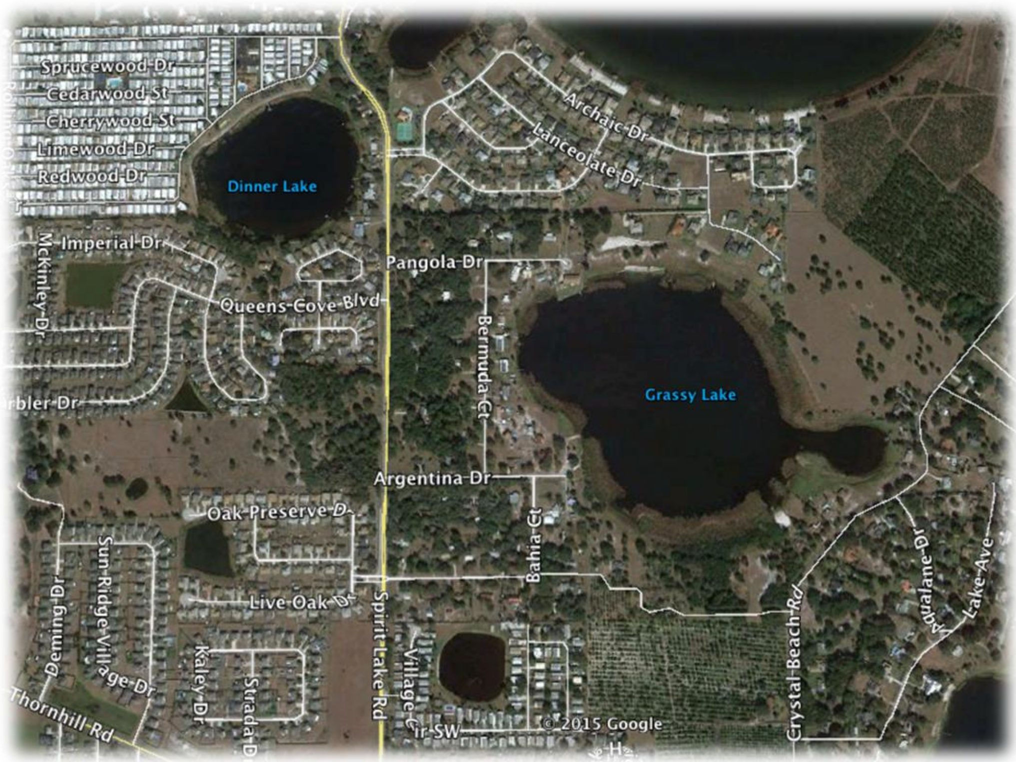
REMOVING POLK COUNTY LAKES FROM THE FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION'S VERIFIED IMPAIRED LIST FOR NUTRIENTS

GRASSY LAKE (WBID 1623M1) CASE STUDY



<u>**Polk County Board of County Commissioners**</u>
Parks & Natural Resources

FINAL REPORT

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Prepared For:

Polk County Board of County Commissioners
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Executive Summary

The United States Environmental Protection Agency (USEPA) accepted the Florida Department of Environmental Protection's (FDEP) listing of Grassy Lake (WBID 1623M1) as a Verified Impaired lake for nutrients in 2010. With this designation, a TMDL (Total Maximum Daily Load) was to be developed, but neither the USEPA nor FDEP could identify a source for impairment.

In Polk County, FDEP has listed over 50 lakes as impaired and requires development of TMDLs. Atkins (2013), after evaluating water quality data from numerous Polk County lakes for Polk County, noted some listed lakes were "false positives." They recommended projects and/or permit-related obligations could be designed, permitted and constructed in the TMDL implementation phase for the "verified impaired" water bodies that might not bring about the desired response in lake water quality. Atkins (2013) further noted it is imperative proper nutrient targets be used as the baseline for impairment designations as the implementation of very costly restoration projects hinges on these determinations.

The State of Florida at the urging of USEPA adopted numeric nutrient criteria (NNC) in 2013 (Chapter 62-302.531, Florida Administrative Code). Because the NNC was supposedly designed to better reflect the variability and unique water quality conditions found throughout the state, NNC would better protect water quality and reduce the number of "false-positives" placed on the Verified Impaired list. Adopted NNC for lakes, however, failed to adequately account for variability in geologic and soil conditions in Florida. To correct this deficiency, the definition of "natural background" conditions in the Florida Administrative Code (F.A.C.) was changed to include six, total phosphorus and five, total nitrogen zones (62-302.200(19) F.A.C.). These zones were specifically added to the F.A.C. because it was not the intent of the State of Florida to place a lake on the Verified List if the lake is functioning naturally. This intent is further clarified elsewhere in the F.A.C.: Rule 62.303.100(2) F.A.C. states "…. when the water quality standards were adopted, many water bodies naturally do not meet one or more established water quality criteria at all times, even though they meet their designated use. It is not the intent of this chapter to include waters that do not meet otherwise applicable water quality criteria solely due to natural conditions or physical alterations of the water body not related to pollutants" and Rule 62-303.420 (1a) Aquatic Life-Based Water Quality Criteria Assessment states "If values exceeding the criteria are not due to pollutant discharges or reflect natural background conditions, including seasonal or

other natural variations, the water shall not be listed on the verified list. In such cases, the Department shall note for the record why the water was not listed and provide the basis for its determination that the exceedances were not due to pollutant discharges."

Atkins (2013) recommended to Polk County a more extensive review of water quality should be completed for those waterbodies deemed impaired using the previous water quality standards for nutrients prior to TMDL development. Grassy Lake (WBID 1623M1) was chosen by Polk County for such a review so any sources of impairment could be identified and management actions recommended. From 2010 to 2014, TP and TN concentrations in Grassy Lake did not exceed numeric criteria established in the NNC. Sampling of the Grassy Lake fish population by the Florida Fish and Wildlife Conservation Commission in early 2015 indicated "good" populations of different fish species, providing evidence that Grassy Lake meets its Class III designated use. Given these findings and the facts that the USEPA, FDEP, and this study could not locate any definitive source(s) of impairment, no TMDL programs have been implemented within the watershed and Grassy Lake's nutrient, chlorophyll and water clarity measurements were within the range of measurements from the appropriate TP and TN nutrient zones, it was concluded Grassy Lake was functioning according to natural background conditions.

Saying a lake is functioning naturally still begs the question as to what environmental factor(s) are responsible for reduction in nutrient concentrations. The answer based on the best available evidence for Grassy Lake, including a January 2015 macrophyte survey performed by Polk County that found aquatic macrophytes growing consistently between 10 feet (ft). and 13 ft and covering over 50% of the lake bottom, is the expansion of the submersed aquatic macrophyte community. Polk County began treating Grassy Lake for hydrilla (*Hydrilla verticillata*) in 2007. Given macrophyte management activities by Polk County, hydrilla abundance were brought to maintenance control levels and native eelgrass (*Vallisneria americana*) expanded.

Expansion of the submersed aquatic macrophyte community has apparently transitioned Grassy Lake without any change in nutrient inputs into an alternative steady state, the clear water-macrophyte stable state. Given that Polk County will for the foreseeable future be managing non-native macrophytes like hydrilla, a well-funded, holistic macrophyte management plan that manages all emergent and submersed aquatic macrophytes could be the most cost-effective approach for managing Grassy Lake's water quality. Additional funding to Polk County's aquatic macrophyte management group to insure sufficient frequent visits to a waterbody as well as sufficient funding to correctly manage aquatic macrophytes can provide Polk County with a less expensive approach for achieving water quality standards.

It is recommended Polk County discuss with FDEP removal of Grassy Lake from the State of Florida's Verified Impaired list. Polk County should also consider implementing within Polk County Parks and Natural Resources Division a hydrophilic-floral reconstruction program at other Polk County lakes. Using the expertise available with current staffing, Polk County could achieve desired water quality standards without implementing expensive TMDLs. Continued long-term management of aquatic macrophyte communities, however, will be necessary because natural factors or anthropogenic activities that substantially reduce the abundance of submersed aquatic macrophytes can lead to the other alternative steady state, a turbid algal dominated system.

Background

Site: Grassy Lake, Polk County, Florida

Grassy Lake (Figure 1) is a named Florida lake (GNIS 283322, Bartow Map) in west-central Polk County (Township 29s, Range 25e, Section 2) located at a latitude 27.9897806 and longitude -81.7783227 (USGS, GNIS 2014). Grassy Lake lies at the interface of Lake Region 75-31 (Winter Haven/Lake Henry Ridges) and Lake Region 75-36 (Southwestern Flatlands), representing a transitional lake between the two regions (Griffith et al. 1997). Grassy Lake is part of the Peace River-Saddle Creek watershed (Figure 2) and lies within the Saddle Creek Stream basin (Figure 3).

Historical and Current Conditions

Land use

Grassy Lake, originally called Crystal Lake, was historically a small (29 ha) seepage lake with no natural surface water inlets or outlets. Land surrounding Grassy Lake was settled around 1880 when John Bingham purchased 160 acres on the knoll located to the northeast of Grassy Lake in between Eagle Lake (east from Grassy Lake) and Spirit Lake (north from Grassy Lake).

From settlement in 1880 to present day, land use in the Grassy Lake watershed changed from agricultural-dominated to residential-dominated. By 1929, three homes were located in the Grassy Lake watershed (Figure 4). Yet, until the mid-1970s, aerial photographs showed citrus was the dominate land use surrounding Grassy Lake, with expansion of citrus occurring to the northeast shoreline during this timeframe (Figure 5-9). Prior to the mid-1970s, much of the undeveloped land was located in land elevation areas below 139 feet above mean sea level (ft msl), where wetlands were present. These areas were most likely floodplains with fluctuating water levels, explaining the lack of major structural development and dominate citrus development in these areas (Figures 5-9).

Land use development of the Grassy Lake watershed was clearly linked to fluctuations in water levels. Examination of the 1941 aerial photograph (Figure 5) taken before major residential development indicates roads and homes were constructed above 139 ft msl, suggesting early residents were aware of flooding potentials. However, by 1968 Grassy Lake's water level dropped significantly (Figure 7) and remained low in the early 1970s, prompting the dredging of a canal to connect the eastern lobe to the main body of

Grassy Lake (Figure 8). With the lowering of the water level, residential land development began around the outer boundary of the Grassy Lake watershed at Dinner Lake and Eagle Lake, yet citrus remained the dominant land use for Grassy Lake. With water levels remaining low through the 1970s, land development shifted from agriculture to residential with building of homes and subdivision roads along the western and southeastern side of the Grassy Lake watershed (Figure 9). Homes were built in the low-lying areas of the Grassy Lake watershed because drought conditions in the 1970s had lowered the lake's water level and it was assumed the level would not increase due to extensive ground-water pumping, which had reportedly lowered aquifer levels and caused the complete drying of springs such as Kissengen Spring in Polk County (Harrington et al. 2008). When the homes were built, however, a floodplain level had not been established. FEMA (1997) proposed (and did) to set the 100-year flood plain at 136 ft msl in the late 1990s.

With continued low water in the early 1980s (Figure 10), additional homes were built below the historical flood plain of 136 ft msl based on the assumption the water level would not rise. The rapid increase in regional developmental pressure was also seen with the completion of a major subdivision along the northwest side of Dinner Lake. By the late 1980s, a subdivision with homes close to the shoreline had been built around the small isolated wetland (WBID 1623N) to the southwest of Grassy Lake (Figure 11). By the mid-1990s there was major citrus land use loss in the northeast section of the Grassy Lake watershed (Figure 12). Along with the shift in land use, there was an increase in water level in Grassy Lake from the late 1980s to mid-1990s. Consequently, to alleviate flooding at the small isolated wetland, which had become a subdivision "lake" (WBID 1623N), Polk County connected the smaller water body to Grassy Lake through a buried culvert system (Figure 13). Polk County also constructed a system for pumping water from Grassy Lake to Dinner Lake (Southwest Florida Water Management District Environmental Resource Permit 13762.001).

In 1995, Sacks et al (1998) began the first detailed limnological study of Grassy Lake. During the study, Polk County pumped water from Grassy Lake to Eagle Lake for two months (November and December 1995) to relieve flooding of homes built in the historical floodplain. During 1998, an El-Nino year with higher than normal winter rainfall, Polk County, took emergency measures reduce flooding at Grassy Lake. Polk County implemented short-term pumping to Eagle Lake in February 1998, but the County reevaluated and pumped water from Grassy Lake to Dinner Lake (Southwest Florida Water Management District Environmental Resource Permit 13762.001).

Dinner Lake is located northwest of Grassy Lake (elevation 134 ft msl) at an elevation of 130 ft msl (Figure 4). Dinner Lake drains through the Lake Lena Stream Basin (Figure 3). Pumping from Grassy Lake only occurs between 129 ft msl and 127 ft msl. Due to the extended period of rainfall deficits in the 2000s, the pumping station has, however, only been used rarely since construction. How often the pumping station will be needed, however, is unknown.

In the early 2000s, development continued in the northern section of the Grassy Lake watershed with homes replacing citrus groves (Figure 14). This replacement of citrus was also seen along the southern shore of Spirit Lake. By 2013, land use drastically shifted to dominate residential use with a small portion of citrus-based land use remaining in the in the southern most section of the Grassy Lake watershed (Figure 15). At the time of this study (2015), residential development was of mix densities (Figure 16) and the watershed hydrology was altered so that Grassy Lake was made into an open basin lake during flood conditions.

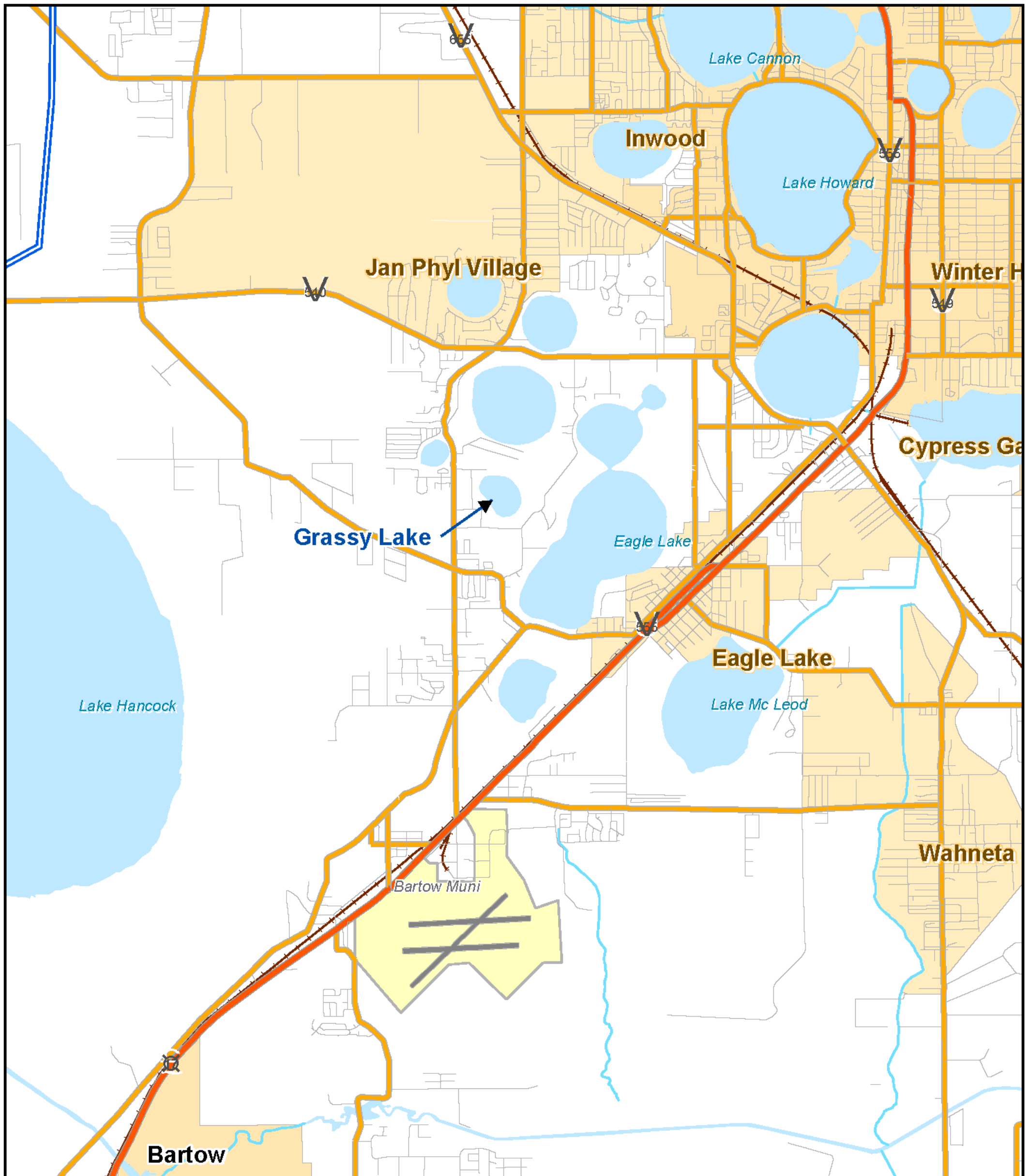

Figure 1 Site Location Map

Grassy Lake Water Quality Management Plan

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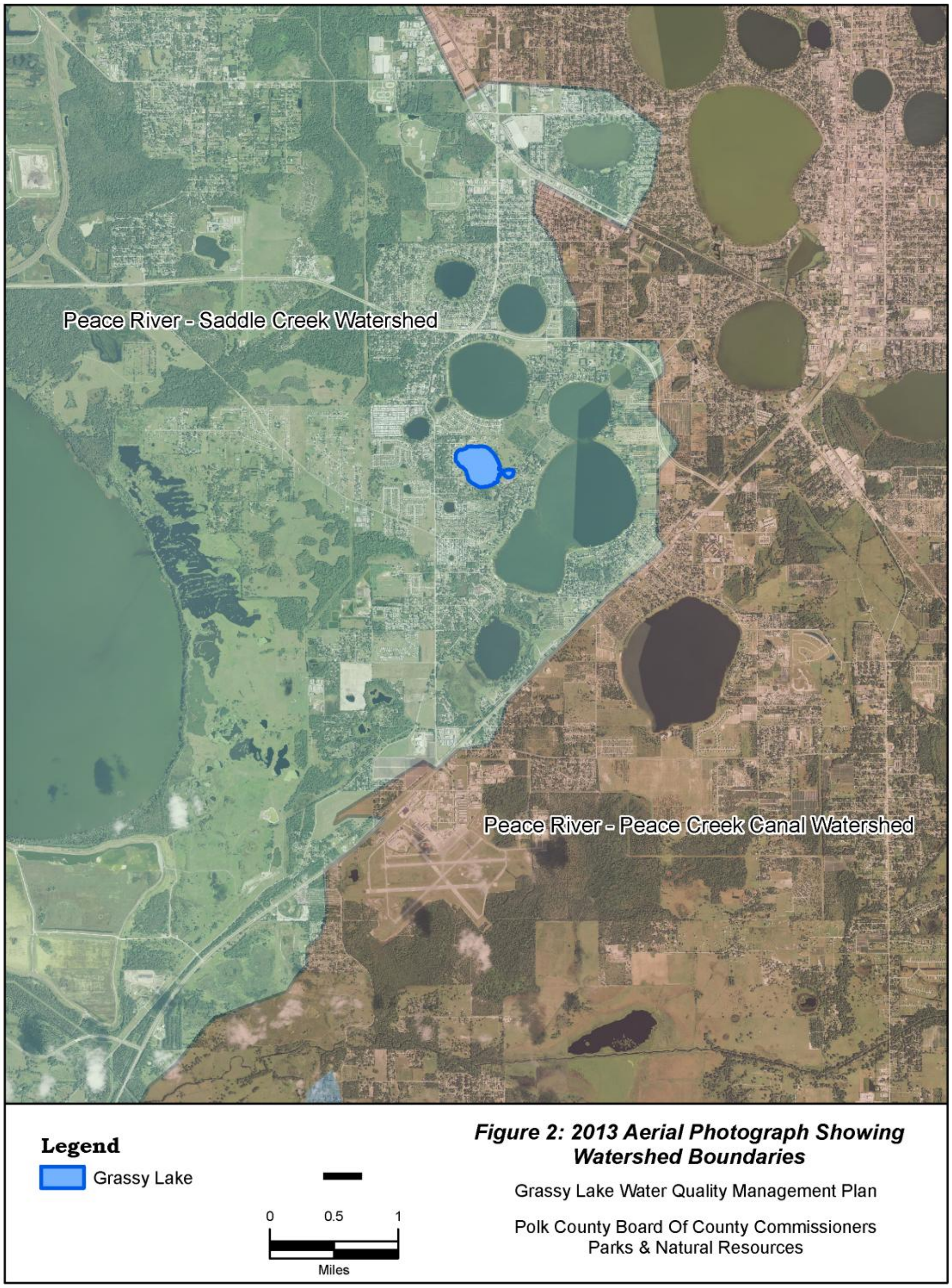

Figure 2: 2013 Aerial Photograph Showing Watershed Boundaries

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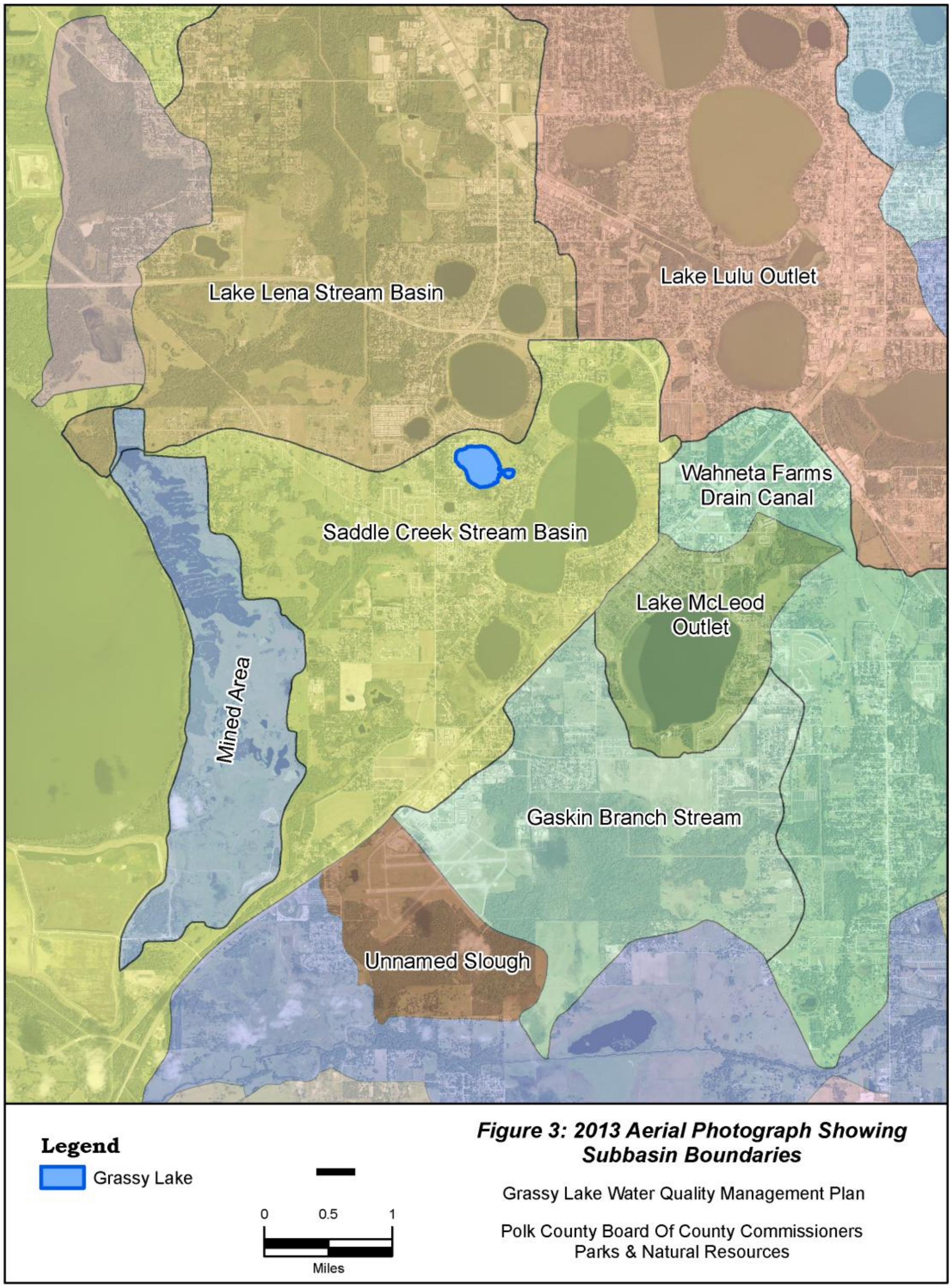

Figure 3: 2013 Aerial Photograph Showing Subbasin Boundaries

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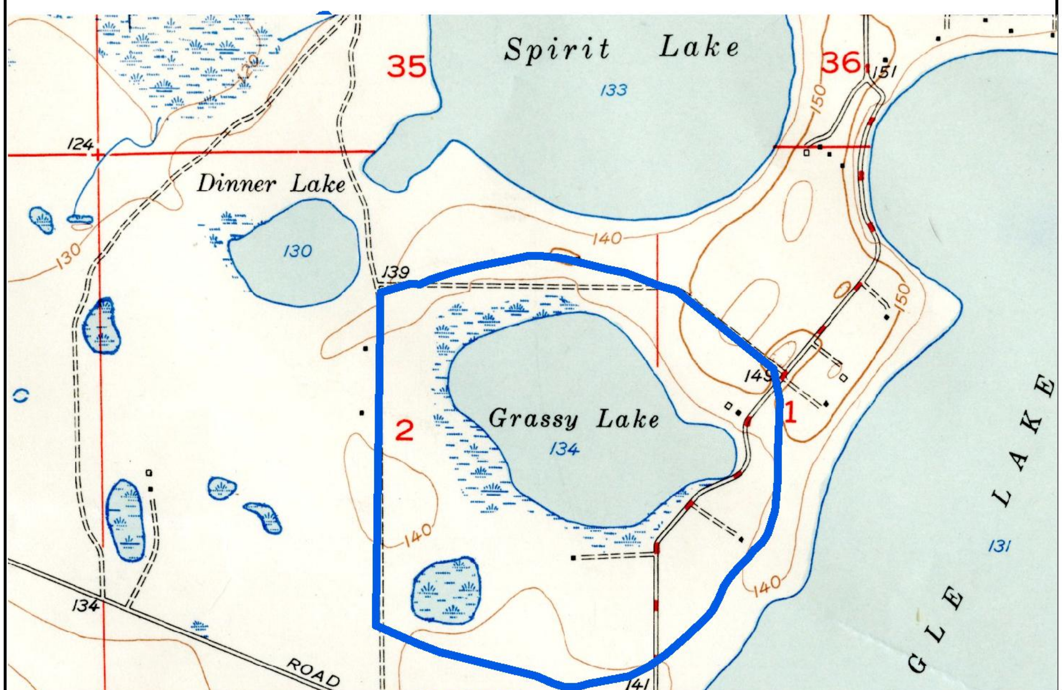

Legend

Approx. Grassy Lake Drainage Area

Not To Scale

Figure 4: 1929 Topographic Map With Grassy Lake Drainage Area

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Legend

Approx. Grassy Lake Drainage Area

Not To Scale

Figure 5: 1941 Aerial Photograph With Grassy Lake Drainage Area

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Legend

Approx. Grassy Lake Drainage Area

Not To Scale

Figure 6: 1958 Aerial Photograph With Grassy Lake Drainage Area

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Figure 7: 1968 Aerial Photograph With Grassy Lake Drainage Area

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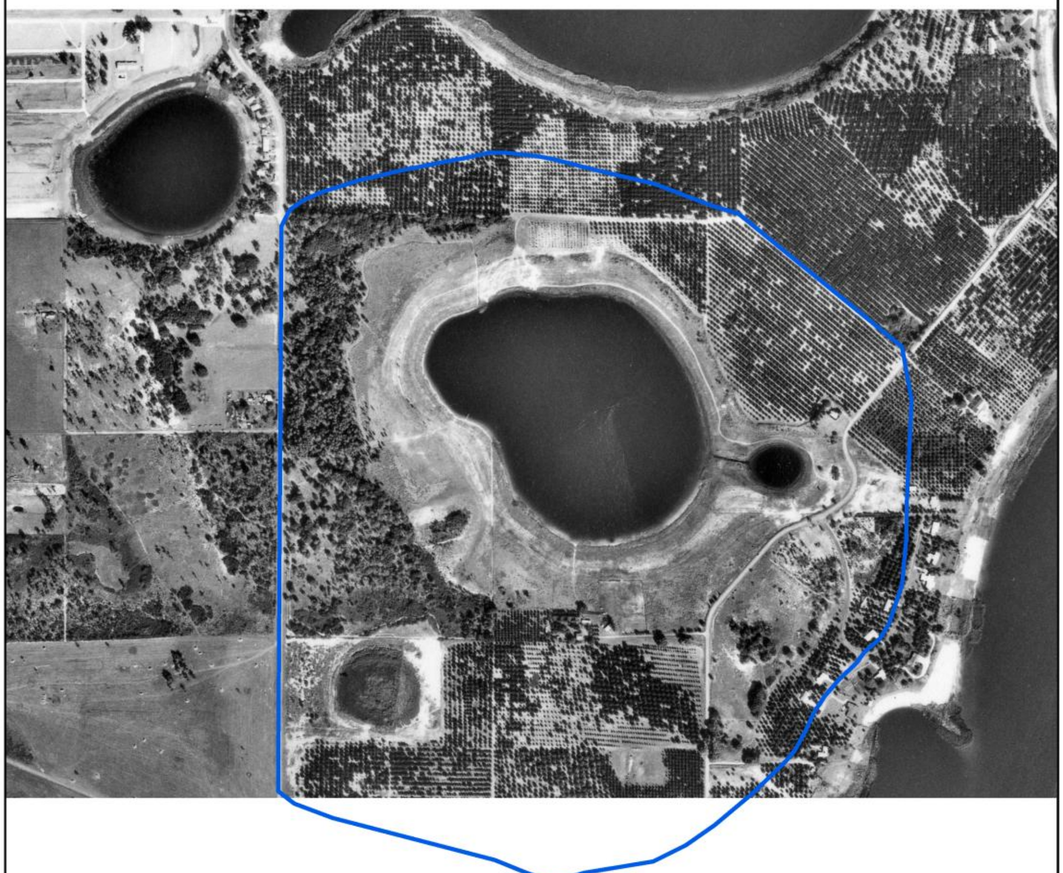

Legend

Approx. Grassy Lake Drainage Area

Not To Scale

Figure 8: 1973 Aerial Photograph With Grassy Lake Drainage Area

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Legend

Approx. Grassy Lake Drainage Area

Not To Scale

Figure 9: 1977 Aerial Photograph With Grassy Lake Drainage Area

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Legend

Approx. Grassy Lake Drainage Area

Not To Scale

Figure 10: 1983 Aerial Photograph With Grassy Lake Drainage Area

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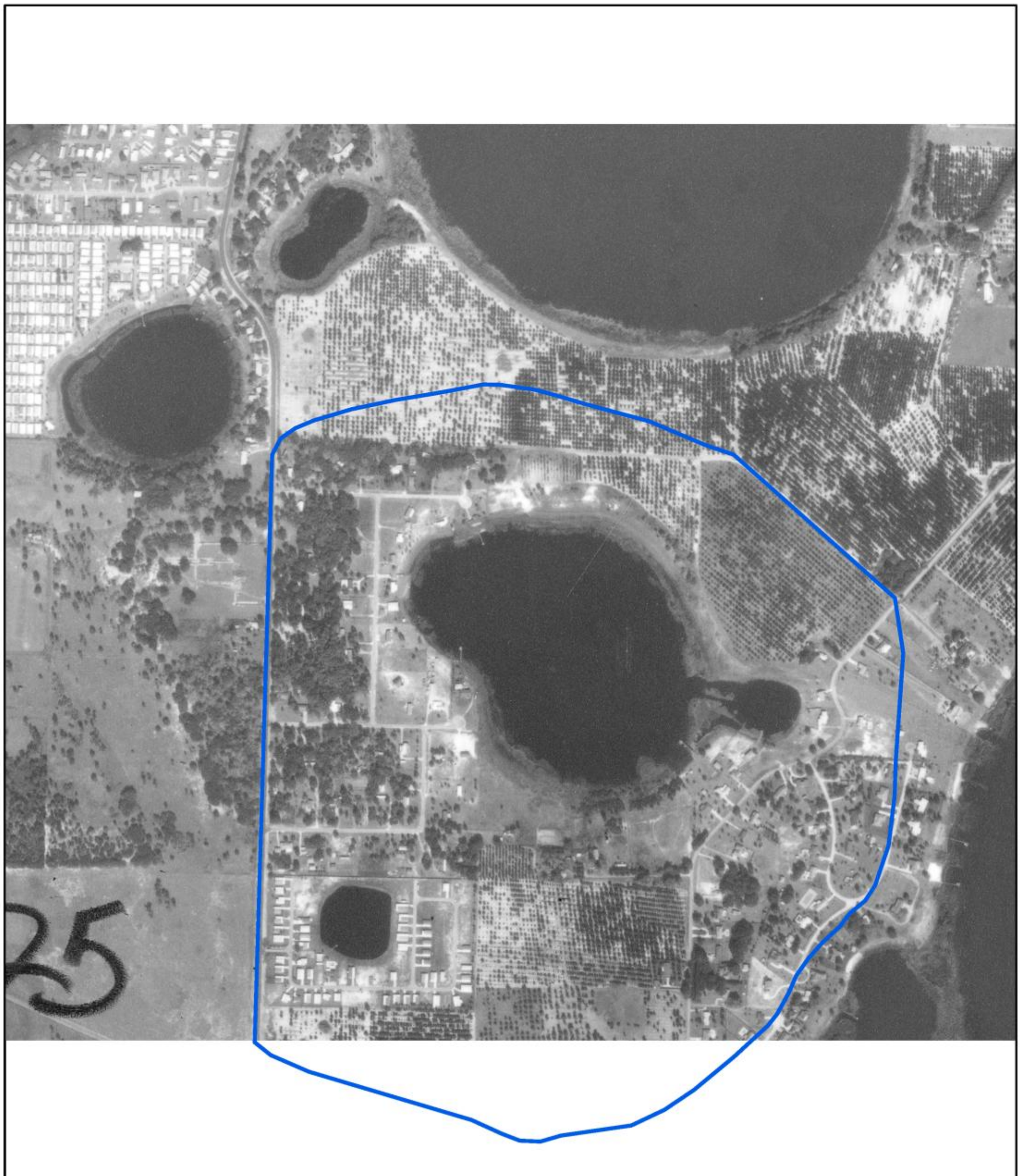

Legend

Approx. Grassy Lake Drainage Area

Not To Scale

Figure 11: 1988 Aerial Photograph With Grassy Lake Drainage Area

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Legend

Approx. Grassy Lake Drainage Area

Not To Scale

Figure 12: 1995 Aerial Photograph With Grassy Lake Drainage Area

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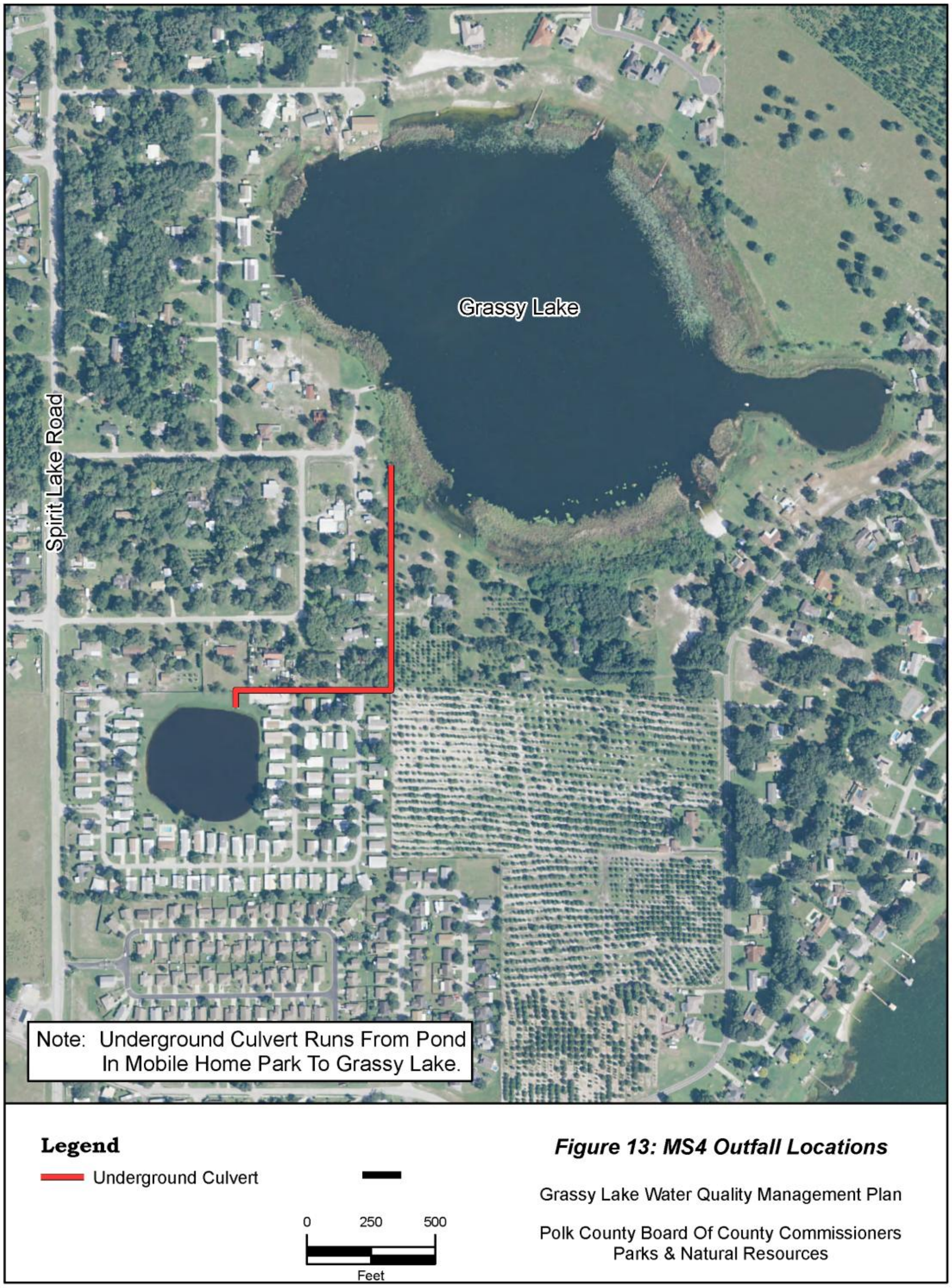

Figure 13: MS4 Outfall Locations

Figure 14: 2001 Aerial Photograph With Grassy Lake Drainage Area

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Legend

Approx. Grassy Lake Drainage Area

0 325 650

Feet

Figure 15: 2013 Aerial Photograph With Grassy Lake Drainage Area

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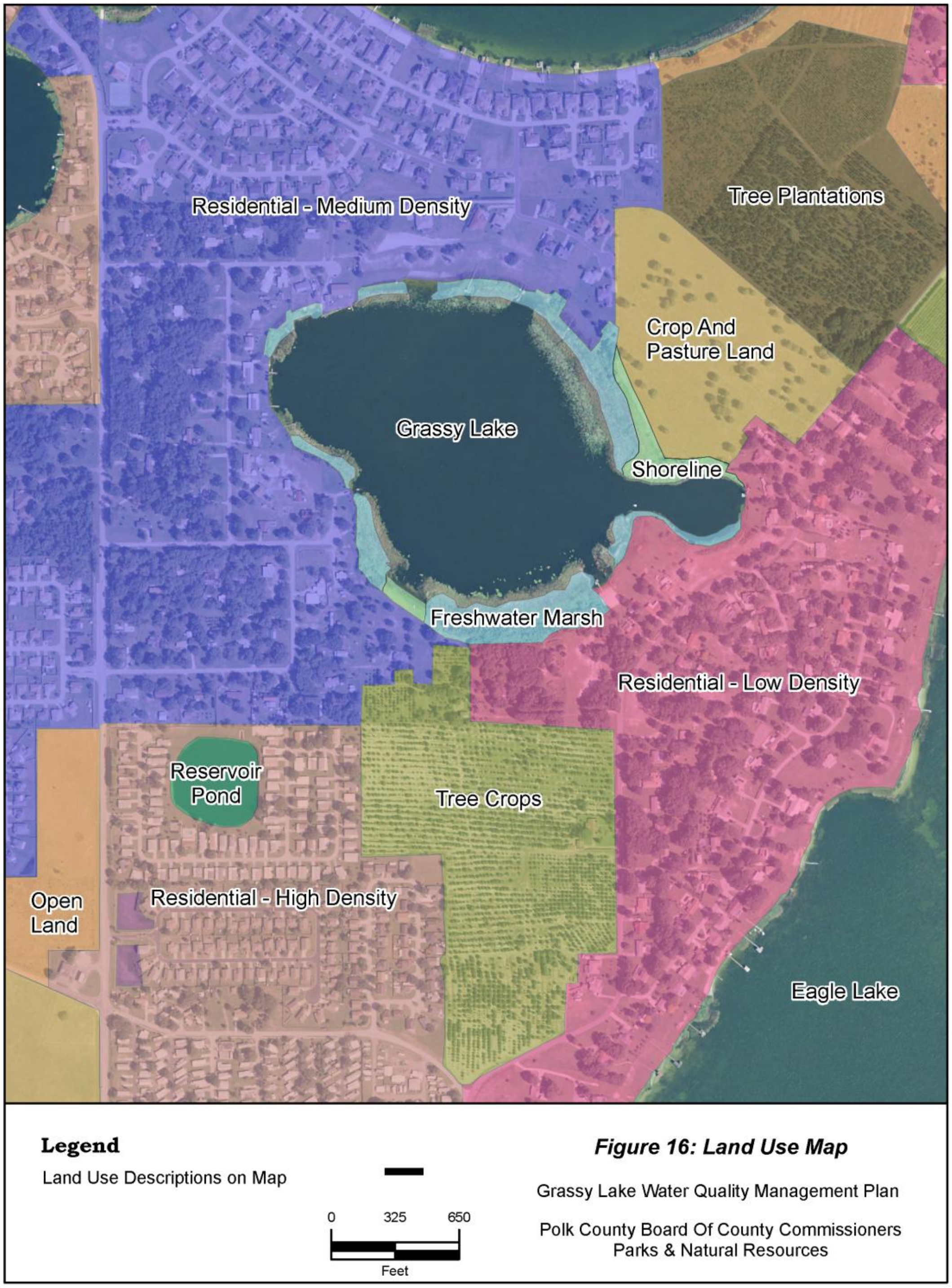

Figure 16: Land Use Map

Grassy Lake Water Quality Management Plan

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Water Level and Rainfall

Grassy Lake's water level has fluctuated 13 ft during the period of measured record, from 1955 until 2015 (Figure 17). Aerial photographs (Figure 5 and 6) and topographic maps (Figure 4) suggest water levels could have been 3+ ft higher during wetter periods. Water level reached a minimum of 123.1 ft in June 1991 and a maximum of 136.59 in September 1960. Mean and median water levels at Grassy Lake were 126.7 ft and 126.2 ft respectively. Ninety percent of the time (1955-2015), however, lake stage was below 129.2 ft

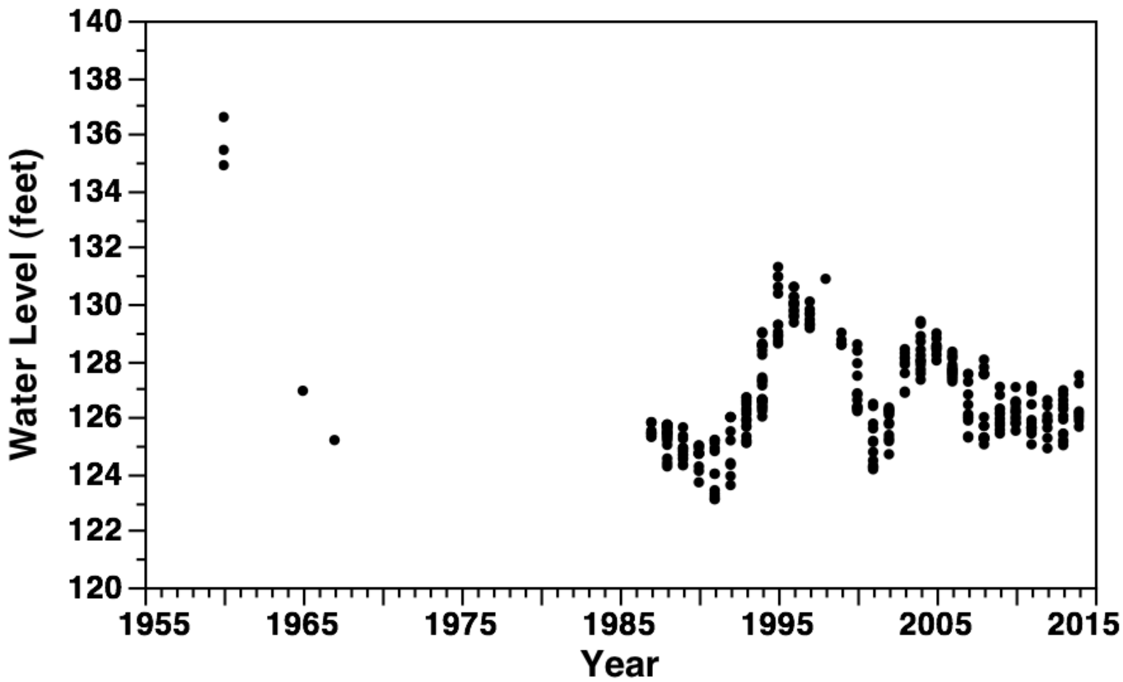

Figure 17. Measured water levels (feet) at Grassy Lake near Bartow Florida. Data retrieved from the Polk County Water Atlas.

Uncertainty as to when pumping will be needed at Grassy Lake is related to rainfall. Precipitation is the ultimate source of water, but it is not constant from year to year, as is the case elsewhere in Polk County (Florida Climate Center 2014). Grassy Lake is located near Bartow where rainfall has been measured since 1896. Average rainfall for the region is about 54 inches per year with a recorded low of 34.6 inches and a recorded high of 83.4 inches (Florida Climate Center 2014). While year-to-year fluctuations are important, Palmer and Nguyen (1986) focused attention on the implication of surplus or deficit rainfall on water management in central Florida. Kelly (2004) eventually linked rainfall surpluses and deficits to a natural phenomenon in the Atlantic Ocean, the Atlantic Multidecadel Oscillation (AMO).

Since 1950, examination of the cumulative surpluses and deficits in the Bartow rainfall data suggested a wet period (above average rainfall) after the 1950s drought that peaked in the early 1960s (Figure 18). Since the late 1960s, the Bartow area experienced a long-term rainfall deficit. However, temporary increases in rainfall surpluses were associated with natural events such as EL Niño in the 1990s and hurricanes in 2004. The AMO cycles about every 60 years so Florida may soon be entering another long-term period of surplus rain.

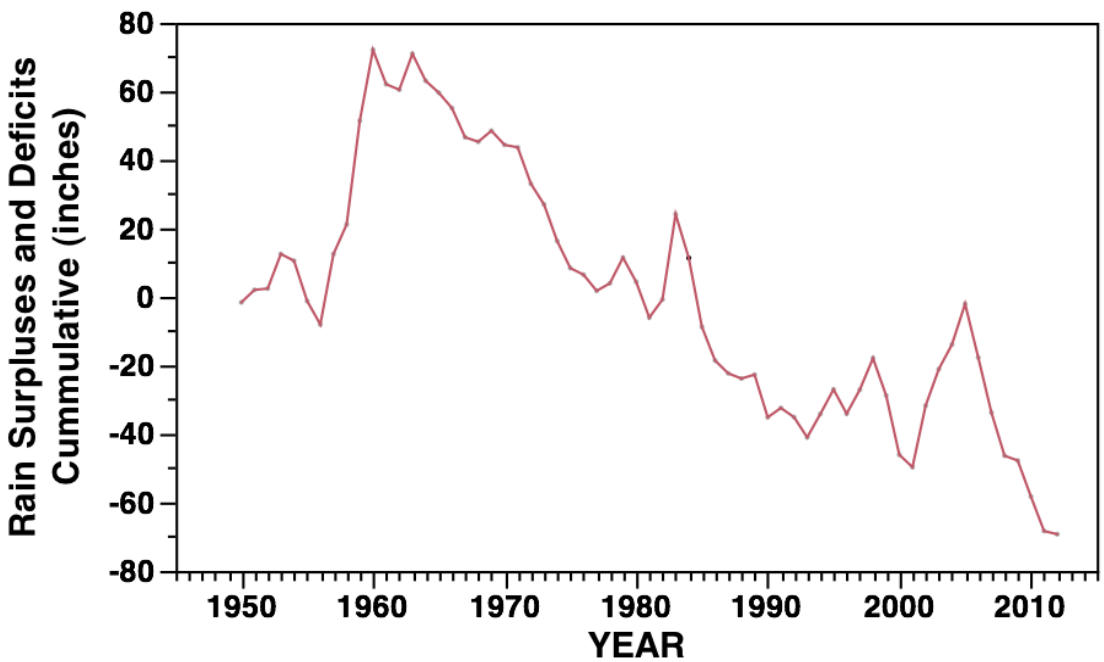

Figure 18. Annual cumulative surpluses and deficits in rainfall (inches) measured at Bartow, Florida.

Groundwater

As rainfall deficits increased from the early 1980s to the 1990s (Figure 18), water shortage became a statewide concern. Starting in 1995 and continuing through December 1996, the United States Geological Survey (USGS) began a cooperative study with the Southwest Florida Water Management District (SWFWMD) to better understand groundwater/lake interactions in ridge areas of the State of Florida. The primary purpose of the study was to estimate the amount of groundwater entering 10 lakes in Polk and Highlands Counties. Grassy Lake was one of seven seepage lakes chosen for study and was selected because it was a closed basin lake, no inflows or outflows, and had no historical point-source pollution discharges. The USGS study became the first detailed limnological study of Grassy Lake (Sacks et al. 1998).

At the time of the USGS study, Sacks et al. (1998) described Grassy Lake as a 72-acre water body with a mean depth of 11 ft and a maximum depth of 23 ft at a lake stage of 130 feet msl (Figure 19). Grassy Lake watershed was estimated to be 318 acres, yet lake area and volume may fluctuate depending lake water level.

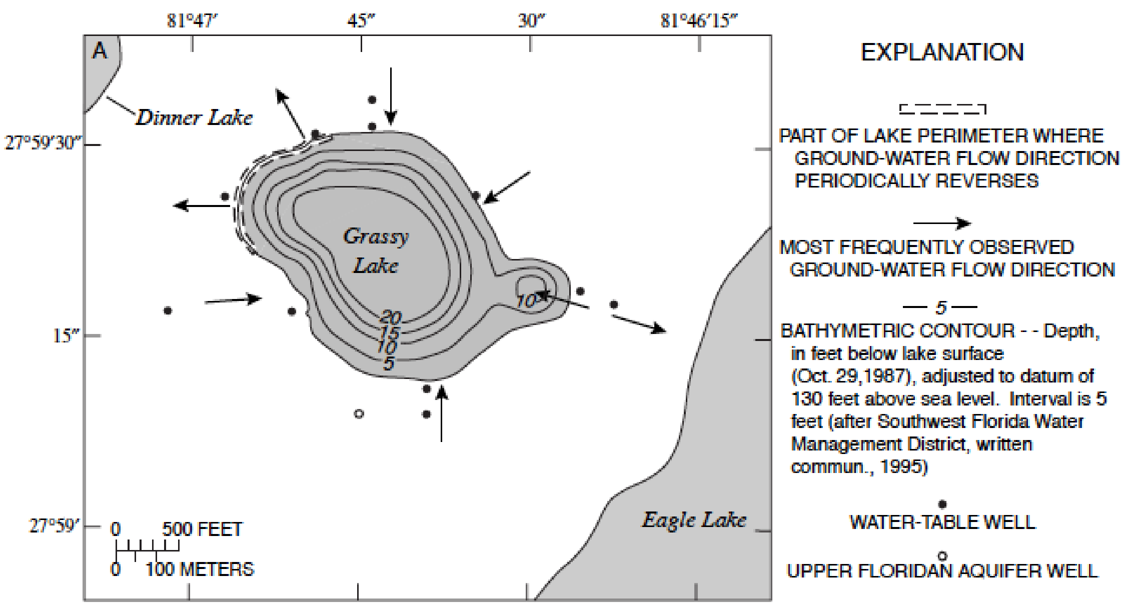

Figure 19. Bathymetric map with location of water table monitoring wells. Arrows indicate ground water flow directions. Taken from Sacks et al. (1998).

During periods of high recharge (i.e., above average rainfall), groundwater entered Grassy Lake around its entire 7,364 ft perimeter (Figure 19). Under average conditions, Sacks et al. (1998) estimated that 87% of the lake's perimeter provided groundwater inflow and 13% of the perimeter had groundwater outflow to Dinner Lake. Lake stage, therefore, would rise during wet periods because of the lack of outflow. Also, net groundwater flow was strongly influenced by rainfall deficit or surplus.

Sacks et al. (1998) reported when Grassy Lake was being pumped the pumping rate was about 20 inches per month. This pumping induced additional groundwater inflow during the pumped period, as well as during the following January through April 1996 time period. Sacks et al. (1998) also determined groundwater inflow paths to Grassy Lake were relatively short, and the water table mounds (rises) significantly following periods of high recharge due to the shallowness of the topographic basin. Such situation causes significant amounts of groundwater inflow to the lake.

Water Quality

Besides researching groundwater flows, USGS was also interested in water quality. Sacks et al. (1998), based on their sampling of water-table sampling wells (Figure 19), found total phosphorus (TP) concentrations in the groundwater of Grassy Lake ranged from 0.01 mg/L to 1.6 mg/L with an average of 0.42 mg/L. Measured groundwater total nitrogen (TN) concentrations ranged from 0.71 mg/L to high of 49 mg/L. The average TN concentration was 15 mg/L, while the median value was 5.2 mg/L.

Tihansky and Sacks (1997) estimated, during the time of study, Grassy Lake was surrounded by approximately 50% citrus agriculture, which extended to the lake shoreline. The residential properties within the watershed used (and still use) individual septic systems for wastewater disposal. Some of these residential properties are located along the lake shoreline, but many homes are located within the northwestern or eastern sections of the Grassy Lake watershed where groundwater flows to either Dinner Lake or Eagle Lake (Figure 14 and Figure 19). Tihansky and Sacks (1997) observed the highest measured nitrate concentrations in groundwater were hydrologically downgradient from citrus groves, suggesting the most significant source of nitrate, as determined from nitrogen-isotope signatures, was inorganic nitrogen (fertilizers). Tihansky and Sacks (1997) suggested residential homes were not a major source of nitrogen to Grassy Lake.

Polk County Parks and Natural Resources Division (Agency ID, PolkCoNRD) began monitoring water quality at a center sampling station in Grassy Lake (Station ID, 21FLPOLKGRASSY1) on September 14, 1995. By 2005, sampling at this station was conducted once during the winter, spring, summer, and fall to provide four water quality samples per year. Spring 2007 was not sampled.

Over the examined period of record (1995-2015), linear regression analysis of available data suggest a long-term reduction in total annual phosphorus concentrations (Figure 20), reduction in annual total nitrogen concentrations (Figure 21), reduction in chlorophyll concentrations (Figure 22), and increase in water clarity as measured by a Secchi disk (Figure 23). No nutrient control programs were implemented during the years 1995 through 2015.

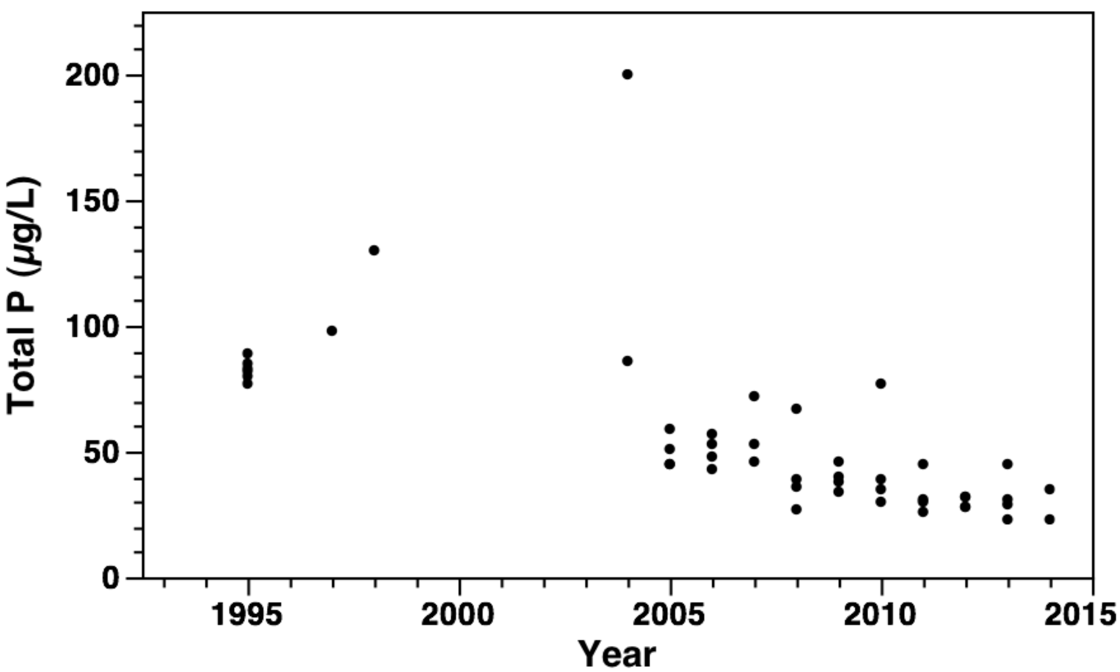

Figure 20. Measured total phosphorus concentrations collected quarterly each year (except 2007 with three samples for the year) in Grassy Lake located in Polk County, Florida.

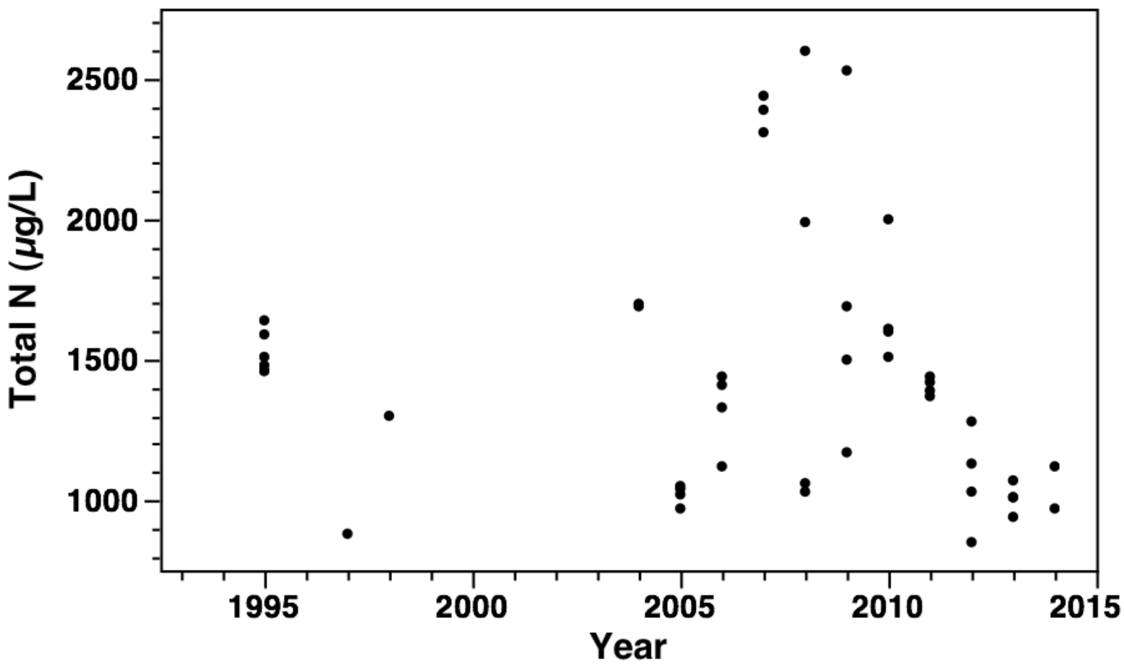

Figure 21. Measured total nitrogen concentrations collected quarterly each year (except 2007 with three samples for the year) in Grassy Lake located in Polk County, Florida.

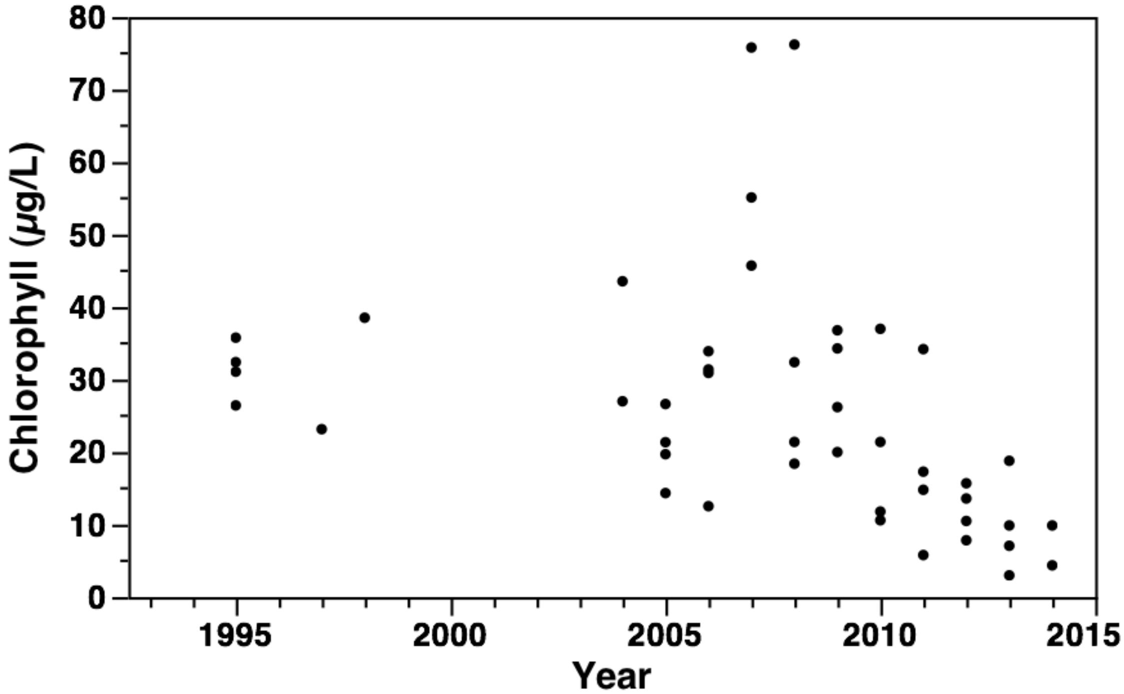

Figure 22. Measured chlorophyll concentrations collected quarterly each year (except 2007 with three samples for the year) in Grassy Lake located in Polk County, Florida.

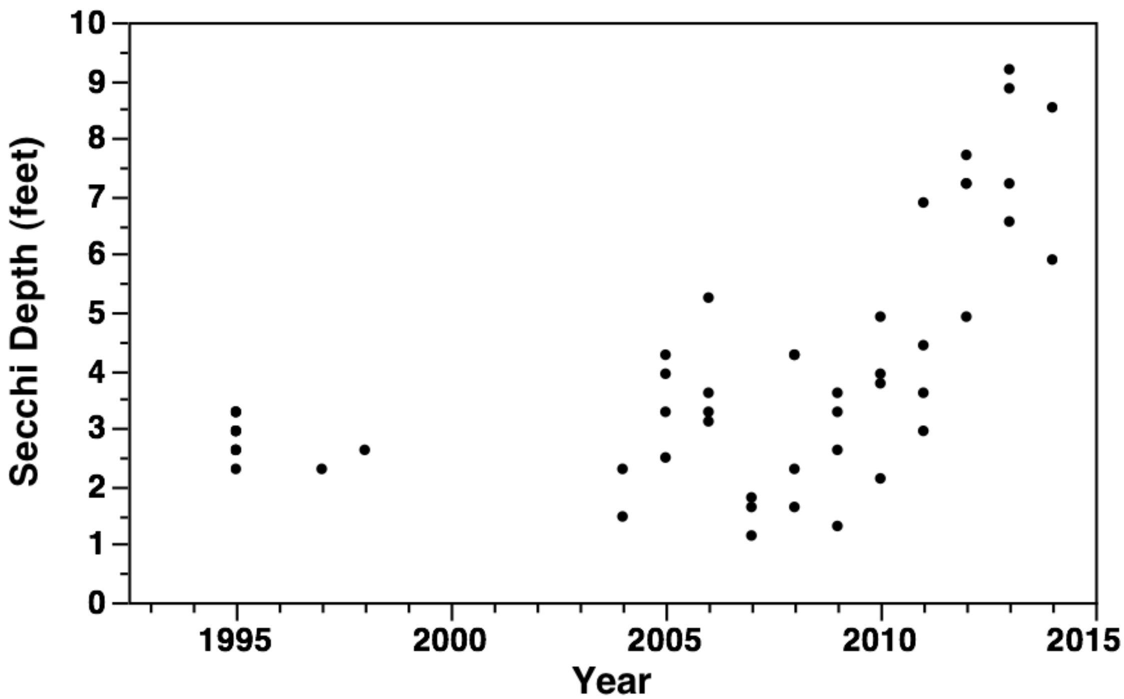

Figure 23. Measured Secchi disk depths collected quarterly each year (except 2007 with three samples for the year in Grassy Lake located in Polk County, Florida.

Nutrient Impairment Classification

Polk County has long been recognized as a region of Florida where there is a high probability that lakes can be erroneously classified as nutrient impaired due to natural edaphic factors (Canfield 1981, Canfield and Hoyer 1988, Bachmann et al. 2012a,b,c). When Numeric Nutrient Criteria (NNC) were being develop by the United States Environmental Protection Agency (USEPA) and the Florida Department of Environmental Protection (FDEP), it was attempted to account for variability in water quality throughout the State of Florida by grouping lakes based on color and alkalinity (Florida Administrative Code Rule 62-302.531). This attempt to account for variability in water quality across Florida's waters was determined inadequate by the Florida Environmental Regulation Committee. Therefore, when NNC was officially established in 2013, the definition of "natural background" conditions was changed to include six, total phosphorus (TP) and five, total nitrogen (TN) nutrient zones (Rule 62-302.200(19) F.A.C.) , which better accounted for variability in water quality due to Florida's geology (i.e., areas of phosphorus-rich soils) and reduced erroneous classifications of Florida's lakes.

Atkins (2013) evaluated FDEP's final *Verified List* of lakes impaired by nutrients within Polk County, Florida. A total of 67 lakes, identified earlier as nutrient impaired by FDEP, were re-evaluated with the NNC. Atkins determined 10 lakes were no longer impaired using the NNC and 13 lakes had insufficient data to evaluate at least one of the variables to determine a nutrient-impairment designation. For those 13 lakes, variables with sufficient data for analysis were found to not be impaired. At least one variable (TN, TP or chlorophyll-a) was found to be impaired in the remaining 44 lakes, suggesting Polk County had a large number of nutrient-impaired lakes.

Using the County's data from January 1, 2002 to June 30, 2009, FDEP declared Grassy Lake impaired for nutrients (TP and TN), using the Florida Trophic State Index (TSI) as part of their Group 3, Cycle 2 review for verifying impairment (Atkins 2013). In 2010, the United States Environmental Protection Agency (USEPA), concurred Grassy Lake was impaired and that a Total Maximum Daily Load (TMDL) plan needed to be established, but no causes of impairment were recorded (USEPA 2010).

Subsequently, Atkins (2013) for the period 2003-2013 used the newly adopted NNC (Rule 62-302.531 F.A. C) and the available water quality data for Grassy Lake to support the initial, nutrient impairment determinations. Atkins (2013) further concluded Grassy Lake was impaired primarily due to elevated TN concentrations and suggested the average annual percent reduction in TN required for achieving NNC criteria ranged from 0 to 34%. However, Atkins (2013) did not identify the source of nitrogen or address whether the recommended reductions were achievable, making it difficult to develop an appropriate TMDL.

Rule 62-302.531 F.A.C. was established to provide numeric interpretations of Florida's Narrative Nutrient Criteria (Rule 62-302.530(47)(a) and (b), F.A.C. The approach (Table 1) adopted by the State of Florida and approved by the USEPA focuses on keeping algal levels as measured by chlorophyll *a* below 20 µg/L, except for the most nutrient-poor lakes where the chlorophyll level was established at 6 µg/L. If the chlorophyll level exceeds the 20 or 6 µg/L criteria, the TP and TN numeric standards become the minimum calculated numeric interpretations in Table 1, but if algal levels are below the established chlorophyll criteria, the maximum calculated TP and TN numeric nutrient criteria are used. The applicable numeric interpretations for TN, TP, and chlorophyll *a* also shall not be exceeded more than once in any consecutive three-year period.

Grassy Lake is classified as a low color (< 40 Platinum Cobalt Units) alkaline (> 20 mg/L $CaCO_3$) lake when using the long-term data collected by the Polk County Parks and Natural Resources Division at the center lake station. The annual geometric mean values for chlorophyll *a* and chlorophyll *a* corrected for the degradation product phaeophytin at this station were generally above 20 µg/L prior to 2010 (Table 2). Beginning in 2010, values were below 20 µg/L, thus the maximum calculated numeric interpretations for TP and TN would be used to assess nutrient impairment rather than the minimum values (Table 1). This change in criteria shifts Grassy Lake from a nutrient-impaired lake to a lake that is not nutrient impaired for the last five years.

Table 1. Numeric nutrient criteria adopted for the different lake types in Florida (Rule 62-302.531 F.A.C.).

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

[1] For lakes with color > 40 PCU in the West Central Nutrient Watershed

Table 2. Quarterly water quality data provided by the Polk County Natural Resources Division from a station located in the center of Grassy Lake.

Annual Geometric Means

Year	Chlorophyll *a* (µg/L)	Chlorophyll *a* Corrected (µg/L)	TP (mg/L)	TN (mg/L)
2005	20.2	17.9	0.050[?]	1.062[?]
2006	25.3	21.9	0.050[*]	1.319[*]
2007[1]	57.6	52.9	0.056	2.379
2008	31.4	28.1	0.040[*]	1.542[*]
2009	28.5	26.1	0.039[*]	1.655[*]
2010	16.4	13.0	0.045	1.657
2011	14.9	13.1	0.032	1.410
2012	11.5	9.5	0.030	1.061
2013	7.9	7.2	0.031	1.006
2014	9.2	7.8	0.030	1.044

[1] Only three samples collected and four samples are needed
[*] Indicates nutrient impairment
[?] Indicates nutrient criteria change depending on chlorophyll value used

Flora and Fauna

In January and February of 2015, an aquatic macrophyte and fish survey were conducted to assess the current condition of the biological community in Grassy Lake. Bryan Finder (Polk County Parks and Natural Resources Division) mapped the vegetation community on January 12, 2015. Bill Pouder (Freshwater Fisheries Administrator, Florida Fish and Wildlife Conservation Commission Southwest Region) sampled the fish population on February 4, 2015.

The aquatic macrophyte survey determined the percent bottom area covered with aquatic macrophytes (PAC) was about 55% and the average percent of the water column occupied by macrophytes (PVI) was about 33%. Macrophytes were consistently found on the bottom of the lake at depths between 10 ft and 13 ft (as deep as 16 ft). The dominant submerged macrophyte was the native, eelgrass (*Vallisneria americana*). Hydrilla (*Hydrilla verticillata*) was present throughout the lake, but in low abundance (Finder 2015 macrophyte survey).

Grassy Lake is a Class III waterbody with designated uses of swimming and fishing. Fishing, however, is the primary use. Based on a single, fish sampling survey, Bill Pouder provided the following evaluation of the fish community in Grassy Lake:

"Pretty neat little lake". Secchi depths averaged around 2 meters and lots of eelgrass in depths up to 7 feet. We found Hydrilla in all sites but in pretty low abundance. Water levels were up according to the gage (38.5). Tough shocking though because it has a dense stands of cattail around most of the perimeter, which limited us from shocking in shallow (< 3 feet) areas. Most of the sampling was conducted in 3-7 feet of water. This is apparent in the attached data as we found very few juvenile bluegill and other forage species. It appears to have a good bass population and fish were in good condition (Wr averaged around 91). We did shock 4 grass carp but didn't collect them, and also saw a fair abundance of tilapia but they were present in the cove on the SE side of the lake and as you know difficult to collect when shocking. We did not see many shad although we did collect 1 threadfin and we found another regurgitated in the live well."

Synthesis of the provided fish community data provided by the Florida Fish and Wildlife Commission, suggests the fish population is not impaired (Table 3). The appropriate number of species (13) is present for a small, closed-basin lake. Largemouth bass (*Micropterus salmoides*) dominate, as expected, because fishing pressure according to the locals is low. Blue tilapia (*Oreochromis aureus*) and is the only non-native fish not stocked on purpose and the species seems to be in low abundance. The only other non-native is the grass carp (*Ctenopharyngodon idella*) that was stocked for the purpose of hydrilla control.

Table 3. Basic fisheries data collected by the Florida Fish and Wildlife Conservation Commission on February 4, 2015 using electrofishing with 8,600 second transects.

Species	# Collected	CPUE (fish/min)	SE	CPUE (weight/min)	SE	% Comp #	% Comp W
Blue Tilapia	2	0.025	0.025	49.538	49.538	0.717	6.724
Bluegill sunfish	105	1.313	0.282	60.725	13.217	37.634	8.243
Brook silverside	43	0.538	0.298	0.713	0.389	15.412	0.097
Brown Bullhead	7	0.088	0.029	17.688	5.715	2.509	2.402
Florida gar	6	0.075	0.037	79.538	37.574	2.151	10.796
Golden shiner	1	0.013	0.013	0.425	0.425	0.358	0.057
Lake chubsucker	2	0.025	0.016	4.738	3.305	0.717	0.643
Largemouth bass	88	1.100	0.127	510.263	68.051	31.542	69.263
Redear sunfish	12	0.150	0.068	10.250	5.000	4.301	1.391
Seminole killifish	5	0.063	0.042	0.750	0.597	1.792	0.102
Spotted sunfish	3	0.038	0.026	1.188	0.777	1.075	0.161
Threadfin shad	2	0.025	0.016	0.438	0.305	0.717	0.059
Warmouth	3	0.038	0.038	0.450	0.450	1.075	0.062
Total	279	3.488	0.580	736.700	95.435	100.000	100.000

CPUE =Catch per unit effort and is reported in fish per minute
SE =Standard error
%Comp # =Percent composition by number collected
%Comp W=Percent composition by weight

Assessment

Water Clarity

In Florida lakes, Secchi depth is generally affected by either dissolved organic matter, measured as color in platinum/cobalt units, or chlorophyll (Canfield and Hodgson 1983). The relationships between both of these water quality variables and Secchi depth are hyperbolic. In the case of Grassy Lake, color has a limited influence on water clarity because the highest concentration measured was 50 Pt-Co units. Color levels, over the period of record measured, averaged 35 Pt-Co units. At these concentrations, Grassy Lake is classified under NNC criteria as a clear-water lake because the average value is < 40 Pt-Co units. Yet, there was a hyperbolic relationship between Secchi depth and chlorophyll concentrations (Figure 24). When these data were logarithmically (base 10) transformed, a negative relationship was found with chlorophyll concentrations explaining 77% of the variance in water clarity as measured by Secchi disk depth (R^2 = 0.77).

Given Grassy Lake's small surface area and depth (Figure 19), the re-suspension of bottom sediments by wind activity is typically not a problem (Bachmann et al. 2000). However, three major hurricanes passed over Grassy Lake in the fall of 2004. When sampling was completed in December 2004, the recorded in-lake TP concentration was 200 µg/L (Figure 20), which suggests strong hurricane winds had thoroughly mixed the lake.

Although the dominant factor affecting water clarity in Grassy Lake is phytoplankton biomass as assessed by measurements of chlorophyll, color cannot be dismissed. Grassy Lake is currently classified as a clear-water lake, but throughout the period of record color values > 40 Pt-Co units have been measured. The elevated values have typically been associated with wet events, thus if the AMO should reverse and Florida becomes wetter (Figure 18), Grassy Lake could become classified as a colored lake. Becoming a tea-colored lake would impact the interpretation of the NNC (Table 1) and the lake would be more similar to lakes in Lake Region 75-36 (Southwestern Flatlands).

Chlorophyll

Whether considering water clarity (Figure 24) or the NNC (Table 1), chlorophyll is a water quality variable of concern. A fundamental assumption of the 2013 established numeric nutrient criteria is nutrients are a stressor that changes chlorophyll concentrations in lakes. This assumption is based on scientific studies that have shown the importance of TP and TN for establishing empirical chlorophyll-nutrient relationships in northern lakes (Dillon and Rigler 1974; Jones and Bachmann 1976) as well as Florida lakes (Canfield 1983). However, use of these relationships in management or regulatory programs must be done with caution, as various caveats are associated with each published empirical chlorophyll/nutrient relationship.

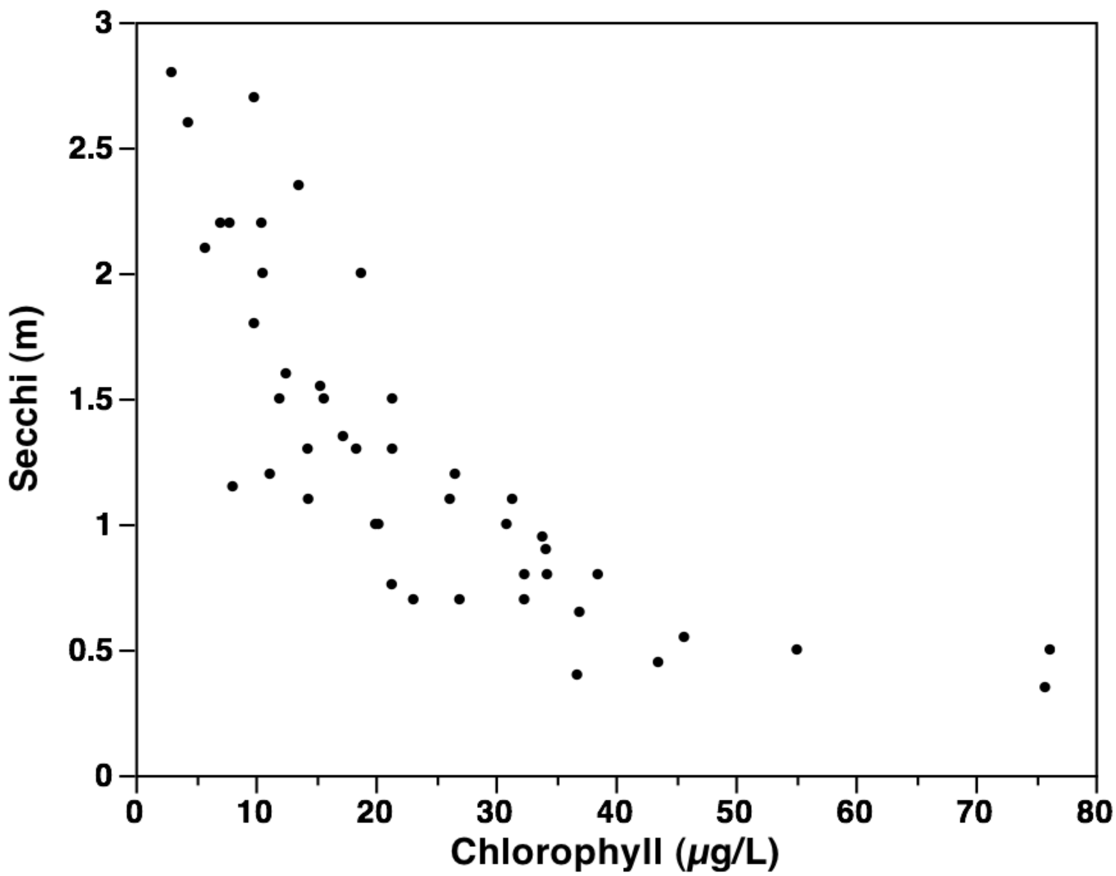

Figure 24. Relationship between water clarity (m) as measured by use of a Secchi disk and chlorophyll concentrations (μg/L) at Grassy Lake located in Polk County, Florida.

Naumann (1929) recognized that the production of phytoplankton in a lake is primarily determined by phosphorus and nitrogen, but that other limnological/environmental factors could override the influence of nutrients. Brown et al. (2000) further noted that TP was the limiting nutrient only when chlorophyll concentrations were near their maximum for a given level of TP. Deviations from the maximum concentrations reflected the importance of other factors, providing additional support for the finding of a frequent lack of nutrient limitation in Florida's open-water phytoplankton communities (Agustí et al. 1990, 1992).

Linear regression analysis of logarithmic (base 10) nutrient and chlorophyll *a* concentration data (annual averages from 1994 through 2015) suggested statistically significant ($p \leq 0.05$) correlations exist in Grassy Lake between Log10 chlorophyll *a* concentrations and Log10 total phosphorus (r= 0.52, Figure 25) and Log10 total nitrogen (r= 0.64, Figure 26). Using chlorophyll values corrected for phaeophytin, similar statistically significant correlations were found with total phosphorus (r = 0.51) and total nitrogen (r = 0.68). Similar relationships were identified as total chlorophyll measurements are strongly correlated to corrected chlorophyll measurements (r = 0.99).

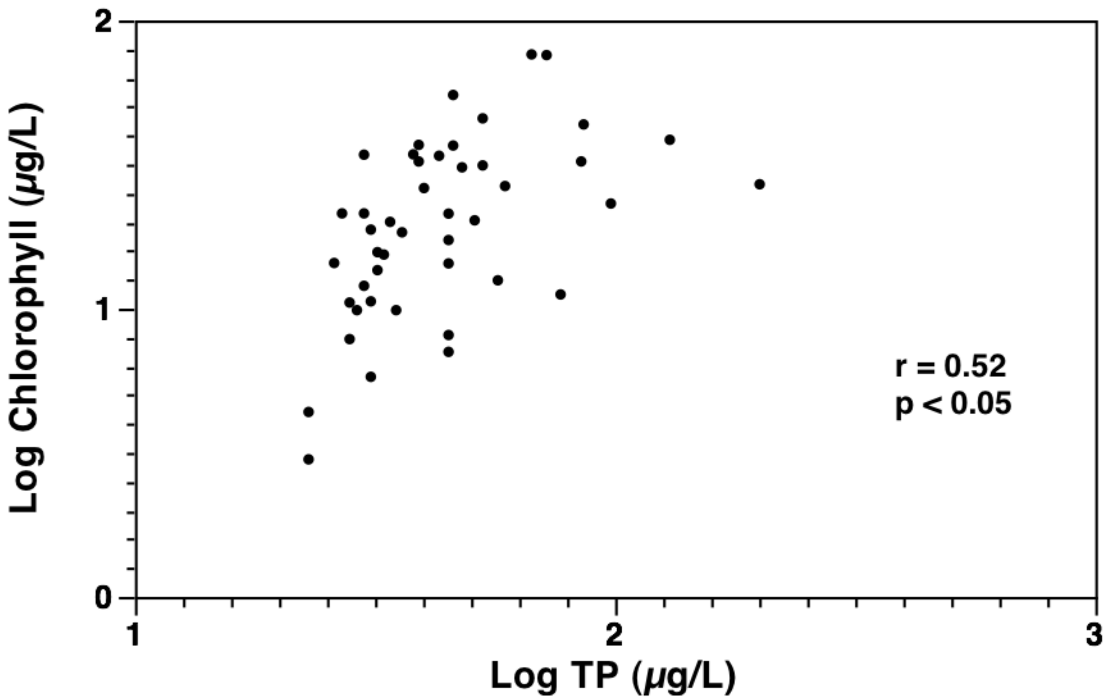

Figure 25. Linear regression analyses of annual logarithmic (base 10) transformed total phosphorus (µg/L) and chlorophyll (µg/L) relationship in Grassy Lake located in Polk County, Florida. Correlation coefficient (r) and significance (p-value < 0.05) are reported.

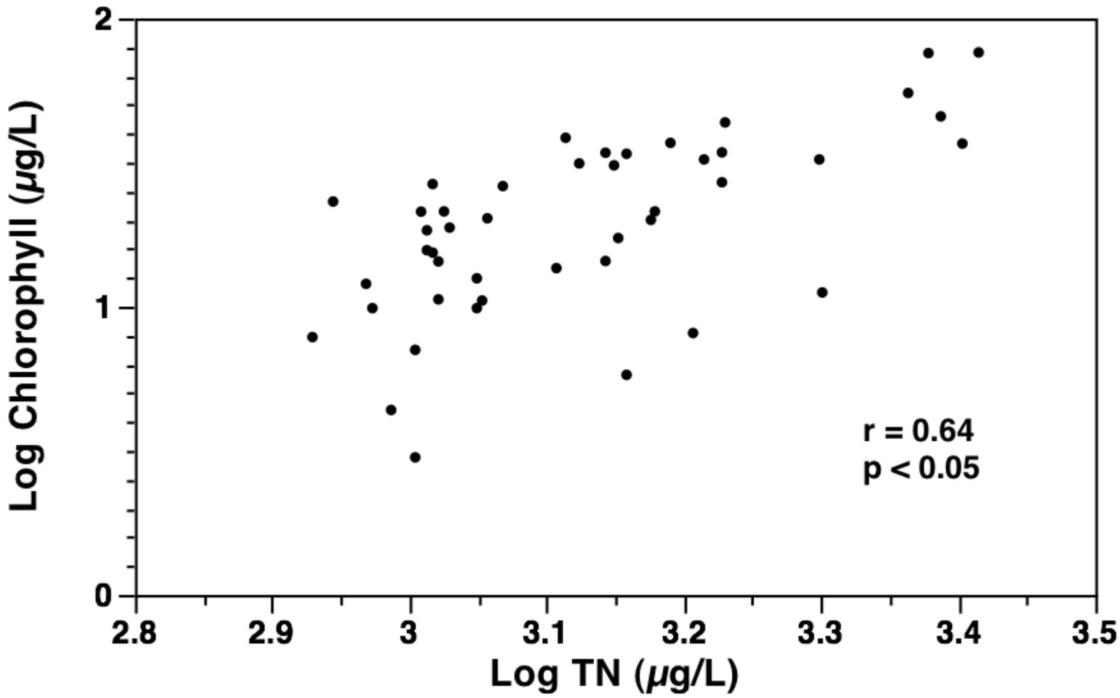

Figure 26. Linear regression analyses of annual logarithmic (base 10) transformed total nitrogen (µg/L) and chlorophyll (µg/L) relationship in Grassy Lake located in Polk County, Florida. Correlation coefficient (r) and significance (p-value < 0.05) are reported.

Following Naumann (1929), the weakness of the relationships at Grassy Lake would suggest that while TP and TN may be the limiting nutrients, there are other limiting environmental factors (e.g., light, another nutrient or a biocontrol) controlling algal biomass in the lake.

Brown et al. (2000) developed a linear empirical relationship for predicting the maximum chlorophyll response for phosphorus concentrations between 0.008 and 0.076 mg/L. When measured chlorophyll concentrations are close to the predicted maximum chlorophyll concentrations, TP is not only the limiting nutrient, but also the limiting environmental factor. Using Brown et al.'s equation {Log (maximum chlorophyll) = -0.12 +1.33Log(TP)} with the individual measured TP concentrations, calculated maximum chlorophyll concentrations exceed measured concentrations at Grassy Lake on average by 80% with the minimum difference being 51%. When using the 2005-2014 quarterly-collected data that provided the basis for assessing nutrient impairment (Table 2), calculated maximum chlorophyll concentrations exceeded measured concentrations on average by 80%, with a prediction range per year ranging from 64% to 89%. Therefore, TP may be the limiting nutrient for chlorophyll concentrations in Grassy Lake, but most likely not the limiting environmental factor.

Prairie (1996) and Bryhn and Dimberg (2011), have shown that statistically meaningful relationships typically have R^2-values $\geq$ 0.65 (i.e., r = 0.80). If data analyses are restricted to the annual mean values for the 2005-2014 period, the statistical relationships become stronger and meaningful (Prairie 1996; Bryhn and Dimberg 2011), suggesting to a water quality manager that effects of nutrients still need to be considered. For chlorophyll *a*, the R^2-values for the relationships with TP and TN become 0.67 and 0.71, respectively and for corrected chlorophyll 0.65 and 0.68, respectively. Although Atkins (2013) suggested nitrogen designated Grassy Lake as impaired, most lake managers would target phosphorus, as nitrogen is readily available from the atmosphere.

When chlorophyll-nutrient relationships are statistically meaningful, the challenge for many lake managers is what nutrient should be controlled. Management decisions for nutrient control include consideration of which nutrient is limiting. Determinations of nutrient limitation are often based on the ratio of TN/TP, with TN being considered the limiting nutrient when the ratio is < 10 (Canfield 1983). In the case of Grassy Lake (Figure 27), the TN/TP ratio was < 10 in fewer than 3% of the samples. TN/TP was > 17 for 90% of the samples suggesting Grassy Lake is phosphorus limited (Canfield 1983). But, over 50% of the measured TN/TP ratios were > 32, which would certainly lead most lake managers to focus on phosphorus control. Control of phosphorus at Grassy Lake, however, may not achieve the objective of reducing chlorophyll concentrations below 20 µg/L.

Bachmann et al. (2003a) proposed using frequency of chlorophyll concentrations that exceed nuisance level as an alternative to using average chlorophyll in setting lake management goals. In Grassy Lake, TP averaged 0.049 mg/L between 1994 and 2015. Based on the findings of Bachmann et al. (2003a), chlorophyll concentrations (uncorrected for phaeophytin) could be expected to exceed 20 µg/L close to 82% of the time over an annual cycle, if TP was the limiting environmental factor. During the warm season (July through November), 20 µg/L would be exceeded 86% of the time. If the in-lake TP could be reduced by new management actions to 0.03 mg/L and TP was the limiting environmental factor, the 20 µg/L-chlorophyll level would be exceeded 48% of the time on an annual basis and 54% during the warm season. Such levels indicate there is a high probability, assuming only phosphorus limitation; the lake would remain classified as impaired based on a criterion of 20 µg/L of chlorophyll. If nitrogen was considered the limiting nutrient (TN/TP < 10), the 20 µg/L criterion would be exceeded 72% of the time over an annual cycle when the TN = 0.8 mg/L.

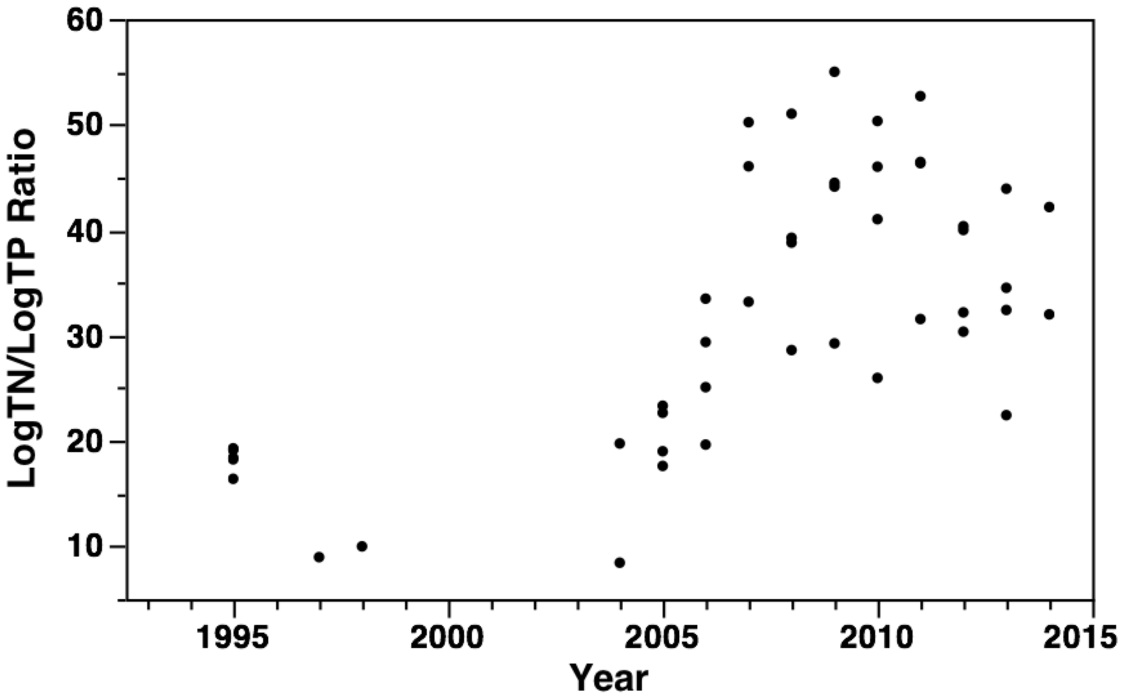

Figure 27. Total nitrogen/ total phosphorus (TN/TP) ratios at Grassy Lake located in Polk County, Florida.

If the findings of Bachmann et al. (2003a) are correct, Polk County should approach any possible non-point source nutrient control recommendations for Grassy Lake with caution, as there is a good probability that after implementing controls the 20 µg/L-chlorophyll criterion would still be exceeded within a three-year period. This information provides further evidence to support the conclusion that nutrients in Grassy Lake are not a major limiting environmental factor.

Macrophytes: An Alternative Stable State

Grassy Lake experienced a shift from nutrient impairment to a non-impaired designation after 2009 (Table 2). Linear regression analyses (1995 to 2014) of annual TP (Figure 20), TN (Figure 21), and chlorophyll (Figure 22) showed a decreasing trend in concentrations from 1995 through 2014 in Grassy Lake. Linear regression analyses of water clarity showed an increasing trend from 1995 through 2014 (Figure 23). These shifts in nutrients and water clarity occurred without the establishment of a TMDL or the implementation of any nutrient control efforts. There are a limited number of environmental changes in Florida lakes that cause a reduction in total phosphorus, total nitrogen, and chlorophyll concentrations and an increase in water clarity over multiple years. One environmental factor that can cause such a change, however, is shifts in abundance of submersed aquatic macrophytes (Canfield et al. 1984).

Importance of macrophytes in lake limnology is now codified in the concept of alternative steady states (Blindow et al. 1993, Scheffer et al. 1993, Moss et al. 1996, and Bachmann et al. 1999). Alternative steady states describe how lakes switch between a clear-macrophyte state and a turbid-algal state without any change in nutrient inputs. When a lake is in one state, there are a number of feedback mechanisms that keep it in that state until a major event switches it to the other. Thus, there are forward switches that move lakes from a macrophyte to algal state and reverse switches that can move them in the opposite direction (Moss et al. 1996). Grassy Lake seems to be an example of reverse switches operating to move the lake to a stable macrophyte-state with clearer water. Unfortunately, there are no quantitative data on submerged macrophyte abundance during the period of water quality sampling. However, conversations with long-time local lake-users indicated an expansion of submersed aquatic macrophytes occurred since hydrilla (*Hydrilla verticillata*) entered (recollections suggest around 2005) the lake. Polk County's Invasive Plant Management Section of the Natural Resources Department chemically treated hydrilla as well as water hyacinths (*Eichhornia crassipes*), water lettuce (*Pistia stratiotes*) and cattails (*Typha typha*) in 2007 (a public boat ramp was built on the western shore of Grassy Lake around 2007). Polk County reported treating about 16 acres of hydrilla in July 2007 and September 2010 and then 25 acres in September 2012 (Bryan Finder, Lead Environmental Tech - Polk County Parks and Natural Resources Division, personal communication). Grassy Lake was also stocked with grass carp (Ctenopharyngodon idella) (Bill Pouder, Florida Fish and Wildlife Conservation Commission Southwest Region, personal communication). Consequently, hydrilla abundance was reduced and lake–users and aquatic macrophyte management personnel reported an increase in abundance of eelgrass (*Vallisneria americana*).

An early study of aquatic macrophytes and their influence on lake water clarity in Florida lakes (Canfield and Hoyer 1992) indicated when the percent area coverage (PAC) of a lake's bottom by aquatic macrophytes exceeded 30%, the probability of finding clear water (a greater Secchi depth) increased, with a PAC > 50% establishing a clear-water lake. Bryan Finder mapped the vegetation community in Grassy Lake on January 12, 2015 and determined PAC was about 55% with a 33% average percent of the water column occupied by macrophytes (PVI). Macrophytes were consistently found on the bottom between 10 ft and 13 ft (as deep as 16 ft) and the dominant submerged macrophyte was the native eelgrass. Hydrilla was still present, but in low abundance. From this macrophyte survey, it is suggested Grassy Lake has moved into an alternative clear-water state due to the proliferation of submersed aquatic macrophytes. If Grassy Lake has entered into an alternative state, the lake should remain non-impaired for nutrients as long as macrophyte PAC remains: 1) greater than 50%, and 2) a forward switch like overstocking with grass carp or excessive chemical control does not push the lake back to an algal dominated state.

Alternative Stable State Management

As Polk County, for the foreseeable future, manages non-native macrophytes like hydrilla, a well-funded, holistic aquatic macrophyte management plan that manages all emergent and submersed aquatic macrophytes could be the most cost-effective approach for managing Grassy Lake's water quality as well as other Polk County lakes (see following discussion regarding Lake Hunter). However, annual activities must be conducted with recognition of the natural forward switches that could push Grassy Lake to an algal state.

There are three important potential forward switches that need to be recognized for Grassy Lake. The first is changes in lake water level. The second is changes in water clarity due to changes in true color concentrations. The third is a change in the aquatic macrophyte management program. Each of these forward switches is discussed in detail along with a management plan example from Lake Hunter, Florida.

Lake Level

Depth of colonization of aquatic macrophytes in Florida lakes has been correlated with light availability as measured by a Secchi disk (Caffrey et al. 2007). In general, the maximum depth of colonization is about twice the Secchi reading, which well aligns with the finding of macrophytes at a depth of 16 ft in Grassy Lake based on measured Secchi depths (Figure 23). Caffrey et al. (2007) suggested the greatest abundance of aquatic macrophytes is found at a depth dictated by the annual average Secchi disk depth. In Grassy Lake, average Secchi readings were between 5 ft and 8 ft (2010 and 2015), which matches with the consistent finding of macrophytes at depths between 10 ft and 13 ft (January 2015 macrophyte survey by Polk County). Consequently, lake managers need to understand the environmental factors influencing the amount of light the lake bottom will receive for sufficient macrophyte growth.

For the period of measured records (1960 to 2014), Grassy Lake's water level fluctuated over 13 ft (Figure 17). When lake stage exceeded 130 ft in 1995, homes were flooded and a pumping station was built. The pumping station is a potential tool for lowering the water level of Grassy Lake for the purpose of insuring at least 50% of the lake bottom receives sufficient light to maintain the extensive eelgrass beds currently present. Additionally, the use of the pump house as a tool may become important with hydrologic shifts over time as old-time residents report that Grassy Lake was tea-colored and free of submersed vegetation in the 1960s.

Water Clarity

NNC divides lakes into clear and colored groupings based on a color level of 40 Pt-Co units. This division was based on the assumption that color reduces phytoplankton biomass in lakes. Although true in dystrophic lakes (low pH, high color concentrations), this is not always the case in Florida lakes (Canfield et al. 1984). Across Florida, color concentrations are positively correlated to chlorophyll ($r = 0.37$) concentrations as well as total phosphorus ($r = 0.46$) and total nitrogen ($r = 0.52$) concentrations (Canfield et al. 1984). If a series of events occurred where algal concentrations increased at the same time true color levels increased, Secchi depths may be reduced. Such change constitutes a forward switch and could prompt a decline in submersed macrophytes. Again, if macrophyte coverage becomes < 30%, the probability of increased algal and nutrient levels increases (Canfield and Hoyer 1992).

Fortunately, there are two potential management tools to prevent a forward switch at Grassy Lake. Hydrilla is present at Grassy Lake and its abundance is connected to increased water clarity. Thus, hydrilla treatments could be delayed if macrophyte surveys show a decline in submersed macrophytes in Grassy Lake. As mentioned previously, pumping could be initiated to reduce the water level and permit more light to reach the bottom. If used properly, Polk County has the tools to maintain the current clearwater-macrophtye state in Grassy Lake without embarking on a major non-point source nutrient management program.

Aquatic Macrophyte Management

Aquatic macrophyte control programs in the past resulted in strong forward switches to a turbid algal state because the tools available typically removed submerged macrophytes to extremely low levels. In many cases, complete removal of macrophytes by the use of heavy stocking of grass carp was practiced with a resulting upsurge in algal levels (Canfield and Hoyer 1992). Currently, most Florida macrophyte management groups, like Polk County, no longer use such practices and conduct programs to establish native macrophytes

In the case of Grassy Lake, Polk County's aquatic macrophyte management personnel have managed hydrilla extremely well and caused a shift at Grassy Lake from a turbid-algal state to a clearwater-macrophyte state. The future threat at Grassy Lake is Polk County's success. Vallisneria has a tendency to uproot and wind pushes macrophytes to the shoreline where beach and boat launch access can become problematic (Nancy Dunn, LAKEWATCH citizen scientist, Bear Lake, Seminole County). At this point, desired native macrophytes become a weed problem. Another example of macrophytes being defined as nuisance by lake-users is the accumulation of soft sediments with cattail growth along the riparian zone of the lake, which inhibits lake access to the open water. In the future, Polk County aquatic macrophyte management personnel may focus additional resources managing native macrophytes to keep a satisfied public.

Lake Hunter

Polk County has many lakes with no discrete point source discharges of nutrients, of which are being declared impaired for nutrients due to non-point source discharges. Lake Hunter is one of these lakes. In developing the Lake Hunter TMDL, FDEP acknowledged the uncertainty associated with TMDL development and allocation, particularly in estimates of non-point source loads (Baniukiewicz and Gilbert 2004).

However, hydrilla became established in Lake Hunter during the late 1970s and a trend towards lower chlorophyll, TN, and TP concentrations as well as improved fisheries was identified (Moxley and Langeford 1982). Unfortunately, grass carp were heavily stocked to remove hydrilla (the management philosophy was complete elimination) and trophic state water quality variables (i.e., total phosphorus, total nitrogen, chlorophyll, and water clarity) returned to previous conditions.

In 1983, Lake Hunter was completely drained and the macrophyte community was reestablished by planting several different native macrophyte species (Moxley et. 1984). Grass carp, however, were again stocked at too high a level (Moxley et al.1985) and the aquatic vegetation has remained low since then. These early studies suggest aquatic macrophyte management may provide the tool by which Polk County can improve in-lake water quality and fisheries at many lakes as well as removing Polk County lakes from the verified impaired list. Polk County aquatic macrophyte management group demonstrated at Grassy Lake how management of hydrilla rather than eradication can encourage growth of native submersed macrophytes and play an important role in the reconstruction of submersed macrophyte communities.

Using the macrophyte management expertise available with current staffing, Polk County could achieve desired water quality standards at many Polk County lakes without implementing expensive TMDLs. Management of aquatic macrophytes, however, must be approached from a reconstruction perspective rather than a weed perspective. If submersed aquatic macrophytes are controlled to < 30% bottom coverage, Polk County lakes will obtain nutrient and chlorophyll levels that lead to a designation of *Verified Impaired*. The focus on reconstructing submersed aquatic macrophyte communities rather than implementing TMDLs is also gaining acceptance at other Florida lakes. For example, water level manipulation was recommended at Lake Okeechobee because low lake levels increased macrophyte abundance and water clarity in the lake without any change in the phosphorus regime. Water level controls, therefore, seemed to have more promise as a management tool for Lake Okeechobee than the established TMDLs (Bachmann et al. 2003b).

Other Management Practices to Protect/Improve Conditions

The USEPA and the State of Florida listed Grassy Lake as *Verified Impaired* in 2010, but no source of impairment was identified. Earlier, FDEP acknowledged the uncertainty associated with TMDL development and allocation, particularly in estimates of non-point source loads (Baniukiewicz and Gilbert 2004). Atkins (2013) concluded implementing TMDLs in Polk County where there is no major point source for the nutrient impairment shall be expensive and the TMDL might not bring about the desired response in lake water quality.

Modeling Nutrient Loading at Grassy Lake

Various types of models are used to predict the impact of increasing or decreasing nutrient loading to a water body (Canfield and Bachmann 1981). These models work best when investigating an extremely large point source of nutrients because all models have a large degree of uncertainty (95% confidence interval of at least 33% to 288% of the predicted value) associated with the predictions.

Developing workable TMDLs for Florida lakes is challenged by assumptions that the TMDL be accepted. For example, USEPA (2000) and FDEP (2001) established phosphorus TMDLs of 198 t/yr and 148 t/yr, respectively, for Lake Okeechobee using excellent nutrient budget data for the lake. After reviewing the assumptions used and the available data, it was determined the proposed TMDLs were too stringent (pre-settlement phosphorus load estimated at 377 t/yr) and that there was no evidence the TMDLs would be effective in our lifetimes (Bachmann et al. 2003b). Since debate emerged, billions of dollars have been expended to further study Lake Okeechobee and implement BMPs. To date, there has been no major reduction in phosphorus loads to Lake Okeechobee (Figure 28). The South Florida Water Management District reported at the June 2014 Northern Everglades Stakeholder Meeting that no trends were observable in nutrient budgets over time and that year to year variation was due to climatic events (R. Thomas James, Lead Environmental Scientist – Lake and River Ecosystem Section, South Florida Water Management District).

In the case of Grassy Lake, Sacks et al. (1998) provided evidence precipitation and groundwater were dominant sources of water and nutrients to Grassy Lake, due to soil permeability in the watershed. They could identify no surface water inputs. Since their report, two drains were placed at Grassy Lake to handle stormwater runoff, but field inspections in 2014 and early 2015 (during rains) indicated little water reached the lake via surface flow, except under extremely wet conditions.

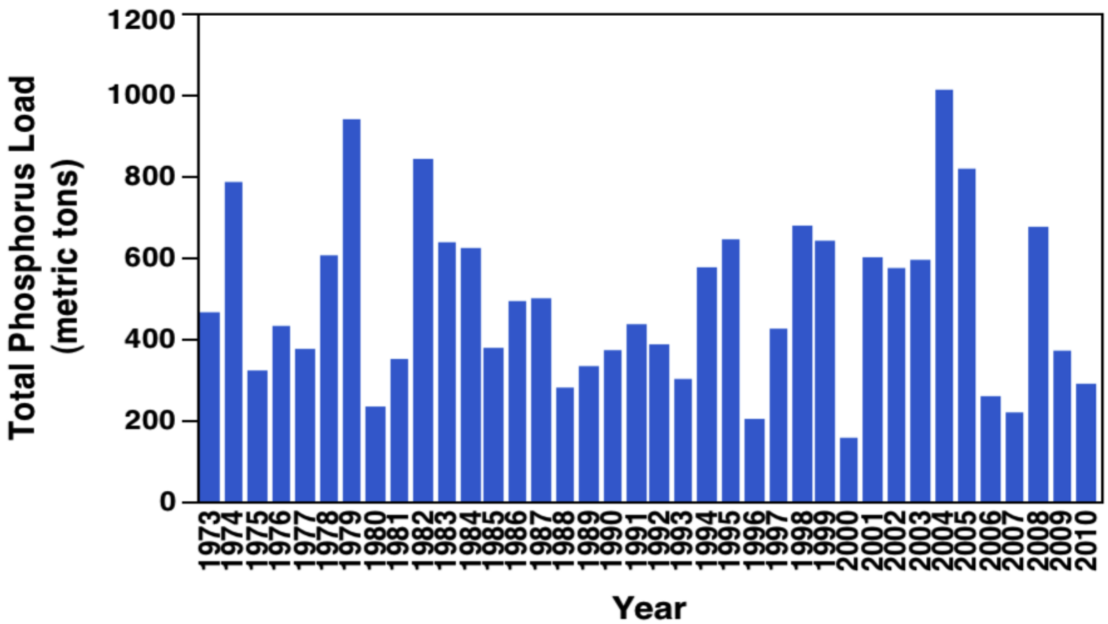

Figure 28. Total phosphorus load to Lake Okeechobee from 1973 to 2010. Data are from the South Florida Water Management District.

A model for estimating potential 1990-2013, wet and dry TP and TN loadings directly to the surface of Polk County lakes was developed by Janicki Environmental of St. Petersburg Florida (data provided by Polk County Parks and Natural Resources Division). Examining the monthly wet-deposition nutrient concentrations indicated considerable variability with TP concentrations ranging from 0.0016 mg/L to 0.027 mg/L and TN ranging from 0.036 mg/L to 2.07 mg/L. Wet deposition averaged 0.0046 mg/L for TP and 0.28 mg/L for nitrogen.

Although no detailed study of nutrient inputs to Grassy Lake has been conducted, the study completed by Sacks et al. (1998), along with some conservative assumptions, permits use of a simple Vollenweider model to assess the impact of estimated TP and TN loadings (see Canfield and Bachmann 1981). In using the model, the surface area of Grassy Lake was designated as 76 acres (30.7 ha) and a mean depth of 11 ft (3.4 m) was used. The volume was calculated at 1,031,227 cubic meters. Using Sacks et al.

(1998)'s estimate of 17 inches of outflow from the lake, assuming 3 inches of rain is added to the groundwater, a hydraulic flushing rate of approximately 4.2 years was estimated for Grassy Lake. Using a rainfall average of 55 inches and the average TP and TN wet-deposition concentrations, the TP and TN loadings to Grassy Lake were estimated at 6.43 mg/m^2/yr and 393 mg/m^2/yr respectively. Groundwater TP and TN loadings were estimated by using the groundwater input of 33 inches (Sacks et al. 1998) and the median groundwater nutrient concentrations (TP = 0.27 mg/L, TN = 5.2 mg/L). The TP loading was estimated at 226 mg/m^2/yr and TN loading was estimated at 4,358 mg/m^2/yr.

Assuming all material entering the lake remains in the lake (exception de-nitrification of nitrogen), the calculated in-lake TP and TN concentrations are 0.045 mg/L and 1.13 mg/L, respectively. Using the average TN concentration measured in the groundwater, the in-lake TN concentration elevated to 3.2 mg/L. When all in-lake TP and TN concentrations measured in Grassy Lake between 1994 and 2015 are averaged, TP equaled 0.49 mg/L and TN equaled 1.40 mg/L. Given the uncertainties associated with the different estimates used in the Vollenweider model, the calculated and measured values are in agreement.

Atkins (2013) indicated Grassy Lake was impaired due to TN and their calculation required TN percent concentration reductions ranged from 0% to 34% to obtain compliance with NNC. Reducing TN loading by 34%, predicted TN concentrations using the average ground water TN concentration, would drop from 3.2 mg/L to 2.1 mg/L. Using mean groundwater concentrations a drop from 1.13 mg/L to 0.8 mg/L would occur. These estimates are based on large amounts of citrus present in the watershed. By 2010, the majority of land use shifted from citrus to residential, so whether the estimated reduction in TN is possible, even with removal of the little remaining agriculture, is questionable. More importantly, given all the uncertainty associated with the various estimates of model parameters, the modeling efforts indicate that it would be very difficult to detect in-lake nitrogen reductions in the short-term or for a 34% load reduction.

Predicting in-lake chemical changes is difficult and modeling efforts can only provide insights. In the case of Grassy Lake, in-lake specific conductance (SC) has increased significantly since 1995 (Figure 29). SC is a measure of the ability of water to conduct an electrical current. Conductivity increases with increasing amount and mobility of chemical ions in the lake. These ions, which come from the breakdown of compounds, conduct electricity because they are negatively or positively charged when dissolved in water. Therefore, SC is an indirect measure of the presence of dissolved solids such as chloride, nitrate, sulfate, phosphate, sodium, magnesium, calcium, and iron. Specific conductance is also strongly related to water level (Figure 30) suggesting a long period of limited rainfall contributes to altering the baseline chemistry of Grassy Lake. This general phenomenon, which has also been detected at other Florida lakes since the 1960s (Florida LAKEWATCH, personal communication), is an important consideration because it affects concentration/dilution processes in the lake and can mask the impact of nutrient control programs.

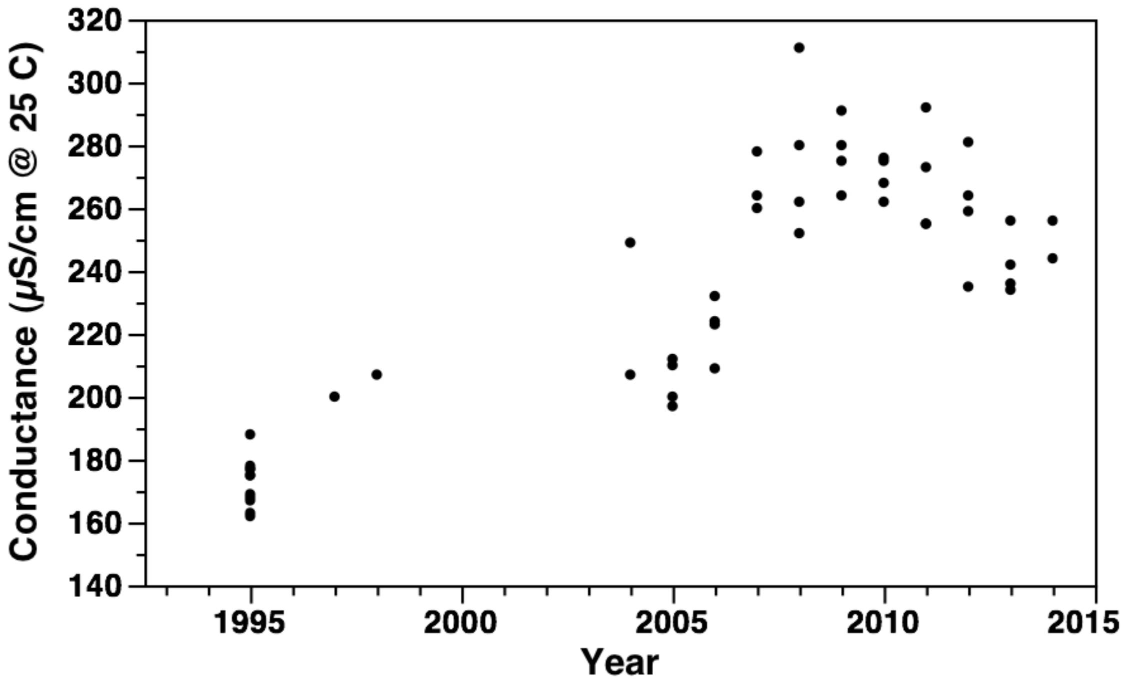

Figure 29. In-lake specific conductance (µS/cm @ 25 C) measured from 1995 through 2015 in Grassy Lake located in Polk County, Florida.

Modeling effort and findings (Bachmann et al. 2004 and available data) at Lake Okeechobee raised an interesting question as to what are "natural background" conditions at Grassy Lake. Phosphorus loading to Lake Okeechobee from 1973 to 2010 significantly and positively correlated (r = 0.86) to water inflow (Figure 31). TMDLs (< 200 metric tons) proposed by the USEPA and FDEP can only be achieved with limited to no rain additions, thus the TMDLs are deemed inappropriate (Bachmann et al. 2004). Recognizing the importance of climatic events at Lake Okeechobee (R. Thomas James, Lead Environmental Scientist – Lake and River Ecosystem Section, South Florida Water Management District), it is likely climatic events are linked to changes in Grassy Lake as well. In fact, the influence and impact of natural conditions is written in the Florida Administrative Code where FDEP shall not strive to abate natural conditions (Rule 62-302.300(15) F.A.C.) and it is not FDEP's intent to list waters that do not meet otherwise applicable water quality criteria solely due to natural conditions (Rule 62.303.100(2) F.A.C.).

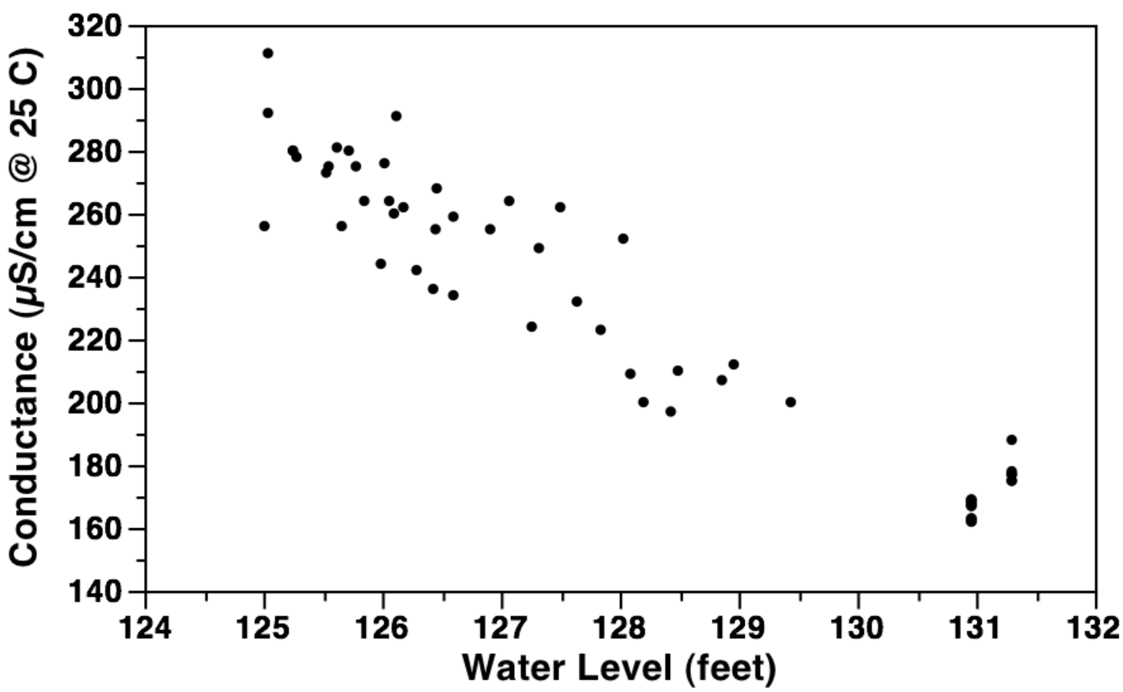

Figure 30. Relationship between Water Level (feet) and specific conductance (µS/cm @ 25 C) in Grassy Lake located in Polk County, Florida.

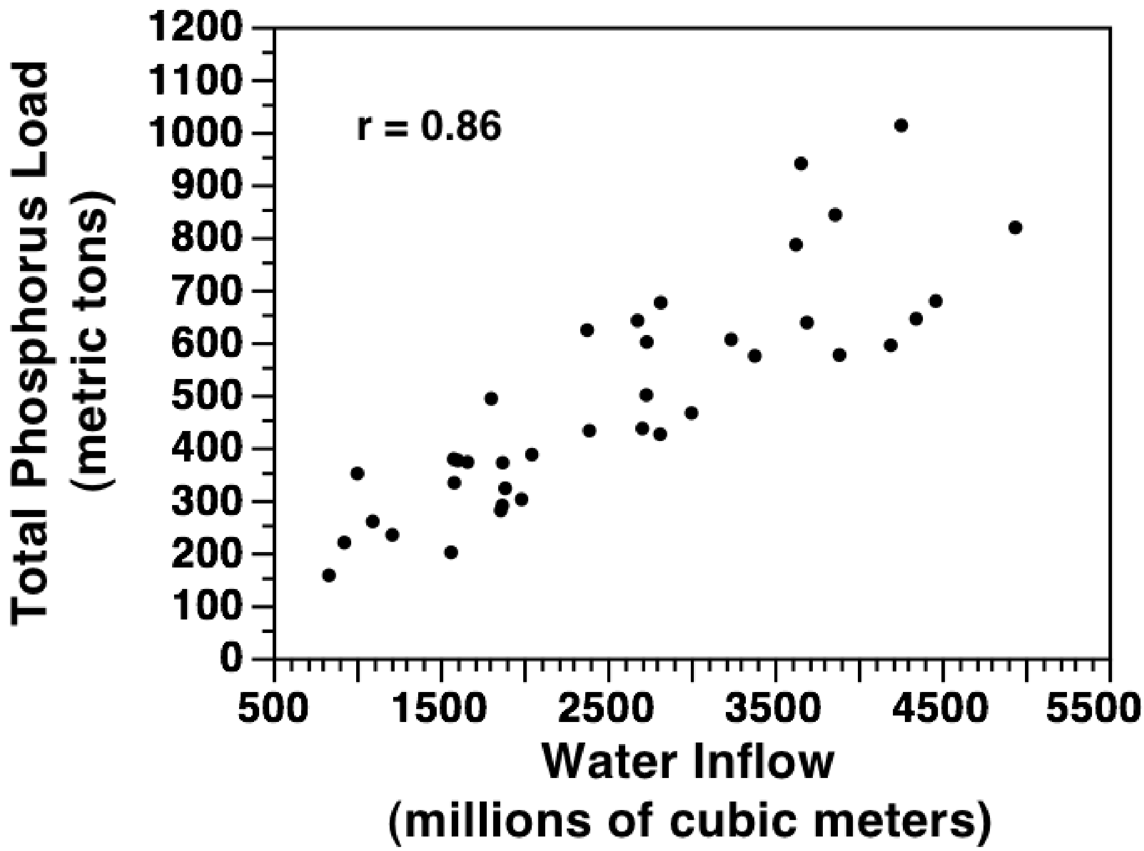

Figure 31. Relationship between Total Phosphorus Load (metric tons) and Water Inflow (million cubic meters) in Lake Okeechobee located in south Florida.

Identification of Nutrient Impaired Lakes in 2015

The State of Florida provides applicable surface water quality standards in the Florida Administrative Code (Chapter 62-302) and the methodology to identify waters to be included on the state's verified list of impaired waters (Chapter 62.303). Prior to the establishment of the NNC in 2013, the State of Florida used the TSI as the primary methodology for identifying impaired waters. The TSI and NNC approaches, however, both share two fundamental limitations. First, both approaches equate the trophic state of the lake to water quality (Carlson 1977, 2007) and second, both approaches did not consider the natural background conditions (i.e., soils and geology) determining the distribution of TP, TN, and chlorophyll *a* in Florida lakes (Bachmann et al. 2012a).

There were also several troublesome implied-assumptions behind USEPA's NCC (Bachmann et al. 2012a,b,c). Because the intent of the NNC was to regulate alterations in the nutrient concentrations of lakes and not their natural, unaltered concentrations, USEPA assumed in the past all Florida lakes were oligotrophic or mesotrophic. Such conclusion implied currently eutrophic lakes may have been subject to sufficient anthropogenic increases in nutrient loading shifting to a eutrophic state, and regulation of nutrient inputs will shift them to a mesotrophic state. It further implied oligotrophic lakes in Florida could be identified as those with an alkalinity of 20 µg/L or less. Using data from 1387 lakes collected over 3 decades, Bachmann et al. (2012a,b,c) tested in several ways the hypothesis that the majority of eutrophic lakes in Florida without known point source pollution were the result of nonpoint source nutrient pollution. The hypothesis was rejected.

Another problem associated for the development of effective TMDLs was the lack of identified correlation between the Landscape Development Intensity index (LDI) and the concentrations of TP, TN, and chlorophyll-*a* in Florida lakes (Bachmann et al. 2012a,b,c). Several of Florida's 30 benchmark lakes (lakes with minimal human impact and meeting designated uses) were eutrophic, and there was no significant difference between the mean concentrations of TP and TN in the benchmark lakes versus compared Florida lakes. Paleolimnological studies further showed several Florida lakes were eutrophic to hypereutrophic prior to 1900, a time before significant population growth in the State of Florida. Bachmann et al. (2012a,b,c), therefore, argued when applying the USEPA's proposed NNC about 44% of Florida's lakes would be inappropriately deemed "impaired."

When Rule 62-302.531 F.A.C. was established to provide numeric interpretations of Florida's Numeric Nutrient Criteria (Rule 62-302.530(47)(a) and (b), F.A.C.), there was another change to the Florida Administrative Code that has been overlooked by many individuals charged with identifying impaired waters. This change involved an extensive rewriting of the definition for natural background condition (Rule 62-302.200). The definition was changed to prevent the inappropriate listing of lakes as "verified impaired" when the water body is functioning naturally. For Polk County, examination of the revised definition is important because of the high probability of erroneously listing lakes in the county as impaired due to phosphorus-rich soils in the region of Florida (Bachmann et al. 2012a,b,c).

Natural background conditions for lakes (Rule 62-302.200) are now defined as:

(19) "Natural background" shall mean the condition of waters in the absence of man-induced alterations based on the best scientific information available to the Department. The establishment of natural background for an altered waterbody may be based upon a similar unaltered waterbody, historical pre-alteration data, paleolimnological examination of sediment cores, or examination of geology and soils. When determining natural background conditions for a lake, the lake's location and regional characteristics as described and depicted in the U.S. Environmental Protection Agency document titled Lake Regions of Florida (EPA/R-97/127, dated 1997, U.S. Environmental Protection Agency, National Health and Environmental Effects Research Laboratory, Corvallis, OR), which is incorporated by reference herein, shall also be considered. The lake regions in this document are grouped according to ambient total phosphorus and total nitrogen concentrations in the following lake zones:

(a) The TP1 phosphorus zone consists of the USEPA Lake Regions 65-03, and 65-05.
(b) The TP2 phosphorus zone consists of the USEPA Lake Regions 75-04, 75-09, 75-14, 75-15 and 75-33.
(c) The TP3 phosphorus zone consists of the USEPA Lake Regions 65-01, 65-02, 75-01, 75-03, 75-05, 75-11, 75-12, 75-16, 75-19, 75-20, 75-23, 75-24, 75-27, 75-32 and 76-03.
(d) The TP4 phosphorus zone consists of the USEPA Lake Regions 65-04, 75-02, 75-06, 75-08, 75-10, 75-13, 75-17, 75-21, 75-22, 75-26, 75-29, 75-31, 75-34, 76-01and 76-02.
(e) The TP5 phosphorus zone consists of the USEPA Lake Regions 75-18, 75-25, 75-35, 75-36 and 76-04.
(f) The TP6 phosphorus zone consists of the USEPA Lake Regions 65-06, 75-07, 75-28, 75-30 and 75-37.
(g) The TN1 nitrogen zone consists of the USEPA Lake Region 65-03.
(h) The TN2 nitrogen zone consists of the USEPA Lake Regions 65-05 and 75-04.

(i) The TN3 nitrogen zone consists of the USEPA Lake Regions 65-01, 65-02, 65-04, 75-01, 75-02, 75-03, 75-09, 75-11, 75-15, 75-20, 75-23, 75-33 and 76-03.
(j) The TN4 nitrogen zone consists of the USEPA Lake Regions 65-06, 75-05, 75-06, 75-10, 75-12, 75-13, 75-14, 75-16, 75-17, 75-18, 75-19, 75-21, 75-22, 75-24, 75-26, 75-27 and 75-29, 75-31, 75-32, 75-34 and 76-02.
(k) The TN5 nitrogen zone consists of the USEPA Lake Regions 75-07,75-08, 75-25, 75-28, 75-30, 75-35, 75-36, 75-37, 76-01 and 76-04.
The Lake Regions document may be obtained from the Department's internet site at http://www.dep.state.fl.us/water/wqssp/swq-docs.htm or by writing to the Florida Department of Environmental Protection, Standards and Assessment Section, 2600 Blair Stone Road, MS 6511, Tallahassee, FL 32399-2400.

When the USEPA and the State of Florida reached an agreement on the NNC (Rule 62-302.531 F.A.C.), it was recognized six total phosphorus zones and five total nitrogen zones reflected natural background conditions. Nutrient concentrations used to establish the nutrient zones, Bachmann et al.'s 2012a Table A5, are provided:

Table A5. Summary of the concentrations of total phosphorus (µg/L) and total nitrogen (µg/L) in their respective nutrient zones.

Nutrient zones	Number of lakes	mean	Percentiles 10	25	50	75	90
Total phosphorus							
TP1	18	4	2	3	4	5	9
TP2	175	11	5	7	11	15	22
TP3	556	19	8	12	17	27	45
TP4	485	34	14	20	33	53	93
TP5	76	77	26	43	73	139	280
TP6	77	124	27	76	141	250	359
Total nitrogen							
TN1	12	214	98	105	239	400	472
TN2	90	341	143	229	362	535	663
TN3	427	611	341	459	616	822	1099
TN4	670	842	510	647	830	1086	1375
TN5	188	1397	726	969	1394	2032	2708

While Grassy Lake is in the upper 10% of lakes enriched with nitrogen for Region 75-31, it is below the 75th total phosphorus percentile for lakes in nutrient zone TP4. If Grassy Lake is placed in nutrient zone TN5, the measured nitrogen concentrations are well within the expected range since 2005 (Table 1). Existing water quality measurements, therefore, provide evidence the documented exceedances were not due to pollutant discharges, but to natural stochastic events (drought, El Nino rains, and hurricanes) elevating nutrients. Also, there are times when color values in Grassy Lake exceed the 40 Pt-Co criteria used in the NNC. If hydrology changes to a wetter cycle, Grassy Lake may be classified as a "colored" lake rather than a clear water alkaline lake. With a shift in classification to a "colored lake," the TP and TN criteria shift upwards (Table 1) and Grassy Lake would no longer be impaired.

Another approach to removing a lake from FDEP's Verified Impaired list is to complete a paleolimnological study in Grassy Lake. Such study has not been conducted for Grassy Lake, but paleolimnological studies of five Polk County lakes indicate pre-disturbance conditions of the lakes were either mesotrophic or eutrophic. Therefore, expected maximum water quality improvement in Polk County is either a mesotrophic or eutrophic condition (Whitmore and Brenner 1995). Grassy Lake is currently in such a condition. Part of the reason, as Sacks et al. (1998) determined, lies with the fact that the groundwater at Grassy Lake is rich in nitrogen (average 15 mg/L, maximum 49 mg/L) and phosphorus (average 0.42 mg/L, maximum 1.6 mg/L). Whitmore and Brenner (1995) also noted changes in hydrologic conditions caused changes in the studied Polk County lakes, emphasizing the need to consider baseline conditions resulting from long-term changes in rainfall (Figure 18).

It is imperative that proper nutrient targets be established as the baseline for impairment designations. Otherwise, Polk County may potentially implement costly restoration projects that do not achieve desired water quality. In the case of Grassy Lake, current water quality measurements and the nutrient zones demonstrate the lake should not be on the Verified Impaired list. Synthesis of all examined components of Grassy Lake suggest best management approaches to protect water quality at Grassy Lake is to continue management of aquatic macrophytes. Redirecting water quality funds to aquatic macrophytes management program in order to provide the funds necessary for intensely managing aquatic macrophyte communities would constitute an excellent investment for Polk County.

Table 4. Rank position for Grassy Lake compared to other lakes in Lake Regions where Grassy Lake could be placed. Rankings are the position of Grassy Lake relative to the greatest long-term lake average. Secchi ranking is based on the greatest clarity.

RANK	TP	TN	CHLA	SECCHI
75-31(47 LAKES)	41	43	30	19
75-36 (83 LAKES)	25	45	37	65

Recommendations

Polk County should engage with FDEP in a discussion regarding the removal of Grassy Lake from the Verified Impaired list. Scientific evidence suggests Grassy Lake is functioning naturally for its appropriate nutrient zones. With implementation of NNC, the lake would not be designated impaired per Rule 62-302.200 of the Florida Administrative Code. Additionally, water quality at the center sampling station has not exceeded the numeric nutrient criteria since 2010 (Table 2) with no programs in place to control nutrient inputs. Under the Florida Administrative Code, it is not the intention of the State of Florida to abate natural conditions so Polk County should request that FDEP delist Grassy Lake because the waterbody meets the water quality standard(s) that was previously established as not being met (Rule 62-303.720 (2) F.A.C.).

Changes in water quality at Grassy Lake were linked to changes in submersed aquatic macrophyte abundance. This finding indicates that a hydrophilic-floral reconstruction program followed by the proper management of aquatic macrophytes is a tool for Polk County to use to prevent exceedances of the NNC when nutrient load reductions are too expensive or not technologically feasible. Polk County has well trained macrophyte management personnel. It is recommended funding for the program be allocated to increased monitoring, promote submersed aquatic macrophytes, and manage aquatic macrophytes to help the County achieve the NNC.

Polk County should evaluate water quality in their lakes considering the definition of natural background conditions (Rule 62-302.200 F.A.C.). There is a probability that numerous waterbodies are inappropriately listed as “impaired” and the County may have to develop TMDLs that may not achieve desired changes in water quality. As Atkins (2013) noted, it is imperative proper nutrient targets are used as the baseline for impairment designations as the implementation of very costly restoration projects hinges on these determinations.

Polk County needs to prioritize management efforts because of costs. Recently Atkins and ESA (2014) produced a report entitled “Prioritizing Future Actions Related to Impaired Lakes and the FDEP TMDL Program.” They reported Polk County previously prioritized 23 lakes with either a FDEP adopted or EPA approved nutrient related TMDLs as required by the County’s NPDES MS4 permit. The report reviewed those TMDLs, the prioritization scheme and prioritized an additional 97 lakes. Given the newly established definition for natural background conditions (Rule 62-302.200 F.A.C.), Polk

County should prioritize those lakes whose water quality exceeds that established for that waterbody's respective nutrient zones. Then, Polk County can list the top 5% of the water bodies in each nutrient zone as possible targets to account for statistical uncertainties. Following this prioritization approach, programs can be initiated and monitored to insure nutrient control is working.

Recognizing FDEP shall not strive to abate natural conditions (Rule 62-302.300(15) F.A.C.) and it is not FDEP's intent to list waters that do not meet otherwise applicable water quality criteria solely due to natural conditions (Rule 62.303.100(2) F.A.C.), Polk County should consider funding a paleolimnological study if FDEP and Polk County cannot agree on the “impaired' status of an individual lake. This approach would be less expensive than implementing a TMDL and it is the final data gap for lakes in Polk County.

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