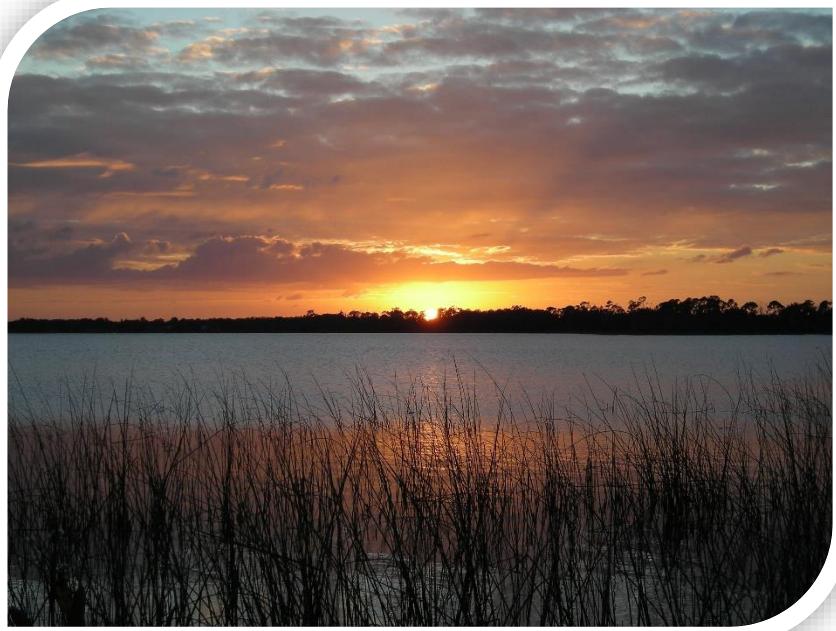
WINTER HAVEN
The Chain of Lakes City

2018

Annual Lakes Report

Presented by the Lakes Advisory Committee



CITY OF WINTER HAVEN
Public Works Department
Natural Resources Division

City of Winter Haven Natural Resources

Mission:
Maintain and improve local natural resources through management based on a sound understanding of social, economic, and ecological systems.

Vision:
To be the premier knowledge base for local natural resources, with an engaged public, supporting natural systems through a community ethic.

Purpose:
Balance the needs of diverse user groups to sustain natural resources the community can be proud of.

Values:
Courteous, Cognizant, Cooperative, Resourceful, Responsive, Accurate, Adaptive

Executive Summary

The ecologic, cultural, and economic significance of Winter Haven's lakes is continually demonstrated by the residents and visitors who utilize them. The City's Lakes Advisory Committee, comprised of members representing a variety of local interests, serves the community by advising the City Commission on the direction of management strategies using the best information available. The Committee seeks to achieve this objective by presenting the following report.

Each of the 35 waterbodies included in this study were evaluated based on a series of water quality and biological metrics. In addition, each lake's hydrologic conditions were assessed to supplement this evaluation. City staff have developed a standardized methodology to track changes in comprehensive lake health over time and prioritize waterbodies for the implementation of effective management strategies. The effort put into this report serves to fulfill the Division's Mission, Vision, Purpose, and Values—core concepts which were developed, in part, by the Lakes Advisory Committee.

A general overview of the data shows that 2018 was a period of hydrologic recovery which resulted in an increase in lake surface levels over the previous year. This likely contributed to the decisively improved water quality conditions observed in many of the lakes during 2018. With regards to long-term water quality trends, 66% of Winter Haven's waterbodies experienced significant recovery from 2000 to 2018; with 91% exhibiting some form of positive trend during this period. From an ecological perspective, over half of the lakes evaluated saw a decrease in the presence of managed invasive species while the vast majority of waterbodies showed a marked increase in vegetative abundance and diversity from previous survey years. This combination of results indicates an increase in native, beneficial flora and a rise in biological resiliency. Based on these data, the Natural Resources Division has identified several underperforming waterbodies that require more thorough examination to determine the primary factors contributing to poorer health relative to the other Winter Haven lakes.

This document also presents the structural and non-structural practices and initiatives currently utilized in the City's lake management program. Several projects underwent substantial progress during the 2018 year. Of particular note is the work accomplished on the Stormwater Assessment and Improvement Project which will allow the City to better prioritize future infrastructure improvements. The wetland communities of several Winter Haven stormwater treatment parks have been brought into a satisfactory maintained state and great strides have been made to streamline the City's NPDES reporting process. On the research front, Natural Resources has tested the effectiveness of floating wetlands on treating stormwater runoff and a new study has been developed to explore the utility of remote sensing with regards to water quality monitoring and tracking algae blooms.

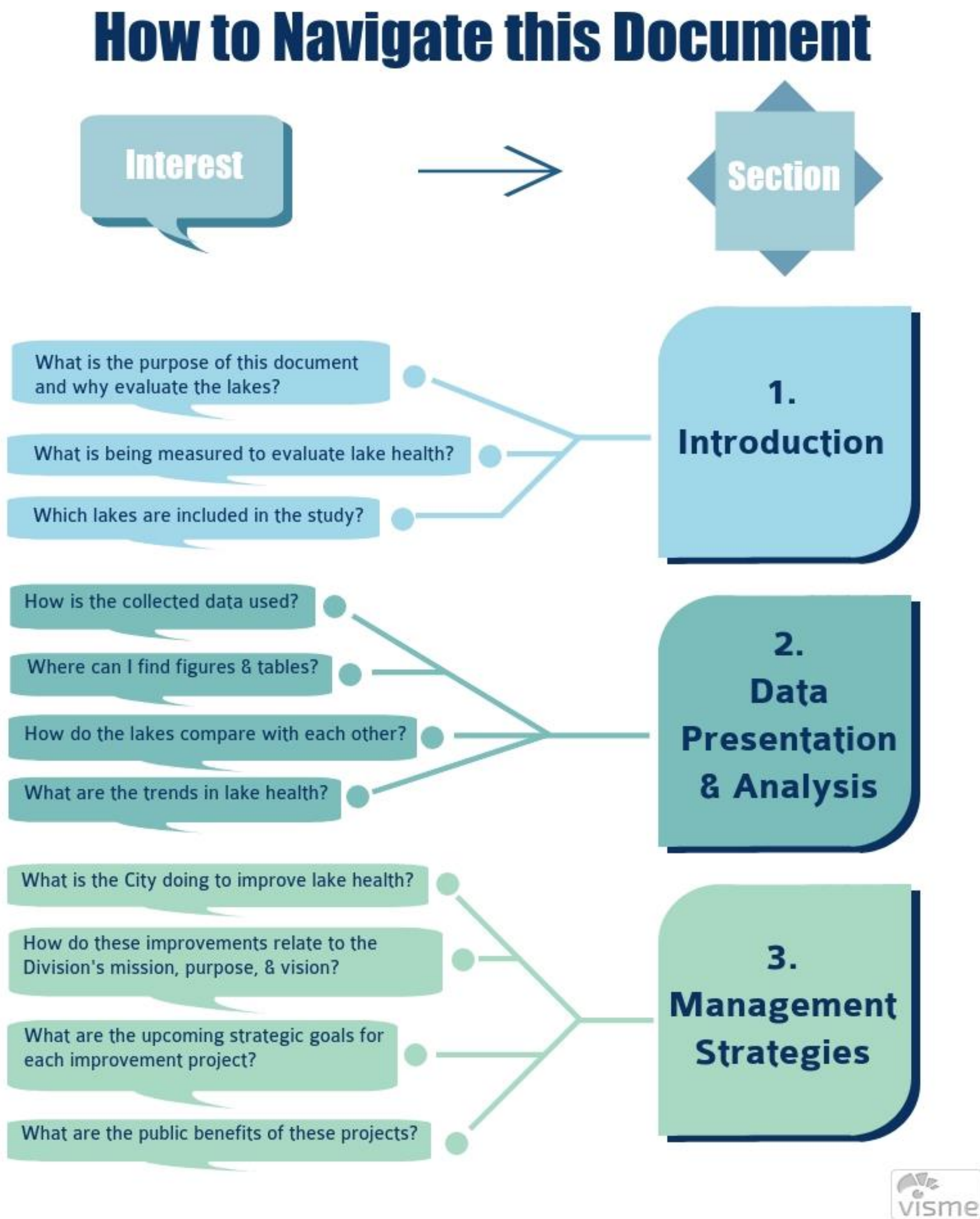
Compiling all of this information affords objective insights into the status of our shared waterbodies and documents the efforts the City has made to improve and maintain lake health. Armed with this understanding, City staff are in a position to work with local and State agencies to enhance our current management strategies and implement new practices where they will be most effective.

In recognition of their help and support, the Natural Resources Division would like to give special acknowledgement to the Lakes Advisory Committee, the various community partners, as well as other City of Winter Haven staff who helped make this report possible. We would also like to thank you, the reader. Our hope is that the information contained within sparks your interest to become an engaged steward of our lakes and other natural resources. Should you have any questions, comments, or concerns, we invite you to reach out.

Sincerely,

Devon Moore

City of Winter Haven
Natural Resources Division
Environmental Scientist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1- Introduction

1.1 Purpose

The lakes of the greater Winter Haven area are considered some of its most important natural assets. The utilization of these waterbodies by visitors and residents alike have cemented their role as economic, social, and ecological resources. By virtue of this, one of the primary objectives of the City's Natural Resources Division is to monitor their overall wellness and to implement best management practices that will ensure the continued enjoyment of their benefits by our diverse user groups.

The purpose of this report, therefore, is to present a more comprehensive outlook on the characteristics that comprise lake health as well as provide a detailed list of management strategies aimed at improving water quality. In using this holistic assessment approach, the City can prioritize waterbodies based on their condition and implement specific management practices geared toward each lake's individual characteristics. Using methods and techniques that are technically sound, yet presented in a manner that is accessible ensures that the information contained herein can be understood and applied by the scientific community as well as the general public.

Lastly, this annual report serves to document the City's evolving approach to environmental stewardship. As we continue to gain a better understanding of our natural systems, we hope to use that knowledge to refine our analytical methods and management practices. The principles we learn today will certainly drive how we preserve our lakes for the future.

1.2 Background on the Waterbodies

The lakes of the Winter Haven area are located within the Winter Haven Ridge and Polk Uplands physiographic regions of Central Florida. The regional topography indicates that the Winter Haven lakes are at the top of the Peace River watershed in what is known as the Peace Creek sub-basin. As such, these waterbodies are a major contributor of surface and groundwater flow to the Peace River which meanders southwest and terminates at the Gulf of Mexico. The lakes chosen for this study discharge directly or indirectly to the Peace Creek Drainage Canal—a major tributary that flows south of the Winter Haven area from Lake Hamilton and then west to join with Saddle Creek to become the Peace River. Figures 1-1 and 1-2 depict the Peace River and Peace Creek Watersheds respectively.

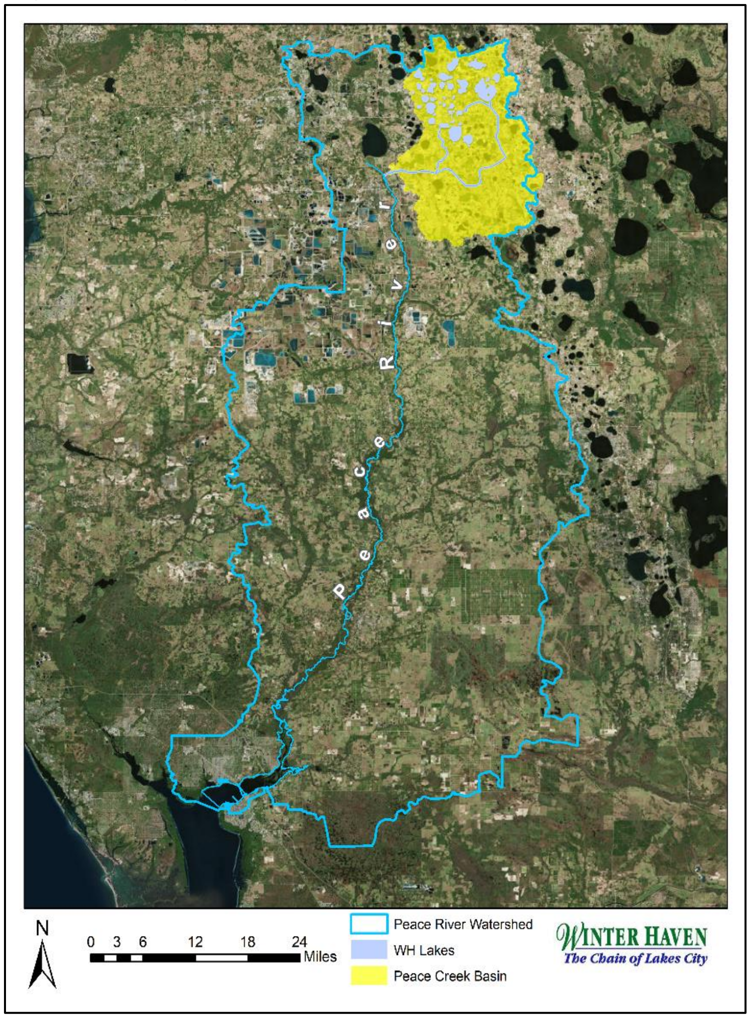


Figure 1-1. Map of Peace River & Peace Creek Watersheds

There are numerous waterbodies in the municipal limits of Winter Haven and surrounding unincorporated Polk County. For the purposes of this study, the 35 lakes chosen for analysis were selected based on the following criteria:

- *Possess improved public access (i.e. boat ramp or navigable entry point)*
- *Located within or adjacent to City limits; or discharge directly to a waterbody within City limits*
- *Discharge surface water to the Peace Creek Canal; either directly or via a series of conveyances*
- *Possess a sufficient record of water quality and/or hydrologic data*

In past reports, the selected lakes were categorized into three groups: the Northern Chain of Lakes, Southern Chain of Lakes, and Isolated Lakes. The Northern and Southern Chains were grouped based on their historic designations while the Isolated Lakes included any other waterbodies that were not part of either chain. This iteration of the report further subcategorizes the Isolated Lakes based on their spatial distribution and surface flow pathways.

The majority of lakes discussed in this report discharge surface water to other waterbodies in the area on their way to the Peace River. Flow of water through these connections is determined by the various water control structures put in place primarily to conserve water in the lakes at desirable levels. The numerous control structures can be grouped into active or passive categories. Active structures rely on the deliberate opening/closing of a gating mechanism to allow water to pass through the flowway, whereas passive structures include weirs or pipes set at the lake's maximum desired water level—only allowing for the overflow of water above that set level. The various control structures, maximum desired surface levels, and the entities that manage them are listed in Table 1-1.

Control Structure ID	Contributing Waterbody	Managing Organization	Lake Group	Maximum Desired Elevation (NGVD29)
P-5	Lake Henry	SWFWMD	North Chain of Lakes	126.00
P-6	Lake Smart	SWFWMD	North Chain of Lakes	128.50
P-7	Lake Fannie	SWFWMD	North Chain of Lakes	125.50
P-8	Lake Hamilton	SWFWMD	North Chain of Lakes	121.25
Lulu-CS	Lake Lulu	LRLMD	South Chain of Lakes	132.00
Silver-CS	Lake Silver	LRLMD	North Central Lakes	146.50
Martha-CS	Lake Martha	LRLMD	North Central Lakes	142.00
Maude-CS	Lake Maude	LRLMD	North Central Lakes	140.50
Idyl-CS	Lake Idyl	LRLMD	North Central Lakes	132.00
Link-CS	Lake Link	LRLMD	South Central Lakes	128.00
Mariam-CS	Lake Mariam	LRLMD	South Central Lakes	124.75
Mariana-CS	Lake Mariana	LRLMD	Outlying Lakes	137.50
Blue-CS	Lake Blue	Polk County	Outlying Lakes	148.86
Deer-CS	Lake Deer	Polk County	Outlying Lakes	138.61

Table 1-1. Control Structure Elevations

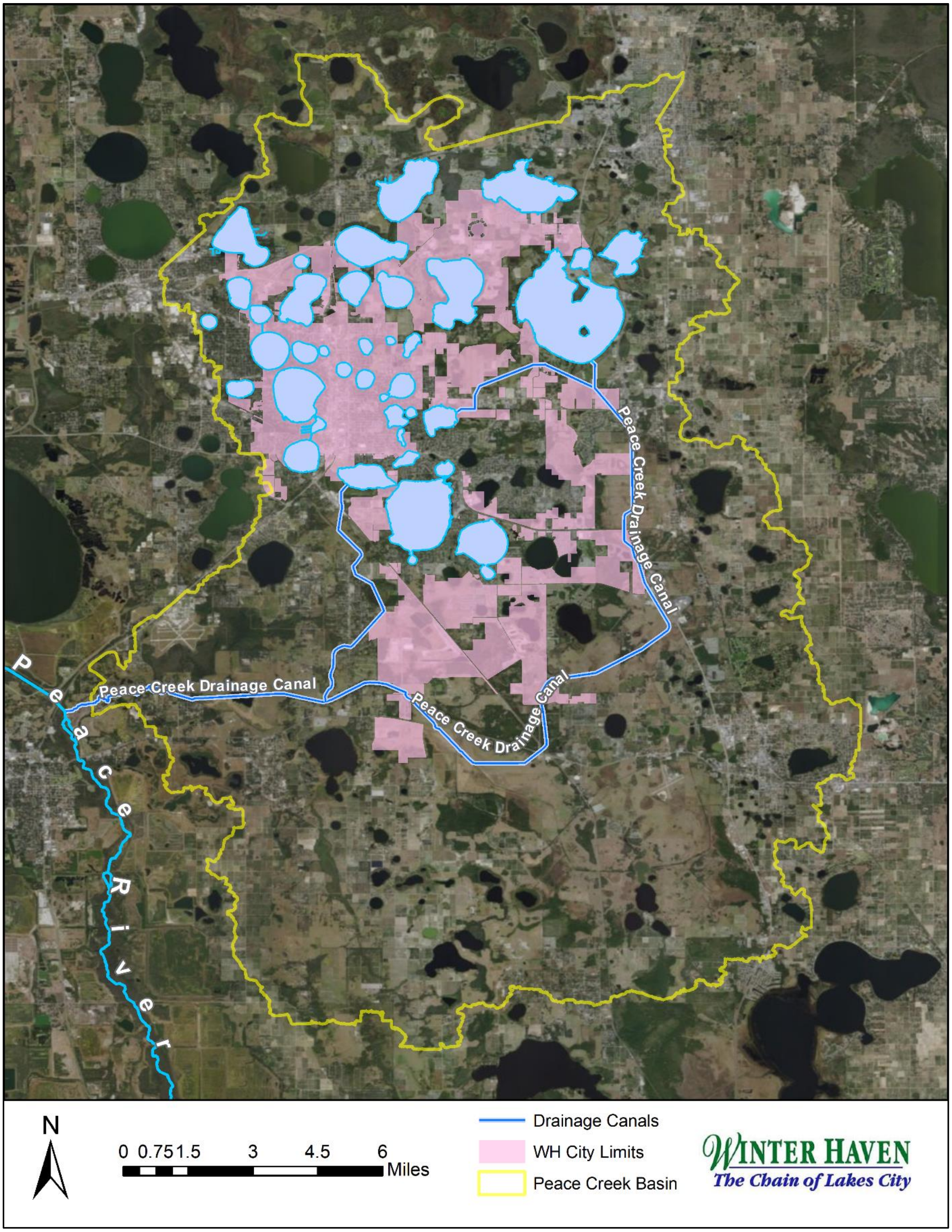


Figure 1-2. Map of Peace Creek Sub-Basin & Lakes Study Area

North Chain of Lakes

The Winter Haven Chain of Lakes has historically been comprised of the distinct Northern and Southern sections that are separated by a boat lock system to allow for navigation between the two. The Northern Chain is made up of the following 9 waterbodies:

- *Lake Conine*
- *Lake Fannie*
- *Lake Haines*
- *Lake Hamilton*
- *Little Lake Hamilton*
- *Middle Lake Hamilton*
- *Lake Henry*
- *Lake Rochelle*
- *Lake Smart*

The Southwest Florida Water Management District (SWFWMD) manages the surface level of the Northern Chain of Lakes via a series of active water control structures. For the purposes of water conservation, the SWFWMD sets maximum desired levels at each of these structures—discharging water to the Peace Creek Drainage Canal when surface levels exceed the upper limits [1]. Lakes Conine, Haines, Rochelle, and Smart are all held roughly equal via a series of navigable canals. The P-6 water control structure, located downstream of Lake Smart, maintains the desired surface level for these four lakes. From Smart, water discharges to Lake Fannie which is controlled by the P-7 structure. Discharge from Lake Fannie flows to the Hamilton Chain (Lakes Hamilton, Little Hamilton, & Middle Hamilton) where the P-8 control structure maintains water in these three lakes before discharging to the Peace Creek Drainage Canal. In addition to these 8 waterbodies, Lake Henry discharges to Hamilton via the P-5 structure. However, because Lake Henry lacks public access and a means of water quality data collection, it has been excluded from this study. The flow pathways and drainage basins for the Northern Chain are illustrated in Figure 1-3.

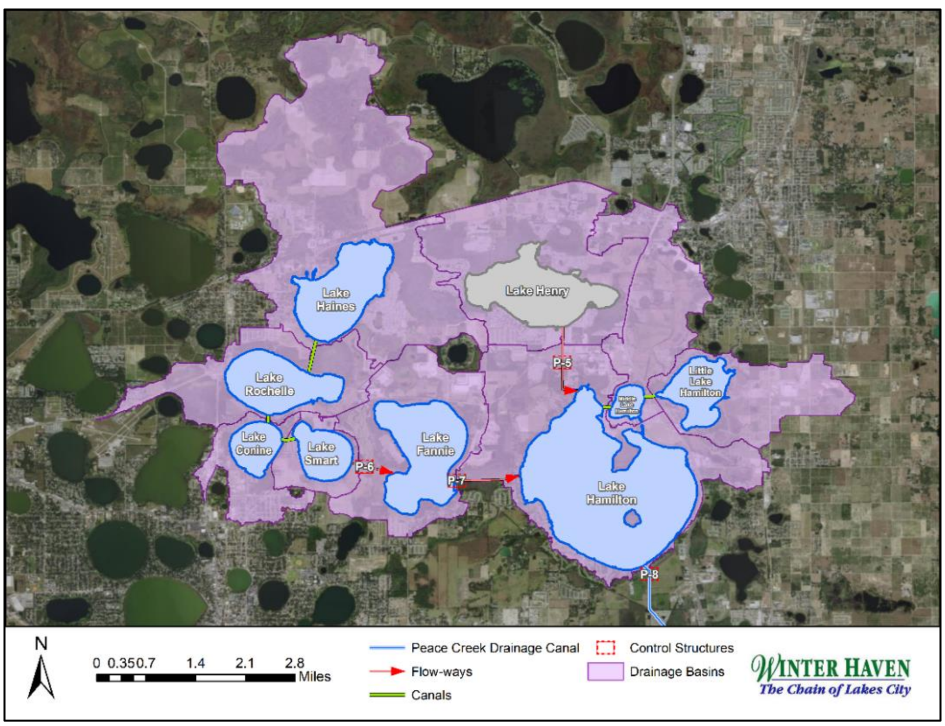


Figure 1-3. Map of North Chain of Lakes, Flow Pathways & Drainage Basins

Southern Chain of Lakes

Spanning the majority of the City of Winter Haven boundary, the Southern section of the Chain of Lakes is composed of the following 14 waterbodies:

- *Lake Cannon*
- *Lake Eloise*
- *Lake Hartridge*
- *Lake Howard*
- *Lake Idylwild*
- *Lake Jessie*
- *Lake Lulu*
- *Lake May*
- *Lake Mirror*
- *Lake Roy*
- *Lake Shipp*
- *Lake Summit*
- *Lake Winterset*
- *Spring Lake*

Unlike the Northern Chain of Lakes, the entirety of the Southern Chain is connected via a series of navigable canals. Many of the canals between these lakes were constructed in the early 1900's, in part as a means to transport citrus through the region [2]. A passive control structure located on the southern shore of Lake Lulu and managed by the Lake Region Lakes Management District (LRLMD), maintains the surface level of this chain. From this structure, the Southern Chain discharges to the Wahneta Farms Drainage Canal; travelling south until it joins with the final stretch of the Peace Creek Drainage Canal near the City of Bartow. Figure 1-4 shows the flow pathways and drainage basins for the Southern Chain of Lakes.

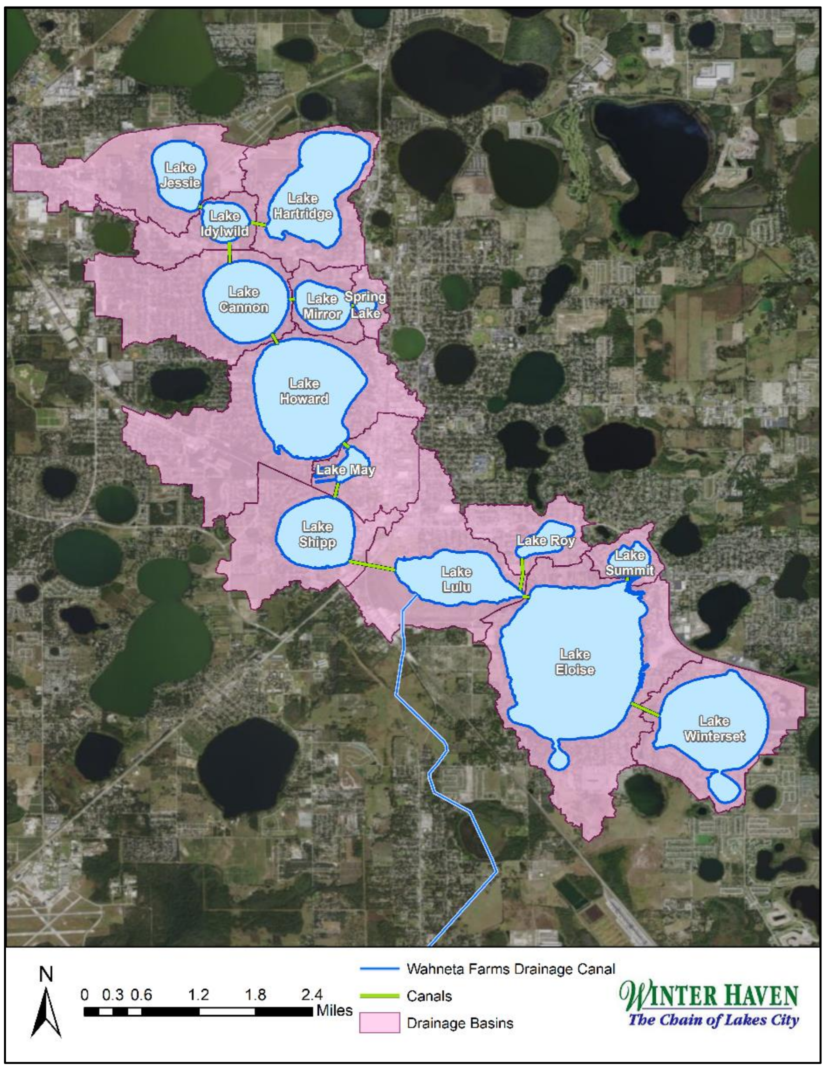


Figure 1-4. Map of South Chain of Lakes, Flow Pathways & Drainage Basins

North Central Lakes

Initially part of the larger Isolated Lakes group, this series of lakes is grouped due to its distinctly separate flow pathway and its location relative to the other lake groups. The following 5 lakes make up the North Central group:

- *Lake Buckeye*
- *Lake Idyl*
- *Lake Martha*
- *Lake Maude*
- *Lake Silver*

Beginning in the heart of downtown Winter Haven, water flows from Lake Silver to Martha, Maude, Idyl, and Buckeye, respectively. Connected via a series of ditches and pipes, each lake is held at a unique management level controlled by a series passive weirs managed by the LRLMD. Overflow from Lake Buckeye discharges north to Lake Fannie through a natural wetland area. Figure 1-5 provides more detail on the flow pathways and drainage basins for the North Central Lakes.

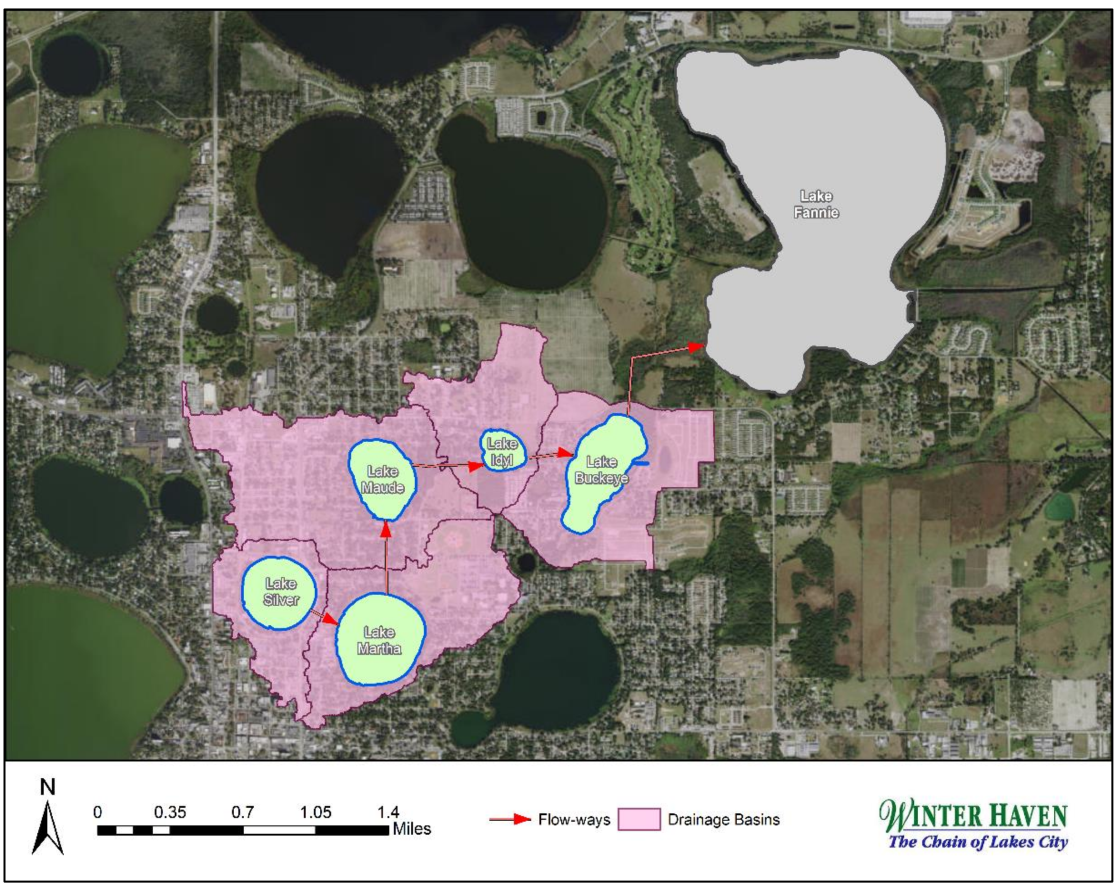


Figure 1-5. Map of North Central Lakes, Flow Pathways & Drainage Basins

South Central Lakes

Similar to the North Central group, the South Central Lakes are categorized based on their relative location and historic flow pathway. Comprised of the following 4 waterbodies, the South-Central group contributes surface flow to the Peace Creek Drainage Canal:

- *Lake Elbert*
- *Lake Link*
- *Lake Mariam*
- *Lake Otis*

Starting at Lake Elbert, water flows through an underground pipe to Lakes Otis and Link which are connected via a navigable canal. From Link, surface water is conveyed via another pipe to Lake Mariam which discharges to a small ditch that travels east until it meets with the Peace Creek Drainage Canal. Again, weirs control the maximum desired surface level of these lakes for the purposes of flood prevention and water conservation. The flow pathways and drainage basins for the South Central Lakes are illustrated in Figure 1-6.

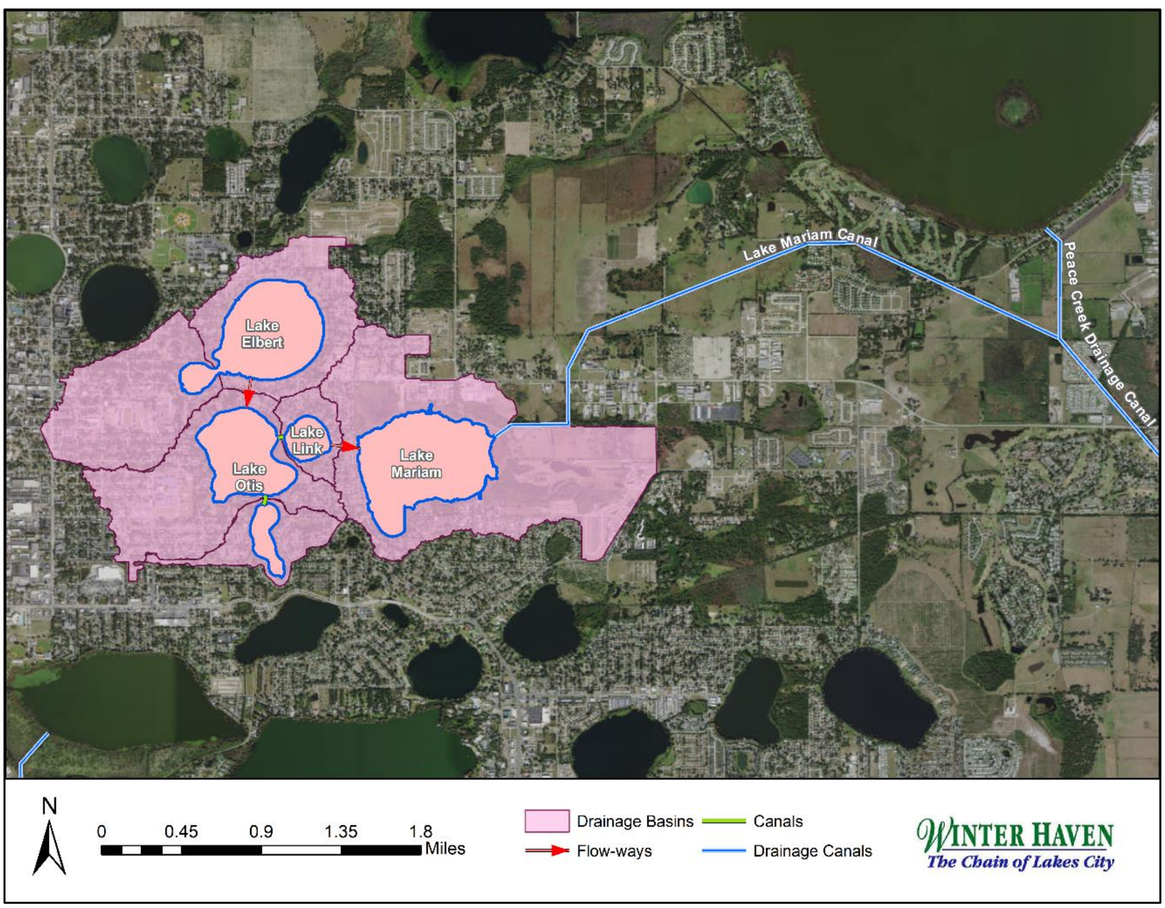


Figure 1-6. Map of South Central Lakes, Flow Pathways & Drainage Basins

Outlying Lakes

Finally, the Outlying lakes are made up of isolated waterbodies that don't discharge directly to the Peace Creek Drainage Canal, but still meet the selection criteria presented at the beginning of this section. These lakes are also located to the north-west of the other lake groups. The 4 lakes in this category include:

- *Lake Blue*
- *Lake Deer*
- *Lake Mariana*
- *Lake Pansy*

Lakes Blue and Deer, located west of downtown Winter Haven, both discharge to the Southern Chain of Lakes (Lake Cannon) via underground stormwater pipes managed by Polk County. Located in the City of Auburndale, Lake Mariana was selected due to its contribution to the Southern Chain through a ditch and pipe system as well, which discharges into Lake Jessie. Lake Pansy doesn't appear to possess any man-made conveyances to other lakes. However, there is evidence to suggest that Lakes Pansy and Rochelle share a surface water connection via the wetland area between them. Because Pansy lacks a dedicated control structure, the surface level required for flow to occur is not well known. A map of the Outlying Lakes and their drainage characteristics is presented in Figure 1-7.

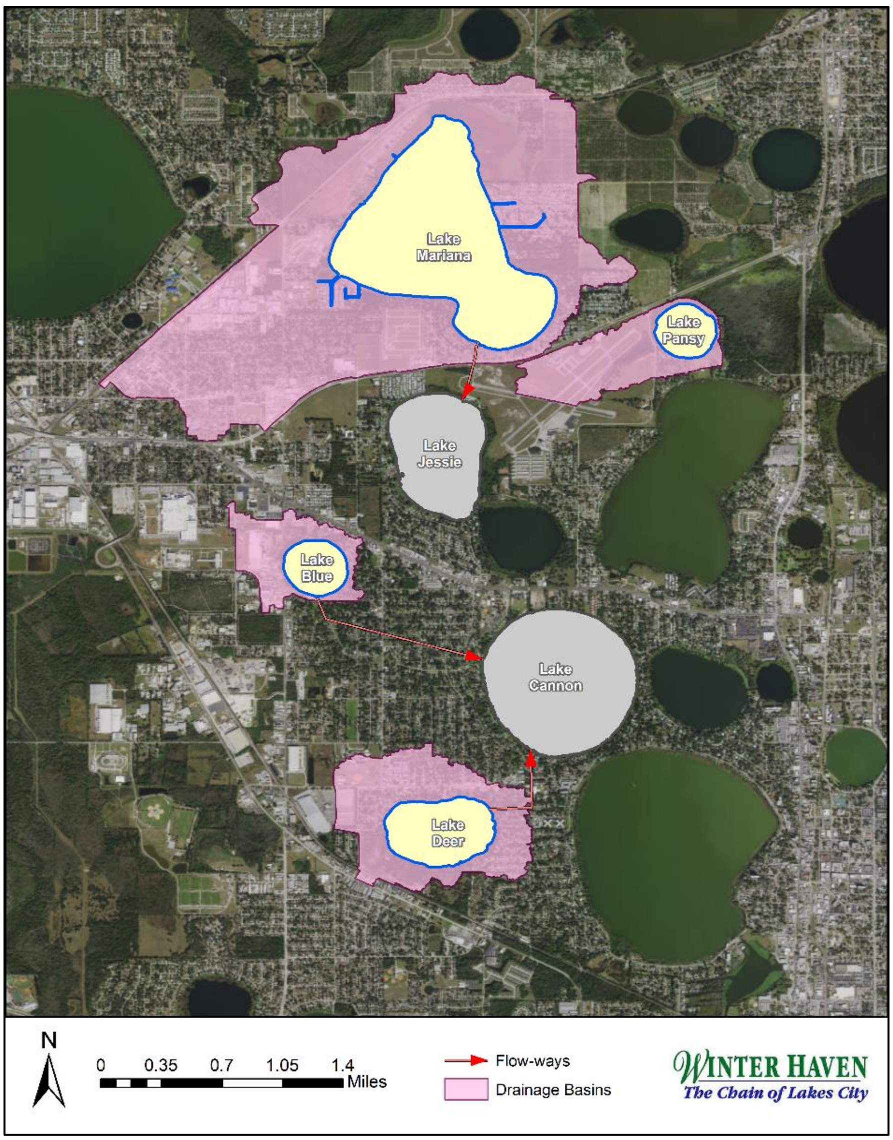


Figure 1-7. Map of Outlying Lakes, Flow Pathways & Drainage Basins

1.3 Background on the Metrics

Just as a person's well-being is reliant on multiple factors such as physical health, genetic predispositions, and individual mental health; so are the facets of limnology built upon complex, dynamic relationships. While significant insights can be gained by studying the individual components, a more comprehensive approach is needed to identify systemic issues and prescribe effective solutions. For the purposes of this study, focus will be placed on understanding the interactions amongst water quality, hydrology, and ecology.

Water Quality

Out of context, the term "water quality" can be fairly nebulous. At face value, it simply refers to the relative perceived condition of a water source based on a selection of its physical and chemical characteristics. Different user groups may often judge a lake based on what they consider good or bad qualities. An attribute such as a waterbody's color or trophic state can have a different connotation to swimmers than it would to anglers or nature enthusiasts. Managing these waterbodies in a way that strikes a balance between usability and ecological health ensures that the greatest number of people can take advantage of the benefits our lakes have to offer.

In the context used by the scientific community and regulatory agencies, water quality refers to specific chemical characteristics of a waterbody and how they affect its intended use. The following parameters have been adopted by State and Federal agencies as objective metrics used to assess Florida's waterbodies. Throughout the following sections, the core water quality metrics used in the City's analysis will be described in the context of overall lake health.

Primary Water Quality Metrics

Chlorophyll-a (Chla): *Measured as the concentration of the primary photosynthetic pigment of plants and algae in the water column, Chla is used to estimate algal abundance and can represent the trophic state or biological productivity of a waterbody.*

Nutrient Concentrations: *Measured as the concentration of total nitrogen (TN) and total phosphorus (TP) in the water column, TN and TP are the primary nutrients that contribute to anthropogenic eutrophication.*

Water Clarity: *Measured as Secchi depth, or the maximum depth in the water column that a Secchi disk remains visible to the naked eye. Clarity can be used to measure both suspended and dissolved matter in the water column. Turbidity and true color are separate parameters that impact overall water clarity.*

Regulatory Background

A major effort by State and Federal environmental agencies in recent decades was the development of an objective set of standards for surface waters and a regulatory system that acts to reduce anthropogenic impacts to waterbodies. These impacts primarily come from the discharge of pollutants such as bacteria, heavy metals, and nutrients. For the purposes of this report, the focus will be placed on nutrient pollution as it is the primary catalyst of lake eutrophication and the main impairment parameter observed in the study area. On the geologic time scale (thousands of years), lakes go through a natural process called eutrophication which will be discussed further in a later section of this report. However, many anthropogenic sources of pollution can expedite this process until lakes become hypereutrophic—a productive state that facilitates harmful algal blooms (HABs), fish kills, and unrestricted growth of nuisance or invasive plants.

In 2011, under section 303(d) of the Clean Water Act, the US Environmental Protection Agency (EPA) and the Florida Department of Environmental Protection (FDEP) established sets of Numeric Nutrient Criteria (NNC) for all of Florida's Surface waters. These criteria are based on a waterbody's intended use classification, estimated pre-disturbance conditions, natural trophic state, and the human-related influences that contribute to eutrophication.

FDEP Intended Use Classifications

- **Class I**: *Potable Water Supply*
- **Class II**: *Shellfish Propagation & Harvesting*
- **Class III**: *Recreation; Propagation, & Maintenance of a Healthy, Well-Balanced Population of Fish & Wildlife*
- **Class IV**: *Agricultural Water Supply*
- **Class V**: *Navigation, Utility, & Industrial Use*

The NNC are specific chemical concentration goals that waterbodies must meet for their intended use classification, of which all of the Winter Haven lakes fall under Class III. Chlorophyll-a (Chla), a measure of algal abundance, is generally used as a response metric for a waterbody's trophic state; with high Chla concentrations indicating an increased trophic status. The EPA and FDEP have established that the two main drivers of eutrophication in freshwater systems are TN and TP. These nutrients are often the limiting component for Chla increase as illustrated by their relationships (Figure 1-8). Based on the correlation coefficients in this figure, it can be inferred that TN is a greater contributing factor of Chla than TP for the South Chain of Lakes. As a result NNC thresholds were established as a means to determine if a waterbody is impaired. Once impairment has been established, action is taken to reduce concentrations back to acceptable levels.

In addition to the parameters mentioned above, additional chemical characteristics can impact how a lake responds to increased nutrient concentrations. FDEP further categorizes freshwater lakes based on long term concentrations of True Color and Total Alkalinity. True Color, measured in Platinum-Cobalt Units (PCU), is indicative of the amount of dissolved tannins and other organic compounds present in the water column. Color partly affects the depth light can reach in the water column, impacting the growth of aquatic plants as well as algae. Total Alkalinity, measured in milligrams per liter of Calcium Carbonate (mg/L $CaCO_3$), indicates a waterbody's ability to neutralize acids and buffer against changes in pH. Generally, lakes with more alkalinity can support more productivity which is why this metric is used to classify lakes [3]. A more common synonym for alkalinity is water hardness. Due to the increased presence of underlying carbonate rock (limestone) in this region of Florida, the majority of Winter Haven's lakes possess relatively high natural alkalinity concentrations.

In order to simplify the NNC impairment determination process, a flow chart was developed by City staff as a step-by-step guide (Figure 1-9) [4]. The initial step of the assessment process involves lake categorization based on the long-term geometric mean true color and total alkalinity concentrations. Winter Haven's lakes generally fall into two categories: colored lakes (>40 PCU) and clear/alkaline lakes (<40 PCU & >20 mg/l $CaCO_3$) These categories are subject to individual thresholds for the annual geometric mean (AGM) concentrations of Chla, TN, & TP. Once a lake is categorized, annual Chla impairment is determined. If the AGM Chla exceeds the NNC threshold, or if there is insufficient data to determine Chla impairment, the AGM TN & TP concentrations are subject to the minimum impairment limit for that year. If there is no Chla exceedance, AGM TN & TP concentrations are subject to the maximum limit. In order to assess long-term water quality trends, 7.5 years of AGM concentrations are evaluated. If the Chla, TN, or TP threshold is exceeded more than once in any consecutive 3 year period, then the waterbody is placed on the verified impaired list. By this process, a lake can be considered impaired for nutrients in response to exceedances by Chla, TN, and/or TP.

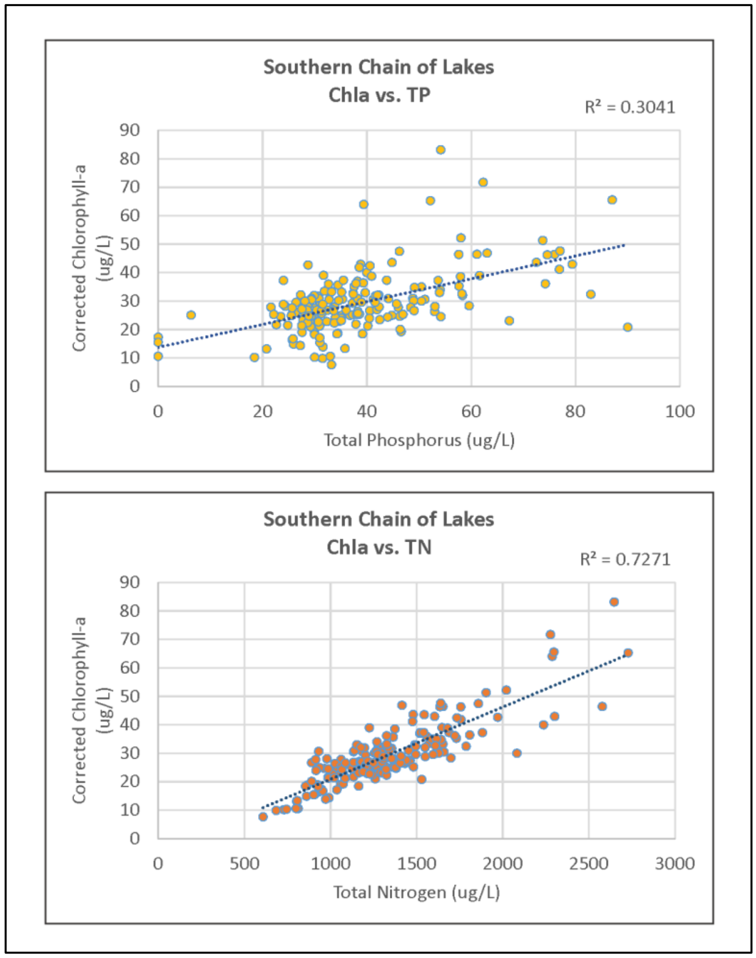


Figure 1-8. Linear Regression of Chlorophyll-a vs. Total Phosphorus & Total Nitrogen

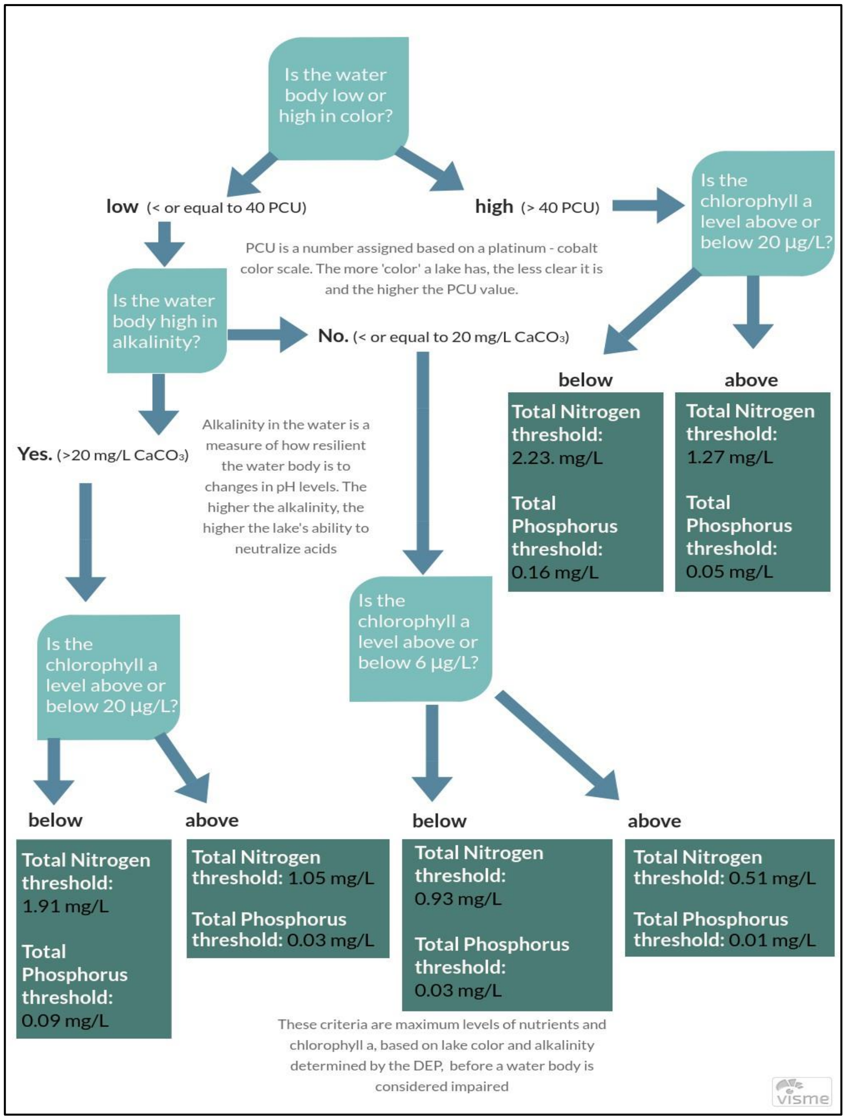


Figure 1-9. NNC Impairment Determination Flowchart

Once a waterbody is assessed with a nutrient impairment, the FDEP develops pollutant reduction goals for stakeholders that contribute surface water or groundwater to that waterbody. Referred to as a Total Maximum Daily Load (TMDL), the reduction goals represent the total allowable amount of substance that can be discharged to a waterbody per day while still meeting the intended use. TMDLs are established for the pollutant of concern which is typically the nutrient of impairment, but can also be the limiting nutrient(s). A nutrient is considered limiting if present in lower relative concentrations than other nutrients or if it would be the first to be used up through natural processes. When a limiting nutrient is depleted, plant and algal growth cannot continue regardless of the presence of other nutrients. Most freshwater lakes are phosphorus limited, however if the ratio of TN to TP is less than 10, that waterbody is considered co-limited by nitrogen and phosphorus [5].

In order to establish appropriate nutrient reduction goals that will lead to water quality improvement, the FDEP must estimate the current pollutant loading rate of point sources and non-point sources in weight of nutrient per year (e.g. lbs/year of TP). Point sources refer to discharge from wastewater treatment plants and municipal separate storm sewer systems (MS4s). Non-point sources refer to the introduction of pollutants through surface runoff, atmospheric deposition, groundwater, sediments, and any other sources that don't possess a discreet entry point. Calculating the current loading rate for each stormwater outfall is accomplished by incorporating estimated annual runoff volumes, size of the contributing drainage areas, land uses, and their respective average loading rates per storm event—referred to as event mean concentrations (EMCs).

With a developed TMDL clearly outlining reduction goals for all relevant loading sources, the next step is the creation of a Basin Management Action Plan (BMAP) that mandates stakeholder compliance of the TMDL through the implementation of best management practices (BMPs). BMP is a blanket term that refers to any structural or non-structural practice or initiative that contributes to water quality improvement. The same BMPs aren't applicable for every scenario, therefore the development of BMAPs requires a thorough understanding of the unique challenges associated with individual waterbodies. Successful reduction of pollutant concentrations below the impairment thresholds for an extended period will allow FDEP to remove waterbodies from the verified impaired list to a study list to be monitored for long-term compliance. Once deemed stable in an unimpaired status, waterbodies can then be delisted until such a time they exceed NNC thresholds again.

The FDEP evaluates nutrient impairment of State waterbodies via a cyclical assessment schedule. Impairment determination incorporates the most recent 7.5 years of quality controlled data. Due to the large number of waterbodies in the State and FDEP staffing limitations, statewide annual re-evaluations of impairment aren't feasible. Using the FDEP methodology, the City of Winter Haven has begun evaluating NNC exceedances of local lakes on a yearly basis. The ability to evaluate individual lake exceedances at an annual frequency is beneficial in that it provides insights into the incremental changes in water quality. While impairment doesn't typically change from year to year, extrapolation of the water quality trends can allow for predictions of when NNC goals will be met or exceeded in the future.

Nutrient Cycles

Nitrogen (N) and Phosphorus (P) have been established as the primary pollutants of concern from an anthropogenic standpoint, but each is involved in a complex natural cycle within lake ecosystems. Both nitrogen and phosphorus enter aquatic systems through similar external pathways: surface runoff, groundwater infiltration, and atmospheric deposition (i.e. air and precipitation). Nitrogen is typically present in three forms: organic N, inorganic N, and atmospheric N. Typically, only the inorganic, mineral form of N is biologically available for plants and algae to uptake. Most inorganic N is derived from a microbial process called mineralization that converts it from organic forms. Bioavailable N can also be introduced via anthropogenic sources such as fertilizers and wastewater. One of the more important aspects of the nitrogen cycle is denitrification—a process by which soil bacteria in anoxic conditions can convert inorganic N to atmospheric N; effectively removing it from the aquatic environment.

Similarly to nitrogen, phosphorus also cycles in and out of inorganic (bioavailable) and organic (unavailable) forms. Plants and algae uptake inorganic P from the water column and sediments and convert it into organic P as it's incorporated into their cellular structure. When plant and algal cells die or are eaten, the remains are left to decompose on lake bottoms. Bacteria convert the organic P to inorganic P which can return to the water column depending on the current TP gradient in the lake. This process, called phosphorus flux, can allow large amounts of P to be stored and released periodically over long periods of time—facilitating a continual source of TP. Unlike the nitrogen cycle, phosphorus doesn't undergo a bacterial transformation to an atmospheric form; meaning the only effective means to reduce TP in aquatic environments is through the physical removal of plants, animals, or sediments. Due to the large costs associated with these strategies, it's often more economically feasible to develop methods to lock phosphorus in the sediments or prevent it from entering aquatic environments altogether.

Underscoring the concepts of phosphorus flux and nitrogen mineralization is the concern regarding the dominant sediment type and its impact on internal nutrient loading. Sand is generally low in organic material, while silt or muck, is a fine, nutrient-rich sediment. Muck is easy to stir up, stays suspended in the water column for long periods of time, and can significantly contribute to the release of bioavailable nitrogen and phosphorus. Compounding internal loading is the presence of legacy nutrients originating from historic wastewater or industrial discharges and deposits of phosphatic soils. These legacy nutrients require special consideration in planning BMPs as even a significant reduction of stormwater input may not have much effect on water quality if the majority of loading originates from the underlying sediments.

Additional Parameters

Trophic state was mentioned previously as a concept describing a waterbody's level of primary productivity. Productivity is a term that relates to the amount of plants, algae, and wildlife a waterbody can support. Trophic status is broken down into several classes (Figure 1-10) [6]:

Trophic States

- **Oligotrophic:** *Low productivity*
- **Mesotrophic:** *Low-moderate productivity*
- **Eutrophic:** *Moderate-High productivity*
- **Hypereutrophic:** *Very high productivity*

As stated above, lakes naturally increase in productivity as they age due to the deposition of sediments over time. Generally, oligotrophic lakes are fairly clear, relatively deeper, and possess smaller populations of plants and fish. Eutrophic lakes, on the other hand, are often highly colored or turbid due to increased amounts of organic sediments. These lakes are typically shallower and have higher natural nutrient concentrations—as such they can support more plants, algae, and wildlife. Mesotrophic waterbodies fit the middle ground between these two while hypereutrophic waterbodies fall on the extreme side of eutrophic. Due to an overabundance of nutrients in hypereutrophic lakes, they are often associated with harmful algal blooms, fish kills, and the unrestricted growth of invasive or nuisance plants. Impairment regulations attempt to set achievable nutrient targets to reduce lake trophic state or prevent them from becoming hypereutrophic.

Prior to the use of the current NNC system, FDEP relied on a ranked system known as the Trophic State Index (TSI) to determine impairment [7]. The index ranks trophic state from low to high productivity on a scale from 1 – 100; calculated using concentrations of TN, TP, total chlorophyll, and Secchi depth. It was determined that a combined trophic state metric cannot always accurately represent the overall quality of a lake. A waterbody with high average TSI values may not be preferable for swimming or skiing, but it could still easily meet the intended use for other forms of recreation such as fishing or boating [3].

Paleolimnology, or the ecological study of historic lake conditions, can provide insights into the predisturbance trophic state of inland waterbodies. By testing the layers of sediment that have accumulated on the lake floor, inferences regarding historic phosphorus and chlorophyll concentrations can be made. Several studies performed on Winter Haven area lakes have shown that the majority of these waterbodies were naturally eutrophic prior to human development in the region [8] [9].

Water clarity is a metric that indicates the depth light can penetrate in the water column. This parameter is measured by lowering a Secchi disk into the water column until it is no longer visible. Unlike true color, clarity is impacted by the dissolved *and* suspended particulate matter in the water column. This includes algae, turbidity, and color imparted by dissolved solids. Turbidity or total suspended solids (TSS) is the component of water clarity associated with particulate matter. Often, recreational user groups misconstrue clarity as a mark of water cleanliness. Since many components factor into the overall clarity metric, an unclear lake may not always suffer from water quality issues. Due to this, Secchi depth is no longer used as an impairment determination parameter. Nevertheless, clarity can still provide insights into general water quality trends.

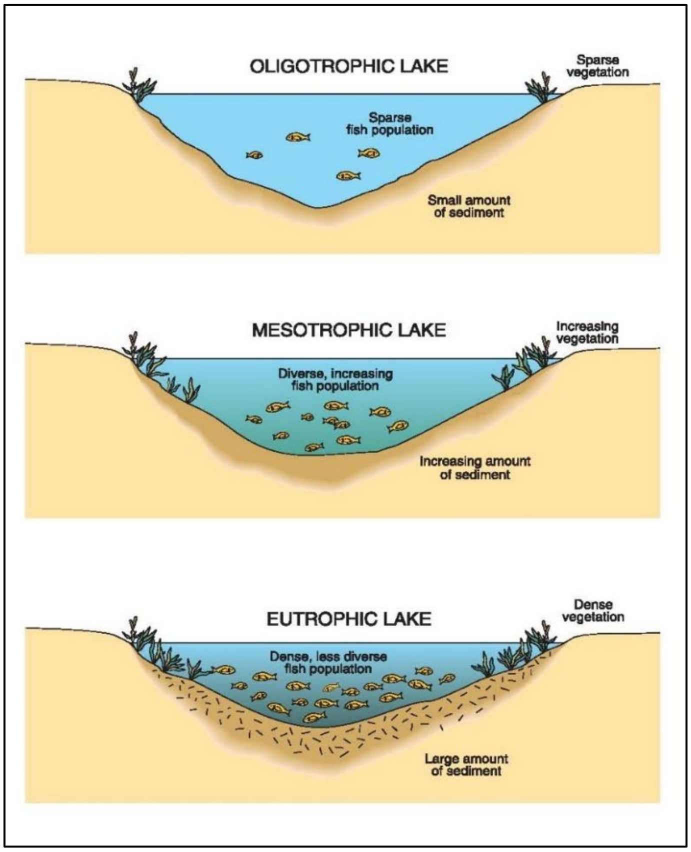


Figure 1-10. Diagram of Lake Trophic States [6].

Hydrology

In the simplest terms, hydrology is the study of the pathways that water takes through our environment. Water's journey is long and varied and each molecule travels the Earth in one way or another. The way water enters, leaves, and interacts with our lakes plays a large part in their overall health. The following metrics are the primary hydrologic response variables and characteristics that are assessed by the City and other environmental agencies. While the metrics listed below are not direct indicators of lake health, they are useful for determining underlying causes of poor water quality and/or biological health. In addition, management practices can be tailored to specific waterbodies based on their unique hydrologic characteristics. In the health and wellness analogy, lake hydrology is akin to a patient's genetics—something that cannot be changed, but that can impact health.

Primary Hydrologic Metrics

Surface Level: *The elevation of a waterbody's surface measured in feet above sea level. Also known as lake stage, surface level changes over time in response to environmental stimuli such as precipitation, evaporation, and groundwater influence.*

Lake Morphology: *Physical characteristics of a waterbody that determine its size and shape. Parameters such as surface area and volume can impact environmental factors such as evaporation, wind and wave impacts, and groundwater influence.*

Drainage Basin Characteristics: *The aspects of the land surrounding a lake that impact surface level flow. Parameters such as drainage area, impervious surfaces, and land uses can affect the quantity and quality of stormwater that drains to a given waterbody.*

Precipitation

Precipitation in all its forms (rain, snow, sleet, hail) is one of the main drivers of the hydrologic cycle. Winter Haven is a great example of the importance of precipitation as our local hydrologic system is completely rainfall driven. The topography of the Winter Haven Ridge and Polk Uplands regions essentially place these lakes on a hilltop, forcing water to naturally migrate downstream toward the Peace River. Rainfall in this area is responsible for fluctuations in lake level as well as the recharge of groundwater reservoirs.

Precipitation can reach a lake directly or via surface runoff from the surrounding land. The total area that contributes stormwater runoff to a waterbody is referred to as that lake's drainage basin. In a natural system the effective drainage basin of a lake is relatively small. Abundance of vegetation and a lack of impervious surfaces cause much of that stormwater to infiltrate into the groundwater system before it reaches the lake. Installation of "gray" infrastructure such as stormwater pipes or concrete ditches and swales can significantly alter a lake's drainage basin—often increasing the volume of direct stormwater flow. This can cause issues such as rapid surface level fluctuations as well as increased nutrient loading. Restoring some of the natural drainage pathways can be accomplished through the implementation of "green" infrastructure BMPs that reduce runoff and increase stormwater storage and infiltration.

In addition to alterations caused by stormwater infrastructure the types of soils found in lake drainage basins can significantly impact hydrology. The United States Department of Agriculture (USDA) has classified soils into several hydrologic groups based on sediment types (e.g. sand, clay, loam) and the rate of water infiltration.

USDA Hydrologic Soil Groups

Group A: *Soils consisting mostly of excessively drained sands or gravel with a high infiltration rate when thoroughly wet.*

Group B: *Soils consisting of moderately well-drained course or fine texture sediments with a moderate infiltration rate when thoroughly wet.*

Group C: *Soils consisting of fine textures having a layer that impedes the downward movement of water with a slow infiltration rate when thoroughly wet.*

Group D: *Soils consisting chiefly of clays or clay layers near the surface or over nearly impervious material with a very slow infiltration rate.*

Dual Groups: *(A/D, B/D, C/D) Mixed soils with no dominant type where the first letter is assigned to drained areas and the second is for undrained areas.*

The proportion of each soil group making up a given lake drainage basin can indicate the infiltration potential surrounding that waterbody. This information can also be used to determine adequate locations for BMPs that promote groundwater recharge and treatment of stormwater. Finally, land use can provide insights into the quality of stormwater entering lakes from within their drainage basins. Basins with large proportions of industrial or agricultural uses may be prioritized for stormwater treatment measures due to their increased pollutant load EMCs. Figure 1-11 displays the soils groups within each of the lake drainage basins.

Groundwater

There are two primary tiers of groundwater in Florida: the upper layer known as the surficial aquifer, and the deeper Floridan aquifer, confined under a layer of impermeable clay. Measurement of the elevation above sea level of the upper surface of each aquifer is the accepted method for determining their current water quantity. The surficial aquifer level is referred to as the water table. Since the Upper Floridan is a confined aquifer, its level is measured as the potentiometric surface, or the level at which water will rise in a well pipe due to the pressure exerted on it. Where there are breaks or perforations in this confining layer, water can be exchanged with the surface. Fluctuations of both the surficial and Upper Floridan levels can significantly impact lake surface levels as shown in Figure 1-12. During periods of time or locations where the aquifer surfaces are high, water may flow to the surface via the bottom of lakes. Of course, the opposite occurs when the water table and potentiometric surface are low.

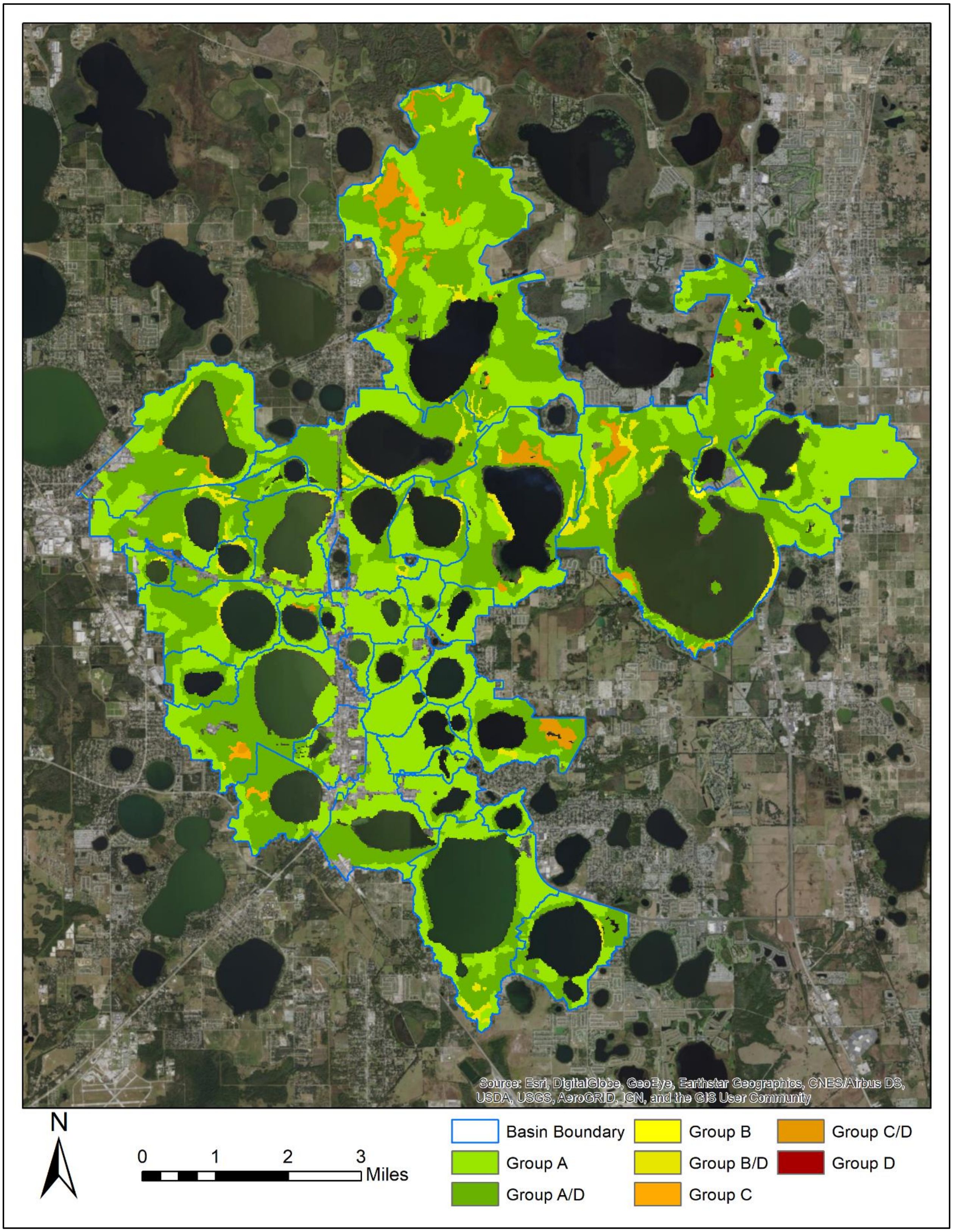


Figure 1-11. Hydrologic soil groups of the Winter Haven lakes

The Upper Floridan Aquifer is the sole municipal water source for the City of Winter Haven. As one of the fastest growing metropolitan regions in the Country [10], the potential hydrologic impacts of water use must be considered not only for the ecological outlook of our lakes, but also for the future of our drinking water supply. The primary hydrologic strategies for this area include promoting recharge of the Upper Floridan and the long-term storage, treatment, and slow recharge of surface waters in areas where fast recharge isn't feasible.

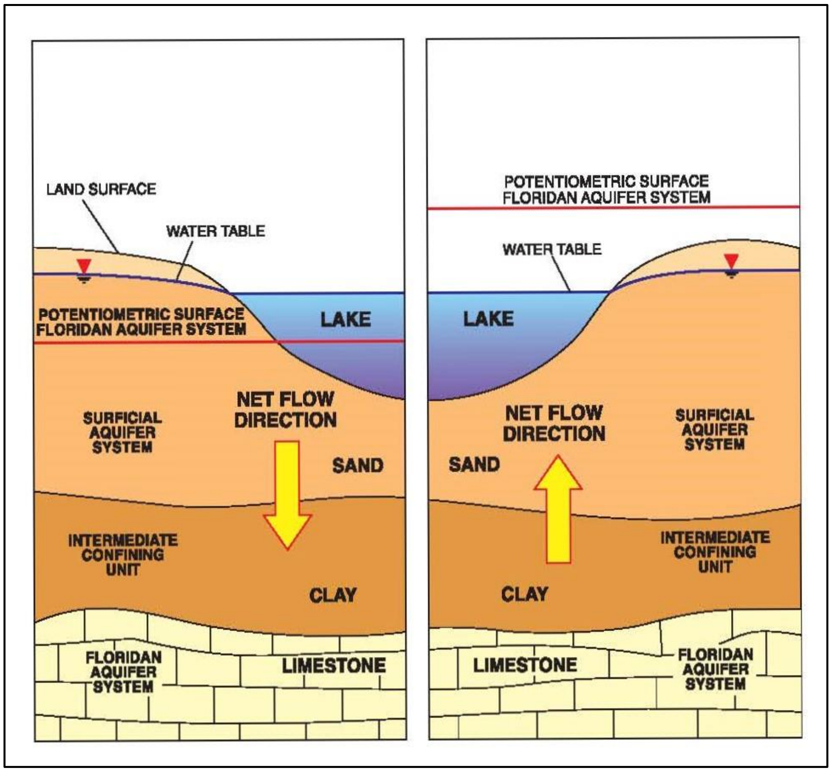


Figure 1-12. Diagram of Lake Groundwater Interactions [6].

Lake Morphology

Lake morphology refers to the physical attributes that describe the overall shape of a waterbody. The purpose of studying these characteristics is not because they directly affect lake health, but because they provide insights as to how various lake shapes respond to environmental stimuli. Small to large; deep to shallow, a waterbody's position on these spectra can affect hydrologic, ecologic, and water quality responses. For example, a large, shallow lake will often undergo less extreme surface level fluctuations, have the capacity for more aquatic vegetation, and will be more susceptible to wind and wave disturbance of benthic sediments compared to its smaller, deeper counterpart. No two lakes behave the same, but understanding how these morphological characteristics impact lake health can be useful in developing management strategies.

The primary morphometric parameters the City uses to evaluate lake shape are surface area, bathymetry, and volume. Calculated as the planar area of the lake surface, surface area represents the 2-dimensional size and shape of the waterbody. Volume can be calculated with the help of depth data. With enough depth points over the area of a waterbody, a profile or bathymetric map can be determined (Figure 1-13). Bathymetry provides statistics such as mean and maximum depth and allows for a more accurate calculation of volume. Again, while these metrics don't inherently affect lake health, they can be used to explain a lake's response to changes in water quality, surface level, or biology and are useful for prescribing the most effective management strategies based on a lake's unique characteristics. For example, it was discovered that a significant, relationship exists between turbidity and the morphometric characteristics of the Winter

Haven waterbodies. In a linear regression between long-term mean turbidity and the ratio of average depth to surface area, 22% of the variability in turbidity can be attributed to lake size and depth ($R^2 = 0.22$; $p \leq 0.005$; DF = 34). This means that a lake's morphometric qualities have a relatively minor, but still significant effect on water quality. Clearly, additional factors can impact water quality, but it is undeniable that these physical characteristics play a role.

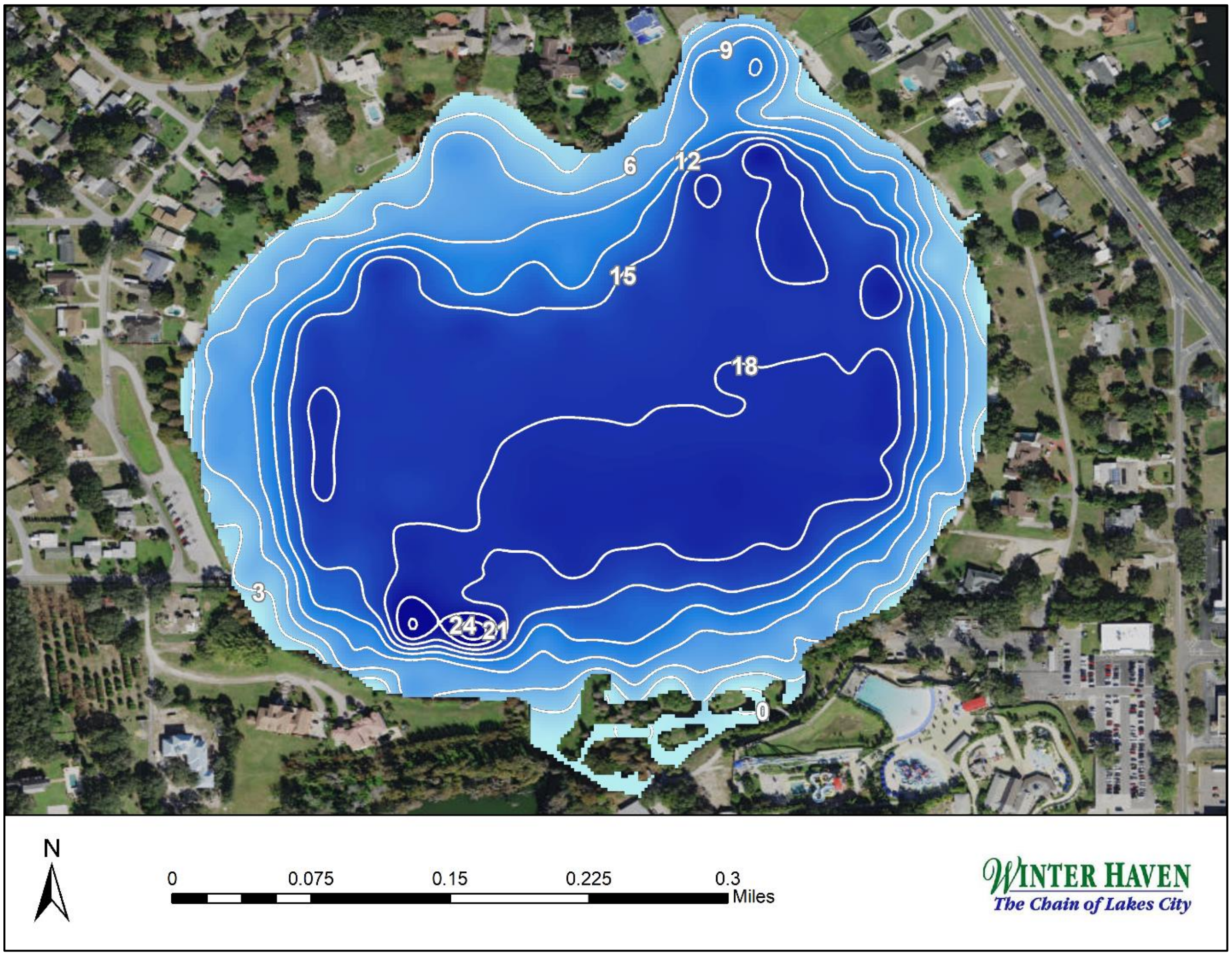


Figure 1-13. Bathymetric map of Lake Summit. Isolines indicate depth gradients at 3 ft intervals

Ecology

Ecology is a subsection of biology that focuses on the study of living organisms and their interactions with one another and their environment. An understanding of these biological communities is necessary to meet the intended use requirements for Class III waterbodies, referenced earlier in this document.

> **Class III**: *Recreation; Propagation, & Maintenance of a Healthy, Well-Balanced Population of Fish & Wildlife*

One of the main components of any ecosystem is the presence of primary producers (i.e. plants and algae). These photosynthetic organisms provide multiple benefits for the aquatic environment. The management of macrophytes ensures that their populations remain healthy and well-balanced. The quantity and quality of vegetation in a waterbody respond to and impact the response of both hydrologic and water quality metrics. It is for this reason that the City decided to focus on aquatic vegetation as a vital component of lake health.

Primary Ecological Metrics

Biological abundance: *The quantity of vegetation growing in a waterbody can be estimated through the use of remote monitoring methods. Percent area coverage (PAC) and biological volume (BV) represent the respective 2-dimensional and 3-dimensional quantification of plant matter relative to a waterbody's size.*

Species Composition: *Ecological surveys are performed to estimate the overall population of aquatic plants in each lake. A count of each species present during a survey allows for the evaluation of diversity, dominant taxa, and the ratio of natives to invasives.*

Species Diversity: *Species diversity is a measure of the overall richness (number of unique species) and evenness (relative species proportion) of a lake's biological community. Multiple indices are used to evaluate overall diversity.*

Aquatic Plant Types

Of the different types of primary producers in aquatic environments, both microscopic algae and macrophytes (large aquatic plants) fill a similar ecological role as an oxygen producing food source for primary consumers. A healthy balance of each is necessary for a functioning, diverse aquatic community. However, macrophytes provide additional ecological benefits such as their role as habitat for aquatic fauna. Based on their various fundamental growth strategies, aquatic macrophytes are separated into three categories: submerged aquatic vegetation (SAV), emergent aquatic vegetation (EAV), and free-floating vegetation (FV) (Figure 1-14).

Submerged plants grow completely under the water's surface and are usually rooted in the benthic sediments. Since the main body of the plant is supported by water, SAV isn't hampered by the energy requirements needed to develop rigid support structures to keep them upright. Due to this, SAV species typically grow relatively quickly. However, this evolutionary strategy ties the growth of submerged plants to the availability of sunlight—

meaning that water clarity, bathymetry, and surface level can significantly impact available real estate where SAV can grow. Common examples of SAV in our lakes include eel grass (*Vallisneria americana*) and the invasive species hydrilla (*Hydrilla verticillata*).

Emergent plants are similar to SAV in that they are rooted in the benthic substrate, however the main photosynthetic body of the plant grows above or floats on the water's surface. This adaptation negates some of the issues associated with light availability, however these plants must put more energy into structural components that allow them to rise above the surface. In addition, the growing depth of EAV is limited by the capacity to transport air and nutrients to their root systems—meaning that most species are relegated to the shallow margins of lakes. Duck potato (*Sagittaria lancifolia*) and cattail (*Typhus spp.*) are a couple examples of emergent plants.

Floating plants are unique in that they have evolved beyond the need to root into the underlying substrate. To prevent them from sinking, most are small in size while some species possess adaptations that create buoyancy. The ability to float negates many of the challenges that SAV and EAV must contend with. By virtue of this, some of the most prolific invasive plant species in Florida are floating plants. Examples of FV species are water hyacinths (*Eichhornia crassipes*) and duckweeds (*Lemnoideae spp*.).

Figure 1-14. Examples of Aquatic Vegetation Types [11].

Vegetation Quantity

The areas of saturated or inundated ground along the peripheries of some lakes can support emergent vegetation. These areas, known as wetlands, are a unique habitat area that many species of wildlife rely on. Wetlands can act as a pollutant sink as well as a source of beneficial chemical components [12]. Surface water that comes into contact with wetland areas deposits sediments, nutrients, and other contaminants. Also, most forested wetlands provide a source of dissolved organic compounds that impart color to the water column. Figure 1-15 illustrates the correlation between surface level and true color in a system with surrounding wooded wetland area and one without significant wetlands. Lake Haines, with its surrounding wetlands elicits a much stronger relationship between surface level and color than Lake Blue which lacks any substantial forested wetland area. Reductions in wetland connectivity through land development or surface level alteration can diminish these benefits. Identification and restoration of historic wetland connections is one management strategy that can be employed to improve water quality.

For submerged vegetation, the area within a lake that can support the growth of SAV is referred to as the littoral zone. This area, measured as the percent of area covered (PAC), is limited by the depth that light can penetrate in the water column. As such, the size of the littoral zone is determined by lake morphology, water clarity, and the unique requirements of the species of plants that inhabit it. Since most SAV species are rooted, they contribute to the stabilization of the benthic sediments [13]. Therefore, it can be inferred that greater PAC generally equates to lower potential suspended sediment concentrations. A target range of 15 – 30 PAC is generally considered a beneficial amount of coverage for the purposes of wildlife habitat; as communicated by FWC personnel.

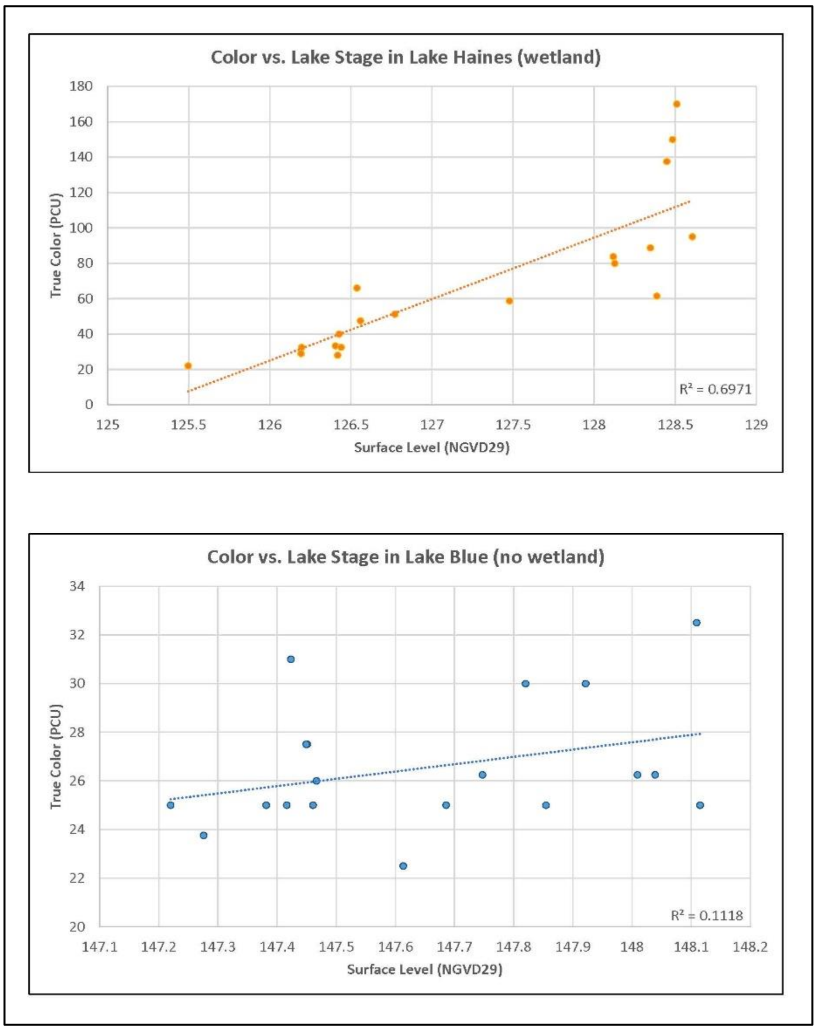


Figure 1-15. True Color vs. Surface Level Regression Comparison

One additional benefit of SAV in lakes is their increased capacity to uptake nutrients directly from the water column compared to most emergent species [14]. Monitoring the total quantity of SAV can help determine a lake's ability to buffer against changes in nutrient concentrations. The use of SONAR mapping technology allows for the 3-dimensional quantification of SAV. By finding the difference between depth to bottom and depth to vegetation, the volume of water inhabited by plants can be calculated. This metric, known as biological volume, or biovolume (BV), is often recorded as a percentage in relation to total lake volume. The City has been recording the annual changes in BV in most study area lakes since 2016.

Vegetation Diversity

Species diversity is a complex metric that takes into account the number of species present (richness) as well as the relative proportion of each species (evenness). Since each individual plant can't feasibly be counted, scientists can use a variety of survey methods to identify what a representative sample of the overall population looks like. Using a point-intercept method to sample regularly spaced points across each lake area, the City can record not only the total number (frequency) of each species surveyed, but also their relative spatial distribution.

Species frequency values, illustrated in Figure 1-16, can be used to calculate species richness and evenness as a ranked score. The resulting scores, referred to as diversity index values, can be used to evaluate the health of vegetation communities. Ecologically, a healthy population is a diverse and evenly distributed one. As an example, a lake that is dominated by one or two species is at a substantially greater risk of collapse than one with numerous, equally abundant species. Common sources of collapse include climatic changes, pests and diseases as well as competition from invasive species. Since species diversity is such a complex metric, no single index can adequately represent diversity in all cases. Moreover, some indices make assumptions regarding the population being studied and are applicable only in specific scenarios. For the intents and purposes of this study, these indices are only used to compare the changes in vegetation communities over time and not for site comparisons:

Primary Species Diversity Indices [15]

- **R2**: known as *Menhinick's richness index, represents the number of unique species sampled in a given site or area. This index is reliant upon sampling effort, therefore it is useful only for comparing richness of the same site over time (assuming sample size remains constant).*
- **E3**: *One of many popular indices that represent how evenly the species in a population are distributed. E3 ranks a sample from 0 – 1 where the index approaches 1 when all species are present in equal proportions.*
- **H**: *Referred to as Shannon's Diversity Index, this metric incorporates concepts of richness and evenness. H represents the uncertainty of sampling the same species multiple times in a row; as such this value increases as a population becomes more diverse.*

In the realm of vegetation management, knowing where a given species is located is equally as important as understanding the diversity dynamics of the local population. Where a particular plant species is commonly found can provide information about its optimal growing conditions (e.g. light, depth, or substrate). It can also be used as a handy method for tracking invasive species. Exotic species such as hydrilla and water hyacinth have few natural checks that would limit their growth in this region. As such, these invasive species can outcompete most natives; often to the detriment of navigation and ecological diversity.

The City of Winter Haven does not actively manage invasive aquatic species in public waterbodies, however it provides support to the organizations that do. The Florida Fish and Wildlife Commission (FWC) is the governing body with jurisdiction over treatment of waters of the State. Through funding from FWC, Polk County assists in the treatment of invasive plants in this area using various methods including herbicide, mechanical removal, and biological controls. Excluding physical removal methods, the treatment of invasive species can facilitate reintroduction of nutrients as the treated plants decompose. Fortunately, the release of nutrients can be mitigated by limiting treatment area and intensity. The City's monitoring efforts allow for the early detection of invasives so that they may be managed before their populations expand and require large scale treatment. This concept of early detection and rapid response is critical to the maintenance of species diversity and overall ecological health. Since complete eradication of invasives is often not a feasible goal, reduction of invasive presence to a maintenance state is the general target. These targets are typically based on percent of lake surface area covered and are species specific. Since the point-intercept survey methods aren't the most applicable means of measuring species area, the City considers reduction in invasive frequency an adequate indicator of improvement.

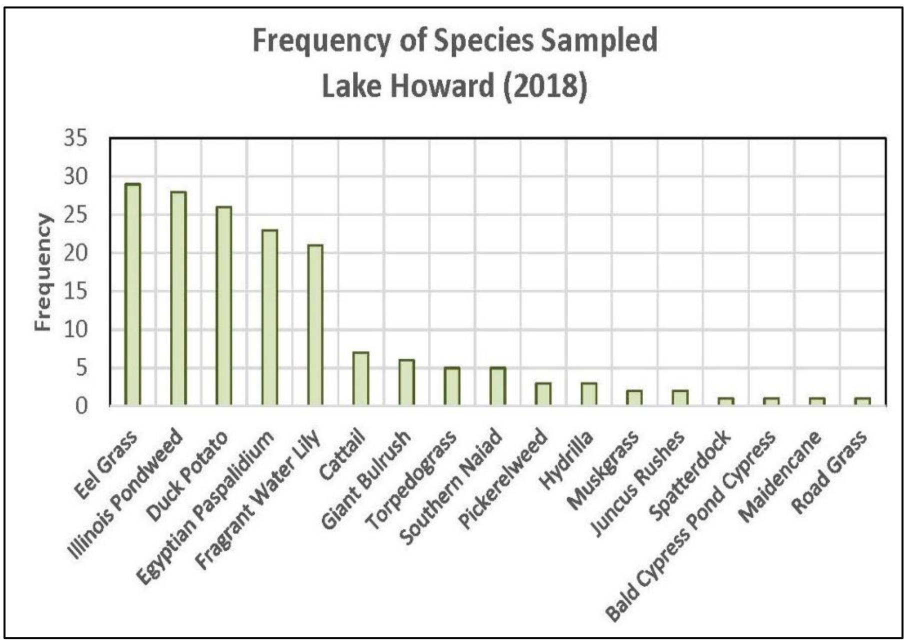


Figure 1-16. Species Frequency Chart of Lake Howard 2018 Survey

2- Data Presentation & Analysis

Summary

Using the concepts and metrics presented in the previous section, the following is a presentation of the chemical, hydrologic, and ecological data collected by various environmental agencies and organizations. For the purposes of organization and readability, the data has been arranged by the lake groups established in section 1.2. These groups are based on their drainage pathways and spatial distribution, however not all lakes within a group may exhibit similar responses to environmental stimuli. No doubt, comparisons can be made between lakes and/or lake groups, but the focus of this report is on site-specific evaluations. Consideration of each waterbody's unique characteristics is necessary to develop effective management strategies aimed at maintaining and improving lake health.

This evaluation has been performed by reviewing various water quality and ecological criteria in order to ascertain the relative health of each waterbody. Each criterion is assigned a value indicating whether the target waterbody is meeting the recommended standard and/or exhibiting improvement. The individual criterion values are then aggregated, resulting in a semi-quantitative lake health score that can be used to prioritize management of lakes within the study area. The following are the individual lake health criteria:

- *Water Quality Criteria*
  - *NNC Impairments*
    - *Chlorophyll-a*
    - *Total Nitrogen*
    - *Total Phosphorus*
  - *Chlorophyll-a Trends*
  - *Total Nitrogen Trends*
  - *Total Phosphorus Trends*
  - *Clarity Trends*
- *Biological Criteria*
  - *Vegetation Abundance*
  - *Invasive Species Percentage*
  - *Species Diversity*
    - *Menhenick Richness Index (R2)*
    - *Hill Evenness Index #3 (E3)*
    - *Shannon's Diversity Index (H)*

NNC Impairments: For the impairment indicator, a score of 1 is given for each metric not determined to be impaired, while 0 is assigned to any currently impaired metrics. Each metric score is combined for a possible score of 3 which indicates a lake without any impairments. Impairment is determined as more than one consecutive AGM exceedance of NNC thresholds in any 3-year period during the assessment period (2010 – 2018).

Water Quality Trends: Each water quality metric is evaluated based on monotonic trend direction (+/-) and statistical significance (p-value ≤ 0.05) based on AGM concentrations from 2000 to 2018. Significant improving Chla, TN, TP, and Secchi depth trends are assigned a score of 3; non-significant improving trends are given a score of 2; non-significant deteriorating trends are scored as a 1; and significant deteriorating trends are scored as a 0.

Vegetation Abundance: Abundance is scored based on 2018 percent area coverage (PAC) values as determined by SONAR mapping. A score of 3 is given to lakes with PACs exceeding 30%; between 30% and 15% receives a score of 2; a 1 is assigned to lakes between 15% and 2.5%; a score of 0 is given to lakes with less than 2.5% PAC.

Invasive Species Percentage: Invasive indicator scores are based on 2018 species frequency numbers as a percent of sample for each waterbody. Scores are assigned for total percentage of invasive species managed by environmental agencies. A score of 3 is assigned to lakes with no managed invasive presence; a 2 is given to lakes with less than 2.5% total invasive percentage; lakes with between 2.5% and 10% are given a score of 1; while 0 scores are given to lakes with greater than 10% total invasive percentage of the sample.

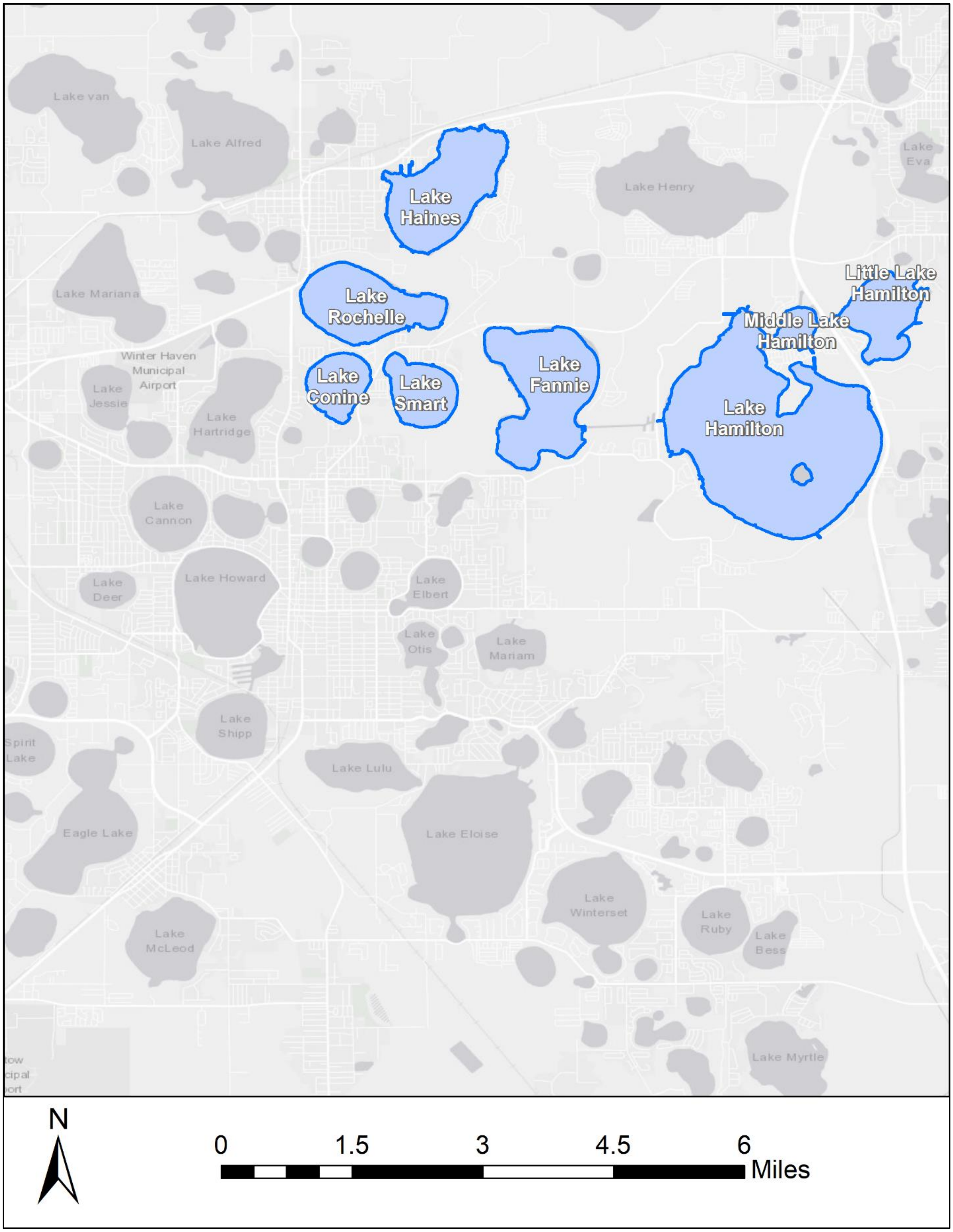
Species Diversity: Diversity scores are assigned per lake based on a measurable increase or decrease of index values. A score of 1 is given to each index exhibiting an increase from the previous year to the current; 0 scores are assigned to indices exhibiting a decrease from the previous year. For each waterbody, index scores are combined for a total possible score of 3. Lakes without multiple years of data are assigned a score of 0 as there is no way to indicate improvement.

Lake Health Score: The individual lake health indicator scores are averaged for each waterbody. The resulting value represents each lake's annual relative health on a scale of 0 to 3 with 3 being an exceptionally healthy waterbody. This lake health score methodology was not developed to be an official evaluation metric, but is intended to be used to track overall changes in the Winter Haven area lakes over time. Since many of the individual indicator criteria are based on a binary scale, the overall lake health metric does not incorporate magnitude. As a result, these scores are not applicable as absolute measurements of overall lake condition, only as a means to compare the lakes within the study area. Moreover, this metric is meant to be evaluated annually which means that lake health index values will fluctuate due to environmental or anthropogenic stimuli—these values are not static.

Additional quantitative and qualitative data is also presented to highlight unique characteristics and help to establish a profile for each waterbody or lake group. These data include recent surface level trends, land use and soil characteristics, morphological qualities, and any other pertinent anecdotal information. This information has been included to support the lake health criteria and assist in selecting appropriate management strategies.

The City of Winter Haven would like to recognize the following organizations for providing support with data collection and analysis. The water quality data used in this analysis is sourced via the Polk Water Atlas which is curated by the University of South Florida (USF) with funding through the Charlotte Harbor National Estuary Program (CHNEP); water quality data is collected quarterly by the Polk County Natural Resources Division. Surface level datasets have been sourced from the Southwest Florida Water Management District (SWFWMD) and the Lake Region Lakes Management District (LRLMD). Bathymetric and biological survey data for Lakes Hamilton, Middle Hamilton, and Little Hamilton were collected by the Florida Fish and Wildlife Conservation Commission (FWC) via their Invasive Plant Management Section. Watershed soils data was obtained from the Natural Resources Conservation Service's Soil Survey Geographic Database (SSURGO). Land use data was obtained via the 2014 SWFWMD land use survey shapefile. All other data have either been collected by City of Winter Haven staff or are cited directly in the report. Much of the analysis and data visualization presented here has been made possible through ESRI's ArcGIS software as well as Tableau's public data visualization software.

2.1 North Chain of Lakes



The Winter Haven North Chain of Lakes (NCoL) is made up of eight waterbodies: Lakes Conine, Fannie, Haines, Hamilton, Rochelle, Smart, Little Hamilton, and Middle Hamilton. While Lake Henry is also considered part of this Chain, it has been excluded from this study due to a lack of public access and means to collect water quality data. The primary surface water contributors and Municipal Separate Storm Sewer System (MS4) permit holders within the NCoL watersheds include the Florida Department of Transportation, Polk County, and the cities of Winter Haven, Lake Alfred, and Haines City. As recently as 1992, Lake Conine received wastewater discharge from the City's Wastewater Treatment Plant #2.

Water Quality

In order to determine water quality impairment, the NCoL waterbodies were categorized based on long-term geometric mean true color and total alkalinity concentrations. Of the nine waterbodies, Lakes Fannie, Haines, Hamilton, and Middle Hamilton were determined to be highly colored while Lakes Conine, Rochelle, Smart, and Little Hamilton were categorized as clear, alkaline waterbodies. Annual geometric mean (AGM) chlorophyll-a (Chla), total nitrogen (TN), and total phosphorus (TP) concentrations between 2010 and 2018 were evaluated to determine impairment status. The AGM concentrations are displayed in Tables 4-1 through 4-3 located in the Appendix. Based on this dataset, all eight NCoL waterbodies are considered impaired due to multiple consecutive Chla, TN, and TP exceedances in a 3 year period. It should be mentioned that Lake Fannie has consistently exhibited improved water quality for the last 5 years and should be removed from the City's provisional impairment list in 2019 if current trends hold.

A snapshot of the 2018 AGM Chla, TN, TP, and Secchi depth values for the NCoL is displayed in Figure 2-1. Also represented are each lake's long-term mean and normal range (+/- 1 standard deviation) derived from the period between 2000 and 2018. Despite the impairment evaluation, comparison of 2018 water quality levels with long-term values indicates that the majority of these waterbodies are currently exhibiting below average Chla, TN, and TP concentrations as well as above average water clarity. Lake Hamilton is the only lake in this chain experiencing poorer water quality with regards to Chla, TN, and Secchi depth than its long-term averages. However, one positive note is that current TP concentrations for Lake Hamilton are actually much lower than the 18 year mean—indicating that phosphorus is most likely not driving the decline in clarity and increase in chlorophyll-a.

To determine whether each lake is experiencing overall water quality improvement or deterioration, analysis of the long-term trends was performed. The monotonic (directional) trend test involves linear regressions of AGM Chla, TN, TP, and Secchi depth from 2000 to 2018. The magnitude of the correlation coefficient (R^2) was not factored into the lake health criterion, however the regression direction (+/-) and statistical significance (p-value ≤ 0.05) were used to determine the trend relationship and validity respectively. The regression trendlines are represented in Figure 2-2 whereas the regression statistics can be found in Table 4-4 in the Appendix.

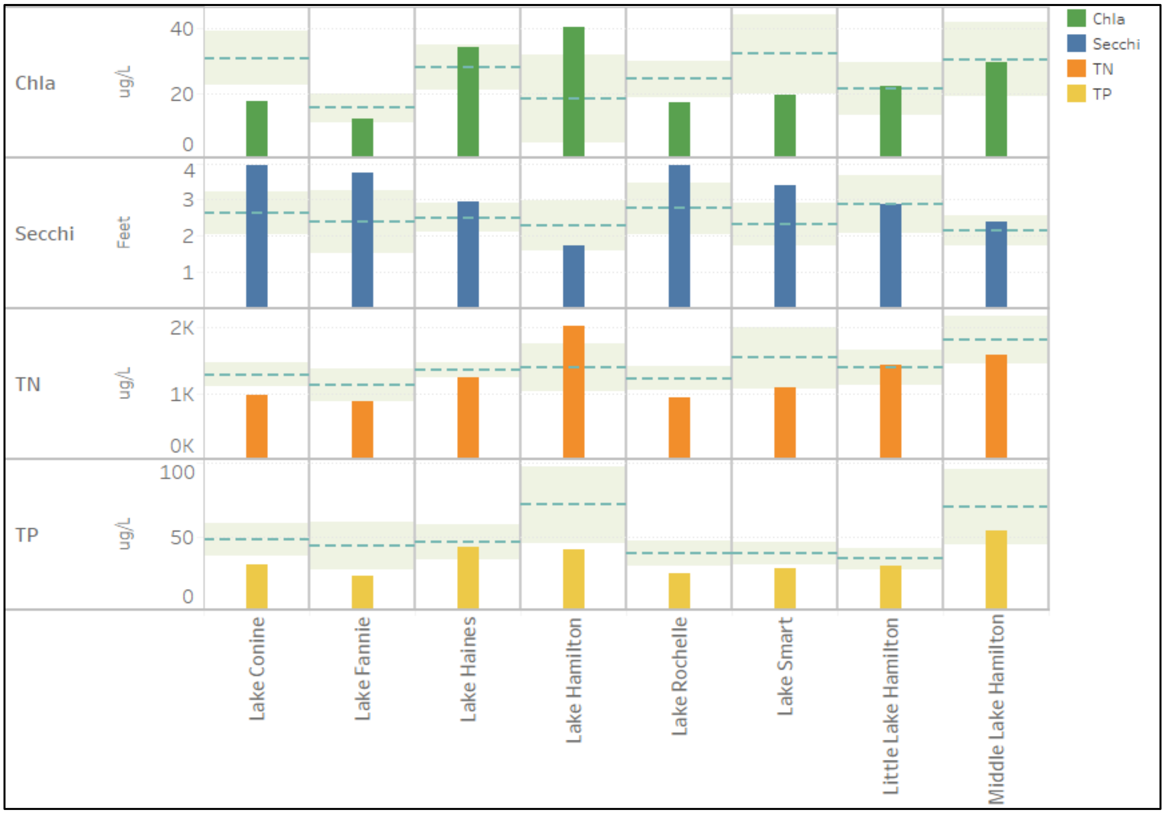


Figure 2-1. 2018 AGM Chla, TN, TP, & Secchi depth values for the North Chain of Lakes; dotted line represents long-term mean and the shaded area refers to the standard deviation range.

Chlorophyll-a Trends: Of the eight waterbodies of the NCoL, only two exhibited significant Chla trends from 2000 – 2018. Lake Hamilton experienced a substantial increasing relationship of Chla over time, whereas Lake Rochelle displayed a slight decreasing trend, both of which were statistically significant as evidenced by their respective p-values. Lakes Conine, Haines, and Smart experienced non-significant decreasing trends, while Lakes Fannie, Little Hamilton, and Middle Hamilton exhibited non-significant upward trends over time.

Total Nitrogen Trends: With regards to TN, Lake Hamilton exhibited a significant positive correlation with TN over time, however Lake Haines experienced a significant downward trend, albeit with a much weaker correlation. Lakes Conine, Rochelle, and Middle Hamilton displayed non-significant downward TN trends, while Lakes Fannie, Smart, and Little Hamilton possessed very slight, non-significant, upward regression curves.

Total Phosphorus Trends: Unlike the other NNC metrics, all lakes exhibited downward trends in TP from 2000 – 2018. Statistically significant regressions were observed for Lakes Hamilton, Rochelle, and Middle Hamilton. Lakes Conine, Fannie, Haines, Smart, and Little Hamilton experienced non-significant decreasing trends.

Water Clarity Trends: Between 2000 and 2018, Lakes Conine, Haines and Rochelle experienced significant positive trends in clarity. Lakes Fannie, Smart, and Middle Hamilton displayed non-significant positive regressions, whereas Little Lake Hamilton exhibited a non-significant decreasing trend in Secchi depth. Lake Hamilton, concurrent with increasing trends in Chla and TN, displayed a significant negative correlation with clarity over time.

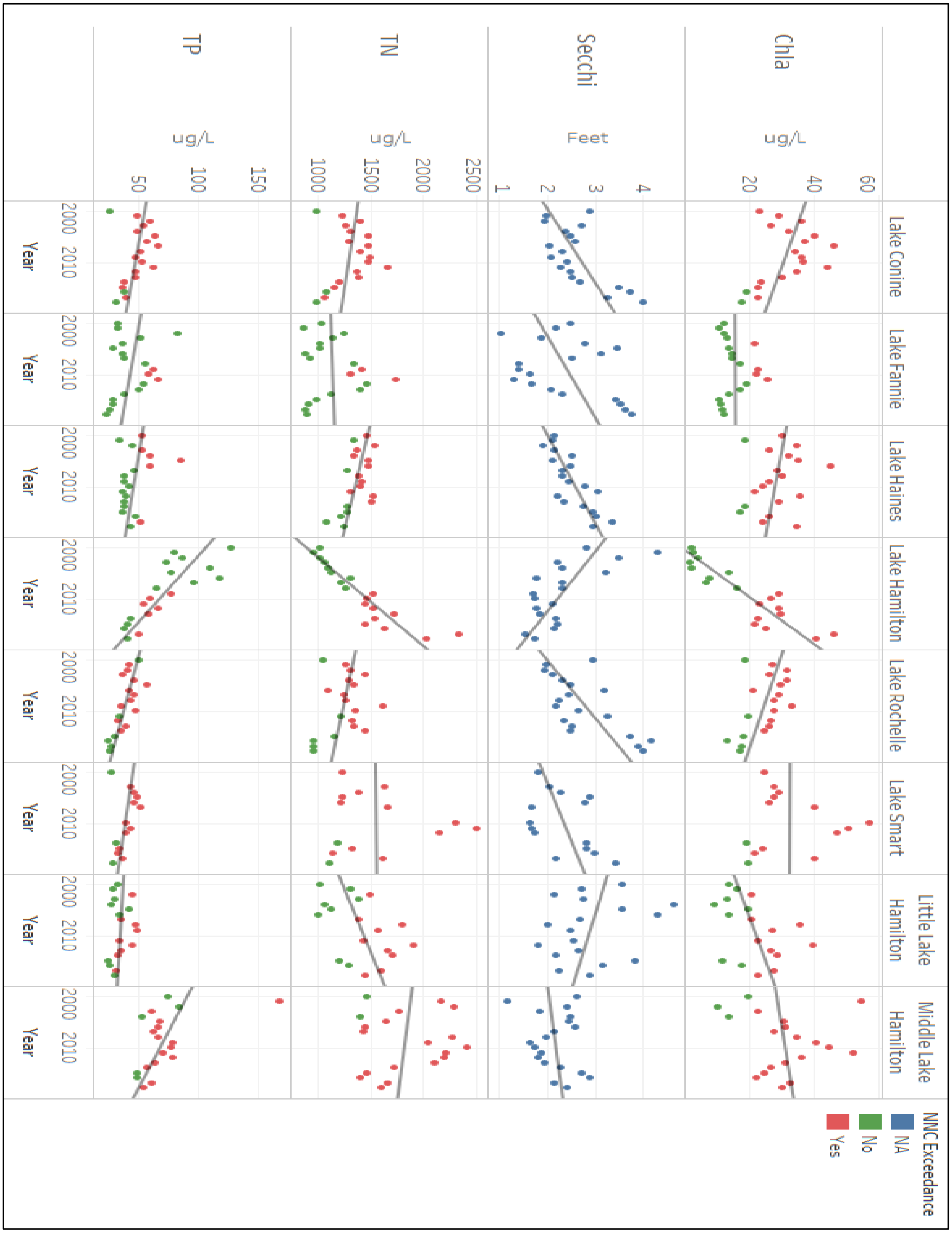


Figure 2-2. North Chain of Lakes regression trend graphs of AGM Chla, TN, TP, & Secchi depth from 2000 – 2018. Red dots represent exceedance of the NNC threshold for that year

Hydrology

As part of the hydrologic cycle, lake surface levels (SL) fluctuate on a regular basis. Not only are there annual cycles, but long-term ups and downs that correspond with extended periods of drought and excess rainfall. Figure 2-3 is a hydrograph of the monthly NCoL SLs from 2000 to 2018 as well as annual rainfall totals. This hydrograph illustrates both these seasonal and long-term changes in lake level as a result of varying amounts of rainfall. Average annual precipitation for the Winter Haven area is roughly 52 inches. Due to consistent below-average rainfall between 2006 and 2013, SLs dipped below each lake's period of record mean. The return of normal rainfall patterns allowed for recovery and stabilization of levels after 2014. Also shown in this graphic are boxplots that represent each lake's relative variation—the blue boxes represent the upper and lower quartile for the period of record with the central divide indicating the median. Based on these figures, Lake Fannie has exhibited the largest swings in level, whereas Lake Henry shows the least variability. It should be noted, that the Southwest Florida Water Management District (SWFWMD) has recently updated their infrastructure and structure operations guidelines to reduce wild SL fluctuations in an effort to improve recreational use and meet minimum flows to the Peace Creek [1].

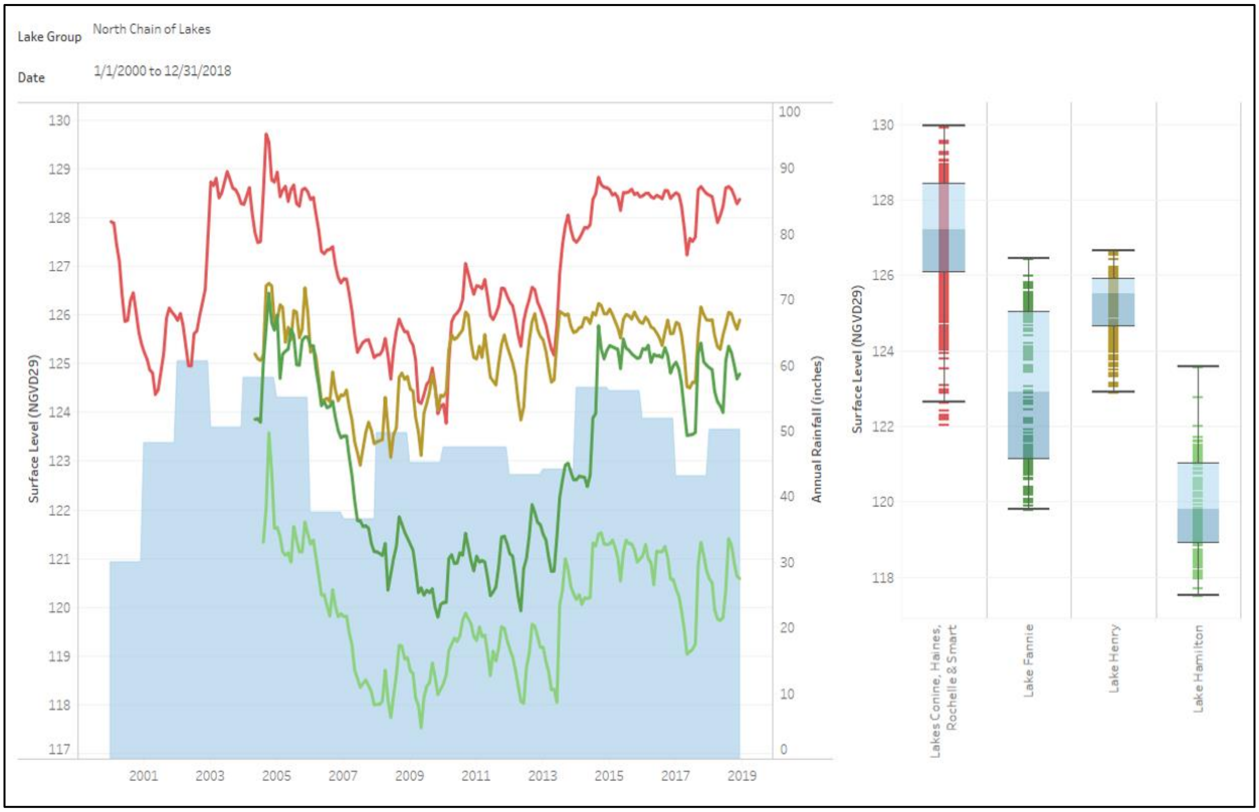


Figure 2-3. North Chain of Lakes hydrograph with box & whisker plots detailing long-term surface level variability. Annual rainfall totals indicate hydrologic response to precipitation.

The level of impact that hydrologic fluctuations have on water quality varies from lake to lake dependent on each waterbody's unique characteristics. In order to identify the lakes that possess a statistically significant relationship between SL and the four primary water quality metrics, linear regressions were performed. A confidence level of 95% (p-value ≤ 0.05) was required to denote a significant relationship. The regression values can be found in Table 4-5 in the Appendix.

SL vs. Chla: Lakes Conine, Fannie, Rochelle, Smart, Little Hamilton, and Middle Hamilton exhibited a significant inverse correlation between surface level and Chla. This indicates that a rise in lake levels was generally accompanied by a drop in Chla concentration.

SL vs. TN: Lakes experiencing a significant inverse correlation between SL and TN include Conine, Fannie, Smart, Little Hamilton, and Middle Hamilton. Again, the direction of the trend lines reveal that TN decreases in accordance with increasing surface levels.

SL vs. TP: Similar inverse relationships between SL and TP exist for the following waterbodies: Lakes Fannie, Smart, Little Hamilton, and Middle Hamilton. Strangely, Lake Haines exhibited a significant direct, albeit weak, correlation between SL and TP.

SL vs. Clarity: In contrast with the NNC metrics listed above, the relationship between SL and Secchi depth is often direct—meaning that a rise in lake level typically brings an increase in water clarity. The NCoL waterbodies that exhibit a significant positive correlation include Lakes Conine, Fannie, Rochelle, Smart, Little Hamilton, and Middle Hamilton.

In an attempt to provide more information to support the relationship between water quality and hydrology, analysts looked to each waterbody's morphometric and drainage basin characteristics. Lake drainage basin soil class makeup can be found in the Appendix in Table 4-6. Land use proportions are broken down by lake in Table 2-1, while land use percentages aggregated by lake group can be found in the Appendix in Table 4-7.

With regards to hydrologic soil types, the majority of the NCoL drainage basins are dominated by class A/D soils. Exceptions to this are Lakes Conine and Little Hamilton

Land Use

	Waterbody							
Land Use	Lake Conine	Lake Fannie	Lake Haines	Lake Hamilton	Lake Rochelle	Lake Smart	Little Lake Hamilton	Middle Lake Hamilton
AGRICULTURE	1.34	12.80	24.20	10.86	8.31	29.78	42.81	35.27
BARREN LAND				0.12			4.63	0.78
COMMERCIAL	4.85	0.42	1.00	1.10	1.47		0.67	6.54
COMMUNICATION	7.19	0.07	1.43	0.57	2.65		0.30	5.40
INDUSTRIAL	2.39	8.90	0.87	2.67	1.50		5.59	0.44
INSTITUTIONAL	6.42	0.54	0.77	1.06	0.69	1.31		0.02
OPEN LAND	3.17	2.77	1.86	1.59	5.78		0.01	2.68
RANGELAND	0.00	1.33	0.16	0.00	1.21	0.42		
RECREATIONAL	0.25	5.09	2.17	1.97	0.00	0.09		
RESIDENTIAL	36.75	9.11	13.18	13.50	14.66	15.79	9.85	14.31
UPLAND FOREST		3.87	2.73	2.62	3.49		2.40	2.34
WATER	26.71	28.85	13.32	46.33	30.87	41.74	22.21	8.29
WETLANDS	10.93	26.26	38.30	17.62	29.38	10.87	11.53	23.91

Table 2-1. North Chain of Lakes land use percentage found within each lake drainage basin.

which possess primarily class A soils. These soil conditions follow with the geographic location of these lakes and the surrounding topology. The NCoL straddle the line between the Winter Haven Ridge and Polk Uplands regions. Since the Polk Uplands sit at a lower elevation than the surrounding ridge areas, the basins in this area are a settling place for water and sediments as they travel downstream. Accompanied by a higher relative surficial aquifer, this equates to a larger proportion of less well-drained soils compared to the other lake groups. The A/D class represents soil drainage characteristics in dry/saturated conditions, respectively; equating to higher runoff potential during wetter periods. Management strategies for less well-drained soils should focus on surface water treatment and storage over groundwater infiltration.

On an individual lake basis, land use within the NCoL drainage basins is somewhat diverse. This is likely due to these waterbodies' location in a transition zone between urban and rural areas. Intrinsically tied to land use is pollutant load potential. While modeling of pollutant loading is not within the scope of this report, it should be considered as part of future water quality analysis. The main point in mentioning land uses is to determine the applicability of specific BMPs in this lake group. The lack of stormwater infrastructure in many of these basins should drive management efforts toward reducing direct runoff and internal nutrient loading.

Consideration of wetland land uses within each drainage basin is also important. Wetland area varies considerably from lake to lake within this group, however this group as a whole possesses a greater proportion of wetland areas than any of the other lake groups. Theoretically, surface level fluctuations can influence the nutrient absorption potential by changing the area of wetland inundation. Analysis of the statistically significant SL vs. water quality correlations against the area of wetlands within individual lake basins was not conclusive enough to indicate that a strong relationship exists. However, it was observed that the number of these statistically significant regressions was greater in the North Chain of Lakes. In the presence of this evidence, it seems likely that managing surface levels to improve wetland connection would help to improve water quality.

The morphology of the North Chain of Lakes is varied, however this group can be generalized as mostly large, shallow waterbodies. Surface areas range from 132 acres up to 2795 acres with average depths ranging from 4 ft to 10 ft during 2018. Figure 2-4 displays hypsographs of the NCoL depicting cumulative surface area below each depth category in one meter intervals. Lakes Conine, Smart, and Little Hamilton are representative of more bowl-shaped lakes while Hamilton and Fannie are much more pan-shaped. Lakes Haines, Rochelle, and Middle Hamilton fall somewhere between these two general shapes.

In the case of the pan-shaped lakes, a moderate change in surface level can lead to drastic fluctuations in lake surface area. For waterbodies with extensive shoreline vegetation or wetland areas, this can severely impact the benefits gained from wetland connectivity. Based on lake shape, it would be expected for these waterbodies to also support robust littoral zones with the ability to mitigate large influxes of nutrients.

However, as will be explained in the biological discussion, many other factors can impact habitable areas for vegetation. Additionally, the ratio of surface area to depth of these waterbodies is such that they may be subject to greater sediment suspension which is supported by the regression mentioned in section 1.3. Due to these hydrologic factors, management strategies for these lakes should promote maintaining beneficial surface levels through water conservation as well as a greater focus on vegetative assimilation of nutrients via wetlands and submerged aquatic plants. Due to historic wastewater discharges into Lake Conine, there is a greater potential for nutrient flux from these legacy sediments. Special consideration should be made for mitigating this internal loading through sediment removal or capping.

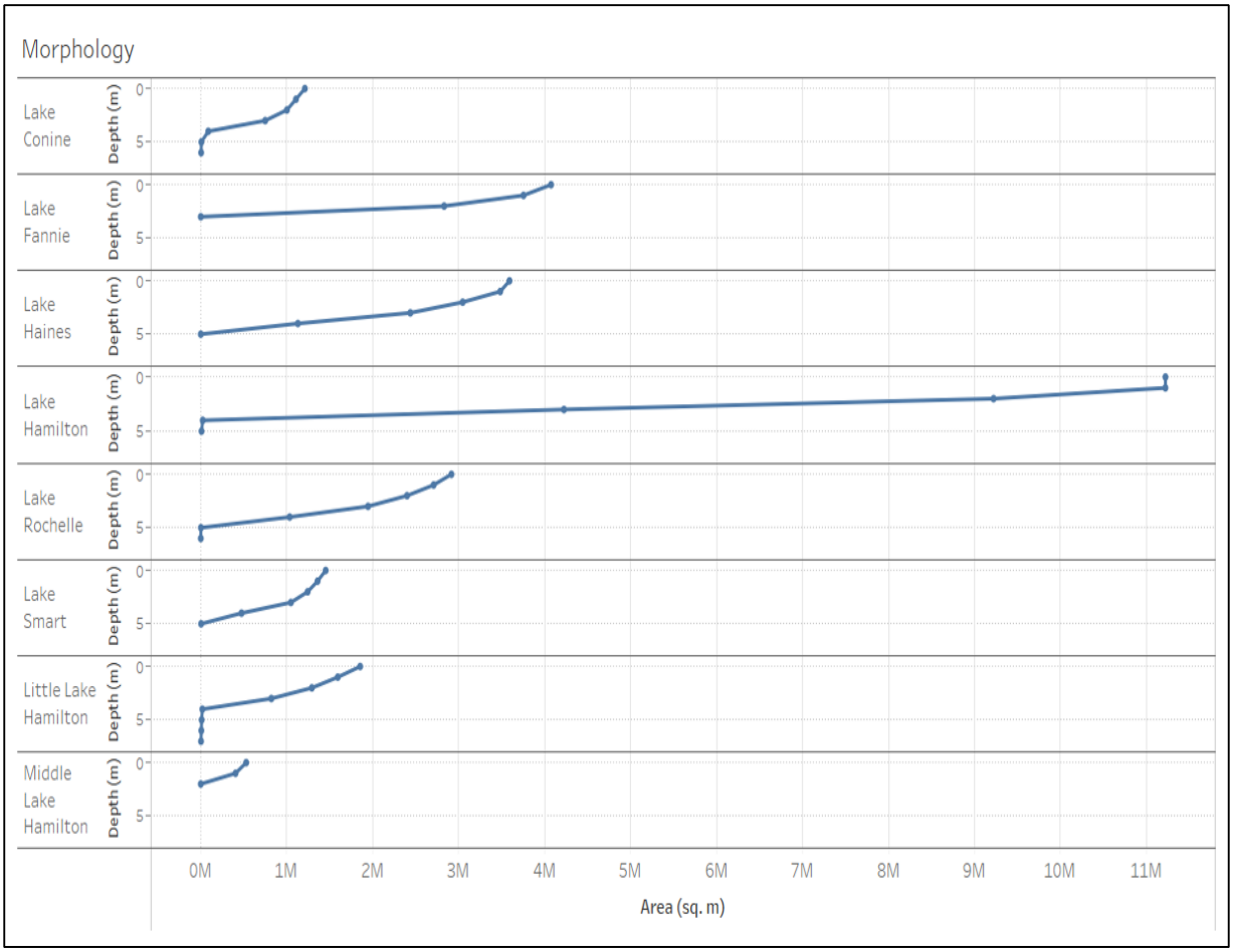


Figure 2-4. North Chain of Lakes hypsographs depicting cumulative area in descending 1 meter intervals.

Ecology

The abundance and diversity of each lake's aquatic vegetation community can provide insights into overall lake health. By virtue of this, the City of Winter Haven has incorporated aquatic vegetation monitoring as part of its overall lake management strategy with surveys initiated in 2016. As a result of time and staffing limitations, some lakes do not possess multiple consecutive years of aquatic plant data with which to analyze. Nonetheless, this long-term monitoring effort should yield valuable information in the years to come. Specific to the North Chain of Lakes group, 2016 surveys were performed on Lakes Rochelle and Smart, 2017 saw Lakes Conine, Fannie, and Haines surveyed, while 2018 marks the first year that the City has been able to acquire data for all NCoL waterbodies.

The aquatic plants of the Northern Chain have been categorized into three groups—submerged aquatic vegetation (SAV), floating vegetation (FV) and emergent aquatic vegetation (EAV). Figure 2-5 indicates the proportion of each plant category found in the North Chain of Lakes based on aggregated species frequency data. It was discovered that the majority of the NCoL is dominated by EAV with only Lake Conine showing SAV dominance. Of the EAV dominant waterbodies, Lakes Haines, Little Hamilton, Rochelle, and Smart possess a higher percentage of SAV on average (38%) compared with Lakes Fannie, Hamilton, and Middle Hamilton (13%). EAV in the NCoL is mostly comprised of cattails (*Typha spp.*) and spatterdock (*Nuphar advena*). Dominant SAV taxa include eel grass (*Vallisneria americana*) and hydrilla (*Hydrilla verticillata*).

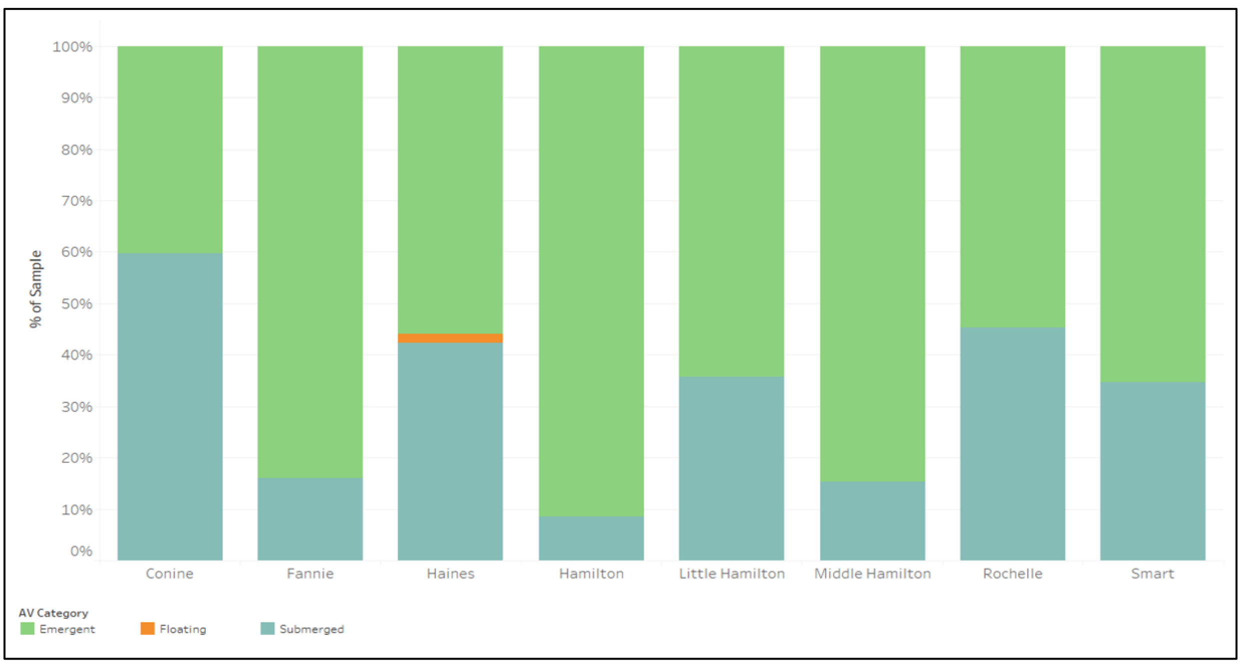


Figure 2-5. North Chain of Lakes categorical proportion of aquatic vegetation as emergent, submerged, or floating.

Incidentally, SAV percentage appears to relate to lake shape as discussed in the previous section—the more bowl-shaped lakes tend to have a greater proportion of SAV. One explanation for the lack of SAV in the pan-shaped lakes may be tied to an increase in suspended sediment via a positive feedback loop. A significant loss of rooted vegetation could lessen substrate stabilization and lead to increased suspended sediments. This subsequently reduces the area supporting new growth, limiting recovery and further increasing sediment suspension. Without substantial vegetation data prior to 2016, it's unlikely to determine the historic extent of the littoral zone in these waterbodies. However, one possible recovery strategy may involve planting of mature SAV to promote substrate stabilization and nutrient uptake—thereby improving water clarity and expansion of the littoral zone.

Aquatic vegetation abundance has been measured using two metrics—percent area cover (PAC) and average percent biovolume (% BV) of rooted vegetation as it relates to lake surface area and volume respectively. The data used to quantify abundance was collected via SONAR as part of the City's monitoring efforts. With regards to lake health, favorable PAC levels fall at or above a target of 15%. This target, selected by the Florida Fish and Wildlife Commission (FWC) as adequate for fish habitat, is also important for sediment stabilization and nutrient uptake. Alternatively, % BV is representative of SAV abundance and nutrient absorption potential. Figure 2-6 displays annual vegetation abundance values for the NCoL. As of 2018, Lakes Conine, Fannie, Haines, Little Hamilton, and Rochelle were meeting the PAC target. In 2016, Lake Smart was meeting the target, however the recent survey indicates that abundance dropped below 15%. With regards to % BV, Lakes Conine, Fannie, and Haines exhibited an increase from 2017 to 2018. Lakes Rochelle and Smart showed a decrease in % BV from the previous survey year, however the initial surveys in 2016 were performed prior to whole-lake hydrilla treatments in Conine, Rochelle, and Smart and is likely indicative of a reduction of invasive species abundance.

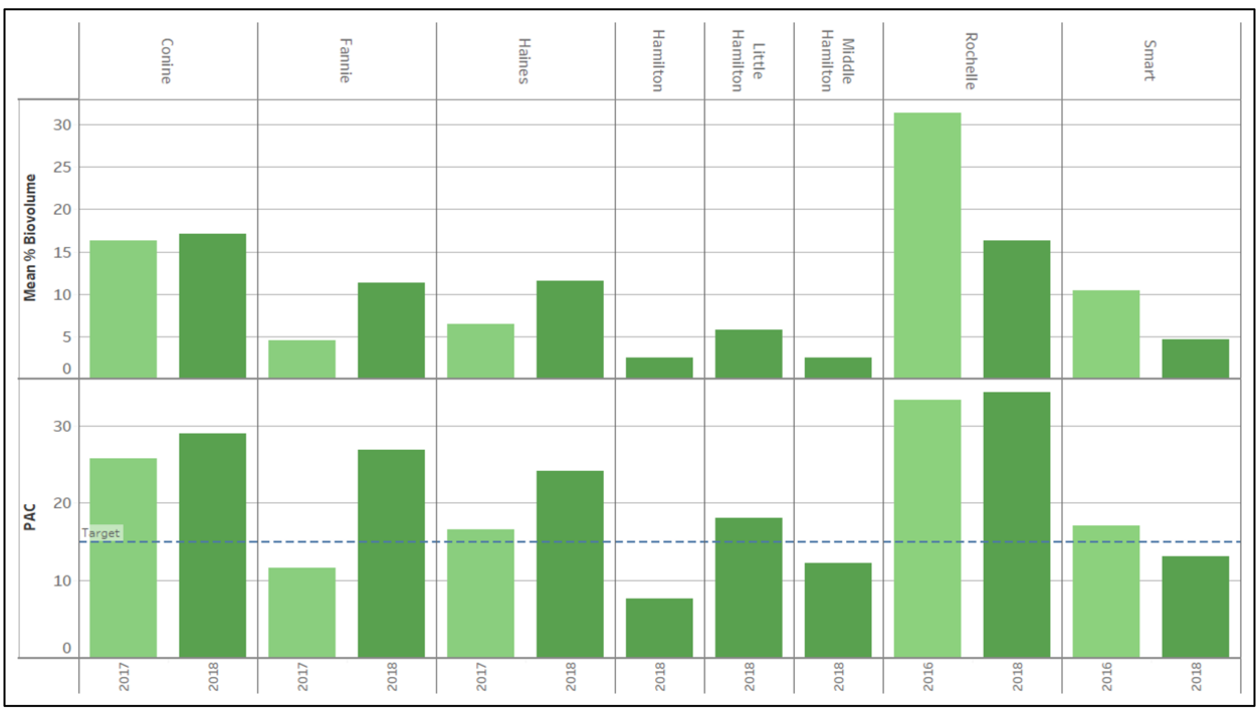


Figure 2-6. North Chain of Lakes annual aquatic vegetation percent area coverage and mean percent biovolume.

The percentage of invasive species is an important lake health indicator for lake managers. Figure 2-7 presents the annual percentage of actively managed invasives sampled during the City's surveying. The primary exotic species that are managed by local and state organizations in this lake group include hydrilla (*Hydrilla verticillata)*, burhead sedge (*Oxycaryum cubense)*, and water hyacinth (*Eichhornia crassipes*). Between 2016 and 2018, Lakes Conine, Rochelle, and Smart experienced a considerable reduction in hydrilla. There occurred an overall increase of invasives in Lakes Fannie and Haines, however the presence of both burhead sedge and water hyacinths was reduced in Haines. The Hamilton lakes lack more than a single year of vegetation data, preventing a comparison, however they will be surveyed again in 2019. It should be noted that the Hamilton chain would likely be considered in a maintained state due to the low frequency of invasives. The FWC, partnering with Polk County, performed hydrilla treatments in Lakes Conine and Rochelle in 2017. These treatments likely contributed to the reductions seen here. Alternatively, data indicates that Lakes Fannie and Haines are due for hydrilla treatment.

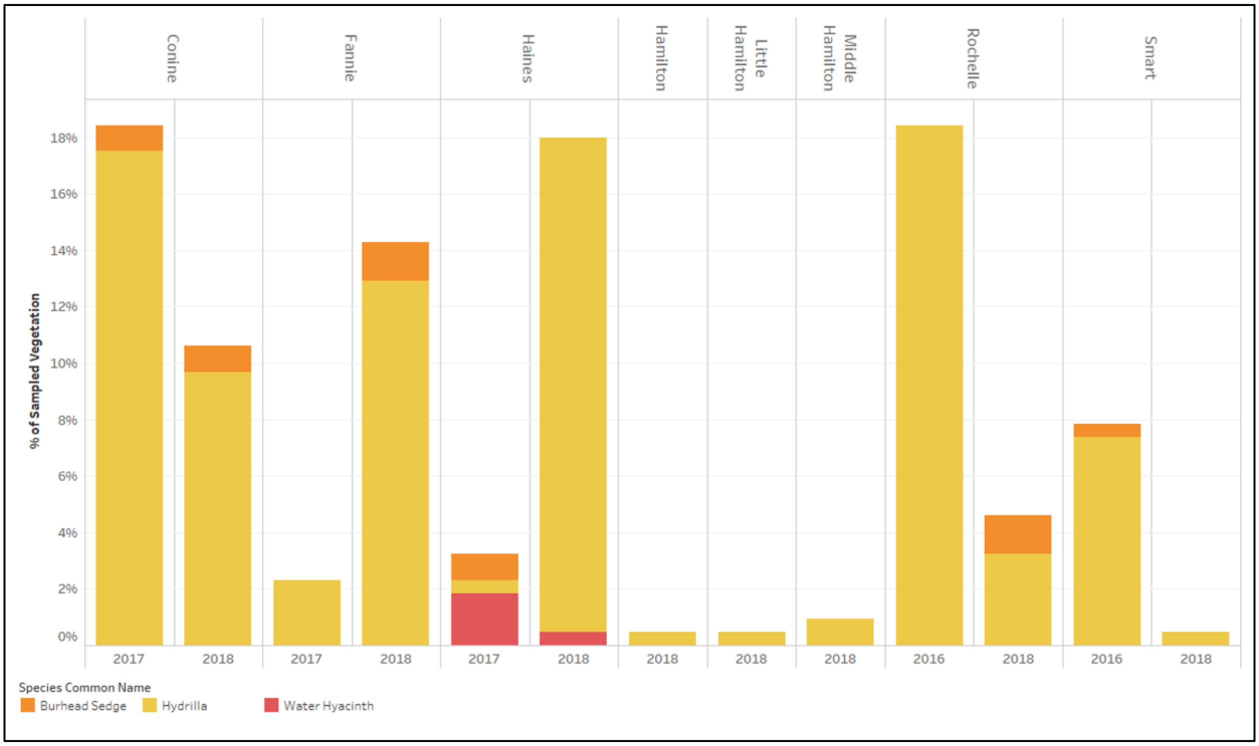


Figure 2-7. North Chain of Lakes annual percentage of managed invasive species.

Changes in species diversity contribute the final vegetative health indicator of these waterbodies. Observation of an increase or decrease in each of the three index values constitutes an improvement or deterioration respectively. It must be stressed that these index values are dependent on site-specific sampling effort—as such, these values are not be used to compare one lake to another. Graphical representation of these index values can be found in Figure 2-8. Of the NCoL, Lakes Conine, Fannie, and Rochelle experienced an overall increase in all three diversity indices in 2018.

Menhenick's Richness (R2): Comparison of 2018 data with each lake's previous survey year, Lakes Conine, Fannie, Rochelle, and Smart experienced an increase in species richness. Lake Haines exhibited a decrease in the number of unique species sampled. Due to a lack of multiple survey year data, the Hamilton lakes were not able to be assessed this year. As a result, these diversity criteria will be evaluated as not improving until such a time that adequate data can be collected to indicate otherwise.

Hill's Evenness #3 (E3): Lakes Conine, Fannie, Haines and Rochelle showed some amount of increase in species evenness between 2018 and their respective previous survey year. Lake Smart experienced a decrease in evenness between 2016 and 2018. Again, since the Hamilton lakes lack multiple years of data, they are evaluated as not improving.

Shannon's Diversity (H): As a combination of species richness and evenness, Shannon's index indicates the overall species diversity for each site. Lakes Conine, Fannie, and Rochelle exhibited an increase in diversity, while Haines and Smart experienced some decline between the initial survey and subsequent sampling in 2018. The Hamilton lakes will, once again, receive a not improving evaluation for species diversity due to a lack of data.

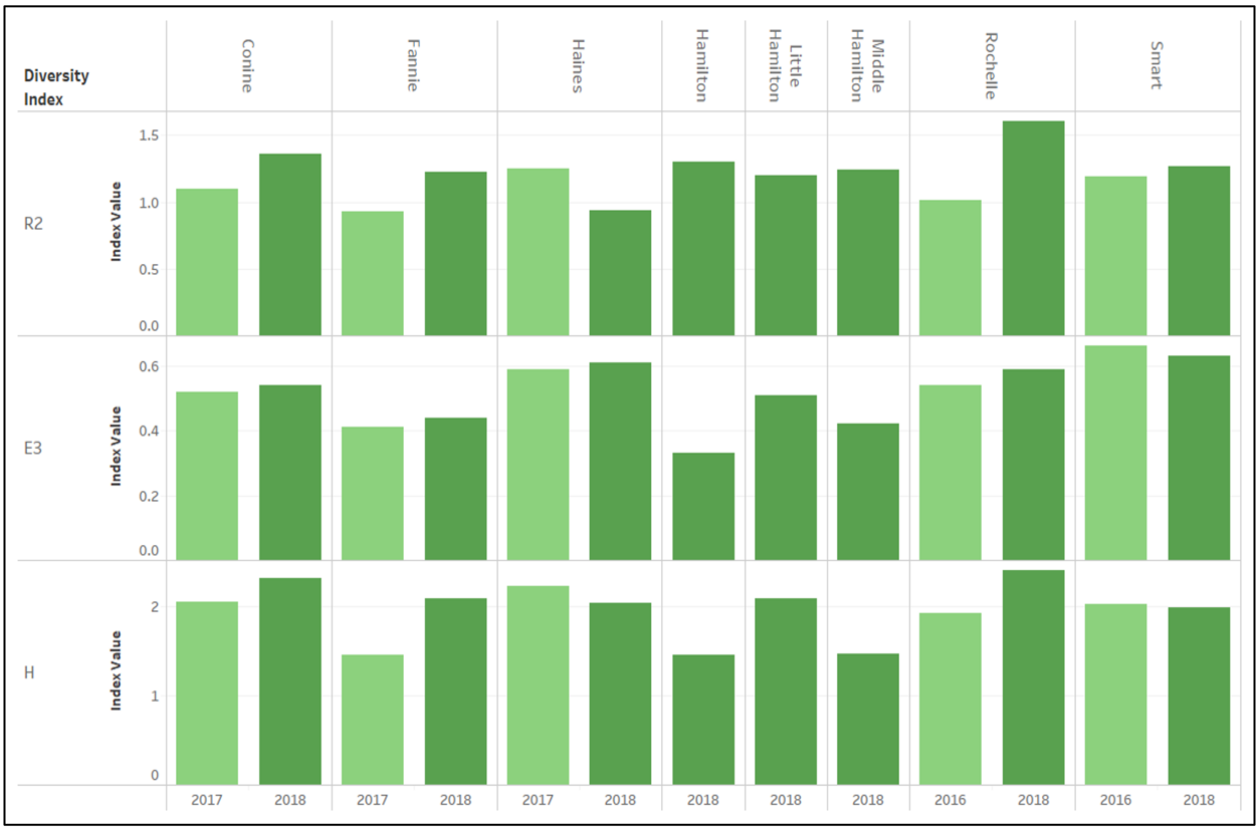
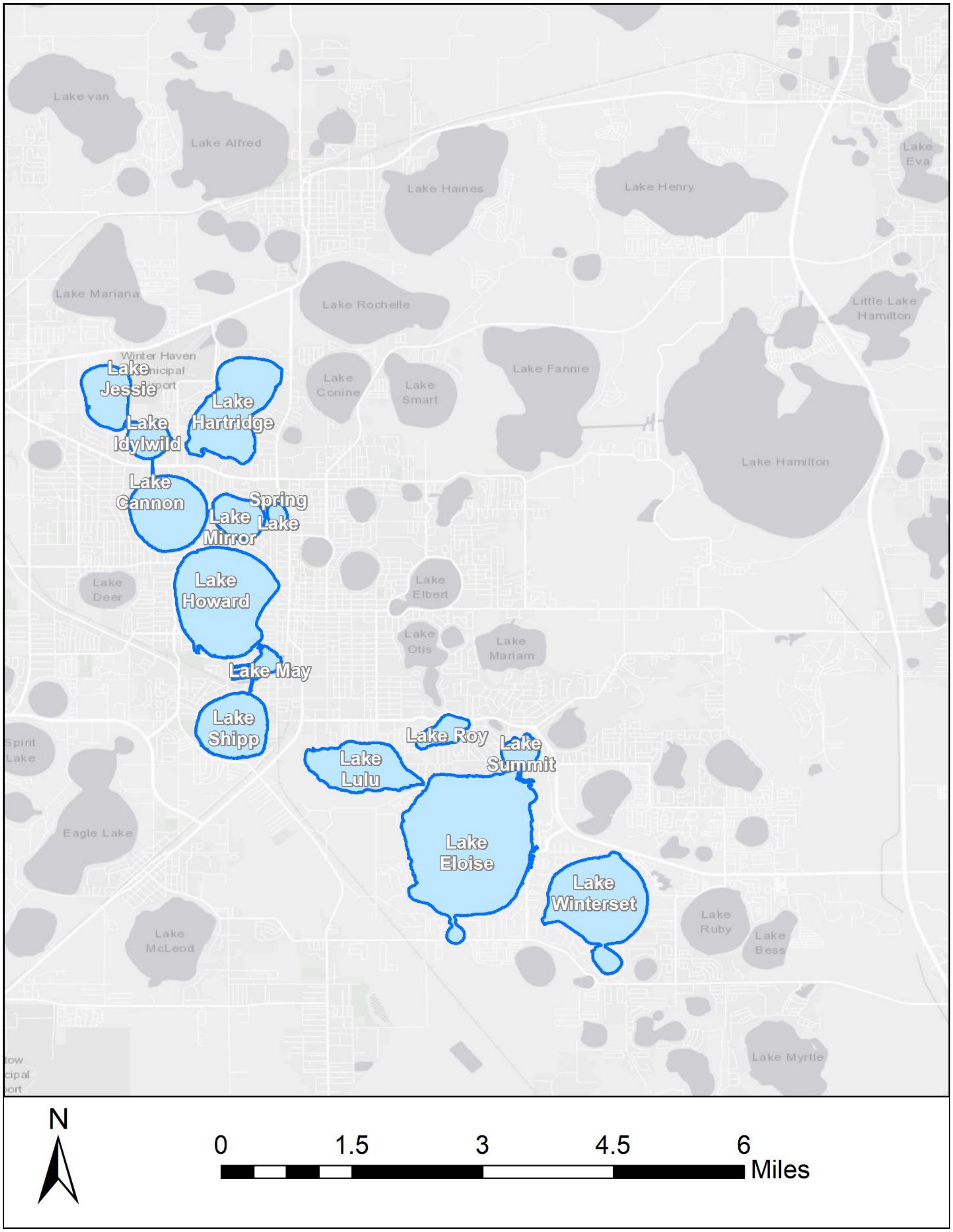


Figure 2-8. North Chain of Lakes annual index values for species richness, evenness, and diversity.

2.2 South Chain of Lakes



The Winter Haven South Chain of Lakes (SCoL) is made up of 14 waterbodies: Lakes Cannon, Eloise, Hartridge, Howard, Idylwild, Jessie, Lulu, May, Mirror, Roy, Shipp, Summit, Winterset, and Spring. The major surface water and MS4 contributors to the SCoL include the City of Winter Haven, FDOT and Polk County. In addition, Lakes Eloise, Howard, Jessie, Lulu, May, and Shipp have all received historic wastewater discharges from multiple sources including the City of Winter Haven and various commercial and industrial processing facilities [20].

Water Quality

Water quality impairment is one of the primary lake health indicators that is also monitored closely by the FDEP. Through assessment of the long-term geometric mean true color and total alkalinity of the SCoL, it was determined that all 14 waterbodies fall into the low color, high alkalinity category and are subject to the NNC thresholds established for that group. Impairment status was determined through analysis of the annual geometric mean (AGM) Chla, TN, and TP concentrations between 2010 and 2018 displayed in Tables 4-1 through 4-3 in the Appendix.

Impairment

Chlorophyll-a: The following waterbodies were determined to be impaired for Chla based on NNC exceedances during the assessment period: Lakes Cannon, Eloise, Hartridge, Howard, Idylwild, Jessie, Lulu, May, and Shipp.

Total Nitrogen: Lakes Cannon, Eloise, Hartridge, Howard, Idylwild, Jessie, Lulu, May, and Shipp experienced more than one consecutive TN exceedance from 2010 to 2018 and were determined to be impaired.

Total Phosphorus: Multiple consecutive exceedances during the assessment period established Lakes Cannon, Eloise, Hartridge, Jessie, Lulu, May, and Shipp as impaired for TP. It should be noted that if current trends continue, Lake Cannon should drop off the impaired list in 2019.

Represented in Figure 2-9 are the 2018 AGM Chla, TN, TP, and Secchi depth values for the SCoL as well as the long-term mean and normal range (+/- 1 standard deviation) calculated based on data from 2000 to 2018. This data represents a snapshot of the most recent annual data. Note that the current concentrations of Chla, TN, and TP are at or below average levels and Secchi depths at or above average levels for the majority of lakes in this group. Lake Hartridge is experiencing slightly above average Chla and TN concentrations as well as below average clarity—yet still within their respective normal ranges.

In order to determine if monotonic (directional) trends in water quality are occurring, AGM Chla, TN, TP, and Secchi depth were plotted against time in years. The resulting regression analyses show direction (+/-), magnitude (R^2), and statistical significance (p-value ≤ 0.05) of each lake's water quality trends. While the magnitude of these linear relationships is useful to determine the strength of these trends, only direction and significance are used in the lake health evaluation. The regression trendlines are displayed in Figure 2-10, while the statistics can be found in Table 4-4 in the Appendix.

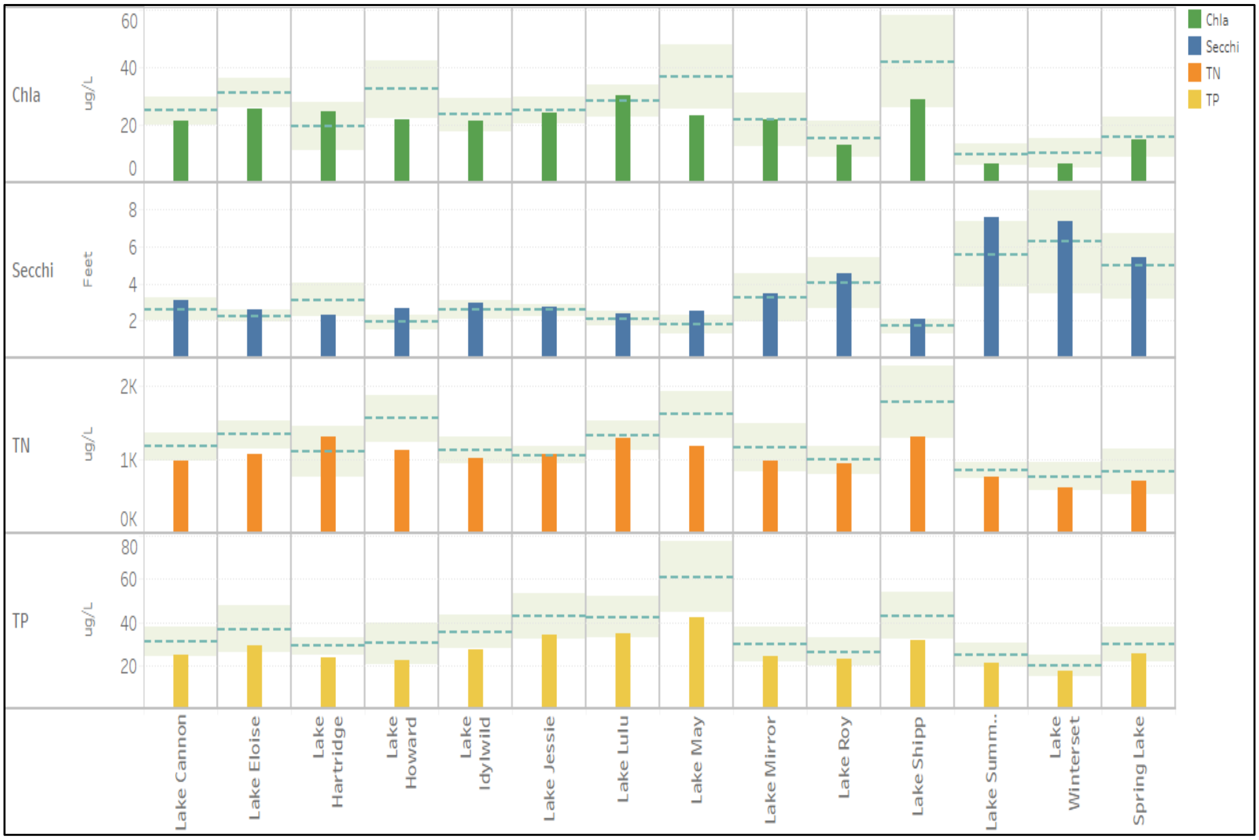


Figure 2-9. 2018 AGM Chla, TN, TP, & Secchi depth values for the South Chain of Lakes; dotted lines represent long-term mean and the shaded areas refer to the standard deviation range.

Chlorophyll-a Trends: Of the 14 SCoL waterbodies, Lakes Howard, Lulu, May, Mirror, Roy, Shipp, Summit, Winterset and Spring exhibit decreasing Chla trends from 2000 - 2018. Lake Hartridge is the only waterbody currently experiencing a significant increase in Chla. Lakes Cannon, Eloise, and Idylwild show non-significant decreasing trends while Lake Jessie exhibits a non-significant increasing relationship of Chla over time.

Total Nitrogen Trends: Lakes Cannon, Howard, May, Mirror, Roy, Shipp, Summit, Winterset, and Spring show significant decreasing TN trends with time. Again, Lake Hartridge is the only waterbody in this group experiencing a significant TN increase. Lakes Eloise and Lulu exhibit non-significant decreasing trends, while Lakes Idylwild and Jessie show non-significant increasing trends in AGM TN.

Total Phosphorus Trends: No SCoL waterbodies are currently experiencing increasing trends in TP. Significant decreasing TP trends are shown for Lakes Idylwild, Jessie, Lulu, May, Mirror, Shipp, Summit, Winterset, and Spring. Lakes Cannon, Eloise, Hartridge, Howard, and Roy are exhibiting non-significant downward trends.

Water Clarity Trends: With regards to Secchi depth, the following lakes are experiencing significant increasing trends: Lakes Cannon, Eloise, Howard, Lulu, May, Mirror, Roy, Shipp, Summit, Winterset, and Spring. Lake Hartridge AGMs are indicative of a significant downward trend in water clarity, while Lakes Idylwild and Jessie show non-significant increasing trends.

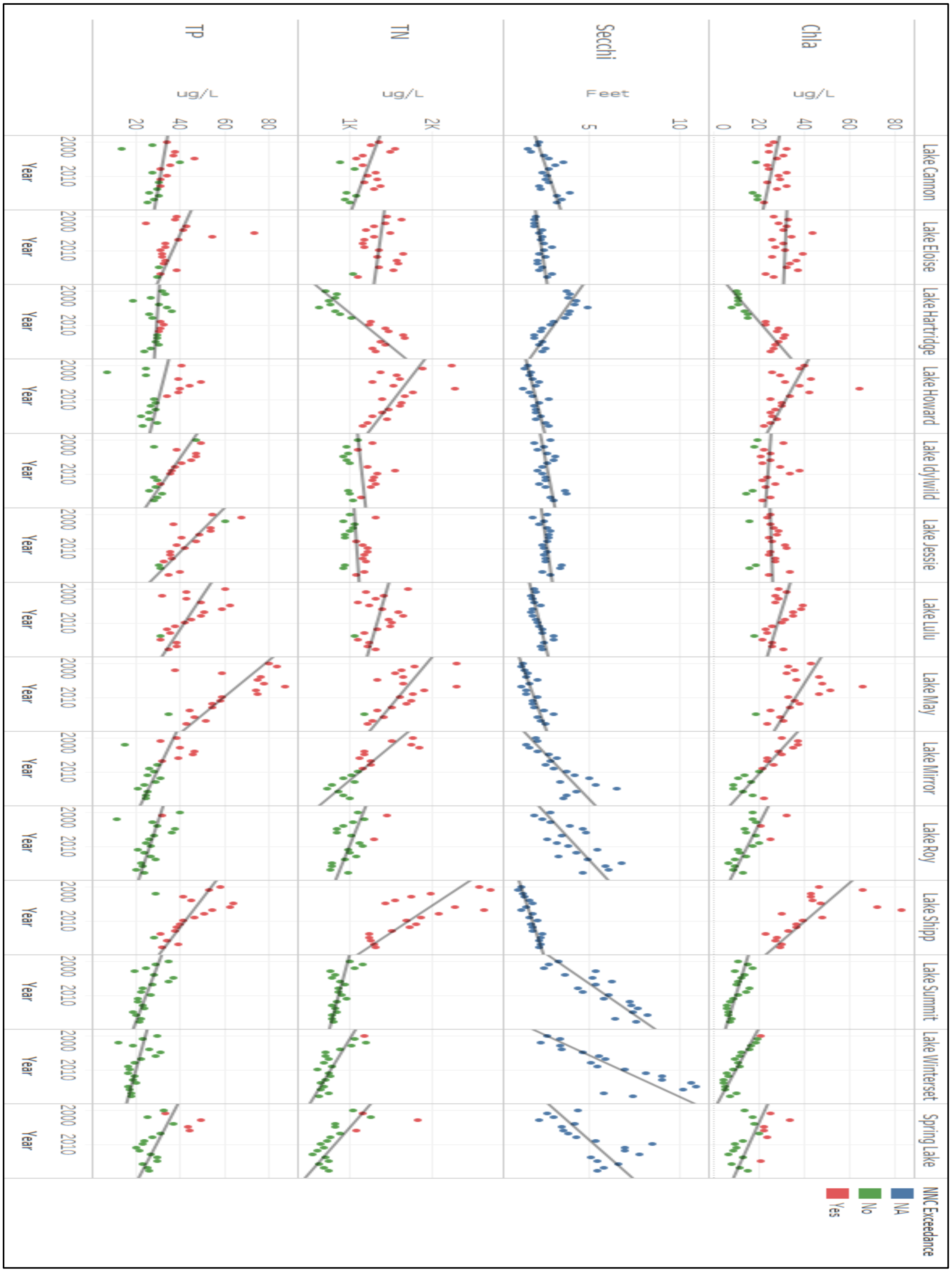


Figure 2-10. South Chain of Lakes regression trend graphs of AGM Chla, TN, TP, & Secchi depth from 2000 – 2018. Red dots represent exceedance of the NNC threshold for that year.

Hydrology

The South Chain of Lakes are connected via a series of navigable canals. As a result, individual surface levels are held at roughly the same elevation. Figure 2-11 is a hydrograph of the SCoL which incorporates monthly surface level (SL) readings between 2000 and 2018, annual rainfall totals as well as a box and whisker plot showing the variability in surface levels over this group's period of record. Based on this plot, it can be inferred that the SCoL level generally tracks with rainfall. The Winter Haven area receives roughly 52 inches per year on average. During years with below average precipitation, SL will drop below the long-term mean (130.5 ft), with the opposite occurring during periods of above average rainfall. The period from 2006 – 2013 was especially dry for the area and led to consistently lower SLs. In recent years, normal rainfall patterns returned and allowed for hydrologic recovery. From 2016 to the present, the SCoL has returned to a normal variation cycle of seasonal highs and lows.

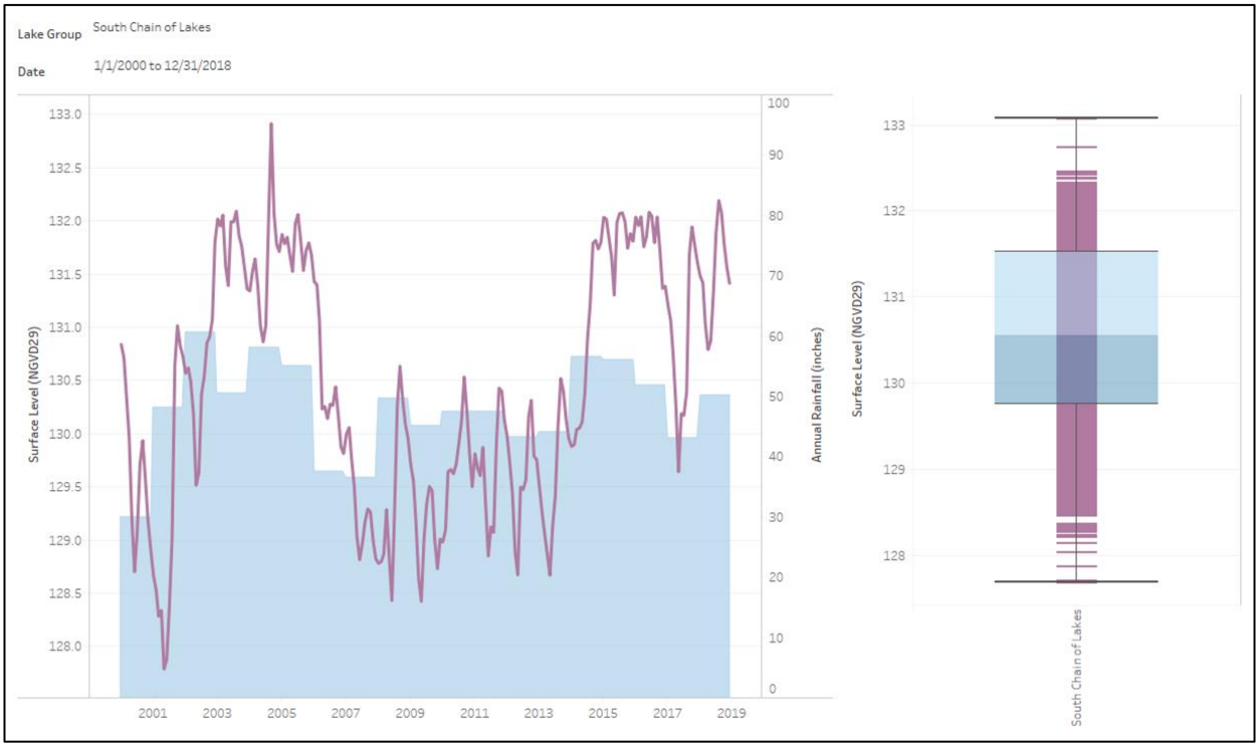


Figure 2-11. South Chain of Lakes hydrograph with box & whisker plots detailing long-term surface level variability. Annual rainfall totals indicate hydrologic response to precipitation.

In order to determine the impacts of surface level on water quality, linear regressions were performed for each waterbody in the Southern Chain. AGM Chla, TN, TP, and Secchi depth were plotted against annual mean surface level from 2000 – 2018. The resulting regression statistics can be found in Table 4-5 in the Appendix. As with the water quality trends over time, a confidence level of 95% (p-value ≤ 0.05) was used to indicate a statistically significant relationship.

SL vs. Chla: Of the 14 waterbodies in the SCoL, only Lakes Idylwild, May, and Roy exhibit any significant relationship between Chla and surface level. In each case, the correlation was inverse—indicating that as SL increases, Chla should decrease.

SL vs. TN: Lakes Howard, Idylwild, Jessie, Lulu, May, Roy, Shipp, and Summit show significant inverse correlation between TN and SL. All other lakes within this group exhibit a non-significant response.

SL vs. TP: Lake May is the only waterbody in this group with a significant (inverse) relationship between TP and SL. Most of the Southern Chain exhibit non-significant relationships.

Clarity vs. SL: Data for Lakes Idylwild, Jessie, May, Roy, and Shipp indicate significant direct relationships between Secchi depth and surface level. Lake Spring strangely possesses a non-significant inverse correlation, while the rest of the lake group exhibit non-significant direct regressions.

Each lake's hydrologic characteristics may provide additional information to support the relationships explained above as well as be useful in determining the most effective management strategies. Drainage basin soil classification and aggregated land use information (by lake group) can be found in Tables 4-6 & 4-7 in the Appendix. Table 2-2 presents land use proportions for each waterbody within the SCoL group.

Land Use

	Waterbody													
Land Use	Lake Cannon	Lake Eloise	Lake Hartridge	Lake Howard	Lake Idylwild	Lake Jessie	Lake Lulu	Lake May	Lake Mirror	Lake Roy	Lake Shipp	Lake Spring	Lake Summit	Lake Winterset
AGRICULTURE	0.73	5.59	3.99		5.14	9.42	3.82			4.17	9.46			0.90
COMMERCIAL	2.93		5.59	12.67	19.56	13.87	12.57	37.65	5.97	16.04	7.45	45.86		1.34
COMMUNICATION	0.25	0.37	9.25	0.62	5.20	17.83	2.56	2.37		4.36	2.02	6.75	1.94	1.31
INDUSTRIAL	0.97			0.00		0.37	4.56	17.25			5.45			
INSTITUTIONAL	5.51	0.13	2.35	2.24	3.35	0.88	0.79	4.24	0.01	5.11	1.85	6.77		0.36
OPEN LAND	0.05	0.42		0.51	2.35	2.00	2.84	4.85	3.66		0.89	2.41		2.63
RANGELAND		3.21		0.39		0.54		2.38						
RECREATIONAL	1.02	6.74		1.22	0.01		6.15				2.98	1.00	9.52	
RESIDENTIAL	54.92	27.78	29.71	40.30	36.07	32.02	17.17	19.50	44.39	50.89	33.79	14.32	50.91	34.90
UPLAND FOREST	1.58	0.06	0.71	3.86		1.64	1.11	0.85			2.22			2.32
WATER	31.03	53.78	46.92	35.52	25.88	18.97	25.02	6.40	42.79	18.31	29.67	20.10	36.06	53.70
WETLANDS	1.02	1.92	1.49	2.68	2.43	2.45	23.41	4.51	3.18	1.11	4.21	2.79	1.57	2.55

Table 2-2. South Chain of Lakes land use percentage found within each lake drainage basin.

In the SCoL drainage basins, the dominant soil classes are either A or A/D. Lakes Eloise, May, Mirror, Roy, Spring, and Summit possess A dominant soils, while Lakes Idylwild, Jessie, and Shipp are made up of predominantly A/D soils. The rest within this group have a fairly even mix. There are also small pockets of less well-drained soils, but these are few and far between. Of note are relatively large areas within the Lake Howard and May drainage basins that remain unclassified due to the high proportion of impervious surfaces. Extrapolating the dominant soil type of the surrounding downtown area, it stands to reason that a majority of class A soils underlay the unclassified sections of these two drainage basins. The greater proportion of well-drained soils in this lake group should drive stormwater infiltration via green infrastructure and low-impact developments as priority strategies where appropriate.

Land uses in the SCoL area vary significantly from lake to lake, however the predominant classes are generally residential and commercial—indicating more urban drainage basins compared with the Northern Chain. By virtue of this, stormwater influence is generally greater for the majority of waterbodies within this lake group. As a result, reduction of external nutrient loading has been and will continue to be a priority management strategy for this group as a whole. In addition, special consideration for internal loading via historic wastewater discharges in Lakes Eloise, Howard, Jessie, Lulu, May, and Shipp should be noted as part of any subsequent management plan. Lake Lulu's drainage basin possesses a relatively large proportion of wetland area located along the lake's southern shoreline. Contrary to expectations, Lake Lulu doesn't appear to exhibit very strong relationships between SL and water quality—indicating that wetland connectivity is likely not the primary contributor to changes in Chla, TN, and TP.

The morphology of the South Chain of Lakes is the most varied out of any other lake group which is unsurprising due to the large number of waterbodies. Surface area ranges from 32 acres to 1520 acres, with maximum depths between 6 and 31 feet. Figures 2-12 and 2-13 illustrate the morphology of the SCoL in the form of hypsographic curves. The shallower waterbodies include Lakes Idylwild, Jessie, Lulu, May, and Shipp while the remainder of the lakes in this group have areas that are greater than 5 meters in depth. The deepest in this group, Lakes Roy, Summit, Winterset and Spring, are of particular interest as they potentially experience comparatively greater groundwater influence. This may be a factor contributing to generally better water quality relative to the other lakes in this group. Lake depth can also contribute to sediment suspension potential which is evident when comparing average Secchi depths of the deep versus shallow lakes.

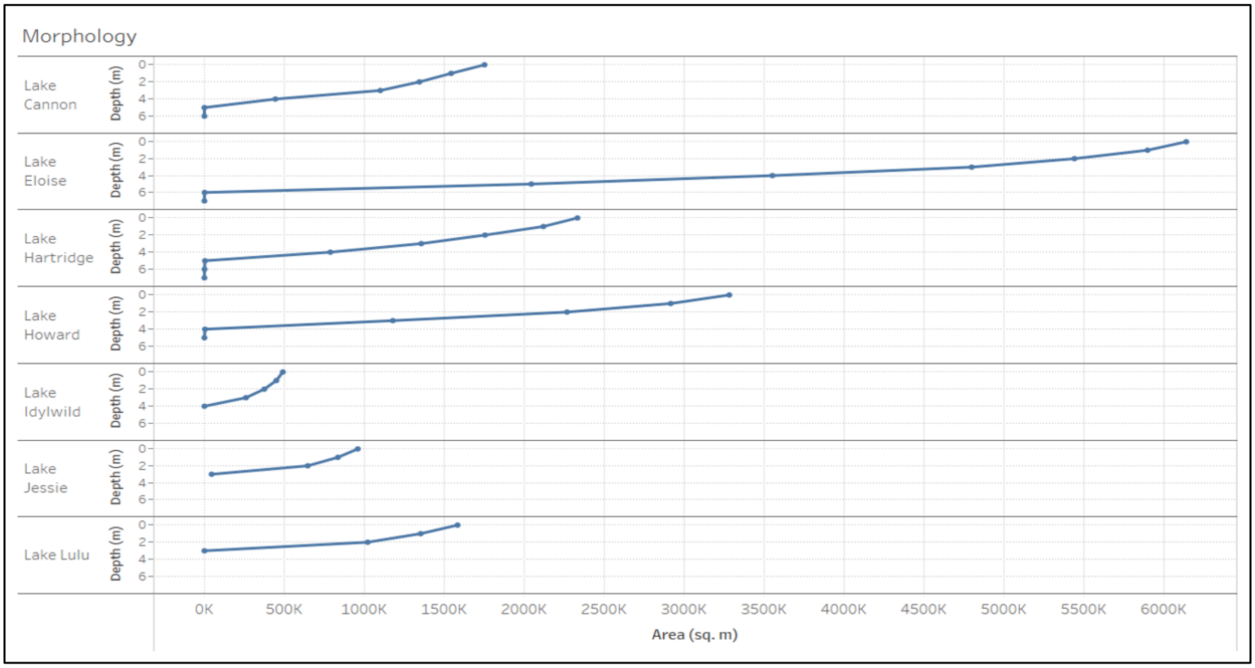


Figure 2-12. South Chain of Lakes (Group 1) hypsographs depicting cumulative area in descending 1 meter intervals.

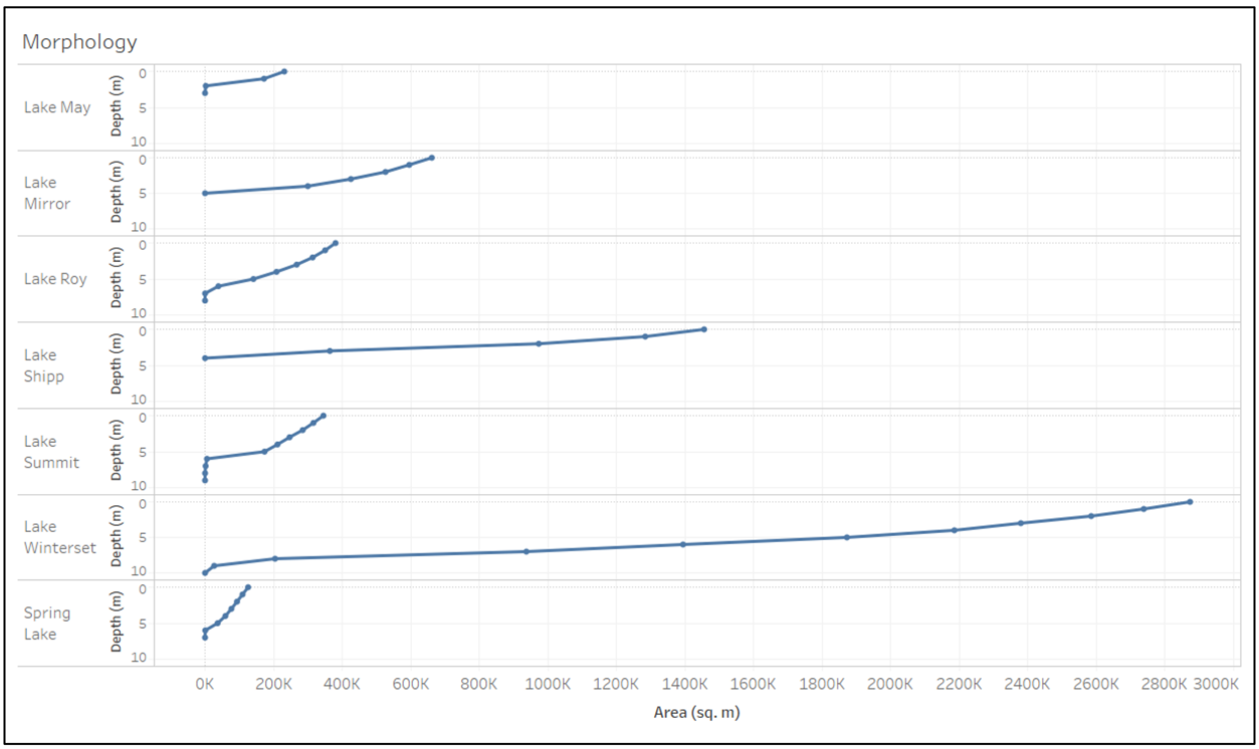


Figure 2-13. South Chain of Lakes (Group 2) hypsographs depicting cumulative area in descending 1 meter intervals.

Ecology

As a major component of the lake health evaluation process, aquatic vegetation abundance and diversity data have been collected for the South Chain of Lakes. Vegetation surveys were initially performed in 2016 on Lakes Lulu, Mirror, Spring, Summit, and Winterset. In 2017 data were collected from Lakes Cannon, Eloise, Hartridge, Howard, Idylwild, Jessie, May, Roy, and Shipp while 2018 marks the first year that vegetation surveys were performed on all lakes within the study area. As a result, data representing multiple years is available for analysis of the SCoL.

Understanding the distribution of emergent (EAV), submerged (SAV), and floating (FV) plants can help to answer questions that relate water quality and hydrology to the biological components of these waterbodies. Figure 2-14 illustrates the proportion of each vegetation type in the SCoL. Collectively, the Southern Chain possesses a good mix of emergent and submerged vegetation. According to 2018 data, the dominant EAV species for the SCoL as a whole are duck potato (*Sagittaria lancifolia*) and Kissimmee grass (*Paspalidium geminatum*)—both of which are excellent Florida natives. The most abundant SAV species throughout the chain is eel grass (*Vallisneria americana).* Lakes Roy, Summit, and Winterset are SAV dominant, while emergent species make up the greatest proportion of the other lakes in this group. Comparing these SAV proportions to recent Secchi depths shows some relationship as Lake Roy, Summit, and Winterset also have some of the best water clarity in the chain. As stated previously, SAV contributes to substrate stabilization as well as increased nutrient absorption from the water column.

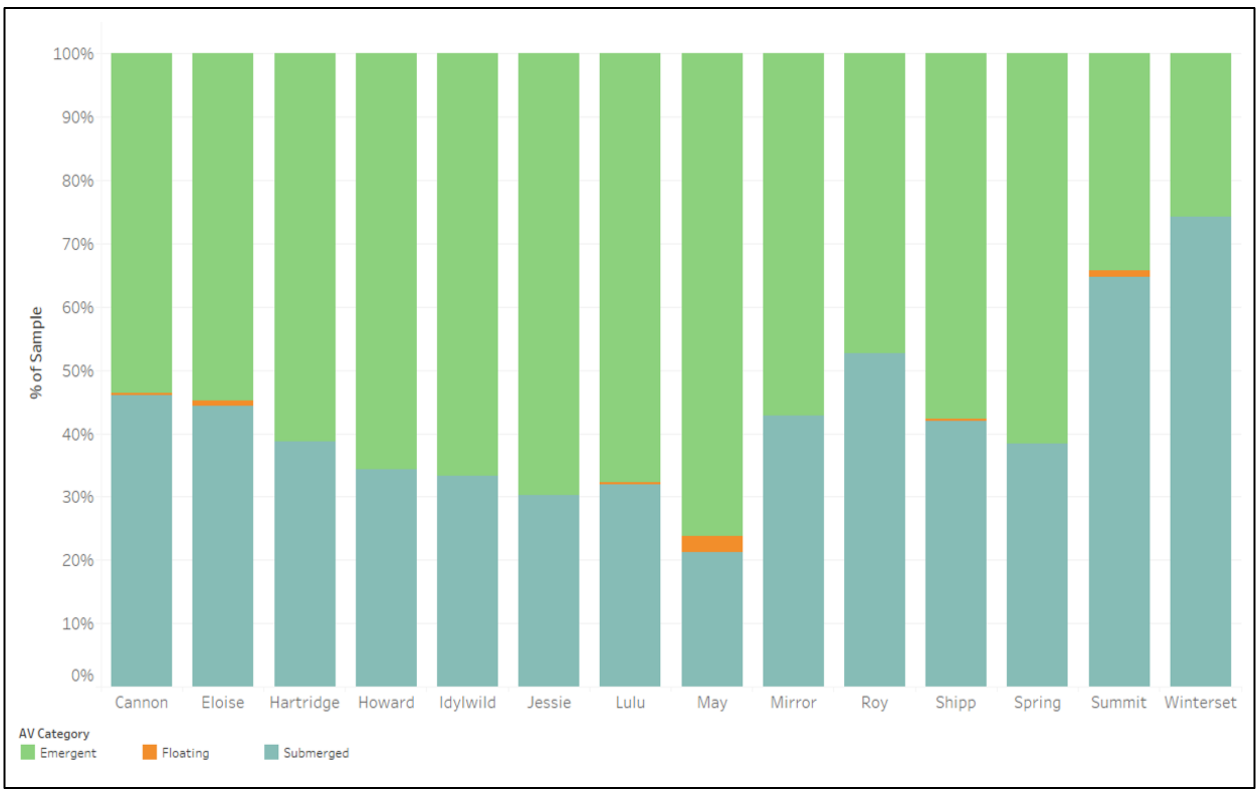


Figure 2-14. South Chain of Lakes categorical proportion of aquatic vegetation as emergent, submerged, or floating.

With regards to vegetation abundance in the littoral zone, measurements of percent area cover (PAC) and mean percent biovolume (% BV) are exceptional for the SCoL (Figure 2-15). In 2018, every Southern Chain waterbody exceeded the 15% PAC target except for Lake Eloise. The vast majority possessed >30% PAC which is considered optimal for fish habitat. Average biovolume numbers were also relatively high in 2018, with aquatic plants taking up greater than 10% of lake volume in the majority of waterbodies. Comparing each lake's previous survey year to 2018, ten waterbodies exhibited an increase in PAC. Observations of mean % BV change were less impressive, with the majority of lakes experiencing a decrease from the previous year. However, this change may be related to seasonal fluctuations that should be rectified in subsequent assessments by scheduling surveys during similar times each year.

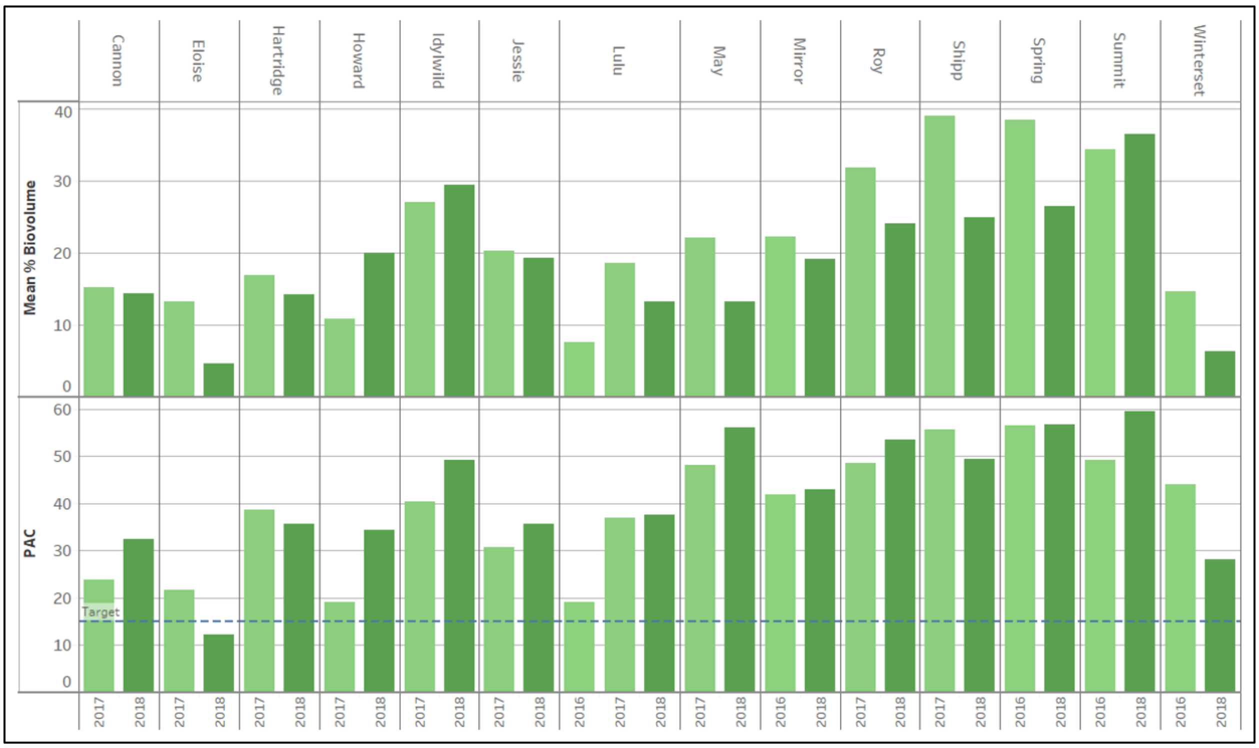


Figure 2-15. South Chain of Lakes annual aquatic vegetation percent area coverage and mean percent biovolume.

With regards to invasive species, the South Chain of Lakes has experienced the success of a well-managed invasive treatment program. Figure 2-16 illustrates the annual percentages of managed invasives in this lake group. The primary species that are treated regularly in the Southern Chain include hydrilla (*Hydrilla verticillata*), burhead sedge (*Oxycaryum cubense*), and water hyacinths (*Eichhornia crassipes*). According to 2018 survey data, Lakes Cannon, Eloise, Howard, Idylwild, Jessie, Lulu, Mirror, Shipp, Summit, and Winterset appear to be in a maintained state with invasive species present in very low proportions (<2.5%). While Lakes May, Roy, and Spring possess comparatively greater numbers of invasives, they are still within proportions that would be considered marginally controlled. Recent hydrilla reductions in Lakes Eloise and Winterset are indicative of substantially successful invasive treatment. In 2017, no highly managed invasive species were observed in Lake Howard which is why previous year data is not displayed. This does not mean that invasives were eradicated during that period, just that species of concern were not present in sampling areas. Based on this data, treatment should be prioritized for Lakes May, Roy, and Spring in the future.

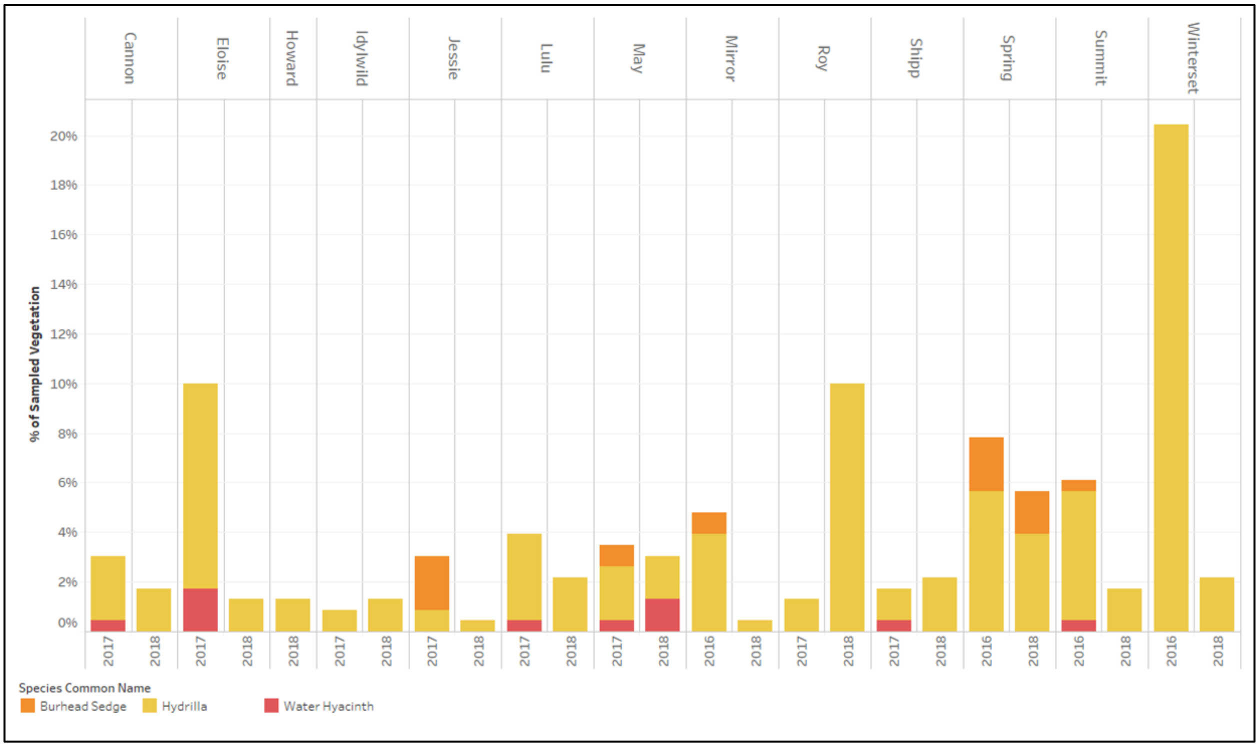


Figure 2-16. South Chain of Lakes annual percentage of managed invasive species.

Species diversity index values for the South Chain of Lakes were calculated using at least two years of survey data. Species richness, evenness, and uncertainty index values constitute the overall species diversity for the SCoL (Figure 2-17). An increase or decrease in each index value from the previous year contribute to this lake health criterion score. Only Lake Winterset showed an overall increase in all three diversity indices in 2018; Lakes Jessie, May, and Mirror experienced a general decline in all three metrics.

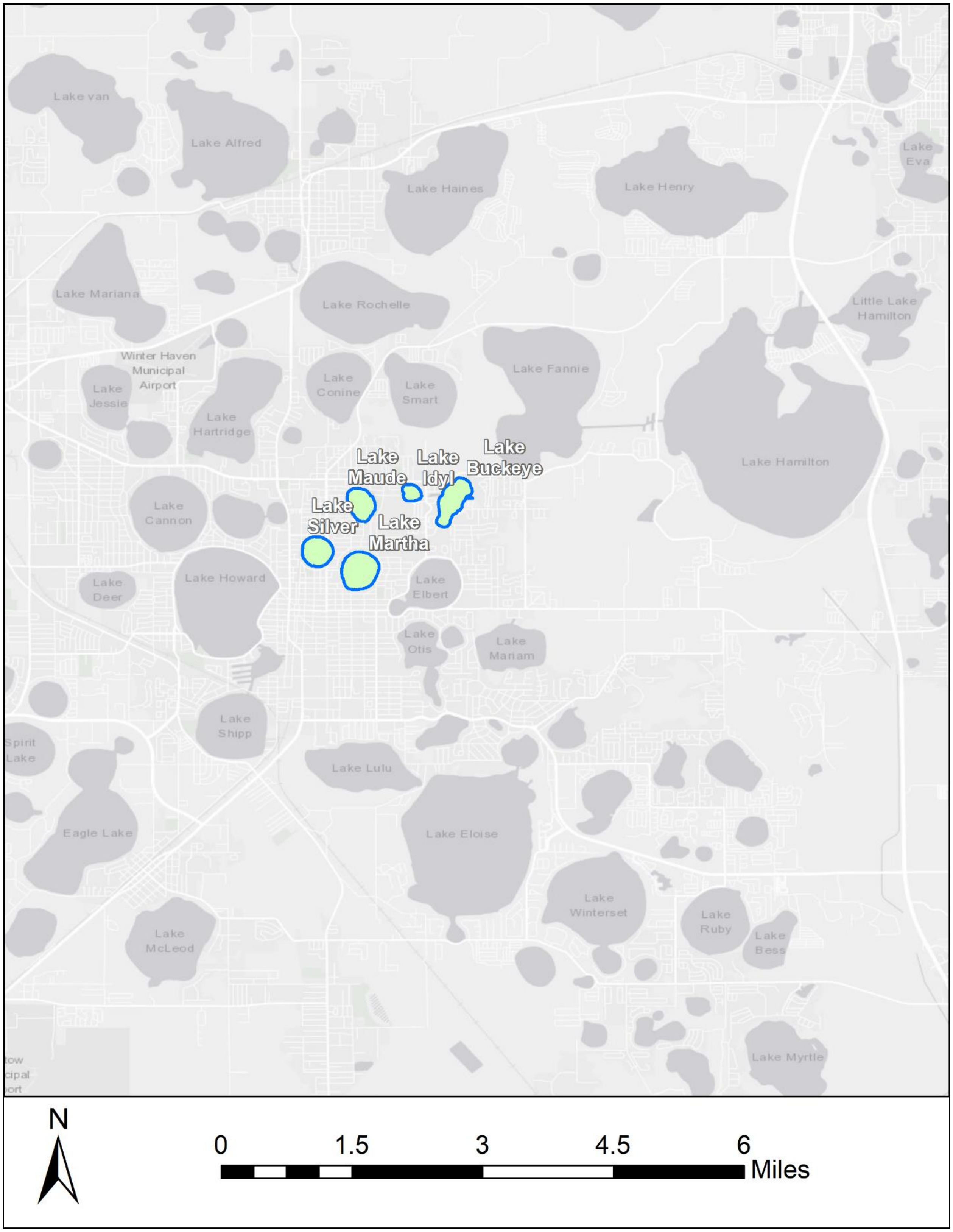
Menhenick's Richness (R2): The following waterbodies experienced an increase or no change (in the case of Lake Summit) in species richness in 2018 from the previous survey year: Lakes Cannon, Howard, Lulu, Roy, Shipp, Summit, and Winterset. Lakes Eloise, Hartridge, Idylwild, Jessie, May, Mirror, and Spring exhibited a decrease in richness over the same period.

Hill's Evenness #3 (E3): An equally diverse population generally constitutes a healthier community of plants. Lakes Eloise, Idylwild, Spring, and Winterset underwent an increase in species evenness in 2018, while Lakes Cannon, Hartridge, Howard, Jessie, Lulu, May, Mirror, Roy, Shipp, and Summit, exhibited declines in E3 values.

Shannon's Diversity (H): Of the 14 waterbodies in the SCoL, Lakes Cannon, Hartridge, Howard, Roy, Spring, and Winterset experienced an increase in overall diversity. Alternatively, Lakes Eloise, Idylwild, Jessie, Lulu, May, Mirror, Shipp, and Summit, showed a decrease in Shannon's index.

Figure 2-17. South Chain of Lakes annual index values for species richness, evenness, and diversity.

2.3 North Central Lakes



The Winter Haven North Central Lakes (NCL) are a group of waterbodies connected by overflow conveyances and can contribute surface water to the North Chain of Lakes via Lake Fannie. The group of five lakes include Lakes Buckeye, Idyl, Martha, Maude, and Silver. The major surface water and MS4 contributors to the NCL are the City of Winter Haven, the FDOT, and Polk County.

Water Quality

Determination of water quality impairment is one of the ways that environmental agencies such as the FDEP can monitor general improvement of lake health. As such it is one of the most important indicators that the City keeps track of. Using long-term geometric mean true color and total alkalinity values, all five lakes in the NCL were determined to fall in the low color, high alkalinity category and are subject to the appropriate NNC thresholds for this classification. Impairment status was determined through analysis of the annual geometric mean (AGM) Chla, TN, and TP concentrations between 2010 and 2018 displayed in Tables 4-1 through 4-3 in the Appendix. Within this lake group, Lake Idyl is the only waterbody exhibiting impairments, however, it was determined to be impaired for Chla, TN, and TP due to multiple consecutive exceedances in the last two years.

A comparison of 2018 AGM Chla, TN, TP, and Secchi depth values with each lake's long-term average and normal range (+/- 1 standard deviation) are presented in Figure 2-18. These long-term values are based on data between 2000 and 2018. Based on this comparison, it can be observed that Lakes Buckeye, Maude, and Silver are currently experiencing above average clarity and below average Chla, TN, and TP concentrations. Alternatively, Lakes Idyl and Martha are both experiencing poorer water quality with below average Secchi depths and extremely high Chla, TN, and TP levels.

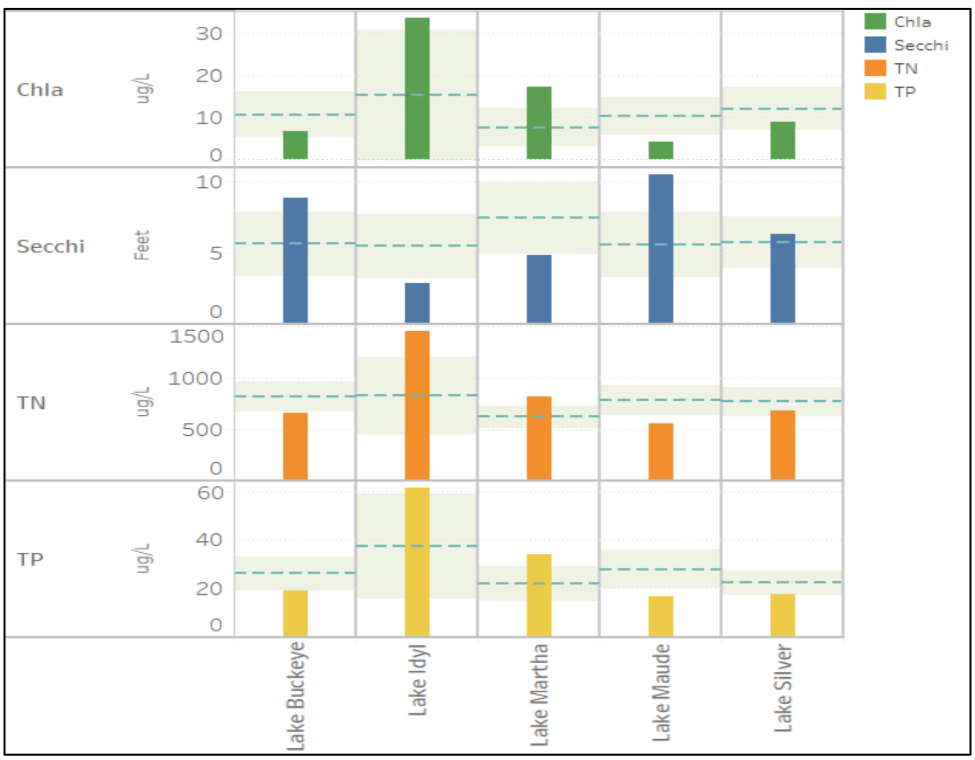


Figure 2-18. 2018 AGM Chla, TN, TP, & Secchi depth values for the North Central Lakes; dotted lines represent long-term mean and the shaded areas refer to the standard deviation range.

Evaluation of water quality trends is an important lake health indicator that can be utilized to indicate general improvement or deterioration. Trend analysis was performed by plotting AGM Chla, TN, TP, and Secchi depth values against time in years from 2000 - 2018. The resulting linear regression statistics were then used to determine trend direction (+/-) and significance (p-value ≤ 0.05). The linear regression trendlines are displayed in Figure 2-19, while the monotonic (directional) trend test statistics can be found in Table 4-4 in the Appendix.

Chlorophyll-a Trends: Waterbodies exhibiting significant decreasing trends in Chla include Lakes Buckeye and Maude. Trends for Lake Silver and Lake Idyl are non-significant decreasing and increasing respectively. Lake Martha is currently showing a significant increase in Chla over time.

Total Nitrogen Trends: Similar to Chla trends, Lakes Buckeye and Maude are experiencing significant decreasing trends in TN. Lake Martha is exhibiting a significant increasing regression over time. Lake Idyl shows a non-significant increasing trend, while Lake Silver has a non-significant decreasing trend.

Total Phosphorus Trends: With regards to TP, Lakes Buckeye and Martha are exhibiting significant trends—trend direction for Buckeye is decreasing while TP is increasing in Martha. Non-significant decreasing trends are exhibited by Lakes Maude and Silver. Lake Idyl is showing a non-significant increasing relationship with TP over time.

Clarity Trends: Lakes Buckeye and Maude are experiencing a significant increasing Secchi depth trend. Lake Martha is showing a significant decreasing clarity trend. Lake Idyl and Silver are experiencing non-significant increasing and decreasing Secchi depth trends respectively.

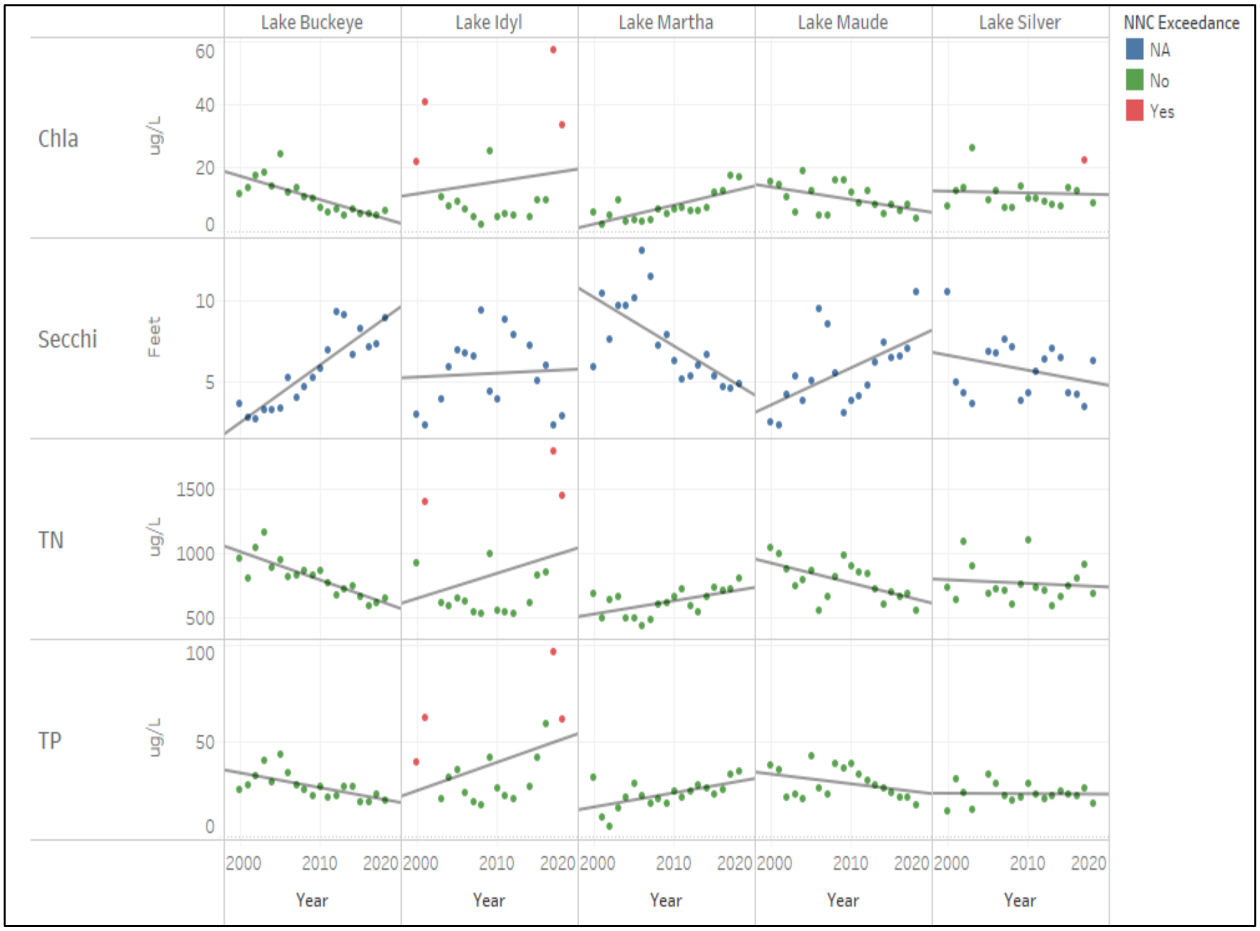


Figure 2-19. North Central Lakes regression trend graphs of AGM Chla, TN, TP, & Secchi depth from 2000 – 2018. Red dots represent exceedance of the NNC threshold for that year.

Hydrology

The North Central Lakes are linearly connected via a series of passive overflow structures. As a result, each lake undergoes separate surface level fluctuations without discharging or receiving flow except during extremely high levels. Figure 2-20 illustrates these fluctuations with a series of hydrographs depicting monthly lake levels as well as annual rainfall and box and whisker plots displaying the relative variability of each waterbody. Like with other lake groups, surface levels generally fluctuate with rainfall. That is, above-average rainfall will typically lead to a rise in lake levels and vice versa. One item to make note of is the relatively small variance in level observed in Lake Idyl. It may be that this lake is more of a flow-through system—meaning that water flow in and out are generally equal; leading to little change in lake level.

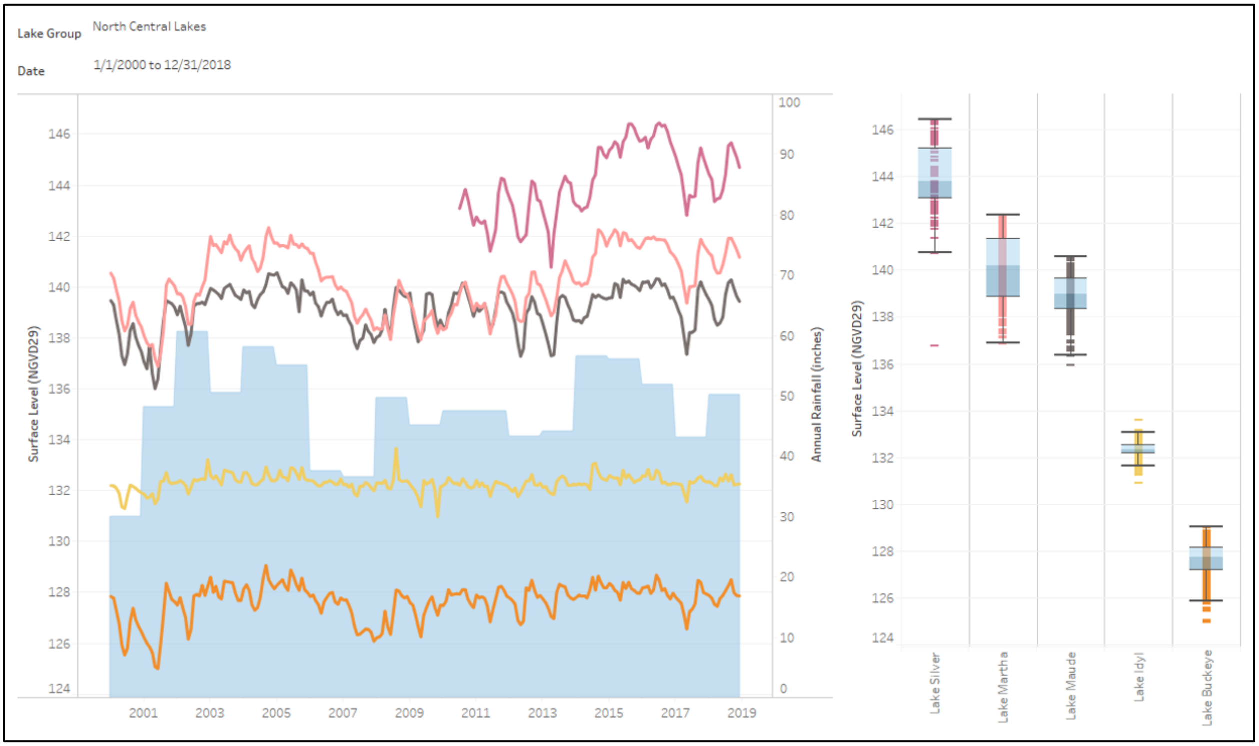


Figure 2-20. North Central Lakes hydrographs with box & whisker plots detailing long-term surface level variability. Annual rainfall totals indicate hydrologic response to precipitation.

In order to determine the impacts of surface level on water quality, linear regressions were performed for each waterbody in the North Central Lakes group. AGM Chla, TN, TP, and Secchi depth were plotted against annual mean surface level from 2000 – 2018. The resulting regression statistics can be found in Table 4-5 in the Appendix. As with the water quality trends over time, a confidence level of 95% (p-value ≤ 0.05) was used to indicate a statistically significant relationship. The results indicate very little relationship between water quality and surface level for this group. Lake Martha was the only waterbody that exhibited a significant relationship; the regression of Chla against surface level infers that only 21% of the variability in Chla can be accounted for by a change in lake level (R^2 = 0.21; p = 0.04).

In addition to surface level, there are other hydrologic qualities unique to each waterbody. Lake morphology and drainage basin characteristics such as soil makeup and land use proportion can provide valuable insight into how water, and by extension pollutants, make their way a particular lake. Drainage basin soil classification and aggregated land use information (by lake group) can be found in Tables 4-6 & 4-7 in the Appendix. Table 2-3 presents land use proportions for each waterbody within the NCL group.

The dominant soil class for the NCL is type A with a very small proportion of type A/D and almost no presence of less well-drained soils in each of the individual drainage basins. This equates to a strong potential for percolation—meaning that implementation of green infrastructure and low-impact developments are prime options to manage stormwater runoff for this lake group.

Land Use

Land Use	Waterbody: Lake Buckeye	Lake Idyl	Lake Martha	Lake Maude	Lake Silver
AGRICULTURE	8.58	26.04			
COMMERCIAL			3.36	9.66	43.97
COMMUNICATION		0.65	0.02	3.50	5.94
INDUSTRIAL				4.01	1.67
INSTITUTIONAL		16.23	35.40	8.29	10.74
OPEN LAND	0.05	4.02		7.36	
RANGELAND	0.00				
RECREATIONAL				1.57	2.60
RESIDENTIAL	60.68	35.18	34.10	52.64	3.50
UPLAND FOREST	0.01	8.13			
WATER	24.37	5.67	25.99	12.65	30.94
WETLANDS	6.30	4.07	1.12	0.32	0.65

Table 2-3. North Central Lakes land use percentage found within each lake drainage basin.

With regards to land use, the NCL is surrounded by majority urban categories (i.e. Commercial, Institutional, and Residential). Accompanying these urban land uses is a greater intensity of stormwater infrastructure directing runoff to the lakes. One outlier in this group is Lake Idyl which possesses a substantial percentage of agricultural land within its drainage basin. Coupled with the high soil infiltration rates in the area, it can be inferred that agricultural pollutant loads could enter Idyl via groundwater infiltration. However, since poor water quality has only recently been observed in Lake Idyl, it is unlikely that this is the primary driver of eutrophication in this waterbody. Nonetheless, management strategies that reduce direct stormwater discharge to the lakes should be a priority in these areas.

The five waterbodies of the NCL group can generally be described as small from a morphological perspective. Surface areas range from 24 to 106 acres—collectively the smallest of the various lake groups. Below the surface, these lakes really showcase how unique each waterbody is. Maximum depths range from 10 feet in Lake Idyl to over 33 feet in Lake Silver, which makes Silver the deepest lake in the study area. Hypsographic curves, displaying each lake's depth profile, can be found in Figure 2-21. Based on its depth characteristics, it is likely that Lake Silver experiences substantial groundwater influence—receiving water during periods when aquifer levels are high and contributing water when they are low. Aside from a few deep holes in Lake Buckeye, the rest of this group is relatively shallow. Relative to each lake's surface area, it would be expected for the littoral zones to be fairly large in these shallower waterbodies. Despite possessing the habitat area for vegetation, plant growth is effectively determined by a multitude of factors such as water clarity and sediment type. The biological characteristics of the NCL will be examined in the next section.

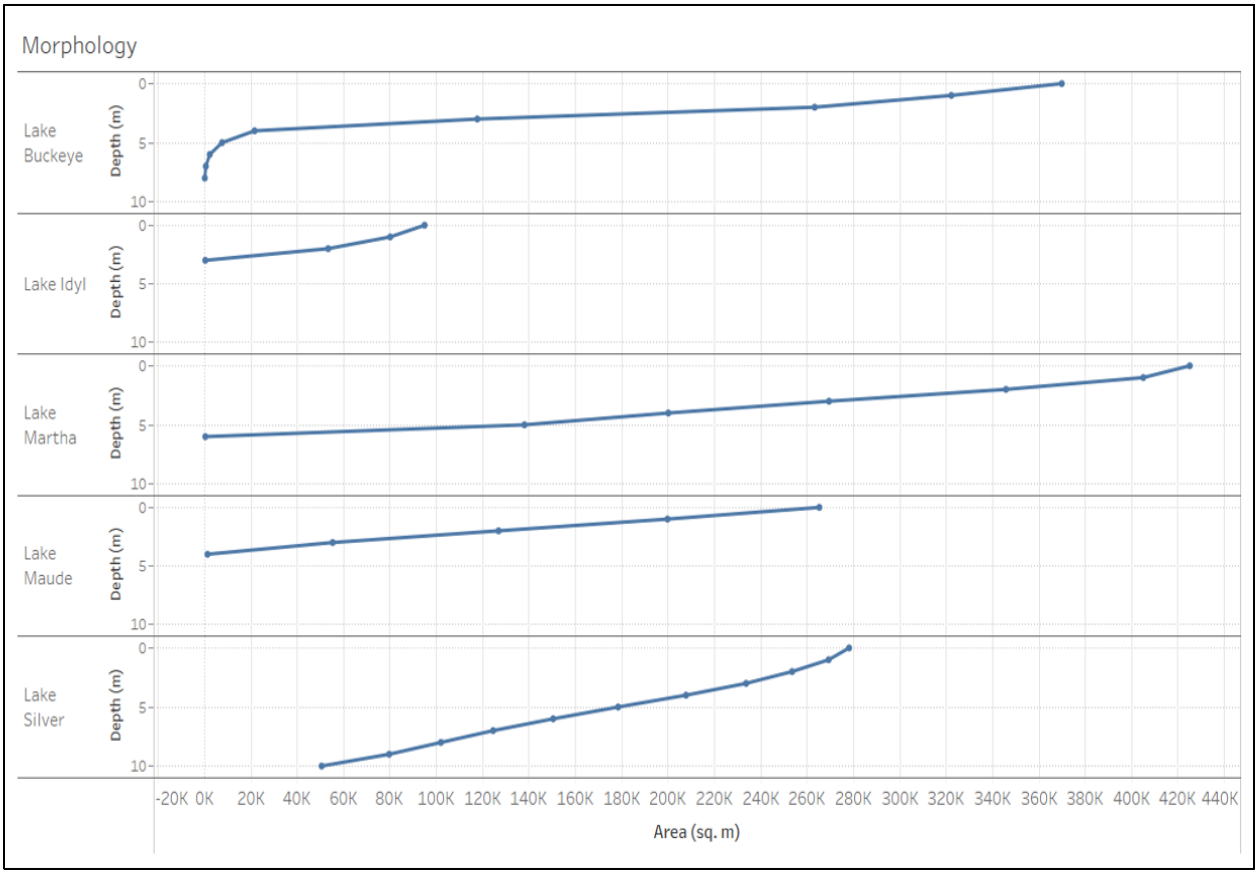


Figure 2-21. North Central Lakes hypsographs depicting cumulative area in descending 1 meter intervals.

Ecology

As part of the City's vegetation monitoring program, each waterbody in the North Central Lakes group was surveyed in 2017 and again in 2018. Monitoring efforts include SONAR mapping to quantify abundance of submerged aquatic vegetation (SAV) and some emergent aquatic vegetation (EAV) species. Additionally, point-intercept sampling is performed to identify the relative proportion of each species present. The City can then use this data to better understand how much and what types of vegetation are present in each lake.

Calculating the relative proportions of EAV, SAV, and floating vegetation (FV) allows for general inferences to be made regarding the health of each waterbody. A healthy balance of EAV and SAV is indicative of good species diversity and habitat for aquatic fauna. Dominance by EAV or FV is not always cause for alarm, however in most instances where this is the case, water quality issues are typically observed. In the NCL group, Lakes Buckeye and Maude possess majority SAV species, while Lakes Idyl, Martha, and Silver are dominated by EAV. Figure 2-22 displays these relative percentages using aggregate data from both survey years. There are no consistently dominant taxa for this lake group as a whole. By far, the most abundant species in Lake Buckeye is coontail (*Ceratophyllum demersum*). Spatterdock (*Nuphar advena*) dominates Lake Idyl, while coontail and eel grass (*Vallisneria americana*) are co-dominant in Lake Maude. The most abundant species in Lake Silver is torpedograss (*Panicum repens*), but cattails (*Typha spp.*) are present as a close second. Lake Martha is fairly unique in that it possesses a fairly even mix of species, however most are in low frequencies. What should also be noted here is that Lakes Idyl, Martha, and Silver effectively possess no discernable SAV presence as of 2018. It is not wholly understood why these lakes lack submerged plant communities, however the City is constantly seeking information to discover the underlying cause(s).

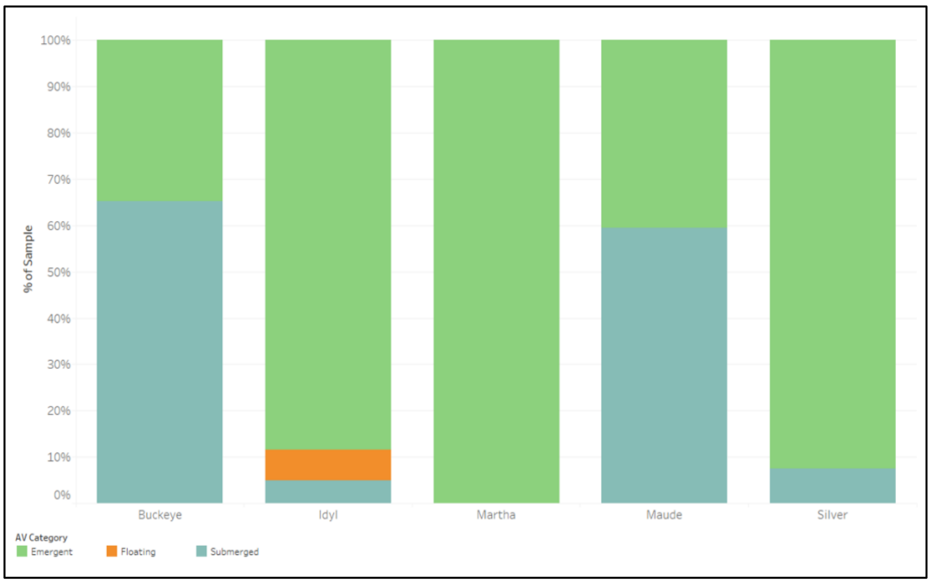


Figure 2-22. North Central Lakes categorical proportion of aquatic vegetation as emergent, submerged, or floating.

Monitoring vegetation abundance with SONAR yields two metrics: percent area cover (PAC) and percent biological volume (% BV). These criteria, PAC and % BV, quantify how much vegetation is present relative to a waterbody's surface area and volume respectively. As a value representing the amount of rooted vegetation, PAC is an important lake health indicator. In the majority of cases, PAC is comprised of SAV species which not only help to stabilize lake sediments, but actively pull nutrients from the water column. Additionally, PAC values between 15 – 30% are preferable for fish habitat. Vegetation abundance information is displayed in Figure 2-23. In 2018, Lakes Buckeye and Maude possessed PAC values well over 90%. With vegetation abundances this high, it is no wonder that these lakes have excellent water quality. Lake Idyl also had coverage exceeding the PAC target, however it should be noted that the species contributing to this was spatterdock which is less effective at sequestering nutrients from the water column than SAV taxa. With effectively no SAV, Lakes Martha, and Silver exhibited extremely low PAC values in 2018.

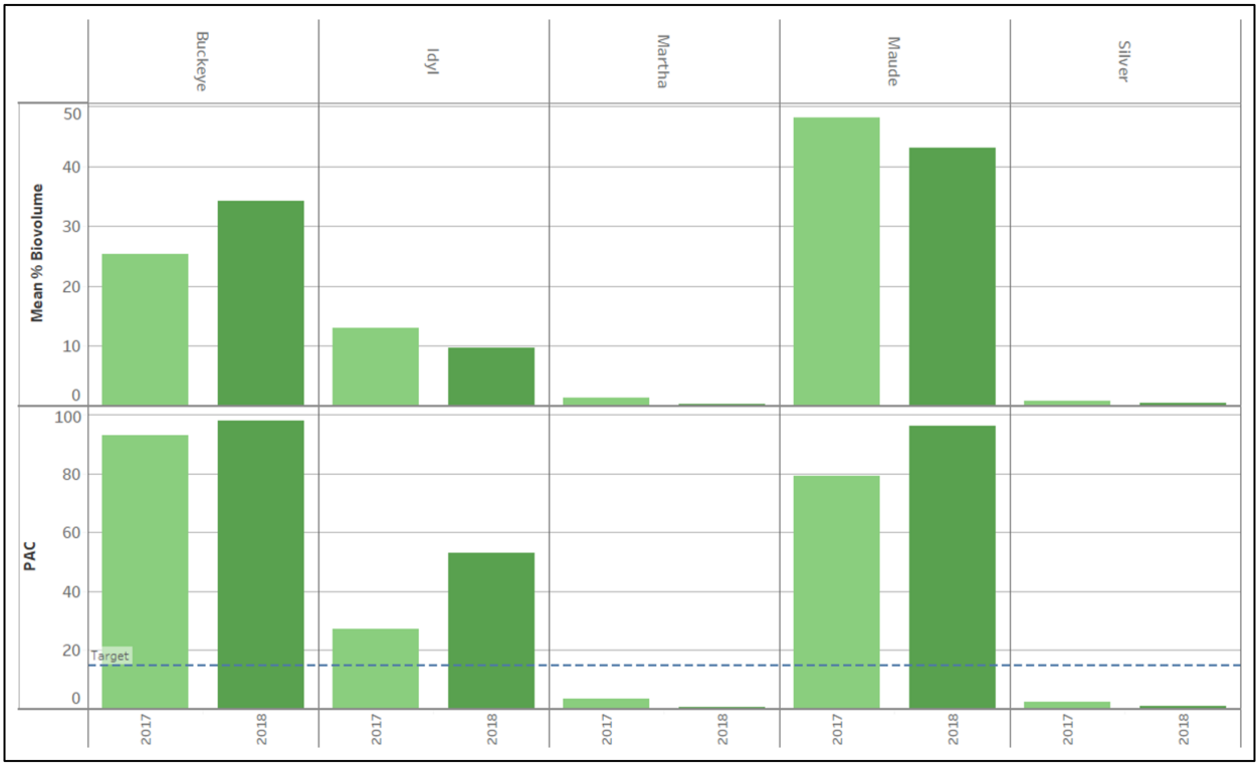


Figure 2-23. North Central Lakes annual aquatic vegetation percent area coverage and mean percent biovolume.

Monitoring efforts afford a look into the presence of invasive exotic species in the Winter Haven area lakes. Management of invasive species depends on knowledge of their density and location in order to prescribe the most effective treatment options. Tracking percentages of these managed invasives also provides a means to measure treatment effectiveness with the goal of bringing each lake into a managed state. Figure 2-24 displays these percentages as they relate to the NCL. From 2017 to 2018, Lake Buckeye experienced a substantial increase in hydrilla—indicating that this lake is in need of treatment. On a positive note, managed invasive percentages decreased in Lakes Idyl and Maude. Lake Martha saw a 100% reduction in burhead sedge in 2018 which may be due to a change in the vegetative community, however it would be unwise to rule this a complete eradication. Due to the limitations of the point-intercept sampling method, there is a good possibility that this species is still present in Lake Martha; continued sampling is still needed to track any return or introduction of invasives. Both Lake Silver surveys showed no presence of managed invasives. Based on these data, it can be determined that Lakes Idyl, Martha, and Silver are currently in a managed state.

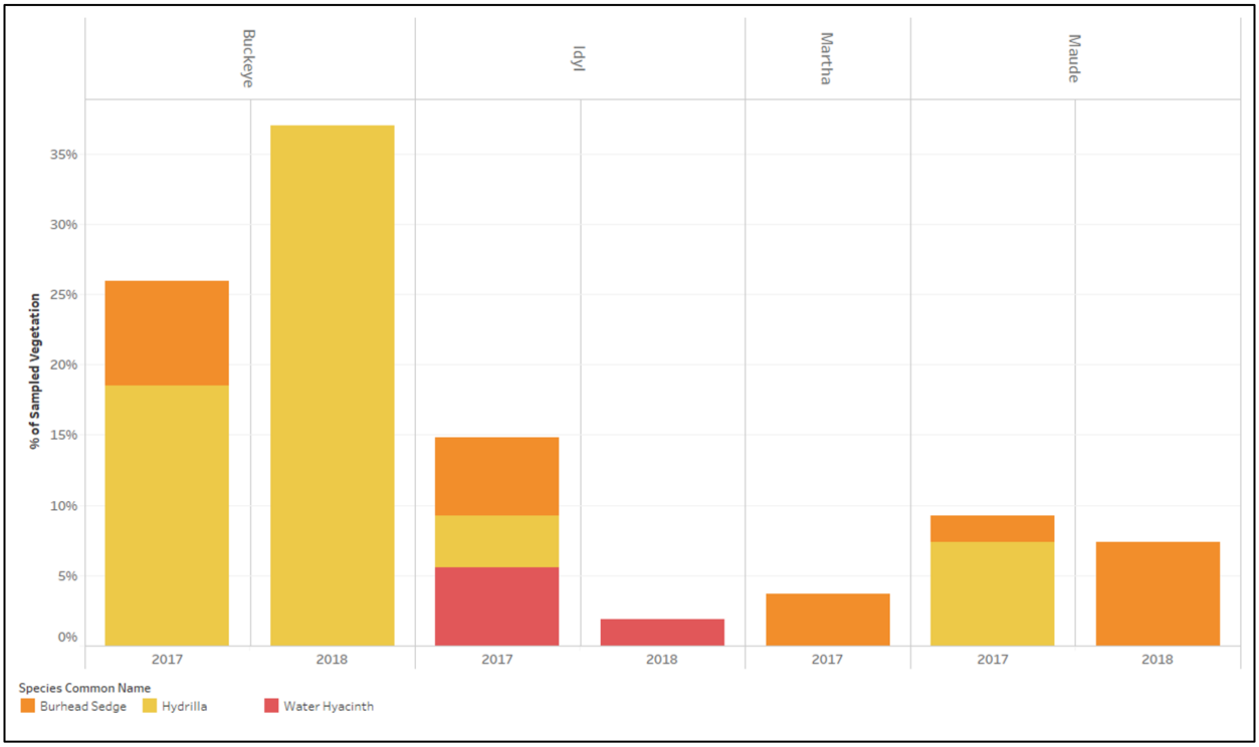


Figure 2-24. North Central Lakes annual percentage of managed invasive species.

Collection of species data allows for the calculation of diversity index scores. As one of the lake health indicators, a change in diversity index values from year to year shows general improvement or deterioration of the aquatic plant community of each lake. The indices used for this evaluation include species richness (R2), evenness (E3), and overall diversity (H). The annual diversity index values can be observed in Figure 2-25.

Menhenick's Richness (R2): From 2017 – 2018, Lakes Buckeye and Idyl experienced a decrease in species richness, while Lakes Martha, Maude, and Silver all showed increases in the number of unique species present.

Hill's Evenness #3 (E3): All five lakes of the NCL exhibited a decline in species evenness from 2017 to 2018. This is indicative of one or more species dominating the vegetation community. Ideally, each lake would have a perfectly even population of plants.

Shannon's Diversity (H): As a measure in the uncertainty of finding the same species more than once during sampling, Shannon's index is indicative of overall species diversity. From 2017 – 2018, only Lake Maude experienced an increase in diversity, while the other lakes within this group showed decreases.

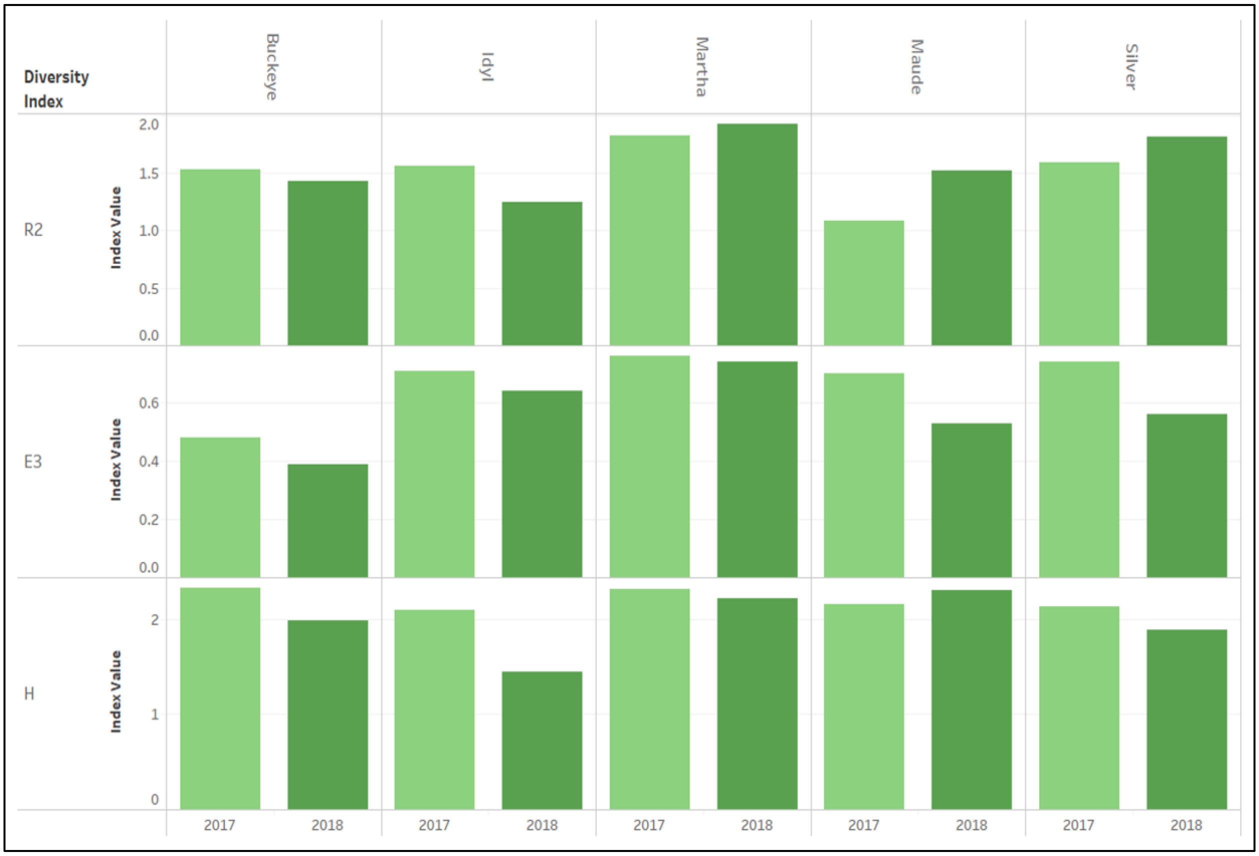
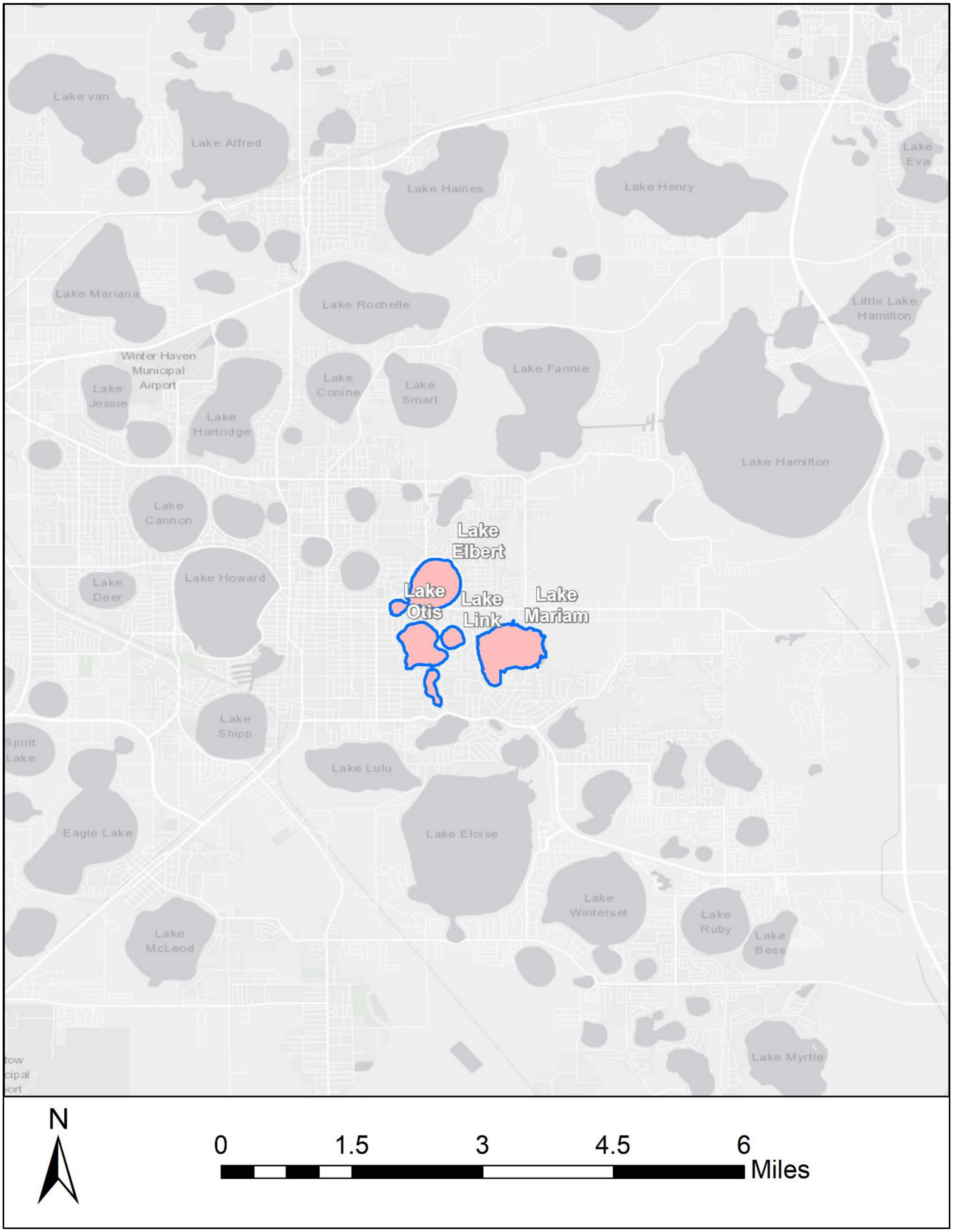


Figure 2-25. North Central Lakes annual index values for species richness, evenness, and diversity.

2.4 South Central Lakes



The Winter Haven South Central Lakes (SCL) is comprised of four waterbodies: Lakes Elbert, Link, Mariam, and Otis. Connected by a series of overflow conveyances, these lakes may contribute surface flow to the Peace Creek Drainage Canal via a discharge point to the east of Lake Mariam. The City of Winter Haven, FDOT, and Polk County all contribute surface water to and hold Municipal Storm Sewer System (MS4) permits for stormwater discharge to the SCL.

Water Quality

In order to determine water quality impairment, the South Central waterbodies were categorized based on long-term geometric mean true color and total alkalinity concentrations. Lakes Elbert, Link, and Otis are all considered clear, high alkalinity waterbodies, while Lake Mariam was determined to be highly colored. Impairment was determined as more than one consecutive exceedance of the Numeric Nutrient Criteria (NNC) thresholds by annual geometric mean (AGM) Chla, TN, and TP concentrations between 2010 and 2018. The AGM concentrations during this time period are displayed in Tables 4-1 through 4-3 in the Appendix. Based on this methodology, Lake Otis was determined to be impaired for Chla. No other impairments were determined for this lake group.

A snapshot of the 2018 AGM Chla, TN, TP, and Secchi depth values for the SCL are displayed in Figure 2-26. Included in these depictions are the long-term (2000 – 2018) mean and normal range (+/- 1 standard deviation) for each waterbody. Lakes Elbert, Link, and Mariam are currently experiencing above average Chla levels; Lakes Elbert and Mariam are exhibiting above average TN concentrations; and Lake Mariam is experiencing above average TP levels. All lakes within this group are currently experiencing at or below average water clarity. While a snapshot is useful to observe recent conditions, a closer look at the long-term trends is necessary to determine if water quality is improving or declining.

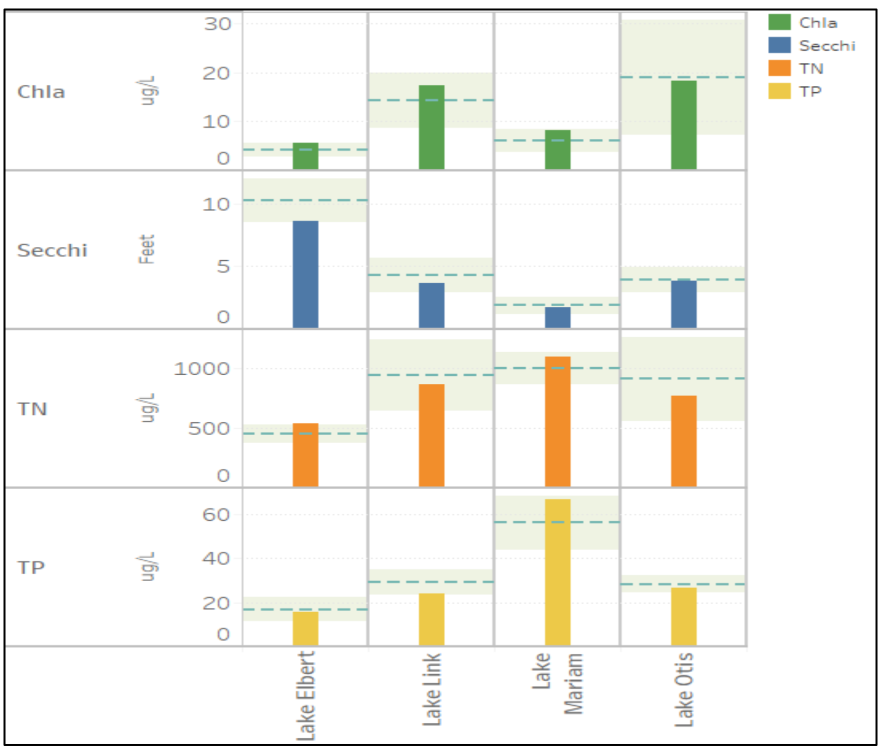


Figure 2-26. 2018 AGM Chla, TN, TP, & Secchi depth values for the South Central Lakes; dotted lines represent long-term mean and the shaded areas refer to the standard deviation range.

Water quality trend evaluation was performed by plotting AGM Chla, TN, TP, and Secchi depth against time, in years, from 2000 to 2018. Monotonic trend direction (+/-) and statistical significance (p-value ≤ 0.05) were determined based on the resulting linear regression statistics (Table 4-4 in Appendix). The AGM data and regression lines are plotted in Figure 2-27.

Chlorophyll-a Trends: The only waterbody in this group exhibiting a significant Chla trend was Lake Elbert—trend direction was increasing over time. Lakes Link and Otis experienced non-significant downward trends, while Lake Mariam showed a non-significant increasing trend from 2000 – 2018.

Total Nitrogen Trends: Lake Link exhibited a significant decreasing trend in TN over time. Lakes Mariam and Otis experienced non-significant downward trends; Lake Elbert non-significantly trended upward during the same time period.

Total Phosphorus Trends: None of the NCL lakes exhibited significant TP trends from 2000 – 2018. Of the non-significant trends in TP, Lake Elbert showed an increase over time, while Lake Link, Mariam, and Otis trended downward.

Clarity Trends: Lake Mariam was the only waterbody experiencing a significant trend in Secchi depth over time—the regression was increasing. Lakes Link and Otis exhibited non-significant increasing clarity trends, while Lake Elbert trended downward.

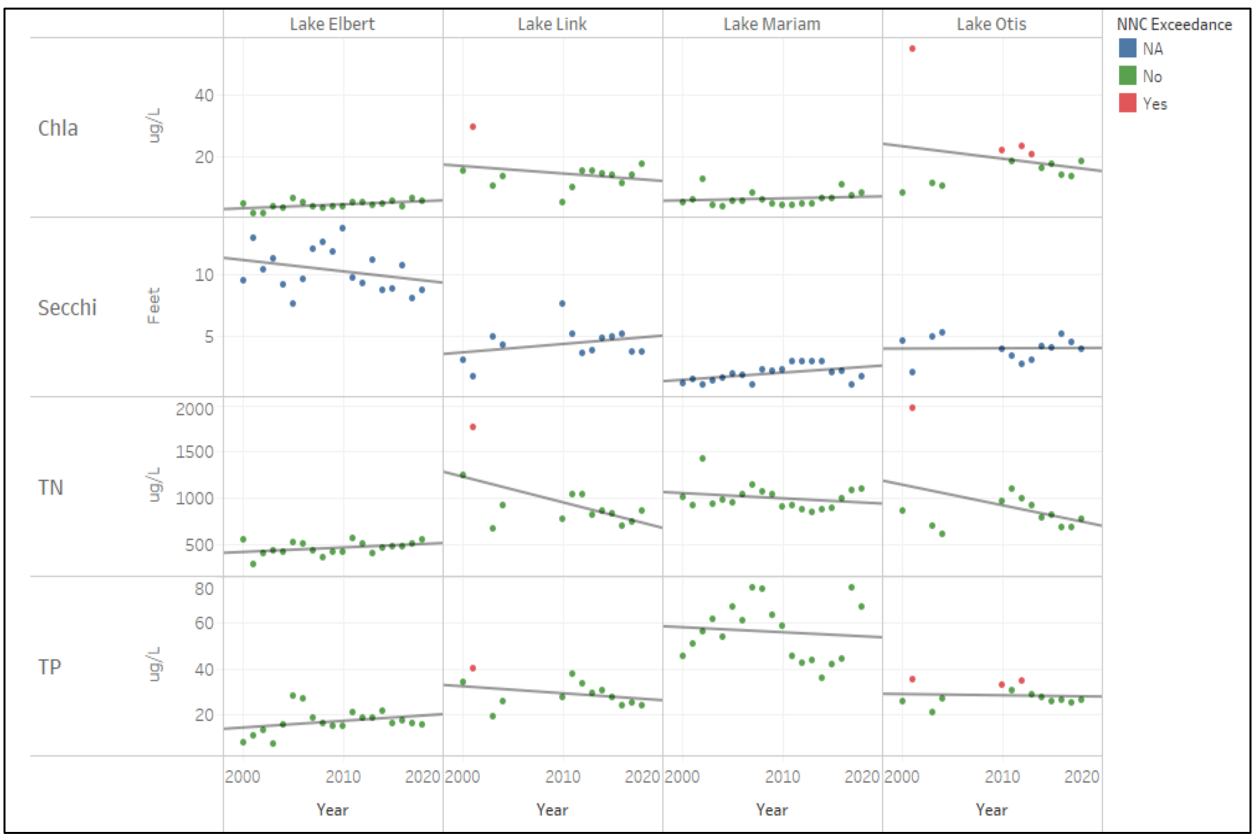


Figure 2-27. South Central Lakes regression trend graphs of AGM Chla, TN, TP, & Secchi depth from 2000 – 2018. Red dots represent exceedance of the NNC threshold for that year.

Hydrology

Similar to the North Central Lakes group, the South Central waterbodies are connected via a series of passive overflow structures and conveyances; Lakes Link and Otis are connected by a navigable canal which means they are held at the same elevation. For water to flow downstream from one lake to another, surface levels must exceed the control structure elevations; this occurred briefly in 2004. Figure 2-28 displays monthly surface level (SL) readings for the SCL from 2000 to 2018. Included are annual rainfall totals and box-and-whisker plots detailing each lake's relative variability. Since rainfall drives the hydrology of the area, the SCL surface levels track fairly consistently with annual precipitation above and below the Winter Haven area average of 52 inches. Of the lakes in this group, Lake Elbert experiences significantly more variation is SL. This is likely due to the relative size of its drainage basin and the fact that it may never reach levels in which it overflows to Lake Otis.

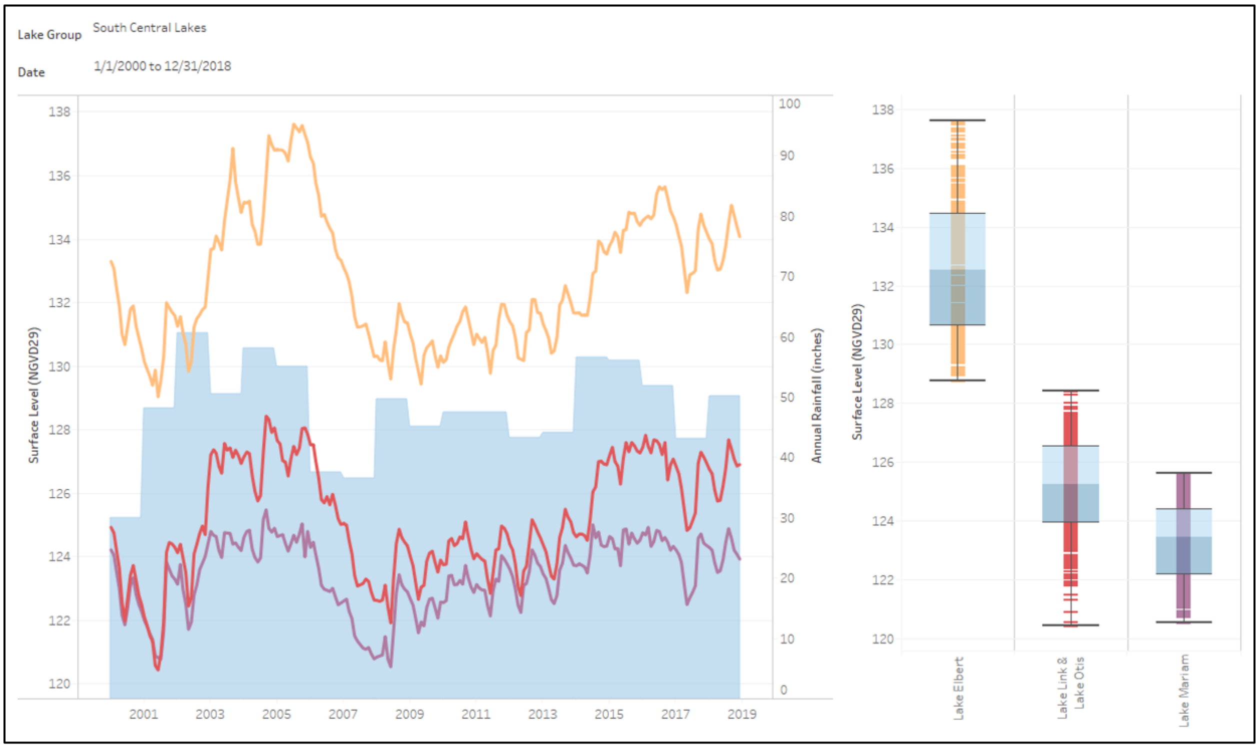


Figure 2-28. South Central Lakes hydrographs with box & whisker plots detailing long-term surface level variability. Annual rainfall totals indicate hydrologic response to precipitation.

In order to determine if relationships exist between SL and water quality, linear regressions were performed using annual mean surface level and AGM Chla, TN, TP, and Secchi depth values. Regression significance was determined using a 95% confidence level (p-value ≤ 0.05). Resulting statistics can be observed in Table 4-5 in the Appendix.

SL vs. Chla: Regression analysis shows that Lake Elbert has experienced a significant positive relationship—meaning that an increase in SL also results in a rise in Chla concentrations. Alternatively, Lake Otis exhibits a significant inverse relationship. Since Elbert is at the top of the watershed and receives stormwater discharge from a relatively large drainage basin, an increase in SL (due to rainfall) may also contribute a significant amount of nutrient loading. The relationship with Chla in Lake Otis could be attributable to a dilution effect.

SL vs. TN: Regressions of surface level versus TN yielded two significant correlations. Lakes Link and Otis exhibit inverse relationships indicating a rise in SL will be accompanied by a reduction in TN.

SL vs. TP: Once again, Lakes Link and Otis show a significant inverse relationship with SL plotted against TP.

SL vs. Clarity: Similar to the regressions of SL against Chla, Lakes Elbert and Otis experienced significant relationships with Secchi depth. Lake Elbert shows a direct relationship, while Lake Otis exhibits an inverse one. Since clarity is intrinsically tied to chlorophyll-a concentration, it is reasonable that these two water quality parameters share similar relationships.

In an effort to better understand the relationships between hydrology and water quality, as well as build support for the selection of appropriate management strategies, each lake's hydrologic components are considered. Drainage basin characteristics including soil classification and land use (by lake group) can be found in Tables 4-6 & 4-7 in the Appendix. Additionally, each lake's land use classifications are displayed in Table 2-4.

The SCL are primarily dominated by class A soils. The exception to this is Lake Mariam's drainage basin which is comprised mostly of A/D soils; the second most dominant soil type is class A, with minimal presence of less well-drained soil types. Lakes Elbert, Link, and Otis are situated higher up on the Winter Haven Ridge which is comprised mostly of sandy soils that facilitate infiltration. Lake Mariam, by contrast, is located closer to the transition zone with the Polk Uplands. The predominant soil class reflects this with a somewhat less well-drained. Due to these soil characteristics, management practices that incorporate stormwater infiltration would be more applicable to Lakes Elbert, Link, and Otis; Lake Mariam may see more benefit from in-lake treatments like vegetation planting or wetland restoration.

Land uses in the SCL basins are predominantly residential. Lakes Elbert, Link, and Otis also possess small proportions of other urban land use categories such as commercial and institutional. These categories are typically accompanied by webs of impervious surfaces and stormwater infrastructure that act as thoroughfares for runoff to enter lakes. Similar to other lake groups with more urban land uses, focus

Land Use

	Waterbody			
Land Use	Lake Elbert	Lake Link	Lake Mariam	Lake Otis
AGRICULTURE	0.37		12.31	
COMMERCIAL	15.92		4.24	2.32
COMMUNICATION	0.96			
INDUSTRIAL			0.06	
INSTITUTIONAL	11.60	1.61	5.02	9.35
RECREATIONAL	2.08			
RESIDENTIAL	54.00	64.66	31.27	65.09
UPLAND FOREST			0.85	2.53
WATER	23.98	32.68	23.16	23.81
WETLANDS	0.75	1.06	23.10	2.83

Table 2-4. South Central Lakes land use percentage found within each lake drainage basin.

should be placed on diverting this runoff and/or treating it prior to discharge to waterbodies. Lake Mariam possesses a considerable percentage of wetlands in its drainage basin—an especially large portion is located along its southwestern shoreline. This wetland was likely historically connected to the lake, which may account for its high color concentration. Lacking significant relationships between SL and water quality, it is unlikely that recent Lake Mariam levels reach elevations that would facilitate significant wetland connectivity. Restoring this connection is one potential management strategy for this waterbody.

Analysis of the morphology of the South Central Lakes allows for inferences to be made regarding the impacts of lake shape on water quality and ecology. The lakes in this group range in size from 36 to 262 acres. Maximum depths are also highly variable; with observed depths in Lake Mariam reaching 6.75 feet, contrasting with depths of 30 feet in Lake Elbert. Many similarities can be drawn between the SCL and the Northern Chain of Lakes. There are generally two shapes displayed in this group: deep, bowl-shaped waterbodies, and shallow, pan-shaped lakes. Within the SCL, Lakes Elbert, Link, and Otis display qualities of bowl-shaped lakes, while Lake Mariam is very much a pan lake (Figure 2-29). Due to the depths found in Lakes Elbert, Link, and Otis, these waterbodies likely experience greater hydrologic influence from changes in groundwater levels. Annual TP concentrations in Lake Mariam appear to fluctuate considerably. Due to this lake's shape, wind-driven suspension of sediments may be causing phosphorus influx, however it is unknown why TP spikes in some years over others. Since there isn't a significant relationship between SL and TP, it's unlikely that a change in lake level is the primary driver; or perhaps there is a lag in TP response from a change in SL. Fortunately, water quality in Lake Mariam remains at acceptable levels and exhibits no signs of negative trends.

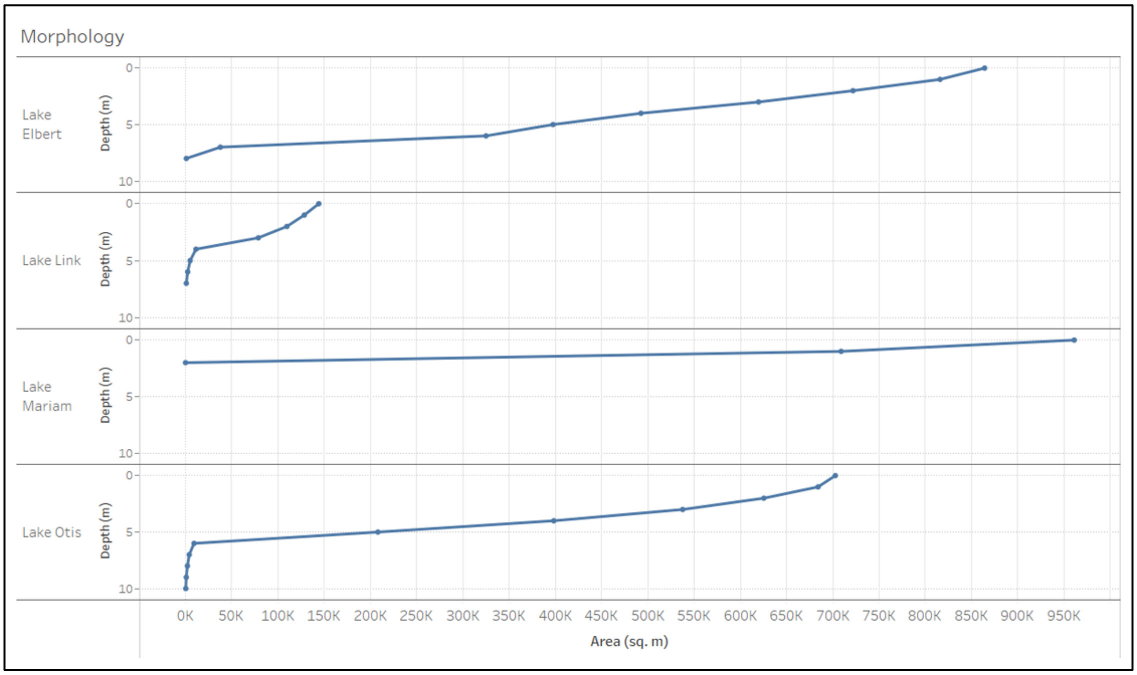


Figure 2-29. South Central Lakes hypsographs depicting cumulative area in descending 1 meter intervals.

Ecology

The City of Winter Haven's ecological monitoring program involves annual surveys of aquatic vegetation found in the study area lakes. The lakes in the South Central group have all been surveyed twice—once in 2017 and again in 2018. Survey methods include point-intercept sampling to determine the representative species present in each waterbody as well as SONAR mapping which provides data relating to the abundance of submerged and some emergent species.

Analyzing the proportion of each vegetation type found in a given lake is useful to determine the general vegetation community at a glance. Ideally, waterbodies should possess a healthy mix of submerged aquatic vegetation (SAV), emergent aquatic vegetation (EAV), and floating vegetation (FV). However, due to the unique characteristics and environmental stimuli found in each lake, an equal mix is not always indicative of a healthy waterbody. Figure 2-30 displays the relative percentages of vegetation types found in the SCL. Lake Elbert possesses an even mixture of EAV and SAV. Lakes Link and Otis are dominated by EAV, but have not insignificant percentages of SAV. Emergent vegetation is clearly the dominant type found in Lake Mariam, as there has been no SAV present during the last two surveys.

During 2018, the dominant species in Lake Elbert was eel grass (*Vallisneria americana*)—a submerged plant. Lakes Link and Otis both had emergent species as the most dominant with torpedograss (*Panicum repens*) as the most frequent species found. The taxa with the greatest presence in Lake Mariam was cattails (*Typha spp.*); a native emergent species that can display some invasive tendencies.

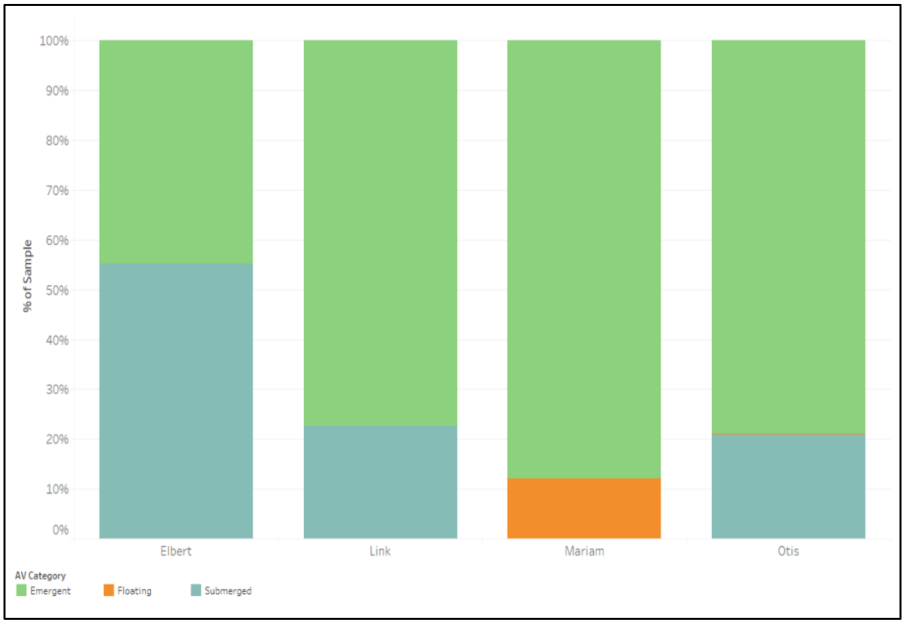


Figure 2-30. South Central Lakes categorical proportion of aquatic vegetation as emergent, submerged, or floating.

Measures of vegetation abundance are useful metrics that can provide insights into sediment stabilization, fish habitat, as well as nutrient absorption potential. The primary measures used by the City include percent area coverage (PAC) and average percent biological volume (% BV). Tracking changes in these metrics over time allows lake managers to determine if rooted vegetation communities are increasing or receding. The Florida Fish and Wildlife Commission (FWC) has set a target range of 15 – 30% PAC as ideal for fish habitat. Figure 2-31 shows these metrics for the South Central Lakes. In 2017 and 2018, Lake Elbert had PAC levels well over the target of 30% as well as healthy % BV numbers. Lake Link saw a substantial increase in vegetation abundance from 2017 to 2018 with PAC numbers rivaling Lake Elbert during the most recent survey. In contrast, Lake Otis's abundance values dropped slightly during this period. Despite this, PAC levels still remained within the target range. Lake Mariam experienced a moderate decrease in PAC and % BV as of the 2018 survey. Percent coverage dropped below the target of 15% and biovolume declined to almost nothing. Since the plants observed would have been EAV taxa, this reduction could potentially be a result of the SONAR device's limitations sensing shoreline emergent vegetation.

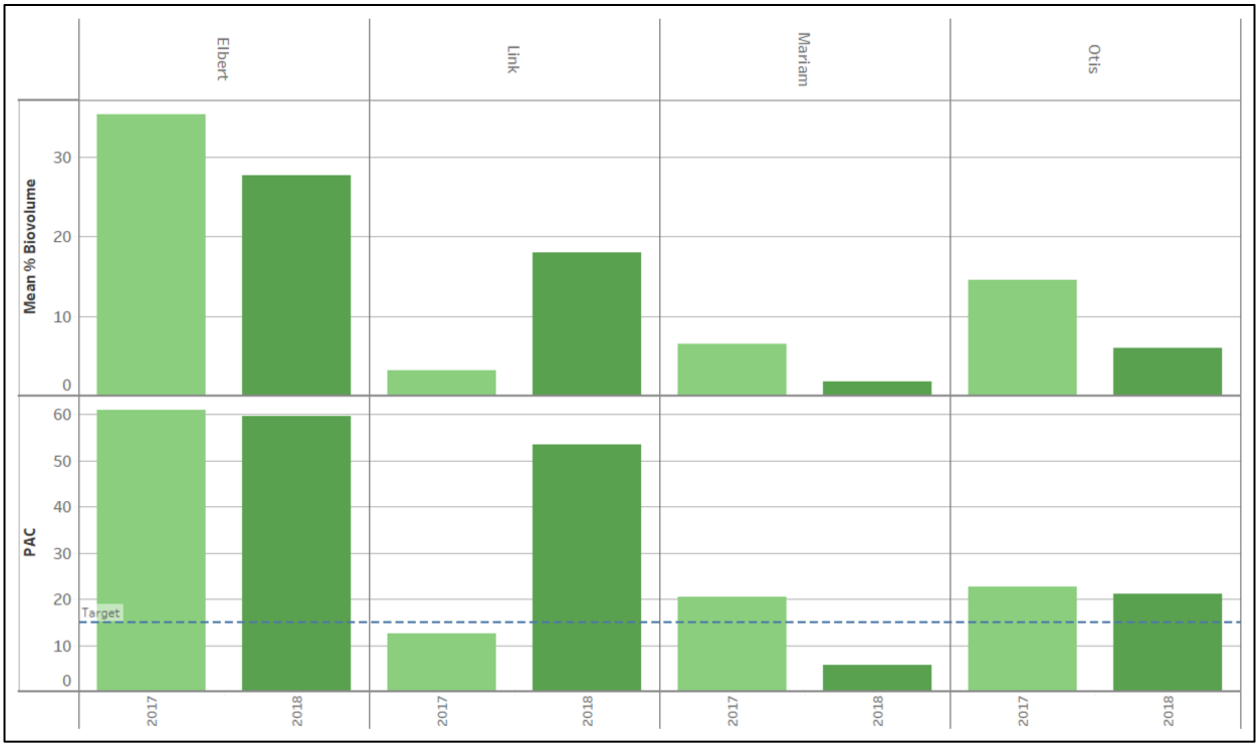


Figure 2-31. South Central Lakes annual aquatic vegetation percent area coverage and mean percent biovolume.

Ideally, a perfectly healthy biological community would be free from exotic and invasive species. Therefore, the monitoring and treatment of invasives is an integral part of the City, County, and State's management strategy. In addition to causing ecological harm to native species, wholesale treatment of exotic plants can release a considerable amount of nutrients into the water column as they decompose. The City's response is to promote early detection and rapid response measures that seek to reduce these nutrient releases by limiting the amount of vegetation treated at one time. For the last two years, the City has collected invasive species frequency data and can track changes in the presence of managed exotic plants (Figure 2-32). From 2017 to 2018, Lake Elbert saw a roughly 50% reduction in hydrilla (*Hydrilla verticillata*). Despite this, the percentage of managed invasives still remains above what is considered a managed state. Hydrilla is also present in Lakes Link and Otis, but at much lower levels. Continued monitoring and treatment is likely required to prevent expansion and keep hydrilla at managed levels. Lake Mariam saw a significant increase in water hyacinths (*Eichhornia crassipes*) in 2018—pushing the total invasive percentage above the target threshold. Considering that hyacinths were not detected in 2017, this is an example of how prolific these exotics can be when it comes to out competing with native species. The City has since passed this information to the FWC to ensure that treatment measures are taken.

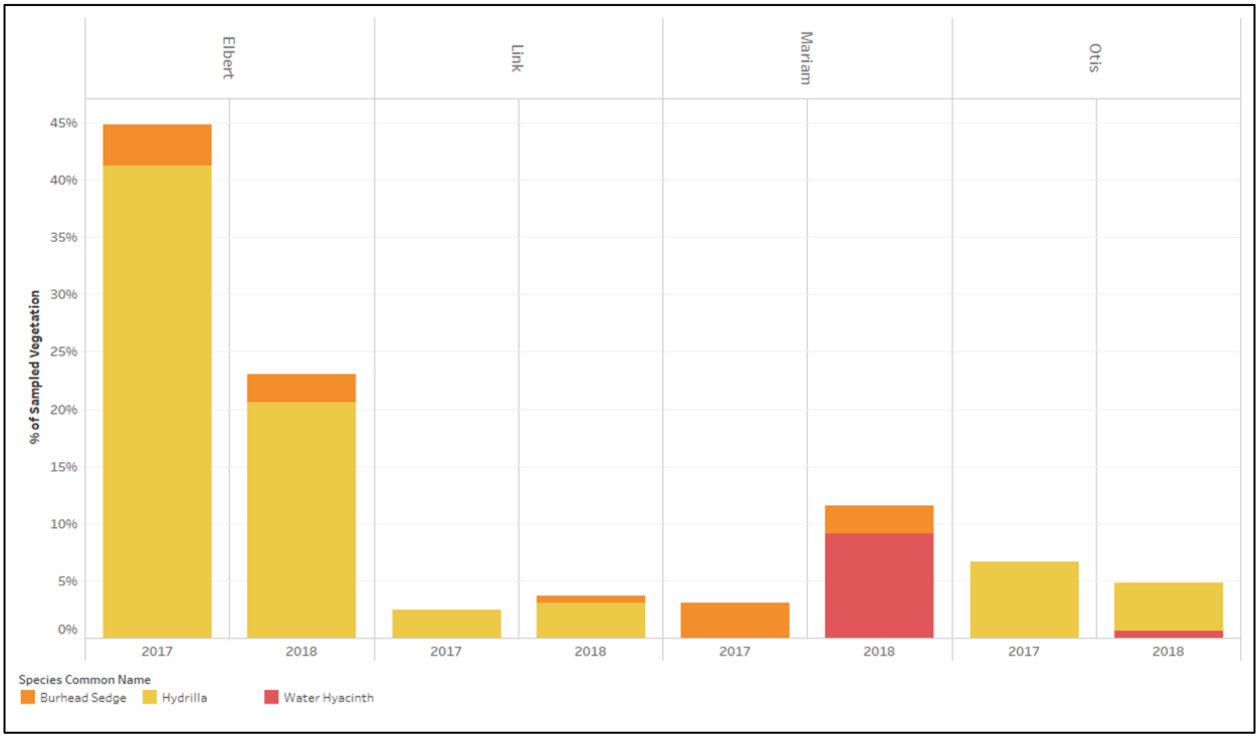


Figure 2-32. South Central Lakes annual percentage of managed invasive species.

As the final biological lake health indicator, species diversity is essential to ensuring a long-lasting, healthy vegetative community. Species richness, evenness, and overall diversity are all separate metrics incorporated into the diversity score. Tracking changes in this score over time should provide some indication as to ecological trends in Winter Haven's lakes. Figure 2-33 displays the annual index values for the South Central Lakes.

Menhenick's Richness (R2): From 2017 to 2018, all four lakes in this group experienced an increase in species richness. Since a rise in species present can include exotics or invasives, richness alone is not the best indicator for vegetation community health.

Hill's Evenness #3 (E3): Species evenness is a measure of the relative proportion of each species in a waterbody. Generally, a more evenly distributed population is healthier as it prevents one or a few species from dominating. Unfortunately, all four lakes in the SCL experienced a decrease in evenness between 2017 and 2018.

Shannon's Diversity (H): Shannon's index measures the uncertainty of finding the same species multiple times during a given survey. As this uncertainty grows, this equates to greater species diversity. Within the SCL, Lakes Elbert, Mariam, and Otis all experienced a decrease in Shannon's index value from 2017 to 2018. Lake Link, however, exhibited a slight increase in diversity from the previous year.

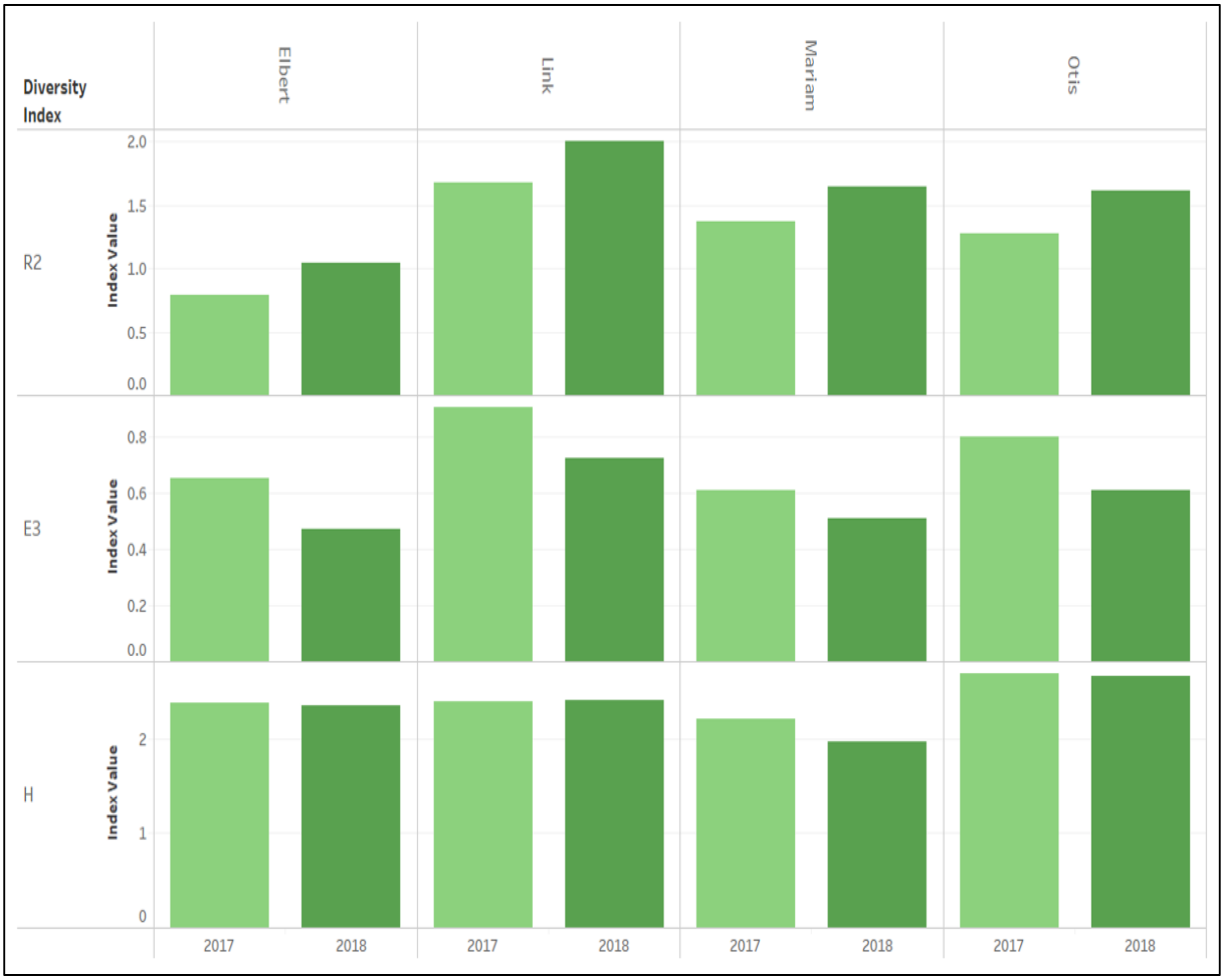
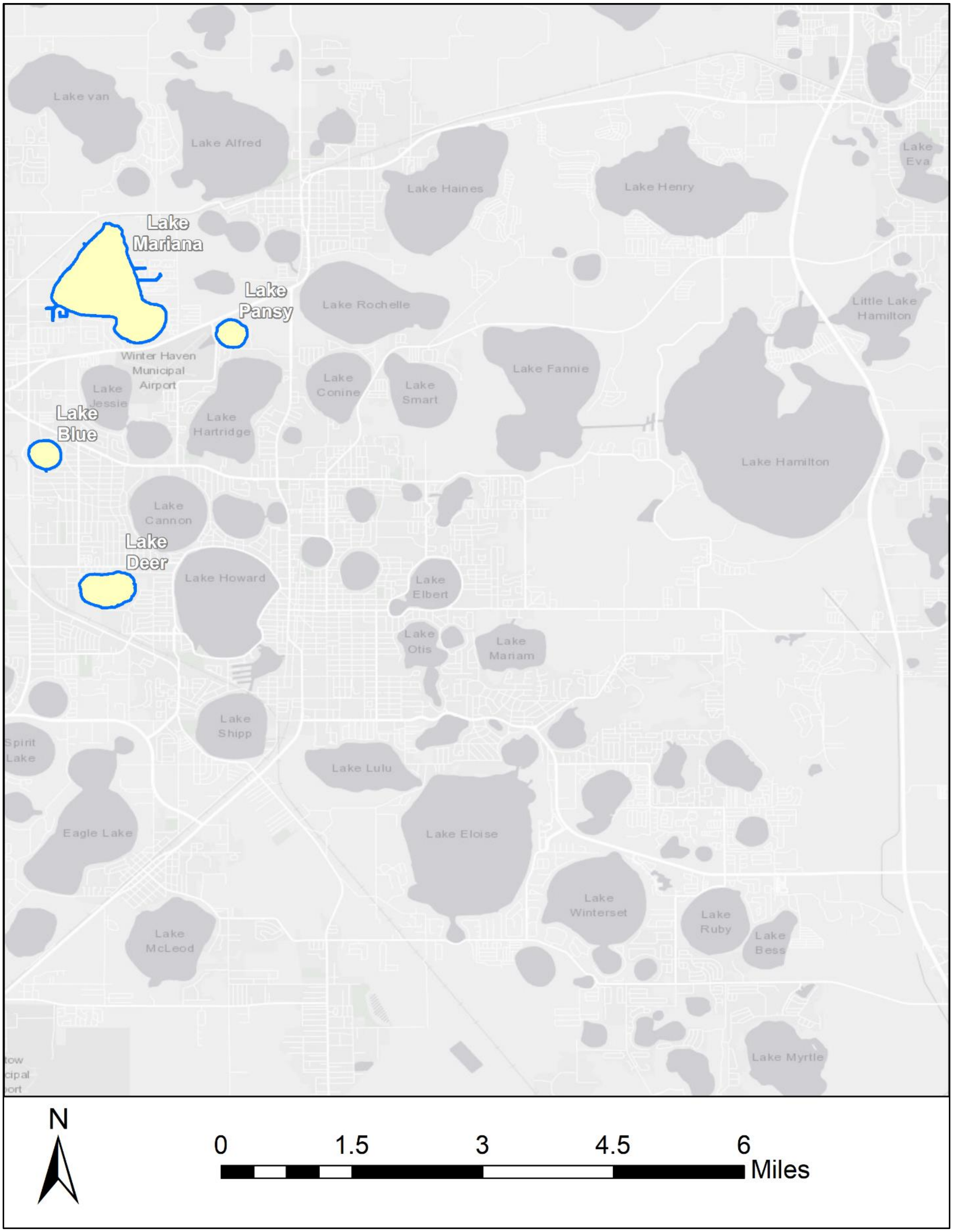


Figure 2-33. South Central Lakes annual index values for species richness, evenness, and diversity.

2.5 Outlying Lakes



The Winter Haven Outlying Lakes (OL) group is composed of four seemingly isolated waterbodies primarily located beyond the northwest boundary of the City. Lakes Blue, Deer, and Mariana all possess known passive overflow connections to the Southern Chain of Lakes. While Lake Pansy has no known conveyances directly connecting it to other lakes in the study area, it is possible during periods of extremely high surface level that water may flow through its adjacent wetland and into the Northern Chain via Lake Rochelle. The governmental entities that contribute surface water flow and/or possess Municipal Storm Sewer System (MS4) permits to this lake group include the Cities of Winter Haven and Auburndale, Polk County, and the FDOT.

Water Quality

As a lake health indicator, determination of impairment is used by the FDEP to assess whether a waterbody is currently meeting water quality standards that fit with its intended use. Categorizing lakes based on long-term geometric mean true color and total alkalinity is the first step to determine which Numeric Nutrient Criteria (NNC) targets to meet. Within the Outlying Lakes group, Lakes Blue, Deer, and Mariana are considered clear, high alkalinity waterbodies, while Lake Pansy was determined to be highly colored. Impairment is determined by more than one consecutive exceedance of NNC thresholds by annual geometric mean (AGM) Chla, TN, and TP concentrations during the assessment period from 2010 to 2018. These AGM concentrations can be found in Tables 4-1 through 4-3 in the Appendix. Based on these criteria, Lakes Blue, Deer, and Mariana were all determined to be impaired for Chla, TN, and TP during this period. Lake Pansy exhibits no impairments. It should be noted that recent water quality trends in Lake Deer are indicative of improvement. Should these trends continue, Deer may be taken off the City's provisional impaired list by 2021.

A snapshot of 2018 AGM Chla, TN, TP, and Secchi depth values shows that water quality may be improving in recent years in the OL group (Figure 2-34). Lakes Blue and Deer experienced Chla concentrations well below their long-term averages, while Lakes Mariana and Pansy were just slightly above average. All four lakes in the OL exhibited below average TN and TP concentrations in 2018. Recent Secchi depths for Lakes Blue, Mariana, and Pansy were at or above long-term levels, while Lake Deer's 2018 clarity far exceeds its historic normal range. This 2018 snapshot is useful for determining where current water quality sits, however in order to determine if improvement or deterioration is occurring, the long-term trends must be studied.

Analysis of the long-term water quality trends was performed by plotting AGM Chla, TN, TP, and Secchi depth against time, in years, from 2000 to 2018. Linear regression lines were plotted in order to determine trend direction (+/-) and statistical significance (p-value ≤ 0.05). By performing these regressions, the resulting statistics indicate whether lakes are improving or declining in each of the four previously mentioned water quality parameters. Figure 2-35 displays these trend lines while the regression statistics can be found in Table 4-4 in the Appendix.

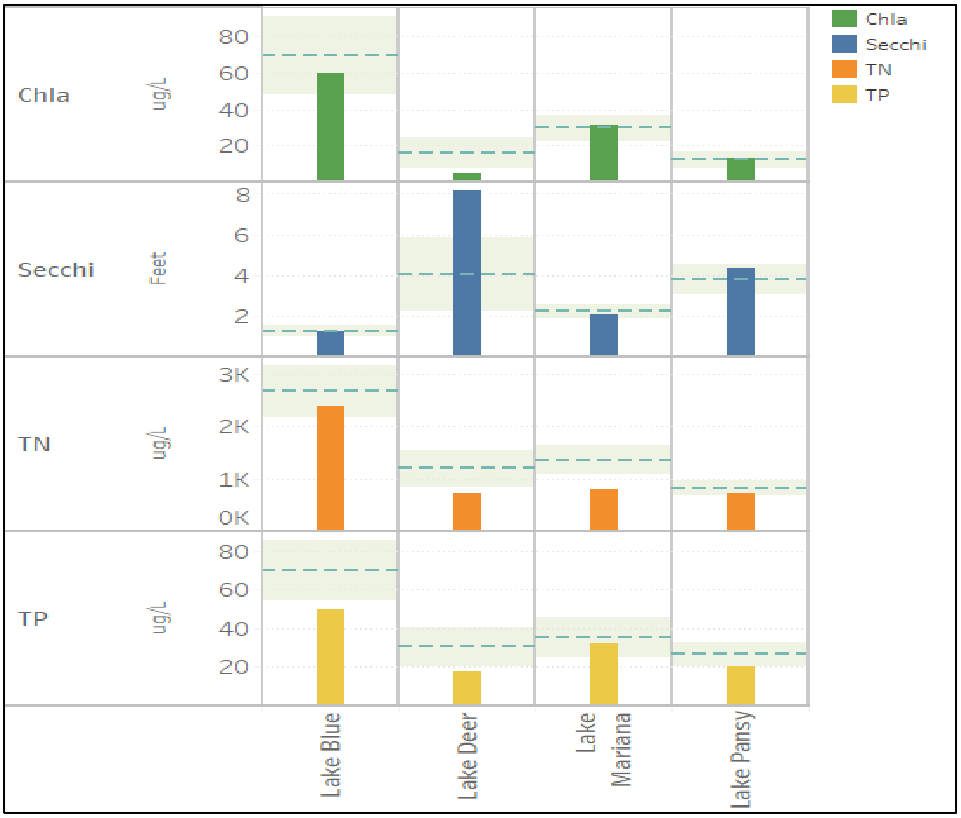


Figure 2-34. 2018 AGM Chla, TN, TP, & Secchi depth values for the Outlying Lakes; dotted lines represent long-term mean and the shaded areas refer to the standard deviation range.

Chlorophyll-a Trends: Of the OL group, Lake Pansy experienced a significant increasing trend in Chla from 2000 – 2018. Lakes Blue and Deer exhibited non-significant decreasing trends and Lake Mariana showed a non-significant increasing trend.

Total Nitrogen Trends: No Outlying Lakes experienced significant TN trends over time, however Lakes Blue and Deer show non-significant decreasing relationships, while Lakes Mariana and Pansy show opposite non-significant trends.

Total Phosphorus Trends: Lake Blue exhibited a significant declining trend in TP from 2000 – 2018. Lakes Deer and Mariana experienced decreasing trends, while Pansy showed an increasing trend in TP over time; all of which were non-significant.

Clarity Trends: None of the waterbodies in this group exhibited significant trends in Secchi depth during this period. Lakes Blue and Deer had non-significant improving trends over time, while Mariana and Pansy show declining relationships.

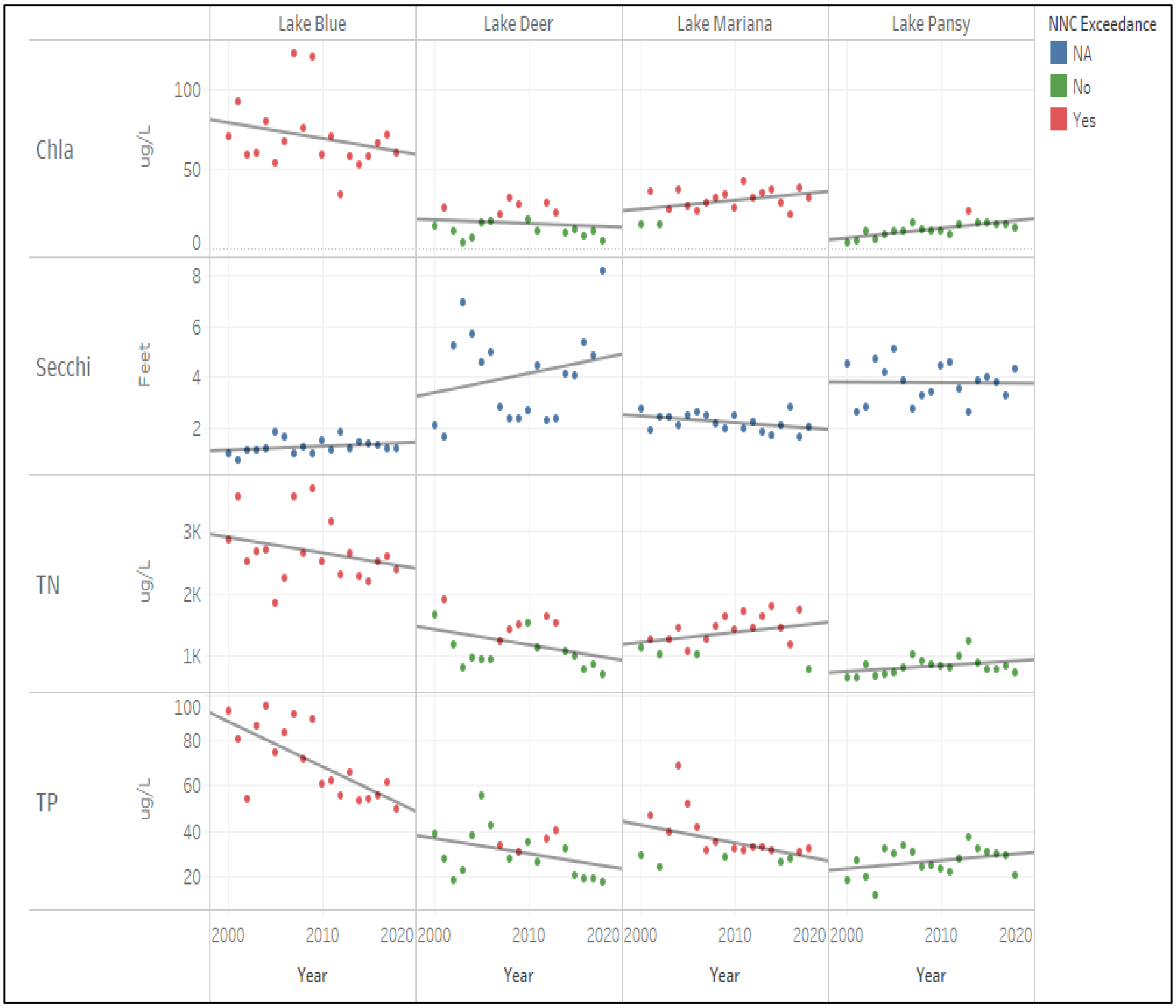


Figure 2-35. Outlying Lakes regression trend graphs of AGM Chla, TN, TP, & Secchi depth from 2000 – 2018. Red dots represent exceedance of the NNC threshold for that year.

Hydrology

As previously mentioned, each of the Outlying Lakes possesses some form of passive overflow connection with other lakes in the study area. Unlike other lake groups, these waterbodies are not connected in a linear fashion, nor are they all located within or adjacent to City boundaries. They do, however, have the capacity to impact downstream surface waters in the Winter Haven Chain of Lakes; this makes them worth investigating. Each of these waterbodies are essentially isolated systems with little impact on one another. Monthly surface level (SL) readings from 2000 - 2018 as well as annual precipitation totals and box-and-whisker plots detailing relative variability are displayed in Figure 2-35. At first glance, the seasonal variations in surface level are clearly evident by the peaks and troughs each year. What is striking is the distinct lack of long-term fluctuations in surface level exhibited by Lakes Blue, Mariana, and Deer to a lesser extent. Unlike Lake Pansy, which experienced consistently depressed SLs during and after years when precipitation fell below the annual average of 52 inches. It is likely that the lack in long-term variability is due to artificial surface level adjustments for the sake of development. While it is expected for SLs to become more stable under a strict management program, this lack of natural fluctuation can be detrimental to lake health. Natural SL drawdowns are healthy in that they allow for oxidation of organic sediments. As muck oxidizes and dries, it can be removed from a lake system through wind action. This process can also prevent the accumulation of excessive muck near the shoreline which allows for the growth of aquatic plant species that prefer a hard substrate.

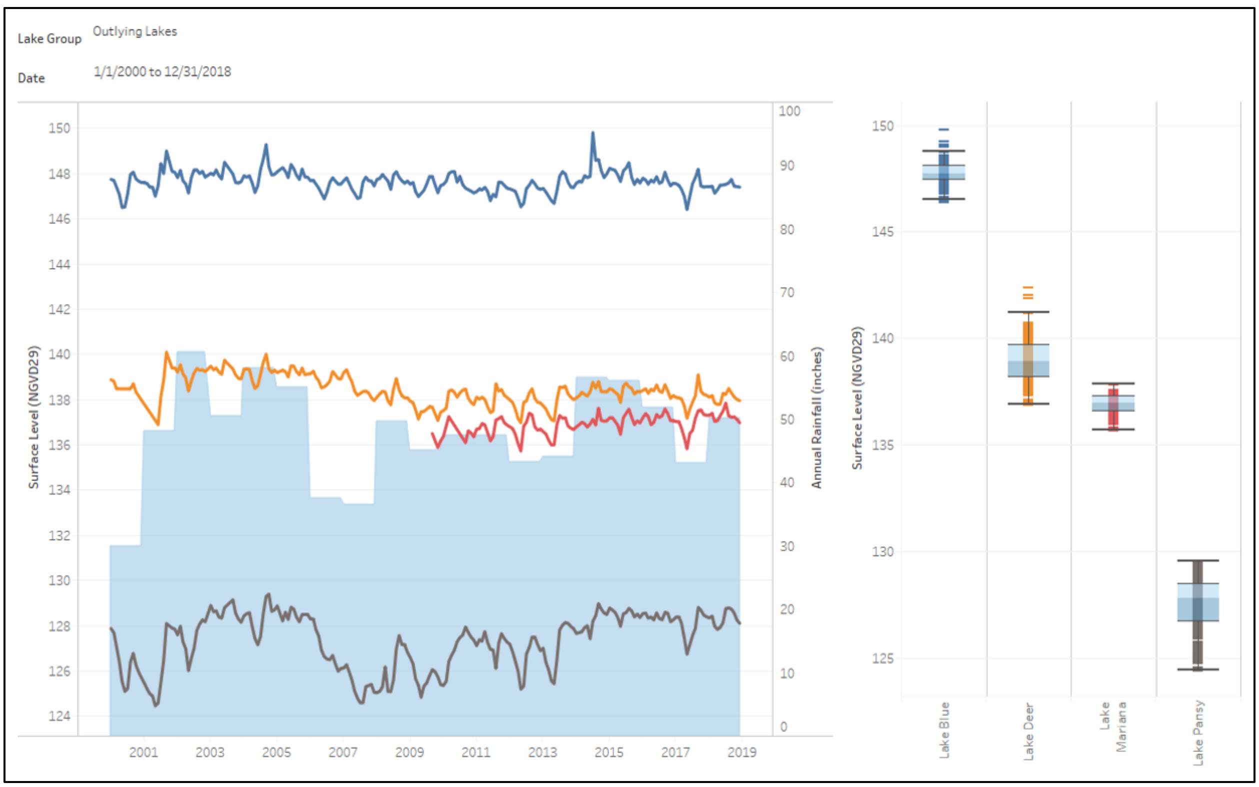


Figure 2-36. Outlying Lakes hydrographs with box & whisker plots detailing long-term surface level variability. Annual rainfall totals indicate hydrologic response to precipitation.

Perhaps as a result of the overall lack of surface level fluctuation in this lake group, there are no significant relationships between SL and Chla, TN, TP, or Secchi depth. It would be expected for Lake Pansy to exhibit some significant correlations, but like with other waterbodies in this study area with substantial adjacent wetland area, these relationships are meager. It could be that wetland connectivity is not quite a primary driver of Chla, TN, or TP reduction, however there certainly seems to be a relationship with color. It seems the role of wetlands is somewhat more complex than can be explained by a simple linear regression; nonetheless, they provide benefits to lakes and should be considered as necessary components of aquatic habitat and lake health in general.

Looking deeper into the drainage basin components and physical characteristics may provide a greater understanding of the complex processes at play within each of the lakes in this group. This understanding can then be used to choose the most effective management strategies for each lake. Soil type and land use proportions (by lake group) can be found in Tables 4-6 & 4-7 in the Appendix, while land uses are broken down by lake in Table 2-5.

The predominant soil types found in this lake group include class A and A/D. In Lakes Blue, Deer, and Mariana, the A/D soil class is slightly more dominant to class A, however Lake Pansy clearly possesses a much greater proportion of A/D soils. These lakes can be found further away from the City center and the central line of the Winter Haven Ridge. Therefore, it stands to reason that somewhat less well-drained soils will be found in the general vicinity. By virtue of this, stormwater management practices that promote infiltration must be selected for areas with adequate soils. Additionally, storage and treatment of runoff can be accomplished with green infrastructure such as constructed wetlands.

Considering land uses, drainage basins within this lake group are quite varied. Industrial parcels dominate Lake Blue's drainage basin; Lake Deer is predominantly residential; Lake Mariana has mostly residential, but with a moderate proportion of agricultural; and Pansy possesses mostly communication land use with some residential, agricultural, and wetland areas as well. Like with the North Chain of Lakes, these waterbodies straddle the line between urban and rural land uses. The majority of these waterbodies are outside of Winter Haven boundaries, so the City lacks stormwater infrastructure information for much of these drainage basins. Despite this, some inferences can be made. Due to the greater proportion of industrial land uses within Lake Blue's basin, its categorically poor water quality may be due to historic industrial discharges. With supporting sediment analysis, in-lake management strategies could be implemented to reduce internal nutrient loading. For the other waterbodies in this group, treatment of stormwater runoff is likely the most efficient management practice.

Land Use

	Waterbody			
Land Use	Lake Blue	Lake Deer	Lake Mariana	Lake Pansy
AGRICULTURE		4.64	18.77	3.40
COMMERCIAL	17.78	8.92	5.54	
COMMUNICATION			2.37	57.37
INDUSTRIAL	31.31	4.61	5.15	
INSTITUTIONAL	3.59	6.36	2.49	
OPEN LAND		0.05	0.57	
RECREATIONAL	7.15		0.26	
RESIDENTIAL	9.61	38.58	32.86	8.71
UPLAND FOREST		4.92	0.81	
WATER	30.21	28.29	26.72	21.53
WETLANDS	0.35	3.64	4.46	9.00

Table 2-5. Outlying Lakes land use percentage found within each lake drainage basin.

Lake size and shape, known as morphology, are useful for determining how a lake with respond to hydrologic changes, but it also governs some of the biological components that will be discussed in the next section. Figure 2-37 displays the relative depth profiles of the OL group. Surface areas of the Outlying Lakes range from 63 acres to 665 acres, while maximum depths range from 7 – 18 feet. Collectively, these are some of the shallowest waterbodies in the study area. Combined with the less well drained soils in the area, these lakes likely receive less Upper Floridan aquifer influence than other lake groups. With these shallow depths, the effective littoral zone should make up a fairly large percentage of each lake's area.

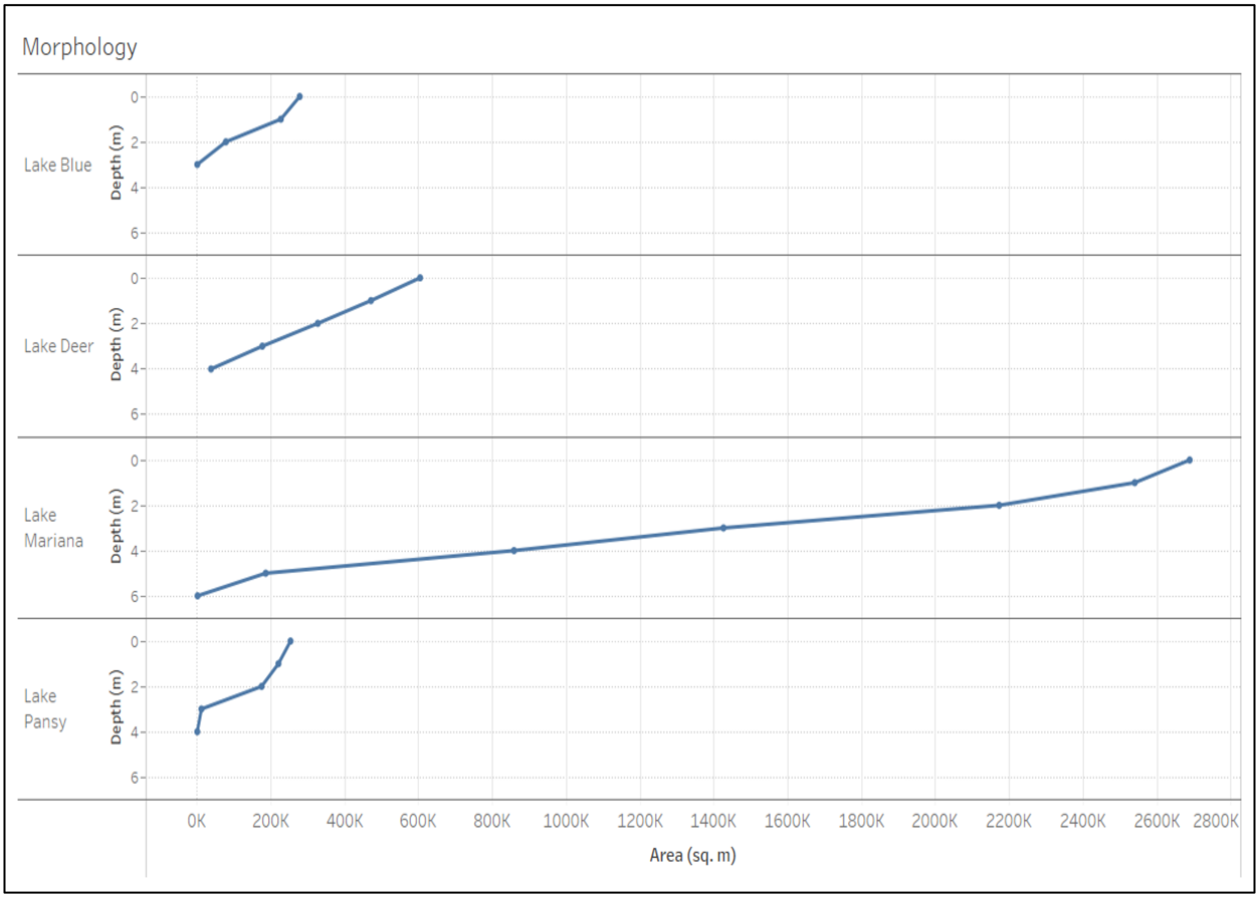


Figure 2-37. Outlying Lakes hypsographs depicting cumulative area in descending 1 meter intervals.

Ecology

Ecological evaluation is a major component of the lake health assessment. Aquatic vegetation abundance and diversity measures are used to determine the overall health of each waterbody's biological communities. In order to obtain this information, the City performs annual vegetation surveys using point-intercept sampling and SONAR mapping methods. The City's dataset for the Outlying Lakes began in 2017, with a subsequent survey performed in 2018. Future surveys will allow lake managers to track changes in these communities over time and implement appropriate management strategies for each lake's unique characteristics.

Categorizing the vegetation types found in each waterbody allows for general assumptions to be made about the communities found within. These categories include emergent aquatic vegetation (EAV), submerged aquatic vegetation (SAV), and floating vegetation (FV). Figure 2-38 shows the vegetation percentage of each lake in this group. Within the OL, Lakes Deer and Mariana both possess a healthy balance of EAV and SAV, while Lakes Blue and Pansy have very little in the way of SAV. Lake Blue's inability to support much SAV is expected due to its poor water clarity. Lake Pansy, however, has moderate Secchi depths and a shallow basin which should facilitate SAV growth. It may be that the benthic sediments are not ideal or that the lake's color is block too much sunlight for SAV to expand. Further study is needed to better understand the underlying cause.

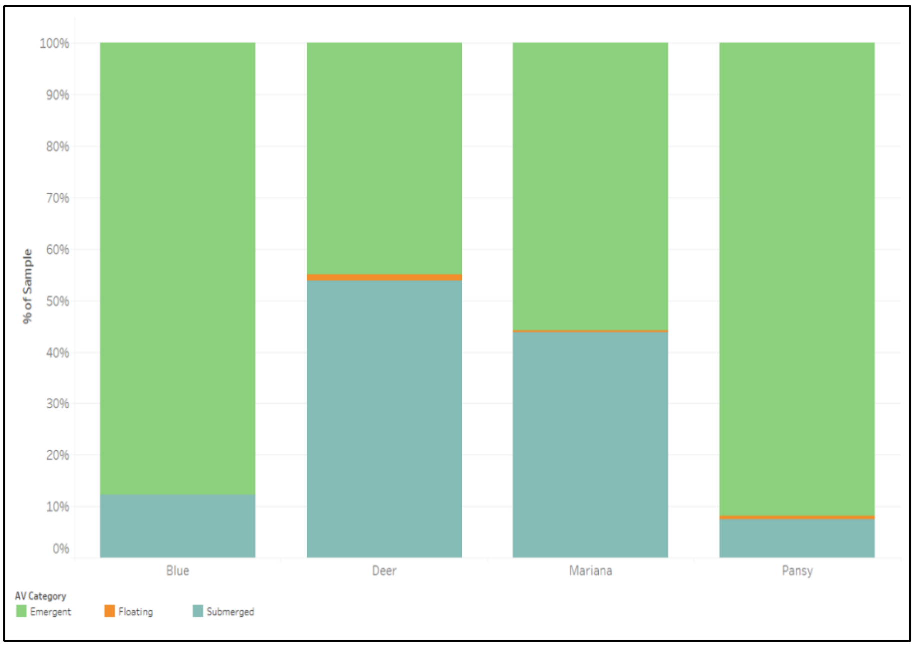


Figure 2-38. Outlying Lakes categorical proportion of aquatic vegetation as emergent, submerged, or floating.

Vegetation abundance data has been collected via SONAR mapping. Two primary metrics are incorporated into abundance—percent area cover (PAC) and mean percent biological volume (% BV). These metrics represent the amount of rooted vegetation detected as it relates to lake surface area and volume respectively. State environmental agencies consider a PAC range of 15 – 30% ideal for the propagation of healthy fish populations. As a result, the City utilizes these values as a lake health indicator. Figure 2-39 displays 2017 and 2018 PAC and % BV for the Outlying Lakes. As of 2018, all OL lakes met the 15% target threshold for vegetation coverage—in all cases, PAC increased from the previous year. Lake Deer, in particular, had a very dense eel grass (*Vallisneria americana*) population which contributed to its high PAC value. The dominant taxa in Lake Blue was the EAV species: pickerelweed (*Pontederia cordata*); in Lake Mariana, Illinois pondweed (*Potamogeton illinoensis*) presence was greatest; and spatterdock (*Nuphar advena*) was the predominant species in Lake Pansy.

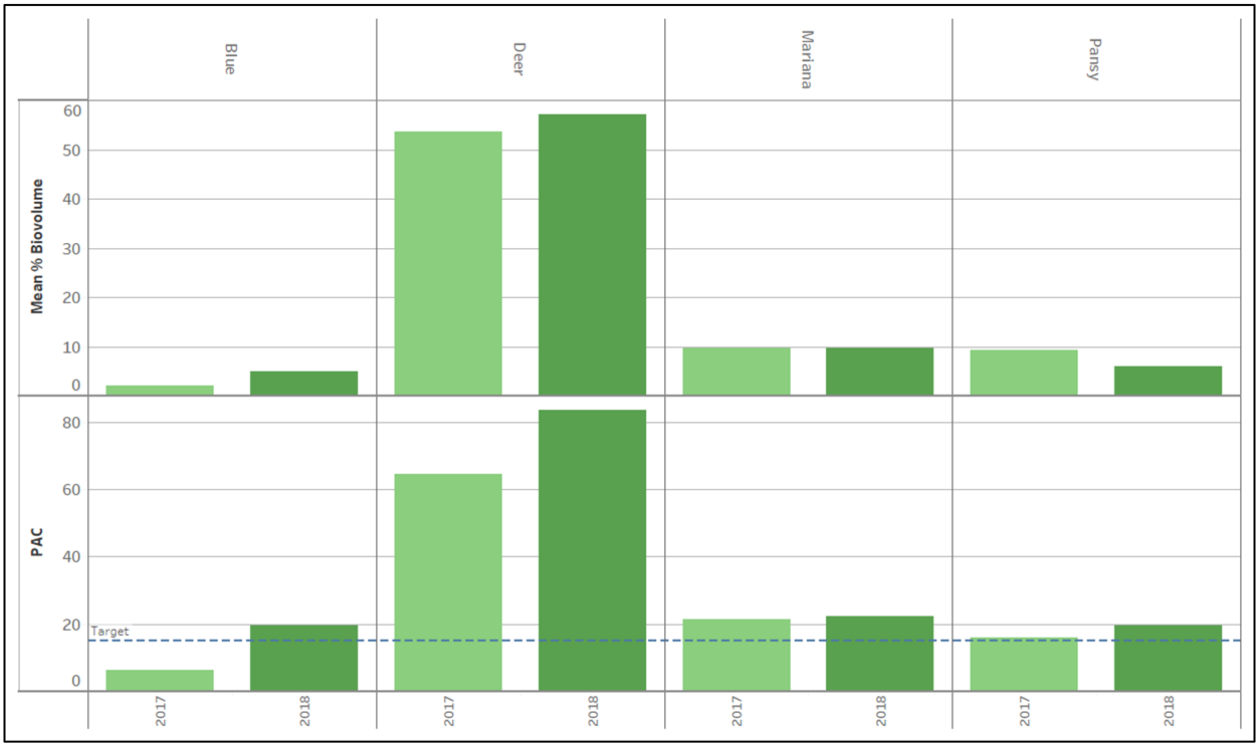


Figure 2-39. Outlying Lakes annual aquatic vegetation percent area coverage and mean percent biovolume.

The presence of invasive species is another important lake health indicator. Exotic species can outcompete natives causing wildlife that rely on the native vegetation to decline. The City employs an early detection, rapid response strategy to manage invasive species as the treatment of large quantities at one time can facilitate the release of large amounts of nutrients as the treated plants decompose. Tracking these exotic species is one of the primary reasons why the current monitoring program exists. The primary managed invasives found in the Outlying Lakes from 2017 to 2018 are displayed in Figure 2-40. Lake Blue is absent from this chart due to its lack of managed invasive species such as hydrilla (*Hydrilla verticillata*) and 2017 data for Lake Pansy is not represented due to a lack of managed invasives sampled during that time. Lake Deer, on the other hand, saw a considerable increase in invasive percentage from 2017. This waterbody is currently undergoing treatments to reduce hydrilla and water hyacinth (*Eichhornia crassipes*) numbers. Lake Mariana saw little change in its overall invasive percentage, however some hydrilla was traded for water hyacinths. Mariana will be monitored closely to ensure these species do not expand. Lake Pansy possesses a large percent of the emergent species known as burhead sedge (*Oxycaryum cubense*). This species can often form floating tussocks and spread to other areas of a lake which is why it is placed on the list of managed invasives in this study area.

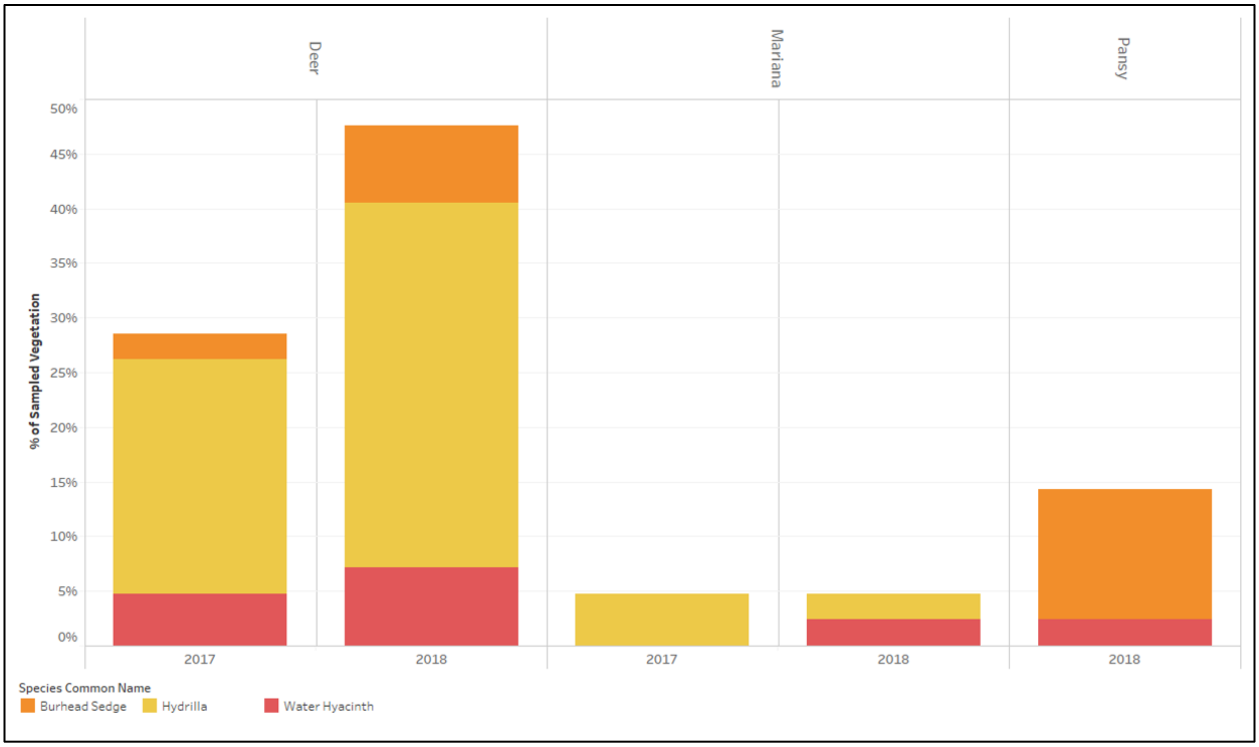


Figure 2-40. Outlying Lakes annual percentage of managed invasive species.

Species diversity is the final biological lake health indicator presented here. Species frequency data is used for the calculation of diversity index values. Species richness, evenness, and overall diversity are accounted for in the diversity lake health score. Monitoring changes in these index values over time allows for the tracking of vegetation community health over time. Figure 2-41 displays the 2017 and 2018 diversity index values for the Outlying Lakes.

Menhenick's Richness (R2): A change in R2 represents a change in the number of unique species found during sampling. From 2017 to 2018, Lake Blue, Deer, and Mariana experienced a decrease in richness, while Lake Pansy saw an overall increase.

Hill's Evenness #3 (E3): Species evenness is a measure of the relative proportion of each species in a waterbody. Lakes Blue and Deer exhibited an increase in E3 from 2017 values, while Lake Mariana and Pansy showed a decreased in evenness during the same period.

Shannon's Diversity (H): This index measures the uncertainty of finding the same species multiple times during sampling—the higher this uncertainty, the greater the diversity. Lakes Blue, Deer, and Mariana experienced a decrease in overall diversity in 2018. In contrast, Lake Pansy saw an increase in overall diversity from 2017 to 2018.

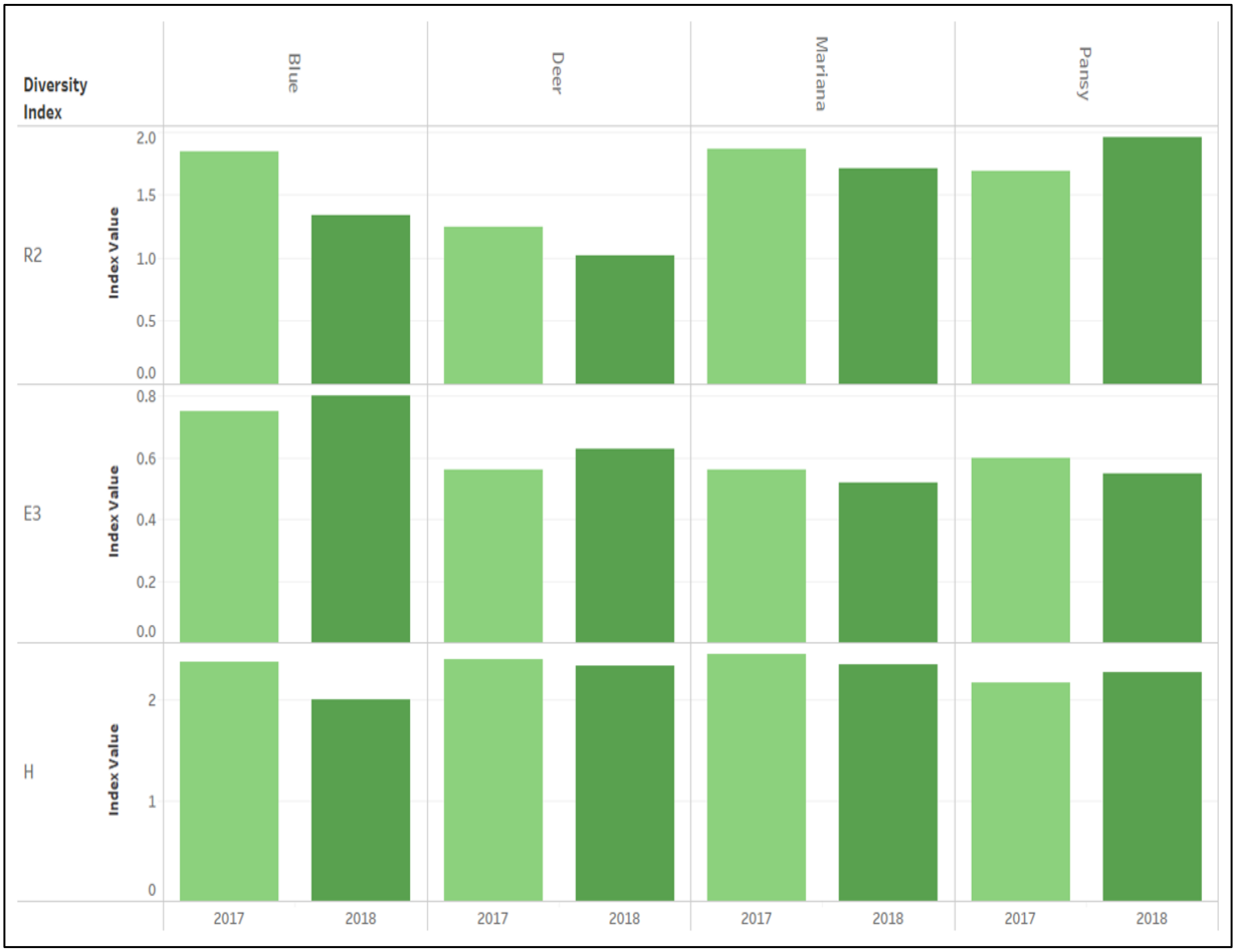


Figure 2-41. Outlying Lakes annual index values for species richness, evenness, and diversity.

2.6 Lake Health Scoring

Utilizing the data presented in this chapter, each waterbody has received scores for the various lake health indicators. These individual indicator scores have been averaged to derive an overall lake health index value. The index ranges from 0 (poor) to 3 (exceptional) and allows for an objective comparison of lakes based on water quality and ecological components (see Table 2-6). While this evaluation technique does not incorporate all factors that contribute to lake health, it provides a more comprehensive evaluation.

It should be noted that individual lake health values are relative to the waterbodies in this study area and are not absolute measurements of lake condition. Therefore, a low score may not necessarily indicate an unhealthy waterbody in a state-wide or national context, only that the lake in question is underperforming when compared to local waterbodies. Since lakes are evaluated annually, index values are not static and can change from year to year due to natural fluctuations or human influence. Moreover, the lake health index is not intended to be used in any official regulatory capacity. This data-driven tool was developed by Winter Haven's Natural Resources Division to identify waterbodies requiring greater management influence. With this information, the City hopes to maximize the effectiveness of its current lake management strategies and increase environmental stewardship from residents through knowledge and understanding. While this report does not include lake-specific strategic recommendations, it is anticipated that any subsequent management plans and future annual reports will delve into the subject.

Below are the top-priority waterbodies in each lake group with an explanation for why they received relatively low scores:

North Chain of Lakes: Lake Hamilton received a low index value due to multiple NNC impairments as well as negative trends in Chla, TN, and clarity. Due to a lack of data, it could not be determined whether plant species diversity is increasing or decreasing—leading to a low indicator score.

South Chain of Lakes: Lake Hartridge scored low because of current NNC impairments as well as declining water quality trends in Chla, TN, and clarity.

North Central Lakes: Despite a lack of current NNC impairments, Lake Martha is exhibiting negative trends in all water quality parameters. In addition, its low aquatic vegetation abundance means that it lacks habitat for fish and wildlife as well as the ability to buffer against changes in water quality.

South Central Lakes: Lake Elbert ranks lowest in this group, however its index score is marginally higher than the other waterbodies listed here. The primary contributors of this score stem from a large presence of invasive species as well as a decrease in overall plant diversity from the previous year.

Outlying Lakes: Lake Mariana received a low index score due to its multiple NNC impairments and a decrease in species diversity from 2017.

Lake Group	Waterbody	NNC Impairment	WQ Trend				PAC	% Inv	Diversity	Lake Health Score
			Chla	TN	TP	Secchi				
North Chain of Lakes	Lake Conine	0	2	2	2	3	2	0	3	1.8
	Lake Fannie	0	1	1	2	2	2	0	3	1.4
	Lake Haines	0	2	3	2	3	2	0	1	1.6
	Lake Hamilton	0	0	0	3	0	1	2	0	0.8
	Lake Rochelle	0	3	2	3	3	3	1	3	2.3
	Lake Smart	0	2	1	2	2	1	2	1	1.4
	Little Lake Hamilton	0	1	1	2	1	2	2	0	1.1
	Middle Lake Hamilton	0	1	2	3	2	1	2	0	1.4
South Chain of Lakes	Lake Cannon	0	2	3	2	3	3	2	2	2.1
	Lake Eloise	0	2	2	2	3	1	2	1	1.6
	Lake Hartridge	0	0	0	2	0	3	2	1	1.0
	Lake Howard	1	3	3	2	3	3	2	2	2.4
	Lake Idylwild	1	2	1	3	2	3	2	1	1.9
	Lake Jessie	0	1	1	3	2	3	2	0	1.5
	Lake Lulu	0	3	2	3	3	3	2	1	2.1
	Lake May	0	3	3	3	3	3	1	0	2.0
	Lake Mirror	3	3	3	3	3	3	2	0	2.5
	Lake Roy	3	3	3	2	3	3	2	2	2.6
	Lake Shipp	0	3	3	3	3	3	2	1	2.3
	Spring Lake	3	3	3	3	3	3	1	2	2.6
	Lake Summit	3	3	3	3	3	3	2	1	2.6
	Lake Winterset	3	3	3	3	3	2	2	3	2.8
North Central Lakes	Lake Buckeye	3	3	3	3	3	3	0	0	2.3
	Lake Idyl	0	1	1	1	2	3	2	0	1.3
	Lake Martha	3	0	0	0	0	0	3	1	0.9
	Lake Maude	3	3	3	2	3	3	1	2	2.5
	Lake Silver	3	2	2	2	1	0	3	1	1.8
South Central Lakes	Lake Elbert	3	0	1	1	1	3	0	1	1.3
	Lake Link	3	2	3	2	2	3	1	2	2.3
	Lake Mariam	3	1	2	2	3	1	0	1	1.6
	Lake Otis	2	2	2	2	2	2	1	1	1.8
Outlying Lakes	Lake Blue	0	2	2	3	2	2	3	1	1.9
	Lake Deer	0	2	2	2	2	3	0	1	1.5
	Lake Mariana	0	1	1	2	1	2	1	0	1.0
	Lake Pansy	3	0	1	1	1	2	0	2	1.3

Table 2-6. Lake health score chart for the Winter Haven area waterbodies.

3- Management Strategies

Summary

Successful lake management programs are not solely defined by the number and types of strategies and practices implemented. Managers must also be cognizant of the characteristics and challenges presented by the waterbodies and their surrounding watersheds and use this understanding to select the most effective practices for each scenario. The lakes in the Winter Haven management area are unique due to their density, location, and status as social, economic, and environmental resources to the surrounding community. One of the primary challenges of managing dozens of lakes located within a relatively urban environment involves balancing the diverse needs of the various lake user groups while also maintaining the health of the waterbodies being used. A robust vegetative community, for example, may be considered favorable for fishing and water quality, however too much can cause issues for recreational activities such as boating or skiing. Furthermore, a data-driven approach is necessary to ensure that any proposed management strategies are based on objective, factual information. These concepts are such an integral part of the City's Natural Resources Division strategy that they have been incorporated into its Mission, Vision, Purpose, and Values (MVPV) detailed below. The City's Lakes Advisory Committee was integral to the development of the Division's MVPV. This chapter presents information on the primary lake management strategies employed by the City as seen through the lens of the Division's MVPV.

Mission:

Maintain and improve local natural resources through management based on a sound understanding of social, economic, and ecological systems.

Vision:

To be the premier knowledge base for local natural resources, with an engaged public, supporting natural systems through a community ethic.

Purpose:

Balance the needs of diverse user groups to sustain natural resources the community can be proud of.

Values:

Courteous, Cognizant, Cooperative, Resourceful, Responsive, Accurate, Adaptive

3.1 Structural Management Practices

Stormwater Assessment and Improvement Project

Summary:

Winter Haven's stormwater system is a network of drainage pipes, ditches, and other conveyances that capture surface water runoff and move it to storage ponds or, more often, directly into lakes. The Stormwater Assessment and Improvement Project (SAIP) was drafted by the City, in conjunction with various agencies and organizations, employing a holistic approach to planning maintenance and improvements to the stormwater infrastructure. This project was 100% funded by a legislative appropriation administered by the Florida Department of Environmental Protection (FDEP) and involves a four-pronged approach that includes:

1. Refining the current geospatial database of stormwater infrastructure: The City utilizes ArcGIS—a geographic information system (GIS) program that allows users to create, analyze, and manipulate geospatial data—to store information on the network of stormwater pipes and outfalls. The engineering firm, Chastain Skillman, has been employed by the City to update the currently outdated and fragmented inventory map to one that is more cohesive. Additionally, this updated database will include a standardized procedure for entering new stormwater information.

2. Ground truthing existing and previously unidentified stormwater infrastructure: Chastain Skillman has worked closely with the City to evaluate the current condition of the various pipes, drains, and other conveyances. Factors such as pipe and drain size, material type (e.g. concrete, steel, etc…) and flow capacity. This evaluation allows the City to more efficiently prioritize management and repairs to the existing stormwater infrastructure.

3. Hydrologic modeling contracted through Chastain Skillman, which incorporates accurate topographic, surface water, and groundwater information to identify surface water flow to the lakes and estimate pollutant loading. Results from this model can be used to identify areas within the City that experience the greatest potential for flooding during storm events as well as drainage basins with high nutrient loading potential. Cooperation with the Southwest Florida Water Management District (SWFWMD) has allowed for the collection of Light Detection and Ranging (LiDAR) data used in the development of a highly detailed topographic map of the City. This collaboration with the District provides the City with services and data it could not have achieved alone with a limited budget.

4. Identification and prioritization of targets for improvement by incorporating all of the previously mentioned methods. This suite of information will allow City employees to pinpoint problem areas and make informed decisions when prioritizing improvements. Understanding where resources should be focused is paramount when time and funds are in limited supply. Moreover, the implementation of an asset management program will greatly enhance the speed and efficiency of repairs, maintenance, and improvements to Winter Haven's stormwater systems. Figure 3-1 displays the locations of high priority target areas within the City as identified by initial evaluation by the SAIP.

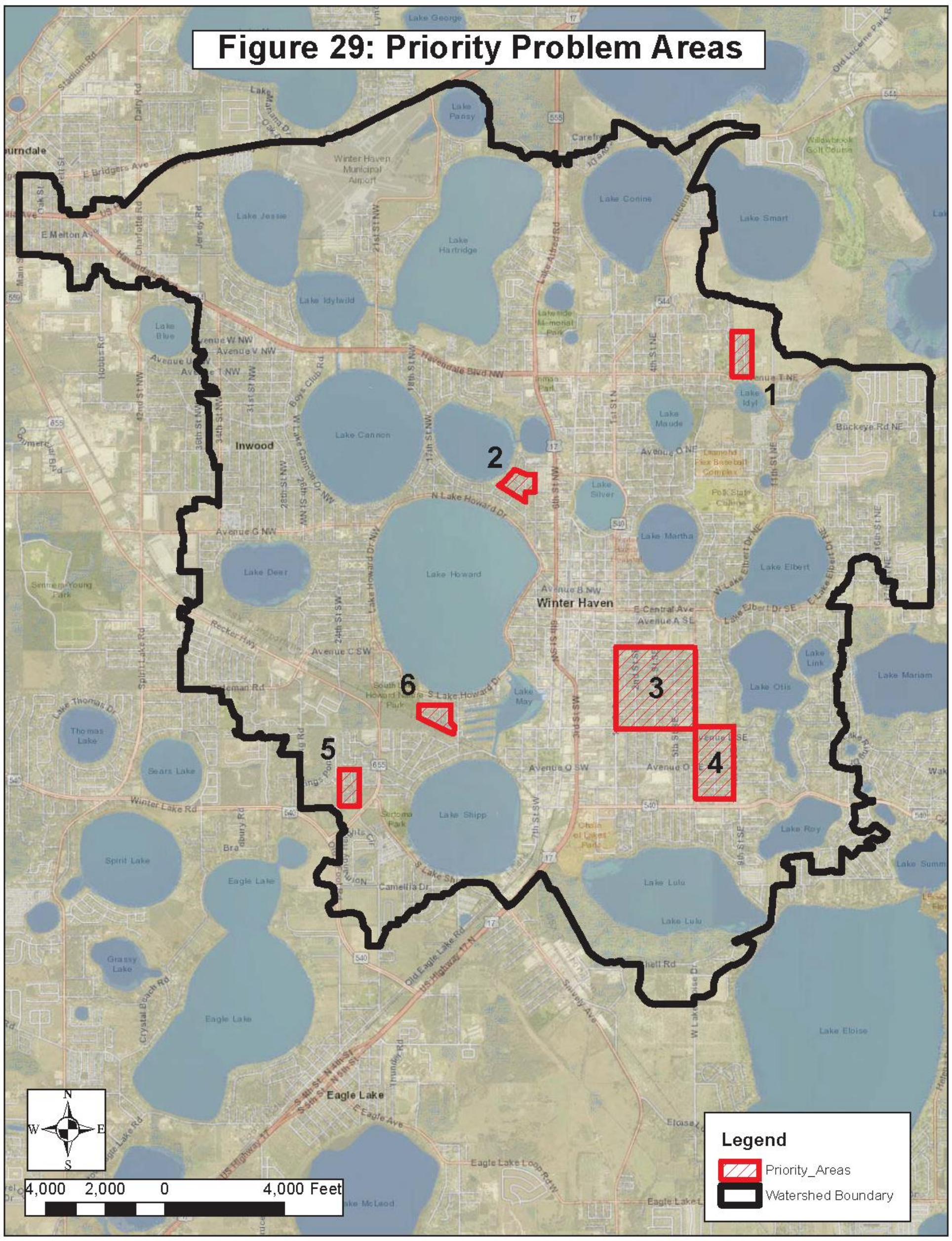


Figure 3-1. Priority sites indicated by increased flooding and pollutant load potential as determined by the Winter Haven SAIP.

Public Benefit:

Using this data to drive decisions related to stormwater maintenance and improvement allows the staff to make efficient decisions about projects with the highest return on investment.

Support of Mission, Purpose, and Vision:

Stormwater is a major component of the “social, economic, and ecological systems” identified in the Mission and having a “sound understanding” of this system positions staff to fulfill the Division’s Purpose. Having this understanding also positions the City to be the “premier knowledge base for local resources” in support of the Vision which gives the community an advantage when working to address State and Federal mandates.

Strategic Goals:

- By early 2019, identify high priority areas within the City and begin development of infrastructure improvement plans
- By the end of 2019, full implementation of asset management programs within Public Works to improve infrastructure maintenance procedures

Completed Objectives:

- ✓ Inventoried and assessed all City stormwater infrastructure
- ✓ Collected LiDAR and developed a stormwater flow & inundation model for the Winter Haven area

Alum Treatment

Summary:

Aluminum sulfate (Al_2SO_4), also known as alum, has been a popular treatment option for surface waters in order to reduce concentrations of phosphorus, total suspended solids (TSS), algae and nitrogen originating from stormwater inputs. Alum injection is a stormwater management solution that can be especially useful in locations where the area for large settling ponds does not exist or as an alternative to less stable chemical coagulants. On contact with water, alum forms a precipitate or gelatinous floc in the water column. Nutrients and sediments adsorb to the alum floc which eventually falls out of solution and can be collected in settling reservoirs or allowed to settle in the treated waterbody (Figure 3-2). This alum floc is stable in a pH range of 5.5 – 7.5 [17]. Since Winter Haven's lakes are generally alkaline with stable pH levels, they make good candidates for alum treatment as there is little risk of the precipitate re-dissolving into the water column. The efficiency of pollutant removal via alum treatment varies dependent upon dosage, injection method, and ambient pollutant concentration in the treated waterbody. Alum may also be broadcast across an entire lake surface in order to create a barrier over nutrient-rich sediments, thereby reducing the influx of pollutants such as phosphorus. This capping process is one solution for lakes that have received historic point-source discharge.

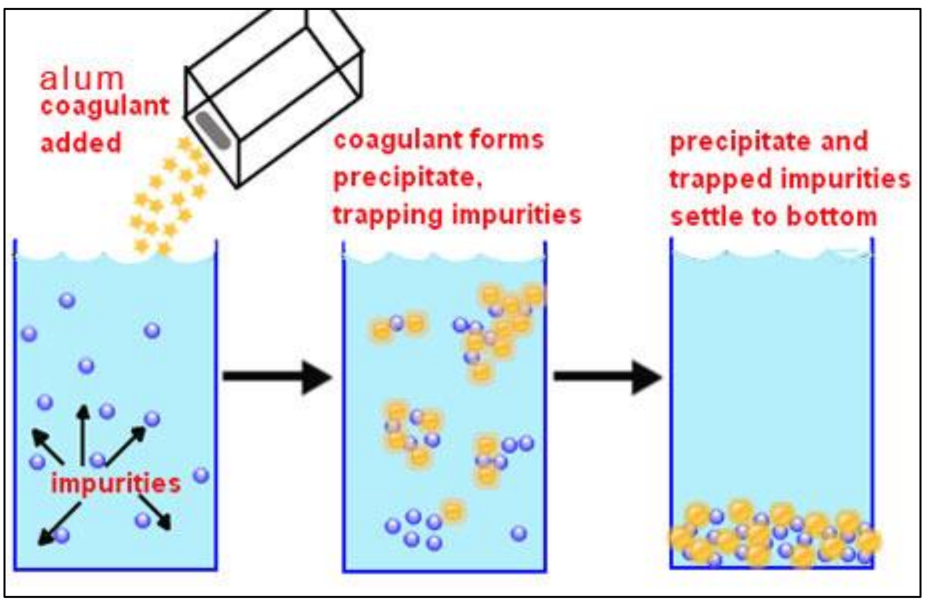


Figure 3-2. Diagram of alum floc adsorption properties. [16]

The City currently maintains three alum injection sites at points on Lakes Howard, Lulu, and May. Additionally, a broadcast alum treatment was contracted by the County in the mid-1990's to cap internal phosphorus loading from historic point-source discharges in Lake Conine [18]. The City's management goals for the three alum injection sites on the South Chain of Lakes involve updating the outdated equipment and developing an internal maintenance plan. Additionally, the City is interested in developing a study to determine current nutrient reduction efficiency of alum in these lake systems.

Public Benefit:

Alum's ability to make nutrients biologically unavailable is a viable option to reduce pollutant loads from stormwater. While alum does not intrinsically reduce ambient TN or TP concentrations in a waterbody, it actively works to prevent further decline in water quality.

Support of Mission, Purpose, and Vision:

Alum Injection is a management strategy that strives to "Maintain…local natural resources" as stated in the Mission. Alum injection will not solely cause improvements in lakes, but it does help to limit further impacts from being realized. By reducing stormwater impacts, lake systems become more predictable making it is easier to manage systems to "the needs of diverse user groups" as outlined in the Purpose. Alum injection is an interesting process and it provides an opportunity to talk with residents about it and other management tools and the effectiveness of different management strategies. This helped to create the "engaged public" identified in the Vision.

Strategic Goals:

- Prepare to implement improvements as part of FY 19-20 budget
- Coordinate the development of a maintenance strategy during the improvement process
- By the end of 2020, develop a strategy to evaluate pollutant load reduction efficiency of systems

Completed Objectives:

✓ Inspected the City's alum injection facilities to identify repair & improvement needs

Low Impact Development & Green Infrastructure

Low impact development (LID) and green infrastructure are terms referring to practices that incorporate natural processes in the development of stormwater systems. Traditional, or “gray”, stormwater infrastructure relies on impervious materials, gutters, and pipes to transfer runoff from one area to another. Typically, these systems are implemented in urban areas to prevent flooding by directing stormwater to a nearby catchment or basin. In the Winter Haven area, gray infrastructure diverts runoff, as well as any pollutants, directly to lakes or stormwater ponds. In contrast, green infrastructure and LIDs utilize plants and soil characteristics to promote stormwater treatment and groundwater infiltration; resulting in cleaner and/or less runoff entering local waterbodies. Examples of green infrastructure and LIDs include raingardens, bioswales, pervious pavement, and exfiltration structures (French drains). Figure 3-3 displays one of several raingardens located within downtown Winter Haven.

Figure 3-3. Photo of a raingarden capturing runoff and road debris in downtown Winter Haven.

If designed properly and placed in appropriate areas, LIDs are able to capture sediments, heavy metals, and solid refuse during the first flush of a rainfall event, preventing it from entering the stormwater infrastructure. Employing well-drained soils to promote percolation, flooding along roadways can be reduced during 1-year to 10-year storm events. Planting of appropriate vegetation can also allow for nutrient uptake while also beautifying the urban landscape. In many cases, LIDs can be utilized in lieu of traditional stormwater ponds in city planning; often occupying smaller footprints than traditional stormwater ponds while mitigating similar volumes of stormwater. Green infrastructure can benefit developers by reducing the area devoted for stormwater mitigation and can often be more aesthetically pleasing.

Currently the City has constructed over 60 raingardens and exfiltration systems in and around Winter Haven’s urban center. Lakes receiving stormwater benefits from these systems include: Lakes Elbert, Howard, Martha, Maude, May, Otis, Roy, and Silver. Nutrient removal capabilities are minimal on an individual basis, however LIDs can collectively have a greater impact in larger numbers as more stormwater is treated. Moreover, relatively low construction costs in addition to the aforementioned benefits make low impact projects an elegant solution for future stormwater treatment in the urban cityscape.

Public Benefit:

Low impact development and green infrastructure projects provide multiple benefits including stormwater pollutant load reduction, groundwater recharge, reduced ponding in roadways, and aesthetic improvements. These social, economic, and environmental benefits make LID implementation an efficient and effective management strategy for the City.

Support of Mission, Purpose, and Vision:

LID implementation directly supports the Mission by using "a sound understanding of social, economic, and ecological systems." To "Maintain and Improve local natural resources". Improving hydrology and water quality help to "balance the needs" identified in the Purpose. LID construction is a realization of the Vision, in that the City has received outside support because other agencies recognized the City is the "premier knowledge base for local natural resources".

Strategic Goals:

- By the end of 2019, incorporate all LIDs and green infrastructure into the City's asset management inventory
- Pursue funding to design and construct additional LIDs
- By end of 2019, begin incorporating LIDs into a routine maintenance schedule

Completed Objectives:

- ✓ Renegotiated contracts with funding partners to more realistically meet defined benefits

Stormwater Treatment Parks

Stormwater treatment parks, or nature parks, are engineered wetlands that perform similar functions as other forms of low impact development. The primary focus of nature parks is to reduce the impact of non-point source pollution on target waterbodies by treating surface runoff and stormwater effluent. Comprised of one or more reservoirs, designed with long retention times, and seeded with communities of natural wetland vegetation, nature parks receive redirected stormwater discharge and allow it to slowly pass through the reservoirs before releasing the treated water to an adjacent lake. The multiple aspects of this treatment process include: nutrient reduction via plant uptake, reductions to turbidity and suspended solids via sedimentation, capture of solid refuse, and an increase in water color through the introduction of dissolved tannins (organic matter). Secondary goals for these treatment parks are to create wetland habitat, increase biodiversity of wetland flora and fauna, introduce opportunities for public education, and provide recreational areas and green spaces. Maintenance of stormwater treatment parks involves ensuring all flow-ways are clear and free of dense vegetation or debris, treating invasive species, and occasionally removing excess sediment that builds up over time.

Figure 3-4. Map depicting the Winter Haven nature parks and their drainage basins. Also included is the proposed location of the Lake Conine Nature Park.

The City of Winter Haven maintains three nature parks adjacent to Lakes Howard, Hartridge, and Maude respectively. The South Lake Howard Nature Park is a roughly 16-acre park that treats a sizable 394-acre drainage area. The 9.4-acre Lake Hartridge Nature Park receives and treats runoff from a 56-acre basin. Lake Maude Nature Park, the smallest of the three at 6.4-acres, treats an approximately 18-acre contributing drainage basin. A fourth park which will be located on the southern shore of Lake Conine is currently in the process of selecting a construction contractor. This constructed wetland is designed to treat a drainage greater than 300 acres. A map of these nature parks and their drainage basins are displayed in Figure 3-4.

Public Benefit:

Stormwater treatment parks reduce stormwater pollutants from entering lakes. The uptake of nutrients via the aquatic plants, sediment settling in ponds, and capture of solid waste are the mechanisms that benefit lake health. In addition, each park benefits the community by providing a recreational space utilized by local residents.

Support of Mission, Purpose, and Vision:

Nature Parks are similar to LIDs in that they directly support the Mission by using "a sound understanding of social, economic, and ecological systems." To "maintain and improve local natural resources". Improving hydrology and water quality help to "balance the needs" identified in the Purpose. Their Construction is a realization of the Vision, in that the City has received outside support because other agencies recognized the City is the "premier knowledge base for local natural resources".

Strategic Goals:

- Continue to maintain beneficial communities of native vegetation in Lakes Howard, Hartridge, and Maude nature parks
- By FY 19-20, complete contractor selection for construction of the Lake Conine Treatment Wetland

Completed Objectives:

- ✓ Lake Hartridge and South Lake Howard Nature Parks have been brought to a satisfactory maintenance phase
- ✓ As of early 2019, the marsh and forested wetland areas of Lake Maude Nature Park have been brought to a satisfactory maintenance phase

Floating Wetland Treatment

Summary:

Due to the nutrient absorption qualities of aquatic plants and wetland areas, they are often considered a natural treatment mechanism in lakes and ponds. During the normal plant life cycle, the nutrients that are sequestered in plant tissue can be released again as aquatic vegetation decomposes. Removing vegetation before it can undergo decomposition effectively reduces the nutrient load within a given waterbody. Recent research into temporary wetlands has yielded positive results with regards to ambient nutrient concentration reduction in lakes and ponds [UCF FTW Report]. Implementation of floating treatment wetlands (FTW) provides this benefit at generally lower installation and maintenance costs compared with a constructed shoreline wetland.

In late 2017, the City installed a FTW as a pilot project in a wet retention pond that discharges to Lake Martha at high surface levels (see Figure 3-5). The pond drains a sizable recreational ball park owned by Polk State College and maintained by City Parks and Grounds staff. This site was chosen because of its ongoing issues with nuisance plants like duckweed (*Lemnoideae spp*.) and snails that feed on aquatic vegetation—likely caused by nutrient-rich runoff from the ballfields. For several years, the snails have undergone a population explosion and subsequent die-off resulting in an unpleasant odor for the surrounding neighborhood. The City sought a means to lower nutrient concentrations in hopes of reducing the snails' food source and preventing their exponential growth. Partially funded through a Florida Lake Management Society grant, the goal of this project was to determine the effectiveness of FTWs as a nutrient reduction best management practice while also incorporating an educational citizen outreach component.

Figure 3-5. Photo of Floating Treatment Wetland installed at Polk State College recreational complex.

After a 12 month growing cycle, the pond experienced a marked reduction in TN from initial concentrations, albeit with little change in TP. More significantly, no reports of foul odors from the pond were received in 2018. In an effort to fulfill the educational component, the City hosted an aquatic plant giveaway for local lakeshore property owners. Attendees of the event received several plants harvested from the floating wetland to transplant on their property while also learning about the aesthetic and ecological benefits of aquatic plants and living shorelines. In total, over 120 individual plants were distributed. The City also replanted the FTW in order to continue studying the long-term effectiveness of nutrient reduction in the pond.

Public Benefit:

Through the City's efforts, it was determined that the floating wetland significantly reduced nitrogen concentrations in the study pond. The absence odor reports from nearby residents may indicate a shift in the pond's ecology as a result, however this claim is purely anecdotal until evidence can be brought forth. Finally, this project has contributed to citizen engagement by providing an educational opportunity in the plant giveaway event.

Support of Mission, Purpose, and Vision:

This pilot project is an implementation of the Mission as it is derived from an understanding of the "social, economic, and ecological systems" that govern the existing stormwater pond and the impacts that can be felt by the community and the adjacent lake. Currently this pond can reach conditions deemed undesirable by the local stakeholders, this project is designed to alleviate those conditions by restoring "natural resources the community can be proud of" as is part of the Division's Purpose. By engaging in this pilot project the City will deepen it's understanding of potential best management practices, further supporting its position as "the premier knowledge base for local natural resources" and creating an opportunity to engage the public in conversations about management strategy which works to achieve the Vision.

Strategic Goals:

- Continue to monitor water quality and ecology in the stormwater pond until end of 2019
- By end of 2019, harvest and restock FTW
- Develop feasibility plan to install additional FTWs by 2020
- By early 2020, host another public education & plant giveaway event

Completed Objectives:

- ✓ Successfully hosted a public education & outreach event which allowed for the distribution of over 120 wetland plants to be planted on private lakeshores in the Winter Haven area
- ✓ Restocked the FTW with multiple species of native aquatic plants
- ✓ Documented the FTW's effectiveness in reducing TN concentrations and limiting the impact of snail population growth

3.2 Non-structural Management Practices

319 Gray to Green

Summary:

The use of low impact development (LID) and green infrastructure can provide benefits over traditional "pipe and pond" (gray) infrastructure by means of slowing, spreading, and soaking stormwater runoff; thereby promoting groundwater recharge and reducing pollutant loading from urban areas. The City of Winter Haven has become a forerunner in the process of prioritizing the design and implementation of green stormwater infrastructure. It was determined, however, that the adoption of the gray to green mindset by the local community would be necessary to protect our surface water and groundwater resources. By virtue of this, the City has initialized a plan to develop and implement a public education program targeting local engineers, developers, and City staff to provide the tools and information required for this shift in stormwater management focus.

In 2018, the City held public meetings with the local development community in an effort to create guidelines for the design and implementation of LIDs. Funding for this effort was sourced from a United States Environmental Protection Agency (EPA) 319 Education Grant administered by the Florida Department of Environmental Protection (FDEP) through "DEP AGREEMENT NO. NF015". Based on feedback from these meetings, the community identified several barriers for the utilization of green infrastructure. As a result, the City's Natural Resources Division developed a strategy to work with state permitting agencies and create a localized design methodology and manual based on Winter Haven's specific hydrologic conditions. To offset the cost of this endeavor, the City applied for and received a second 319 Education Grant through "DEP AGREEMENT NO. NF050".

The primary objectives for this upcoming phase of the 319 Gray to Green program, to be completed by July 2021, are summarized below:

1. Develop a localized stormwater permit design methodology and manual in cooperation with state permitting agencies.

2. Implement an education program to guide local developers, engineers, and designers on how to utilize the methodology and technical manual.

3. Draft a final report for the FDEP summarizing the results of this project.

Public Benefit:

Developing tools and methods that allow local developers to capitalize on the benefits of LIDs and green stormwater infrastructure supports hydrologic restoration and water quality improvement in Winter Haven's lakes. This forward-thinking, educational effort will ensure that the community as a whole is aware of environmental issues and engaged in practices that enhance our natural resources.

Support of Mission, Purpose, and Vision:

This is an effort driven by the "sound understanding of the social, economic, and ecological systems" identified in the Mission. Development has economic and social benefits to the area and can also have ecological benefits if planned properly, this approach strives to "Balance the need of diverse user groups" as identified in the Purpose. By providing tools and education to the development community and internal staff the hope is to further perpetuate the "community ethic" therefore realizing the Vision.

Strategic Goals:

- By end of 2019, develop a LID design and implementation methodology and technical manual
- Begin implementing educational outreach programs by January of 2020
- By July 2021, submit a final report to FDEP detailing the results of this project

Completed Objectives:

- ✓ Hosted public meetings to obtain stakeholder feedback on the needs and limitations of the current stormwater permit regulations
- ✓ Applied for and obtained funding to continue creating opportunities for the implementation of Green Development practices

National Pollutant Discharge Elimination System

Summary:

As a directive of the United States Environmental Protection Agency (EPA), the National Pollutant Discharge Elimination System (NPDES) was created in 1972 under the Federal Clean Water Act. The NPDES is a permit system designed to regulate point source discharge into U.S. waters in an effort to improve water quality. The EPA works closely with the Florida Department of Environmental Protection (FDEP) to administer this program within the State of Florida.

Polk County is a primary permit holder in the region with numerous co-permittees under it; the City of Winter Haven is included as a co-permittee. The permit requires each co-permittee to list of all Municipal Separate Storm Sewer Systems (MS4s) maintained in their jurisdiction, document the functional maintenance of all infrastructure, track any public education initiatives that support pollutant load reduction, and monitor lake health to determine any measurable impacts.

Public Benefit:

The NPDES permit provides accountability and transparency to residents that every precaution is being taken by the organization to protect natural resources in all operations. The permit also requires the City to constantly improve their understanding of the potential local impacts and create plans for addressing those impacts.

Support of Mission, Purpose, and Vision:

By requiring the City to continually improve its understanding of the potential impacts it drives the Division to improve their "understanding of the social, economic, and ecological systems" directly supporting the Mission. "Sustaining natural resources" is a central focus of the Division's Purpose and the tracking associated with the permit has the same focus. The transparency created by the permit and the assurance to the residents that impactful activities are appropriately tracked supports the "engaged public" and "community ethic" outlined in the Vision.

Strategic Goals:

- Submit Cycle 4 Year 2 permit by end of March 2019
- Distribute Cycle 4 Year 3 permit data requests to City department heads by November 2019
- Deploy stormwater sampler and collect requisite storm event data for the primary Lake May outfall by September 2019

Completed Objectives:

- ✓ Successfully submitted Cycle 4 Year 1 permit before the March due date

- ✓ Developed internal best management practices to improve data collection and reporting efficiency

Street Sweeping

Summary:

One significant source of pollutant loading comes from sediment and debris accumulation in streets which drain to waterbodies via stormwater. Street sweeping is what is referred to as a non-structural best management practice (BMP) that helps to reduce pollutant loading by removing this debris before it can enter the stormwater infrastructure. In 2013, the City entered into a three-year contract with USA Services to sweep curbed streets in specified areas to mitigate this pollutant loading source. Areas swept include downtown and much of Winter Haven's residential areas. Department of Transportation (DOT) roads were prioritized for sweeping on a bi-weekly basis, owing to the larger concentration of nutrient runoff. The remaining residential areas were covered on a semi-annual basis. Many of the roads included in the sweeping plan fall within a major outfall basin, which is a drainage area that flows directly to the lake via a larger stormwater pipe. In 2016, the City renewed a service contract and issued an updated task order that improved upon these benefits by increasing residential sweeping to monthly and expanding sweeping coverage to priority basins (Figure 3-6). Since the contract renewal, City staff has played an active role in assessing the cost-effectiveness of the program and identifying any issues in service, producing monthly reports on the contractor's performance, to be in a good position to identify cost-savings and service improving changes in service that may need to be made when the contract period is complete in 2019.

Public Benefit:

This non-structural BMP provides a physical removal of potential pollutant sources--sediments. It also limits debris from blocking the stormwater conveyance system which can lead to flooding. Removing this debris helps to extend street lifespans while also improving the cleanliness and overall aesthetic of City roadways. This is a true preventative maintenance approach that strives to reduce pollutant loading issues at the source which is exponentially more efficient and cost-effective than in-lake nutrient reduction practices.

Support of Mission, Purpose, and Vision:

Street sweeping is a preventative maintenance activity that is managed based on the understanding of the "social, economic, and ecological systems" identified in the Mission. Debris coming out of a stormwater pipe is one of the most visible forms of pollution and street sweeping helps to alleviate this issue in an effort to "sustain natural resources the community can be proud of" as identified in the Purpose. The location and efficiency of street sweeping activities are closely monitored to understand the effectiveness of the program making the City "the premier knowledge base", as outlined in the Vision, for understanding pollutant loading of local water bodies which is beneficial in addressing State and Federal mandates.

Strategic Goals:

- Develop an outline of opportunities for alternative approaches to be contemplated for the FY 19-20 budget
- Continue to conduct monthly surveys of street sweeping activities to gauge the effectiveness and communicate deficiencies with the contractor

Completed Objectives:

- ✓ Implemented in-house strategy to evaluate the effectiveness of contracted street sweeping services

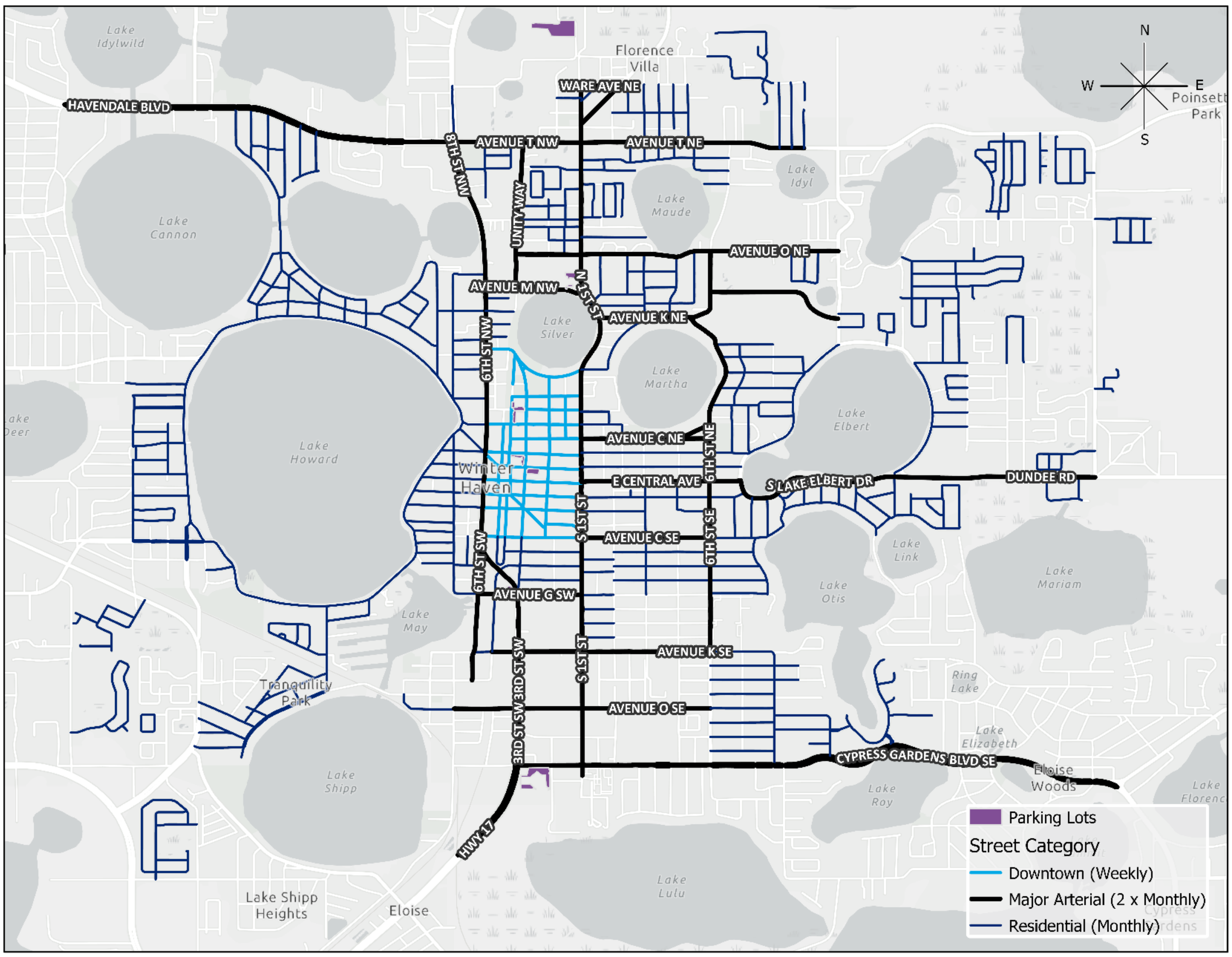


Figure 3-6. Map depicting roadways undergoing street sweeping. Legend indicates sweeping frequency of each street category.

Aquatic Vegetation Monitoring

Summary:

Aquatic vegetation monitoring (AVM) is a methodology employed by the Winter Haven Natural Resources Division to regularly assess plant abundance and diversity in City lakes. This protocol is based on a survey process developed by the Florida Fish and Wildlife Commission (FWC). Utilizing sound navigation and ranging (SONAR) technology, the Division is capable of measuring the distance from the surface to the lake bottom as well as to any vegetation in the water column. Percent area cover and biological volume make up the vegetation abundance metrics obtained through SONAR mapping. Figure 3-7 represents a biovolume heat map produced from SONAR mapping in Lake Maude. In addition, the Division performs point-intercept sampling; identifying the species present at regularly spaced points across a lake to provide a representative sample of plant diversity.

This information is then analyzed, allowing the City to incorporate vegetation data into the overall lake health evaluation. Information regarding invasive species is shared with Polk County and FWC for use in planning treatment. As this monitoring program continues, the City plans to collect multiple years of aquatic plant data to better understand the nuances of each lake's vegetative community. In addition, the Division works closely with the environmental departments of other agencies including the Cities of Lakeland and Haines City, FWC, and Polk County to coordinate monitoring strategies. The development of this Polk Regional Aquatic Vegetation Working Group has fostered beneficial relationships and support chain useful for representing the needs and interests of all parties in the region.

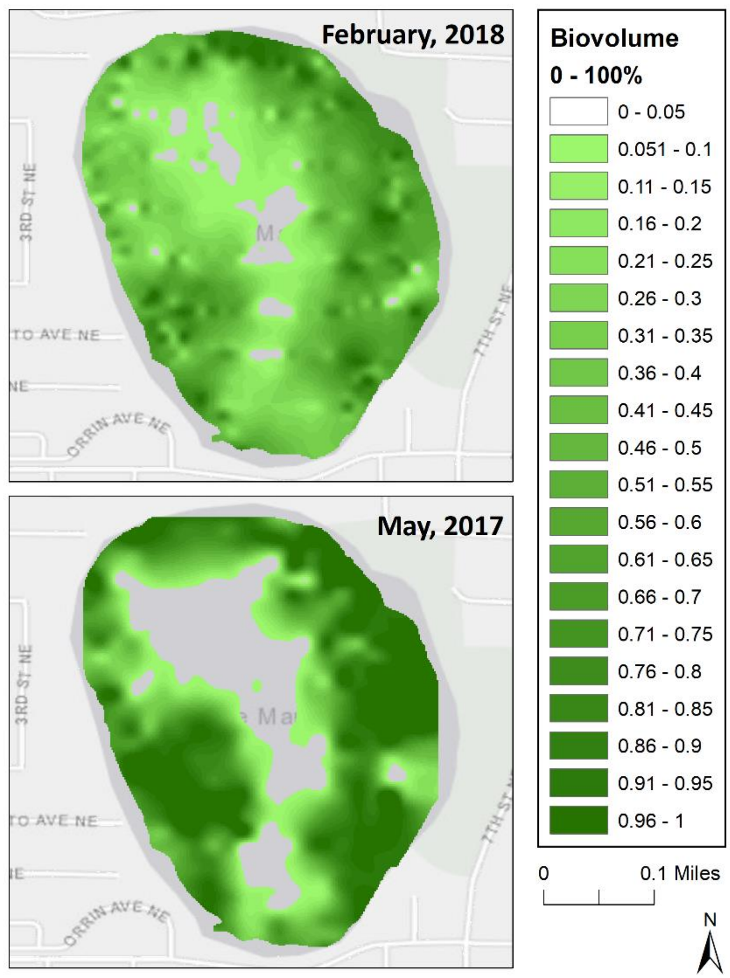


Figure 3-7. Biovolume heat map of Lake Maude. Color scale represents percent of water column occupied by plants.

Public Benefit:

Aquatic vegetation is a significant component of lake health. The early detection and rapid treatment response to invasive species ensures that waterbodies are clear and navigable for all user groups. More importantly, a thorough understanding of the ecological dynamics of aquatic plant life is crucial for lake management efforts. Major changes in vegetation communities can be indicative of negative ecological impacts. By closely monitoring these plant communities, the City can hopefully answer difficult questions and be prepared to respond with data-driven management strategies.

Support of Mission, Purpose, and Vision:

This effort supports the Mission by developing a “sound understanding of social, economic, and ecological systems” which enables the Division to serve its Purpose and “Balance the need of diverse user groups while sustaining natural resources”. This is also in fulfillment of the Vision by establishing the City as “the premier knowledge base for local natural resources” and ensuring the community is represented at the table for discussions about management of the resource.

Strategic Goals:

- By the end of 2019, collect annual vegetation data for all study area lakes; continually refine survey methods to ensure accuracy and best practices
- By the end of 2019, compare current survey protocol with Lake Vegetation Index methodology to determine efficacy
- Continue to represent Winter Haven’s interests in the Polk Regional Aquatic Vegetation Working Group

Completed Objectives:

- ✓ Completed 2018 vegetation surveys for all targeted waterbodies of interest in the study area
- ✓ Helped to re-establish the Polk Regional Aquatic Vegetation Working Group
- ✓ Performed new analysis based on time-series data; deepening understanding of local vegetative communities

Hydrologic Monitoring

Summary:

Hydrologic monitoring is a practice that provides information on the quantities and movement of water in an area. Collection and analysis of rainfall, surface water, and groundwater data allows the City to build a better understanding of the relationships amongst these parameters as well as their impacts on water quality and drinking water supply. The Natural Resources Division and Utilities Department work together to obtain this data through a network of rainfall sensors, monitoring wells, and surface level gauges located throughout the City. Additional data, collected by the Southwest Florida Water Management District (SWFWMD) and the Lake Region Lakes Management District (LRLMD), is available to all interested in better understanding the local hydrology.

Hydrologic modelling was performed to identify areas with greater flooding potential as part of the Stormwater Assessment and Improvement Project. This modelling effort will also be useful in developing lake nutrient budgets as will be explained in the next section. Despite the wealth of information currently available, additional data is needed in order to build a more accurate model. As a result, the City has planned to expand its hydrologic monitoring network via installation of additional rainfall, groundwater, and surface level sensors.

Public Benefit:

Understanding the surface level impacts on lake health is crucial in the development of effective management strategies. Additionally, climate and groundwater monitoring have become increasingly important components in planning for municipal water supply needs for the future. These hydrologic elements directly impact residents' usage of local resources, therefore continued assessment is needed to ensure they are usable for years to come.

Support of Mission, Purpose, and Vision:

This activity directly supports the Mission by developing "a sound understanding of social, economic, and ecological systems". Due to the unique nature of the local system, water levels are critical not just for water quality, but also for navigation through the Chain of Lakes. Navigability is of the utmost importance to the "diverse user groups" in the Purpose, and by understanding how the local hydrology works the City is able to be the "premier knowledge base", mentioned in the Vision, that can drive decision making about management of the resource.

Strategic Goals:

- Include hydrologic monitoring expansion as part of the FY 19-20 budget preparations

- By the end of 2019, install additional weather sensors at locations throughout the City
- Coordinate with the City's Information Technology Department to identify new potentially viable monitoring options from a "Smart City" viewpoint

Completed Objectives:

- ✓ Established weather sensors at four locations throughout the City
- ✓ Assessed the limitations of current surface level monitoring equipment and explored alternative solutions
- ✓ Established monthly hydrologic reports which are displayed on the Winter Haven Natural Resources webpage

Nutrient Budgeting

Summary:

A nutrient budget utilizes external pollutant load modelling data, internal load modelling data, as well as vegetation abundance and species composition data to estimate the amount of nutrients entering and leaving a lake system. External loading includes stormwater and surface runoff, atmospheric deposition of nitrogen and phosphorus, and groundwater seepage. Internal loading accounts for the nutrient cycling or flux from lake sediments and is calculated by evaluating the physical and chemical properties of these sediments. The biological component of a nutrient budget is determined by estimating nutrient amounts sequestered in the various species of aquatic vegetation in a waterbody.

The City is currently able to model for most forms of external loading through endeavors such as the Stormwater Assessment and Improvement Project. Internal loading requires an understanding of groundwater interactions as well as benthic sediment analysis—something the City is interested in pursuing. Estimating the nutrients bound in vegetative tissues involves evaluating the chemical properties of the most common aquatic plant species found in the study area lakes. This component requires laboratory analysis to determine typical nutrient ranges within each species by weight or volume. Linking this chemical information to the vegetation abundance data collected through the City's monitoring program should allow for the calculation of nutrients bound in a given lake's aquatic plant community.

This process of nutrient budgeting is useful as it provides lake managers more information that can be used to drive decisions. For example, if the nutrient-per-mass range for an invasive species such as hydrilla is known, the City could estimate the total nitrogen and phosphorus reduction in a given lake if a specified amount of hydrilla is removed. This information can provide a quantifiable, data-driven basis to support these types of management practices.

Public Benefit:

The nutrient budgeting initiative stands to benefit residents by providing support for management practices that would improve water quality in Winter Haven's lakes. This supporting data may be used to apply for State or Federal funding to implement more intensive management strategies and assert the City's commitment to promoting healthy waterbodies.

Support of Mission, Purpose, and Vision:

This effort supports the Mission by developing a "sound understanding of social, economic, and ecological systems" which enables the Division to "balance the needs of diverse user groups to sustain natural resources". This is also in fulfillment of the Vision by establishing the City as "the premier knowledge base for local natural resources" and ensuring the community is represented at the table for discussions about management of the resource.

Strategic Goals:

- Incorporate laboratory testing as part of the Division's FY 19-20 budget and/or seek potential grant funding
- Develop a plan to incorporate sediment flux modeling as a management strategy by the start of 2020

Completed Objectives:

- ✓ Identified needs to develop a nutrient budgeting methodology

Education & Outreach

Summary:

Public education and outreach programs can be an extremely effective non-structural best management practice (BMP) recognized and employed by regulatory agencies both in Florida and nationwide. Teaching residents about the issues impacting the local environment can spark community engagement and lead to shifts in perception that can benefit people and nature alike. Discussing issues such as fertilizer use, water consumption, impacts of invasive species and herbicides, and harmful algal blooms creates relationships between the City and its residents; allowing their voices to be heard and responding with factual information.

The Winter Haven Natural Resources Division and Utilities Department actively pursue educational opportunities on a regular basis. Participation at events such as Project Eagle, the 7 Rivers Water Festival, and Water Wings and Wild Things allows the City to reach hundreds of children and adults in family-friendly venues with information on water, lakes, and wildlife. The City also hosts holiday events for the Fourth of July and Easter (Rock N' Freedom Fest & Hoppin' Hunt) where participants have the opportunity to kayak. These events allow City staff to increase awareness of our lakes as community resources. For roughly 30% of participants, this marks the first time they've participated in recreational activities on a lake, ever! Other outreach activities include Summer Camps where from June to July the Natural Resources Division hosts water education field trips for over 300 children ranging from kindergarten to 8th grade. The children are introduced to concepts of lake hydrology and biology and also get to participate in fun activities such as kayaking (Figure 3-8). The Division actively encourages practical education for high-school and college-aged students who are interested in the natural sciences as well through an internship program that focuses on data collection and analysis. Recently, focus has been placed on developing an educational program for grade-school students. The Division is currently working with the Cypress Junction Montessori School to implement a pilot program that incorporates hands-on learning in unique environments.

Figure 3-8. Photo depicting kayakers during the 2018 Summer Camp.

Public Benefit:

By providing opportunities to educate and receive feedback from residents, the City fosters public engagement on local environmental issues. An informed community is more likely to support practices and initiatives that benefit lake health. Educational initiatives aimed at children are especially important for building interest and understanding as well as promoting an environmental focus at a young age. Moreover, many residents are not aware of the resources available to them locally. By providing these introductory opportunities, the public can discover the amenities and benefits afforded by our lakes.

Support of Mission, Purpose, and Vision:

This initiative supports the City's Vision by fostering "an engaged public" through education and outreach opportunities. Over time, the hope is to see an increase in support of "natural systems through a community ethic" as residents improve their understanding of local environmental issues.

Strategic Goals:

- Continue to update and develop fun and engaging learning opportunities as part of the City's Summer Camp program
- By Fall 2019, develop and implement educational lesson plans for the Cypress Junction Montessori School
- By the end of 2019, Increase Division's outreach presence through social media and events such as Lunch-and-Learns and neighborhood discussions
- Continue to promote the City's internship program

Completed Objectives:

- ✓ Developed a more education oriented approach to City Summer Camp activities
- ✓ Staff mentored several high-school and college aged students as part of its internship program in 2018

Remote Sensing

Summary:

Water quality is a vital metric used to indicate changes and trends in lake health. The accuracy and frequency with which data is collected largely determines its effectiveness and applicability in understanding the drivers of water quality. Water quality data is currently sampled quarterly by the Polk County Natural Resources Division. While this sampling frequency is certainly useful to understand long-term trends, it overlooks weekly, monthly, and seasonal changes that occur in the short-term. Unfortunately, collection of additional water quality data for such a high density of waterbodies in the region is beyond the financial and staffing capabilities of the County and City of Winter Haven. As a result, the City has sought out remote sensing methods as a more efficient and cost effective means to gather this additional information.

The primary objective of this pilot project is to utilize remote sensed multispectral imagery to calculate ambient chlorophyll-a (Chla) concentrations in Winter Haven's lakes. As was explained in Chapter 1, Chla is the primary metric used to represent trophic status in waterbodies. Chlorophyll's unique spectral properties allow multiband imagery platforms such as satellites, drones, and manned aircraft to collect information on a larger scale and greater frequency than traditional *in-situ* sampling. These remote sensing efforts can provide useful information on short-term responses to pollution and potentially allow lake managers to track harmful algal blooms with greater accuracy. While remote sensing is not currently an accepted data source for regulatory applications in aquatic environments, it is a powerful tool that is steadily becoming more widely recognized by the scientific community. For example, satellite imagery is currently utilized to monitor red tides in coastal waters [19].

In order to achieve this objective, the City has partnered with TerrAvion, Inc. to collect monthly multispectral imagery of several Winter Haven lakes via fixed-wing aircraft. Alongside this imaging, City staff gather water samples during flight times—providing a ground truth used to correlate ambient algal concentrations with the pixel values obtained through the imagery. The development of this correlative model is necessary to remotely track Chla levels in the multitude of lake conditions found in the region. Not only is this monitoring strategy more efficient for tracking temporal changes in Chla, it can be used to depict spatial variation across a lake's surface as illustrated in Figure 3-9. As of late 2018, this project is still in its initial phases, however the progress made thus far is promising.

In addition to Chla monitoring, there are a number of ancillary applications for the imagery collected through this project. The ability to track changes in terrestrial and emergent aquatic vegetation, monitor invasive species treatment effectiveness, and manage fouling of stormwater outfalls are all potential applications the City is pursuing through this project. As a result, the City has decided to continue studying the feasibility of remote sensing as a non-structural management strategy into the 2019 fiscal year.

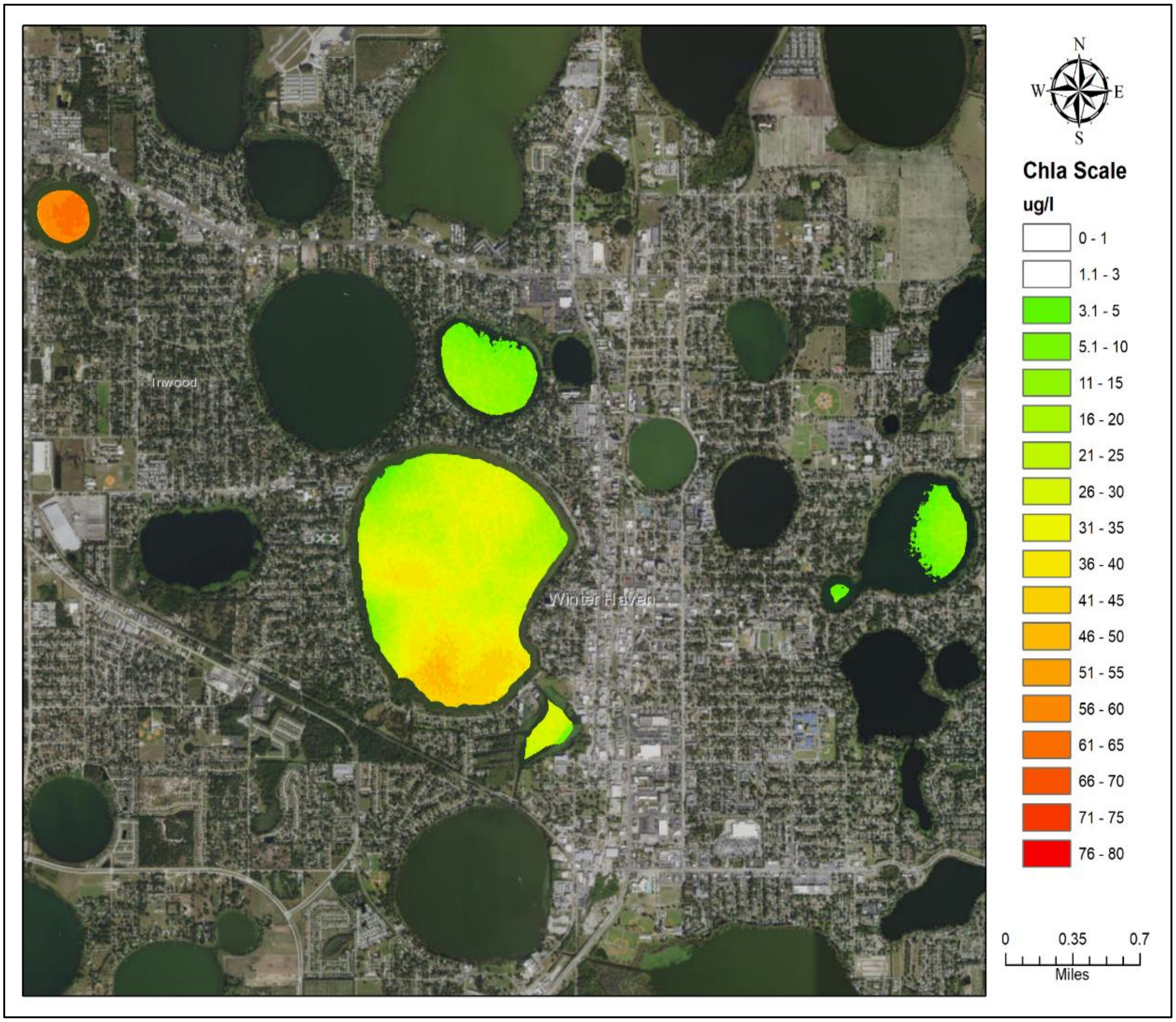


Figure 3-9. Map depicting the spatial variability of estimated Chla concentrations derived through remote sensing of Lakes Blue, Elbert, Howard, May, and Mirror in October 2019.

Public Benefit:

With the development of a standardized model, the City will be able to utilize remotely sensed data to track monthly changes in Chla concentrations in Winter Haven's lakes. The improved frequency and efficiency of data collection equates to an increase in cost-savings and effectiveness when compared with current sampling techniques. Moreover, this information will be used to gain a better understanding of the temporal and spatial variation in water quality. This understanding can be implemented to drive management decisions that improve lake health for the benefit of the residents who utilize these waterbodies.

Support of Mission, Purpose, and Vision:

This project supports the Mission by developing a “sound understanding of social, economic, and ecological systems” which enables the Division to “maintain and improve local natural resources”. This is also in fulfillment of the Vision by establishing the City as “the premier knowledge base for local natural resources” through the application of new and powerful technologies in its drive to more effectively manage resources.

Strategic Goals:

- By FY 19-20, determine the feasibility in continuing to develop remote sensing as a viable monitoring strategy
- By the end of 2019, draft a feasibility report detailing the applications and limitations of multispectral imaging for the Natural Resources Division

Completed Objectives:

- ✓ Worked with TerrAvion to develop a methodology for chlorophyll-a remote sensing

4- Appendix

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4.2 Supplemental Data

Annual Geometric Mean Data

Chlorophyll-a

Lake Group	Waterbody	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
North Chain of Lakes	Lake Conine	23.1	28.8	35.8	26.2	32.0	39.6	36.8	45.9	34.0	36.1	36.2	44.1	34.5	30.1	23.3	22.7	19.0	22.3	17.5
	Lake Fannie	12.1	10.6	11.9	13.0	21.3	13.4	14.7	14.3	16.9	22.6	22.0	25.6	19.1	17.1	13.7	10.5	11.3	11.5	12.0
	Lake Haines	29.8	18.6	34.3	26.1	31.7	34.9	44.8	28.3	29.8	25.8	23.7	21.3	35.2	28.7	18.7	16.8	26.0	23.8	34.4
	Lake Hamilton	2.3	2.7	3.9	1.5	2.0	13.6	7.7	6.8	16.0	28.9	26.5	22.8	29.0	29.2	22.5	21.3	24.9	45.8	40.5
	Lake Rochelle	18.6	26.7	31.3	25.8	31.2	29.3	20.9	28.8	27.4	33.1	27.6	19.7	26.6	26.0	24.5	18.2	13.0	17.4	17.2
	Lake Smart	24.3			27.5	28.7	27.5	25.7	40.1			56.9	50.5	46.9		19.0	23.7	21.3	39.8	19.5
	Little Lake Hamilton	13.3	16.0	20.6	13.2	9.1	19.4	13.6	20.4	35.4	26.8		22.6	39.2	26.4	28.3	11.6	17.3	27.5	22.2
	Middle Lake Hamilton	19.4	54.5	10.3	22.4	13.6	30.6	31.0	27.2	34.4	40.1	44.3	51.7	35.9	31.1	26.3	24.3	22.0	32.2	29.8
South Chain of Lakes	Lake Cannon	26.2	24.0	31.9	24.2	30.6	27.8	18.5	22.9	23.7	32.2	28.0	28.7	23.1	31.7	27.3	16.5	19.0	19.0	21.5
	Lake Eloise	26.4	32.9	28.1	32.1	30.6	43.7	34.1	25.5	30.5	27.1	31.0	39.0	25.6	36.0	33.5	32.0	37.0	22.8	25.9
	Lake Hartridge	9.9	10.6	10.6	10.2	10.3	7.7	13.3	14.9	14.4	22.9	22.8	28.5	27.5	31.0	30.5	28.1	26.7	25.9	24.6
	Lake Howard	40.0	37.3	25.1	28.8	42.9	31.0	37.4	64.0	41.9	33.3	24.7	30.0	29.6	26.9	25.0	25.4	27.6	24.7	21.7
	Lake Idylwild	19.2	30.2	17.3	21.9	24.7	20.1	25.0	21.3	29.3	37.3	33.2	23.3	21.0	26.8	22.5	16.8	13.9	24.8	21.3
	Lake Jessie	24.5	23.1	15.6	25.0	26.4	28.1	27.8	24.0	25.4	30.9	31.9	25.0	24.0	26.8	26.8	18.3	15.4	33.0	24.3
	Lake Lulu	28.4	32.0	26.6	28.0	26.7	39.0	38.6	35.0	34.8	30.9	29.6	25.2	22.3	23.1	17.2	21.2	25.4	25.7	30.2
	Lake May	42.9	32.4	35.1	32.0	46.4	36.1	47.6	65.6	51.3	46.3	32.6	35.3	37.3	33.0	24.4	18.5	29.1	30.6	23.5
	Lake Mirror	29.8	36.9	37.2	34.4	28.2	29.6	23.6	22.9	26.4	21.0	19.5	13.5	10.5	15.8	8.2	8.1	12.4	16.7	21.7
	Lake Roy	16.7	32.2	17.0	18.1	20.0	13.5	14.2	18.4	24.6	19.4	17.1	10.4	11.4	13.9	8.6	6.2	8.7	8.3	12.8
	Lake Shipp	46.4	65.3	42.7	42.5	43.6	46.9	71.7	83.2	30.0	47.5	38.8	36.4	36.2	32.5	22.7	27.2	26.6	29.6	28.9
	Lake Summit	10.0	14.9	16.7	9.0	13.2	11.7	10.3	9.8	15.1	13.8	10.6	8.1	6.4	5.5	5.0	6.3	6.2	7.3	6.7
	Lake Winterset	20.1	19.2	18.0	16.0	15.2	11.7	11.1	9.1	10.3	11.0	8.5	5.5	6.2	4.2	3.5	4.7	4.8	9.5	6.6
	Spring Lake	13.0	24.8	16.8	33.1	17.2	22.1	21.6	19.7	22.9	12.6	9.2	9.7	8.0	5.7	12.3	20.7	7.4	11.4	14.8
North Central Lakes	Lake Buckeye	11.8	13.6	17.6	18.3	14.3	24.2	12.1	13.6	10.6	10.2	7.4	6.0	7.1	4.9	7.1	5.3	5.4	4.9	6.5
	Lake Idyl	22.0	41.0		10.6	8.0	9.2	7.0	4.4	1.9	25.1	4.4	5.5	4.8		4.7	9.7	9.6	57.5	33.6
	Lake Martha	6.1	1.9	5.0	9.6	3.2	3.6	3.0	3.4	7.1	5.6	7.1	7.1	6.3	6.3	7.3	12.2	12.7	17.7	17.2
	Lake Maude	15.5	14.5	10.6	6.1	18.9	12.8	4.7	4.9	16.3	15.9	12.3	8.7	12.6	8.2	5.3	8.3	6.5	8.2	4.1
	Lake Silver	8.1	12.8	13.6	26.4		9.8	12.9	7.1	7.6	14.0	10.2	10.4	9.4	8.1	8.0	13.6	12.9	22.2	8.7
South Central Lakes	Lake Elbert	4.7	1.6	1.4	3.5	3.1	6.2	5.2	3.7	3.1	3.7	3.6	4.9	5.0	4.0	4.4	5.5	3.7	6.2	5.6
	Lake Link	15.2	29.6		10.4	13.6						5.2	10.0	15.5	15.3	14.5	13.8	11.1	13.9	17.3
	Lake Mariam	5.1	5.8	12.6	4.2	3.8	5.4	5.4	8.0	6.0	4.7	4.0	4.1	4.8	4.7	6.3	6.3	10.9	7.1	8.2
	Lake Otis	8.0	55.0		11.2	10.4						21.9	18.3	23.2	20.4	16.3	17.3	13.9	13.5	18.3
Outlying Lakes	Lake Blue	69.9	92.1	59.2	60.1	79.2	53.8	66.8	122.4	75.7	120.5	58.8	70.7	34.4	57.7	52.3	58.1	65.9	70.9	59.8
	Lake Deer	13.9	25.8	11.3	3.7	7.6	16.4	17.3	21.6	31.6	27.9	18.8	11.5	28.4	22.2	10.3	12.4	8.1	11.3	4.9
	Lake Mariana	15.8	35.7	15.1	24.3	37.0	26.9	23.4	28.9	32.5	34.2	25.5	42.1	32.4	35.0	37.1	29.1	21.3	38.2	31.5
	Lake Pansy	3.7	4.8	11.6	6.4	8.8	10.9	11.7	15.9	12.1	11.2	11.4	8.7	15.4	23.3	16.5	16.4	15.6	15.3	13.0

Table 4-1. Annual geometric mean corrected chlorophyll-a concentrations from 2000 – 2018 for all study area lakes.

Total Nitrogen

Lake Group	Waterbody	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
North Chain of Lakes	Lake Conine	964.86	1214.9	1388.9	1251.1	1289.9	1460.6	1278.6	1464.4	1378.7	1475.8	1455.7	1647.9	1359.1	1364.1	1193.2	1140.2	1056.7	1054.4	969.97
	Lake Fannie	1022	851.7	1239.8	1124.3	1003.1	997.52	863.37	913.47	1326.9	1401.4	1288.3	1727.9	1453.5	1389.2	1114.5	970.32	898.22	869.98	873.45
	Lake Haines	1445.3	1328.7	1518.4	1357.6	1329.2	1464.2	1458.5	1263.5	1363.9	1398.7	1379.8	1292.2	1506.4	1497	1267.2	1258	1204.3	1069.2	1232.2
	Lake Hamilton	995.84	933.38	997.51	1053.1	1083	1113.9	1286.9	1194.5	1244.7	1511.3	1451	1426.4	1503.2	1715.9	1524.7	1432.8	1620.9	2329	2016.4
	Lake Rochelle	1030.5	1251.8	1289	1434.1	1274.2	1322.9	1084.7	1228.4	1249.6	1603.5	1346.9	1208.9	1306.6	1319.5	1426.7	1134	946.54	942.11	934.56
	Lake Smart	1216.9			1622.9	1374.9	1221.8	1194.7	1654.9			2300	2490.1	2141.4		1173	1316.8	1122	1606.6	1093.4
	Little Lake Hamilton	1001.2	1297.6	1476.6	1371	1052	1108	986.69	1365.8	1786.2	1559.7		1416.7	1891.5	1650	1701.6	1191.7	1274.2	1580.4	1433.1
	Middle Lake Hamilton	1446.3	2160	2284.1	1761.6	1388	1630.4	1426.8	1412.3	2260	2030	2408.9	2196.3	2183.4	2096.8	1711.7	1442.3	1379.1	1648.2	1582
South Chain of Lakes	Lake Cannon	1347.1	1248.9	1535.7	1479.5	1142.8	1061.8	856.1	1137.4	1046.9	1306.1	1206.3	1328.2	1162.7	1355.1	1289.6	931.8	1059.8	922.6	985.7
	Lake Eloise	1432.3	1615.6	1416.1	1276.9	1186.3	1480.1	1270.1	1166.6	1134.4	1167.2	1344.5	1648.2	1313.7	1559.7	1574.9	1336.2	1519.4	1012.7	1078.5
	Lake Hartridge	684.7	812.9	801.5	729.4	744.5	608.9	808.0	860.8	991.8	1246.7	1217.5	1415.4	1463.1	1638.1	1659.3	1355.7	1425.4	1251.6	1308.5
	Lake Howard	2237.2	1882.3	1364.6	1550.7	1605.2	1266.3	1521.1	2288.3	1758.0	1652.8	1381.3	1628.9	1597.2	1461.6	1378.6	1267.8	1439.4	1196.6	1134.1
	Lake Idylwild	1074.3	1256.7	949.0	1080.8	965.7	891.5	937.7	988.8	1203.7	1540.9	1328.4	1288.4	1260.8	1299.4	1243.2	955.9	973.4	1125.5	1022.2
	Lake Jessie	986.9	1302.7	909.3	1040.2	1027.3	980.0	914.4	916.8	1063.3	1140.5	1197.3	1208.6	1163.6	1134.2	1174.0	927.9	902.1	1153.5	1067.4
	Lake Lulu	1698.8	1177.0	1404.8	1308.6	1087.4	1226.5	1373.9	1587.7	1643.1	1454.7	1495.6	1482.5	1327.1	1164.7	1037.9	1084.7	1219.6	1204.9	1296.0
	Lake May	2302.5	1787.7	1616.6	1549.2	1635.4	1326.4	1640.6	2298.1	1904.8	1756.5	1609.6	1731.9	1688.7	1490.8	1322.8	1163.8	1409.7	1268.1	1190.9
	Lake Mirror	1751.8	1500.0	1748.6	1832.8	1169.5	1161.1	1091.6	1246.5	1234.8	1138.2	1077.6	991.4	900.0	1038.8	756.2	696.5	836.7	897.9	984.4
	Lake Roy	1078.9	1441.9	1168.8	1011.4	890.9	812.8	814.9	1009.2	1277.0	1103.3	1142.8	964.3	977.3	1062.2	925.4	754.1	759.1	742.0	950.8
	Lake Shipp	2579.4	2728.9	1970.7	1734.9	1544.2	1415.8	2277.6	2647.7	2082.6	1859.5	1681.1	1808.3	1722.2	1495.5	1228.1	1217.1	1249.6	1274.7	1307.9
	Lake Summit	985.2	1149.8	1038.8	733.6	798.0	764.0	856.8	912.2	849.1	830.5	882.4	931.1	819.9	762.4	800.2	821.6	755.6	767.2	773.4
	Lake Winterset	1162.2	1049.0	1174.3	995.6	851.0	688.9	686.6	713.8	669.4	760.4	589.7	713.0	739.0	674.7	618.6	654.0	625.2	712.5	609.9
	Spring Lake	1014.1	1130.0	1230.2	1811.1	793.6	809.7	1052.9	867.8	741.2	707.8	613.3	665.3	580.0	510.6	680.5	721.0	593.7	666.1	712.8
North Central Lakes	Lake Buckeye	956.2	805.0	1045.4	1163.8	888.8	944.3	818.3	834.9	870.2	830.4	864.2	773.2	671.7	716.7	744.2	657.7	592.0	618.9	653.9
	Lake Idyl	920.0	1400.0		619.0	594.0	649.8	630.0	544.4	530.0	1000.0	557.8	546.8	529.6		619.3	825.2	850.2	1797.4	1446.9
	Lake Martha	682.1	495.8	644.6	657.3	500.4	500.1	433.3	479.2	601.1	613.0	664.4	720.1	597.1	539.6	660.5	732.7	716.3	717.2	811.3
	Lake Maude	1041.2	996.3	876.1	748.3	796.1	870.4	559.2	663.1	822.7	984.9	898.3	859.1	836.4	718.1	607.2	694.8	658.5	691.5	559.3
	Lake Silver	730.0	640.0	1090.0	900.0		689.4	718.6	713.0	603.7	763.1	1098.1	735.7	712.1	595.9	666.8	749.4	805.7	910.1	681.4
South Central Lakes	Lake Elbert	549.9	273.3	391.3	422.5	409.5	520.7	504.1	424.7	353.7	415.4	409.9	560.0	506.3	397.0	454.2	477.1	476.7	501.3	542.3
	Lake Link	1250.0	1770.0		660.0	920.0						764.9	1036.5	1043.3	816.5	855.2	829.0	688.3	734.2	862.4
	Lake Mariam	1003.9	913.9	1429.1	927.7	976.3	947.5	1036.9	1147.3	1070.5	1042.3	897.1	915.7	878.2	836.4	867.3	891.0	996.5	1078.0	1092.6
	Lake Otis	860.0	1980.0		690.0	600.0						970.0	1095.3	985.8	921.0	788.0	819.8	681.1	673.0	769.7
Outlying Lakes	Lake Blue	2847.2	3548.9	2521.3	2664.8	2692.6	1836.2	2239.6	3561.0	2633.2	3691.4	2508.2	3155.2	2308.2	2633.9	2280.7	2203.4	2515.2	2587.2	2387.2
	Lake Deer	1670.6	1912.9	1172.8	809.3	980.8	955.2	932.4	1235.3	1425.5	1511.5	1519.0	1129.2	1629.6	1515.7	1079.4	990.6	782.3	850.8	716.1
	Lake Mariana	1123.6	1256.4	1016.1	1271.7	1456.3	1075.1	1030.1	1250.7	1476.0	1648.0	1421.1	1726.8	1456.3	1635.1	1789.2	1441.2	1190.6	1746.0	786.9
	Lake Pansy	642.8	659.9	865.1	669.9	705.8	720.3	810.7	1025.4	920.9	855.6	835.3	813.2	1007.9	1233.7	885.8	796.2	788.9	835.8	726.1

Table 4-2. Annual geometric mean total nitrogen concentrations from 2000 – 2018 for all study area lakes.

Total Phosphorus

Lake Group	Waterbody	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
North Chain of Lakes	Lake Conine	25.9	48.6	59.2	53.9	48.1	63.2	56.6	66.5	50.9	47.7	52.7	61.5	47.2	47.1	37.4	36.9	37.6	39.1	30.4
	Lake Fannie	32.9	32.5	81.9	50.6	37.1	27.7	37.0	37.9	55.1	62.0	58.4	65.9	53.8	50.4	38.2	28.8	28.1	26.1	23.3
	Lake Haines	53.0	33.6	44.3	52.5	60.0	84.7	58.9	45.9	38.4	38.2	42.3	36.7	39.0	38.4	37.4	36.8	46.6	50.9	42.6
	Lake Hamilton	127.0	80.3	86.5	72.6	110.0	76.8	117.1	95.2	64.5	76.6	59.8	53.7	66.0	58.2	43.3	41.1	38.2	50.1	40.9
	Lake Rochelle	49.9	41.9	40.7	37.1	45.6	56.9	42.0	45.3	42.8	35.5	47.4	33.6	33.0	39.2	35.7	29.6	24.2	27.4	25.1
	Lake Smart	27.3			42.8	46.5	48.6	45.9	51.0			39.0	42.9	38.5		30.6	33.2	32.1	35.9	28.1
	Little Lake Hamilton	32.1	28.5	44.4	29.9	27.0	41.4	33.9	35.2	46.9	48.0		34.1	44.4	35.0	32.6	24.9	25.7	30.9	29.8
	Middle Lake Hamilton	74.3	167.0	83.5	60.5	53.0	67.4	66.5	61.4	66.0	78.0	76.6	69.5	78.2	62.8	56.8	49.0	48.2	60.7	53.5
South Chain of Lakes	Lake Cannon	33.3	27.1	13.4	37.3	36.3	46.0	39.2	34.8	30.4	27.3	33.8	31.0	29.9	30.6	29.0	25.7	30.0	27.6	24.9
	Lake Eloise	38.2	37.4	24.4	42.3	41.2	72.5	54.0	38.6	32.8	33.2	30.8	31.7	31.3	32.6	31.9	29.9	38.2	30.7	29.3
	Lake Hartridge	31.5	33.0	26.1	18.4	30.0	33.2	35.8	25.9	27.3	30.6	32.3	30.9	30.1	29.4	29.4	28.6	29.8	26.3	23.5
	Lake Howard	40.0	24.0	6.3	24.0	38.8	48.8	43.8	39.4	38.5	33.3	28.0	28.1	26.4	28.6	25.5	22.2	25.7	29.3	22.6
	Lake Idylwild	46.6	49.0	28.0	37.9	46.3	46.4	44.8	40.2	37.3	35.5	35.2	27.7	29.2	30.4	28.7	25.8	31.6	28.9	27.5
	Lake Jessie	54.2	67.3	60.0	36.7	53.0	53.1	48.4	40.5	46.9	38.2	41.7	35.1	35.1	36.0	32.4	30.0	31.0	39.7	34.0
	Lake Lulu	59.6	42.0	31.3	42.4	49.0	61.6	58.0	50.5	49.1	44.2	41.6	37.3	33.7	35.1	31.0	30.9	38.0	38.3	34.6
	Lake May	79.4	82.9	37.5	58.3	76.0	74.2	77.0	87.0	73.7	74.6	58.2	57.7	53.7	53.9	44.0	34.3	45.7	51.1	42.4
	Lake Mirror	37.9	31.0	14.4	39.2	46.0	45.2	38.5	31.2	29.1	25.5	27.9	24.7	31.0	28.2	23.4	20.9	25.2	24.3	24.3
	Lake Roy	39.5	31.5	11.2	26.9	28.9	37.5	35.5	28.0	25.8	24.4	26.2	20.4	23.3	26.3	28.6	22.2	22.6	19.7	23.2
	Lake Shipp	57.6	52.2	28.7	40.6	44.8	63.1	62.3	54.2	50.5	46.2	40.9	39.3	37.9	37.4	30.7	27.5	33.7	39.0	31.6
	Lake Summit	34.0	28.8	24.0	19.4	27.9	36.7	34.4	27.2	23.0	22.0	26.0	20.6	20.8	22.9	23.4	18.7	20.1	21.8	21.1
	Lake Winterset	28.9	23.0	11.7	18.3	25.5	30.4	28.8	21.9	19.4	16.0	16.9	16.4	19.1	18.5	19.5	15.9	16.9	17.7	17.6
	Spring Lake	32.1	33.0	25.1	49.2	36.5	43.3	44.0	30.8	27.2	23.2	22.8	19.9	21.0	26.1	29.1	29.3	22.9	24.8	25.6
North Central Lakes	Lake Buckeye	24.1	27.1	32.0	39.9	28.8	42.5	33.3	26.5	24.8	21.6	26.1	20.5	20.9	25.9	26.5	17.8	18.2	21.7	19.2
	Lake Idyl	39.0	62.0		20.0	31.0	34.7	23.0	17.9	16.7	41.3	25.1	21.4	20.0		26.5	41.6	58.8	96.8	61.0
	Lake Martha	31.2	9.9	5.0	15.2	20.9	27.3	21.6	16.9	19.3	17.2	23.7	20.3	23.5	27.1	25.2	22.1	24.5	32.7	34.0
	Lake Maude	37.3	35.2	20.1	21.8	19.5	42.1	25.5	22.3	38.3	35.4	38.2	32.3	29.5	27.1	25.4	22.6	20.4	20.8	16.7
	Lake Silver	13.0	30.0	23.0	14.0		32.2	27.9	21.4	18.8	20.4	27.6	22.2	19.5	21.0	23.9	21.7	21.3	25.5	17.5
South Central Lakes	Lake Elbert	7.7	10.6	13.5	7.1	15.6	28.4	27.0	18.8	16.3	15.2	15.2	20.7	18.4	18.5	21.7	16.4	17.3	16.2	15.5
	Lake Link	34.0	40.0		19.0	26.0						27.5	37.5	33.7	29.2	30.7	27.7	23.9	25.0	23.9
	Lake Mariam	45.4	51.0	56.1	61.4	53.6	66.7	61.1	75.0	74.8	63.2	58.5	45.7	42.3	43.6	35.9	42.0	44.1	75.4	66.8
	Lake Otis	26.0	35.0		21.0	27.0						33.0	30.5	34.8	28.5	27.8	25.6	26.3	25.4	26.4
Outlying Lakes	Lake Blue	93.1	80.3	54.0	86.2	95.2	74.2	83.2	91.2	71.2	89.3	60.6	62.4	55.4	65.7	53.1	54.1	55.8	61.0	49.4
	Lake Deer	38.5	28.1	17.9	22.6	38.1	55.4	42.5	33.7	27.9	30.8	34.7	26.5	36.2	40.5	32.0	20.4	19.2	19.4	17.5
	Lake Mariana	29.4	46.6	24.2	39.5	68.7	51.7	41.6	31.1	34.8	28.6	32.1	31.1	33.0	32.7	31.4	26.2	27.9	30.9	31.9
	Lake Pansy	18.4	27.1	19.8	11.5	32.4	30.3	33.9	30.5	24.2	24.8	23.5	21.8	27.6	37.1	32.0	30.6	29.6	28.9	20.5

Table 4-3. Annual geometric mean total phosphorus from 2000 – 2018 for all study area lakes.

Linear Regression Statistics

Water Quality Trends

Waterbody	Chl-a			Secchi			TN			TP		
	Dir.	R^2	p-value	Dir.	R^2	p-value	Dir.	R^2	p-value	Dir.	R^2	p-value
Lake Blue	-	0.0652	0.291	+	0.0847	0.227	-	0.0806	0.239	+	0.5001	0.001
Lake Buckeye	-	0.6153	0.000	+	0.7874	0.000	-	0.7009	0.000	-	0.4117	0.003
Lake Cannon	-	0.1501	0.101	+	0.3507	0.008	-	0.2240	0.041	-	0.0523	0.346
Lake Conine	-	0.1569	0.093	+	0.4391	0.002	-	0.0539	0.339	-	0.1535	0.097
Lake Deer	-	0.0237	0.529	+	0.0565	0.327	-	0.1575	0.093	+	0.1388	0.116
Lake Elbert	+	0.2897	0.017	-	0.0870	0.220	+	0.1344	0.123	+	0.0919	0.207
Lake Eloise	-	0.0051	0.771	+	0.3023	0.015	-	0.0305	0.475	-	0.1353	0.121
Lake Fannie	+	0.0001	0.970	+	0.1588	0.091	+	0.0015	0.876	-	0.0725	0.265
Lake Haines	-	0.0575	0.323	+	0.6488	0.000	-	0.3164	0.012	-	0.1093	0.167
Lake Hamilton	+	0.8040	0.000	-	0.4606	0.001	+	0.8067	0.000	-	0.6749	0.000
Lake Hartridge	+	0.7775	0.000	-	0.7075	0.000	+	0.7112	0.000	-	0.0227	0.538
Lake Howard	-	0.2293	0.038	+	0.4632	0.001	-	0.3372	0.009	-	0.0508	0.354
Lake Idyl	+	0.0197	0.591	+	0.0037	0.817	+	0.0838	0.260	+	0.1514	0.123
Lake Idylwild	-	0.0130	0.642	+	0.1889	0.063	+	0.0215	0.549	-	0.5840	0.000
Lake Jessie	+	0.0039	0.800	+	0.2069	0.050	+	0.0175	0.589	-	0.6656	0.000
Lake Link	-	0.0733	0.371	+	0.0926	0.312	-	0.3412	0.036	-	0.1015	0.289
Lake Lulu	-	0.2087	0.049	+	0.5150	0.001	-	0.1297	0.130	-	0.3459	0.008
Lake Mariam	+	0.0243	0.524	+	0.2311	0.037	-	0.0553	0.333	-	0.0099	0.686
Lake Mariana	+	0.1706	0.079	-	0.1771	0.073	+	0.1047	0.177	-	0.1754	0.074
Lake Martha	+	0.5643	0.000	-	0.4389	0.002	+	0.3135	0.013	+	0.3277	0.010
Lake Maude	-	0.2460	0.031	+	0.3223	0.011	-	0.3681	0.006	-	0.1351	0.122
Lake May	-	0.2357	0.035	+	0.6352	0.000	-	0.3882	0.004	-	0.4055	0.003
Lake Mirror	-	0.7038	0.000	+	0.6071	0.000	-	0.7300	0.000	-	0.2619	0.025
Lake Otis	-	0.0466	0.479	+	0.0003	0.953	-	0.1568	0.180	-	0.0070	0.786
Lake Pansy	+	0.5176	0.001	-	0.0003	0.942	+	0.1363	0.120	-	0.1037	0.179
Lake Rochelle	-	0.2856	0.018	+	0.4849	0.001	-	0.1107	0.164	-	0.5743	0.000
Lake Roy	-	0.4867	0.001	+	0.5374	0.000	-	0.2692	0.023	-	0.1851	0.066
Lake Shipp	-	0.3764	0.005	+	0.7501	0.000	-	0.5309	0.000	-	0.3619	0.006
Lake Silver	-	0.0036	0.812	-	0.0836	0.244	-	0.0119	0.667	-	0.0006	0.924
Lake Smart	-	0.0000	0.991	+	0.1805	0.130	+	0.0000	0.983	-	0.2271	0.085
Lake Summit	-	0.5367	0.000	+	0.7664	0.000	-	0.3441	0.008	-	0.3776	0.005
Lake Winterset	-	0.7815	0.000	+	0.7002	0.000	-	0.6200	0.000	-	0.2238	0.041
Little Lake Hamilton	+	0.1684	0.091	-	0.0591	0.331	+	0.1910	0.070	-	0.0397	0.428
Middle Lake Hamilton	+	0.0159	0.607	+	0.0350	0.443	-	0.0098	0.687	-	0.2481	0.030
Spring Lake	-	0.3037	0.014	+	0.4673	0.001	-	0.4634	0.001	-	0.3038	0.014

Table 4-4. Trendline statistics for linear regressions of chl-a, TN, TP, and Secchi depth over time. Stats include regression direction (+/-), R-squared value, and p-value.

Surface Level vs. Water Quality

Waterbody	Chl-a			Secchi			TN			TP		
	Dir.	R^2	p-value	Dir.	R^2	p-value	Dir.	R^2	p-value	Dir.	R^2	p-value
Lake Blue	-	0.0147	0.620	+	0.0026	0.837	-	0.0990	0.189	+	0.0018	0.865
Lake Buckeye	-	0.0019	0.859	+	0.1075	0.171	-	0.0124	0.650	+	0.0337	0.452
Lake Cannon	-	0.1207	0.145	+	0.0848	0.227	-	0.0980	0.192	+	0.0318	0.465
Lake Conine	-	0.2834	0.019	+	0.4872	0.001	-	0.2560	0.027	-	0.0979	0.192
Lake Deer	-	0.1939	0.059	+	0.1578	0.092	-	0.1047	0.177	+	0.0416	0.402
Lake Elbert	+	0.2348	0.036	-	0.3835	0.005	+	0.1656	0.084	+	0.1245	0.138
Lake Eloise	+	0.0752	0.256	-	0.0003	0.940	-	0.0143	0.626	+	0.1033	0.180
Lake Fannie	-	0.5485	0.002	+	0.8750	0.000	-	0.6806	0.000	-	0.8710	0.000
Lake Haines	+	0.0014	0.877	+	0.1819	0.069	-	0.1665	0.083	+	0.2307	0.037
Lake Hamilton	-	0.0603	0.378	+	0.1533	0.149	-	0.0065	0.775	+	0.0019	0.878
Lake Hartridge	-	0.0027	0.832	+	0.0094	0.693	-	0.0086	0.706	-	0.0942	0.201
Lake Howard	-	0.1440	0.109	+	0.1542	0.096	-	0.3714	0.006	-	0.0045	0.786
Lake Idyl	-	0.1500	0.125	+	0.1226	0.168	-	0.0874	0.249	-	0.0164	0.624
Lake Idylwild	-	0.3580	0.007	+	0.4141	0.003	-	0.4738	0.001	-	0.0159	0.607
Lake Jessie	-	0.0677	0.282	+	0.2710	0.022	-	0.2410	0.033	-	0.0574	0.323
Lake Link	-	0.1825	0.145	+	0.1430	0.203	-	0.5894	0.002	-	0.7446	0.000
Lake Lulu	-	0.0183	0.581	+	0.1255	0.137	-	0.3219	0.011	-	0.0043	0.790
Lake Mariam	-	0.0000	0.989	+	0.0238	0.528	-	0.0893	0.214	-	0.1129	0.160
Lake Mariana	-	0.0369	0.595	+	0.0133	0.751	-	0.2439	0.147	-	0.0253	0.661
Lake Martha	+	0.2143	0.046	-	0.0087	0.704	+	0.0569	0.325	+	0.1501	0.101
Lake Maude	-	0.0365	0.433	+	0.0739	0.260	-	0.1769	0.073	-	0.0794	0.242
Lake May	-	0.2408	0.033	+	0.3782	0.012	-	0.4728	0.001	-	0.2089	0.049
Lake Mirror	-	0.0041	0.794	+	0.0293	0.484	-	0.4728	0.001	+	0.0303	0.476
Lake Otis	-	0.3867	0.023	+	0.5717	0.003	-	0.6137	0.002	-	0.5517	0.004
Lake Pansy	+	0.0187	0.577	+	0.2804	0.020	-	0.1048	0.176	+	0.0000	0.981
Lake Rochelle	-	0.2489	0.030	+	0.2903	0.017	-	0.1488	0.103	-	0.0687	0.279
Lake Roy	-	0.2418	0.032	+	0.2997	0.015	-	0.0335	0.453	-	0.0020	0.854
Lake Shipp	-	0.1407	0.113	+	0.2139	0.046	-	0.4980	0.001	-	0.0796	0.242
Lake Silver	+	0.1394	0.322	-	0.2510	0.169	-	0.0000	0.999	-	0.0218	0.705
Lake Smart	-	0.8451	0.001	+	0.7772	0.004	-	0.8549	0.001	-	0.6511	0.015
Lake Summit	-	0.0854	0.225	+	0.1110	0.163	-	0.3344	0.009	-	0.0086	0.706
Lake Winterset	-	0.0133	0.638	+	0.0206	0.557	-	0.0244	0.523	+	0.0033	0.815
Little Lake Hamilton	-	0.5169	0.004	+	0.5472	0.002	-	0.4536	0.008	-	0.5257	0.003
Middle Lake Hamilton	-	0.5008	0.003	+	0.6534	0.000	-	0.4942	0.003	-	0.4926	0.004
Spring Lake	+	0.0638	0.297	-	0.0376	0.426	+	0.0302	0.477	+	0.1757	0.074

Table 4-5. Trend statistics for linear regressions of lake surface levels against chl-a, TN, TP, and Secchi depth. Stats include regression direction (+/-), R-squared value, and p-value.

Hydrologic Data

Soil Classification Percentage

Soil Class

	Soil Group %						
Waterbody	A	A/D	B	B/D	C	C/D	D
Lake Blue	27.43	32.02	0.00	2.67	0.00	0.00	0.00
Lake Buckeye	65.24	11.19	0.00	0.00	0.00	0.00	0.00
Lake Cannon	34.66	32.99	0.00	1.67	0.00	0.00	0.00
Lake Conine	43.60	17.83	0.00	1.76	0.00	0.00	0.00
Lake Deer	35.71	40.91	0.00	0.00	0.00	0.00	0.00
Lake Elbert	73.44	0.00	0.00	0.00	0.00	0.00	0.00
Lake Eloise	28.55	15.25	0.00	1.93	0.00	0.00	0.00
Lake Fannie	27.56	31.00	0.00	3.01	0.02	3.98	0.00
Lake Haines	31.99	46.07	0.00	1.97	1.10	4.96	0.00
Lake Hamilton	17.19	25.03	0.25	5.29	0.09	2.19	0.00
Lake Hartridge	21.50	23.64	0.00	2.23	0.00	0.00	0.00
Lake Howard	22.20	32.30	0.00	0.13	1.25	0.55	0.00
Lake Idyl	82.48	8.21	0.00	0.32	0.00	0.00	0.00
Lake Idylwild	15.05	39.54	0.00	4.87	0.00	0.00	0.00
Lake Jessie	25.34	45.44	0.00	5.86	0.00	0.00	0.00
Lake Link	68.33	8.08	0.00	0.00	0.00	0.00	0.00
Lake Lulu	36.40	25.18	0.00	0.00	0.00	0.00	0.00
Lake Mariam	26.95	37.29	0.00	1.68	0.00	9.51	0.00
Lake Mariana	31.49	32.40	0.00	2.62	0.00	0.73	0.00
Lake Martha	56.10	9.85	0.00	0.00	0.00	0.00	0.00
Lake Maude	76.41	3.75	0.00	0.00	0.00	0.00	0.00
Lake May	28.17	12.02	0.00	0.00	0.00	0.00	0.00
Lake Mirror	44.46	9.23	0.00	0.00	0.00	2.97	0.00
Lake Otis	72.02	1.99	0.00	0.00	0.00	0.00	0.00
Lake Pansy	22.73	52.29	0.00	1.35	0.00	0.00	0.00
Lake Rochelle	21.95	38.94	0.00	3.24	0.22	0.00	0.00
Lake Roy	65.47	7.40	0.00	0.00	0.00	0.00	0.00
Lake Shipp	19.17	42.30	0.00	0.00	1.85	0.00	0.00
Lake Silver	35.44	0.00	0.00	0.00	0.00	0.00	0.00
Lake Smart	32.60	20.29	0.00	3.96	0.00	0.00	0.00
Lake Spring	40.57	9.07	0.00	0.00	0.00	0.00	0.00
Lake Summit	50.51	13.60	0.00	0.00	0.00	0.00	0.00
Lake Winterset	20.67	24.84	0.00	0.78	0.00	0.00	0.00
Little Lake Hamilton	61.53	12.57	0.51	0.00	0.00	0.00	0.00
Middle Lake Hamilton	28.15	56.67	0.17	0.92	0.25	0.47	0.15

Table 4-6. Soil class percentages for all study area lakes.

Land Use Percentage

Land Use

Land Use	Lake Group: North Central Lakes	North Chain of Lakes	Outlying Lakes	South Central Lakes	South Chain of Lakes
AGRICULTURE	17.31	20.67	8.93	6.34	4.80
BARREN LAND		1.84			
COMMERCIAL	19.00	2.29	10.75	6.20	15.12
COMMUNICATION	2.53	2.51	29.87	0.96	4.22
INDUSTRIAL	2.84	3.19	13.69	0.06	4.77
INSTITUTIONAL	17.66	1.54	4.15	7.84	2.58
OPEN LAND	3.81	2.55	0.31		2.05
RANGELAND	0.00	0.52			1.63
RECREATIONAL	2.08	1.60	3.71	2.08	3.58
RESIDENTIAL	37.22	15.89	22.44	55.69	34.76
UPLAND FOREST	4.07	2.91	2.86	1.69	1.60
WATER	19.93	27.29	26.69	25.24	31.73
WETLANDS	2.49	21.10	4.36	5.22	3.95

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