameters. As necessary, the non-parametric Spearman rank order correlation will be used.

10 References

ACEPD, 2006. The Water Quality and Sediment Characteristics of the Canals of Santa Fe Lake. Alachua County Environmental Protection Department, Gainesville, FL.

ACEPD, 2014. Santa Fe River Springs Basin Poe and Hornsby Springs Nitrate Source Investigation. Alachua County Environmental Protection Department.

Anderson, D.L., 1988. Natural denitrification in groundwater impacted by onsite wastewater treatment systems.

Boniol, D., K. Mouyard, 2016. Recharge to the Upper Floridan Aquifer in the St. Johns River Water Management District, Florida.

Brezonik, P.L., W.H. Morgan, E.E. Shannon, H.D. Putnam, 1969. Eutrophication factors in north central Florida lakes. Fla., Univ., Eng. Ind. Exp. Stn., Bull. Ser.;(United States) 233.

Brezonik, P.L., E.E. Shannon, 1971. Trophic State of Lakes in North Central Florida.

Brink, N., 1964. , in: Nordisk Kollokvium Om Eutrofieringsproblemer. Norsk Insta.Vannforsyning, Blindern, Norway.

Brown, M.T., M.B. Vivas, 2005. Landscape Development Intensity Index. Environ Monit Assess 101, 289–309. https://doi.org/10.1007/s10661-005-0296-6

Canfield, D.E., 1981. Chemical and trophic state characteristics of Florida lakes in relation to regional geology. University of Florida, Gainesville, FL.

Canfield, D.E., M.V. Hoyer, R.W. Bachmann, D. Bigham Stephens, I. Ruiz-Bernard, 2016. Water quality changes at an Outstanding Florida Water: influence of stochastic events and climate variability. Lake and Reservoir Management 32, 297–313. https://doi.org/10.1080/10402381.2016.1193576

Clark, W.E., R.H. Musgrove, C.G. Menke, J.W. Cagle Jr., 1964. Water Resources of Alachua, Bradford, Clay, and Union Counties, Florida (43), Open-File Report. U.S. Geological Survey, Tallahassee, Florida.

DBE, 2020. Comprehensive Quality Assurance Plan.

DBE, 2021. Identifying Nutrient Sources for Potential Reduction Projects in the Lochloosa Lake Watershed, Lochloosa Lake Nutrient Source Evaluation Final Report. Alachua County Environmental Protection Department, Gainesville, FL.

ECT, 2021a. Lake Alto and Lake Santa Fe Water Budget Modeling Technical Report – Update to Include Reference Timeframe Analysis. Environmental Consulting & Technology, Inc.

ECT, 2021b. Minimum Recommended Lake Levels: Lake Santa Fe, FL. Suwannee River Water Management District.

ENCO, 2015. Statement of Qualifications.

FDEP, 2006. Orange Creek Basin Onsite Wastewater Treatment System Loading Analysis. Florida Department of Environmental Protection (FDEP), Tallahassee, FL.

FDEP, 2013. Implementation of Florida's Numeric Nutrient Standards. Florida Department of Environmental Protection, Tallahassee, FL.

FDEP, 2017. Florida Department of Environmental Protection Standard Operating Procedures (SOP) Revised January 2017 [WWW Document]. URL https://floridadep.gov/dear/quality-assurance/content/dep-sops (accessed 2.21.20).

FDEP, 2018. Santa Fe River Basin Management Action Plan. Florida Department of Environmental Protection (FDEP), Tallahassee, Florida.

Fore, L.S., R. Frydenborg, N. Wellendorf, J. Espy, T. Frick, D. Whiting, J. Jackson, J. Patronis, 2007. Assessing the Biological Condition of Florida Lakes: Development of the Lake Vegetation Index (LVI). Florida Department of Environmental Protection (FDEP), Tallahassee, FL 32399.

Franklin, M.A., G.L. Giese, P.R. Mixson, 1995. Statistical Summaries of Surface-Water Hydrologic Data Collected in the Suwannee River Water Management District, Florida, 1906-93 (94–709). U.S. Geologic Survey, Tallahassee, FL.

Fulton, R.S., 1995. External nutrient budget and trophic state modeling for lakes in the Upper Ocklawaha River Basin. (SJ95-6). St. Johns River Water Management District.

Fulton, R.S., D. Smith, 2008. Development of phosphorus load reduction goals for seven lakes in the Upper Ocklawaha River Basin, Florida. Lake and Reservoir Management 24, 139–154. https://doi.org/10.1080/07438140809354057

Grimshaw, H.J., D.A. Dolske, 2002. Rainfall concentrations and wet atmospheric deposition of phosphorus and other constituents in Florida, USA. Water, Air, and Soil Pollution 137, 117–140.

Hazen and Sawyer, 2009. Task A.2 - Literature Review of Nitrogen Reduction Technologies for Onsite Sewage Treatment Systems. Florida Department of Health.

Hunn, J.D., L.J. Slack, 1983. Water Resources of the Santa Fe River Basin, Florida (83–4075). U.S. Geological Survey, Tallahassee, Florida.

Kenney, W.F., M.N. Waters, C.L. Schelske, M. Brenner, 2002. Sediment records of phosphorus-driven shifts to phytoplankton dominance in shallow Florida lakes. Journal of Paleolimnology 27, 367–377. https://doi.org/10.1023/A:1016075012581

LAKEWATCH, 2020. Alachua County Lake Report 2020.

Lowe, K.S., Maria B. Tucholke, Jill M.B. Tomaras, K. Conn, C. Hoppe, Dr.J.E. Drewes, Dr. John E. McCray, 2009. Influent Constituent Characteristics of the Modern Waste Stream from Single Sources. Water Intelligence Online 6, 9781843397731–9781843397731. https://doi.org/10.2166/9781843397731

Lusk, M., G.S. Toor, T. Obreza, 2011. Onsite Sewage Treatment and Disposal Systems: Phosphorus 9.

Magley, W., 2017. Nutrient TMDLs for Lochloosa Lake (WBID 2738A) and Cross Creek (WBID 2754) and Documentation in Support of the Development of Site-Specific Numeric Interpretations of the Narrative Nutrient Criterion. Florida Department of Environmental Protection.

McCray, J.E., S.L. Kirkland, R.L. Siegrist, G.D. Thyne, 2005. Model Parameters for Simulating Fate and Transport of On-Site Wastewater Nutrients. Groundwater 43, 628–639. https://doi.org/10.1111/j.1745-6584.2005.0077.x

Millar, C.E., 1955. Soil fertility. LWW.

Olson, F.S., 2003. Alachua County Invasive Plant Inventory and Property Owner Education Project on Lake Santa Fe. Current Problems, Inc.

Pirkle, E.C., H.K. Brooks, 1959. Origin and Hydrology of Orange Lake, Santa Fe Lake, and Levys Prairie Lakes of North-Central Peninsular Florida. The Journal of Geology 67, 302–317.

Poor, N.D., J.R. Pribble, D.B. Schwede, 2013. Application of watershed deposition tool to estimate from CMAQ simulations the atmospheric deposition of nitrogen to Tampa Bay and its watershed. Journal of the Air & Waste Management Association 63, 100–114. https://doi.org/10.1080/10962247.2012.739109

Rao, D.V., S.A. Jenab, D.A. Clapp, 1990. Rainfall Analysis for Northeast Florida Part V: Frequency Analysis of Wet Season and Dry Season Rainfall. St. Johns River Water Management District.

Reckhow, K.H., M.N. Beaulac, J.T. Slmpson, 1980. Modeling phosphorus loading and lake response under uncertainty: A manual and compilation of export coefficients 225.

Reckhow, K.H., S.C. Chapra, 1983. Engineering approaches for lake management; Volume 1: Data analysis and empirical modeling. Butterworth Publishers Boston. 1983. 340.

Robertson, W.D., S.L. Schiff, C.J. Ptacek, 1998. Review of Phosphate Mobility and Persistence in 10 Septic System Plumes. Groundwater 36, 1000–1010. https://doi.org/10.1111/j.1745-6584.1998.tb02107.x

Ruiz-Bernard, I., 2012. Effects of a Catastrophic Forest Fire on Trophic Parameters of an Outstanding Florida Water System. University of Florida, Gainesville, FL.

Scott, T.M., 1988. The lithostratigraphy of the Hawthorn Group (Miocene) of Florida, Bulletin / State of Florida, Department of Natural Resources, Division of Resource Management, Florida Geological Survey ;no. 59. Florida Geological Survey, Tallahassee.

Shannon, E.E., P.L. Brezonik, 1972. Limnological characteristics of north and central Florida lakes. Limnol. Oceanogr. 17, 97–110. https://doi.org/10.4319/lo.1972.17.1.0097

Soil Conservation Society of America Minnesota Chapter, 1969. Water Pollution by Nutrients-sources, Effects and Control: Papers Presented at 1969 Annual Meeting of Minnesota Chapter Soil Conservation Society of America. Water Resources Research Center, University of Minnesota, Graduate School.

Stefanova, P.L., D.J. Brouillette, D. Zierden, 2017. Climate Summary for Florida – June 2017 4.

Sylvester, R.O., 1961. Algae and metropolitan wastes. US Public Health.

Taylor, N., K. Olander, Robb Price, B. Spatz, T. Kyzar, P. Jones, 2020. Florida H2OSAV Insights: Home Water Use in the Gainesville Regional Utilities (GRU) Service Territory.

The HDR Team, 2010. Nutrient Budget Analysis for the Lake Okeechobee Watershed, Final Comprehensive Report to South Florida Water Management District, West Palm Beach, FL.

Toor, G.S., M. Lusk, T. Obreza, 2011. Onsite Sewage Treatment and Disposal Systems: Nitrogen 6.

Ursin, E., 2016. Florida Water Management Inventory Project - Florida Onsite Sewage Treatment and Disposal Systems Inventory (DEP Contract No. G0431). Florida Department of Health.

Vollenweider, R.A., 1968. The scientific basis of lake and stream eutrophication, with particular reference to phosphorus and nitrogen as eutrophication factors. Organisation for Economic Cooperation and Development, Paris 159.

Wang, L., M. Ye, J. Fernando Rios, R. Fernandes, P.Z. Lee, R.W. Hicks, 2013. Estimation of nitrate load from septic systems to surface water bodies using an ArcGIS-based software. Environ Earth Sci 70, 1911–1926. https://doi.org/10.1007/s12665-013-2283-5

Weibel, S.R., 1969. Urban drenage as a factor in entrophication.«Eutrophication etc.», in: Proceed. Symposium. Nation. Acad. Sci. Washington.

Zurawsky, M.A., W.D. Robertson, C.J. Ptacek, S.L. Schiff, 2004. Geochemical stability of phosphorus solids below septic system infiltration beds. Journal of Contaminant Hydrology 73, 129–143. https://doi.org/10.1016/j.jconhyd.2004.01.003