Nutrient Loading in Lake Wauberg: Sources and Potential Management Strategies

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Abstract

Lake Wauberg in Micanopy, FL currently exceeds water quality standards for total nitrogen and total phosphorus, as indicated in DEP's 2003 Total Maximum Daily Load document, and subsequent Orange Creek Basin Management Action Plans. Management strategies must be developed to help meet nutrient reduction goals within the Lake Wauberg Watershed. Based on more recent data and modeling capabilities, allocations of nutrient inputs from different sources, including septic, runoff, atmospheric deposition, and internal loading, should be re-evaluated. Sediment samples demonstrate the potential for internal nutrient loading and redox-sensitive release of phosphorus from sediment to the water column. Data included in this report also suggest that nutrient loading from bird defecation may contribute as much as 78.4 kg/year total nitrogen and 24.4 kg/year total phosphorus to the lake. Management strategies including septic remediation, vegetation planting, floating treatment wetlands, and chemical sedimentation agents could aid in achievement of nutrient reduction goals for the Lake Wauberg Watershed.

Part I: Lake Wauberg Background and TMDL

1.1 The Basin Management Action Plan (BMAP)

The Total Maximum Daily Load (TMDL) program is implemented by the Florida Department of Environmental Protection (FDEP) as a means of protecting Florida's valuable water resources. The safeguarding of Florida's surface waters is an important measure to support ecological diversity, wildlife habitat, economic interests and tourism, protection of public health, and the preservation of cultural resources. A TMDL for an impaired waterbody calculates the maximum amount of a specific pollutant that the waterbody can tolerate without degradation of water quality (Wu et al., 2003). These water quality standards are dependent upon a waterbody's designated uses, pursuant to the EPA's Clean Water Act. Pollutant contributions from various sources within the watershed are estimated, and pollutant reduction goals are established in the TMDL document. Florida's DEP has implemented Basin Management Action Plans (BMAPs) as a mechanism to coordinate efforts among different stakeholders with the goal of achieving TMDLs and restoring water quality.

BMAPs are developed with the input of local, regional, state, and private entities to put forth management strategies that will help achieve restoration goals by reducing pollutant loadings to a watershed basin. The BMAP process incorporates an adaptive management approach that allows for modifications to be made as more information becomes available or monitoring indicates a need for different management strategies (FDEP, 2014). Public meetings encourage stakeholder involvement and provide a forum to share ideas and information throughout the 5 year cycles of the BMAP process.

Lake Wauberg in Alachua County was listed as impaired in 2002 for nitrogen and phosphorus, and has since been incorporated into the Orange Creek Basin Management Action Plan. Phase I of the Orange Creek BMAP was adopted in May 2008, and Phase II was implemented in July 2014 with a priority focus on management actions to reduce nutrient loading to Lake Wauberg, and other lakes within the basin. The Phase II BMAP indicates that further characterization of potential nutrient sources to Lake Wauberg may be needed to help identify additional management strategies, with a possible increased emphasis on within-lake management rather than management of external sources (FDEP, 2014). Given the need for a better understanding of Lake Wauberg's nutrient dynamics, this report will attempt to further assess potential sources and management strategies for this lake.

1.2 Introduction to Lake Wauberg

Lake Wauberg is a small, shallow lake located about 8 miles south of Gainesville along the eastern edge of Highway 441 in Micanopy, FL (Figure 1). It has a surface area of 248 acres, and an average depth of 12 feet (Orange Creek, 2007). The lake was noted as an alkaline colored lake by Brezonik and Shannon (1973), and can still be described as such today. The entire watershed area delineated by DEP is 717 acres, and the climate is generally humid and subtropical (Wu et. al., 2003). During a detailed 15-month study of the lake's hydrogeology, Opper (1982) described Lake Wauberg as a fairly closed hydrologic system, with rainfall and shallow groundwater being the only significant sources of water inflow, and some lake discharge occurring on the eastern side to Sawgrass Pond under high water conditions. The Lake Wauberg watershed has minimal development and is bordered by Paynes Prairie Preserve State Park, two University of Florida Recreational facilities, some private residential properties, and US HWY 441 to the west/southwest. Lake Wauberg is underlain by portions of the Hawthorne Formation, which is known to be rich in phosphatic clays (Opper, 1982).

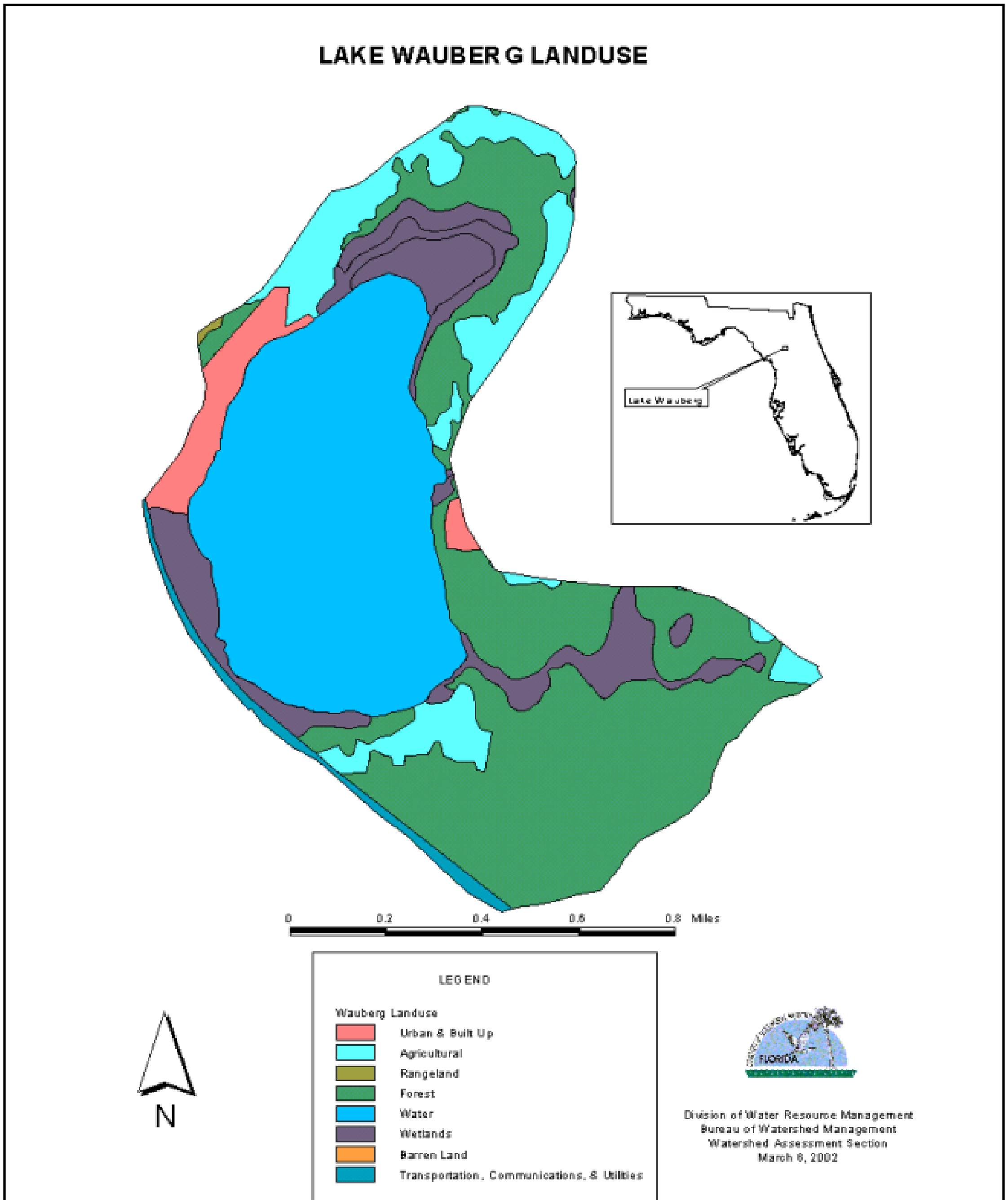

Figure 1: Lake Wauberg Watershed and Land Use (Wu et al., 2003)

Lake Wauberg has been established as a class III surface water body, meaning it should have suitable water quality for recreation, fish consumption, and the propagation and maintenance of a healthy, well-balanced population of fish and wildlife (Orange Creek, 2008).

The Lake is utilized by local residents, University of Florida students, and Paynes Prairie visitors for a number of activities including swimming, fishing, boating, and picnicking; the lake also supports a diversity of plant and animal species.

A lake's water column contains bacteria, algae, and small animals called zooplankton that feed on algae; nitrogen and phosphorus can fuel the growth of algae and cause a shift from smaller types that are easily grazed, to larger types of blue-green algae (cyanobacteria) that resist grazing and can form noxious blooms (Havens, 2015). The nutrient impairment designation for Lake Wauberg was based on an average annual Trophic State Index (TSI) that is derived from chlorophyll-a, total nitrogen, and total phosphorus concentration measurements. A shift in the phytoplankton communities towards cyanobacterial dominance is an indicator of an unbalanced ecosystem, and this shift was determined to be more likely above the TSI threshold of 60 (Wu et al., 2003). The average annual TSI for Lake Wauberg for the years 1990 and 2000 was 72.3, which exceeds the Florida-based TSI threshold of 60 (Wu et al., 2003). As indicated in Figure 2, the average TSI for Lake Wauberg shows an increasing trend throughout the period of 1990 - 2013 for which water quality data are available (FDEP, 2014).

Figure 2: Trend in TSI for Lake Wauberg over the Period of Record (FDEP, 2014)

1.3 Impacts of Nutrient Pollution

High nutrient loads in freshwater systems can fuel the growth of cyanobacterial and algal blooms, with potential for adverse ecological, economic, and public health impacts. Excessive algal growth can shade out other organisms that rely on sunlight for energy, disrupting the natural balance of the system and potentially resulting in a loss of biodiversity. High densities of algal biomass can also result in decreased dissolved oxygen levels in the water column when large numbers of cells die off, and decomposition processes rapidly consume oxygen. Low dissolved oxygen levels can create difficult living conditions for other aquatic organisms, and can result in fish kills. Consequently, the negative aesthetic associations of these blooms can deter tourism and recreation, impacting the economic value of the water resource. Dense algal mats can also serve as substrate for unwanted bacteriological growth in swimming areas (Watson and Molot, 2013).

Some strains of cyanobacteria are known to produce toxins that can cause harm to humans and other organisms via ingestion, dermal contact, or inhalation. Cyanobacterial toxins, or cyanotoxins, can affect the liver (hepatotoxins), nerves (neurotoxins), and skin cells (dermatotoxins), and they also have the potential to accumulate through the food chain in fish that may be consumed by humans (Abbot et al., 2009). While there are currently no U.S. federal standards for cyanobacteria in recreational waters, the World Health Organization guidelines suggest that relative probability of acute health effects is high at levels of 100,000-10,000,000 cyanobacterial cells/mL (Watson and Molot, 2013). In an April 2011 phytoplankton sampling event at Lake Wauberg, Alachua County Environmental Protection Department found phytoplankton densities as high as 438,617 cells/ml, of which more than 90% were classified as cyanobacteria; certain taxa identified in this sampling event, including *Cylindrospermopsis raciborskii*, *Microsystis aeruginosa*, and *Mycrosystis wesenbergii,* are capable of producing harmful toxins. Lake Wauberg is a popular recreational swimming area, and thus monitoring and reduction of conditions that could be conducive to harmful algal blooms is of particular importance here.

1.4 Nutrient Load Allocations

The Orange Creek Basin Management Action Plans have identified nutrient reduction targets of 50% for total phosphorus (TP) and 51% for total nitrogen (TN) in the Lake Wauberg watershed based on load allocations calculated in the TMDL document by Wu et. Al (2003); potential sources identified include atmospheric deposition (65% contribution), onsite sewage treatment and disposal systems (OSTDSs)(32% contribution), and surface runoff (3% contribution). Given that all residences and recreational facilities within the watershed utilize septic systems rather than centralized sewer for waste disposal, OSTDSs have been identified as the primary controllable factor for nutrient management at Lake Wauberg. However, DEP estimates that even complete removal of OSTDSs in the watershed would not reduce nutrient loading enough to be achieve the TMDL targets of 936 kg/year total nitrogen (TN) and 170 kg/year total phosphorus (TP) (FDEP, 2014). This paper will further explore potential nutrient inputs including OSTDSs, fertilizers and runoff, legacy inputs from previous land uses, atmospheric deposition, wildlife, interactions with the phosphorus-rich clays of the Hawthorne Group, and internal loading. Further studies and potential management strategies are also proposed to aid in the achievement of TMDLs for Lake Wauberg.

Part II: Anthropogenic Sources of Nutrient Inputs to Lake Wauberg

2.1 Onsite Sewage Treatment and Disposal Systems (OSTDS)

Lake Wauberg is located in an area where there is currently no central sewer availability, and sewage must be disposed of through the use of onsite sewage treatment and disposal systems, generally referred to as OSTDSs or septic systems. There are at least two onsite systems associated with the University of Florida recreational facilities on the north shore and south shore of the lake. According to the University of Florida Campus Master Plan (University of Florida, 2015), the north and south shore OSTDSs were both upgraded in 1998, though I was unable to locate further data on these systems. Paynes Prairie Preserve State Park is the other high-use facility within proximity to Lake Wauberg, with a total of at 16 septic systems, 6 of which are for public use, and 3 of which appear to be within 300 m of the lake's edge**.** Paynes

Prairie is currently in the process of replacing 2 of these failing systems that are in proximity to the lake with new conventional drainfields, which may help reduce some nutrient loading to the lake. There are also about 16 private residences bordering the lake that rely on OSTDS for waste disposal, and about 40 total within the basin (Wu et al., 2003).

In a conventional septic system, wastewater is transported to a septic tank, where it receives partial treatment under anaerobic conditions via physical settling of solids, microbial digestion, and ammonification of organic nitrogen. The wastewater that leaves the septic tank is referred to as effluent, which then travels to the drainfield where it is dispersed into the soil for further treatment. Effluent generally contains between 30 - 70 mg/L total nitrogen, mostly in the form of ammonium-N (Toor et al., 2011). In the drainfield soil, effluent receives further treatment of bacteria, pathogens, phosphorus, nitrogen, and other contaminants as the wastewater percolates down through the action of gravity. In the unsaturated zone immediately below the drainfield, most of the ammonium-N will be converted to nitrate in the process of nitrification due to the presence of oxygen in soil pores. Ammonium-N can also be taken up by plants, volatilized and converted to ammonia gas, adsorbed to soil particles, or metabolized by soil microbes. Nitrogen that remains as nitrate in the soil has the potential to leach into the groundwater below the drainfield, convert to environmentally benign nitrogen gas (denitrification) when it reaches low-oxygen conditions, or be taken up by plants or microbes. Denitrification can be limited in conventional OSTDS systems because of the need for anaerobic conditions and significant source of carbon; 10-50% of effluent total nitrogen is likely to be removed through drainfield action (Toor et al., 2011, Harris and Blanco, 2013).

Phosphorus is also present in effluent wastewater, though this has become less of a contributor since it has been eliminated or reduced in most laundry and dishwasher detergents since the 1970s. Effluent phosphorus can be present in organic forms (from human feces and food residue) and inorganic forms (from household cleaning products and detergents), with a median concentration of 10 mg/L total phosphorus in domestic septic tank effluent (Lowe et al., 2007). In the drainfield soil, much of the effluent phosphorus can become unavailable when it adsorbs to soil surfaces or precipitates out of solution to form mineral complexes, though some phosphorus can still leach to groundwater. Phosphorus loading to groundwater or nearby waterbodies is variable, and can be enhanced by high groundwater velocities, highly permeable/sandy soils, high loading rate of wastewater, uneven distribution of wastewater in a drainfield, and a lack of a biofilm/clogging zone beneath the drainfield (Lusk et al., 2011). Removal of effluent phosphorus within a sandy loam drainfield was reported at 99% by Lowe and Siegrist (2008), but other research also suggests that phosphorus attenuation in soils can be reversible, and that it can become de-sorbed over time (Robertson, 2008); generally, the potential for phosphorus adsorption increases with greater distance away from the septic drainfield. Efroymson et al. (2007) have noted that when water quality impairment with phosphorus is associated with septic tanks, it is usually due to hydraulic failures of those systems, or inadequate distance between the drainfield and an adjacent surface waterbody. Proper installation and maintenance of OSTDSs in accordance with Florida Administrative Code should limit the influence of phosphorus generated from septic systems.

The 2003 TMDL models calculated phosphorus and nitrogen loading from septic tanks using the following equation:

$$TL = NO \times LOAD \times (1-RET)$$

TL = total load for TN and TP per year

NO = number of people per capita per year

LOAD = total load per capita-year (assumes 0.876 kg for TP and 4.600 kg for TN)

RET = portion of loading retained in the soil (assumes 0.110 for TP and 0.085 for TN).

Nutrient loading from Paynes Prairie Preserve State Park was not included in the calculations, because it was assumed that this waste went to dump stations (taken off-site) rather than OSTDSs; this calculation should be revisited, as many visitors are likely to utilize the park's septic systems. Visitor use data provided by Paynes Prairie from 7/1/2010 – 3/31/2015 indicates an average of 76 overnight visitors/day and 618 day-use visitors/day. These figures should be included in TMDL calculations, as they are likely to impact the calculated contribution of nutrient loading from septic systems within the watershed.

Septic loading calculations in the TMDL document (Wu et al., 2003) were based solely on Wauberg visitation and an estimated 40 private residences within the watershed. Visitation to Lake Wauberg recreational facilities was assumed to be 6,000 visitors/month, or 200 visitors/day, which was equated to loading from 100 permanent residents, for an annual contribution of 421 kg TN and 78 kg TP. Loading from septic systems at private residences was calculated by multiplying the number of residences (40) by the assumed LOAD and RET rates, for an annual contribution of 168 kg TN and 31.2 kg TP (Wu et al, 2003).

Phosphorus loading may be overestimated for septic systems in this watershed. The assumed phosphorus retention rate of 0.11, or 11%, is very low compared to many published studies. Mechtensimer and Toor (2017) found 98% reduction of total phosphorus in 18-month studies of two different types of conventional drainfields. Regensberger et al. (2010) suggest that there may be no phosphorus contribution from septic systems to surface waters unless they are within 100 ft. of the water or in hydraulic failure. Harris and Blanco (2013) with the Florida Department of Health assert that 85% - 95% of total phosphorus is removed in the vadose zone of the septic drainfield; an average of 90% removal rate, as opposed to 11%, could be more appropriate for phosphorus loading calculations. Likewise, TMDL-estimated attenuation of total nitrogen at 8.5% in septic drainfield and soils may also be low. Harris and Blanco (2013) estimate that between 10% - 50% of total effluent nitrogen is removed in the septic tank and drainfield; an average of 30% reduction may be more appropriate for calculations.

Septic tank effluent contains an average of 60 mg/L total nitrogen and 10 mg/L total phosphorus; drainfield and soil action can reduce effluent nitrogen by 30% and total phosphorus by 90% in properly constructed and maintained systems (Harris and Blanco, 2013, Lowe et al., 2007). Based on the Florida administrative code, 1 full-time resident can contribute 50 gallons of wastewater flow per day (State of Florida DOH, 2013). The estimated contribution per visitor for a park restroom with toilets only is 4 gallons per day, and for a park with a bathhouse, it is 10 gallons per day (State of Florida DOH, 2013). Visitor data for Paynes Prairie's southern facilities that are in proximity to Lake Wauberg indicates an average of 618 day-use visitors per day. Overnight visitors at Paynes Prairie, who are likely to use the bath house at a higher loading rate, average 76 visitors per day. At the University of Florida facilities, Lake Wauberg visitation is estimated at 200 visitors/day. Census information for Alachua county indicates an average of 2.46 people/household, with 40 residences estimated in the Lake Wauberg Watershed by Wu et al. (2003)(U.S. Census Bureau, 2016). Incorporating all of these numbers, I have estimated nutrient loading from septic systems to the Lake Wauberg Watershed in Figure 1, below.

Septic Location	Total Nitrogen (kg/year)	Total Phosphorus (kg/year)
UF Facilities	46.4	1.1
Paynes Prairie	188	4.5
Private Residences	286	6.8
Total (my estimate)	**520**	**12.4**
TMDL estimates:	**589**	**109**

Table 1: Estimates of Nutrient Loading from Septic Systems

Phosphorus attenuation can vary based on site specific conditions such as distance to surface water, wet season high water table depth, and soil characteristics, but these calculations indicate that phosphorus contributions from septic tanks in the Lake Wauberg Watershed may have been largely overestimated.

2.2 Expanded Watershed and Georges Pond Connection

Georges Pond is a small waterbody east of Lake Wauberg that could potentially be included within the Lake Wauberg watershed. According to the Paynes Prairie Unit Management Plan, Burnt Pond (to the north) and Georges Pond (to the west) contribute surface water flow under very wet conditions; the Burnt Pond wetland drains west under U.S. 441 to Georges Pond, which then overflows eastward under the highway again to Lake Wauberg when water levels are very high (State of Florida DEP, 2013). Discussions during Orange Creek BMAP meetings have indicated that the drainage area for Lake Wauberg basin could actually be larger than the 717 acres originally modeled in the TMDL document (Figure 1), encompassing more than 3,000 acres based on more recent mapping (Figure 3) (Alachua County EPD, 2015). If the Basin area were to be expanded accordingly for BMAP purposes, it would then encompass Georges Pond.

Located near Georges Pond is an extended aeration wastewater treatment facility, known as a package treatment plant, for Camp McConnell. Package treatment plants provide a method for onsite wastewater disposal when an OSTDS cannot be permitted due to an estimated domestic sewage flow greater than 10,000 gpd; an extended aeration plant provides secondary sewage treatment by introducing air into the wastewater to encourage digestion of waste by aerobic bacteria (FDOH and FDEP, 2015). Based on data from 2010 and 2011, the Alachua County Environmental Protection Department (EPD) calculated the average flow rate of the system to be 0.0015 million gallons per day (MGD), with an estimated total nitrogen loading rate of 30 lbs/year and a total phosphorus loading rate of 9 lbs/year (Alachua County EPD, 2012). While Camp McConnell is currently not operational, it is in the process of changing ownership and will likely be operational again soon. These contributions are small but could be pertinent to future TMDL discussions for Lake Wauberg.

If the drainage area for TMDL allocations were expanded to reflect updated topological mapping as indicated in Figure 3, this would also greatly affect runoff/land use calculations, and other modeling that was used in the original TMDL. Current DEP geospatial data online for the Lake Wauberg Outlet reflects this larger watershed area, and thus any calculations or models that incorporated the smaller 717 acre watershed area should now be revisited.

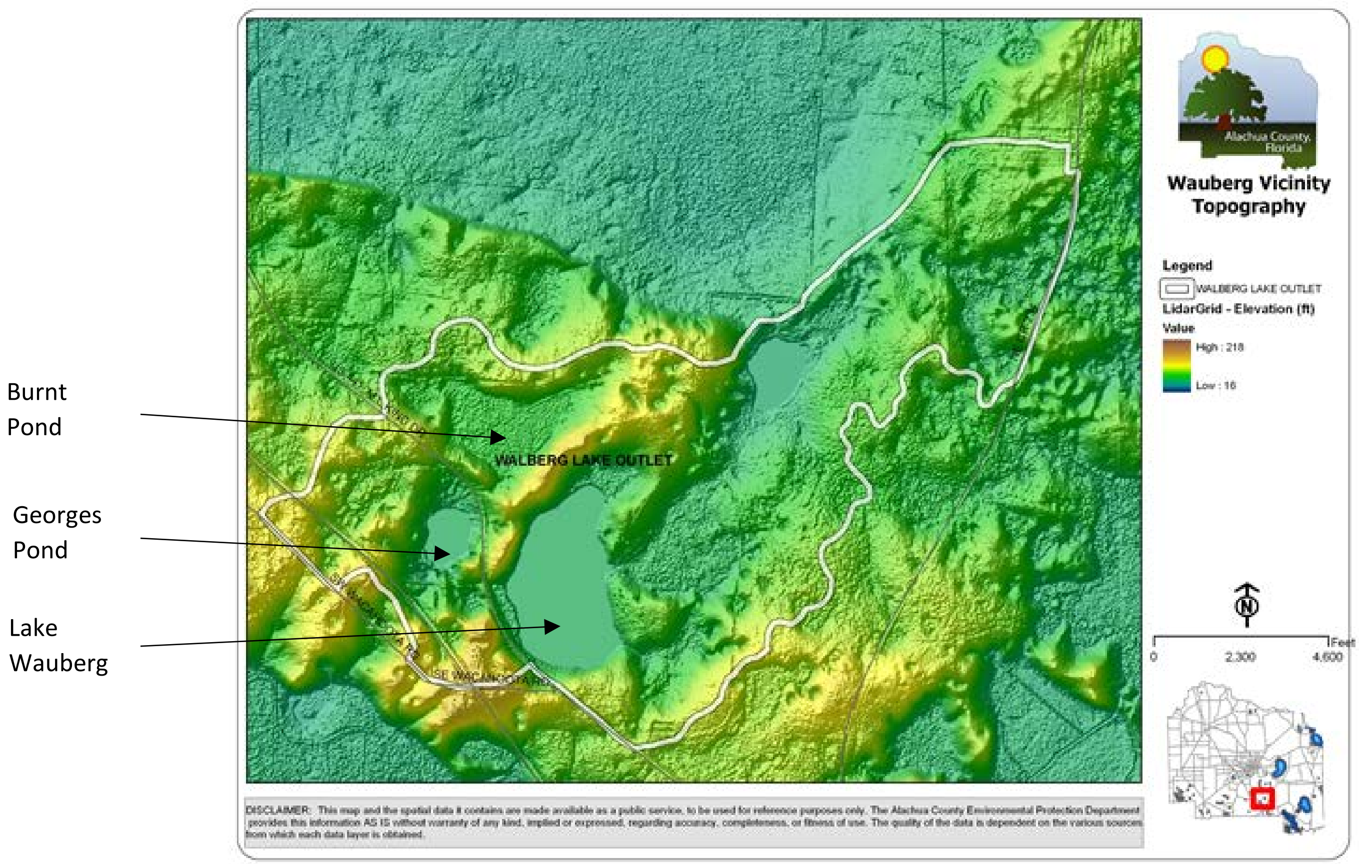

Figure 3: Potential Lake Wauberg Watershed (Alachua County EPD, 2015)

2.3 Legacy Nutrient Inputs

Much of the Lake Wauberg watershed lies within Paynes Prairie Preserve State Park. The prairie has been used for cattle ranching as far back as the 1600s, and continuous cattle grazing over the past 300 years has helped shape the landscape (State of Florida DEP, 2011). The park still maintains a small population of cattle (about 40-50 head) that are not likely to significantly contribute to current nutrient loading. However, some areas in the park have undergone periods of intensive management for cattle production in the past, and periodic fertilization of agricultural and pasture areas has also occurred throughout the park (State of Florida DEP, 2013). Historic cattle grazing did take place in much of the northern portion of the watershed;

remnant cattle dip vats from the 1950s and 60s and historic aerial photographs (Figure 4) provide indications of where cattle may have been concentrated in the past (personal communication, Andi Christman, 10/10/2017). It should be noted that most fertilizer application and cattle grazing practices in the area would most likely have ceased or been largely diminished after the state acquired the land in 1970.

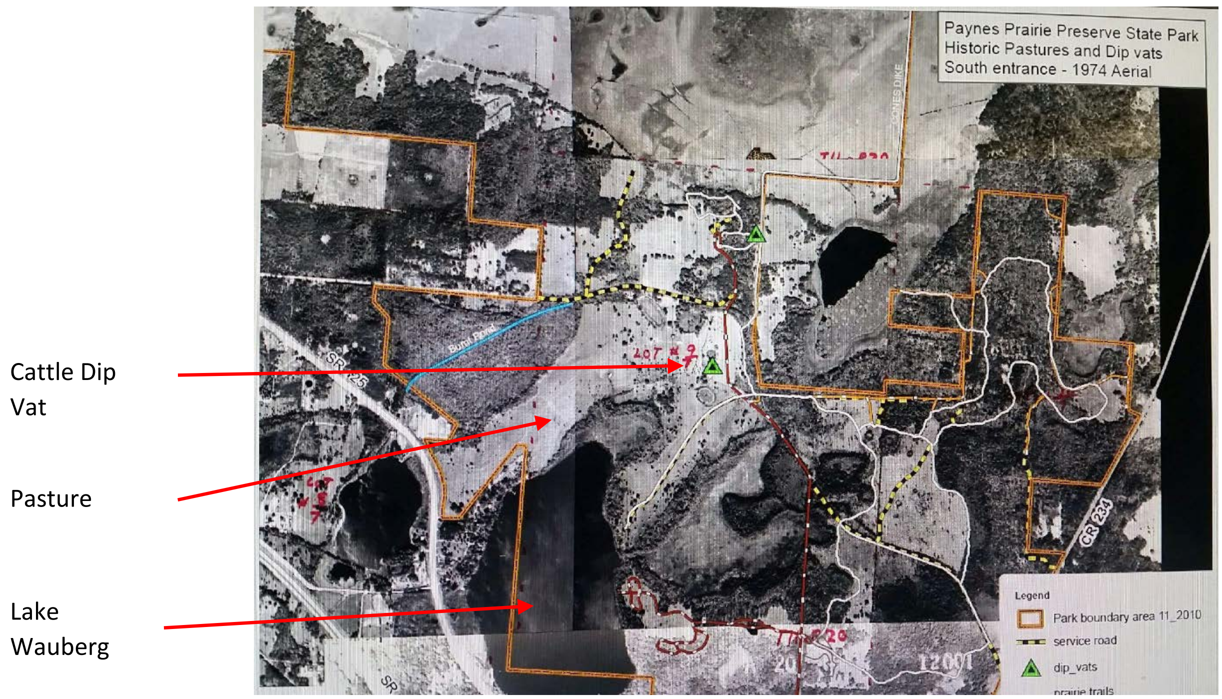

Figure 4: Paynes Prairie Preserve State Park Historical Pastures and Dip Vats – 1974 Aerial (Christman, 2017)

Cattle grazing operations commonly utilize nitrogen and phosphorus fertilizers on pasture lands. Long-term application of phosphate fertilizers can result in accumulation of phosphorus in soils, increasing the risk of phosphorus runoff to surface waters from soil solution or erosion of phosphorus-laden soil particles (Capece et al., 2007). When cattle are concentrated near streams or surface waters, they can also contribute to nutrient pollution through their waste or by triggering nutrient release while stirring up sediments (Line et al., 1998). Given past land uses, it is possible that historical fertilizer application and cattle operations have contributed to nutrient pools within the soil and water systems of the Lake Wauberg basin. Neglecting to address or acknowledge these potential legacy nutrient inputs can make it more difficult to achieve desired outcomes of nutrient mitigation (Levi and Destouni, 2017).

2.4 Atmospheric Deposition

Atmospheric deposition allocations for the 2003 TMDL were based on rainfall data and DEP modeling. Because of the relatively large water-to-watershed ratio in this basin, (the lake is 33% of the total acreage of the watershed), a large portion of nutrient loading (65% for both TN and TP) has been attributed to atmospheric deposition (Wu et al., 2003). Nutrients can be released into the air due to combustion of fossil fuels and volatilization of agricultural nutrients throughout the landscape, and deposited to aquatic ecosystems in the process known as atmospheric deposition (Carpenter et al., 1998). There is little that can be done from a watershed management perspective to reduce loading from atmospheric deposition, other than encouraging lower emissions from surrounding industries and utilities.

Methods for estimating nutrient loading from atmospheric deposition can vary. In a more recently developed TMDL document for another lake within the Orange Creek basin, Lochloosa, atmospheric loading was calculated based on data provided from Dr. Rolland Fulton of the St. Johns River Water Management District summarizing average wet and dry deposition measurements in the Upper Ocklawaha River Basin from April 1991 – January 2013 (Table 2) (Magley, 2017). These monitoring sites are located within 45 miles of Lake Wauberg, and so the data could potentially be extrapolated for this watershed. If this method were used for Lake Wauberg, estimates for loading of atmospheric deposition would be very different than calculated in the original TMDL document. Using the average rainfall of 47.5 in. calculated in Wu et al. (2003), and the surface area 248 acres for Lake Wauberg, wet deposition rates would be about 55.9 lbs/year TP and 1,630.4 lbs/year TN. Dry deposition would contribute another

53.1 lbs/year TP and 2,411.6 lbs/year TN. These estimates of 109 lbs/year TP and 4,042 lbs/year TN are drastically different from the original atmospheric deposition estimates of 486 lbs/yr TP and 2,642lbs/yr TN from Wu et al. (2003), and indicate that perhaps the original method should be updated or somehow reconciled with current methods.

Parameter	Wet Deposition Number of Samples	Wet Deposition (mg/L)	Dry Deposition Number of Samples	Dry Deposition (lbs/acre/year)
NH3 + NH4 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 2: Summary of Wet and Dry Deposition Rates from SJRWMD Monitoring Sites in the Apopka Basin (Magley, 2017)

2.5 Runoff

Runoff from the landscape surrounding Lake Wauberg can transport nutrients that are bound to soil particles and present in soil solution to the surface water. For the Lake Wauberg Watershed, nutrient contributions from runoff were modeled based on imperviousness and estimated event mean concentrations (EMC) of TN and TP from land uses within the basin (Wu et al., 2003). Nutrients from agricultural practices, fertilized lawns, stormwater streams, plant litter, and animal waste can be present in runoff. The UF and Paynes Prairie facilities near Lake Wauberg likely do not use fertilizers on their properties, though private residences could (FDEP, 2014). Some runoff from paved area and ditches along HWY 441 could contribute to stormwater loading in the watershed. During field investigations, I have noticed some small ditches that drain to lake Wauberg, in which stormwater appeared to be scouring into a clayey layer of soil; as will be discussed in later sections, the phosphorus-rich clays of the Hawthorn Formation are present at or near the soil surface throughout the watershed and could be a potential source of phosphorus input to the lake. If there are any small streams emptying into the lake from areas of higher elevation on the northern side of the basin, erosion of hawthorn sediments could be a source of phosphorus loading. A more detailed field investigation would be needed to determine if there are any such significant areas of erosion or scouring of the Hawthorn layer in the surrounding areas. DEP has determined that 3% of total phosphorus and total nitrogen loading is due to runoff within the Lake Wauberg watershed (Wu et al., 2003).

Part III: Natural Sources of Nutrient Inputs to Lake Wauberg

3.1 Wildlife

If nutrients are present in lake sediment, benthic invertebrates and fish could potentially enhance the release of these nutrients to the water column through the process of bioturbation. Organisms that feed at the sediment surface (benthivorous) or live in sediments can stir up nutrient-rich particles, potentially inhibiting lake recovery even after external nutrient sources have been controlled (Havens, 2015). Sunfish and gizzard shad, both present in Lake Wauberg, are also planktivorous fish, meaning that they feed on zooplankton, which in turn can reduce zooplankton grazing on the smaller planktonic algae that are known to contribute to algal blooms and high chlorophyll *a* levels in freshwater lakes (Bernes et al., 2015). A systematic literature review by Bernes et al. (2015) has indicated that removal of planktivorous and benthivorous fish can be a successful means of improving water quality in eutrophic lakes, particularly in small lakes with high phosphorus levels.

Field observations and identification by research zoologist Dr. Anna Phillips (personal communication, 2017) have indicated the common presence of leeches on the bottom of Lake Wauberg. Leeches can burry themselves in sediment to survive cold temperatures and drought, or as a safe place to digest food; the leeches observed in Lake Wauberg, tentatively identified as erpobdellids, likely feed on aquatic invertebrates and insect larvae. These processes could potentially contribute to bioturbation within the lake.

High concentrations of birds within the Lake Wauberg basin could be another potential source of nutrient input to Lake Wauberg due to loading from excrement. A study by Manny et al. (1994) found that nutrient contributions from waterfowl at a Michigan lake did cause degraded water quality. Based on bird surveys conducted on Lake Wauberg, I will attempt to further quantify nutrient loading from this source in part V of this report.

3.2 Hawthorne Formation & Groundwater Interactions

Due to the relatively minimal development within the Lake Wauberg watershed, and the presence of a phosphorus-rich clay layer called the Hawthorn Formation that is at or near the surface throughout the area, it has been suggested that the trophic status of the lake could be largely due to natural conditions; if this is the case, a reduction of external inputs alone would not restore water quality. Cyanobacteria have been indicated as the dominant phytoplankton as far back as 1934, when a University of Florida student named Archie Carr conducted a year-long study of plankton in the lake; at that time, he described the water as being "always slightly colored, ranging in tint from a weak coffee brown to dark green" (Carr, 1934). Opper (1982) also noted the dominance of blue green algae, which he indicated as the cause of the lake's dark green color, even 35 years ago. These historical observations would suggest that the lake may have had consistently high algal biomass concentrations even dating back to a period of minimal human impact.

The Hawthorn Formation in northeastern Florida is a variable mixture of clay, quartz sand, phosphate, and carbonate, with phosphate being almost ubiquitous throughout the sediments; phosphate concentrations can range from 0 - 40% (Scott, 1982). Opper (1982) compiled a geologic framework of the watershed, which indicated that the bottom of Lake Wauberg consists of unconsolidated organic material that overlies organic rich clays of the Hawthorn Formation. Evidence from a seismic refraction study by Weiner (1982) suggests that the Lake Wauberg Basin could have been formed due to solution of underlying Ocala Limestone and Hawthorne sediments along a lineament, followed by subsidence of Hawthorn Clays. Opper (1982) stated that the lower portion of the surficial sediments in Lake Wauberg are thought to be reworked Hawthorn material. Liberation of phosphorus during subsidence of the Hawthorn Clays could be a potential reason for naturally high levels of available phosphorus in the Wauberg basin.

The shallow aquifer in the basin is confined by the low-permeable clays of the Hawthorn, and shallow groundwater inflow represents a considerable portion of Lake Wauberg's hydrologic budget (Opper, 1982). If groundwater phosphorus is high, it could have an especially pronounced effect on the lake during dry periods when there is no freshwater to dilute this input. Groundwater seepage and interaction with the phosphatic Hawthorn layer could be another potential source of phosphorus input to the lake.

3.3 Internal Loading and Nitrogen Fixation

While lake sediments can often act as a sink for nutrients, they can also become a source of nitrogen and phosphorus to the overlying water under certain conditions. Internal loading is a process whereby nutrients present in surface sediments can become bioavailable due natural physical, chemical, and biological processes (Wang and Liang, 2015). At the water-sediment interface, readily available orthophosphate, phosphate bound to iron and aluminum, and organic phosphorus can all become bioavailable to fuel algal growth under the right conditions; this can lead to recycling of nutrients within a lake, even if external nutrient sources have been controlled. Nitrogen fixation is another natural process that contributes to nutrient loading; certain species of cyanobacteria present in the aquatic ecosystem are capable of capturing atmospheric nitrogen that is then converted into bioavailable forms within the water column. Phillips and Ihnat (1995) calculated that nitrogen fixation could account for as much as 30% of nitrogen loading in Lake Okeechobee. Management decisions based on mass balance equations that do not factor in these chemical and biological processes may be not be sufficient to bring about desired water quality improvements (Havens, 2015). The BATHTUB model utilized by DEP for TMDL development can include an option for internal loading rates of phosphorus and nitrogen (Magley, 2016); with the acquisition of more data, DEP could consider incorporating this component into Lake Wauberg loading calculations.

Redox-sensitive mobilization of phosphorus in the anoxic zone just below the sediment surface, as well as microbial processes, can play important roles in phosphorus release to the water column. Under anoxic (low-oxygen) conditions, iron is reduced, and both the iron and sorbed phosphate can be released into solution; therefore, periods of low-oxygen can result in increased phosphorus release rates from the sediment (Sondergaard et al., 2003). Anoxia and stratification can be common phenomena in shallow lakes, especially during summer months when oxygen demand is high. In a study by Zhu et al. (2013), iron-bound phosphorus appeared to be the most mobile fraction of phosphorus in the lake sediment, with aluminum and manganese-bound phosphorus also representing a pool that can be easily released to the water. The water may be considered anoxic at levels below 2.0 g/l dissolved oxygen (DO). About half of organic sediment phosphorus can also be converted into available phosphorus for algal uptake via mineralization and degradation processes (Zhu et al., 2013).

In shallow lakes, wind-induced resuspension can cause increased concentrations of suspended solids in the water, potentially inducing nutrient release due to desorption from suspended sediments and/or release of dissolved nutrients from porewater (Sondergaard et al., 2003). At Lake Wauberg, recreational activities at the public beach can also stir up sediment. High pH in combination with sediment resuspension (as from wind, wildlife, or humans), can also increase the risk of internal phosphorus loading (Sondergaard et al., 2003). Shumate (2004) noted that high sediment porosity in the upper 40 cm of Lake Wauberg sediments, along with lake morphology considerations, indicate that sediment resuspension is likely. Using a sophisticated model for Lake Okeechobee, James et al. (1997) estimated that 701 mg/m^2/year of soluble reactive phosphorus (SRP), 20,184 mg/m^2/year organic phosphorus, and 575,240 mg/m^2/year organic nitrogen were released to the water column by sediment resuspension, demonstrating the significant role that this nutrient input can play in eutrophication processes.

Lake Wauberg is surrounded by several wetland areas, including the area nearest HWY 441 that is likely to receive road runoff, as well as on the north end where there is higher topological relief and potential for natural soil erosion. While wetlands can remove sediment from the water column and act as a sink, wetland soils can also become saturated and export phosphorus, often seasonally. While burial of litter in peat can provide long term phosphorus removal, litter decomposition and microbial cell death can cause phosphorus release; the presence of calcium can be an indicator of potential for more stable phosphorus sorption and storage (NCSU, 1995).

Part IV: Sediment Sampling

4.1 Methods

To help gain a better understanding of the composition of surface sediments within Lake Wauberg, and the potential for internal nutrient loading, I participated in sediment sampling with Alachua County Environmental Protection Department staff on 6/22/2017. Ten sediment samples were collected from the lake bottom using a petite ponar from a motorized boat. Samples were then transferred to a steel bowl and homogenized using a steel spoon, and both were rinsed with deionized water between samples. Because there is higher relief in the northern portion of the watershed, it was hypothesized that there could be more erosion and deposition of phosphorus-rich Hawthorne clay particles in this area. Five of the samples were collected along this northern edge, four others were spread out along the other banks, and one was collected in the center of the lake (Figure 5). Water quality parameters were also measured at the center sampling location (Table 4). The water was pea-soup green with a secchi disk visibility of 1.7 ft., and most of the sediment samples appeared to be highly organic with a dark brown coloring.

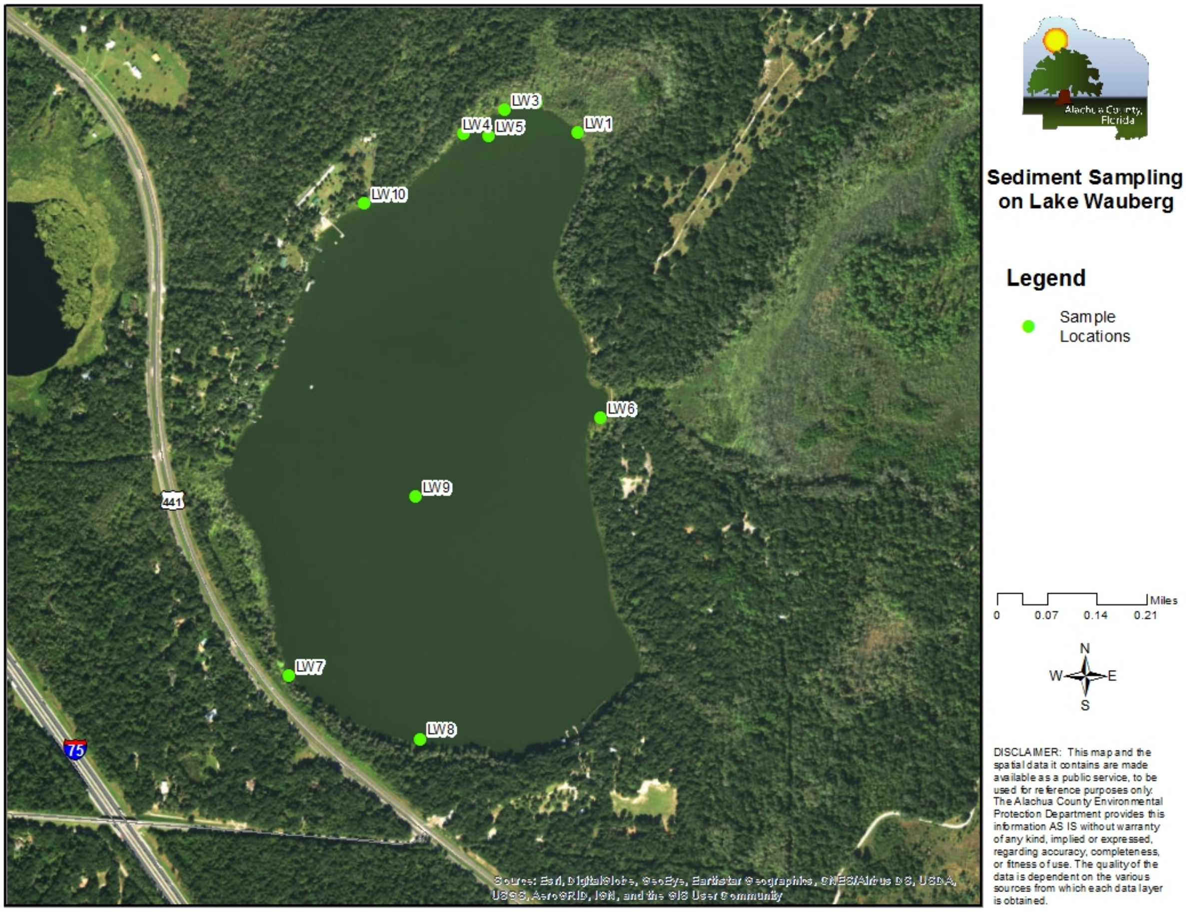

Figure 5: Lake Wauberg Sediment Sampling Locations, 6/22/2017 (Alachua County EPD, 2017)

4.2 Results

Sediment sample results are summarized in Table 3. Total nitrogen for sediment samples ranged from 760 mg/Kg at LW6 to 34,000 mg/Kg at LW9. Total Phosphorus ranged from 110 mg/Kg at LW6 to 3,000 mg/Kg at LW9, and Orthophosphate ranged from undetected at 1.0 mg/Kg at LW6 to 12 mg/Kg at LW4 (Alachua County EPD, 2017). Samples were analyzed by Test America in Savannah, Georgia. When the samples were received on 8/4/17, they had exceeded the recommended hold time, which is why they have the “Q” qualifier. A “U” symbol Indicates that the compound was analyzed for but not detected, while an “I” symbol indicates that reported value is between the laboratory method detection limit and the laboratory practical quantitation limit. Orthophosphate is often referred to as reactive or readily available fraction of phosphorus. Sequential extraction to determine organic phosphorus and iron and aluminum-bound phosphorus was not performed on these samples to further quantify potentially available pools of phosphorus.

Sample Location	Total Nitrogen (mg/Kg)	Soluble Nitrate/Nitrite as N (mg/Kg)	Total Phosphorus (mg/Kg)	Orthophosphate (mg/Kg)	Calcium (mg/kg)	Iron (mg/kg)	Magnesium (mg/kg)	Aluminum (mg/kg)
LW1	14,000 Q	12 I	390 Q	10 U	17,000	2,200	1,400	2,800
LW2	3,300 Q	5.9 U	130 I Q	6.7 I	14,000	3,300	1,100	1,500
LW3	11,000 Q	8.1 U	280 Q	8.7 U	11,000	1,600	900	1,100
LW4	13,000 Q	3.8 U	460 Q	12	11,000	1,800	860	1,800
LW5	11,000 Q	4.4 U	690 Q	4.8 U	4,200	1,900	350	2,000
LW6	760 Q	0.69 U	110 Q	1.0 I	140	28	13	140
LW7	4,000 Q	6.6 U	270 Q	7.0 U	14,000	4,000	1,200	2,200
LW8	970 Q	0.87 U	110 Q	0.93 U	240	94	28	110
LW9	34,000 Q	15 U	3,000 Q	16 U	8,400	4,100	900	5,700
LW10	120 Q	0.85 I	2,300 Q	4.4	77	64	10	560

Table 3: Sediment Sample Results

Compound_Name	Numeric_Result	Compound_Units
Total Phosphorus (as P)	0.134	mg/L
Sulfate	0.27	mg/L
Total Dissolved Solids	72	mg/L
pH for Color Analysis	7.8	SU
Total Nitrogen	2.3	mg/L
Sodium	7.6	mg/L
Magnesium	1.6	mg/L
Color	15	PCU
Alkalinity, Total	31	mg/L
Total Hardness (as CaCO3)	25	mg/L
Coliform Fecal	9	#/100 mL
Orthophosphate	0.002	mg/L
E. Coli	9	#/100 mL
Iron	0.18	mg/L
Total Suspended Solids	31	mg/L
Chlorophyll A	110	mg/m3
Chloride	13	mg/L
Potassium	1.1	mg/L
Total Organic Carbon	13	mg/L

Table 4: Water Quality Parameters at Time of Sediment Sampling

4.3 Discussion

Wang et al. (2015) have documented that the release rate of phosphorus is positively correlated with the total phosphorus (TP) concentrations in sediments. If further studies and modeling indicate internal loading as a major source of phosphorus input, these sediment results indicate that management efforts like chemical treatment should be focused in the northwest corner, center, and northern areas of the lake (LW10, LW9, and LW5, respectively).

According to Hickey and Gibbs (2009), high TP concentrations greater than 2,000 mg/kg, with an N:P ratio less than 6 in the upper 4 cm of lake sediments indicates a potential for significant internal nutrient cycling of phosphorus to support algal growth. These conditions are met at LW10 near the UF boat ramp, and one of the two conditions are met at LW9 at the center of the lake (greater than 2,000 mg/kg).

In 1976, a University of Central Florida (UCF) master's student measured vertical phosphorus profiles within the sediment of Lake Wauberg (Figure 6), noting the enigma of Lake Wauberg's highly eutrophic status and high sediment phosphorus content, despite the almost completely natural watershed setting (Stewart, 1976). Stewart's core was collected on the west side of the lake just north of the recreational area, which would best correspond to the location of LW10 in our study, and reaffirms the potential for high total phosphorus concentrations in this area.

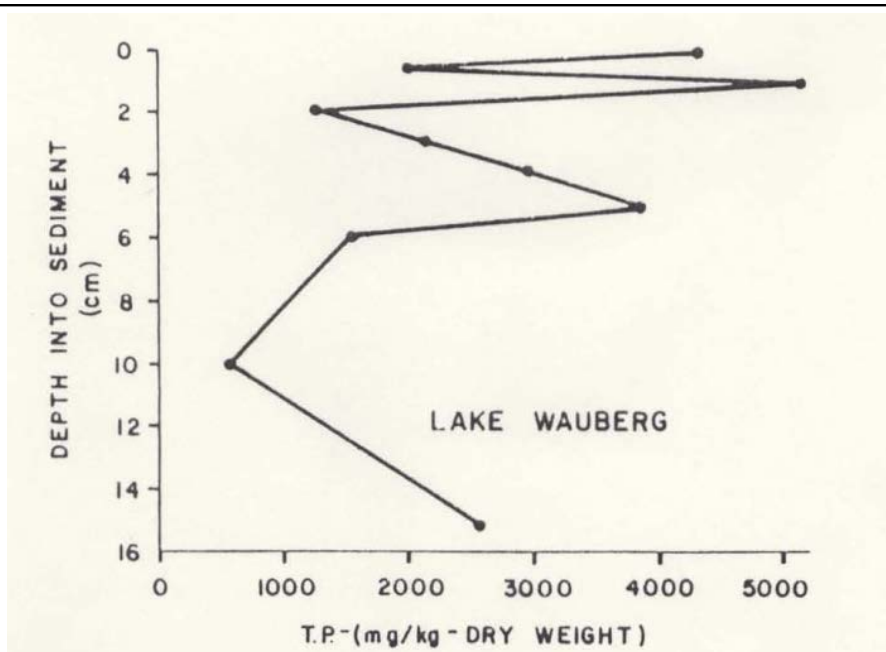

Figure 6: Sediment phosphorus profile for Lake Wauberg (Stewart, 1976)

Stewart (1976) hypothesized that historical phosphorus fluctuations as represented by measurements at different core depths, might indicate cycles of high productivity with a following increase in sedimentation and then anaerobiosis and regeneration. Sondergaard et al. (2003) suggest that in well-mixed eutrophic lakes with organic-rich sediment (as is the case with Lake Wauberg,) redox-dependent release of phosphorus can be particularly important because the oxic surface layer can be too thin to prevent release from deeper parts of the sediment. Sondergaard et al. (2003) also suggest that below an Fe:P ratio of 15, soluble phosphorus release from iron-bound particles can be more likely. This ratio is below 15 for all sediment samples in this study except for LW2, indicating the widespread potential for redox-sensitive phosphorus release in Lake Wauberg.

The sediment samples included in this report are from the organic-rich surface layer, and do not characterize any deeper sediment. Deeper sediment cores and porewater analysis would help to improve a more complete characterization of potential for nutrient release from sediments in Lake Wauberg. A method outlined by Ogdahl et al. (2014) involves collecting sediment cores and water immediately above sediments to determine phosphorus release rates, which could be useful for Lake Wauberg. Sequential extraction to determine bioavailable fractions of phosphorus within the sediments would also be useful.

Part V: Bird Surveys

5.1 Methods

Potential for additional phosphorus and nitrogen contributions from wildlife in the Lake Wauberg Watershed has been noted throughout the BMAP process, but not further characterized, to this point. Relatively large populations of vultures and evidence of their concentrated waste contributions have been commonly observed along the shores of the lake. According to long-term University of Florida Lake Wauberg employee Bill James, the vultures roost year-round at lake, and have been doing so for more than 25 years (personal communication, Bill James, 10/10/2017). To help quantify the potential nutrient loading from bird excrement to the lake, I have conducted several bird surveys from the water via canoe.

Manny et al. (1994) indicate the potential for birds to contribute significant nutrient loads to surface waters, particularly when large populations of birds roost on the lake but feed outside the lake's perimeter; researchers in the study found degraded water quality due to waterfowl at their research site in Wintergreen Lake, Michigan. A study by Hoyer and Canfield (1994) using data from 14 different Florida lakes found that the percentage of total annual phosphorus load contributed by bird populations under natural conditions was low, averaging 2.4%. In a study of black and turkey vultures by Coleman and Fraser (1987), the mean distances of feeding sites from the communal roost were 5.86 km (3.64 miles) and 7.75 km (4.82 miles), respectively; this would indicate that turkey and black vultures at Lake Wauberg are likely to feed outside of the watershed, bringing nutrients in when they roost. Due to the seemingly high abundance of vultures on Lake Wauberg relative to the lake size, and the potential for introducing nutrients from outside the watershed because of their foraging habits, a quantification of this nutrient source could be useful for TMDL discussions.

Four surveyors, including myself, were involved in multiple bird counts throughout the study period of 8/13/2017 – 10/29/2017. Each of us has had past experience conducting bird surveys within Florida State Parks, and we equipped ourselves with binoculars and field guides for bird Identification. Bird counts were obtained by paddling the perimeter of the lake by canoe and counting birds that were observed over the water and on the edge of the aquatic habitat. For each of the surveys, there were three surveyors present, and counts for each event were averaged between surveyors to help reduce counting error. Turkey vultures (*Cathartes aura*) and black vultures (*Coragyps atratus*) were the most commonly observed species. Due to their similarity in feeding habits, average weight, and the difficulty of distinguishing between the two species in the field when present in such high volumes, I have decided to lump these two species into one category of vulture. Both species weigh approximately the same (2,000 g) and feed on carrion; Coleman and Fraser (1987) also found that both of these species within their study foraged over much of the same area and in the same open habitats. Negligible counts of some smaller bird species were not included in calculations.

Mimicking the methods employed by Hoyer and Canfield (1994), average annual bird abundances (birds $km^{-2)}$, were calculated by averaging the counts taken in August, October, and

November; given that the time frame of the study was constrained to a 3-month period, the counts were not representative of all four seasons, which introduces error. This error is hopefully minimized by the fact that both of the most prevalent bird species, black vulture and turkey vulture, are present year-round in Florida and on this lake (Cornell Lab of Ornithology, 2017). Only birds on the lake or on the lake's edge were counted, representing a study area of 247 acres, or about 1 km^2. The annual total phosphorus and total nitrogen loads excreted by birds for the watershed ($kg\ km^{-2}\ yr^{-1}$) were then calculated by multiplying the average bird abundance for each species by the total phosphorus and total nitrogen defecation rates, and summing. Manny et al. (1994) calculated defecation rates of 0.49 $g\ day^{-1}$ P and 1.57 $g\ day^{-1}$ N for Canada Geese based on the mean number of droppings per day and mean proportion of nutrients by weight per dropping. To obtain the mean daily P and N loading rates for different species in this study, the goose defecation rates of P and N (above) were multiplied by the ratio of each species' average body weight to goose body weight (2.56 kg). Results of the surveys are summarized in Tables 5 and 6.

5.2 Results

As suspected, vultures were by far the most commonly observed species during all three surveys, with an average count of 148.7 birds. Anhingas and Great Blue Herons were the next most abundant species on the lake. Nutrient loading was calculated per species based on average weight as compared to the Canada Goose from Manny et al. (1994). With a lake area of about one square kilometer, total annual contributions of 78.43 kg/year total nitrogen and 24.35 kg/year total phosphorus are estimated from birds at Lake Wauberg. Based on total watershed loading calculated in the original TMDL document by Wu et al. (2003), this represents 4.3% of total nitrogen loading, and 7.2% of total phosphorus loading for Lake Wauberg.

Bird Species	8/13/17 (8:15 AM)	10/7/2017 (7:40 AM)	10/29/2017 (7:50 AM)	Average Bird Count	Average Species Weight (kg)
Vultures (*Cathartes aura & Coragyps atratus)*	74	202	170	149	2.00
American Crow (*Corvus brachyrhynchos)*	6	1	3	3.3	.470
Great Egret (*Ardea alba)*	2	1	2	1.7	1.00
Osprey (*Pandion haliaetus)*	4	0	0	1.3	1.70
Anhinga (*Anhinga anhinga)*	12	14	28	18	1.34
Green Heron (*Butorides virescens)*	4	0	0	1.3	0.24
Great Blue Heron (*Ardea herodias)*	3	4	7	4.7	2.30
Little Blue Heron (*Egretta caerulea)*	3	2	4	3	0.35
Snowy Egret (*Egretta thula)*	1	0	2	1	0.37
Bald Eagle (*Haliaeetus leucocephalus)*	0	3	2	1.7	4.65
Red-winged Blackbird (*Agelaius phoeniceus)*	2	0	3	1.7	0.06
Cormorant (*Phalacrocorax auritus)*	0	0	2	0.7	1.85
Kingfisher (*Megaceryle alcyon)*	0	0	3	1	0.16

Table 5: Bird Counts for Species Found within the Perimeter of Lake Wauberg on Three Survey Events

Bird Species	N defecation rate (kg N yr^{-1})	P defecation rate (kg N yr^{-1})	Average Bird Abundance (birds km^{-2})	Annual Total Nitrogen Load (kg km^{-2} yr^{-1})	Annual Total Phosphorus Load (kg km^{-2} yr^{-1})
Vultures (*Cathartes aura & Coragyps atratus)*	0.45	0.14	149	66.9	20.8
American Crow (*Corvus brachyrhynchos)*	0.11	0.03	3.3	0.36	0.10
Great Egret (*Ardea alba)*	0.22	0.07	1.7	0.37	0.12
Osprey (*Pandion haliaetus)*	0.38	0.12	1.3	0.49	0.16
Anhinga (*Anhinga anhinga)*	0.30	0.09	18	5.4	1.62
Green Heron (*Butorides virescens)*	0.05	0.02	1.3	0.07	0.03
Great Blue Heron (*Ardea herodias)*	0.51	0.16	4.7	2.40	0.75
Little Blue Heron (*Egretta caerulea)*	0.08	0.03	3	0.24	0.09
Snowy Egret (*Egretta thula)*	0.08	0.03	1	0.08	0.03
Bald Eagle (*Haliaeetus leucocephalus)*	1.04	0.32	1.7	1.77	0.54
Red-winged Blackbird (*Agelaius phoeniceus)*	0.01	0.003	1.7	0.02	0.01
Cormorant (*Phalacrocorax auritus)*	0.41	0.13	0.7	0.29	0.09
Kingfisher (*Megaceryle alcyon)*	0.04	0.01	1	0.04	0.01
TOTAL				**78.4**	**24.4**
% of Watershed Input				**4.3%**	**7.2%**

Table 6: Calculations for Annual Nutrient Loading from Birds

5.3 Discussion

Nutrient input from bird defecation within the Lake Wauberg watershed represents a significant contribution that should be considered in BMAP discussions. The vulture populations roost along the northwest tip of the lake, but can be seen flying and foraging throughout the surrounding area during the day. I suspect that the lower vulture count on

8/13/17 may have been partially due to the later start time, at which point many of the vultures had left their roosts and were more spread out and difficult to accurately count.

Because the diets of geese are very different from vultures, an average measurement of actual phosphorus and nitrogen concentrations in vulture waste, rather than a weighted ratio based on concentrations in goose droppings, would help to better quantify nutrient contributions from this source. More frequent bird counts over a year-long period would also provide a better characterization of the bird populations at Lake Wauberg.

Part VI: Potential Management Strategies & Future Studies

6.1 OSTDS Remediation

Internal loading should only be addressed once external nutrient sources have been adequately controlled; OSTDS has been identified as one of the only controllable anthropogenic sources in the Lake Wauberg Watershed. For OSTDS, there are technology choices available that can reduce specific contaminants more effectively than a conventional septic tank and drainfield system. Some performance-based treatment systems (PBTSs), can be engineered to meet a specified level of contaminant removal; these systems can employ complex technologies, such as fixed film and suspended growth, which are more efficient than conventional systems at reducing nitrogen and phosphorus concentrations in effluent (targeted reduction of 70%) (Cake et al., 2013) These advanced systems usually require engineer design, pumps and electricity, regular maintenance, an annual operating permit, and are much more expensive when compared to conventional systems that utilize gravity rather than electricity; if not properly maintained, PBTSs can also have inconsistent nutrient reduction capabilities.

The Florida Department of Health is working to standardize and approve lower-cost, low-maintenance technologies that can passively de-nitrify wastewater and reduce the amount of nitrate that leaves a septic system. The idea of passive nitrogen reduction involves using reactive media such as wood chips or sulfur for denitrification, and possibly a single liquid pump if necessary (Baranco et al., 2016). Illustration of these technologies and costs are illustrated in

Figure 7 below; there will be options for denitrification to occur within the tank, or in the drainfield (in-ground).

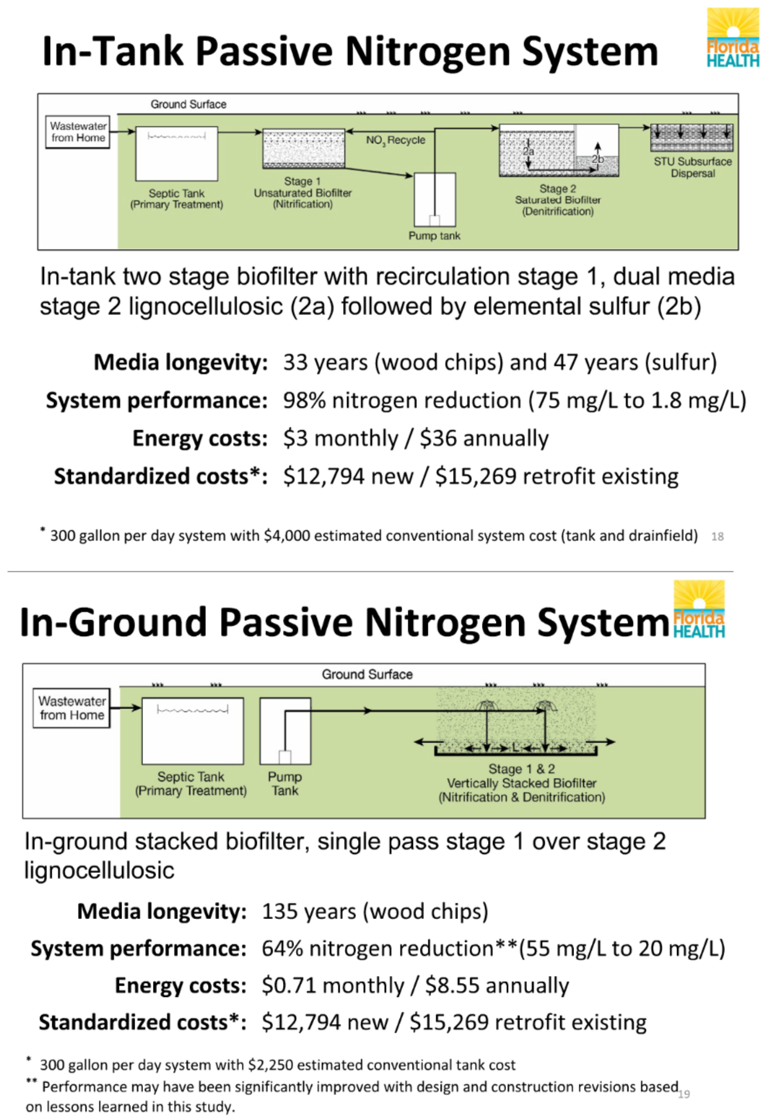

Figure 7: Passive Nitrate-reducing OSTDS Technologies (Baranco et al., 2016)

These new passive technologies have been installed and tested under real-life conditions, and have proven to be successful at significantly reducing nitrogen from wastewater, up to 95% (Scott and Armstrong, 2015). However, they are still more expensive to install than conventional systems, which have estimated life time costs of around $5,542.90 (Scott and Armstrong, 2015). Once the new technologies are approved, policymakers will need to decide how to implement them in TMDL basins and BMAP areas; they could be required upgrades to all systems within a designated basin, or possibly just when a new system is installed or an old system needs to be repaired. If these types of technologies are to be mandated for private homeowners, funding and education would be key to public acceptance and compliance.

Another policy option would be to require a minimum of 24 inches of separation between the bottom of a drainfield and the wet season water table on all septic system repairs, whereas right now it is only required for new septic systems in Florida. Depending on when the septic system was originally installed, the Florida rule currently can allow for as little as 6 inches of separation between drainfield and water table for repairs (Department of Health, 2013). The unsaturated zone beneath a drainfield is very important for treating wastewater contaminants through sorption, nitrification, and denitrification, as well as providing a buffer area to dilute contaminants and reduce the potential for leaching into groundwater. Policies for impaired watersheds could also require greater setback requirements from septic systems to surface waters to increase opportunity for soil sorption of phosphorus (current setback is only 50 ft.).

New septic systems being installed at Paynes Prairie will utilize conventional tanks and drainfields, rather than performance-based or nitrate-reducing technologies. One of these replacement systems will be helpful in reducing nutrient input from a system that is currently in failure at the park's campground; however, groundwater monitoring will be key to ensure that further treatment is not needed to protect water quality in Lake Wauberg.

6.2 Within-Lake Management

With minimal external inputs of nutrients to Lake Wauberg that can be controlled, it may be necessary to incorporate management strategies within the lake to help reach TMDL goals. One other external control that could be explored would be some sort of treatment such as reactive media or periodic sediment removal where drainage ditches and culverts discharge at the lake's southern edge near Highway 441.

Shumate (2004) notes that depletion of dissolved bioavailable nitrate and ammonia in a phosphorus-rich environment could lead to proliferation of nitrogen-fixing cyanobacteria; therefore, it may be prudent to prioritize phosphorus reduction or concurrent nitrogen and phosphorus reduction in this lake. Methods to control nutrient concentrations in the lake water could include incorporation of more submerged aquatic vegetation or floating treatment wetlands, chemical treatments to increase phosphorus sorption, removal of benthivorous fish like shad that stir up sediment, hypolimnetic aeration, and dredging of nutrient-rich sediment.

To avoid upsetting natural conditions in the lake, low-impact management strategies such as planting vegetation or treatment islands may be good tools to start with. Most of the perimeter of Lake Wauberg is already well-vegetated, but additional planting of species such as Egyptian paspalidium (*Paspalidium geminatum*) and giant bulrush (*Schoenoplectus californicus*) can help with uptake of nutrients, filtering runoff, stabilizing the lake bottom, and reducing sediment resuspension (Lippincott, 2015). Manufactured floating treatment wetlands provide an innovative approach to assimilate nutrients and filter out particulate material. In these structures, vegetation is usually planted in plastic material with peat, and anchored to the lake bottom. Plant roots grow through the plastic and provide surface area for microorganisms to thrive; the microbes sequester phosphorus and the wetland acts as a sink for nutrients (Lubnow, 2014). This is a low-maintenance technique that could help improve water quality at Lake Wauberg.

Further characterization of bioavailable phosphorus pools, rather than just total phosphorus, should be conducted before incorporating management strategies that attempt to control internal loading of phosphorus. Chemical methods such as alum (aluminum sulfate) application aim to increase sedimentation of phosphorus and reduce the potential for internal loading and phosphorus release. Alum and similar agents can sequester soluble reactive phosphorus, trap algae, and cap sediments to clarify the lake and shift algal assemblage away from potentially toxic cyanobacteria (Hickey, 2009). This has been proven a successful and low-cost treatment that can be effective for 5-20 years, but potential aluminum toxicity and effects on benthic communities should be considered. Laboratory testing on sediment cores and pilot studies should be conducted before this type of management strategy is implemented. Based on sediment results included in this project, the northwestern, central, and northern portions of the lake could be prioritized for this type of treatment.

Araujo et al. (2016) found that Polyaluminum chloride (PAC) addition can be used as a successful restoration strategy to remove algal biomass from the water column. In their study, removal of benthivorous fish was also found to significantly reduce chlorophyll *a* and phosphorus concentrations in the water; a combination of these two techniques was suggested for optimum results. An attempted gizzard shad harvesting project at Newnan's Lake in Alachua County was discontinued due to depletion of funds, with inconclusive results; more detailed sediment studies and procurement of long-term funding would be needed for this type of project to be successful at Lake Wauberg.

If stratification and periods of anoxia at the sediment surface are determined to occur frequently within Lake Wauberg, hypolimnetic aeration could be considered to decrease the potential phosphorus release from sediments. This would involve blowing air along the lake bed, limiting the release of both nitrogen and phosphorus to the water column; this method is likely to only treat the symptoms of eutrophication in the short-term, and degraded water quality could return when the process is complete if the underlying issues have not been solved (Hickey, 2009).

Whole-lake sediment dredging can be cost-prohibitive, with inconsistent results. Judging from Stewart's sediment cores from 1976, high phosphorus concentrations endure all the way down to 15 cm and possibly further, making this a difficult option for lake restoration. There is also the potential for further nutrient release due to resuspension during the dredging process.

6.3 Re-evaluate TMDL

Management goals for Lake Wauberg are currently based on allocations set forth in the 2003 TMDL document. More recent data and modeling procedures, including for septic, watershed area delineation, atmospheric deposition calculations, and internal loading, could warrant a re-evaluation of nutrient loading allocations and pollutant reduction goals. Sediment samples and bird survey data included here could also serve to support future studies and evaluations of nutrient loading in the Lake Wauberg Watershed.

In some Florida lakes, the natural background trophic state index (TSI) can be different than 60; where paleolimnological data indicate that the background condition for a lake is greater than 60, a higher site-specific threshold could be developed to reflect more attainable pollutant reduction goals (Wu et al., 2003). A study of historical nutrient and chlorophyll *a* concentrations in sediment cores would be a useful tool in trying to determine whether background conditions are set appropriately. If the watershed area is adjusted to reflect a larger area as indicated previously, this would also have an effect on determination of background TSI for Lake Wauberg.

6.4 Future Studies

Several areas of future study in this watershed have been presented already, including further characterization of bioavailable phosphorus pools in sediment, surveys of potential sources of Hawthorn sediment erosion within the watershed, and groundwater studies at locations surrounding Paynes Prairie septic systems; groundwater studies at UF's septic systems have also been proposed in recent BMAP meetings.

Natural groundwater phosphorus contribution is another area that should be further investigated. Measurement of nutrient fluxes between groundwater inputs and exports could provide some indication of loading potential from that source. In Newnan's Lake, Long (2009) has noted that fluoride can be used as a natural indicator of geologically-derived phosphorus because weathering of Hawthorn sediments releases both phosphate and fluoride. DEP and Alachua County EPD have also discussed phosphorus isotope tracing studies as another method to determine whether phosphorus in Lake Wauberg is of geologic origin. Chloride is another compound that could be further evaluated, as an indicator of anthropogenic contamination; chloride is readily leached through soil, and is a common constituent in human waste, fertilizer, and road deicing agents (Mcginley and Turyk, 2003).

Further studies on nitrogen fixation potential in the lake would also help to inform management decisions. Speciation of cyanobacteria to determine the percentage of species that are capable of nitrogen fixation could help estimate the input from that source; species in the genera *Anabaena, Aphanizomenon*, and *Cylindrospermopsis* are likely to contribute loading via nitrogen fixation. Evaluation of stable nitrogen isotopes can also be used as an indicator of nitrogen fixation (Gu et al., 2006).

Part VII: Conclusions

Determination of nutrient inputs and cycles within a watershed is a very complex process. Nutrient load allocations from the original 2003 TMDL document should be re-evaluated before pursuing management strategies in the Lake Wauberg watershed. More recent topological mapping indicates that the watershed may be much larger than originally designated (3,000 acres vs. 717 acres); this would affect land use classes that are included in runoff calculations, as well as background TSI, and onsite sewage disposal calculations. Determinations of nutrient contributions from OSTDS in the original TMDL did not include data for Paynes Prairie Preserve State Park, and may underestimate soil attenuation of effluent phosphorus. Minor wastewater contributions from the Camp McConnell package treatment, as well as legacy inputs from past land uses could also be considered. Methods for calculating atmospheric deposition may need to be updated to reflect current data as well. Enhanced technologies or targeted policies for septic systems within the watershed could help to reduce the impacts of anthropogenic nutrient loading to Lake Wauberg.

Natural processes such as wildlife inputs and bioturbation, nutrient release during basin formation, groundwater inputs, interactions with the Hawthorn Formation, internal loading, and nitrogen fixation could all play roles in the trophic status of this lake. If the background TSI of the lake could be raised to reflect naturally eutrophic conditions, nutrient reduction may be more achievable given the limited external inputs that have been identified. An internal loading component could also be included in load allocation calculations. Nutrient input calculations from bird surveys, as well as sediment data included in this paper could be considered for future BMAP evaluations. Within-lake management strategies can reduce nutrient concentrations for a more well-balanced ecosystem once external inputs are controlled as much as possible. If nutrient levels in the lake cannot be further reduced, continual monitoring of water quality and algal blooms should still be undertaken for the protection of recreational bathers and public health.

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