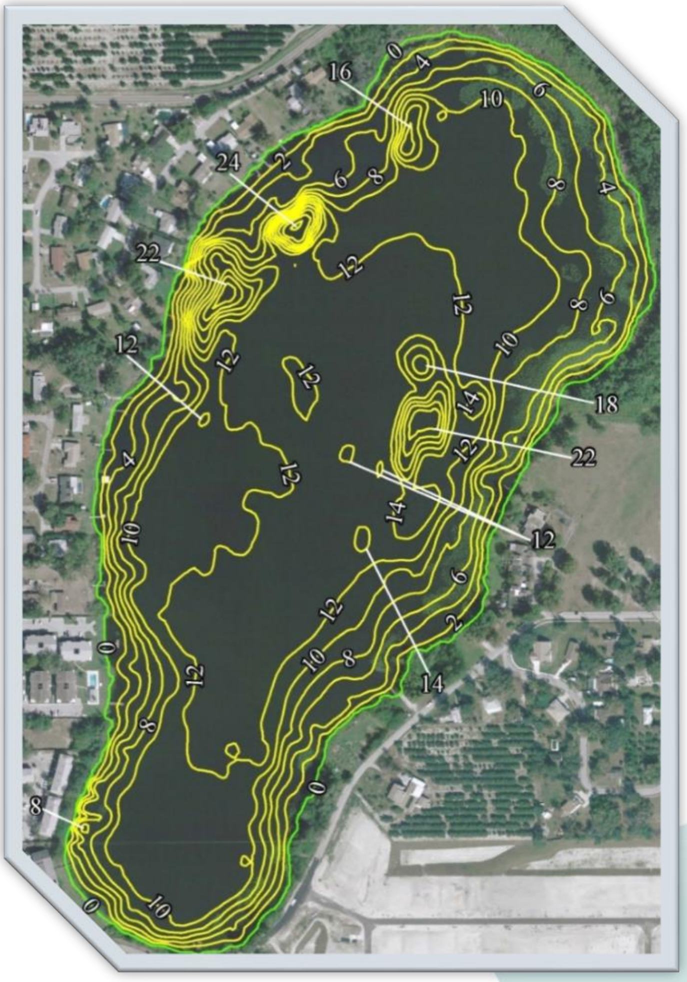
# Lake Buckeye Water Quality Management Plan




**Prepared for:**
Polk County Parks and Natural Resources Division

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**Prepared by:**

# Executive Summary

There are over 500 named lakes in Polk County (County). The lakes provide many benefits and enhance recreational, commercial, and aesthetic opportunities as well as property values. However, many lakes have become ecologically degraded and do not meet their designated uses and appropriate water quality standards. Excess nutrient inputs to lakes are frequently, but not always, the cause of degraded conditions. Nutrient enrichment is one of the leading causes of water quality impairment in the County and the entire nation and the quantity of nutrients reaching surface waters has dramatically escalated over the past decades (EPA 2009). Nitrogen and phosphorus loadings to a water body can impact water quality by stimulating plant and algae growth which subsequently may result in depletion of dissolved oxygen, degradation of habitat, harmful algal blooms, impairment of a water body's designated uses, and impairment of drinking water sources (WERF 2010).

The County recently completed two studies intended to identify reasonable approaches to protect and improve the quality of the County's lakes and to prioritize the lakes further evaluation (Atkins, 2013; Atkins and ESA, 2014). Lake Buckeye, the lake examined in this Water Quality Management Plan (WQMP), is one of 12 priority lakes identified in prior studies. The purpose of this study is to:

- Review relevant data and information to develop an understanding of the existing conditions of the lake and basin;
- Develop a Geographic Information Systems (GIS)-based map series of the lake and watershed;
- Conduct analyses of water quality data and review existing reports to determine if nutrients are a likely cause of lake impairment;
- Examine other factors that may affect lake condition;
- Based on the results of the analyses, identify management activities that can be expected to improve lake water quality;
- Compare the potential actions to determine those most likely to improve lake water quality.

Results from this WQMP will be used by the County to prioritize structural and non-structural management actions for Lake Buckeye. One of the primary features of this WQMP was the recommendation of scientifically based methods for managing lakes as integrated ecological systems, rather than managing based on external nutrient loads alone. Recommendations were made in consideration of management projects implemented in the past that have had successful, documented system responses.

**Findings:**

- Lake Buckeye is a 63 acre lake located within the City of Winter Haven, associated with the Winter Haven Ridge formation. The contributing watershed is 217 acres which was historically comprised predominantly of citrus farming activities. A substantial elevation gradient occurs within the watershed ranging from 123 to 186 feet North American Vertical Datum (NAVD 88).
- The dominant soils within the watershed have a low runoff potential with high infiltration rates and are classified as hydrologic soil group A or A/D.
- There is a substantial accumulation of organic material on the lake bottom which cannot be attributed to existing or historical point source discharges.
- The majority of the lake shoreline presents evidence of limited aquatic vegetative maintenance due to a mixture of existing native and exotic submerged and emergent macrophytes. A portion of the western lake shoreline has been modified due to adjacent residential development that includes landscaping and hardened shorelines.
- Lake Buckeye was declared impaired for nutrients due to its elevated Trophic State Index (TSI) during the January 1, 2002 to June 30, 2009 verified period as part of the Group 3, Cycle 2 review.
- Lake Buckeye is considered a clear, alkaline lake based on a long-term geometric mean color of 17 Platinum-Cobalt Units (PCU) and alkalinity of 67 milligrams per liter (mg/l).
- An evaluation of the water quality within Lake Buckeye using the Numeric Nutrient Criteria (NNC) was not consistent with the initial impairment determination and indicated that Lake Buckeye was not impaired for Total Nitrogen (TN) or Total Phosphorus (TP).
- Improving water quality trends were observed in chlorophyll a, TN, TP and Secchi disk depth.

- Chlorophyll-a concentrations are significantly correlated with both nutrients and management of TN and TP is more likely to result in sustained water quality improvements.
- Groundwater nutrient loading, which appears to largely be driven by the abundance of citrus within the immediate watershed, correlates most strongly with changes in water quality.
- Ambient TN concentrations correlate with annual rainfall indicating that groundwater inflow and/or stormwater runoff could contribute to phytoplankton blooms.

**Recommendations:**

- Pursue removing Lake Buckeye from the 303(d) list based on documented water quality improvements independently verified by the Florida Department of Environmental Protection (FDEP).
- Continued monitoring of surface water quality conditions will be necessary to identify future trends in water quality conditions.
- Measure ambient groundwater nutrient concentrations and water elevations in shallow wells representing various land use types to improve groundwater loading estimates
- Maintain/control submerged and emergent aquatic vegetative growth, which will need to include a vegetative monitoring event to document the percent area covered by submerged aquatic vegetation.
- Implement low impact developments.
- Reduction of direct stormwater run-off loading to the lake.
- Continue/enhance efforts to inform the public of Best Management Practices (BMP's) focused on maintaining water quality in Lake Buckeye, which could serve as a tool to link individual stakeholder's' actions to their waterbody.
- If water quality degradation is observed, the implementation of artificial circulation could be used to reduce phytoplankton abundance and;
- The delineation of MS4 sub-basins to quantify the relative contribution of the nutrient loads from each respective source.

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# 1. Project Background

There are over 500 named lakes in Polk County (County), Florida. The lakes provide many benefits and enhance recreational, commercial, and aesthetic opportunities as well as property values. However, many lakes have become ecologically degraded and do not meet their designated uses and appropriate water quality standards. Excess nutrient inputs to lakes are frequently, but not always, the cause of degraded conditions.

Nutrient enrichment is one of the leading causes of water quality impairment in the County and the entire nation, and the quantity of nutrients reaching surface waters has dramatically escalated over the past decades (United States Environmental Protection Agency (EPA) 2009). Nitrogen and phosphorus loadings to a water body can impact water quality by stimulating plant and algal growth which subsequently may result in depletion of dissolved oxygen, degradation of habitat, harmful algal blooms, impairment of a water body's designated uses, and impairment of drinking water sources (WERF 2010).

The County recently completed two studies intended to help identify reasonable approaches to protect and improve the quality of the County's lakes (Atkins 2013; Atkins and ESA 2014). The specific objectives of the reports were to:

- Evaluate the status of the County's public access lakes that have been determined to be impaired by the Florida Department of Environmental Protection (FDEP) under the Florida Trophic State Index (TSI) standards, using the recently-adopted Numeric Nutrient Criteria (NNC) to determine impairment.
- Review and critique existing draft and final Total Maximum Daily Loads (TMDL) developed by either FDEP or the EPA for lakes in the County.
- Develop lake-specific nutrient criteria.
- Develop and implement a methodology to prioritize public access lakes for further ecological assessment.

The prioritization process developed was utilized to examine 97 lakes for the following criteria:

- Existence of a TMDL or Basin Management Action Plan (BMAP);
- Lake size;
- Potential cooperative partners;
- Socio-economic benefits;
- Number of County-maintained stormwater outfalls discharging to the lake, and the relative proportion of the lake drainage basin draining to the outfalls;
- Frequency of water quality exceedances using NNC;
- Water quality trends.

Using the above criteria, a "long list" of 34 lakes was recommended for further evaluation. Using additional criteria, a "short list" of 12 lakes was selected to have water quality management plans (WQMP) developed during FY2014 – 15. The lake examined in this WQMP, Lake Buckeye, is one of the 12 priority lakes selected.

The purpose of this study is to:

- Review relevant data and information in order to develop an understanding of the existing conditions of the lake and basin;
- Develop a Geographic Information System (GIS)-based map series of the lake and watershed;

- Conduct an analyses of water quality data and review existing reports to determine if nutrients are a likely cause of lake impairment;
- Examine other factors that may possibly affect lake condition;
- Based on the results of the analyses, identify management activities that can be expected to improve lake water quality;
- Compare the potential actions to determine those most likely to improve lake water quality.

The results of the work contained in this WQMP are the next step in the process that was initiated by the lake ranking. Results will be used by the County to prioritize structural and non-structural management actions for priority lakes.

One of the primary features of this WQMP will be the recommendation of scientifically based methods for managing lakes as integrated ecological systems, rather than managing based on external nutrient loads alone. Recommendations will also be made in consideration of management projects implemented in the past that have had successful, documented system responses.

While traditional stormwater treatment projects can successfully reduce external nutrient loadings to lakes, historical point and nonpoint source runoff and subsequent sediment accumulation in some lakes may have resulted in internal nutrient loads that traditional stormwater projects cannot treat. In addition, traditional stormwater treatment would not be expected to reduce groundwater inputs which might be substantial depending on local hydrologic conditions and overlying land uses. Consequently, both traditional and non-traditional water quality management projects will be proposed to address both external and internal nutrient loading to Lake Buckeye in this WQMP.

In addition to nutrients and chlorophyll-a, factors affecting water quality in Lake Buckeye may include long-term land use and hydrologic alterations, stormwater runoff, historical point source discharges (particularly phosphorus), extent of submerged aquatic vegetation (SAV) and emergent aquatic vegetation (EAV), lake water levels, and hydrologic connections to forested wetlands and other lakes. These components will be included as part of a lake management approach for Lake Buckeye. The link between water quality issues and lake-specific water quality restoration projects for Lake Buckeye will be presented in the context of state and federal regulations (e.g. TMDL status).

# 2. Data Inventory

This WQMP incorporates available information and previously completed water quality studies. This additional information was used to evaluate alternatives and best management practices that could be implemented to improve water quality. Sources of pollution, including stormwater, point sources, sediments, groundwater, and septic tanks were considered in the plan. This section presents a summary of the data used to characterize Lake Buckeye water quality and its watershed.

## 2.1. Surface water quality

Surface water quality data from the FDEP Impaired Waters Rule database (Run 49) was provided in a spreadsheet. At minimum, potential eutrophication-related empirical relationships were investigated for the below interactions:

- Correlations between total nutrients and chlorophyll-a
- Correlations between inorganic nutrients and chlorophyll-a
- Correlations between nutrient concentrations and dissolved oxygen
- Correlations between chlorophyll-a and Secchi disk depths.

## 2.2. Groundwater levels

The groundwater level data in a monitoring well (RIDGE WRAP P-2 SURF, site ID 25380), located approximately 0.8 mile north-northwest of the center of Lake Buckeye, are available from March 1992 through the present and are available in electronic format. These data were provided by the Southwest Florida Water Management District (SWFWMD) and were graphed to show changes in water level over time and changes potentially related to rainfall.

## 2.3. Surface water levels

The surface water elevation data from a gage (site ID 25382), located in the north side of Lake Buckeye, were also provided by the SWFWMD and were available from November 1985 through the present in electronic format. These data were graphed to show changes over time and changes potentially related to rainfall.

## 2.4. Rainfall

The daily rainfall data from collection site ROMP 73 WINTER HAVEN, site ID 25167, located approximately 2.4 miles southwest of the center of Lake Buckeye, and are available from June 1998 through the present. These data, provided by the SWFWMD, are available in electronic format and were graphed to present changes over time and rainfall’s potential effect on other characteristics such as surface water levels and surface water quality.

## 2.5. Soil classification

The classifications of the soils within the Lake Buckeye watershed were available from the Natural Resources Conservation Service (NRCS) in GIS format. The information includes the drainage class, infiltration rate, hydrologic group, water transmission rates of the soil classes in the watershed, and the number of acres each class occupies. These data were used to provide relevant information on the transmission of constituents (nutrients, water) from the watershed.

## 2.6. Land use

Land use data were available (from the SWFWMD) for the Lake Buckeye watershed for several years from 1974 through 2011 in GIS format. These data were used to show changes in land use over time to demonstrate changes in development within the lakes' watershed and to calculate nutrient loadings from off the watershed.

## 2.7. Bathymetry

Bathymetry data (provided by the County) for Lake Buckeye were available and used to calculate an approximate volume of the lake and are available in GIS format.

## 2.8. Aerial photography

Aerial photography was available for the Lake Buckeye watershed from 1941 through 2011. This photography was used to indicate the changes in land use over time. Aerial photography was provided by Land Boundary Information System (LABINS, www.labins.org) and the University of Florida (http://ufdc.ufl.edu/aerials).

## 2.9. Onsite sewage treatment and disposal system

The locations of onsite sewage treatment and disposal systems (OSTDS) were provided by the County and are presented as an overlay on a map of the Lake Buckeye watershed. These data are reflective of only the permitted OSTDS and therefore, were used as an approximate accounting of OSTDS in the watershed or modified as appropriate.

## 2.10. Sanitary Sewer

Sanitary sewer, stormwater and lift station data were requested and received from the City of Winter Haven. The data are available in GIS format which allowed for the geographical display of all connections.

## 2.11. Submerged aquatic vegetation treatment

The history of treatment for SAV in Lake Buckeye was provided in a summary report from the County. This data describe the efforts to control the growth of hydrilla (*Hydrilla verticillata*) and cattails (*Typha* spp.).

## 2.12. Municipal separate storm sewer systems outfalls

The location of Municipal Separate Storm Sewer Systems (MS4) outfalls were provided in electronic format by the County. The MS4 outfalls provided relevant information on the direct discharge of stormwater into Lake Buckeye.

## 2.13. Pollutant loadings

A pollutant loading modeling spreadsheet for MS4's in Polk County was provided in Excel format by AMEC Foster Wheeler., A similar method was used to develop stormwater loading estimates for Lake Buckeye. In addition, atmospheric loadings was developed using a spreadsheet model provided by Janicki Environmental. A spreadsheet model patterned after that used by Janicki Environmental for Charlotte Harbor was used to develop OSTDS loadings after adjustment for local conditions as suggested by Polk County.

## 2.14. Watershed delineation

The County provided the watershed delineation for Lake Buckeye in electronic format which was used for characterizing the adjacent watershed.

## 2.15. Additional reports

Atkins has previously provided Polk County with two reports concerning water quality in the county's lakes: "Prioritizing Future Actions Related to Impaired lakes and the FDEP TMDL Program" (Atkins and ESA 2014) and "Evaluation of FDEP Verified Impaired List for Lakes and Streams within Polk County" (Atkins 2013). Additionally, Lake Buckeye was evaluated as part of the "Interior Lakes Water Quality Management Plan, including the Development of Water Quality Goals and Potential Restoration Projects, and Review of NPDES MS4 Permits, TMDLs, and NNC" Atkins 2011. These reports were reviewed to incorporate relevant information related to the status and trends of the water quality within the lake.

## 2.16. Digital Elevation Model

The digital elevation model (LiDAR) data, provided by the SWFWMD, provides topographic data for the Lake Buckeye watershed. The data was presented in graphics as well as summarized in tabular format.

# 3. Historical and recent conditions in lake and watershed

An evaluation of the historical and current conditions of the lake and watershed was performed by reviewing and synthesizing existing information and conducting a site visit. At a minimum the following characterizations were performed:

- Significant changes in land use, hydrology (groundwater and surface water), water quality, and habitat
- Summarize water quality issues (impairment, trends, etc.) and potential sources of pollution
- Summarize and critique previous studies, reports, TMDLs

Lake eutrophication in general is a natural process whereby nutrient enrichment and biological productivity increase. Lake eutrophication can be exacerbated by anthropogenic land uses (Gill et al. 2005) or other anthropogenic activities. The accelerated eutrophication due to human activities is termed “cultural eutrophication”. Increased nutrients associated with eutrophication can increase algal growth (algal blooms) (Smith et al. 1999), in turn increasing turbidity, particulate organic matter, and dissolved organic matter in lakes. Historical water quality patterns in Lake Buckeye, the implications of relevant state and federal regulations for water quality restoration, and water quality were characterized, thereby establishing the need for management projects. If insufficient data or data gaps are identified that could affect the successful development of a WQMP, the County will be notified and recommendations of additional monitoring efforts will be provided.

Many factors may influence in-lake water quality including: long-term hydrologic alterations, stormwater runoff, historic and current point source discharges, septic tank discharge, accumulated sediment, extent of submerged aquatic vegetation (SAV) and emergent aquatic vegetation (EAV), and hydrologic connections to forested wetlands. The potential effects of these factors on water quality (e.g., nutrient enrichment, algal growth, transparency, etc.) in Lake Buckeye were investigated in this effort.

Physical and chemical characteristics specific to Lake Buckeye are presented here in the context of relevant regulatory criteria and requirements. Although we are aware of no specific studies done explicitly on Lake Buckeye, the lake was included in the Interior Lakes WQMP developed for the City of Winter Haven in 2011 (Atkins 2011). The Florida Department of Environmental Protection (FDEP) designated the Lake impaired using the Trophic State Index (TSI) as a metric of impairment in 2005 (FDEP 2014). However, the data analysis completed as part of the Interior Lake WQMP reported insufficient water quality data at the time to determine compliance with the Numeric Nutrient Criteria (NNC); as such, potential water quality restoration projects were not recommended. Subsequently, Atkins (2013) and Atkins and ESA (2014) evaluated Lake Buckeye’s impaired status for Polk County as part of a comprehensive study of lakes and streams within the County. Sufficient data were available to determine the lake would not be classified as “impaired” when compared to the NNC.

## 3.1. Lake description

Lake Buckeye is located in central Polk County within the City of Winter Haven (Figure 3-1) at an elevation of 123 feet NAVD. The lake occurs within the Winter Haven/Lake Henry Ridges lake region of Florida which according to Griffith et al. (1997) contains small to medium sized lakes that can be “characterized as alkaline, moderately hard-water lakes of relatively high mineral content, and are eutrophic” The lake is hydrologically connected to Lakes Idyl and Gem and discharges to Lake Fannie through a slough along the north-eastern portion of the lake. A review of historical aerial photography (1941) indicates that the shoreline has been modified compared to recent (2011) photography (Figures 3-2 and 3-3). The most extensive wetland extent is located along the northern rim that is part of the slough system which interconnects Lakes Buckeye and Fannie.

The lake is 63 acres in size with a perimeter of approximately 7,988 feet. The median water depth (9.7 ft) and volume (684 acre-feet) statistics are based on a water level elevation of 128 feet in June 2007 (Table 3-1). Overall, the watershed to lake surface area (3.4) is lower than an average ratio of 10:1, indicating that the watershed influence on lake water quality may be reduced. Additionally, the surface area to lake volume (0.10) can be used as a metric to evaluate the potential for increased primary production and nutrient cycling between the water column and sediments (Scheffer 1998). For Lake Buckeye, the lake surface area is relatively small in relation to the volume; suggesting that nutrient cycling may be less pronounced than in a larger lake of similar water depth. Bathymetry data are available for Lake Buckeye based upon February 2010 water level elevations (Figure 3-4). A water level of 128.1 feet was reported in March 2015, reflecting a minor increase in water elevation when compared to 2007. The subsequent changes in overall surface area, water depth, and volume of the lake should be considered during the development and implementation of water quality restoration projects. It is important to note that the watershed delineation prepared for the Interior Lake WQMP which eliminates the portion associated with Lake Idyl and Gem Lake was used to characterize the Lake Buckeye watershed (PBSJ 2011). An evaluation of lake water elevations in Lakes Buckeye, Gem and Idyll indicate that Lakes Gem and Idyll are staged at higher water elevations (Figure 3-5). Therefore, under the appropriate conditions (e.g., water elevation, rainfall), water from these lakes could discharge toward Lake Buckeye.

There are no current or historical wastewater discharges to the lake. However, there is an accumulation of organic material on the lake bottom. An investigative sediment sampling effort by Atkins/ESA staff on April 21, 2015, identified that the lake contained variable depths of organic material on the lake bottom ranging from 0 to over 5 feet. Sediment samples were analyzed by Mote Marine Laboratory in Sarasota, Florida, for nutrient composition and percent organic material. Results from the sediment sampling event are presented in Section 4. Profiles of the water column taken in April 2015, indicate a well-mixed and oxygenated water column to the lake bottom (top of muck layer). Secchi depth readings was approximately 2 meters throughout the lake.

As reported by Polk County, emergent species found in Lake Buckeye includes: spadderdock lily (*Nuphar advena*), cattail (*typha* spp.), burhead sedge (*Oxycaryum cubensis*) as well as various grass species that occur around the shoreline. Lake Buckeye also has an extensive community of submersed species including, but not limited to: coontail (*Ceratophyllum demersum*), hydrilla and eel grass (*Vallisneria Americana*). Additionally, Atkins/ESA identified the following species during a site visit completed in April 2015: evening primrose (*Ludwigia* spp.), torpedo grass (*Panicum repens*), pickerelweed (*Pontederia cordata*), water pennywort (*Hydrocotyl* sp.), parrot feather (*Myriophyllum aquaticum*) and alligator flag (*Thalia geniculata*). The lake is surveyed on a regular basis for hydrilla and spot treatments of aquatic herbicides are applied as needed (Figure 3-6). The entire lake was treated as part of a hydrilla management effort in June of 2013, which effectively removed the hydrilla without detriment to the desirable vegetation (eel grass and coontail). Additional management was performed in August 2014 to treat a narrow band of hydrilla along the western shoreline.

A western portion of the shoreline has been modified as a result of residential encroachment which included landscaping activities and hardened shorelines (Figure 3-7). The majority of the lake shoreline receives limited maintenance for exotic and nuisance vegetative growth due to the amount and composition of existing nuisance and exotic submerged and emergent vegetation (Figure 3-7). The only evident region of wetlands is present at the connection to Lake Fannie (Figure 3-7).

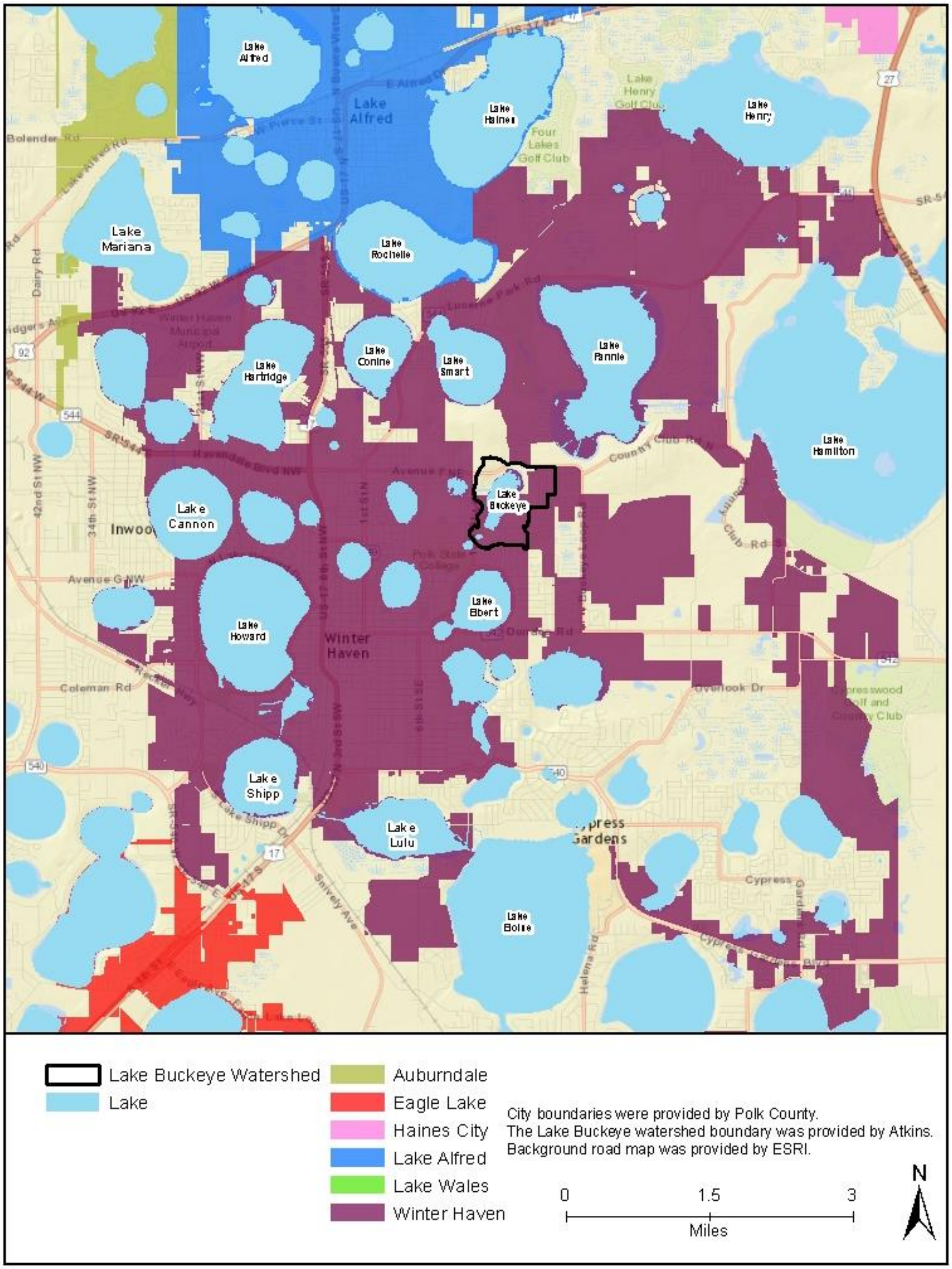


**Figure 3-1 Lake Buckeye and Adjacent Watershed Location Map.**


**Figure 3-2 Historical Aerial (1941) of Lake Buckeye and Adjacent Watershed.**

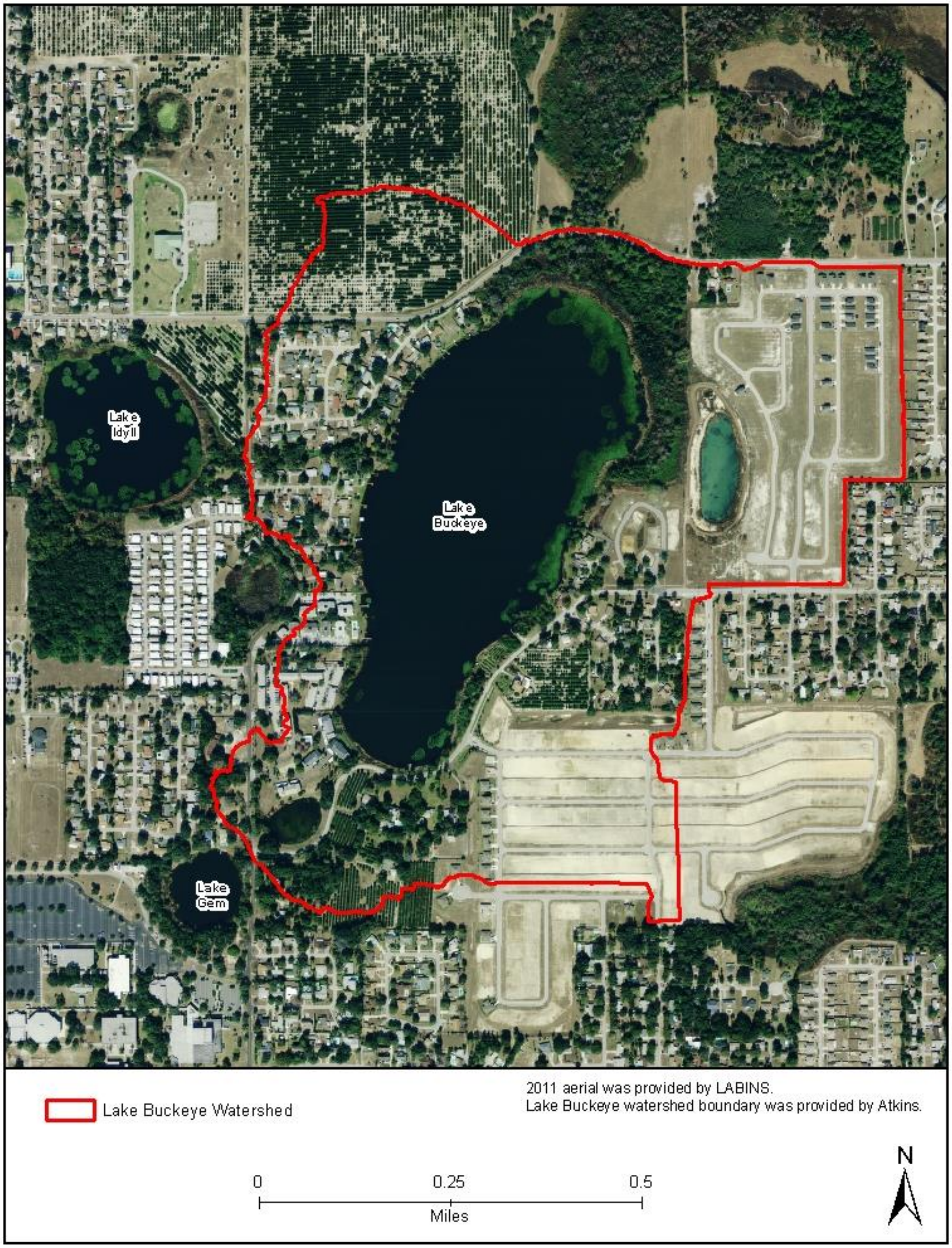


**Figure 3-3 Recent Aerial (2011) of Lake Buckeye and Adjacent Watershed.**

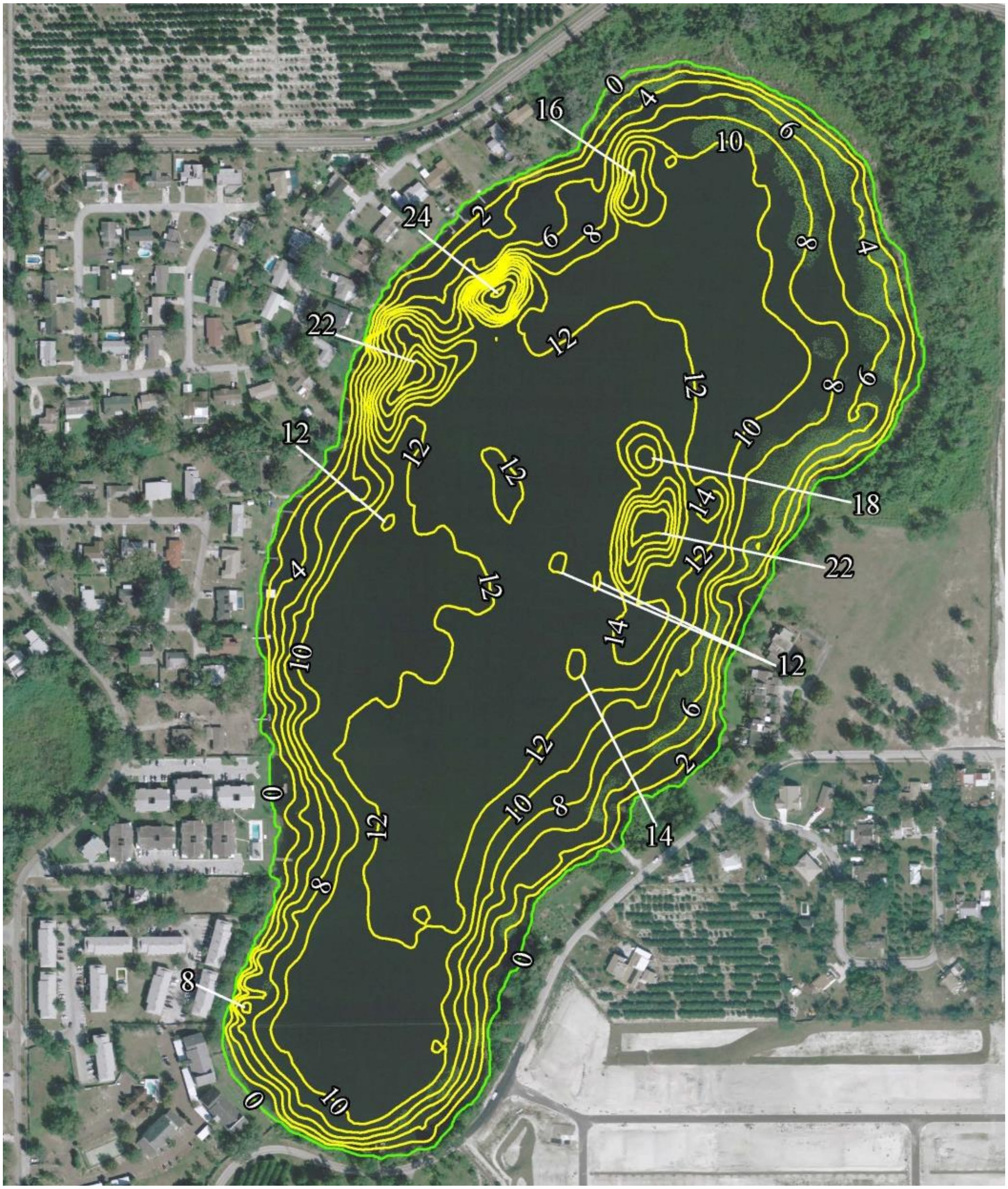

**Figure 3-4 Lake Buckeye Bathymetry Based Upon February 2010 Water Level Elevation (Source: Florida Center for Community Design and Research, Univ. South Florida, 2010).**

**Table 3-1 Physical Characteristics of Lake Buckeye and Adjacent Watershed**

| Physical | | | |
|---|---|---|---|
| **Location** | City of Winter Haven; Polk County | **High infiltration soils (acres)** | 203 |
| **Relation to other lakes** | Connected to Lakes Fannie, Gem and Idyl | **Developed land (acres)** | 96 |
| **Watershed area (acres)** | 217 | **Undeveloped land (acres)** | 121 |
| **Lake area (acres)** | 63 | **Median water depth (ft)*** | 9.7 |
| **Perimeter (feet)** | 7,988 | **Maximum water depth (ft)*** | 27.7 |
| **Surface area: lake volume ratio** | 0.1 | **Volume (acre-feet)*** | 684 |
| **Watershed to surface area ratio** | 3.4 | | |

*at a water level elevation of 128 ft.

## 3.2. Watershed description

There is a substantial elevation gradient within the Lake Buckeye watershed ranging from 123 to 186 ft NAVD (Figure 3-8). The lowest elevation within the watershed is located along the northern rim of Lake Buckeye suggesting that water should flow northward toward Lake Fannie. Lake Buckeye is located adjacent to the peak of the 2010 potentiometric surface (Figure 3-9); additionally, the northern boundary of the intermediate aquifer system is just north of Lake Buckeye (Spelcher and Kroening 2007). Soils within the watershed have a low runoff potential with high infiltration rates and are classified either as hydrologic soil group A (191 acres) or A/D (12 acres) (Figure 3-10).

Land use in the Lake Buckeye watershed has changed substantially in the past 40 years. Presently, the watershed is 217 acres in size and includes 96 acres (44 percent) of developed lands compared to 121 acres (56 percent) of undeveloped land (Figure 3-10). Historically, the watershed was comprised predominantly of agriculture, specifically citrus or tree crops. Development within the watershed at this time is limited to residential housing and institutional land uses; it appears that substantial new residential developments are underway within the south-eastern portion of the watershed (Table 3-2; Figure 3-3). The majority of the existing residential developments within the watershed utilize sanitary sewer for wastewater treatment provided by the City of Winter Haven. Additionally, the large residential development that is underway will be connected to sanitary sewer. These sanitary sewer lines are connected to six lift stations within the watershed, two of which are directly adjacent to the lake. No sanitary sewer overflows have been reported by the City of Winter Haven Utilities Department for the lift stations within the watershed. In addition to sanitary sewer services within the area, there are a number of houses which depend on the on-site treatment and disposals systems (OSTDS; Figure 3-11).

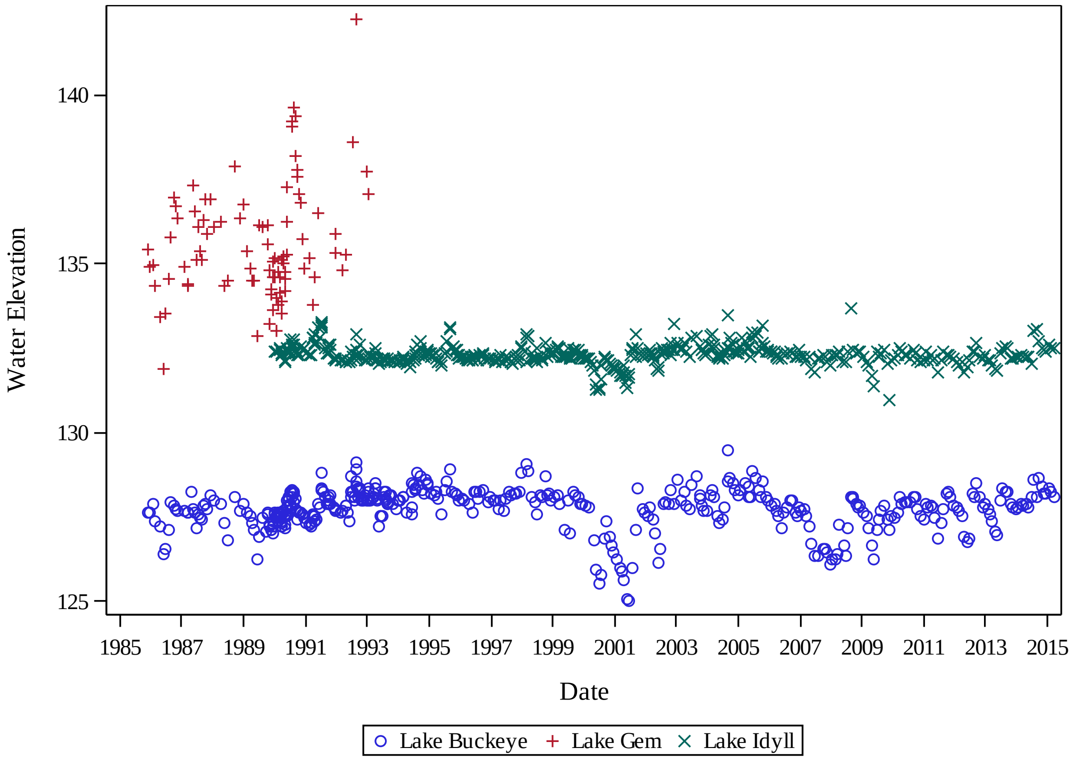


**Figure 3-5 Comparison of Water Level Elevations in Lake Buckeye, Lake Gem and Lake Idyl**

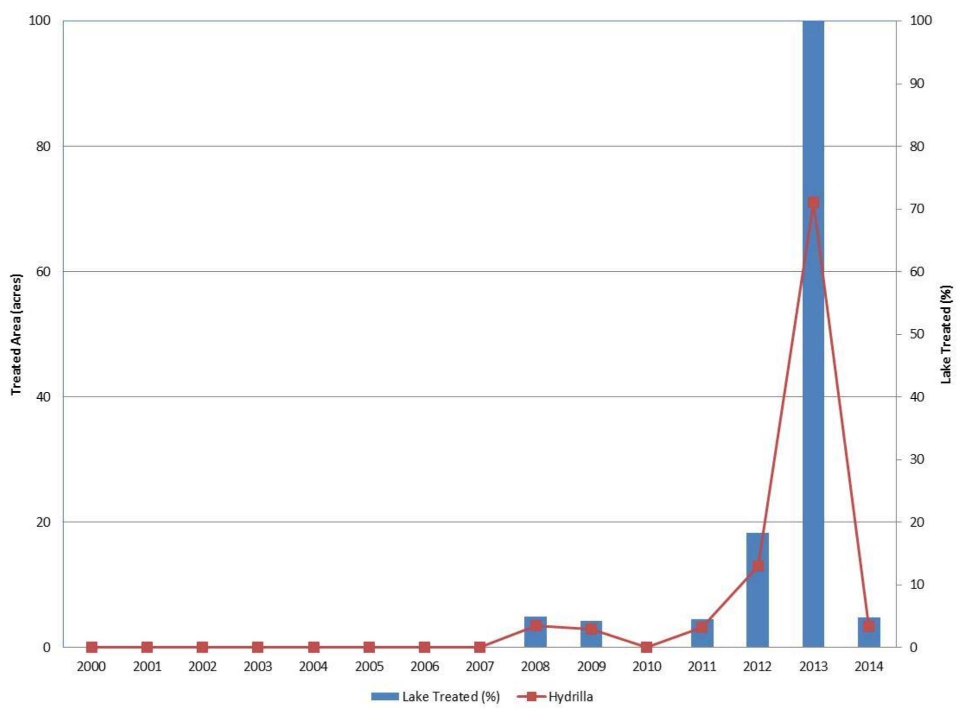


**Figure 3-6 Aquatic Weed Treatment History for Lake Buckeye (Source: Polk County)**

**Figure 3-7 Photographs of Lake Buckeye shoreline. Top: hardened shoreline. Middle: shoreline with mixture of native and exotic vegetation. Bottom: wetland extent at connection to Lake Fannie**

## 3.3. Watershed description

There are five identified County Municipal Separate Storm Sewer Systems (MS4) outfalls which discharge to Lake Buckeye (Figure 3-11). Only one of the MS4 sub-basins has been delineated which accounts for 21 percent of the lake's drainage area (47 acres; AMEC 2013). Unfortunately, the MS4 outfalls which discharge into Lake Buckeye were identified after the development of the pollutant loading provided by AMEC (2013), as such, they are not included in the tool.

For purposes of evaluating various loading sources to Lake Buckeye, rainfall records for the ROMP 73 rainfall site were used due to its close proximity to the lake. However, rainfall data was only collected for this site beginning in June 1998, therefore, the plot in Figure 3-12, which compares rainfall and lake elevation data is limited to lake elevation data gathered for this same time period. It is interesting to note, however, that for the full eight year period from 1999 to 2006, the mean lake elevation was 127.6 feet and total annual rainfall averaged 50.8 inches. For the eight year period from 2007 to 2014, the mean lake elevation was 127.5 feet while total annual rainfall averaged 45.4 inches (more than five inches less than the preceding eight year period). The relatively consistent lake water elevation regardless of changes in rainfall could indicate that the connections with adjacent waterbodies (Lake Fannie), moderate fluctuations in water elevation.

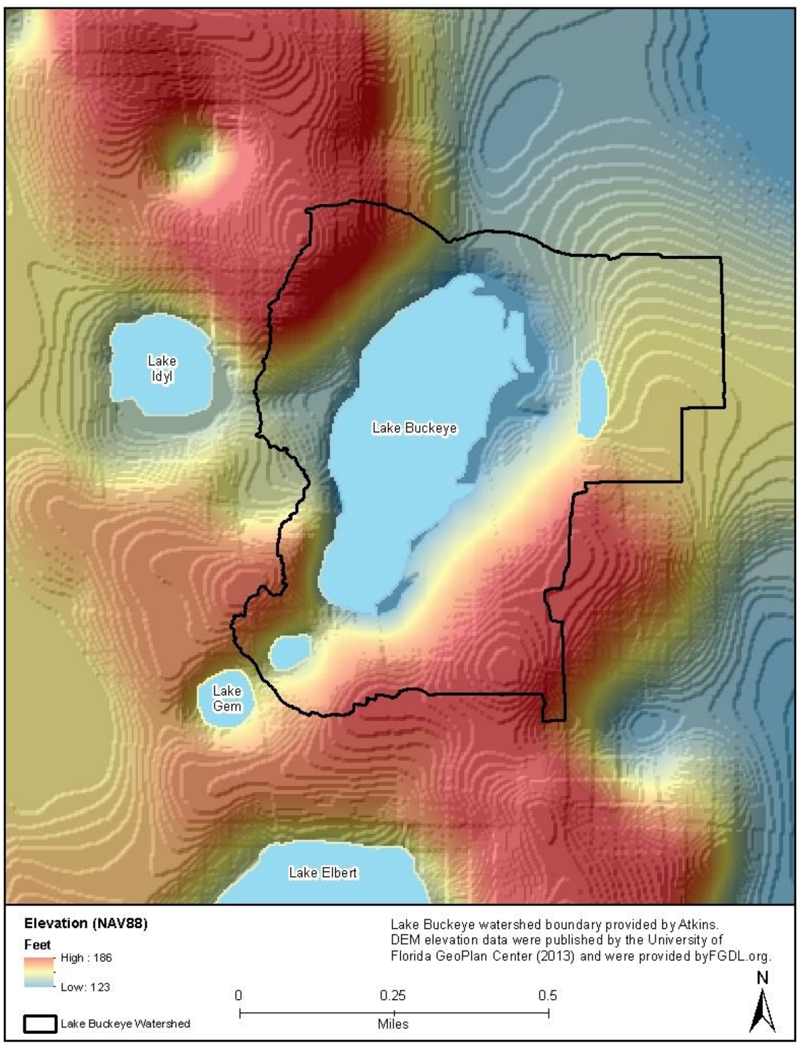


**Figure 3-8 Digital Elevation Model for the Lake Buckeye Watershed**

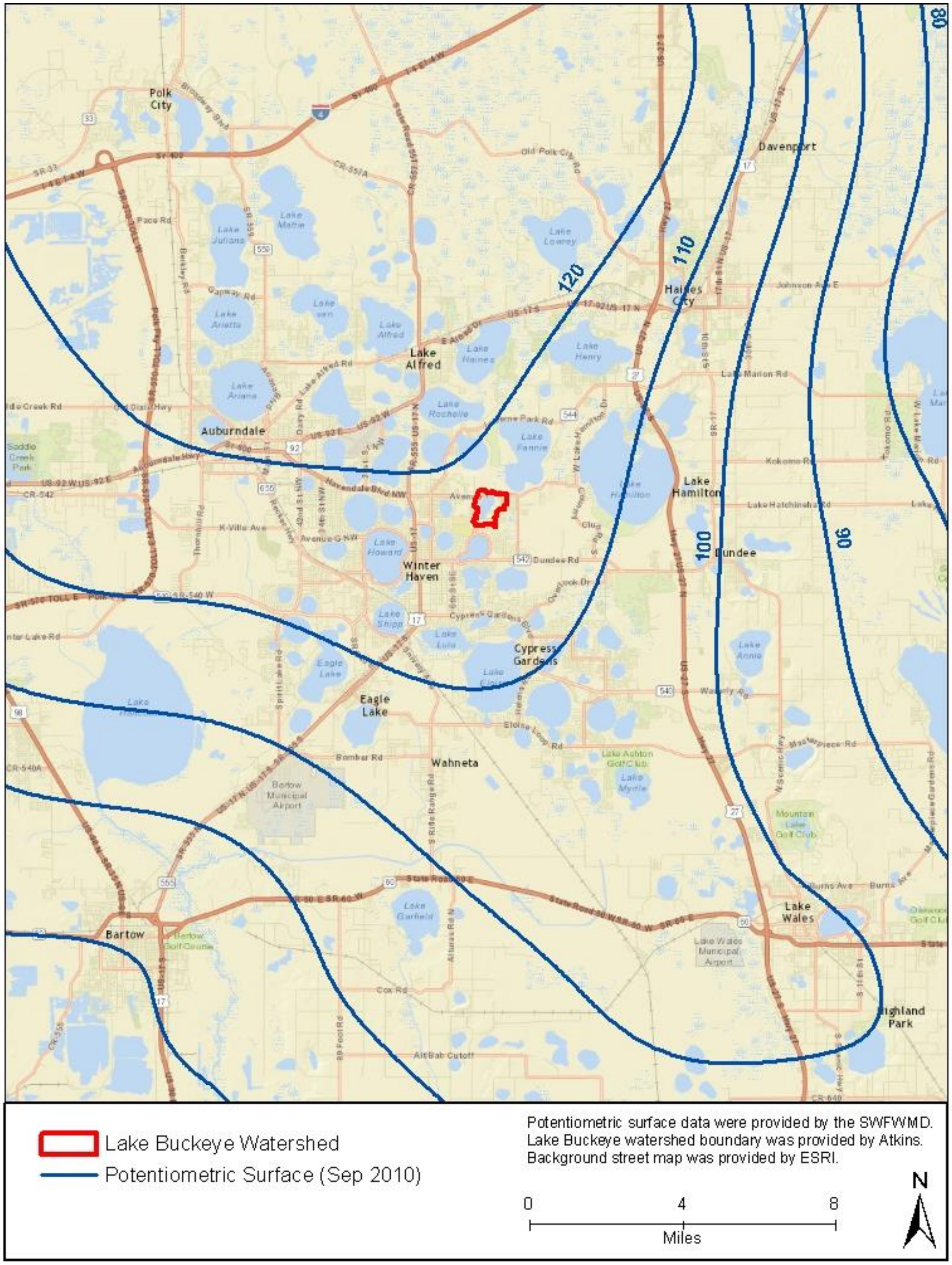


**Figure 3-9 Potentiometric Surface (Sept 2010) in the Lake Buckeye and adjacent Watershed Region (Source: http://www.swfwmd.state.fl.us/data/gis/layer_library/category/potmaps)**

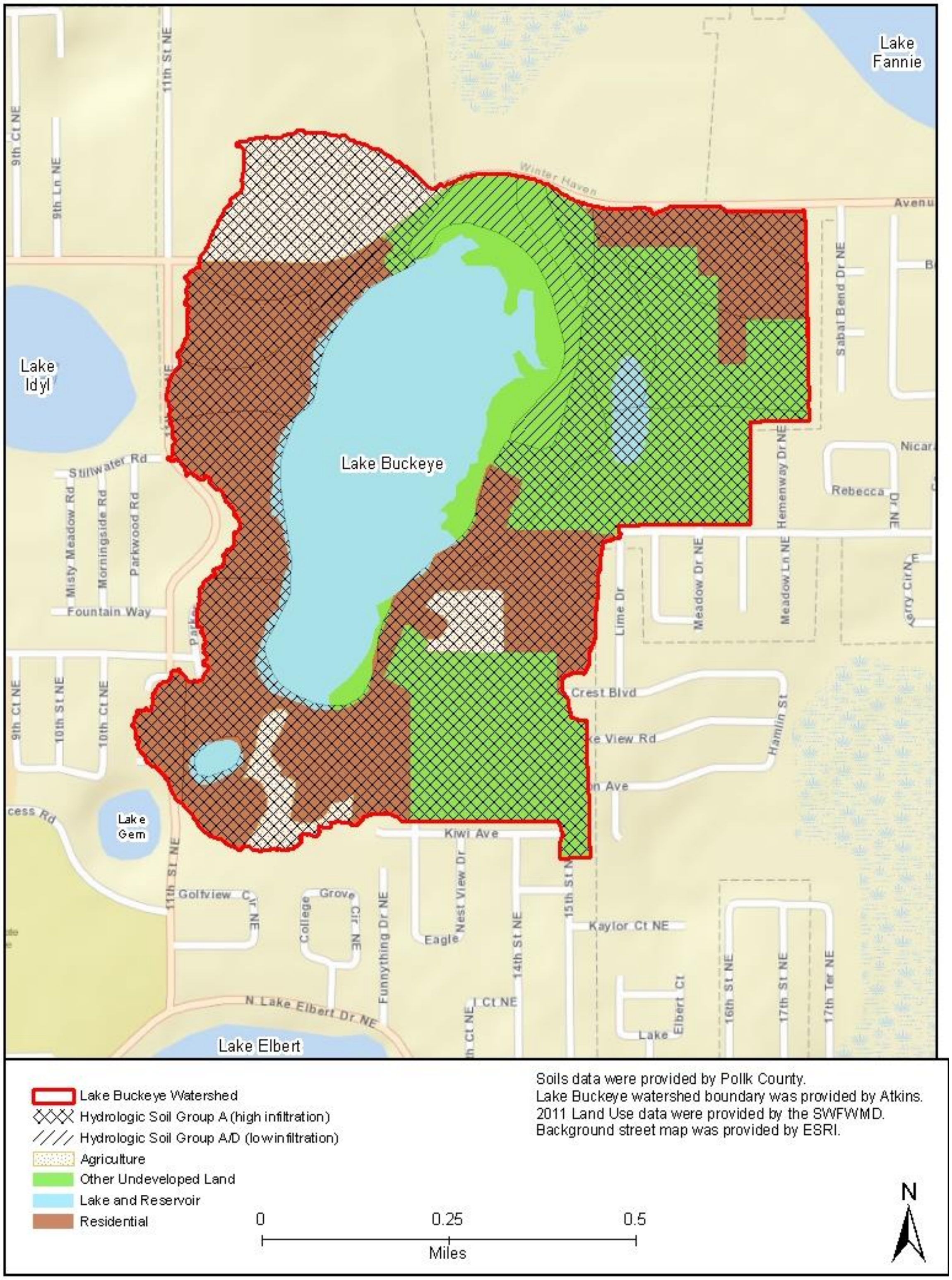


**Figure 3-10 Lake Buckeye and adjacent Watershed with Current Land Use and High Infiltration Soils**

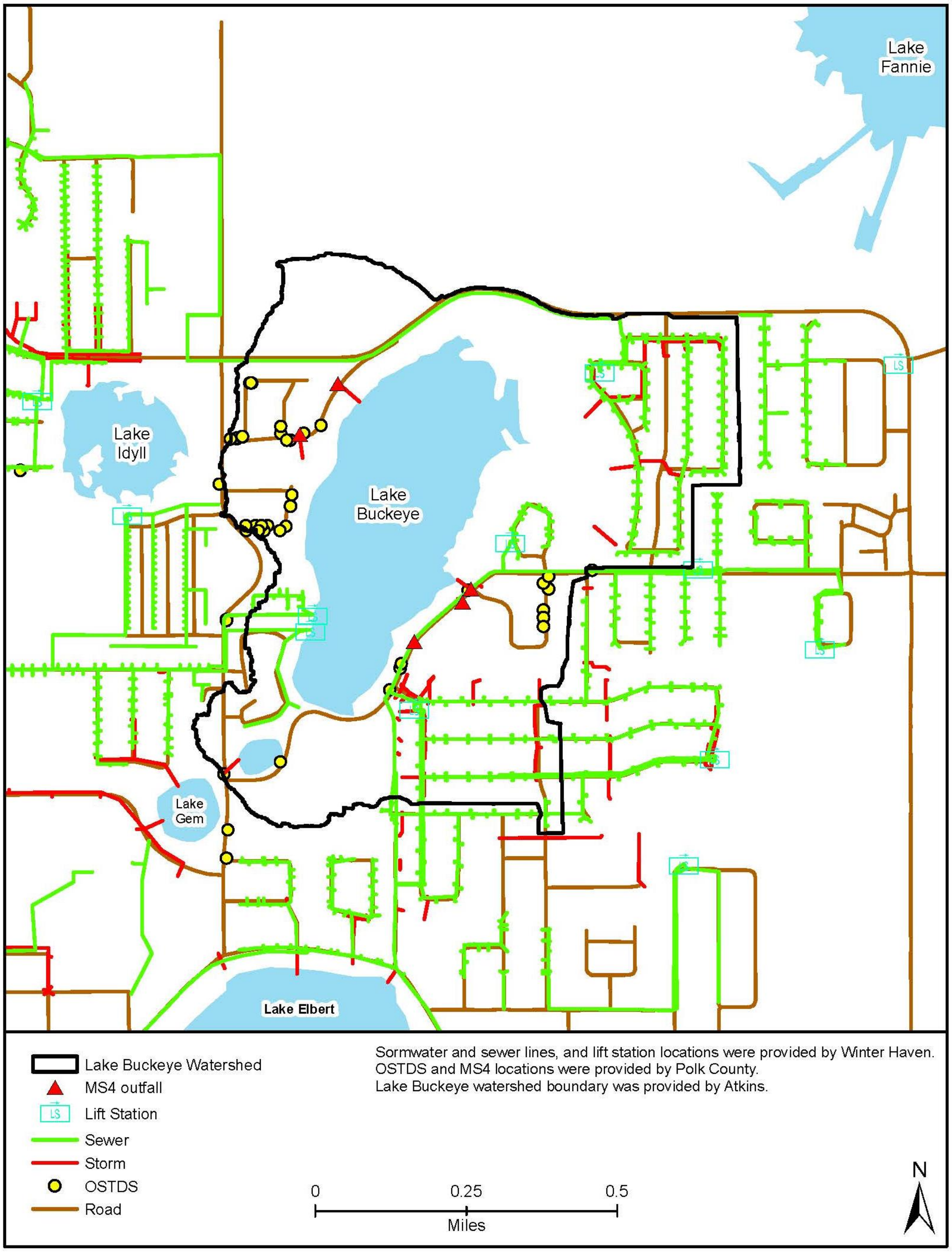


**Figure 3-11 Lake Buckeye and Adjacent Watershed With Current Land-Use (2011), MS4 Outfalls, Lift Station and Known OSTDS Locations. Note: OSTDS Includes Only Those With Florida Department of Health Permits. Approximately, 48 Additional OSTDS are Likely Within the Watershed.**

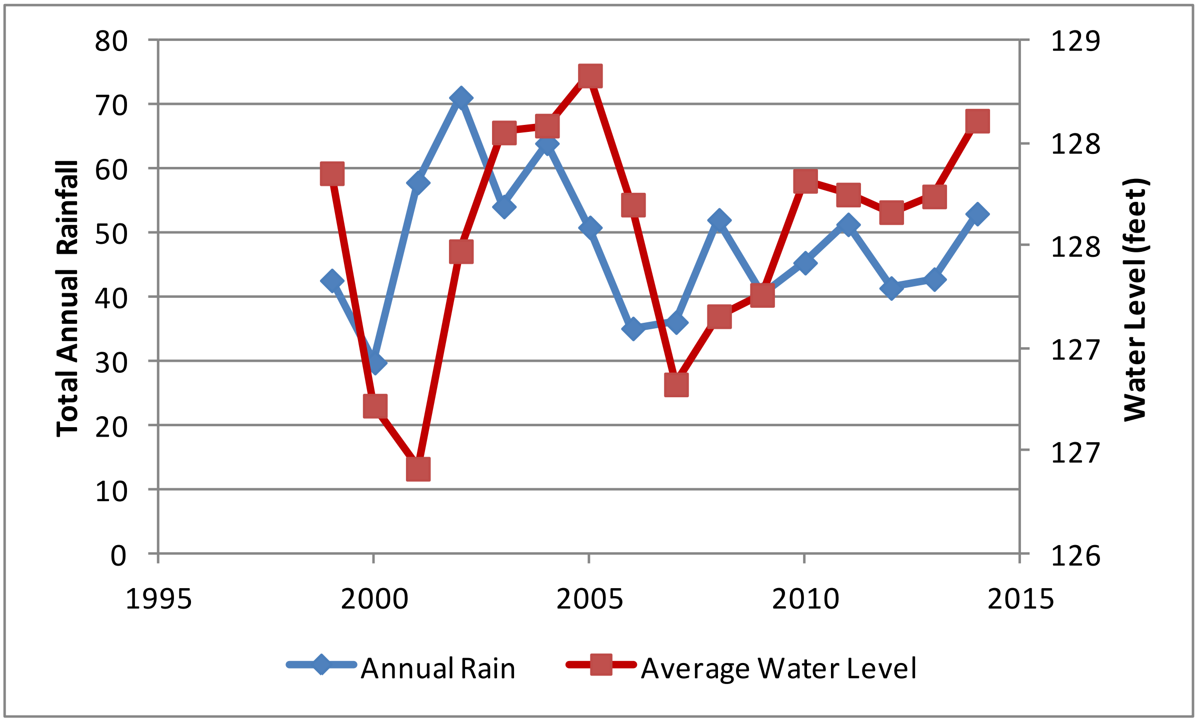


**Figure 3-12 Variation in Total Annual Rainfall as Measured at the ROMP 73 Rain Gage and Mean Annual Water Level Elevation at Lake Buckeye.**

**Table 3-2 Change in Land Use within the Lake Buckeye Watershed Over Time.**

| Land use | 1974 | | 1995 | | 2011 | |
|---|---|---|---|---|---|---|
| | Acres | Percent | Acres | Percent | Acres | Percent |
| Agriculture | 129 | 59 | 116 | 54 | 27 | 12 |
| Other Undeveloped Land | 21 | 10 | 22 | 10 | 94 | 43 |
| Residential | 67 | 31 | 79 | 36 | 96 | 44 |

## 3.4. Water quality

Lake Buckeye was declared impaired for nutrients due to elevated Trophic State Index (TSI) during the January 1, 2002 to June 30, 2009 verified period as part of the Group 3, Cycle 2 review (FDEP 2014). The impairment status of Lake Buckeye was evaluated using the Numeric Nutrient Criteria (NNC) (Atkins 2013) over the verified period used for the initial impairment. Lake Buckeye is considered a clear, alkaline lake based on a long-term geometric mean color of 17 Platinum-Colbalt Units (PCU) and alkalinity of 63 milligrams per litter (mg/L). A review of the specific conductance data is consistent with the alkaline determination (conductivity > 100 microSiemens (us/cm)). Based on the clear, alkaline characterization, nutrient criteria were determined based on a chlorophyll-a concentration of 20.0 microgram per litter (µg/L). An evaluation of the water quality within Lake Buckeye using the NNC was not consistent with the initial impairment determination and indicated that Lake Buckeye was not impaired for Total Nitrogen (TN) or Total Phosphorous (TP) during the 2002 to

2009 verified period and insufficient data were available to evaluate chlorophyll-a concentrations (Atkins 2013; Table 3-3). Additionally, an evaluation of water quality data for the period of 2003 to 2013 indicated that Lake Buckeye was unimpaired for all three parameters using the NNC. This determination was then independently evaluated by the Florida Department of Environmental Protection (FDEP) and validated (Atkins and ESA 2014). As such, it is recommended that the County coordinate with FDEP to de-list Lake Buckeye from the 303(d) impaired waters list. Atkins and ESA 2014 reported a statistically significant ($p<0.05$) declining trend (improving water quality) in chlorophyll-a, Total Nitrogen and Total Phosphorus concentrations using the seasonal Kendall Tau test. Figures 3-13 to 3-15 provide a graphical representation of the water quality improvement identified in Lake Buckeye. A statistically significant increasing (improving) trend in Secchi depth was identified ($p<0.01$; Figure 3-16) in association with the improving water quality conditions (Atkins 2013).

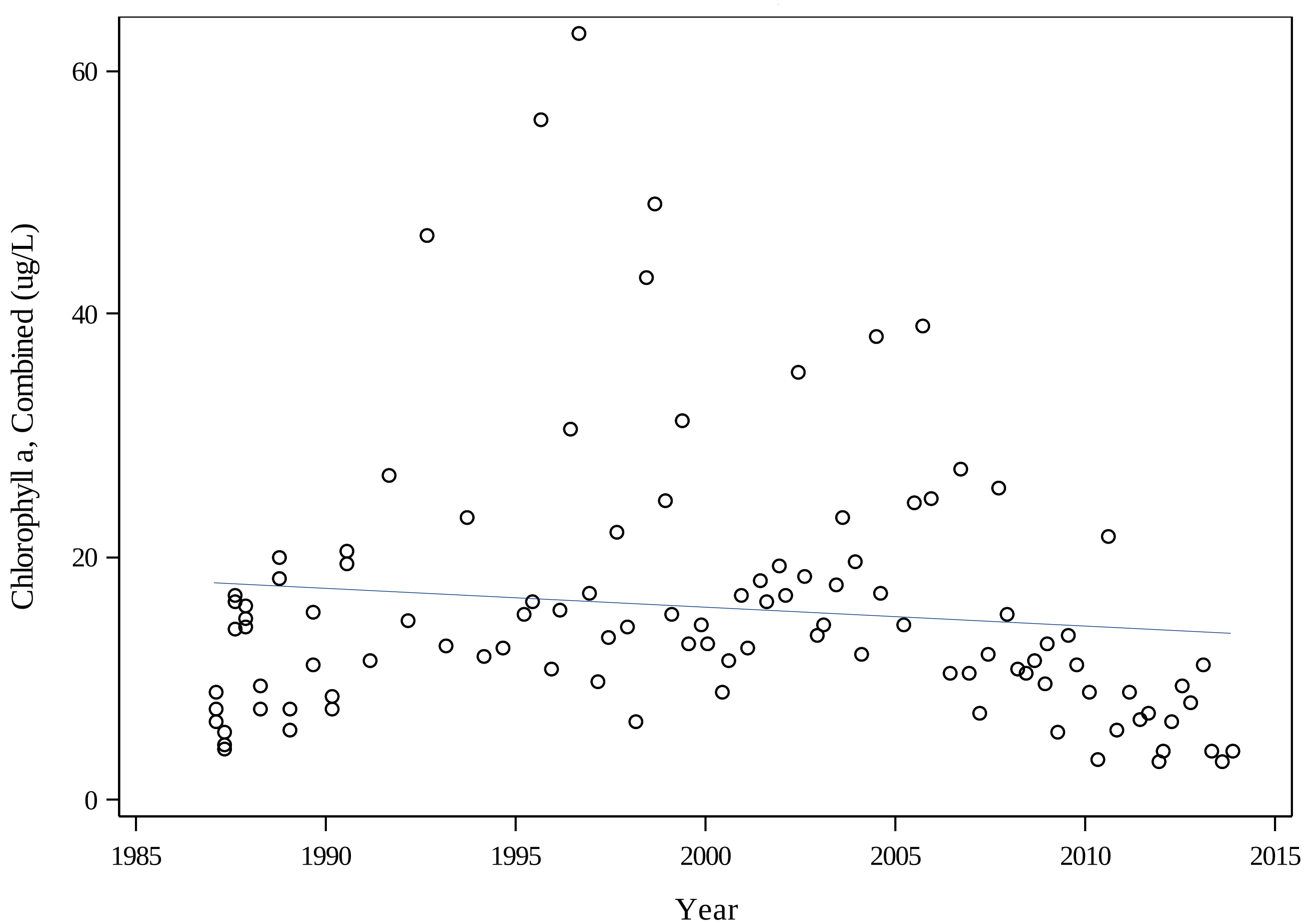


**Figure 3-13 Graphical Representation of Lake Buckeye Chlorophyll-a Concentrations Over Time with Trend Line. Statistical Significance of Trend Determined by Using Seasonal Kendall Tau Analysis ($p<0.05$)**

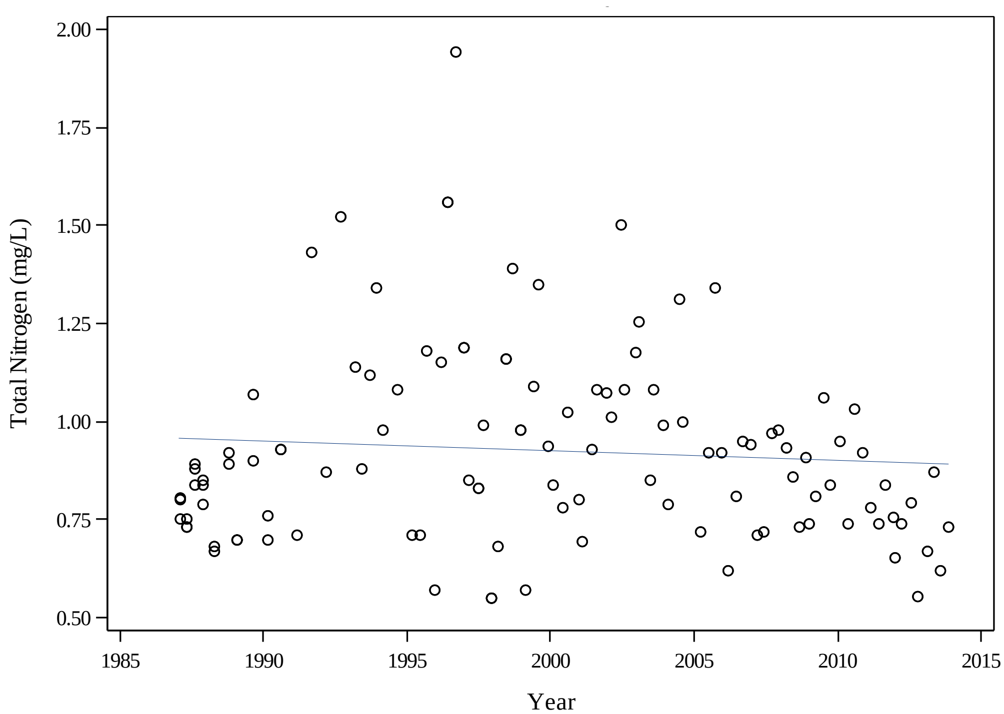


**Figure 3-14 Graphical Representation of Lake Buckeye Total Nitrogen Concentrations Over Time with Trend Line. Statistical Significance of Trend Determined by Using Seasonal Kendall Tau Analysis (p<0.05).**

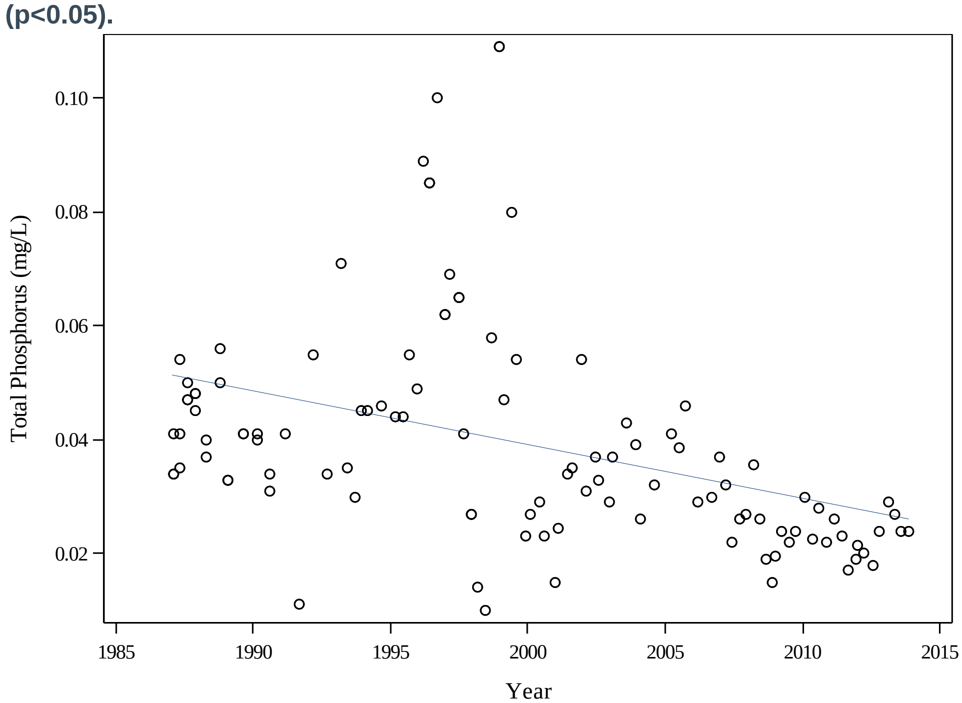


**Figure 3-15 Graphical Representation of Lake Buckeye Total Phosphorus Concentrations Over Time with Trend Line. Statistical Significance of Trend Determined by Using Seasonal Kendall Tau Analysis (p<0.05).**

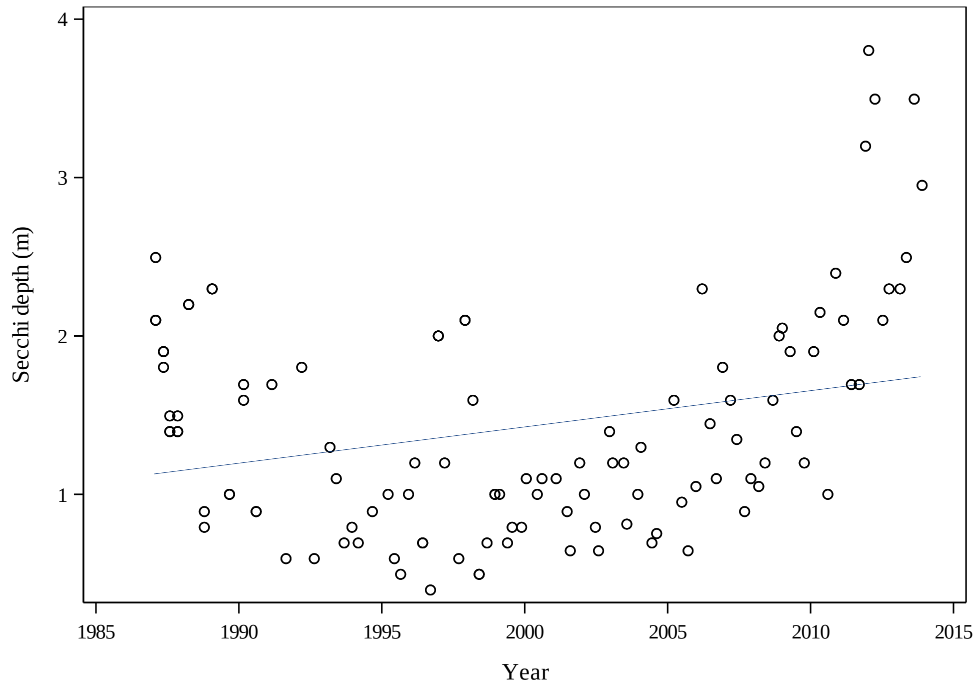


**Figure 3-16 Graphical Representation of Lake Buckeye Secchi Depth Over Time with Trend Line. Statistical Significance of Trend Determined by Using Seasonal Kendall Tau Analysis (p<0.05).**

**Table 3-3 Results of NNC Evaluation for Lake Buckeye (WBID 14898S) Over Recent Time Period (2003-2013).**

| WBID | Waterbody Name | Year | Geometric Mean | | |
|---|---|---|---|---|---|
| | | | Chlorophyll-a, corrected (µg/L) | Total Nitrogen (mg/L) | Total Phosphorus (mg/L) |
| 1488S | LAKE BUCKEYE | 2003 | 18.4 | 1.03 | - |
| 1488S | LAKE BUCKEYE | 2004 | - | - | - |
| 1488S | LAKE BUCKEYE | 2005 | 24.2 | 0.95 | - |
| 1488S | LAKE BUCKEYE | 2006 | - | 0.82 | - |
| 1488S | LAKE BUCKEYE | 2007 | 13.6 | 0.83 | 0.027 |
| 1488S | LAKE BUCKEYE | 2008 | 10.5 | 0.85 | 0.023 |
| 1488S | LAKE BUCKEYE | 2009 | 10.2 | 0.85 | 0.022 |
| 1488S | LAKE BUCKEYE | 2010 | 7.7 | 0.90 | 0.025 |
| 1488S | LAKE BUCKEYE | 2011 | 6.0 | 0.78 | 0.021 |
| 1488S | LAKE BUCKEYE | 2012 | 6.6 | 0.68 | 0.021 |
| 1488S | LAKE BUCKEYE | 2013 | - | - | - |
| - Indicates insufficient data to calculate geometric mean | | | | | |
| Shaded cells indicate an exceedance of clear, acidic NNC criteria | | | | | |

# 4. Identify relationships that may affect lake conditions

A distinct improvement in water quality has occurred in Lake Buckeye (Figures 3-16 to 3-19) as evidenced by a decline in chlorophyll-a and nutrient concentrations. Concurrently, an increase in Secchi depth was evident indicating increased clarity within the water column. This section addresses links between external (watershed) and/or internal processes which could explain the water quality improvement. Relationships that may affect lake conditions are presented. Land use, point source history, septic tank/sanitary sewer coverage, lake level history and water quality data were analyzed. Results have been evaluated to determine if there is clear evidence of an ongoing and negative impact of nutrient supply or other factors on nutrient-related water quality parameters. Should multiple and/or corroborating lines of evidence of such relationships exist, these would indicate the possibility of ongoing nutrient-related impacts to water quality.

## 4.1. Ambient water quality

Water quality data were retrieved from the Impaired Water Rule (IWR) Run 49 database as provided by Polk County. Based on previous correspondence with FDEP, IWR data (IWR and STORET) with any of the following qualifiers were excluded from analysis: presence of material is verified but not quantified (M) and value based on field kit determination (H). Additionally, chlorophyll-a, corrected values with a qualifier of ‘U’ were reported as half the minimum detection limit. Water quality data were reviewed and a daily median value was calculated to eliminate duplicate data entries. Additionally, a modified chlorophyll-a variable (chlacomb) was created whereby the corrected chlorophyll (i.e., corrected for phaeophytin) variable was combined with chlorophyll-a uncorrected results. In other words, chlorophyll-a uncorrected results were used in instances in which chlorophyll-a, corrected data were unavailable. In 2007, FDEP modified the 62-303, Florida Administrative Code (F.A.C), such that chlorophyll-a data collected from September 2007 forward were required to be chlorophyll-a, corrected in order to be included in the assessment of water quality. Data collected prior to September 2007 were exempt from this requirement. These data were used to evaluate the potential empirical relationships that may exist within the lake that could affect the lake water quality condition.

Unless noted, parametric statistics were used to evaluate significant relationships in water quality. Traditionally, parametric statistics require the data analyzed to satisfy three assumptions: independent sampling events, normal distribution of the data, and equal variances. However, it is common for linear correlations to be used in the evaluation of water quality trends in the absence of satisfying data distribution and variances. A p-value statistic of less than or equal to 0.05 was used to identify statistically significant relationships.

The determination of the limiting or co-limiting nutrients of concern can assist in identifying projects for successful lake management. The ratio of TN and TP is a typical metric used to provide a cursory determination of the nutrient of concern responsible for phytoplankton production. For Lake Buckeye, the average TN:TP ratio for the period of record is 28 which is between the thresholds of 10 and 30 that the Florida Department of Environmental Protection (FDEP) uses to identify nitrogen or phosphorus limitation for algal growth (Figure 4-1; FDEP 2007). Based upon the TN:TP ratio alone, Lake Buckeye water quality is classified as co-limited by both nutrients in regards to managing water quality. While identifying phosphorus and nitrogen as co-limiting nutrients, additional evaluation of in-lake and watershed dynamics is necessary to evaluate changes in water quality in Lake Buckeye. It is important to note that in the more recent years, the TN:TP ratios show evidence of P limitation.

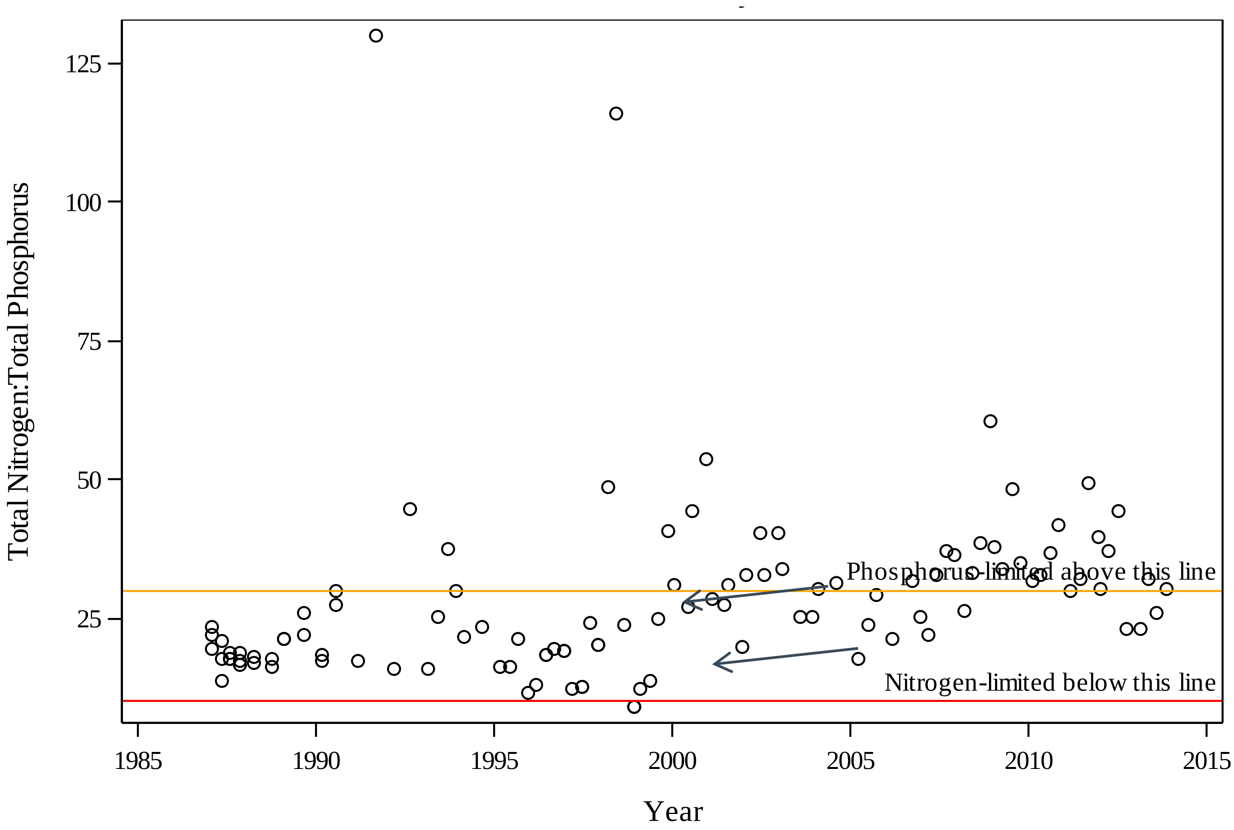


**Figure 4-1 Total Nitrogen:Total Phosphorus Ratio Over Time in Lake Buckeye**

### 4.1.1. In-lake correlations

A correlation between TN or TP and chlorophyll-a was performed to assist in identifying the sensitivity of phytoplankton production to the availability of nutrients. Strong significant correlations between both TN ($p<0.0001$) and TP ($p<0.0001$) with chlorophyll-a were identified (Figures 4-2 and 4-3). The $R^2$ value which identifies the strength of the relationship was greater for TN (0.58) than for TP (0.21). Based on the $R^2$ statistic, 58 percent of the variability in chlorophyll-a concentrations is correlated with fluctuations in TN concentrations within the water column and 42 percent of the chlorophyll-a variability can be attributed to something other than TN. For TP, only 21 percent of chlorophyll-a variability is attributable to TP compared to 79 percent which could be explained by something other than TP. The results of the TN and TP correlations analysis indicate that an increase in both nutrient concentrations is correlated with an increase in phytoplankton production.

The results of the correlation analysis of TN or TP and chlorophyll-a concentrations are consistent with the determination of a co-limited lake. These results would suggest that managing both TN and TP concentrations is necessary to influence phytoplankton production within Lake Buckeye. However, because a stronger correlation was observed with TN, nitrogen is likely the dominant nutrient of concern. Observed ambient TN concentrations suggest that nitrogen fixing cyanobacteria are not a likely concern in Lake Buckeye (Atkins and ESA 2014). TN concentrations range from 0.5 to 1.9 mg/L, with all concentrations below the 2.4 mg/L threshold used to preliminarily identify candidates for lakes with a cyanobacteria population (Atkins and ESA 2014)

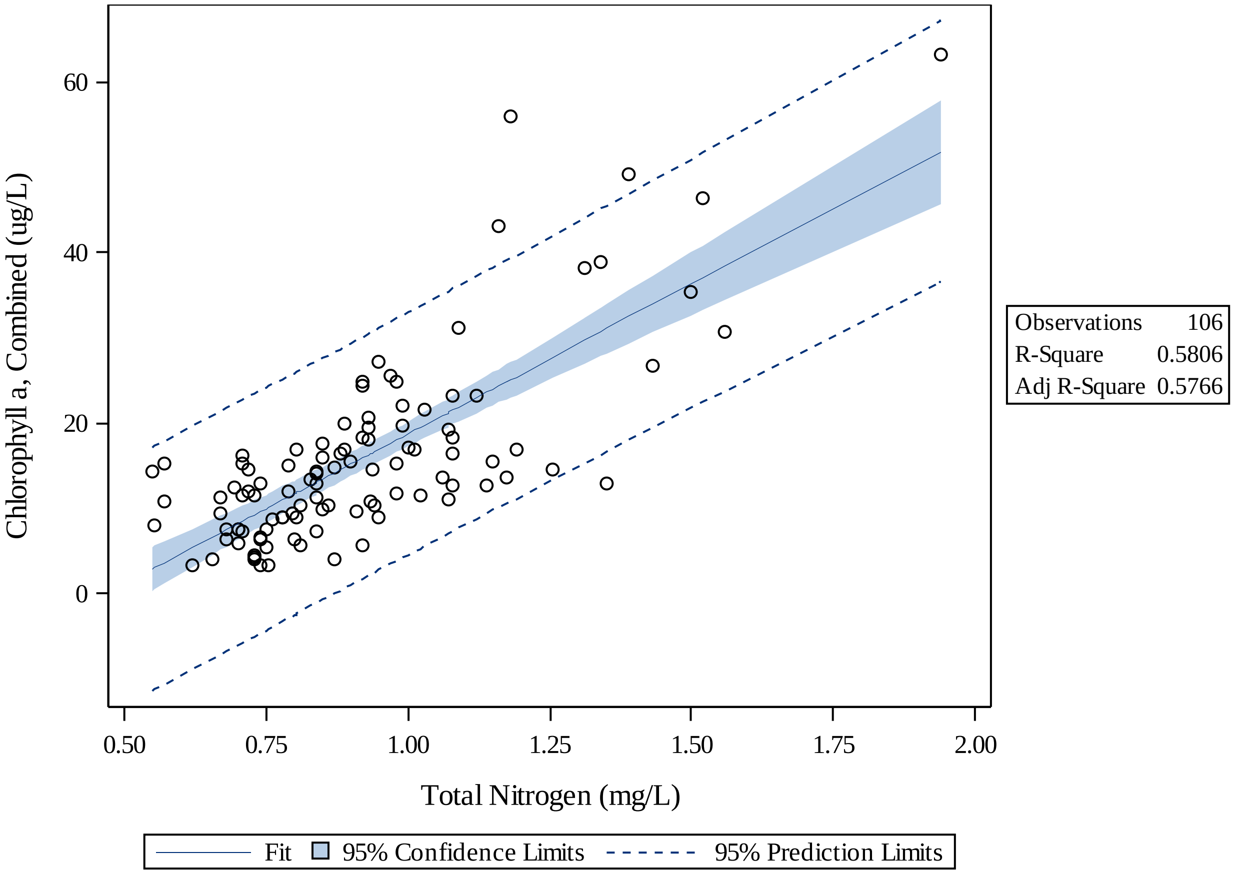


**Figure 4-2 Correlation Between TN and Chlorophyll-a in Lake Buckeye Ambient Water Quality Over the Period of Record (p<0.0001)**

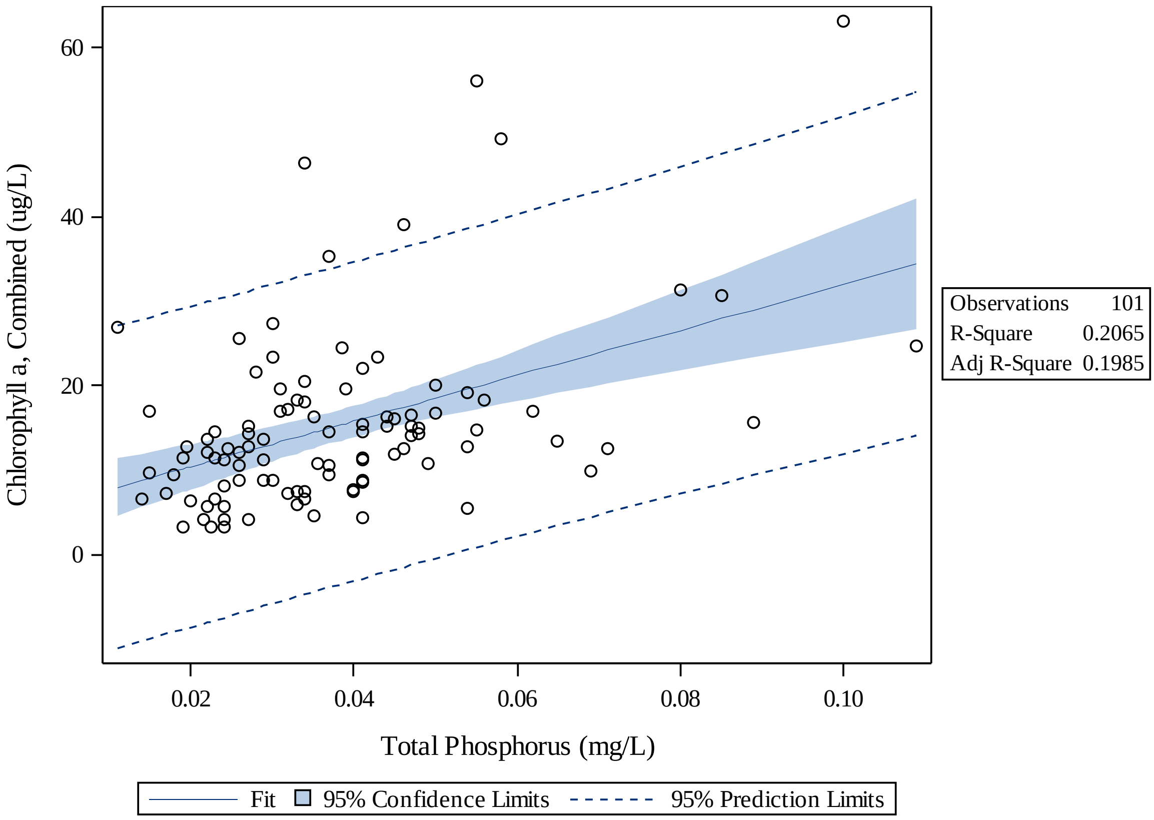


**Figure 4-3 Correlation Between TP and Chlorophyll-a in Lake Buckeye Ambient Water Quality Over the Period of Record (p<0.0001)**

An evaluation of inorganic nutrient trends and correlations with in-lake phytoplankton production was performed. There were insufficient ortho-phosphorus (OP) data to evaluate trends or correlations related to this parameter. Additionally, the majority of nitrate+nitrate data appear to be reported at the minimum detection limit of the procedure used. Therefore, trends and correlations cannot be interpreted effectively. However, comparison of the magnitude of nitrate+nitrite concentrations against total Kjeldahl nitrogen (TKN) concentrations suggests that the dominant form of nitrogen present in the lake is TKN, a combination of both ammonium and organic nitrogen, which is unavailable for direct uptake by plants and phytoplankton without transformation to a more useable form.

As would be expected, a significant inverse correlation between chlorophyll-a concentration and Secchi depth was identified ($p<0.0001$; Figure 4-4) indicating an increase in water clarity during reduced phytoplankton production.

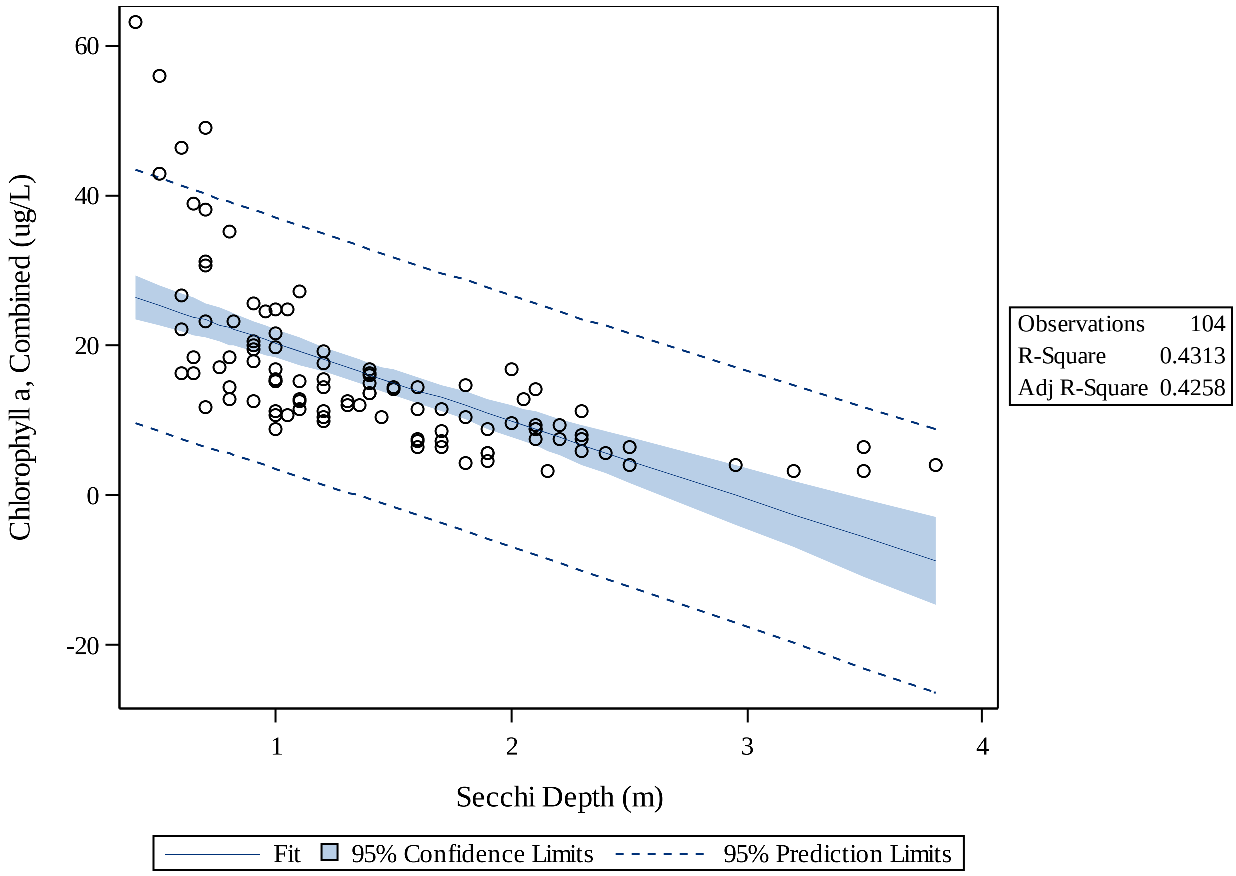


**Figure 4-4 Correlation Between Secchi Depth and Chlorophyll-a in Lake Buckeye Ambient Water Quality Over the Period of Record ($p<0.0001$)**

In addition to available nutrients within the water column, lake-bottom sediments can be responsible for substantial nutrient additions under anoxic conditions. Phosphorus flux via sediments can sustain eutrophication of a lake even when external phosphorus loads have been reduced or eliminated (Larsen et al. 1979, Ryding 1981). Sediment phosphorus release can occur through two mechanisms: 1) dissolved phosphate diffusion into the water column, and 2) the release of sediment pore water phosphorus or release of phosphorus adsorbed to sediment particles into the water column. Phosphorus release into the water column has been attributed to redox status and phosphorus concentration gradients at the sediment-water interface (Penn et al. 2000). As part of the lake characterization completed during an April 2015 site visit, four lake-bottom sediment samples were analyzed for percent solids and nutrient composition to assess the potential nutrient pool (Figure 4-5). Pockets of unconsolidated detrital material were identified which exceeded 5 feet in depth in portions of the lake.

On average, the sediments had greater moisture content (59 percent) compared to solids (41 percent; Table 4-1), supporting the assessment of predominantly unconsolidated sediments. The dry nutrient concentrations were lower than those reported for other lakes in Polk County (eg., Haines, Rochelle, Smart and Conine; PBSJ 2008) and those documented by ERD (2007) in Lakes May, Shipp and Lulu. While a substantial quantity of organic material was present in the bottom of Lake Buckeye, sufficient data on dissolved oxygen concentrations near the sediment-water interface is not available to document the potential for phosphorus release. Prolonged anoxic conditions at the sediment-water interface can lead to phosphorus loading into the water column; potentially exacerbating water quality conditions. Additionally, sediment re-suspension is unlikely due to the low surface water to volume ratio (0.1) and further supported by calculating the Lake Dynamic Ratio (0.17), the square root of lake surface area divided by the mean depth, which has been used to predict sediment resuspension frequency in Lake Hancock (Bachman et al. 2000;Tomasko et al. 2009).

**Figure 4-5 Representative Sediment Sample Collected from Lake Buckeye.**

**Table 4-1 Summary Statistics for Sediment Samples Collected on April 2015**

| Summary Statistic | Composition (Percent) | | | Dry Weight (mg/kg) | |
|---|---|---|---|---|---|
| | Solids | Moisture | Organic | TKN | TP |
| Minimum | 24 | 31 | 3 | 1070 | 155 |
| Maximum | 69 | 76 | 34 | 10500 | 1650 |
| Average | 41 | 59 | 19 | 6190 | 856 |

## 4.2. External pollutant loading

Annual and monthly external pollutant loading estimates were calculated for the Lake Buckeye watershed. External nutrient inputs consist of surface water run-off, loading from onsite disposal systems (i.e., septic tanks), atmospheric deposition and groundwater inflow. It is important to note that nutrient inputs are estimates. For each component, regional and local assumptions were used to calculate loads. Local hydrologic and water quality data from the Lake Buckeye watershed were not collected to supplement calculations or verify assumptions. As such, caution should be used when interpreting the results. However, the nutrient estimates can serve as an indicator of the relevant importance of each component on water quality within the lake.

### 4.2.1. Watershed loads (surface water run-off)

Loading estimates of nitrogen and phosphorus from stormwater draining to Lake Buckeye (i.e., watershed loads) were developed similarly to the methods described by AMEC Environment and Infrastructure, Inc. (AMEC 2013). AMEC was contracted by Polk County to develop annual pollutant loading assessments as required by the National Pollutant Discharge Elimination System Municipal Separate Storm Sewer Systems (NPDES MS4) permit for Polk County. AMEC developed an Excel spreadsheet model to estimate stormwater pollutant loads for drainage basins associated with MS4 outfalls. The model developed by AMEC utilized the U.S. Environmental Protection Agency's (EPA) Simple Method (Schueler 1987) but was modified based on criteria in the Florida Statewide Stormwater Rule (Ch 40D-4.091 FAC). As outlined by AMEC (2013), the Simple Method estimates stormwater pollutant loads as the product of annual runoff volume and pollutant concentrations, and is a three-step process (see Ohrel 2000) that requires development of a runoff coefficient, the determination of runoff volume (based on local rainfall record), and an annual pollutant load using event mean concentrations of the pollutants of interest.

The modification developed by AMEC was the calculation of the runoff volume using a runoff coefficient based on Florida Meterological Zones. "The runoff coefficient 'c' is determined based on the drainage basin non-directly connected imperious area curve number (NDCIA CN) and directly connected impervious area (DCIA) combination and the meterological zone within which the project area falls" (AMEC 2013). In developing our estimates, we used the runoff coefficients and curve numbers provided (Tables 1 and 2, AMEC 2013) and runoff concentrations for a given land use category as summarized from the relevant literature and presented by AMEC (Table 3, AMEC 2010). The only modification generated by the Atkins/ESA team was to utilize monthly rainfall totals to generate monthly loads rather than annual loads. This modification allowed estimates for wet and dry seasons to be generated as was done for atmospheric loading.

### 4.2.2. Septic tank (OSTDS)

Septic system nutrient loads to Lake Buckeye were estimated using an approach similar to that applied by Janicki Environmental (2010) to estimate nitrogen (N) and phosphorus (P) loads for the Charlotte Harbor National Estuary Program. However, based on direction from Polk County (Zarbock 2015, personal communication) the following constants were used in computations: 60 gallons per capita per day water use, wastewater TN concentration of 40 mg/l, wastewater TP concentration of 10 mg/l, and wastewater ortho-phosphorus (OP) concentration of 3 mg/l. The number of persons per household in Polk County is 2.7 (United States Census Bureau 2010); however, in the case of Lake Buckeye, a person per household number of 2.4 based on the 2010 census for the City of Winter Haven was applied.

Using these numbers, the load of the various nutrients (TN, TP, orthophosphate (OP)) contributed by a household to a septic system on an annual basis can be determined. In this case, the estimated annual load to a single septic system per person was determined to be 7.31, 1.83, and 0.55 lbs of TN, TP and OP, respectively. Household loads (obtained by multiplying by 2.42) were then calculated to be 17.7, 4.4 and 1.3 pounds (lbs) of TN, TP and OP, respectively. These values are in the range of those reported by Janicki Environmental (2010). This is the load to a septic system, the actual load to a receiving waterbody was then estimated by taking the load to a septic system and applying an attenuation factor (95.9% for TN and 97.5% for TP and OP); resulting in TN, TP and OP loads to the waterbody of 0.69, 0.10 and 0.03 pounds per year per septic system, respectively. Total estimated septic tank loads to Lake Buckeye also took into account a septic system failure rate. After review of the literature, Janicki Environmental (2010) reported Florida failure rates in the range of 1 to 10% statewide. Because most septic systems in the Lake Buckeye watershed were judged to be in place since 1988 and located principally in soils with a high amount of sand (A and A/D hydrologic soil groups), we applied a failure rate of 10%. It was further assumed that 80% of nitrogen and 50% of phosphorus loads to a failed system actually made it to the receiving waterbody, and as a result, it was estimated that a single failed system contributed 14.2, 2.21 and 0.66 lbs of TN, TP and OP to the lake annually. Using these estimates, a single failed septic system delivers approximately 20.6 times more nitrogen and 22 times more phosphorus to a lake than a properly operating septic system.

### 4.2.3. Atmospheric deposition

Following the procedure outlined by Janicki Environmental (2010) and using a spreadsheet developed by them to estimate loadings for the Charlotte Harbor area, we estimated total atmospheric deposition of nitrogen and phosphorus on to the water surface of Lake Buckeye. Total atmospheric deposition was defined as the sum of wet and dry deposition. Wet deposition is that delivered by rainfall, while dry deposition is defined as gaseous constituent interaction and dust fallout (Janicki et al. 2010). As explained by Janicki Environmental (2010), three data sets are needed to estimate atmospheric deposition: 1) an estimate of the hydrologic load (i.e., rainfall) directly on the waterbody, 2) an estimate of nutrient concentrations in rainfall, and 3) an estimate of dry deposition concentrations.

In the case of Lake Buckeye, the rainfall record was compiled from the long-term Bartow site (NWS 080478) and a SWFWMD station (site ID 25167) located approximately 2.2 miles east of the center of the lake was used to develop the hydrologic load. The SWFWMD station contains rainfall data from 1998 to present; the Bartow gage was used to supplement rainfall data prior to 1998. Nitrogen concentrations in rainfall were based on concentrations measured in monthly rainfall samples collected at the Verna Wellfield from 1995 to 2007 (see Janicki Environmental 2010). Dry deposition was estimated using a ratio of wet to dry deposition developed from the Tampa Bay Atmospheric Deposition Study (TBADS). The TBADS was run from 1996 to 2006 and included both wet and dry deposition sampling at a single intensive monitoring site in the Tampa Bay area. As was done for Charlotte Harbor, “the ration of dry-to-wet deposition and the relationship between TN and TP deposition were assumed to be the same for the data collected at the Verna Wellfield site for the purposes of estimating deposition” onto Lake Buckeye. “Further, dry deposition was estimated using the TBADS-derived seasonal dry-to-wet deposition ration, which was 1.05 for the dry season (months 1-6, 11, and 12) and 0.66 for the wet season (months 7-10) . . . Wet phosphorus concentrations were estimated by the relationship between TN and TP concentrations in rainfall at the TBADS site, applied using the TN concentration data from the Verna site. Estimates of dry deposition of TP were obtained using the same seasonal dry-to-wet ratios as utilized for estimation of TN deposition” (Janicki Environmental 2010).

It should be appreciated that the estimates as described above are clearly dependent on relationships of TN to TP developed for rainfall samples collected outside of the Lake Buckeye watershed. However, long-term studies of atmospheric deposition are few, and for purposes of this report, the methodologies and relationships used represent the best available. We do note, however, that because dry deposition estimates are based on a dry-to-wet ratio as outlined above, for months when total monthly rainfall was zero, dry deposition by default was zero. It does not seem reasonable that dry deposition should be zero in months with no rainfall. However, since zero rainfall months were rare in the record used, we did not make an adjustment to these monthly estimates.

### 4.2.4. Groundwater inflow

Groundwater inflow rates and loads were estimated by assuming that groundwater inflow is a function of rainfall after accounting for surface water runoff and evapotranspiration. The annual total rainfall was calculated using the same compiled dataset indicated for septic tank loadings. In order to estimate potential groundwater nutrient loading to a lake, a simple water balance approach was taken to determine the assumed groundwater hydraulic load. As was done with other estimates in this report, the hydraulic load was then multiplied by an appropriate nutrient concentration to determine load.

The simple water balance can be expressed by the following formula given a number of simplifying assumptions to be explained below:

*Rainfall = Watershed runoff + Groundwater input + Evapotranspiration*

This equation is rearranged to give:

Groundwater input =Rainfall – Evapotranspiration – Watershed runoff

As an example, suppose 50 inches of rain falls annually on a given watershed, and assume that 35 inches of rainfall is lost via evapotranspiration (ET), and then the amount of water entering a lake as either surface runoff or a groundwater input would be approximately 15 inches, if no water is lost vertically to a deeper aquifer. Meeting these assumptions and if we know the amount of water entering as surface runoff (determined using the Simple Model as described by AMEC 2013), we can then subtract surface runoff from 15 inches to determine the amount of water entering as groundwater. Implicit assumptions to this approach include: 1) the groundwater contributing area is equivalent to the watershed area (this could be modified if the groundwater contributing area is known) and 2) no water is lost vertically to underlying aquifers. We justify an ET that is equivalent to 70% of rainfall based on a number of studies, especially one by the United States Geological Survey (USGS) (Knowles 1996) which estimated evapotranspiration in the Rainbow Springs and Silver Springs basins. Because both basins are largely internally drained, most of the water discharged at by these two large spring systems (i.e., springflow) is groundwater. In this study, discharge and rainfall were measure over a 30-year period.

> *"A water-budget analysis for the two-basin area indicated that over a 30-year period (1965-94) annual rainfall was 51.7 inches. Of the annual rainfall, ET accounted for 37.9 inches; springflow accounted for 13.1 inches; and the remaining 0.7 inch was accounted for by streamflow, by ground-water withdrawals from the Floridan aquifer system, and by net change in storage" (Knowles 1996). "*

In this case, ET accounted for approximately 73% of average annual rainfall. For estimation purposes, we think that an ET amount equivalent to 70% of annual rainfall is reasonable. There is, however, as one might anticipate a range of estimated percentages and values (e.g., Tibbals 1990, 58-94% of annual rainfall; Sumner 1996, 53% of annual rainfall; Summer 2001, 74-77% of annual rainfall; Bidlake et al., ET equivalent of 38-42 inches annually; Shoemaker et al. 2011, ET equivalent to 35 to 43 inches annually) depending on location and land cover types examined.

To obtain annual values for the amount of groundwater volume delivered to a lake, we simply took the annual rainfall total and subtracted from this number a value equivalent to 70% of the rainfall total to account for ET loss, and then subtracted from this number the annual runoff volume as computed by the Simple Method as described above.

Once we had the groundwater volume, it was multiplied by the percentage watershed area in a given major land use category and the appropriate nutrient concentration as shown in Table 4-2. There are no empirical nutrient concentration data available for groundwater that contributes to Lake Buckeye. As a result, we relied on literature values to estimate groundwater nutrient loading to the lake. However, the range of values of both TN and TP in groundwater beneath citrus land use (in particular) varies by at least two orders of magnitude (Atkins and ESA 2015). A sensitivity analysis comparing the changes in TN and TP loads estimates using a range of groundwater concentrations was performed for Lake Tennessee, Polk County (Atkins and ESA 2015) to evaluate the sensitivity of the spreadsheet model to assumed groundwater concentrations. For the purposes of developing loading estimates for comparing with other potentially significant sources (e.g., stormwater, atmosphere, and septic systems), we used the values shown in Table 4-2. Annual groundwater nutrient loads were dependent on the land use classifications within a given year.

**Table 4-2 Surficial Aquifer Concentrations for Different Land Use Categories.**

| Land use | Nitrogen (mg/L) | Phosphorus (mg/L) |
|---|---|---|
| Citrus** | 30.0 | 1.30 |
| Undeveloped* | 0.48 | 0.08 |
| Residential* | 1.10 | 0.36 |

*Tihansky and Sacks 1997

**Selected based on range of values presented in Atkins and ESA (2015).

A comparison of surficial aquifer elevations at the RIDGE WRAP P-2 SURF (site ID 25380) site located approximately 0.8 mile north-northwest of the center of Lake Buckeye and lake surface water elevations indicated that the surficial aquifer is higher than lake levels. There is a brief period of time, from 2009-2010, in which surficial aquifer elevations were lower than the lake water elevations; however, overall the data suggest that it is likely that surficial groundwater should be flowing into Lake Buckeye (Figure 4-6).

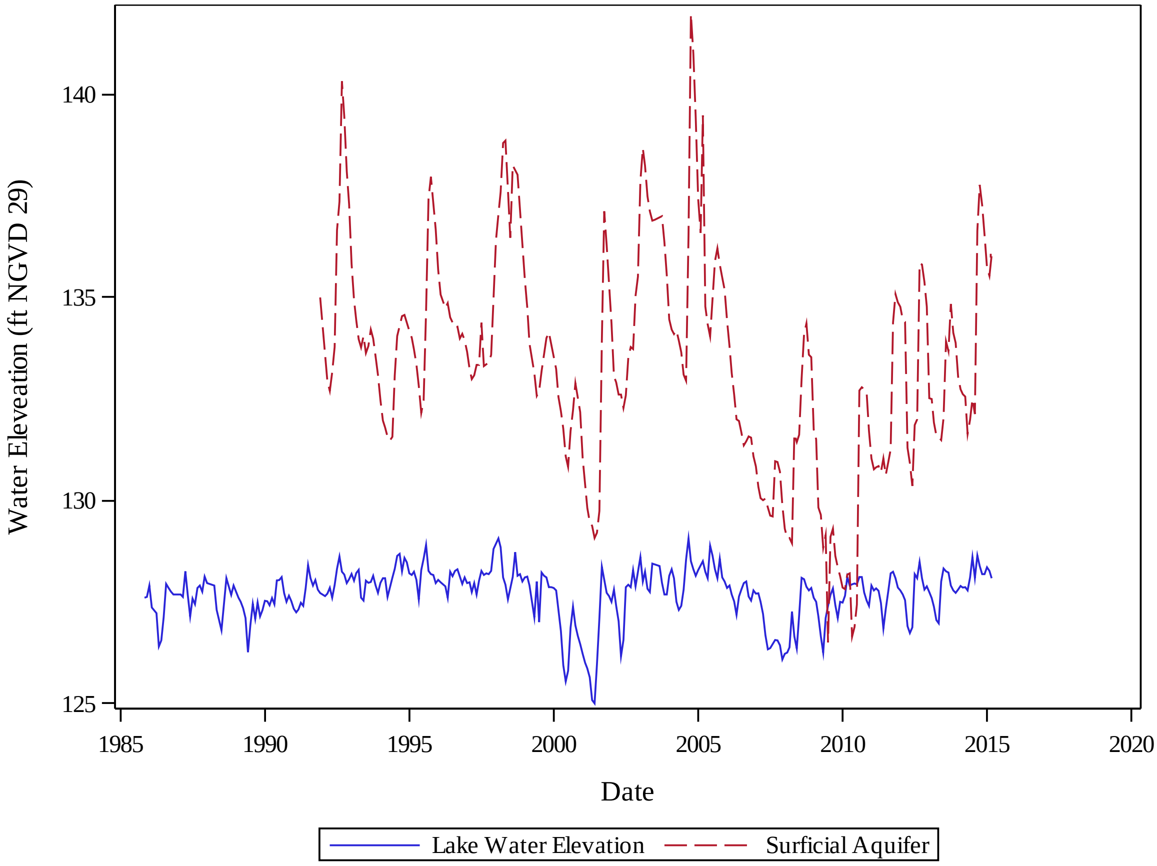


**Figure 4-6 Comparison of Surficial Water Elevations and Lake Buckeye Water Elevations.**

## 4.2.5. Loading model assumptions

Using the methods described above, we estimated nutrient loadings to Lake Buckeye for years 1990 to 2014. A number of assumptions were made in order to generate these loading estimates in addition to those inherent with the methods as previously described and outlined below.

Since land use data were not available for every year from 1990 to 2014, watershed (i.e., stormwater) loadings were generated using land use acreages for the years 1974, 1995, 2004-2009, and 2011. Prior to 1995, land use acreages for 1974 were used. In 1974, 120 acres of the 217 acre watershed (55%) was in a single land use (Florida Land Use Cover and Classification System (FLUCCS) Code 2200 – Tree Crops). In 1999, 110 acres remain classified as citrus; however, in 2006 only 27 acres were classified as citrus while 81 acres were classified as undeveloped/rangeland (FLUCCS Code 1900). In order to avoid an abrupt transition in land use changes due to gaps in land use data, a gradual transition (interpolation) was applied between coverage dates (1995 to 2003, 2004 to 2007,etc). Because of the relatively good coverage of land use from 2004 to 2011, these estimates represent the best estimates of stormwater loadings from the watershed using the methodology applied. Loading estimates were generated for each month for the period 1990 to 2014, and then summed to generate annual totals. If it can be assumed that atmospheric loading data gathered elsewhere (at Verna Wellfield and Tampa Bay area) can be extrapolated to Lake Buckeye as described in the methodology outlined above, then atmospheric loadings to Lake Buckeye are equally valid for all months and years from 1990 to 2014, and no further assumptions were made.

For septic systems (OSDS), a number of assumptions were used to generate loadings as described above. In addition, the following assumptions were made: there is a mixture of houses connected to sewer or septic. The majority of houses in the northwestern and southeastern portion of the watershed appear to utilize septic systems. There was not an available database of septic systems in terms of their location and when they were installed, we used available aerial photography to count the number of homes/businesses (roof tops) in the portion of the watershed with evidence of septic systems for the following years 1968, 1995, and 2011. We further assumed that the number of septic tanks increased linearly between years for which we had no aerial photography and that there were 63 septic systems in the watershed in 1968. In 1995, there were 80 rooftops counted in the watershed, and it was assumed that these structures were on a septic system.

As described elsewhere, nutrient loading from groundwater (in addition to that contributed from septic systems) is likely to occur. This loading source is potentially significant, and may outweigh the contribution of other sources (atmospheric, watershed and septic); however, direct measurements of this source are rarely made. When made, measurements are typically taken over a relatively short time period. As such, annual groundwater nutrient loadings were estimated based on annual rainfall, estimated stormwater run-off and ET.

### 4.2.6. Annual loadings over time

In general, nitrogen and phosphorus loading for all sources (i.e., sum of stormwater, atmospheric, groundwater and septic tank loading) had not changed appreciably between 1990 to 2005 (Appendix A; Figure 4-7. The close correlation between nitrogen and phosphorus loads evident in Figure 4-7 is likely attributable to little change in land use until 2006. There is an apparent reduction in nitrogen and phosphorus loads after 2006 which can largely be explained by a reduction in citrus within the watershed (43% of watershed in 2005 to 12% of watershed in 2006).

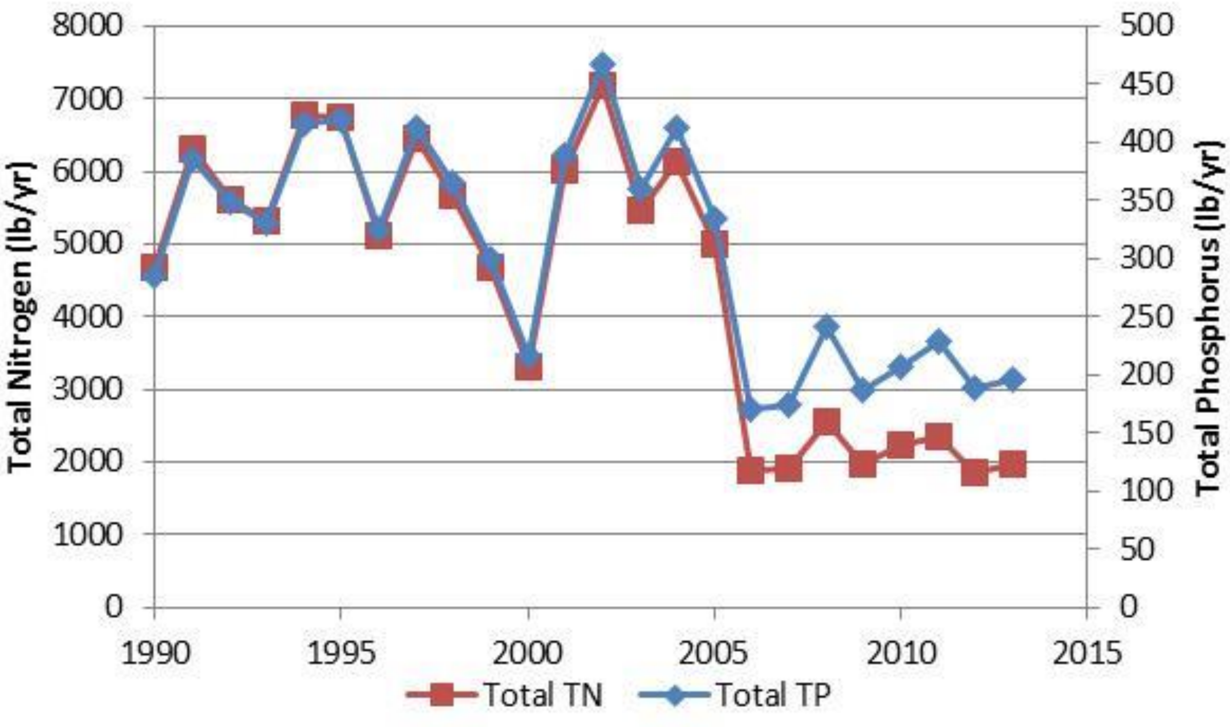


**Figure 4-7 Estimated Annual Nitrogen and Phosphorous Loading from the Combined Loads Generated from Stormwater, Atmospheric, Septic Tank and Groundwater Sources**

### 4.2.7. Source loadings over time

Each of four potential loading sources was evaluated by plotting annual loading estimates for the period 1988 to 2014. It should be expected that septic tank loading should have increased during the period of 1988 to 1995 due to the increased in development and associated OSTDS connections, estimated loading has remained constant since 1995 (Figure 4-8). In 1974, the watershed was predominantly citrus (120 acres); now there are 27 acres ascribed to tree crops (FLUCCS CODE 2200). Residential land uses have increased from 67 acres in 1974 to 96 acres in 2011.

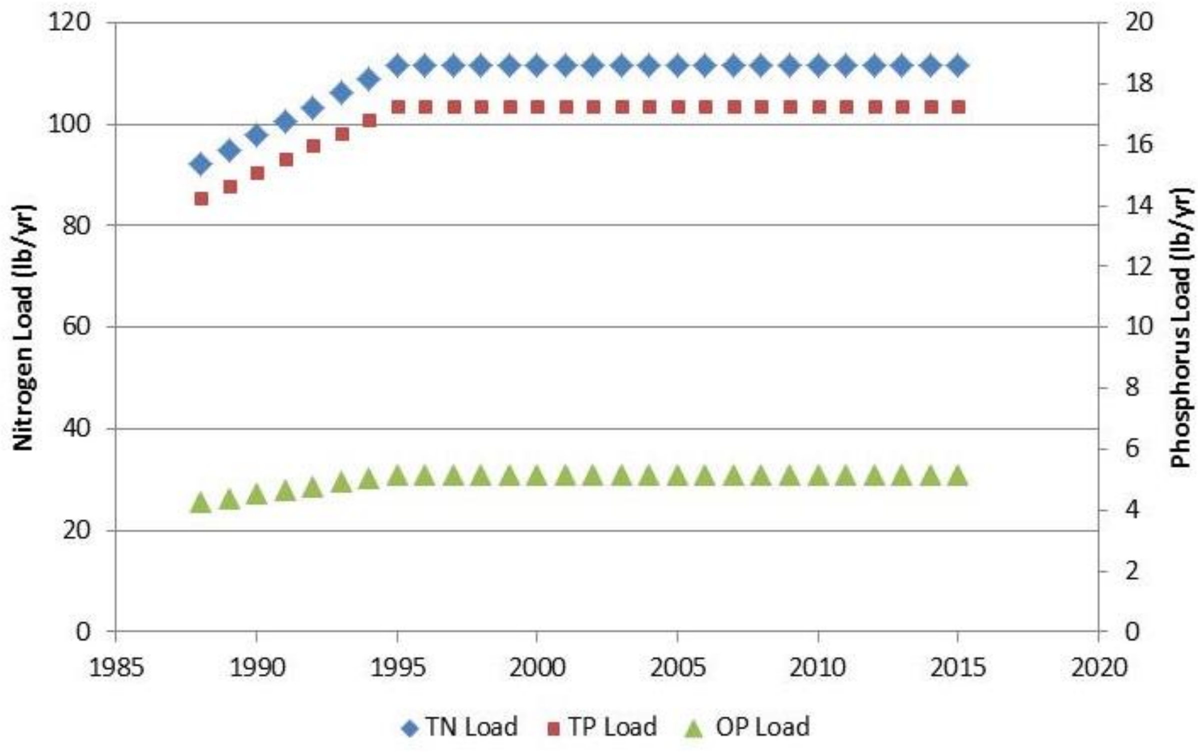


**Figure 4-8 Estimated Annual Nitrogen and Phosphorous Loading From Septic Tank Sources**

Atmospheric loading of both nitrogen and phosphorus has apparently declined during this period (1990 to 2014; Figures 4-9 and 4-10); however, much of this declining trend can be attributed to a generally decreasing trend in rainfall for the period evaluated. Annual variation in loads is due to both variable, but generally decreased rainfall, as well as to unexplained monthly variation in atmospheric pollutant concentrations.

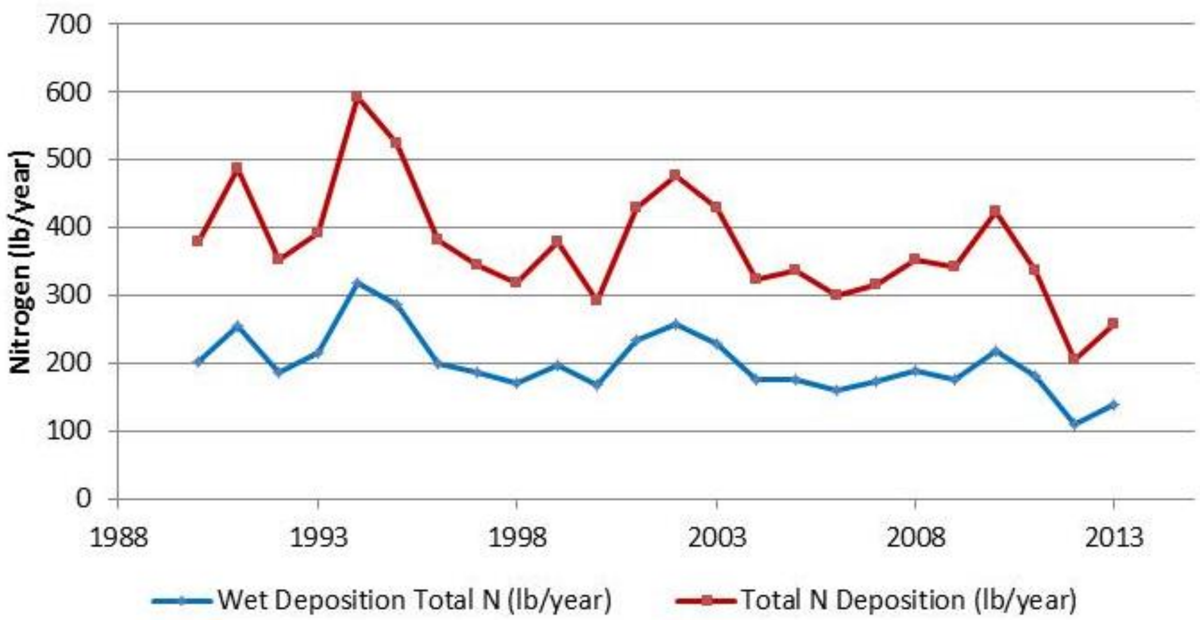


**Figure 4-9 Estimated annual nitrogen loading from atmospheric sources**

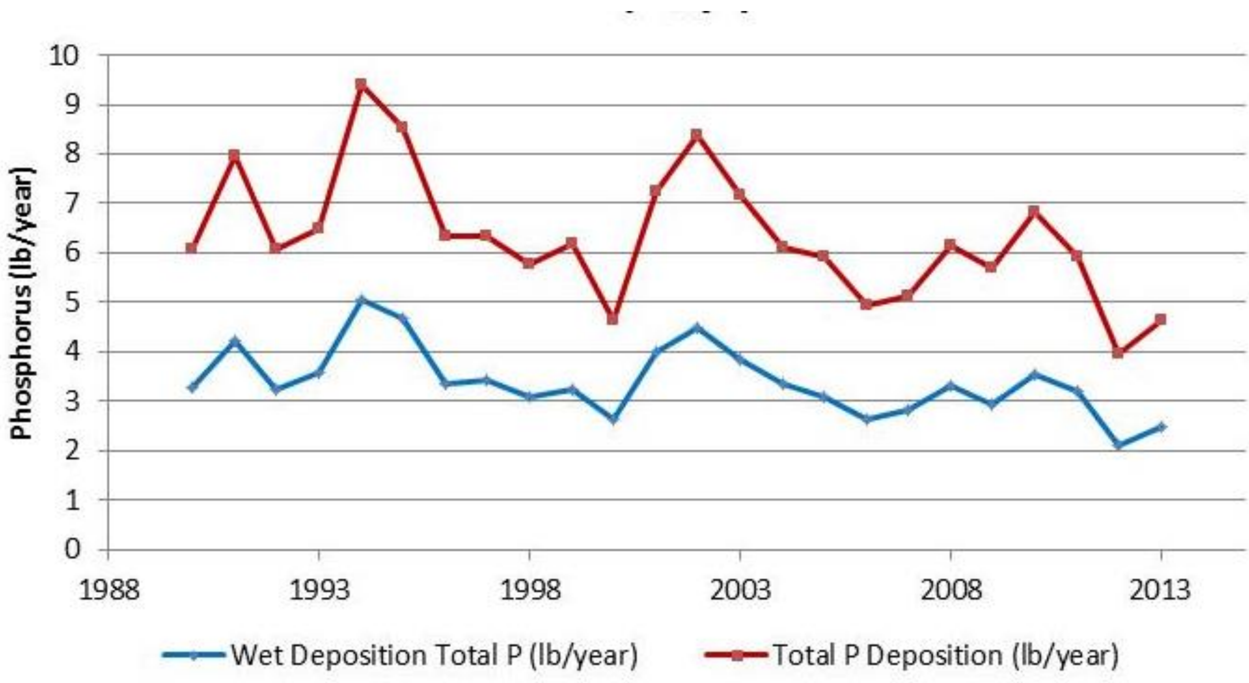


**Figure 4-10 Estimated annual phosphorous loading from atmospheric sources**

As stormwater loads are driven by rainfall, we determined how much of the estimated annual stormwater load occurred in the wet season (defined as the months of July – September) as compared to the dry season. Results are presented graphically for nitrogen in Figure 4-11, and for phosphorus in Figure 4-12. Appreciating that the dry season by definition is twice as long as the wet season, it was determined that the dry season load varied from approximately 20 to 80% of the wet season load.

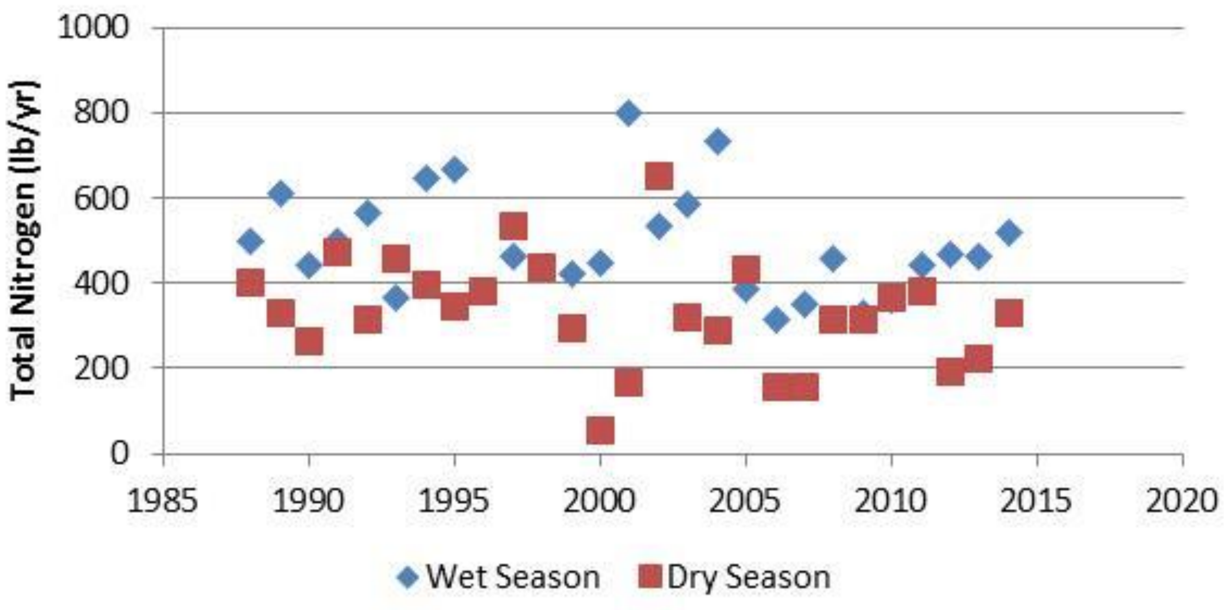


**Figure 4-11 Estimated Wet and Dry Season Nitrogen Loading from Stormwater Runoff (Watershed Sources)**

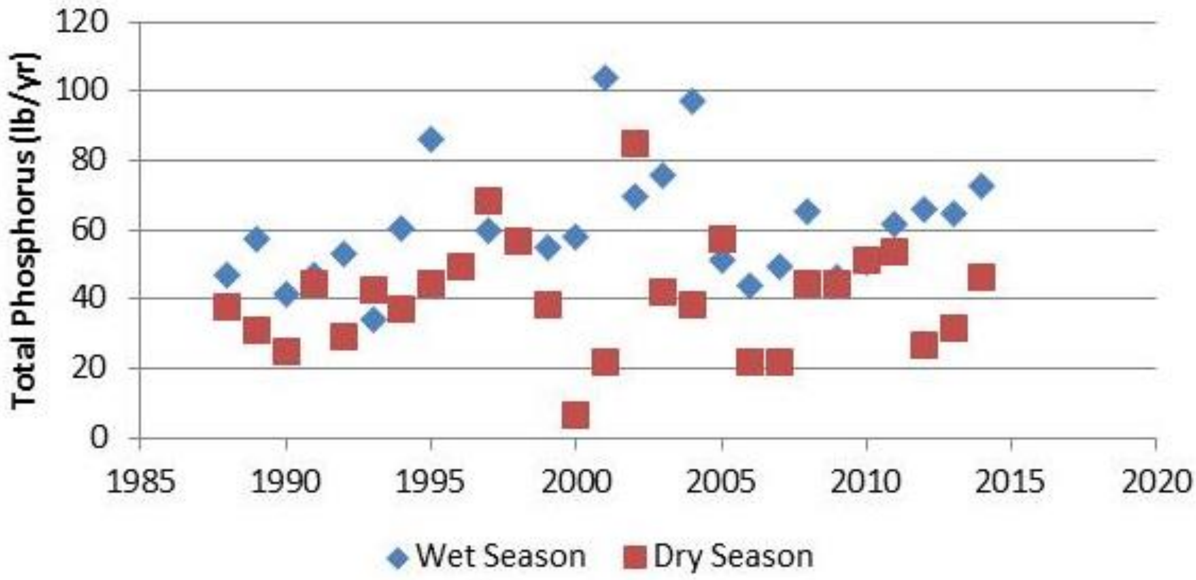


**Figure 4-12 Estimated Wet and Dry Season Phosphorus Loading From Stormwater Runoff (Watershed Sources)**

Groundwater nutrient loading was a major source of nitrogen to Lake Buckeye over time (Figure 4-13). Nitrogen and phosphorus loading has declined since 2005 which corresponds with a conversion from agricultural to residential which led to a decrease in the nutrient concentrations associated with groundwater. Phosphorus and nitrogen loading associated with groundwater has remained relatively constant since 2005 ranging from 65 to 100 lbs TP/year and 800 to 1,000 lbs TN/year, respectively (Figure 4-13).

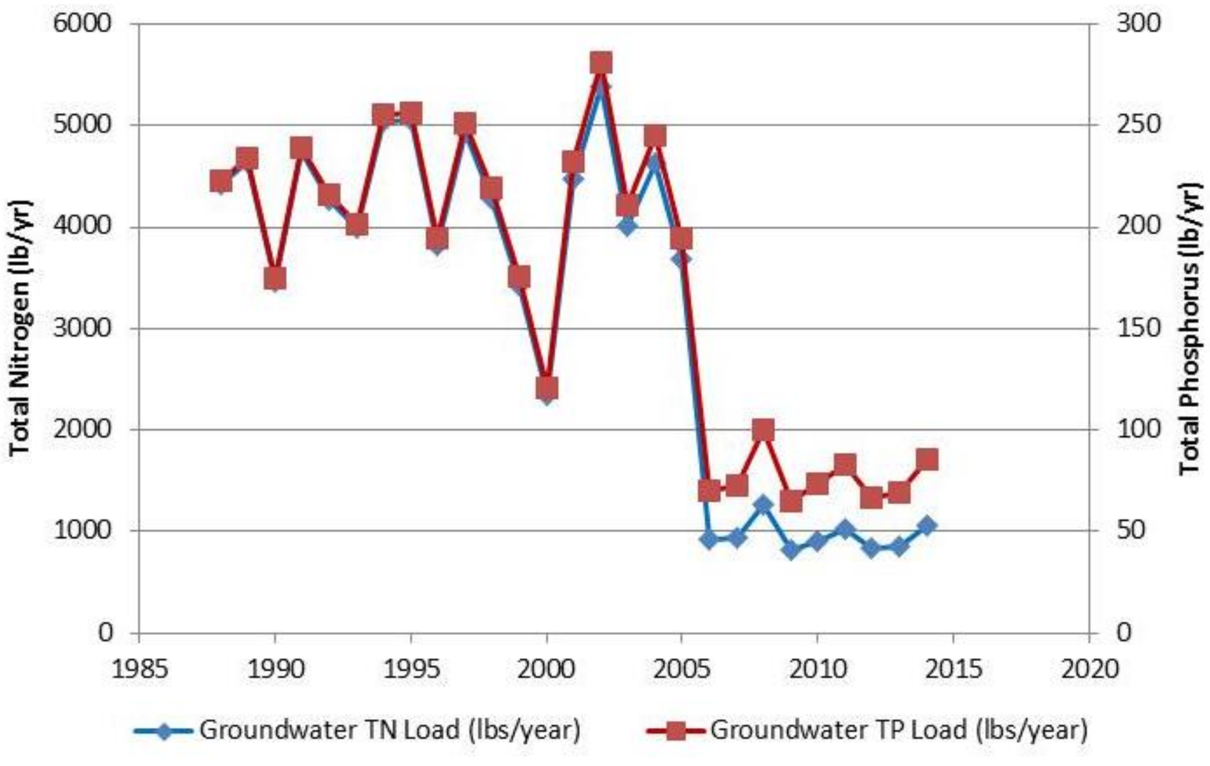


**Figure 4-13 Estimated annual nitrogen loading from groundwater sources**

Of the four potential sources (atmospheric, septic, groundwater and stormwater) evaluated in some detail, groundwater loading was the predominant source of nitrogen (41-77 percent; Figure 4-14). Due to land use conversions, transitioning from a predominantly agricultural watershed to a predominantly residential watershed, the importance of groundwater as source of nitrogen has decreased over time (Figure 4-14). It is important to note that the area contributing to groundwater may extend beyond the delineated watershed; however, estimates presented in this report assume a contributing area equivalent to watershed area. In regards to phosphorus, groundwater was the dominant source until land-use conversions resulted in a predominantly residential watershed. Presently, stormwater runoff is the dominant phosphorus source to Lake Buckeye (Figure 4-15). Phosphorus loads and the relative contributions by source have remained relatively constant since 2005 (Figures 4-13 and 4-15).

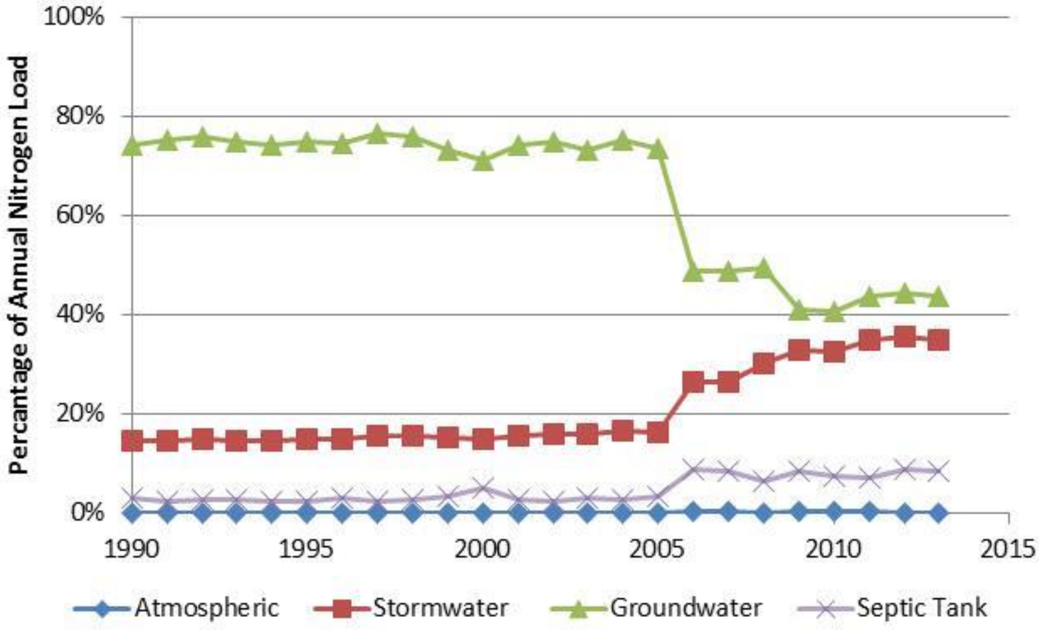


**Figure 4-14 Percentage of Total Annual Nitrogen Load by Source**

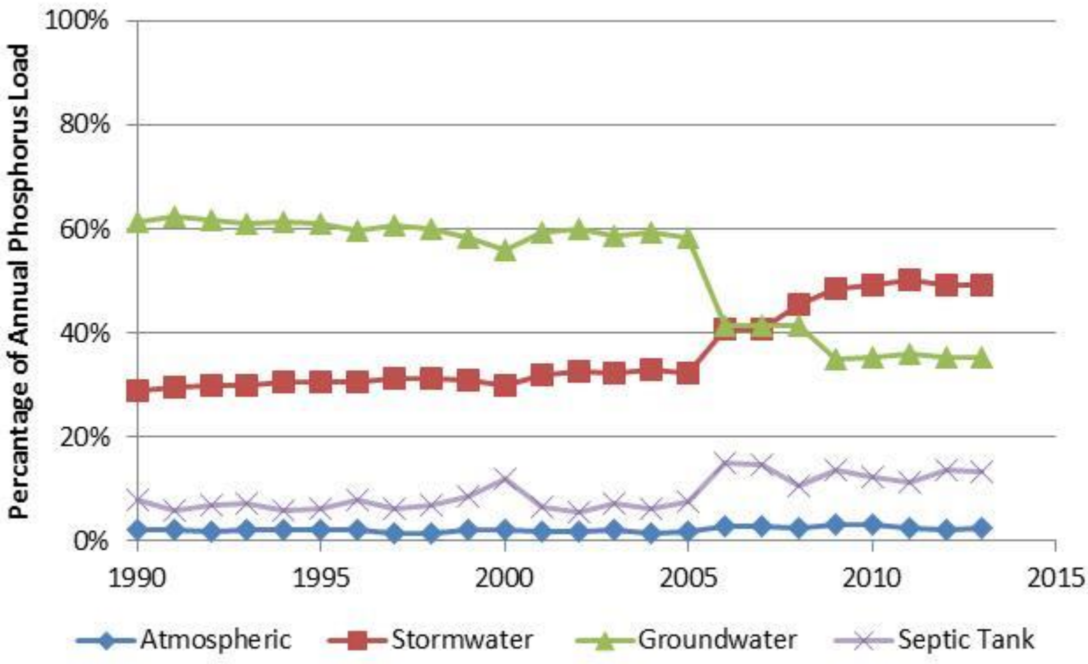


**Figure 4-15 Percentage of Total Annual Phosphorus Load by Source**

### 4.2.8. MS4 load contribution

There are five Polk County Municipal Separate Storm Sewer Systems (MS4) located in the Lake Buckeye watershed which discharge to the lake. At the time this report was prepared, the sub-basin boundary for only one MS4 outfall had been delineated. As such, estimated load contributions for each MS4 have not been calculated. To better resolve the relative contribution of each MS4 to the overall external nutrient loading to Lake Buckeye, it is recommended that the MS4 outfall sub-basins be delineated in the future and their relative contributions be evaluated.

## 4.3. External nutrient load relevance to water quality

Quantification of external nutrient loads is most beneficial if a corresponding link to ambient lake water quality is identified. As appropriate, annual nutrient loads from each component were compared to Lake Buckeye nutrient and chlorophyll-a concentrations. If fluctuations in nutrient loading are evident based on changes in land use, regional and/or seasonal rainfall, or if infrastructure degradation substantially impacts the nutrient availability within Lake Buckeye, a commensurate response in phytoplankton production should be evident.

In the most recent Total Maximum Daily Load (TMDL) documents produced by FDEP (FDEP 2014 a,b,c,d), total annual rainfall and average annual chlorophyll-a concentrations were used to investigate whether stormwater run-off had a direct impact on water quality. For scenarios in which a positive correlation between rainfall and chlorophyll-a concentrations were observed, a more detailed investigation as a prominent nutrient source was performed. For Lake Buckeye, a positive correlation was identified between total annual rainfall and TN ($p=0.005$; $R^2=0.47$; Figure 4-16). Based upon these results, a more comprehensive analysis comparing annual stormwater run-off loads to ambient annual average chlorophyll-a concentrations was performed. No significant correlations were identified between annual average chlorophyll-a concentrations and external nutrient loads from atmospheric deposition, septic tanks or stormwater run-off. However, a significant positive correlation between annual average in-lake chlorophyll-a concentrations and annual groundwater TN ($p=0.0020$, $R^2=0.33$) or TP ($p=0.0025$; $R^2=0.32$) loads was identified (Figures 4-17 and 4-18). The results of this analysis indicate that phytoplankton abundance may be directly linked to the external influx of nutrients from groundwater inflows (which have declined substantially since 2005).

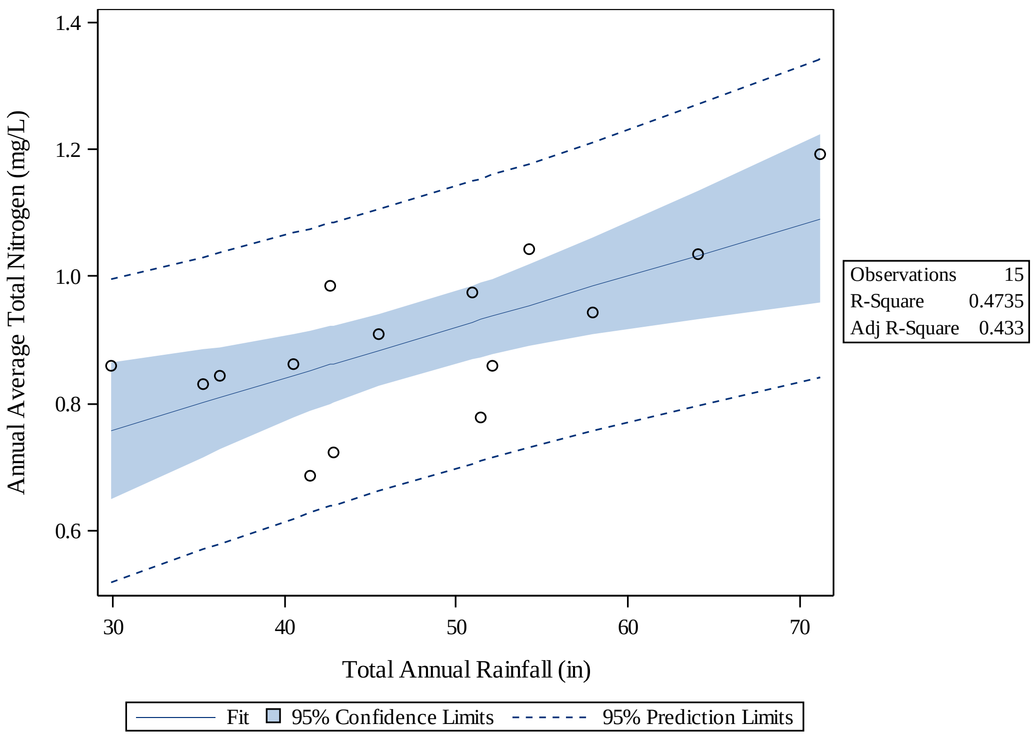


**Figure 4-16 Significant Positive Correlation Between Total Annual Rainfall and Annual Average TN Concentrations (p=0.005)**

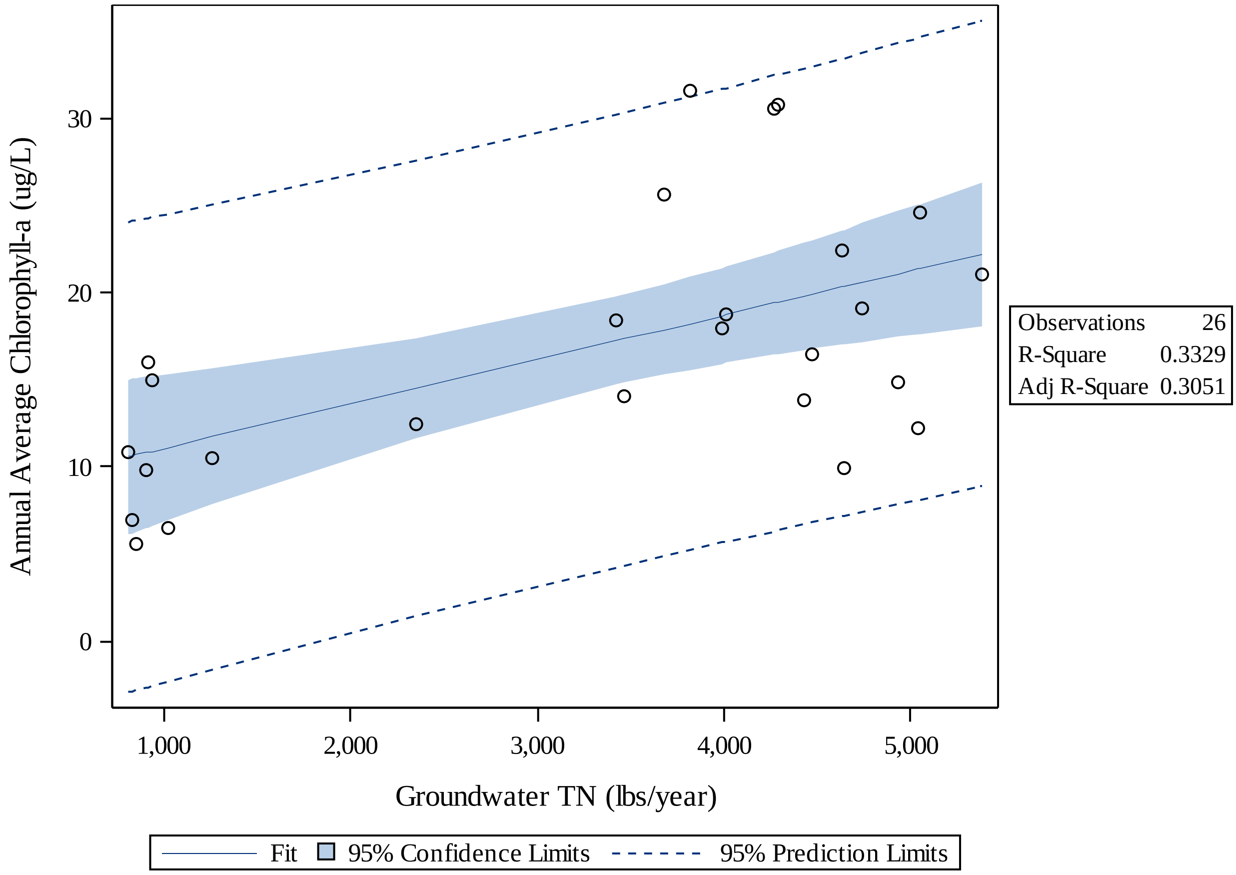


**Figure 4-17 Significant Positive Correlation Between Annual Average In-Lake Chlorophyll-a and Annual Groundwater TN loads (p=0.0020)**

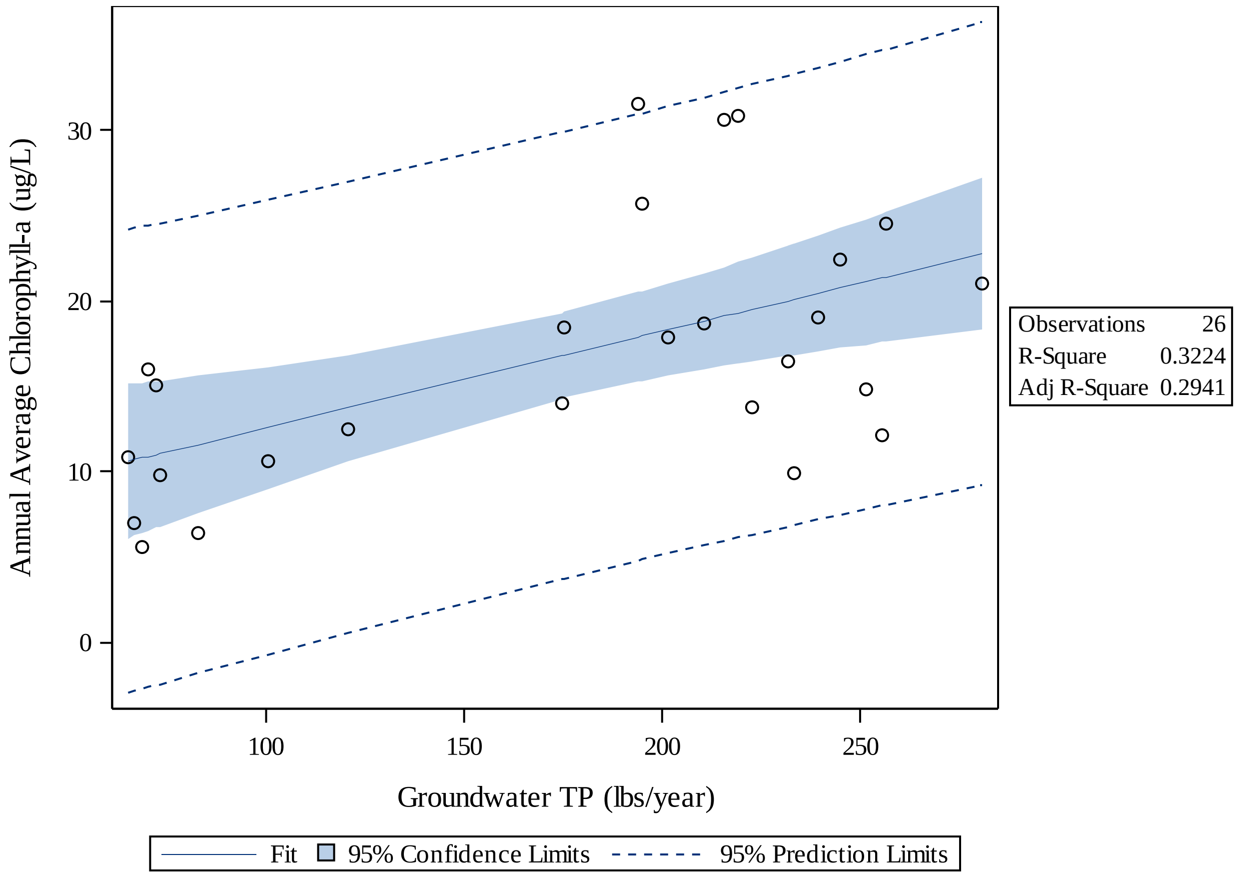


**Figure 4-18 Significant Positive Correlation Between Annual Average in-lake chlorophyll-a and annual groundwater TP loads (p=0.0025)**

### 4.3.1. Groundwater input

Polk County has established itself as a leader in citrus production within the state of Florida harvesting 24.6 million boxes of citrus during the 2012-2013 growing season (Bouffard 2013). As such, the impact of fertilizer application to active citrus groves on groundwater quality is a potential nutrient loading source for downstream waterways. The Lake Buckeye watershed is located in the Winter Haven Ridge and is comprised of predominantly well-drain soils. The 1995 Land Use/Land Cover data classifies the entire watershed as Citrus (116 acres; FLUCFS 2200). Comparatively, the 2011 Land Use/Land Cover data classifies 27 acres as Cropland and Pastureland (FLUCFS 2100), a 77% reduction in potential agriculture production.

Polk County has experienced a reduction in land area available for citrus farming in the past 10 years (NASS 2015). Similarly, a reduction in citrus farming has occurred within an approximate mile radius from the Lake Buckeye shoreline, evident when using imagery available on line. As previously reported, the ambient nutrient (TN and TP) and chlorophyll-a concentrations have been improving over time (Figures 3-14 to 3-16). The in-lake TP concentration declines correlate with a reduction in citrus farming within the adjacent watershed (Figures 4-19). A commensurate reduction in TN was not observed over the more refined time-step (Figure 4-20), which may be related to the strong correlation between rainfall and influxes of TN to the lake (Figure 4-16). This evidence suggests that as previously presented, groundwater may contribute the dominant source of phosphorus to Lake Buckeye. Additionally, a strong, direct correlation between annual groundwater nitrogen ($p=0.0020$; $R^2=0.33$; Figure 4-17) and phosphorus ($p=0.0025$; $R^2=0.32$; Figure 4-18) loads and chlorophyll-a concentrations support the link between the adjacent watershed characterization and in-lake water quality. Therefore, a reduction in active citrus groves has likely resulted in a reduction of nutrient inputs to the Lake, thus resulting in attendant water quality improvements.

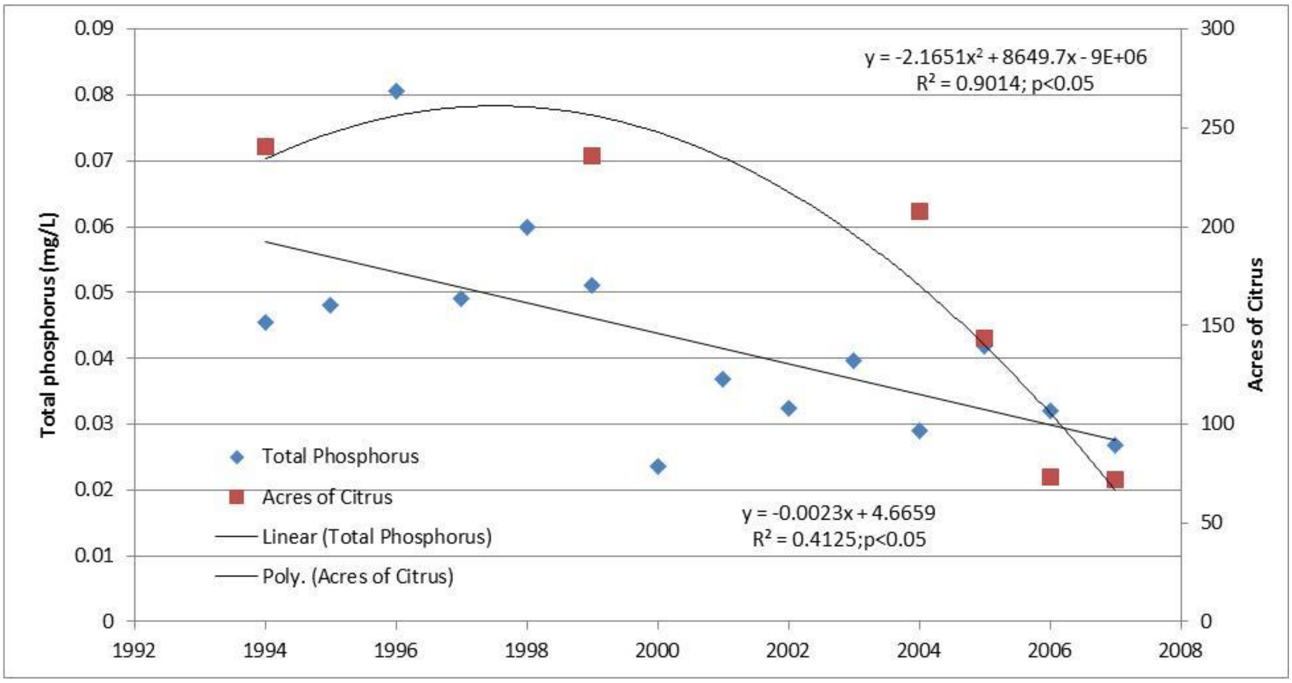


**Figure 4-19 Ambient Annual Mean TP Concentrations Compared to the Citrus Acreage within 1 Mile of Lake Buckeye Shoreline.**

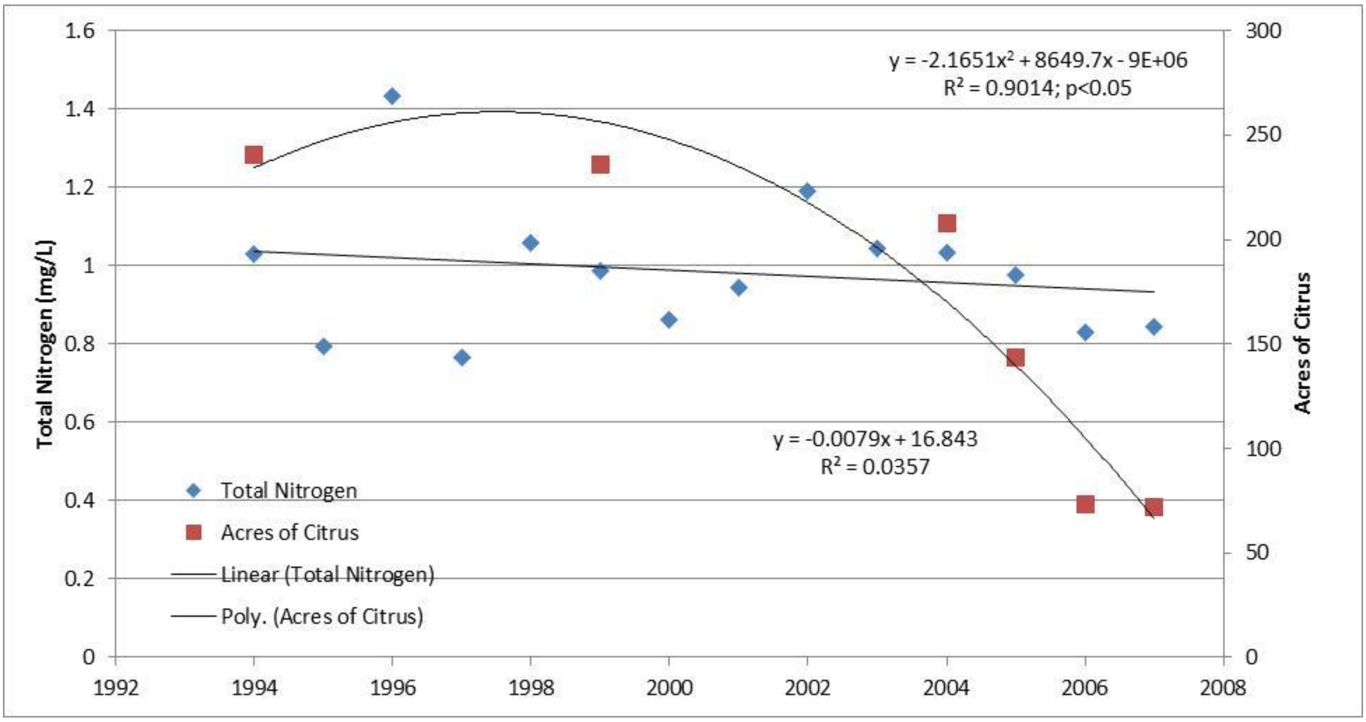


**Figure 4-20 Ambient Annual Mean TN Concentrations Compared to the Citrus Acreage within One Mile of Lake Buckeye Shoreline.**

## 4.4. Impact of water elevation on lake condition

A reduction in rainfall was reported over the period from 2007 to 2014 compared to 1999 to 2006; however, a commensurate change in lake water elevation was not observed (see Section 3). Correlations between monthly rainfall and monthly water elevation were evaluated and a significant correlation was not identified likely due to the large time step (monthly versus daily recordings). Given the high infiltration soils within the Lake Buckeye watershed, water elevation is likely to respond quickly during rainfall events.

It is possible that a natural maximum water elevation exists within Lake Buckeye due to the hydrologic connection with Lake Fannie along the northern rim through a wetland feature. As such, substantial fluctuations in water elevations may not be perceived. Evaluations of Lake Buckeye water elevations compared to nutrient concentrations were performed (Figures 4-21 and 4-22). A significant direct correlation was identified between water elevation and phytoplankton production indicating that TP concentrations increased as water elevation rose ($p=0.0058$; Figure 4-21). No correlation was found between TN and water elevation ($p=0.25$; Figure 4-22). The increase in TP concentrations during higher water elevations is likely explained by the increased stormwater run-off (watershed loading) occurring during rainfall events; however, a correlation between rainfall and TP was not observed.

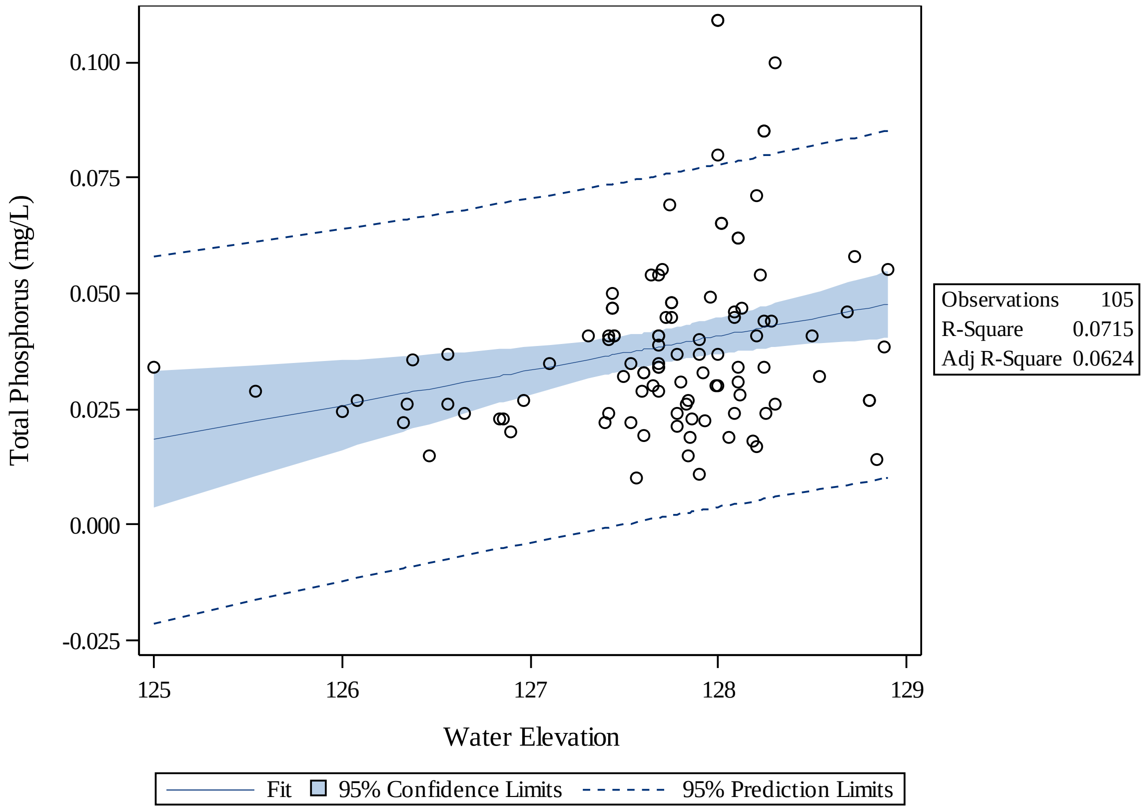


**Figure 4-21 Significant Positive Correlation Between Monthly Water Elevation and Total Phosphorus Concentrations (p=0.0058)**

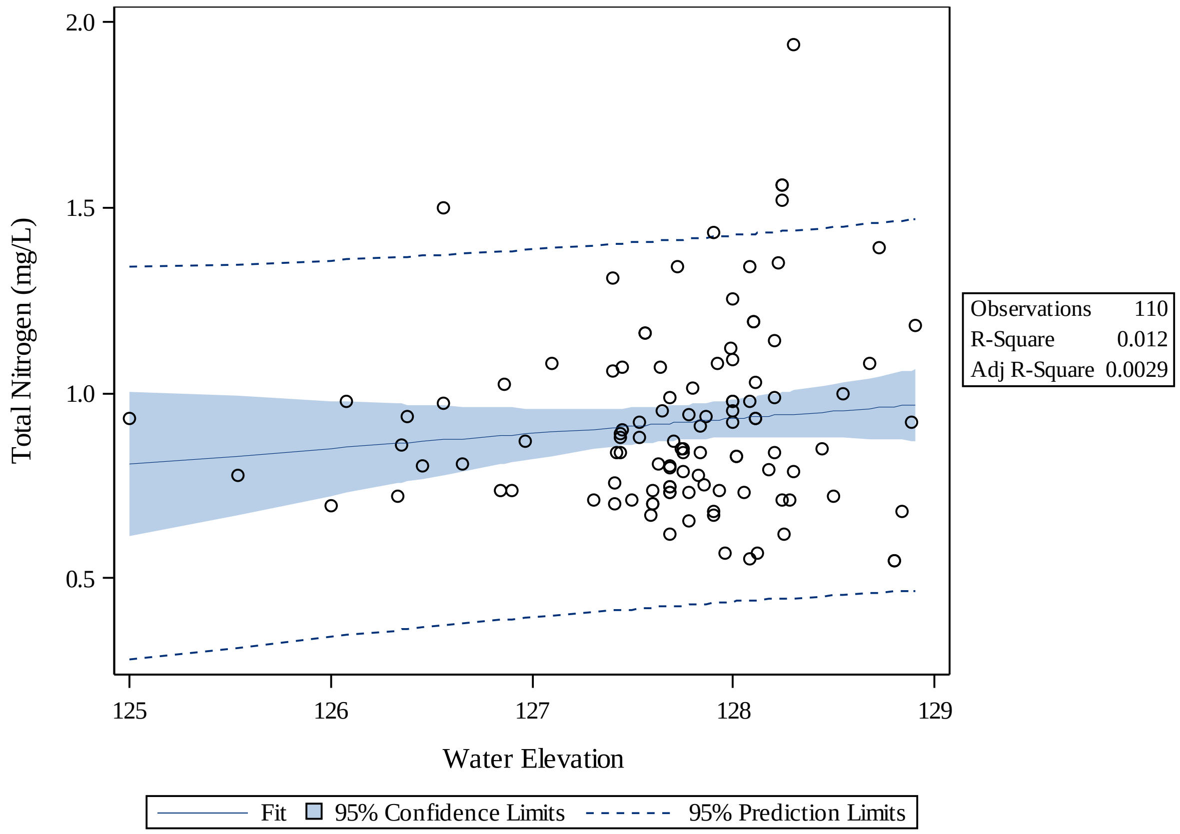


**Figure 4-22 Lack of Significant Correlation Between Monthly Water Elevation and Total Nitrogen Concentrations (p=0.25)**

## 4.5. Water quality response

A declining (improving) trend in several water quality parameters is evident in Lake Buckeye. The current water quality conditions are indicative of a healthy waterbody. Lake Buckeye has been identified as a co-limited lake when evaluating N to P ratios alone. A closer examination of the empirically-derived relationships between in-lake chlorophyll-a concentrations and nutrients (TN or TP) supports this designation with chlorophyll-a concentrations responding to fluctuations in both TN and TP. Since chlorophyll-a concentrations are significantly correlated with both nutrients, management of TN and TP is likely to result in sustained water quality improvement. However, phytoplankton appears to be more sensitive to nitrogen inputs rather than phosphorus. Based on the weight of evidence presented, it is speculated that, water quality improvements in Lake Buckeye may be directly related to land-use alterations that resulted in a reduction in groundwater nutrient loads. Multiple lines of evidence suggest that reductions in nutrient (nitrogen and phosphorus) inputs have resulted in improved water quality conditions.

# 5. Potential remedial action to protect and/or improve lake conditions

Lake water quality management plans have been developed throughout Florida predominantly for hypereutrophic (severely nutrient-enriched) lakes. In terms of implemented projects, those deemed to have the greatest success in terms of water quality improvement have focused on removing point sources of nutrient pollution, as well as activities that sought to reduce the impacts of past nutrient loading events (PBS&J 2010). Lake Buckeye water quality conditions were degraded only in 2005 when compared to the FDEP NNC. Otherwise water quality conditions have remained below the NNC and improving trends in water quality indicate that the lake water quality is indicative of a healthy waterbody. As such, proposed BMPs are focused on maintaining current water quality conditions and reducing pollutant loads, as feasible to ensure continued water quality improvement.

There are a variety of water quality management restoration approaches available toward the management of lake ecosystems. These projects range from structural projects positioned within the watershed (e.g., stormwater retrofits, wetland rehydration), to structural projects located within the lake itself (e.g., artificial circulation, sediment removal) to non-structural options (e.g., monitoring programs, public education). A brief overview of potential water quality restoration projects are provided below:

- **Sediment removal/reactivation**: the physical removal of bottom sediments or application of nutrient-binding agents (e.g., alum, phoslock) to the lake bottom in order to reduce/eliminate the release of nutrients from anoxic bottom-sediments.
- **Artificial circulation**: designed to mix deeper oxygen-deprived water to the lake surface for aeration and disrupting phytoplankton production.
- **Wetland restoration/rehydration**: restoring the natural flow-pathways and lake to wetland interactions with adjacent forested wetlands thereby reducing nutrient and sediment inputs to the lake and potentially increasing color levels.
- **Stormwater retrofits:** projects focused on the reduction/elimination of nutrients from stormwater run-off. Projects could include wet detention or dry retentions ponds, leaf litter collection, baffle boxes to collect large debris, and in-line alum treatments.
- **SAV/EAV enhancement/maintenance:** aquatic plants are capable of direct uptake and nutrient assimilation, sediment stabilization, and nutrient sequestration via epiphytes
- **Floating Treatment Wetlands**: floating mats comprised of (emergent aquatic vegetation) EAV designed to optimize nutrient assimilation, converting the bio-available nutrients to plant biomass.

The selection of specific restoration projects are dependent upon the unique water quality characteristics of an individual lake, its' adjacent watershed and interactions that may occur between the lake and the adjacent watershed. Recommended projects which may improve water quality within the Lake Buckeye system are provided below:

## 5.1. Structural: Watershed

**Reduction of direct stormwater run-off loading to the lake:** Stormwater run-off has been identified as an important nutrient source to Lake Buckeye. The redirection of directly connected impervious areas or outfalls into vegetated buffers would assist in decreasing direct loads to the lake (e.g., boat ramp). As urban development continues throughout the watershed, stormwater run-off will presumably increase. Efforts to reduce/eliminate direct stormwater run-off into the lake would serve to alleviate negative impacts on water quality.

## 5.2. Structural: In-lake

**Maintain/Enhance Submerged and Emergent Aquatic Vegetation:** aquatic vegetation appears critical to maintaining water quality within Lake Buckeye, as such the preservation of the natural shoreline should be a priority. Nutrients and sediments can be reduced and biodiversity improved or restored if a vegetated wetland buffer between land development and water are present (Wall et al. 2001, Dosskey 2001, Brinson et al. 2002, Fiener and Auerswald 2003). If aquatic plant control is necessary, removal of the decaying material is recommended.

**Artificial Circulation:** whole-lake pumping system are designed to circulate lake water to enhance oxygenation and transport phytoplankton to deeper water depths, thereby reducing light availability for continued phytoplankton production (Pastorak et al. 1981, 1982; Cooke et al. 1993). Oxygenation of the bottom sediment to water interface has the potential to reduce internal phosphorus loading to the overlying water column (Stumm and Leckie 1971).

## 5.3. Non-structural

**Monitoring program:**

- Initiate quarterly sampling of surface water samples to monitor water quality conditions in order to detect any degradation in water quality, as well as to meet data acquisition requirements of the State of Florida's newly adopted NNC criteria
- Initiate quarterly sampling of the surficial aquifer to monitor water quality conditions and levels in order to refine groundwater loading estimates contributing to the lake.
- Conduct bi-annual survey of percent area covered (PAC) for submerged aquatic vegetation. PAC has been shown to be a tool for predicting water clarity and chlorophyll-a concentrations in Florida lakes (Robison and Eilers 2014), increased SAV coverage resulting in improved water quality.

**MS4 characterization**: delineation of sub-basin boundaries to facilitate assessing the relative contribution of each to the nutrient loadings into Lake Buckeye.

**Public Education:** Public education related to the following BMPs would assist in maintaining water quality in Lake Buckeye:

- Proper disposal of pet and lawn wastes
- Proper fertilizer application to reduce nutrient loading to the lake
- Importance of aquatic vegetation and wetland buffer along shoreline

**Low Impact Development (LID):** A LID approach to development could ensure that future developments work to manage stormwater run-off. Continued residential development is occurring within the Lake Buckeye watershed, as such, an increase in impervious area and stormwater run-off to the lake may occur.

# 6. Summary and Recommendations

The FDEP has classified Lake Buckeye as a nutrient impaired waterbody based on elevated TSI values (FDEP 2014). By rule (F.A.C. 62-304), the state is required to develop a TMDL and subsequently a BMAP for all impaired waterbodies. TMDLs are developed and adopted by FDEP or the EPA and provide proposed load reductions to meet waterbody (WBID) specific targets. In response, a BMAP is prepared by the stakeholders for the respective WBID which outlines specific projects designed to address load reductions with the ultimate goal of improving water quality. Project implementation is potentially a costly endeavor and usually falls upon the local municipalities and county government for implementation. As such, inaccurate determination of impairment status for a WBID can have significant fiscal repercussions.

In 2013, EPA formally approved the proposed NNC which replaced TSI as the metric for nutrient impairment designation. Due to the implementation of new nutrient standards, many stakeholders have identified WBIDs which reported elevated TSI values yet nutrient and chlorophyll-a concentrations were below the recently adopted NNC. FDEP has indicated that the state is willing to re-evaluate TSI-impaired WBIDs in which a discrepancy between the old and new nutrient standards exists. Additionally, several WBIDs have been identified which had elevated nutrient and chlorophyll-a concentrations but substantial water quality improvements have occurred providing evidence that further load reductions are not necessary. FDEP corroborated an independent evaluation of recent water quality trends in Lake Buckeye confirming that water quality conditions met the NNC (ESA and ATKINS 2014). As such, it is recommended that Polk County pursue removing Lake Buckeye from the 303(d) list based on the implementation of new water quality criteria.

## 6.1. Water quality status

While Lake Buckeye water quality data prior to 1999 would support impairment designation using the current water quality standards (NNC), this determination is predominantly due to the lack of sufficient chlorophyll-a data resulting in a default to the most stringent nutrient criteria. It appears that chlorophyll-a data are not available for Lake Buckeye prior to 1999. For those years in which chlorophyll-a data are available, both phytoplankton abundance and nutrient concentrations remain below the associated NNC (Section 3). Not only are the annual geometric means below the NNC, but significant declining trends (improving water quality) were observed for chlorophyll-a, TN and TP accompanied by an increasing trend in water clarity (Secchi depth). An analysis of potential causes for the historic degradation and current water quality conditions was presented in Section 4. This analysis identified groundwater as a potentially dominant nutrient source contributing to phytoplankton production in the lake. A concurrent transition of the dominant watershed land use (citrus) to residential along with a regional reduction in rainfall likely resulted in a reduction in nutrient supply to the lake. As such, phytoplankton levels decreased thus improving water clarity which provided a suitable environment for submerged aquatic vegetation to become established within the waterbody.

### 6.1.1. Land use change

A reduction in citrus-related agriculture is widespread throughout Florida. Due to a combination of land development (commercial or residential), citrus canker and citrus-greening, citrus acreage has declined since the 1960’s (Figure 6-1). The Florida citrus production is estimated to remain constant or decline over the next ten years (Florida Department of Citrus 2011).

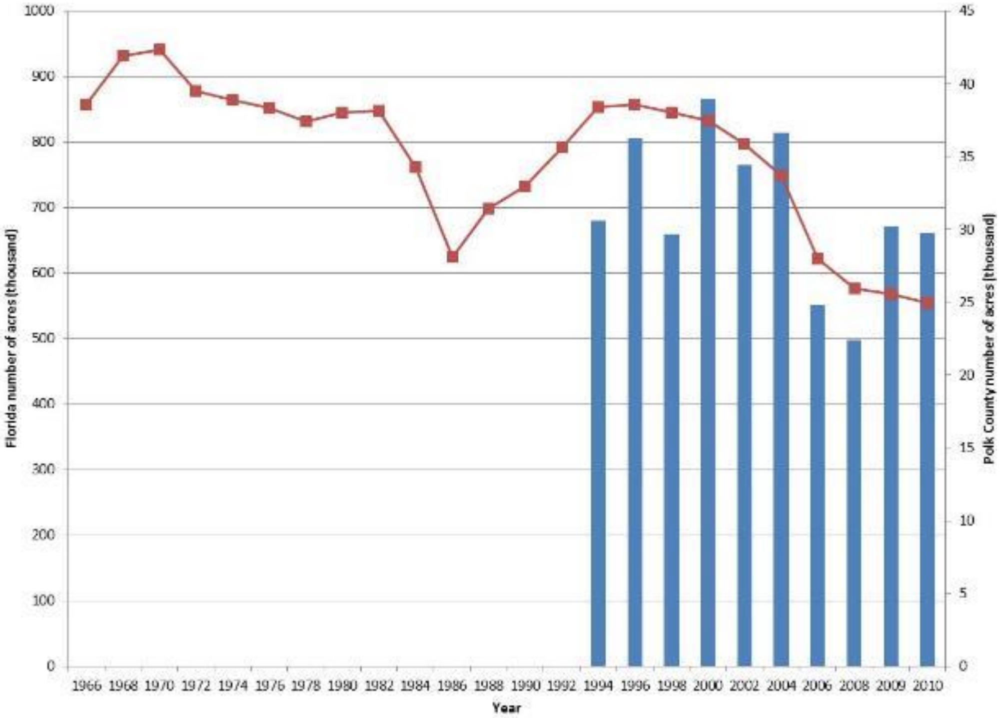


**Figure 6-1 Florida (red line) and Polk County (blue bars) Citrus Acreage Decline from 1966 to 2010 (data taken from Florida Department of Citrus 2011 and NASS 2015).**

The Lake Buckeye watershed is located prominently on the Winter Haven Ridge, an area conducive for agriculture, especially citrus farming. Historically, the majority of the watershed was comprised of agriculture (Figure 6-2). Evidence of residential encroachment is observed from the 1959 historical aerial imagery (Figure 6-2). By 1974, sixty-four percent of the watershed (129 acres) was comprised of agriculture (e.g., tree crops; Figure 6-2; Table 6-1). While imagery is not available between 1968 and 1995, a slight expansion of the residential development along the western shoreline is evident in the watershed in 1995 (Figure 6-3). The extent of agricultural parcels has declined from sixty-four percent in 1971 to twelve percent in 2011. A large portion of the agricultural parcels have transitioned to undeveloped land (Table 6-1). However, 2014 aerial imagery depict ongoing conversion of undeveloped land to residential development (Figure 6-2).

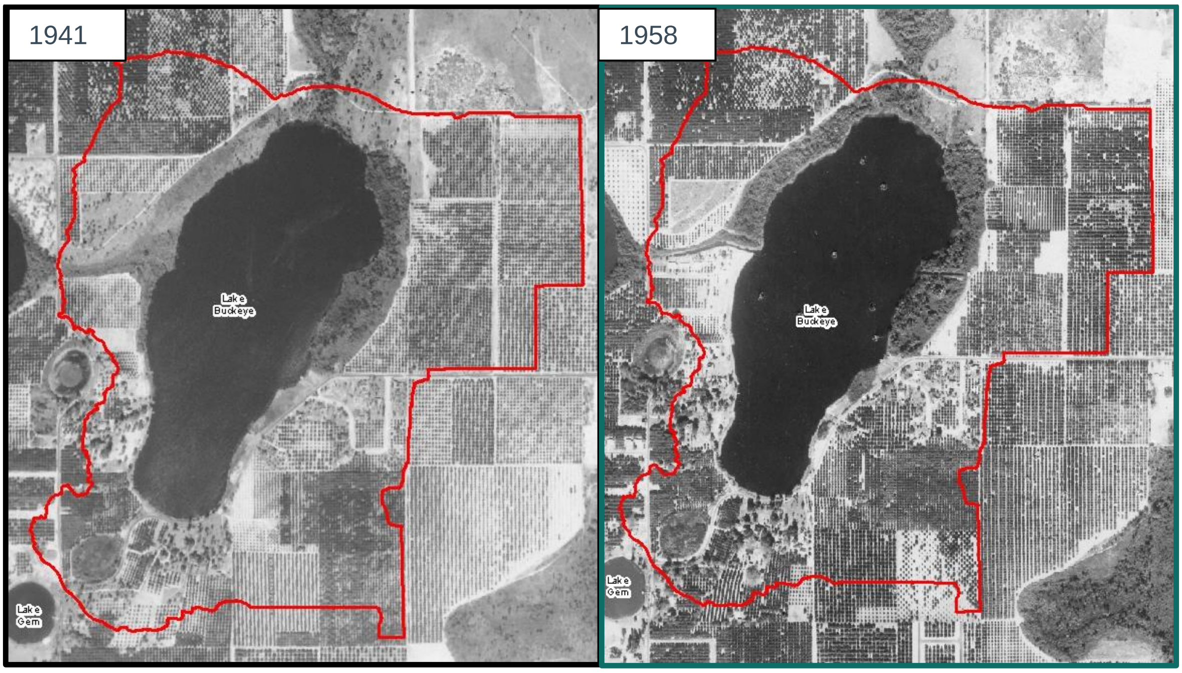


**Figure 6-2 Historical Aerials of Lake Buckeye and Adjacent Citrus Dominated Watershed.**

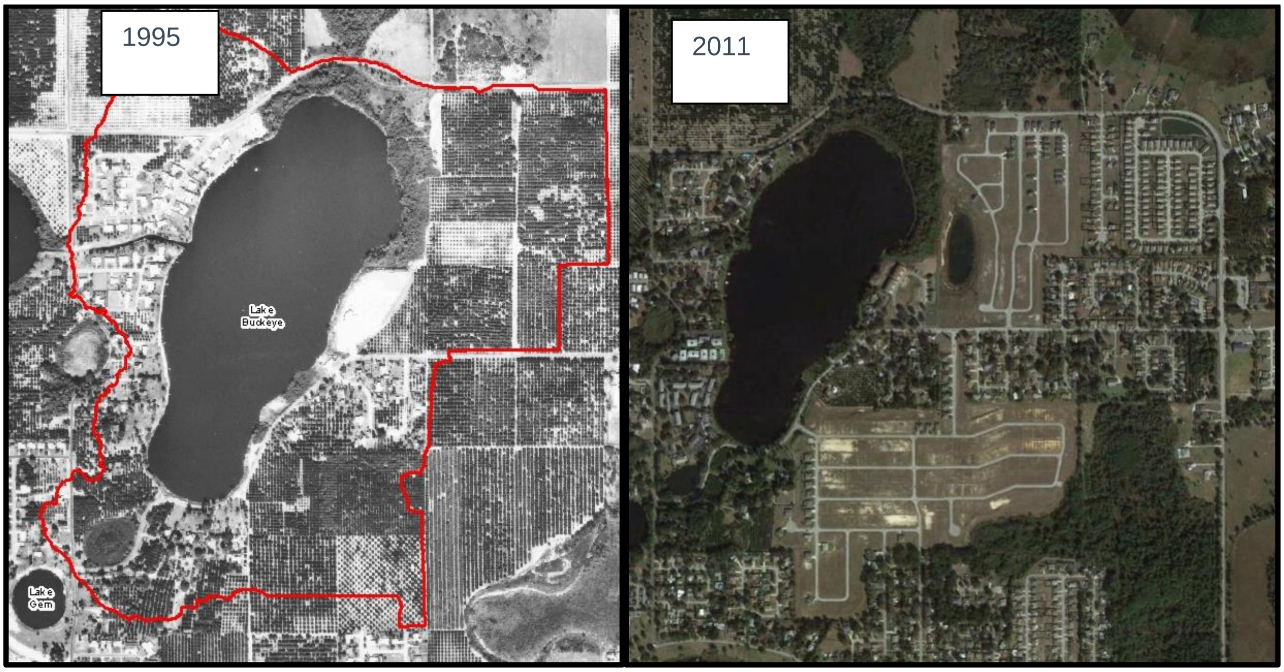


**Figure 6-3 Residential Transition within the Lake Buckeye Watershed.**

**Table 6-1 Change in Land Use within the Lake Buckeye Watershed Over Time.**

| Land use | 1974 | | 1995 | | 2011 | |
|---|---|---|---|---|---|---|
| | Acres | Percent | Acres | Percent | Acres | Percent |
| Agriculture | 129 | 59 | 116 | 54 | 27 | 12 |
| Other Undeveloped Land | 21 | 10 | 22 | 10 | 94 | 43 |
| Residential | 67 | 31 | 79 | 36 | 96 | 44 |

## 6.1.2. Groundwater loading

Fertilizer application has altered groundwater chemistry throughout regions dominated by agriculture (Sacks et al. 1998; Coquette 2004; Crandall 2000; Elrashridi et al. 2001; Li et al. 1999). To quantify the anticipated groundwater load reduction that has occurred based on land use changes within the Lake Buckeye watershed, the estimated groundwater nutrient load was calculated under two scenarios. The first scenario was reflective of documented 1974 land use conditions indicating a watershed comprised of 55% citrus agriculture, 31% residential and 14% undeveloped. The second scenario uses the 2011 land use conditions which provide evidence of a transition from citrus dominated to residential/undeveloped lands; 12% citrus, 44% residential, and 43% undeveloped (Table 6-1).

An estimate of groundwater input was calculated by quantifying the total annual rainfall that will likely enter Lake Buckeye via groundwater taking into account the stormwater component (AMEC 2013) and evapotranspiration. Using the land use designations in 1974 and 2011, the TN and TP groundwater loads were calculating by applying the appropriate groundwater concentration by land use category and applied to the watershed. Figure 6-4 displays the load reduction that has potentially occurred in the Buckeye Lake watershed based on a transition in land use. A 76-percent reduction in nitrogen and 64- percent reduction in phosphorus loading associated with groundwater inputs was observed based on land use changes alone.

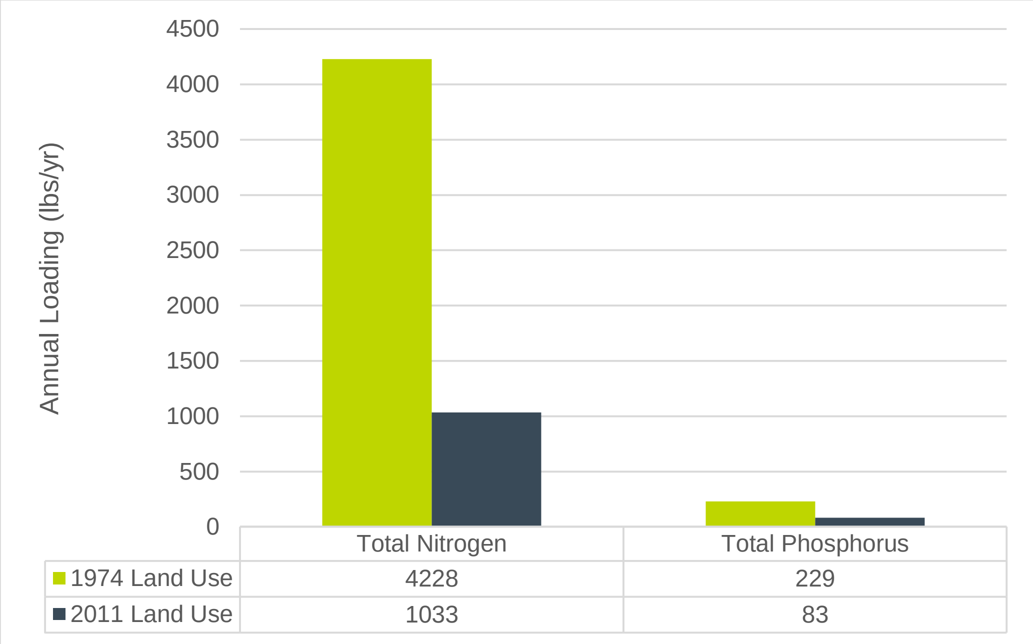


**Figure 6-4 Estimated Groundwater Nitrogen and Phosphorus Load Reductions from 1974 to 2011 in the Lake Buckeye watershed.**

## 6.2. Findings

- Lake Buckeye is a 63 acres lake located within the City of Winter Haven, within the Winter Haven Ridge. The contributing watershed is 217 acres which was historically comprised predominantly of citrus farming. A substantial elevation gradient occurs within the watershed ranging from 123 to 186 feet NAVD.
- The dominant soils within the watershed have a low runoff potential with high infiltration rates and are classified either as hydrologic soil group A or A/D.
- There is a substantial accumulation of organic material on the lake bottom which cannot be attributed to existing or historical point source discharges.
- The majority of the lake shoreline exhibits evidence of limited vegetative maintenance due to the amount of existing nuisance and exotic submerged and emergent aquatic vegetation. A western portion of the shoreline has been modified as a residential development including landscaping and hardened shorelines.
- Lake Buckeye was declared impaired for nutrients due to elevated TSI during the January 1, 2002 to June 30, 2009 verified period as part of the Group 3, Cycle 2 review.
- Lake Buckeye is considered a clear, alkaline lake based on a long-term geometric mean color of 17 PCU and alkalinity of 67 mg/l.
- An evaluation of the water quality within Lake Buckeye using the NNC was not consistent with the initial impairment determination and indicated that Lake Buckeye was not impaired for TN or TP.
- Improving water quality trends were observed in chlorophyll a, total nitrogen, total phosphorus and Secchi disk depth.
- Chlorophyll-a concentrations are significantly correlated with both nutrients, management of TN and TP is more likely to result in sustained water quality improvements.
- Groundwater nutrient loading, which appears to largely be driven by the abundance of citrus within the immediate watershed, correlates most strongly with changes in water quality.
- Ambient TN concentrations correlate with annual rainfall indicating that groundwater inflow and/or stormwater runoff could contribute to phytoplankton blooms.

## 6.3. Project recommendations

Overall, the inclusion/exclusion of Lake Buckeye from the 303(d) list does not influence the projects recommended to sustain current water quality conditions within the Lake. The land use composition within the watershed has changed dramatically in the past 30 years with substantial urban development currently underway. It is expected that these land use changes will impact the water and nutrient inputs which directly impact lake water quality conditions. As such, the proposed structural and non-structural projects provided in Section 5 were prioritized to provide guidance on which projects are most likely to result in sustained water quality health.

### 6.3.1. Highest priority projects

Currently, Lake Buckeye water quality is healthy with lake ambient water quality below current state standards and continuing to improve. A healthy SAV and EAV community is presently providing continuing water quality benefits, in addition to habitat for numerous fauna. As such, continued monitoring of surface water quality conditions will be necessary to identify future trends in water quality conditions. Additionally, multiple assumptions were made in the development of the water and nutrient inputs to Lake Buckeye. In order to refine external pollutant loads and document changes that may occur in the future with continued development of the watershed, additional monitoring of the surficial aquifers is suggested. Historically, groundwater has been the dominant source of water and nutrients to the lake. The watershed has transitioned from a citrus-dominated to urban landscape. With these changes, modifications in external load sources can be anticipated. As such, the implementation of low impact developments designed to reduce the likelihood of increase watershed runoff could mitigate the urban development currently underway in the watershed. Additionally, maintenance/enhancement of the vegetative community as well as documenting the total cover extent may be important should changes in water quality occur. Those projects identified with the most important role in maintaining a healthy lake are presented below:

- Monitoring
  - Surface Water Quality
  - Surficial Aquifer Quality and Levels
  - SAV
- Maintain/Enhance Submerged and Emergent Aquatic Vegetation
- Implement Low Impact Development

### 6.3.2. Moderate priority projects

Though lake water quality is below state standards, continued watershed development may lead to changes in external nutrient loading resulting in further water quality declines. Public education related to BMPs focused on maintaining water quality in Lake Buckeye could serve as a tool to link individual stakeholders' actions to their waterbody. Simple actions such as proper disposal of pet and lawn waste, proper fertilizer application and relaying the importance of aquatic vegetation and wetland buffers along the lake shoreline could assist in maintaining the current water quality status. The project identified with a moderately important role in maintaining a healthy lake is presented below:

- Public Education

### 6.3.3. Lowest priority

Those projects identified with the lowest priority were identified as such, as they are projects recommended for implementation if water quality begins to degrade. Based upon the estimated changes in land use over the last 16 years (1995 compared to 2011), nitrogen loading related to groundwater input has decreased substantially whereas watershed runoff has increased. Therefore, projects which are directed at intercepting stormwater runoff that discharges directly to the lake may assist in reducing nutrient loads to the lake. Delineating the sub-basins associated with the five MS4 outfalls to Lake Buckeye would assist in quantifying the relative load contributions throughout the watershed. This would allow for the prioritization of portions of the watershed for stormwater related projects. Throughout the watershed, the redirection of directly connected impervious areas (e.g., boat ramp) or outfalls into vegetated buffers would assist in decreasing direct loads to the lake. Additionally, artificial circulation is recommended to improve oxygenation which can serve to reducing internal phosphorus loading as well as disrupt phytoplankton production. The projects identified with a low level of importance in maintaining a healthy lake is presented below:

- MS4 characterization
- Artificial Circulation

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# Appendix A. Estimated loading of nitrogen and phosphorus from various sources to Lake Buckeye

Total loading is the sum of loadings from atmospheric, septic tank, groundwater and stormwater sources.

| Year | Annual Rainfall | Atmo-spheric TN | Septic Tank TN | Storm-water TN | Atmo-spheric TP | Septic Tank TP | Storm-water TP | Total TN | Total TP | Operating Septic TN | Failed Septic TN | Operating Septic TP | Failed Septic TP | Ground-water TN | Ground-water TP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (inches) | Load (lbs/yr) | Load (lbs/yr) | Load (lbs/yr) | Load (lbs/yr) | Load (lbs/yr) | Load (lbs/yr) | Load (lbs/yr) | Load (lbs/yr) | Load (lbs/yr) | Load (lbs/yr) | Load (lbs/yr) | Load (lbs/yr) | Load (lbs/yr) | Load (lbs/yr) |
| 1988 | 51.7 | | 136.5 | 869.3 | | 21.2 | 101.7 | | | 43.1 | 93.4 | 6.6 | 14.6 | 4425.1 | 222.6 |
| 1989 | 54.3 | | 140.6 | 911.8 | | 21.8 | 108.2 | | | 44.4 | 96.2 | 6.8 | 15.0 | 4637.1 | 233.5 |
| 1990 | 40.7 | 377.7 | 144.8 | 682.2 | 6.1 | 22.4 | 82.1 | 4670.7 | 285.4 | 45.7 | 99.1 | 7.0 | 15.5 | 3466.1 | 174.8 |
| 1991 | 55.9 | 487.4 | 148.9 | 934.2 | 8.0 | 23.1 | 114.1 | 6313.4 | 384.6 | 47.0 | 101.9 | 7.2 | 15.9 | 4742.8 | 239.4 |
| 1992 | 50.5 | 352.6 | 153.0 | 841.7 | 6.1 | 23.7 | 104.2 | 5616.3 | 349.8 | 48.3 | 104.7 | 7.4 | 16.4 | 4269.0 | 215.8 |
| 1993 | 47.3 | 391.9 | 157.2 | 786.4 | 6.5 | 24.4 | 98.7 | 5320.9 | 331.3 | 49.6 | 107.6 | 7.6 | 16.8 | 3985.3 | 201.7 |
| 1994 | 60.0 | 592.1 | 161.3 | 995.7 | 9.4 | 25.0 | 126.7 | 6790.1 | 416.6 | 50.9 | 110.4 | 7.8 | 17.2 | 5041.0 | 255.5 |
| 1995 | 60.3 | 524.0 | 165.5 | 998.4 | 8.5 | 25.7 | 128.8 | 6738.3 | 419.3 | 52.2 | 113.2 | 8.0 | 17.7 | 5050.4 | 256.3 |
| 1996 | 46.1 | 380.6 | 165.5 | 764.8 | 6.3 | 25.7 | 98.9 | 5129.0 | 325.1 | 52.2 | 113.2 | 8.0 | 17.7 | 3818.2 | 194.2 |
| 1997 | 60.2 | 345.5 | 165.5 | 1000.8 | 6.3 | 25.7 | 129.7 | 6442.7 | 413.1 | 52.2 | 113.2 | 8.0 | 17.7 | 4931.0 | 251.4 |
| 1998 | 53.0 | 319.4 | 165.5 | 882.4 | 5.8 | 25.7 | 114.6 | 5658.0 | 365.3 | 52.2 | 113.2 | 8.0 | 17.7 | 4290.7 | 219.3 |
| 1999 | 42.7 | 378.0 | 165.5 | 712.6 | 6.2 | 25.7 | 92.8 | 4675.5 | 299.8 | 52.2 | 113.2 | 8.0 | 17.7 | 3419.4 | 175.2 |

| Year | Annual Rainfall | Atmo-spheric TN | Septic Tank TN | Storm-water TN | Atmo-spheric TP | Septic Tank TP | Storm-water TP | Total TN | Total TP | Operating Septic TN | Failed Septic TN | Operating Septic TP | Failed Septic TP | Ground-water TN | Ground-water TP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (inches) | Load (lbs/yr) | Load (lbs/yr) | Load (lbs/yr) | Load (lbs/yr) | Load (lbs/yr) | Load (lbs/yr) | Load (lbs/yr) | Load (lbs/yr) | Load (lbs/yr) | Load (lbs/yr) | Load (lbs/yr) | Load (lbs/yr) | Load (lbs/yr) | Load (lbs/yr) |
| 2000 | 29.9 | 292.7 | 165.5 | 494.5 | 4.6 | 25.7 | 64.6 | 3301.6 | 215.9 | 52.2 | 113.2 | 8.0 | 17.7 | 2349.0 | 121.1 |
| 2001 | 58.0 | 429.2 | 165.5 | 951.5 | 7.2 | 25.7 | 124.9 | 6017.5 | 389.6 | 52.2 | 113.2 | 8.0 | 17.7 | 4471.3 | 231.8 |
| 2002 | 71.2 | 475.7 | 165.5 | 1159.1 | 8.4 | 25.7 | 152.7 | 7182.3 | 467.6 | 52.2 | 113.2 | 8.0 | 17.7 | 5382.1 | 280.8 |
| 2003 | 54.2 | 427.9 | 165.5 | 874.7 | 7.2 | 25.7 | 115.7 | 5477.2 | 359.2 | 52.2 | 113.2 | 8.0 | 17.7 | 4009.2 | 210.6 |
| 2004 | 64.1 | 323.0 | 165.5 | 1024.9 | 6.1 | 25.7 | 136.1 | 6145.0 | 413.0 | 52.2 | 113.2 | 8.0 | 17.7 | 4631.7 | 245.1 |
| 2005 | 51.0 | 335.7 | 165.5 | 815.2 | 5.9 | 25.7 | 108.3 | 4998.9 | 334.7 | 52.2 | 113.2 | 8.0 | 17.7 | 3682.6 | 194.8 |
| 2006 | 35.2 | 298.9 | 165.5 | 494.3 | 4.9 | 25.7 | 69.1 | 1872.5 | 170.2 | 52.2 | 113.2 | 8.0 | 17.7 | 913.8 | 70.5 |
| 2007 | 36.2 | 315.0 | 165.5 | 508.1 | 5.1 | 25.7 | 71.0 | 1927.8 | 174.2 | 52.2 | 113.2 | 8.0 | 17.7 | 939.3 | 72.4 |
| 2008 | 52.1 | 352.0 | 165.5 | 772.4 | 6.1 | 25.7 | 109.7 | 2553.3 | 241.9 | 52.2 | 113.2 | 8.0 | 17.7 | 1263.4 | 100.4 |
| 2009 | 40.5 | 343.0 | 165.5 | 647.5 | 5.7 | 25.7 | 90.8 | 1966.3 | 187.4 | 52.2 | 113.2 | 8.0 | 17.7 | 810.4 | 65.3 |
| 2010 | 45.5 | 423.6 | 165.5 | 726.0 | 6.8 | 25.7 | 101.8 | 2223.8 | 207.5 | 52.2 | 113.2 | 8.0 | 17.7 | 908.8 | 73.2 |
| 2011 | 51.4 | 336.5 | 165.5 | 821.4 | 5.9 | 25.7 | 115.2 | 2351.8 | 229.6 | 52.2 | 113.2 | 8.0 | 17.7 | 1028.4 | 82.9 |
| 2012 | 41.5 | 206.2 | 165.5 | 662.8 | 3.9 | 25.7 | 93.0 | 1864.3 | 189.4 | 52.2 | 113.2 | 8.0 | 17.7 | 829.8 | 66.9 |
| 2013 | 42.9 | 257.4 | 165.5 | 685.0 | 4.6 | 25.7 | 96.1 | 1965.5 | 195.5 | 52.2 | 113.2 | 8.0 | 17.7 | 857.6 | 69.1 |
| 2014 | 53.1 | | 165.5 | 848.1 | | 25.7 | 119.0 | | | 52.2 | 113.2 | 8.0 | 17.7 | 1061.8 | 85.6 |

| | Rainfall | Atmo-spheric TN Load | Septic Tank TN Load | Watershed TN Load | Atmo-spheric TP Load | Septic Tank TP Load | Watershed TP Load | Total TN Load | Total TP Load | Operating Septic TN | Failed Septic TN | Operating Septic TP | Failed Septic TP | Ground-water TN Load | Ground-water TP Load |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 50.0 | 373.6 | 161.2 | 809.8 | 6.3 | 25.0 | 106.2 | 4466.8 | 306.9 | 50.9 | 110.3 | 7.8 | 17.2 | 3156.1 | 170.7 |
| Median | 51.4 | 352.3 | 165.5 | 821.4 | 6.1 | 25.7 | 108.2 | 5063.9 | 328.2 | 52.2 | 113.2 | 8.0 | 17.7 | 3818.2 | 194.8 |
| Min | 29.9 | 206.2 | 136.5 | 494.3 | 3.9 | 21.2 | 64.6 | 1864.3 | 170.2 | 43.1 | 93.4 | 6.6 | 14.6 | 810.4 | 65.3 |
| Max | 71.2 | 592.1 | 165.5 | 1159.1 | 9.4 | 25.7 | 152.7 | 7182.3 | 467.6 | 52.2 | 113.2 | 8.0 | 17.7 | 5382.1 | 280.8 |

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