

Winter Haven Chain of Lakes Pre-BMAP Assessment:

An Interpretive Synthesis of Existing Information

Prepared for



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Table of Contents

Table of Contents	i
1.0 Introduction	1-1
1.1. Physical Setting.....	1-1
1.2. Background on Water Quality Goals and TMDLs	1-2
1.3. Purpose of Pre-BMAP Report.....	1-5
2.0 Methods	2-1
2.1. GIS-based Analysis.....	2-1
2.2. Water Quality Data and Analysis	2-2
2.2.1. General Water Quality Assessment.....	2-2
2.2.2. Time Series Analysis	2-5
2.2.3. Water Quality in “Ridge” vs. “Valley” Lakes	2-6
2.3. Lake Levels and Water Quality	2-6
3.0 Results and Discussion.....	3-1
3.1. GIS-based Analysis.....	3-1
3.2. Water Quality Data and Analysis	3-10
3.3. TMDL Findings.....	3-19
3.4. Influence of Lake Levels on Water Quality	3-31
4.0 Recommendations	4-1
4.1. Ridge Lakes	4-1
4.2. Valley Lakes.....	4-11
5.0 References.....	5-1

Appendix A – Data from Polk County Water Atlas

Appendix B – Data from IWR Run 31

Appendix C – Time Series

List of Figures:

Figure 1	Winter Haven Chain of Lakes	1-1
Figure 2	Physiographic Regions within the Vicinity of the WHCL.....	3-1
Figure 3	Digital Elevation Model for WHCL	3-2
Figure 4	Surface Soils in the WHCL Region.....	3-3
Figure 5	Conceptual Model of Ridge and Valley Lakes within the WHCL.....	3-4
Figure 6	Changes in Developed Land Use over Time in the WHCL Region.....	3-6
Figure 7	Median values (1997 to 2007) of Total Phosphorus Levels (mg / liter) for WHCL Lakes	3-11
Figure 8	Median Values (1997 to 2007) of Total Nitrogen Levels (mg / liter) for WHCL Lakes	3-12
Figure 9	Median Values (1997 to 2007) of Chlorophyll-a (μg / liter) for WHCL Lakes	3-13
Figure 10	Median Values (1997 to 2007) of Color (platinum-cobalt units) for WHCL Lakes.....	3-14
Figure 11	Median values of Chl-a (μg / liter), TN (mg / liter x 10), TP (mg / (liter x 100)) and color (PCU) for Ridge and Valley lakes (median values for 1997 to 2007).....	3-15
Figure 12	Lake Color (PCU) vs. Percentage of 500-foot Buffer as Herbaceous Wetlands.....	3-18
Figure 13	Lake Color (PCU) vs. Percentage of 500-foot Buffer as Forested Wetlands	3-18
Figure 14	Relationship between Total Phosphorus and Chlorophyll-a for Ridge Lakes	3-22
Figure 15	Relationship between Total Nitrogen and Chlorophyll-a for Ridge Lakes	3-22
Figure 16	Relationship between Total Phosphorus and Chlorophyll-a for Valley Lakes	3-24
Figure 17	Relationship between Total Nitrogen and Chlorophyll-a for Valley Lakes.....	3-24
Figure 18	Relationship between Lake Level, in feet (NGVD) and Chlorophyll-a (μg / liter) for Lake Blue.....	3-33
Figure 19	Relationship between Lake Level, in feet (NGVD) and Total Phosphorus (mg / liter) for Lake Blue.....	3-33
Figure 20	Relationship between Lake Level, in feet (NGVD) and Total Nitrogen (mg / liter) for Lake Blue.....	3-34
Figure 21	Chlorophyll-a levels in Lake Howard over time. Line is Loess best-fit curve of quarterly means	4-3
Figure 22	Chlorophyll-a levels in Lake May over time. Line is Loess best-fit curve of quarterly means	4-4
Figure 23	Chlorophyll-a levels in Lake Lulu over time. Line is Loess best-fit curve of quarterly means	4-5
Figure 24	Trash Collected by Stormwater Project on Lake Hartridge	4-6
Figure 25	Trash Collected by Stormwater Project on Lake Jessie.....	4-7
Figure 26	Phosphorus Removal Efficiency vs. Residence Time (figure from Harper [2005])	4-8
Figure 27	Nitrogen Removal Efficiency vs. Residence Time (figure from Harper [2005])	4-9
Figure 28	Period of Record for Chlorophyll-a for Lake Conine.....	4-10
Figure 29	Period of Record for chlorophyll-a for Lake Smart	4-10
Figure 30	Canal between Lake Haines and Lake Rochelle.....	4-12

List of Tables:

Table 1	Adopted Listing of Impaired Waterbodies in the WHCL	1-2
Table 2	Water Quality Parameters for which the Polk County Water Atlas Was Queried.....	2-3
Table 3	Water Quality Parameters for which Run 31 of the IWR Database Was Queried.....	2-4
Table 4	List of Lakes in the Winter Haven Chain of Lakes and Associated WBID.....	2-5
Table 5	Classification of lakes of the WHCL into Ridge or Valley Types	3-5
Table 6	Changes in agriculture within the immediate watershed: 1940s to 2006	3-7
Table 7	Changes in Urban Land Use within the immediate watershed: 1940s to 2006.....	3-8
Table 8	Changes in Native Upland Habitat within the immediate watershed: 1940s to 2006.....	3-9
Table 9	Changes in Wetlands within the immediate watershed: 1940s to 2006	3-10
Table 10	Summary of water quality data (1997 to 2007) for lakes classified as either Ridge or Valley lakes.....	3-16
Table 11	Results from regression analyses (data from 1997 to 2007) of TP vs. chlorophyll-a and TN vs. chlorophyll-a in Winter Haven Chain of Lakes	3-20
Table 12	TN:TP ratios and TSI values by Year for WHCL System (from FDEP 2007)	3-27
Table 13	TSI values for Chl-a, TN and TP (from FDEP 1996)	3-29
Table 14	Comparison of Empirically-derived TN and TP Concentration Reductions with FDEP (2007) TMDL Load Reduction Goals.....	3-31
Table 15	Results from Analysis of Lake Levels and Chlorophyll-a, total Nitrogen and Total Phosphorus.....	3-35
Table 16	Estimated TP load Reductions (kg TP / yr) for Various WHCL Projects and Required TP Reductions (kg TP / yr) to meet a TSI goal of 60 as derived from Table 5.2 in FDEP (2007) TMDL report	4-2

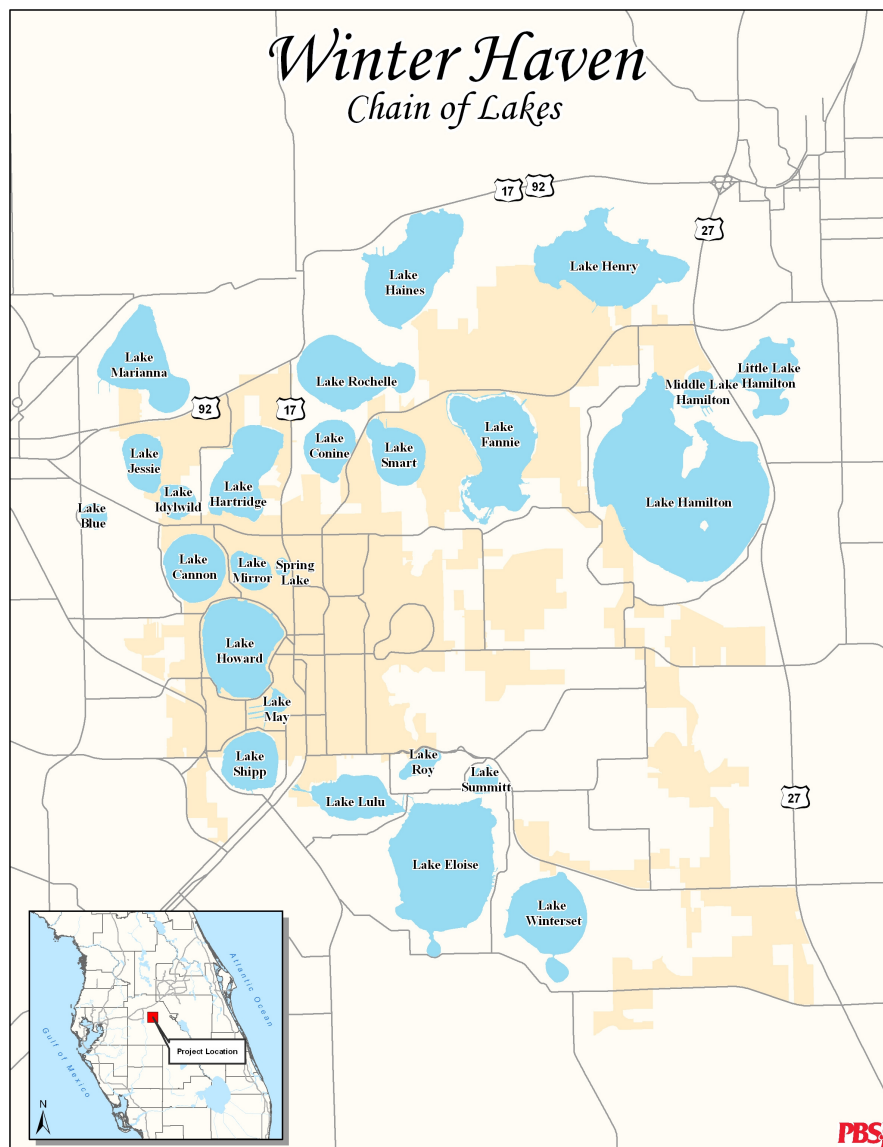
1.0 Introduction

1.1. Physical Setting

The intent of this report is to develop a base of knowledge to guide decision making related to Total Maximum Daily Load (TMDL) and Basin Management Action Plan (BMAP) development and the restoration and preservation of water quality for the Winter Haven Chain of Lakes.

The Winter Haven Chain of Lakes watershed is located in north-central Polk County (Figure 1).

Figure 1
Winter Haven Chain of Lakes



The Winter Haven Chain of Lakes (WHCL) is generally divided into the Northern Chain, consisting of 5 lakes, and the Southern Chain, consisting of 16 lakes. The Northern Chain lakes include Conine, Rochelle, Haines, Smart and Fannie. The Southern Chain lakes consist of Winterset, Eloise, Summit, Lulu, Roy, Shipp, May, Howard, Cannon, Blue, Mirror, Spring, Idylwild, Jessie, Mariana, and Hartridge. Lakes Blue and Mariana connect to the other lakes in the Southern Chain only when water levels reach set lake operational levels. The watershed of the WHCL is approximate 32 square miles in size (Florida Department of Environmental Protection [FDEP] 2007).

The WHCL watershed is part of a rapidly urbanizing portion of Central Florida. As a result of significant changes in land use that have accompanied this population growth, there are water quality concerns within the WHCL system. The WHCL system has a number of waterbody segments (i.e., segments with waterbody identification numbers, or WBIDs) with verified water quality impairments. As listed by FDEP (2007) the applicable verified water quality impairments for the WHCL are shown in Table 1:

Table 1
Adopted Listing of Impaired Waterbodies in the WHCL

WBID	Waterbody Segment	Chain	Parameter Causing Impairment	Priority for TMDL Development	Projected Year for TMDL Development
1521H	Lake Cannon	Southern	Nutrients (TSI)	High	2004
1521F	Lake Howard	Southern	Nutrients (TSI)	High	2004
1521K	Lake Jessie	Southern	Nutrients (TSI)	High	2004
1521	Lake Lulu	Southern	Nutrients (TSI)	High	2004
1521E	Lake May	Southern	Nutrients (TSI)	High	2004
1521G	Lake Mirror	Southern	Nutrients (TSI)	High	2004
1521D	Lake Shipp	Southern	Nutrients (TSI)	High	2004
1488C	Lake Haines	Northern	Nutrients (TSI)	High	2004
1488A	Lake Smart	Northern	Nutrients (TSI)	High	2004
1521J	Lake Idylwild	Southern	Nutrients (TSI)	Medium	2009
1488U	Lake Conine	Northern	Nutrients (TSI)	Medium	2009
1488B	Lake Rochelle	Northern	Nutrients (TSI)	Medium	2009

1.2. Background on Water Quality Goals and TMDLs

Relevant impairments for the WHCL system are all related to excessive nutrient loads, which have resulted in calculated Trophic State Index (TSI) values that exceed guidance outlined in the Impaired Water Rule (IWR). The IWR methodology has two TSI thresholds, depending upon the levels of color (i.e., “tannins”) as quantified via platinum cobalt units (PCU). Lakes where the median annual color is greater than 40 PCU would be placed on the Verified List if the annual median TSI value for the lake exceeds 60. For lakes where levels of color are less than or equal to 40 PCU, those lakes would be placed on the Verified List if their annual median TSI

value exceeds 40. Lakes with high levels of tannins are considered to be more “tolerant” of elevated nutrient availability than lakes with lower levels of tannins.

For the WHCL, FDEP (2007) used a TSI threshold of 60 to develop nutrient TMDLs for listed lakes. This approach was considered to be appropriate, as prior investigations of the paleolimnology of the lakes indicated that lakes within the WHCL system were considered to have natural condition TSI values higher than 40, even for those lakes that had color values less than 40 PCU (Whitmore and Brenner 1995).

The Draft Verified List produced by FDEP included Lakes Winterset, Eloise, Hartridge, and Fannie, as there were a number of annual average TSI values from these lakes that exceeded the original default TSI value of 40, which is the default TSI goal for lakes such as these, which often had color values less than 40 PCU. These four lakes were subsequently removed from the Verified List, as they did not exceed the revised and site-specific TSI threshold of 60, based on the findings of Whitmore and Brenner (1995).

Within this context, a system-wide TSI goal of 60 was selected by the Southwest Florida Water Management District (District) in its Pollutant Load Reduction Goal (PLRG) report (USF 2005). This PLRG was then used by FDEP in its TMDL calculations (FDEP 2007). This PLRG might be overly protective in some lakes, and not fully protective in others. For example, the paleolimnological work conducted on the WHCL used to develop the alternative TSI goal of 60 was limited to five lakes (Lakes Conine, Haines, Hartridge, Howard, and May). The conclusion of the paleolimnological study (Whitmore and Brenner 2005) was that these five lakes were historically mesotrophic to eutrophic, which led the authors to conclude that these lakes would have had pre-development TSI values in the range of 50 to 60. Therefore, the TSI goal of 60 for the WHCL is based on not exceeding the upper end of the range of historical water quality conditions derived from a subset of 5 lakes, out of a total of 21 lakes in the WHCL.

In addition, 3 of the 5 lakes in the Northern Chain (Lakes Conine, Haines, and Smart), require phosphorus load reductions greater than 70 percent to meet the target TSI value of 60 (FDEP 2007). The lakes in the Northern Chain are thought to be reliant on groundwater inflows for a significant portion of their water budget (USF 2005). Additionally, since all the lakes in the Northern Chain are co-limited by nitrogen and phosphorus, reductions in nitrogen loads may also be needed to affect lake eutrophication. Due to complications arising from the need to better document groundwater inputs and the potential role of groundwater-based nitrogen loads, TMDLs were not developed for the four Northern Chain lakes (Lakes Conine, Haines, Smart and Rochelle) that were listed as verified impaired for nutrients (FDEP 2007).

For the Southern Chain of Lakes, adopted TMDL load reductions for phosphorus (FDEP 2007) vary between 22 percent (Lake Mirror) and 60 percent (Lake Shipp). While it is anticipated (e.g., FDEP 2007) that the Watershed Management Plan currently being conducted for the City of Winter Haven and the District can refine a TMDL for the Northern Chain of Lakes, that effort may not be able to accommodate the entirety of data needs and other issues identified by FDEP (2007) which include the following:

- Assessment of impacts of direct atmospheric deposition of nitrogen and phosphorus (both wet and dry deposition).
- Refinement of the potential role of septic tank systems on nutrient (especially nitrogen) loading.
- Assessment of the role of sediment nutrient exchanges.
- Further refinement of the effects of nitrogen limitation on phytoplankton growth, particularly for lakes in the Northern Chain.

In addition, recently completed and ongoing work in Lakes Jesup and Hancock have shown the importance of the role played by nitrogen fixing blue green algae on water quality, at least in hypereutrophic lakes. In these two lakes, the role of phosphorus on water quality is indirect, but important nonetheless, despite these lakes being classified as either being co-limited or nitrogen limited, based on Total Nitrogen to Total Phosphorus (TN:TP) values.

In Lake Hancock, the following paradigm was developed (PBS&J 2007) for consideration by FDEP:

- Increased TP loads have lead to an accumulation of TP in the sediments.
- Due to shallow water, windy conditions resuspend significant amounts of TP into the water column.
- Additional TP is re-mineralized into the water column from the lake's sediments.
- Elevated levels of TP in the water column reduce the water column TN:TP ratio.
- Decreased TN:TP ratios favor increased dominance by blue-green algae.
- Nitrogen-fixation by blue-green algae result in excess values of TN.
- These hypereutrophic lakes can export more TN than what is loaded into them from external sources.

While many of the lakes in the WHCL have fairly good water quality, Lakes Shipp, Conine and Haines have had annual TSI values in excess of 70 (although Lake Conine has shown recent improvements in response to point source load reductions and whole-lake alum treatment).

Additionally, nitrogen concentrations from Lakes Jessie and Shipp have included samples with TN concentrations in excess of 3 mg / liter over the past 15 years (FDEP 2007). In contrast, the event median concentration (EMC) values for TN commonly used in stormwater loading models (e.g., Sarasota Bay, Charlotte Harbor, Lake Seminole, etc.) typically do not exceed 2 mg / liter TN. As such, an excess of TN could be associated with sediment resuspension, inputs of groundwater with high levels of nitrate, and potential nitrogen fixation by blue-green algae.

An examination of water quality data within the WHCL (described later in this report) indicates that nitrogen fixation may be occurring at significant rates in Lakes Blue, Conine, Haines, Hamilton, and Smart. These four lakes have several characteristics that suggest nitrogen fixation, such as;

- Elevated levels of chlorophyll-a.
- TN concentrations higher than stormwater event median concentration (EMC) values used in most loading models.
- TN:TP levels suggesting competitive advantages for blue-green algae.

Preliminary screening process results could be further pursued, to ensure that TMDLs do not, for example, suggest reductions are needed for external TN loads for lakes where much of the TN is actually produced within the lake itself.

An additional topic related to TMDLs and BMAPs for the WHCL is the role of tannins in moderating algal growth. In Wolf Lake, in Highlands County, elevated levels of TN and TP are not expressed as elevated chlorophyll-a, perhaps due to the high levels of tannins in the lake. Highlands County has summarized Wolf Lake's water quality issues as, "Despite the high nutrient levels, algae populations, as estimated by the chlorophyll concentration in the water, are low in this lake. This may be due to heavy natural staining of the water that reduces light penetration needed for algal growth."

Wolf Lake has very little direct shoreline development, as compared to many of the lakes in the WHCL. Therefore, the extensive wetlands fringe along Wolf Lake may act as a source of tannin-loading to the lake, which then acts to reduce the growth potential of phytoplankton within the lake. As there have been significant losses of wetlands coverage in the watershed of the WHCL, it is possible that there has been a significant decrease in tannin levels, which could have made lakes in the WHCL more susceptible to the increased nutrient loads that accompanied population growth. If nutrient loads can be "tempered" by wetland-associated tannin levels, this could have significant impacts on the BMAP development and implementation processes for the WHCL.

1.3. Purpose of Pre-BMAP Report

The FDEP is responsible for developing and implementing TMDLs to restore and protect impaired waters in the WHCL. This involves the potential refinement of TMDLs for the 12 lakes listed as impaired for nutrients (see Table 1). As the next step in the TMDL process, BMAPs identify specific, cost-effective projects that stakeholders agree to carry out to achieve the TMDLs - that is, to restore and protect impaired waters.

Because FDEP is responsible for TMDLs and BMAPs statewide, it has a vested interest in ensuring that projects to restore and protect water quality actually benefit water resources and are implemented correctly. DEP recognizes the need to provide technical assistance to local

governments in developing TMDLs and BMAPs for impaired waters in their jurisdictions. This need is supported by the following general observations:

- There is a need to gain general agreement among all stakeholders that waters identified as impaired are, in fact, impaired. In the WHCL, there is general agreement that lakes listed as “impaired” are in fact impaired.
- There is also a need to gain general agreement among stakeholders on the level of impairment identified in TMDLs. In the WHCL, an issue of concern is whether or not the lakes should be managed based on levels of nutrients and chlorophyll combined, or on chlorophyll alone.
- Due to time constraints that limit the review of existing studies and preclude the collection of additional data, many TMDLs include numerous assumptions that may not have been fully validated during the TMDL development process. These assumptions need to be validated to build support for project implementation. This project is meant to supplement the TMDL model used for the WHCL, which was based on the Southwest Florida Water Management District’s (District) Pollutant Load Reduction Goal (PLRG) model. This model (USF 2005) used a very limited data base for estimating groundwater nutrient loads. The City of Winter Haven, with funding support from the District, is in the process of updating the model to address these deficiencies.
- Many of the barriers to developing and implementing TMDLs are of a highly technical nature. There is a need to synthesize data and other technical information to create a common base of information from which to develop defensible TMDLs and BMAPs and guide future water resource decision making. The level of synthesis required will vary among waterbodies. In the WHCL, it is especially important that water chemistry is evaluated in the context of observed environmental responses, which vary between the lakes.
- Generally, TMDLs do not provide guidance on the type or location of projects that will lead to the successful restoration of water quality. Guidance is needed to achieve the greatest benefit for the least cost, which will become more important over time as communities compete internally and externally for limited public funding. Guidance is also needed to ensure that the right projects are implemented in the right places. Failure to do so could result in the implementation of projects that do not improve water quality, which could undermine BMAP implementation. In the WHCL system, the type and location of projects will be influenced by the management endpoints (i.e. nutrients plus chlorophyll, or chlorophyll alone).
- The preparedness of local governments to develop (if they so wish) or to implement BMAPs varies widely, from those that have limited resources to those that have highly developed resources. Current experience in developing BMAPs demonstrates the need to provide some level of technical guidance and support to all communities, regardless of their level of preparedness to develop BMAPs. This project is meant supplement the

very successful Lakes Management Plan being overseen by the City of Winter Haven, especially in regard to nutrient reduction strategies.

- Because the development and implementation of TMDLs and BMAPs is a highly complex, technical process, transparency is needed in how water resource decisions are made. Appropriate explanations should be provided about what projects are going to look like and the anticipated results, as this information will be critical to building state and local support for funding and implementing projects.

In the WHCL system, FDEP, Polk County, the City of Winter Haven and the District have completed, or are currently working on, a number of projects that seek to address the many different objectives of holistic watershed management, including water supply, flood control, water quality, and the maintenance of natural systems.

This pre-BMAP report is structured to undertake two major tasks, outlined below:

1. Collect, interpret, and synthesize existing information to:
 - a. Understand the local and regional “networking” of water that gives rise to observed water quality.
 - b. Identify the water resource issues related to water quality and natural resource protection that must be considered prior to implementing projects to improve and/or preserve water quality.
2. Work collaboratively with affected stakeholders to build consensus as to the appropriate water quality restoration projects needed.

2.0 Methods

2.1. GIS-based Analysis

A Geographic Information System (GIS) was used to display physical characteristics of the lakes, land use, and wetlands within the contributing watersheds of the WHCL. The study included 25 lakes (see Figure 1). For purposes of this report, a land use change analysis was completed from 1940 through 2006. Data sources and the methodology used are described below.

A database of physical characteristics of the area was queried, including soils, topography, and physiographic delineations. Soils data were obtained from the U.S. Department of Agriculture, Natural Resources Conservation Service. The Polk County soils survey was completed in 1990. Soils in the contributing watersheds of the Winter Haven Chain of Lakes were predominantly Candler-Tavares-Apopka and Samsula-Hontoon map units.

LiDAR point and breakline data were provided by the District and used to create a Digital Elevation Model (DEM) for the WHCL region. Breakline data included hydrography lines and lake polygons. Topography in the study area ranges from 105 feet to 231 feet.

Surficial geology data were obtained from FDEP to display the physiographic regions of the WHCL region. These data were published by FDEP in 1998.

Land use data were reviewed for the 1940s, 1979, and 2006. Land use data from the 1940s were obtained from Avineon, Inc. Land use data from 1979 and 2006 were obtained from the Southwest Florida Water Management District (District) Florida Land Use and Cover Classification System (FLUCCS).

Creation of the 1940s era map was accomplished using 1940s digital orthophotography. Upon completion of the rectified 1940s imagery, a 1940s map layer was created using the 1979 map layer as a base. The 1979 map coverage was placed over the 1940s digital orthophotography during this task. Photointerpreters systematically reviewed and edited the 1979 vector data to reflect the land use signature on the 1940s imagery. Land use and land cover features that did not change between the 1940s and 1999 were left un-edited within the coverage. Land use and land cover features that did change during the timeframe were edited according the 1940s imagery signatures.

Data were initially categorized into four categories including agriculture, urban land use, native upland habitat, and wetlands and later classified as developed (agriculture and urban land use) and undeveloped (native upland habitat and wetlands). Subsequently, the three land use maps produced for the study (1940s, 1979 and 2006 maps) were digitally intersected within ArcGIS in order to extract changes between the maps. The intersection process combines map coverages together within ArcGIS so that changes between the maps can be identified and quantified. Finally, land use data were clipped to a 500-foot buffer around each lake, to determine the

influence of various shoreline features on tannin levels, described later in this report. A 500-foot protective buffer around wetlands is used in neighboring Hillsborough County.

Wetlands data from the United States Fish and Wildlife Service National Wetland Inventory (NWI) and the 2006 District FLUCCS data were also mapped. NWI and FLUCCS data were categorized as forested and non-forested wetlands. Forested wetlands were wetlands in the NWI data with a class description of forested and FLUCCS codes greater than or equal to 6100 and less than or equal to 6300. Non-forested wetlands were wetlands in the NWI data with a class description other than forested and FLUCCS values greater than or equal to 6400 and less than or equal to 6600.

2.2. Water Quality Data and Analysis

2.2.1. General Water Quality Assessment

Two databases were queried for relevant water quality data: the Polk Water Atlas and the FDEP IWR Run 31 dataset. From each database, a suite of water quality parameters were selected (Tables 2 and 3). Data from the Polk Water Atlas were used to identify the reference median values for each parameter for all Polk County lakes. This database was readily queried for all of Polk County. The IWR database was utilized to obtain data for the lakes in the Winter Haven Chain of Lakes. Each lake has its own WBID number (waterbody identification number; Table 4) and this enabled the data to be readily extracted from the statewide database. As a statewide database, it contains data from multiple agencies and a vast amount of water quality data.

Polk County Water Atlas

The Polk County Water Atlas (www.polk.wateratlas.usf.edu) was queried for all available relevant nutrient and clarity data (Table 2) collected between 1997 and 2007 for all lakes in Polk County. This timeframe was chosen as it includes recent data and encompasses the verification period used to produce the list of impaired waterbodies in the WHCL watershed (January 1997 to June 2004). Since some lakes and time periods had data for corrected chlorophyll while others listed uncorrected chlorophyll, the two parameters were combined to create a single parameter CHLACOMB which was preferentially set to corrected chlorophyll if available, and otherwise to uncorrected chlorophyll. This step was considered to be conservative because uncorrected chlorophyll values could be higher than true, or corrected, values. The same procedure was used for color (two parameters were queried from the database, Table 2). “True color” was used preferentially if available and the parameter “Color” was used if true color was not available.

Table 2
Water Quality Parameters for which the Polk County Water Atlas Was Queried

Characteristic	Characteristic Code	Units
Chlorophyll a, corrected for phaeophytin	ChlaC_ugl	ug/L
Chlorophyll a, uncorrected for phaeophytin	Chla_ugl	ug/L
Color	Color_pcu	PCU
Depth	Depth_ft	Ft
Depth, bottom	Depth_bott_ft	Ft
Nitrogen	TN_ugl	ug/l
Nitrogen, ammonia as N	NH3_N_ugl	ug/l
Nitrogen, Kjeldahl	TKN_ugl	ug/l
Nitrogen, Nitrite (NO ₂) + Nitrate (NO ₃) as N	NOx_ugl	ug/l
pH	pH	None
Phosphorus as P	TP_ugl	ug/l
Phosphorus, phosphate (PO ₄) as P	OP_mgl	mg/l
Secchi disk depth	Secchi_ft	Ft
True Color	Color_true_pcu	PCU
Turbidity	Turb_ntu	NTU

Annual median values were calculated for each lake in the water atlas dataset using the MEANS procedure in SAS. Using the same SAS procedure, mean and median values were calculated for each Polk County lake and for all lakes combined for the period 1997-2007. Period (1997-2007) median values for all Polk County lakes combined were subsequently used as reference lines in plots of WHCL data, see below.

IWR Run 31

Run 31 of the IWR dataset “iwr2002_pv_Run31.sas7bdat” was queried for all data for those WBIDs contained in the Winter Haven Chain of Lakes (Table 4). These data were further queried for the parameters of interest (Table 3). Because some parameters were typically measured as profile measurements (i.e. with a Hydrolab[®] or similar devices at multiple depths), records for such parameters were only retained if the available depth information indicated a measurement in less than 1 meter of water. If depth information was missing, it was presumed to be a near surface measurement and retained. The parameters falling in this category were salinity, conductivity, temperature, dissolved oxygen and pH. As stated above for the Polk Water Atlas data, the CHLACOMB parameter was created for the IWR data.

Table 3
Water Quality Parameters for which Run 31 of the IWR Database Was Queried

Parameter	Master Code	Units
Chlorophyll a, corrected for phaeophytin	CHLAC	ug/L
Chlorophyll a, uncorrected for phaeophytin	CHLA	ug/L
Color	COLOR	PCU
Conductance	COND	umhos/cm
Dissolved Oxygen	DO	mg/L
Nitrate	NO3	mg/L
Nitrate Nitrite	NO3NO2	mg/L
Nitrite Nitrogen as N	NO2	mg/l
Nitrogen Ammonia as N	NH4	mg/L
Nitrogen Kjeldahl as N	TKN	mg/l
Nitrogen Total as N	TN	mg/l
Orthophosphate as PO4	PORTH	mg/l
pH	PH	standard units
Phosphorus Total as P	TP	mg/L
Phosphorus in Total Orthophosphate at P	TORTH	mg/L
Salinity	SALIN	
Secchi depth	SD	m
Temperature	TEMP	degrees C
Total Suspended Solids	TSS	mg/L
Turbidity	TURB	NTUs
Unionized Ammonia	UNNH4	mg/L

The IWR dataset contained multiple duplications that were difficult to track (possibly due to multiple agencies uploading the same data, a single agency loading the data more than once with slight variations like rounding errors, etc.). Thus, median values were calculated by water body ID, station, date, and parameter.

The IWR dataset was then parsed to those data collected during 1997 and later, corresponding with the Polk Water Atlas dataset. Mean and median values for each water quality parameter were calculated for each WBID for each year in the dataset, as well as for the period (1997-2007). The period median (1997-2007) was also calculated for TN, CHLACOMB, TP and color for all lakes combined.

Because there was no published median color value for lakes in Florida, the IWR dataset (Run 31) was queried for all records with a body type of “Lake” and for the parameter “COLOR”. A median color value was computed for these records.

Period medians (1997-2007) for TN, TP, CHLACOMB, and COLOR obtained for the Winter Haven Chain of Lakes from the IWR dataset as described above were plotted by lake in Excel. Reference lines representing median values for all Polk County lakes (obtained as described above from the water atlas dataset), median values for Florida lakes (as well as the above

described median value for color in Florida lakes) and the median value for all WHCL lakes (as described above) were superimposed on these plots.

Table 4
List of Lakes in the Winter Haven Chain of Lakes and Associated WBID

Lake	WBID
Lake Henry	1504A
Lake Haines	1488C
Lake Rochelle	1488B
Lake Conine	1488U
Lake Smart	1488A
Lake Fannie	14882
Lake Hamilton	15041
Middle Lake Hamilton	15002
Little Lake Hamilton	15001
Lake Mariana	1521L
Lake Jessie	1521K
Lake Idylwild	1521J
Lake Hartridge	1521I
Lake Blue	1521Q
Lake Cannon	1521H
Lake Mirror	1521G
Spring Lake	1521G1
Lake Howard	1521F
Lake May	1521E
Lake Shipp	1521D
Lake Lulu	1521
Lake Roy	1521O
Lake Summit	1521M
Lake Eloise	1521B
Lake Winterset	1521A

2.2.2. Time Series Analysis

The original plots provided insight to water quality conditions over the recent decade. To investigate a more “historical” period, time series plots were created that extended earlier than the 1997-2007 data previously described. Run 31 of IWR dataset was queried and further processed as described above for WHCL WBIDs. However, for this task, all data from 1980 onward were retained to create time series plots (there were very little data prior to 1980 for the majority of the lakes). Data for chlorophyll (CHLACOMB as detailed above), TN, TP and Color were plotted versus sampling date for each lake.

This subset of the IWR dataset (1980 and later) was also further reduced and plotted. Quarterly medians for each year and parameter were determined and plotted against time for each lake (the

date was set to the first day of the second month of each quarter). A LOESS curve (see <http://support.sas.com/rnd/app/papers/loesssugi.pdf> for further details) was fit to the quarterly data using the LOESS procedure in SAS. An automatic selection of a smoothing function (how many consecutive points the procedure uses as a time to fit the curve) was used.

Following this effort, the data were further reduced to only those years 1997-2007, as this timeframe encompassed the verification period and more recent data. The SAS procedure REG was utilized to test for significant linear relationships of TN, TP and Color with Chlorophyll (CHLACOMB) for each lake. It is important to note that no tests for normality or homoscedasticity (normality of variance) related to parametric test requirements were performed. Chlorophyll data were plotted against TN, TP, and Color and if a significant relationship was found ($p < 0.05$) the regression line was added to the plot.

2.2.3. Water Quality in “Ridge” vs. “Valley” Lakes

Additional data analysis was conducted after preliminary assessments determined that lakes within the WHCL fit within two main class variables: “Ridge” type lakes and “Valley” type lakes. The basis for this additional assessment category is discussed in the section “GIS-based Analysis”.

Further analyses were conducted to compare those lakes in the Winter Haven Chain of Lakes classified as “valley” lakes versus those classified as “ridge” lakes (described later in this report). Run 31 of the IWR dataset “iwr2002_pv.sas7bdat” was queried for the WBIDS and parameters of interest (i.e. TP, TN, CHLACOMB, and Color data).

To eliminate erroneous duplicate data entries, median values were calculated for those entries with the same WBID/station/year/month/day (as described above). The lakes were then divided into categories of “ridge” and “valley” lakes. The SAS procedure MEANS was utilized to calculate annual means for each lake. This minimized the differences between lakes that occurred solely because some lakes have more data than others. Lake Roy had very little data and was eliminated from further analyses.

2.3. Lake Levels and Water Quality

An assessment was made of the relationships, if any, between lake levels and water quality. Data sets examined for lake levels were provided by the District. Many lakes had limited lake level information, with data available for only a few years, or gaps were found in the lake level data. Data sets that were retained for further analysis were those where monthly lake level data were available for ten years or longer. These lake level data were then compared to ambient water quality data for total nitrogen (TN) total phosphorus (TP) and chlorophyll-a (CHLA). For dates where TN, TP and/or CHLA data were collected from a lake, the lake level data from that same lake was obtained. As water quality data were collected less frequently than lake level data, limitations on developing lake level – water quality data relations were mostly imposed by the availability of water quality data (for those lakes with sufficient lake level data). If multiple sites were sampled within a lake, or if a lake was sampled on more than one date per month, all

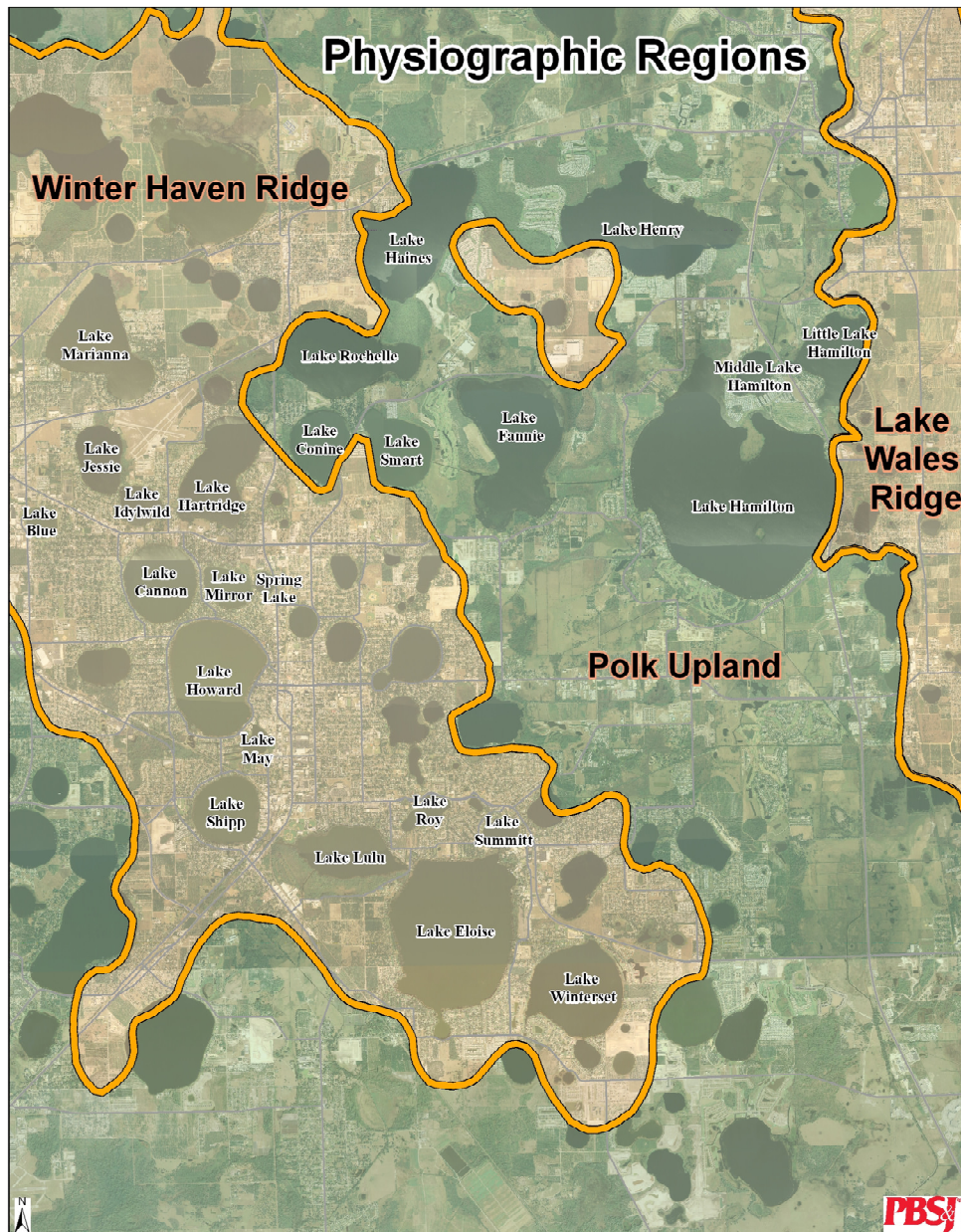
water quality data from all site and date combinations for that month were used for comparisons. This data set was then used to determine if there were any relationships between lake level and water quality, based on linear regression with an *a priori* P value of 0.05.

3.0 Results and Discussion

3.1. GIS-based Analysis

The surface geology in the WHCL region gives rise to three main physiographic regions, the Lake Wales Ridge, the Winter Haven Ridge, and the Polk Uplands (Figure 2).

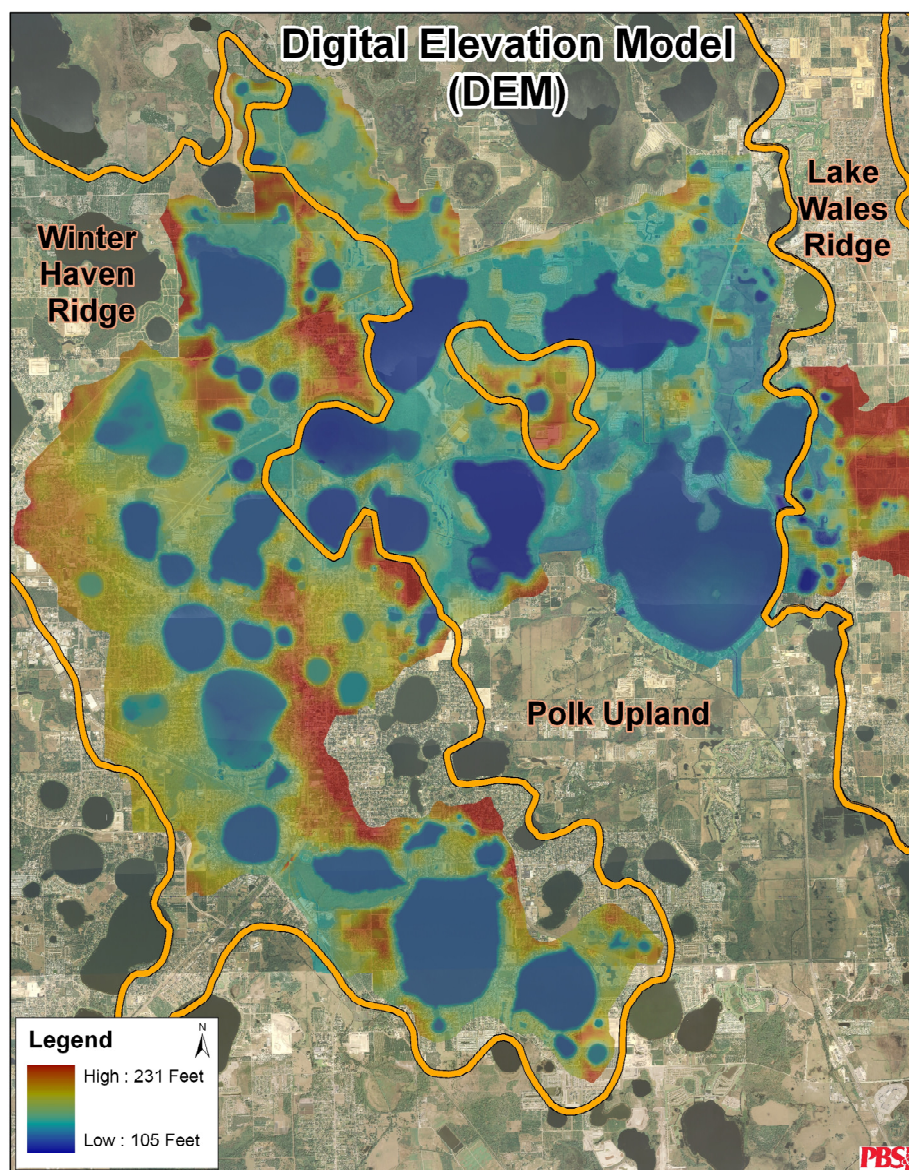
Figure 2
Physiographic Regions within the Vicinity of the WHCL



The Winter Haven and Lake Wales Ridges were formed during the Pliocene Epoch of the Tertiary Period. The Polk Uplands were formed during the Pliocene/ Pleistocene Epoch of the Tertiary/ Quaternary Period.

Data from the LiDAR-derived digital elevation model (DEM) support the characterizations illustrated by the physiographic regimes analysis, as shown in Figure 3. That is, the areas denoted as either Winter Haven Ridge or Lake Wales Ridge are in fact at higher elevations than the somewhat confusingly-named “Polk Uplands”.

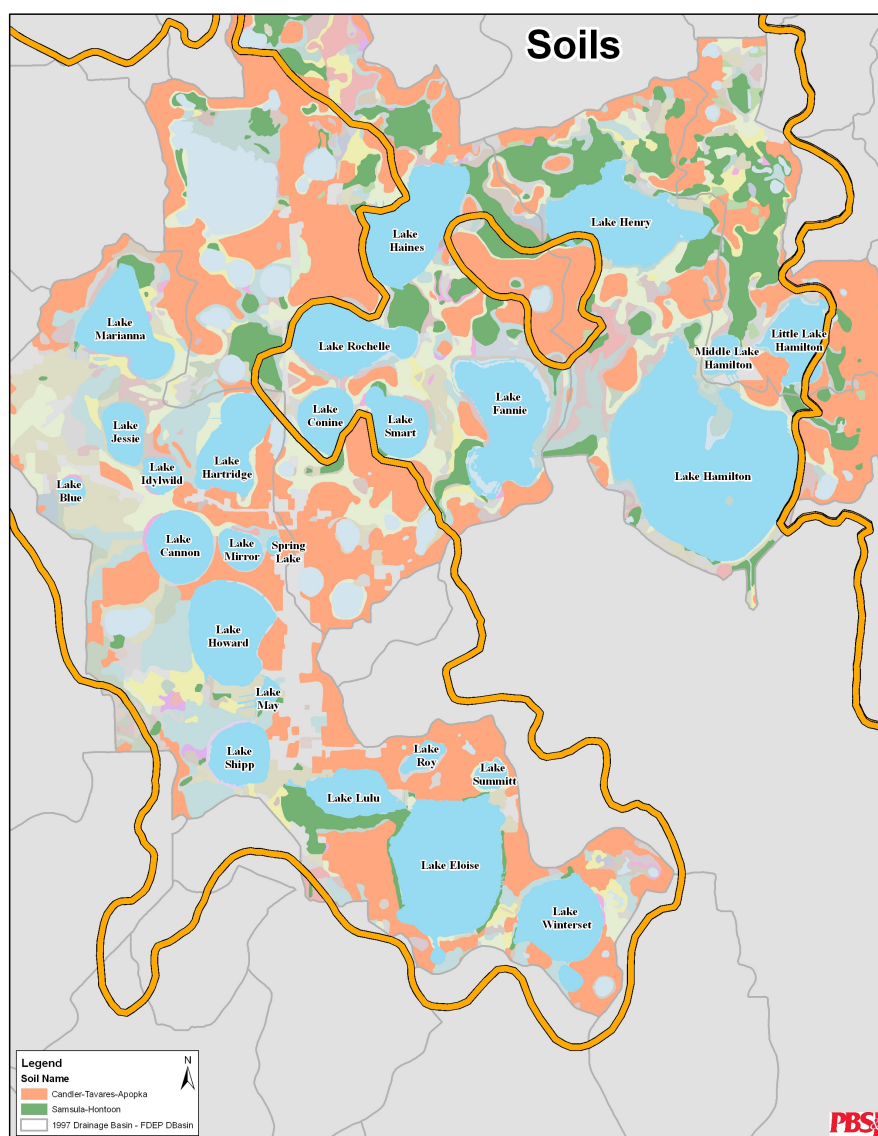
Figure 3
Digital Elevation Model for WHCL



For those lakes located within the Winter Haven Ridge physiographic region, land elevations typically ranged between 170 and 200 plus feet (NGVD) in elevation. Land elevations for those lakes within the Polk Upland physiographic region typically ranged between 100 to 150 feet (NGVD) in elevation. For the most part, lakes in the Polk Upland are located in a “valley” of sorts between lakes perched on the higher elevations of the Lake Wales and Winter Haven Ridges.

Differences in elevation between lakes are manifested as well in differences in surface soils (Figure 4).

Figure 4
Surface Soils in the WHCL Region

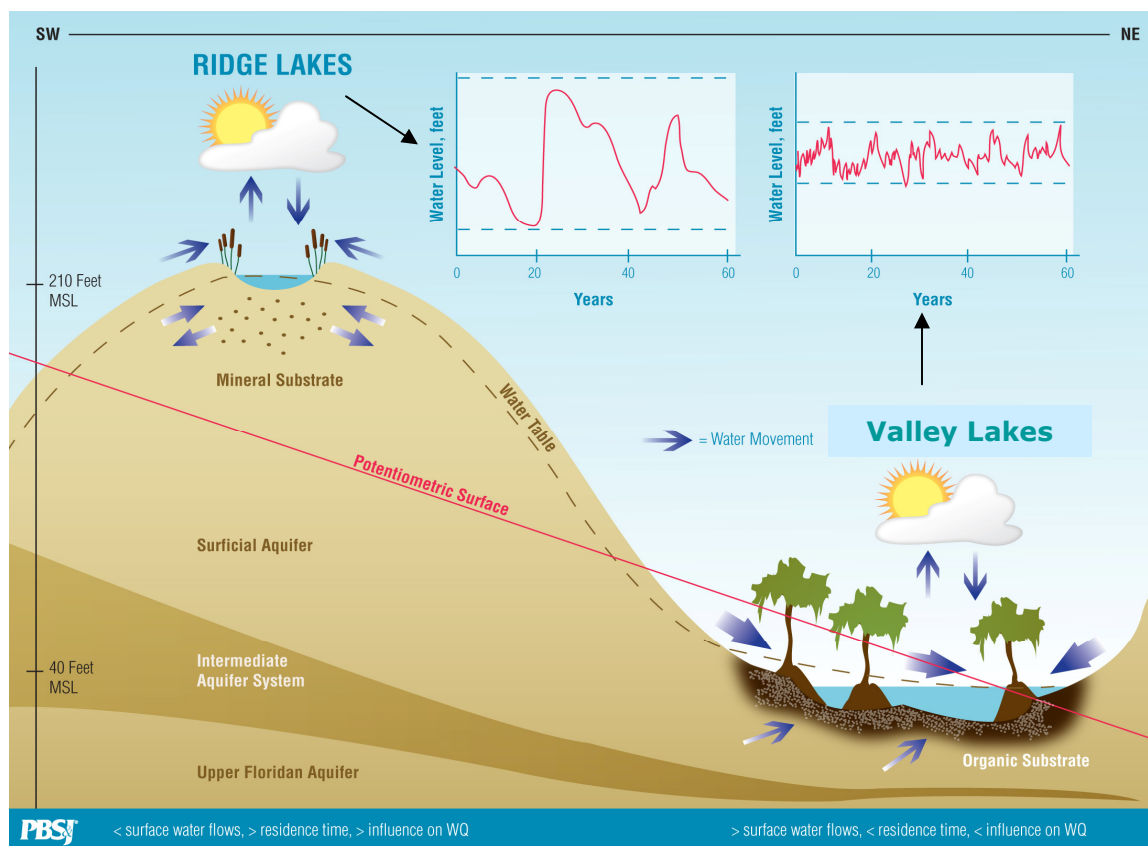


For lakes located within the Winter Haven Ridge physiographic region, soils were mostly those of the Candler-Tavares-Apopka groups. These are well drained and sandy soils with a high mineral content and low organic content. In contrast, lakes located within the Polk Uplands physiographic region were more likely to have soils from the Samsula-Hontoon map units. These soils are moderately to poorly drained, with a lower mineral content and a higher organic content.

Not all lakes fit within these two soil groupings, as there is a significant amount of organic-rich soils located on the south side of Lake Lulu, and there are a number of locations within the Polk Uplands where well-drained soils are found.

These findings led the authors to the conclusion that lakes within the WHCL system tend to fit within two major class variables – “ridge” lakes and “valley” lakes. Ridge lakes are those that are found in higher elevations, where soil types are typically well-drained, mineral-rich and low in organic contents. Valley lakes are those found in lower elevations, where soil types are typically moderately to poorly drained, and where the organic content is higher and the mineral content is lower. Figure 5 illustrates a conceptual model of these two lake types.

Figure 5
Conceptual Model of Ridge and Valley Lakes within the WHCL



Water levels in the Ridge lakes would be expected to vary over a larger range of values. However, fluctuations would be expected to be characterized by a “smoother” hydrograph (Spechler and Kroening 2007). Valley lakes would have more dynamic hydrographs, as they would be expected to be less isolated (in a natural condition) than those lakes located higher up on the Winter Haven and Lake Wales Ridges.

Based on a combination of physiographic regions, DEM-derived elevations, and soil types, the lakes of the WHCL were then classified as either Ridge lakes or Valley lakes, as shown in Table 5.

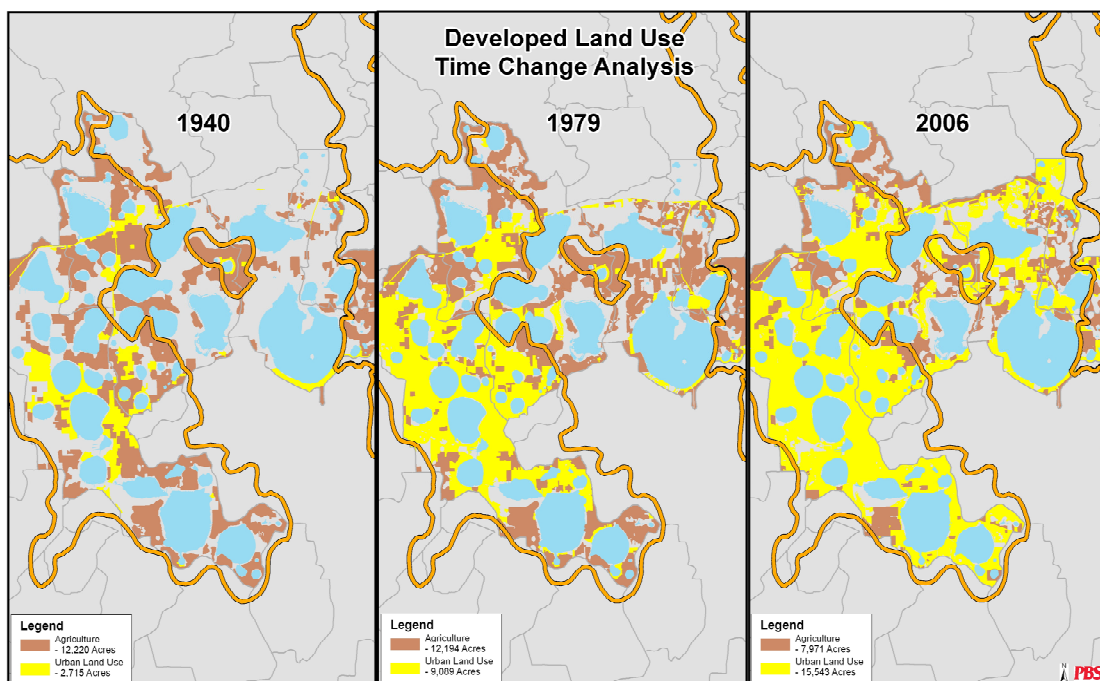
Table 5
Classification of lakes of the WHCL into Ridge or Valley Types

Lake	Chain	Type
Blue	Southern	Ridge
Cannon	Southern	Ridge
Conine	Northern	Ridge
Eloise	Southern	Ridge
Fannie	Northern	Valley
Haines	Northern	Valley
Hamilton	Northern	Valley
Hartridge	Southern	Ridge
Henry	Southern	Valley
Howard	Southern	Ridge
Idylwild	Southern	Ridge
Jessie	Southern	Ridge
Lit. Hamilton	Northern	Valley
Lulu	Southern	Valley
Mariana	Southern	Ridge
May	Southern	Ridge
Mid. Hamilton	Northern	Valley
Mirror	Southern	Ridge
Rochelle	Northern	Valley
Roy	Southern	Ridge
Shipp	Southern	Ridge
Smart	Northern	Valley
Spring	Southern	Ridge
Summit	Southern	Ridge
Winterset	Southern	Ridge

These classifications were then used, as discussed later in the report, as the basis for determining the need, potentially, for different management paradigms for protecting and/or preserving water quality.

Another notable feature that differentiates Ridge and Valley lakes is the rate at which their immediate watersheds were developed. Figure 6 illustrates the pattern of development within the WHCL region.

Figure 6
Changes in Developed Land Use over Time in the WHCL Region



In the 1940s, nearly all of the development in the WHCL watershed occurred along the Winter Haven Ridge, mostly in the areas adjacent to Lakes Howard, Shipp, Mirror and Cannon. These are all classified as Ridge lakes.

By the late 1970s, some development had occurred within the region of the Polk Uplands, where the Valley lakes are located. However, the vast majority of development occurred within the watershed of the Ridge lakes. Only by 2006 does the degree of development within the watershed of the Valley lakes approach that of the Ridge lakes. As modern stormwater regulations were not in place during the 1940s to late 1970s, most of the development that occurred within the watersheds of the Ridge lakes preceded effective stormwater controls. In contrast, a greater proportion of the development within the watersheds of the Valley lakes has occurred during a time during which modern stormwater rules have been in place.

Tables 6 and 7 summarize changes over time in the amount of agricultural and urban land use, respectively, from the 1940s to current conditions within the immediate watershed (within 500 feet of the water's edge) by lake, for the WHCL.

Table 6
Changes in agriculture within the immediate watershed: 1940s to 2006

Lake	1940s		1979		2006	
	Acres	Percent of Total	Acres	Percent of Total	Acres	Percent of Total
Blue	0.0	0.0	0.0	0.0	0.0	0.0
Cannon	22.3	13.0	10.8	6.3	6.5	3.8
Conine	74.7	47.7	33.7	21.5	14.0	8.9
Eloise	176.6	43.6	167.0	41.2	37.7	9.3
Fannie	28.2	6.7	75.2	18.0	61.4	14.4
Haines	67.7	22.6	95.5	31.9	22.7	7.2
Hamilton	163.5	24.4	163.5	24.4	104.0	15.5
Hartridge	146.7	57.5	73.5	28.8	13.7	5.4
Henry	38.3	9.9	96.4	24.9	36.2	9.3
Howard	34.6	13.7	2.4	0.9	0.0	0.0
Idylwild	22.0	22.1	7.4	7.4	0.3	0.3
Jessie	14.0	10.1	4.3	3.1	3.0	2.1
Little Lake Hamilton	82.8	35.9	79.7	34.6	69.2	30.0
Lulu	64.4	26.5	22.7	9.3	10.9	4.5
Marianna	33.7	11.7	69.1	24.0	60.7	21.1
May	4.2	3.2	0.0	0.0	0.0	0.0
Mirror	25.7	23.7	8.6	7.9	0.0	0.0
Rochelle	64.3	24.5	47.0	17.9	33.2	12.7
Roy	100.3	95.4	35.9	34.2	5.9	5.5
Shipp	19.8	11.9	8.9	5.4	8.0	4.8
Smart	105.1	57.9	82.7	45.6	68.9	38.0
Spring	15.9	28.8	13.4	24.1	0.0	0.0
Summit	16.2	18.7	1.9	2.2	0.0	0.0
Winterset	166.7	62.7	139.4	52.4	5.1	1.9

Table 7
Changes in Urban Land Use within the immediate watershed: 1940s to 2006

Lake	1940s		1979		2006	
	Acres	Percent of Total	Acres	Percent of Total	Acres	Percent of Total
Blue	9.5	11.8	78.2	96.7	80.9	100.0
Cannon	111.2	64.9	152.4	89.0	163.0	95.1
Conine	1.8	1.2	81.8	52.2	100.4	64.1
Eloise	13.0	3.2	124.3	30.7	330.5	81.5
Fannie	7.0	1.7	5.2	1.2	67.3	15.8
Haines	19.7	6.6	51.2	17.1	159.8	50.3
Hamilton	193.6	28.9	193.6	28.9	360.5	53.6
Hartridge	9.1	3.5	141.2	55.4	199.5	78.2
Henry	0.0	0.0	22.9	5.9	185.0	47.8
Howard	142.6	56.6	214.6	85.2	214.8	85.3
Idylwild	0.0	0.0	52.5	52.8	92.5	93.0
Jessie	0.0	0.0	99.7	71.7	106.9	76.8
Little Lake Hamilton	0.0	0.0	70.0	30.4	81.4	35.3
Lulu	6.4	2.6	92.8	38.2	120.0	49.4
Marianna	21.6	7.5	148.4	51.4	175.3	60.8
May	18.8	14.7	92.5	72.1	117.5	91.6
Mirror	47.8	44.1	83.6	77.2	92.2	85.1
Rochelle	25.4	9.7	50.5	19.2	85.9	32.7
Roy	0.0	0.0	69.0	65.6	98.4	92.0
Shipp	29.6	17.7	139.8	83.8	151.1	90.0
Smart	0.0	0.0	37.2	20.5	49.3	27.2
Spring	6.3	11.5	31.3	56.6	44.7	80.7
Summit	0.0	0.0	74.9	86.3	83.7	93.8
Winterset	0.0	0.0	70.3	26.4	230.2	84.0

Tables 8 and 9 summarize changes over time in the amount of native upland habitat and wetlands land use cover, respectively, from the 1940s to current conditions within the immediate watershed, by lake, for the WHCL.

Table 8
Changes in Native Upland Habitat within the immediate watershed: 1940s to 2006

Lake	1940s		1979		2006	
	Acres	Percent of Total	Acres	Percent of Total	Acres	Percent of Total
Blue	60.0	74.1	0.0	0.0	0.0	0.0
Cannon	12.0	7.0	0.0	0.0	0.0	0.0
Conine	39.3	25.1	10.1	6.4	6.0	3.8
Eloise	72.8	18.0	50.5	12.5	0.7	0.2
Fannie	151.8	36.3	123.7	29.6	98.3	23.1
Haines	77.0	25.7	34.9	11.7	30.4	9.6
Hamilton	179.1	26.7	179.1	26.7	31.2	4.6
Hartridge	55.9	21.9	26.1	10.2	10.9	4.3
Henry	119.0	30.8	87.0	22.5	0.0	0.0
Howard	21.9	8.7	0.5	0.2	0.0	0.0
Idylwild	32.4	32.6	30.3	30.5	0.0	0.0
Jessie	44.0	31.6	14.9	10.7	10.7	7.7
Little Lake Hamilton	79.7	34.6	10.3	4.5	11.7	5.1
Lulu	8.2	3.4	5.5	2.3	0.0	0.0
Marianna	151.0	52.4	15.5	5.4	0.0	0.0
May	36.5	28.5	26.0	20.2	7.8	6.1
Mirror	15.5	14.3	83.6	77.2	7.7	7.1
Rochelle	61.8	23.5	59.1	22.5	50.5	19.2
Roy	0.0	0.0	0.0	0.0	1.8	1.7
Shipp	39.8	23.9	5.8	3.5	0.1	0.1
Smart	40.1	22.1	36.2	20.0	29.9	16.5
Spring	19.9	36.0	8.1	14.6	8.1	14.6
Summit	52.3	60.3	0.4	0.4	0.0	0.0
Winterset	47.6	17.9	25.1	9.4	6.9	2.5

Table 9
Changes in Wetlands within the immediate watershed: 1940s to 2006

Lake	1940s		1979		2006	
	Acres	Percent of Total	Acres	Percent of Total	Acres	Percent of Total
Blue	11.4	14.1	2.7	3.3	0.0	0.0
Cannon	25.2	14.7	6.2	3.6	1.3	0.7
Conine	14.2	9.0	29.3	18.7	30.3	19.3
Eloise	131.4	32.4	54.8	13.5	35.8	8.8
Fannie	77.8	18.6	114.2	27.3	194.5	45.7
Haines	129.3	43.1	106.3	35.5	85.3	26.9
Hamilton	122.8	18.3	122.8	18.3	141.8	21.1
Hartridge	33.6	13.2	11.3	4.4	12.5	4.9
Henry	209.2	54.1	164.2	42.4	162.5	42.0
Howard	23.7	9.4	10.8	4.3	34.1	13.5
Idylwild	44.1	44.3	8.3	8.3	5.6	5.7
Jessie	81.0	58.2	20.1	14.4	18.4	13.3
Little Lake Hamilton	19.4	8.4	46.6	20.2	67.5	29.3
Lulu	150.8	62.1	108.5	44.7	110.3	45.4
Marianna	80.5	27.9	55.5	19.2	46.8	16.2
May	66.4	51.7	7.6	5.9	2.1	1.6
Mirror	9.2	8.5	5.3	4.9	8.5	7.8
Rochelle	71.8	27.3	83.2	31.6	92.2	35.1
Roy	4.6	4.4	0.0	0.0	0.0	0.0
Shipp	69.3	41.6	6.3	3.8	7.4	4.4
Smart	31.9	17.6	22.8	12.6	22.6	12.5
Spring	10.0	18.1	0.9	1.7	2.6	4.7
Summit	16.0	18.4	9.5	11.0	5.5	6.2
Winterset	30.7	11.6	13.5	5.1	26.2	9.6

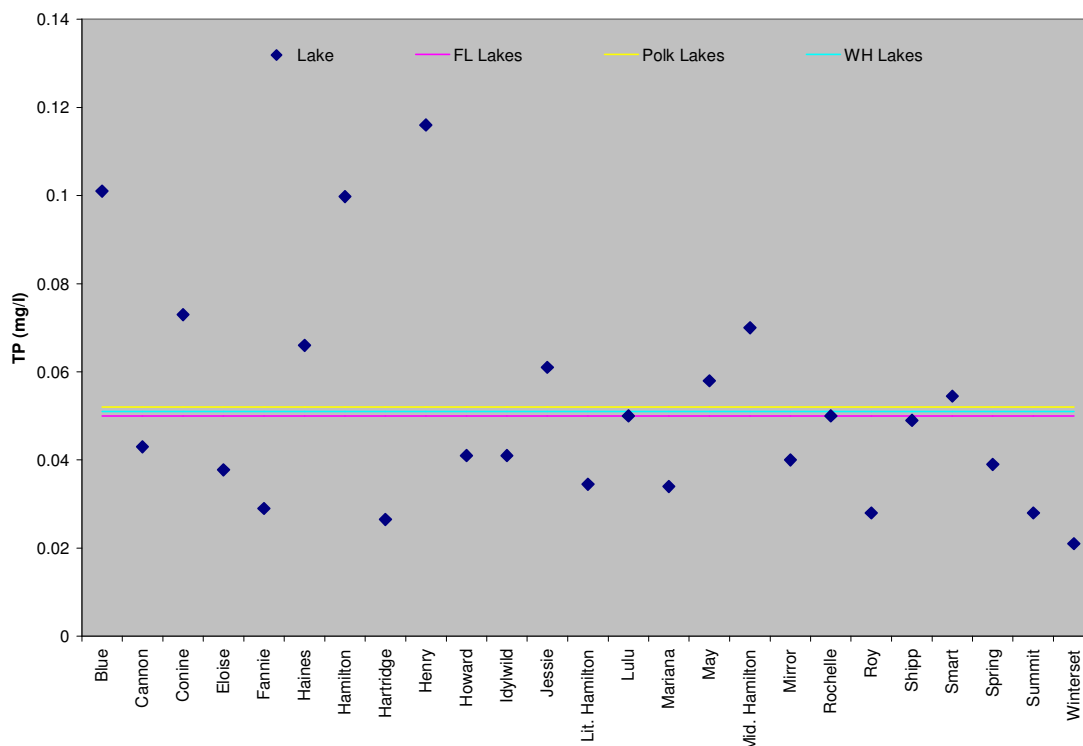
3.2. Water Quality Data and Analysis

As a preliminary data screening tool, water quality was compared among and between the WHCLs, as well as to lakes within the rest of Polk County, and throughout Florida, as described in Section 2.2 - Water Quality Data Analysis.

Figure 7 illustrates the relative levels of TP for the WHCL, as compared to lakes within Polk County as a whole, compared to the median value for TP for Florida lakes.

Figure 7
Median values (1997 to 2007) of Total Phosphorus Levels (mg / liter)
for WHCL Lakes

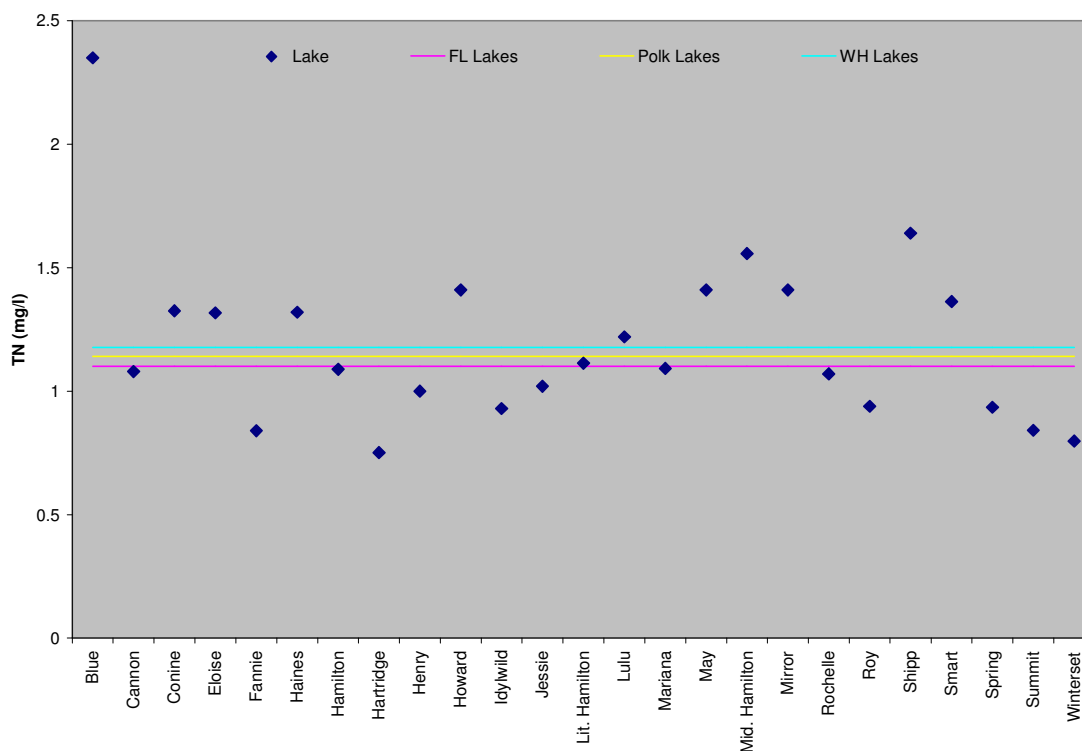
(Compared to median value for Polk County lakes and the median value for Florida lakes (FDEP 1996))



While much variation exists between individual lakes, the median TP value for lakes of the WHCL system is not much different from the median value for Polk County lakes as a whole, nor is that value much different from the median value for Florida lakes. All three values fall within the range of 0.045 to 0.055 mg TP / liter. However, levels of TP within Lakes Blue, Hamilton and Henry are all higher than 0.080 mg / liter.

Figure 8 illustrates TN levels for the WHCL, as compared to lakes within Polk County as a whole, compared to the median value for TN for Florida lakes.

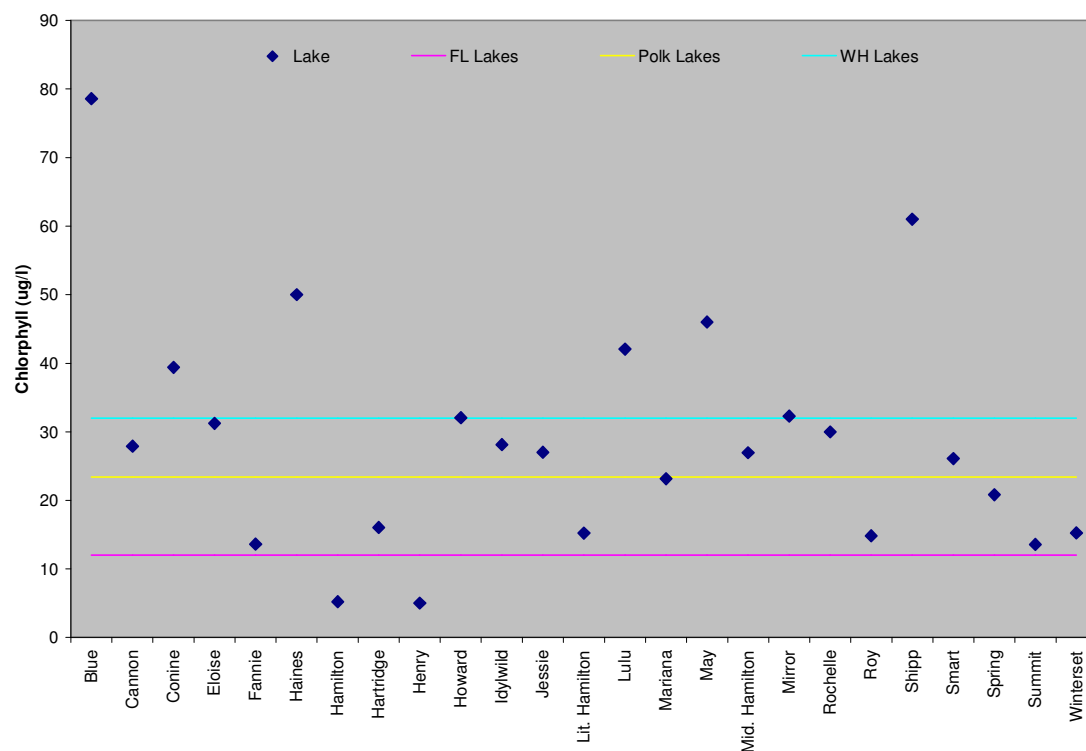
Figure 8
Median Values (1997 to 2007) of Total Nitrogen Levels (mg / liter) for WHCL Lakes
 (Compared to median value for Polk County lakes and the median value for Florida lakes (FDEP 1996))



The median value for TN for lakes of the WHCL system is not much different from the median value for Polk County lakes as a whole, nor is that value much different from the median value for Florida lakes. All three values fall within the range of 1.0 to 1.2 mg TN / liter. However, levels of TN in Lake Blue are substantially higher than levels from any of the other lakes within the WHCL.

Figure 9 illustrates the levels of chlorophyll-a for the WHCL, as compared to lakes within Polk County as a whole, compared to the median value for chlorophyll-a for Florida lakes.

Figure 9
Median Values (1997 to 2007) of Chlorophyll-a (μg / liter) for WHCL Lakes
 (Compared to median value for Polk County lakes and the median value for Florida lakes (FDEP 1996))

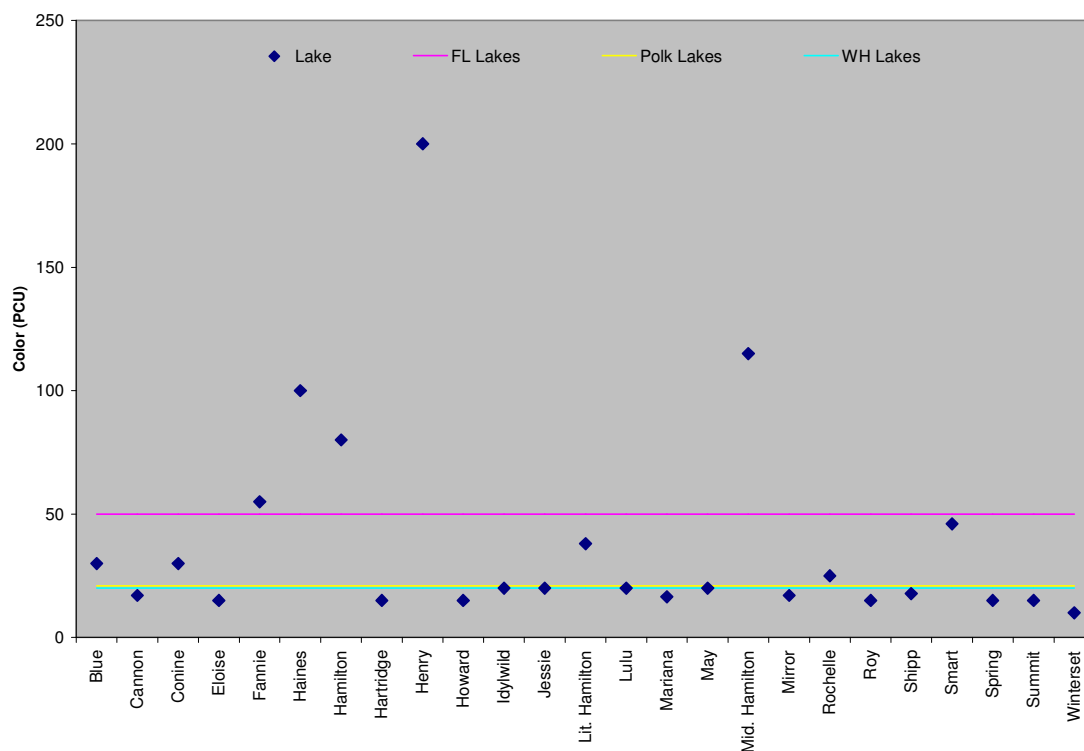


In contrast to the results seen when examining levels of TN and TP, the average level of chlorophyll-a for lakes of the WHCL system is substantially higher than levels seen for Polk County lakes as a whole, and more than twice as high as the median value ($11 \mu\text{g}$ / liter) for Florida lakes. Of the 25 lakes examined within the WHCL, 9 had median chlorophyll-a values higher than $30 \mu\text{g}$ / liter. Sixteen (16) of the 25 lakes within the WHCL examined had chlorophyll-a levels at least twice as high ($22 \mu\text{g}$ / liter) as the median value for Florida lakes.

As nutrient levels within the WHCL are not much different, as a whole, from the “typical” Florida lake (as expressed by median values for Florida Lakes [FDEP 1996]), the question then is why are the lakes of the WHCL characterized by higher levels of chlorophyll-a than would be expected based on their levels of TN and TP?

Figure 10 illustrates the relative levels of “color”, expressed as platinum-cobalt units (PCU), for the WHCL, as compared to lakes within Polk County as a whole, compared to the median value for chlorophyll-a for Florida lakes.

Figure 10
Median Values (1997 to 2007) of Color (platinum-cobalt units) for WHCL Lakes
 (Compared to median value for Polk County lakes and the median value for Florida lakes (FDEP 1996))



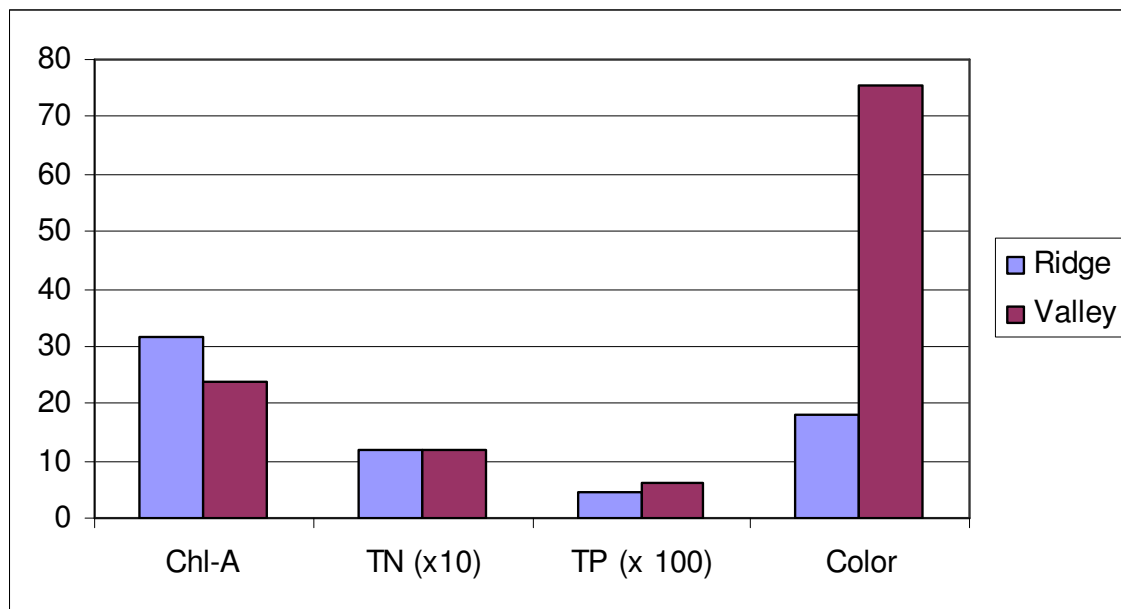
Lakes within the WHCL are characterized as having much less color, on average, than the “typical” Florida lake (as expressed as the median value calculated for “lake” water body types in Florida). While the median value for color for Florida lakes is over 50 PCU, only 5 of the 25 lakes of the WHCL had color values in excess of 50 PCU. Fifteen of the 25 WHCL lakes examined had median PCU values less than 20 PCU.

It thus seems that lakes within the WHCL are perhaps more “susceptible” to turning nutrients (both nitrogen and phosphorus) into phytoplankton biomass, as they seem to be characterized by lower levels of tannins than the typical lake in Florida.

To determine whether differences in nutrient susceptibility varied further between Ridge and Valley lakes within the WHCL, a comparison of water quality between lakes classified *a priori* into Ridge and Valley lakes was conducted.

Figure 11 illustrates differences in levels of TN, TP, chlorophyll-a, and color between Ridge and Valley lakes within the WHCL.

Figure 11
Median values of Chl-a ($\mu\text{g} / \text{liter}$), TN ($\text{mg} / \text{liter} \times 10$), TP ($\text{mg} / (\text{liter} \times 100)$) and color (PCU) for Ridge and Valley lakes (median values for 1997 to 2007)



In greater detail, the comparison of water quality for lakes designated by their shoreline features and physiography to be either Ridge Valley lakes are summarized below in Table 10.

Table 10
Summary of water quality data (1997 to 2007) for lakes classified as either Ridge or Valley lakes

Lake	Valley(V) or Ridge (R)	Median TN (mg / liter)	Median Chl-a (comb) (µg / liter)	Median TP (mg /liter)	Median Color (PCU)	TN:TP Ratio
Blue	R	2.350	78.600	0.101	30.000	23.267
Cannon	R	1.080	27.910	0.043	17.000	25.116
Conine	R	1.325	39.385	0.073	30.000	18.151
Eloise	R	1.317	31.240	0.038	15.000	34.894
Hartridge	R	0.752	16.040	0.027	15.000	28.358
Howard	R	1.410	32.040	0.041	15.000	34.390
Idylwild	R	0.930	28.130	0.041	20.000	22.683
Jessie	R	1.020	27.000	0.061	20.000	16.721
Mariana	R	1.092	23.150	0.034	16.500	32.103
May	R	1.410	46.000	0.058	20.000	24.310
Mirror	R	1.410	32.290	0.040	17.000	35.250
Roy	R	0.939	14.845	0.028	15.000	33.518
Shipp	R	1.640	61.000	0.049	17.750	33.469
Spring	R	0.935	20.830	0.039	15.000	23.974
Summit	R	0.842	13.565	0.028	15.000	30.054
Winterset	R	0.798	15.240	0.021	10.000	38.000
Mean		1.203	31.704	0.045	18.016	28.391
Std. Dev.		0.403	17.686	0.020	5.306	6.496
Fannie	V	0.840	13.620	0.029	55.000	28.966
Haines	V	1.320	50.000	0.066	100.000	20.000
Hamilton	V	1.089	5.208	0.100	80.000	10.912
Henry	V	1.000	5.000	0.116	200.000	8.621
Lit. Hamilton	V	1.113	15.220	0.035	38.000	32.261
Lulu	V	1.220	42.050	0.050	20.000	24.400
Mid. Hamilton	V	1.558	26.965	0.070	115.000	22.250
Rochelle	V	1.070	30.000	0.050	25.000	21.400
Smart	V	1.363	26.100	0.055	46.000	25.009
Mean		1.175	23.796	0.063	75.444	21.535
Std. Dev.		0.215	15.611	0.029	57.018	7.690

Within the WHCL, levels of chlorophyll-a tend to be higher in Ridge lakes than in Valley lakes, despite having little difference in levels of TN, and having lower levels of TP, on average, than Valley lakes.

Differences in levels of chlorophyll-a between Ridge versus Valley lakes appear related to Ridge lakes having lower levels of color. Lower levels of color appear to make Ridge lakes more susceptible to nutrient availability than Valley lakes.

To determine the likely sources of color within the various lakes in the WHCL system, a GIS-based assessment was used. Current land use data (from FLUCCS) were clipped to a 500-foot buffer around each lake. The acreage estimates were then used to derive a percentage of the 500-foot buffer classified as different land use types. These percentages were then plotted for each lake against the median value (1997 to 2007) for color, in PCU, for each lake within the WHCL. Figure 12 and 13 illustrate the relationships between levels of color for the lakes of the WHCL and the percentage of the 500-foot buffer characterized as herbaceous wetlands and forested wetlands, respectively.

Figure 12
Lake Color (PCU) vs. Percentage of 500-foot Buffer as Herbaceous Wetlands

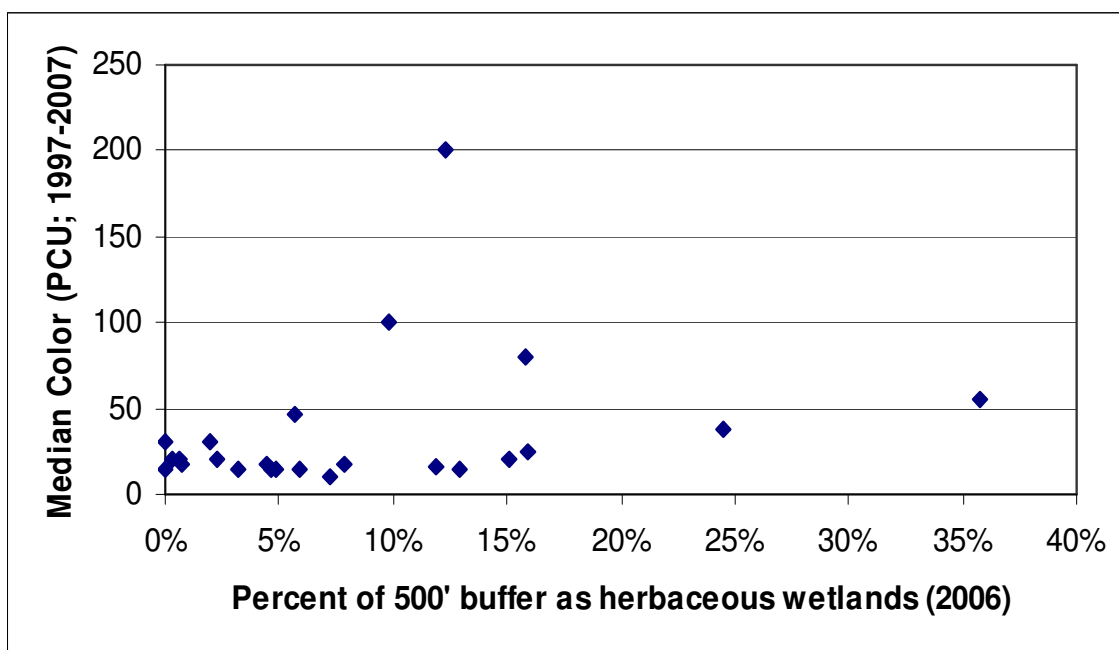
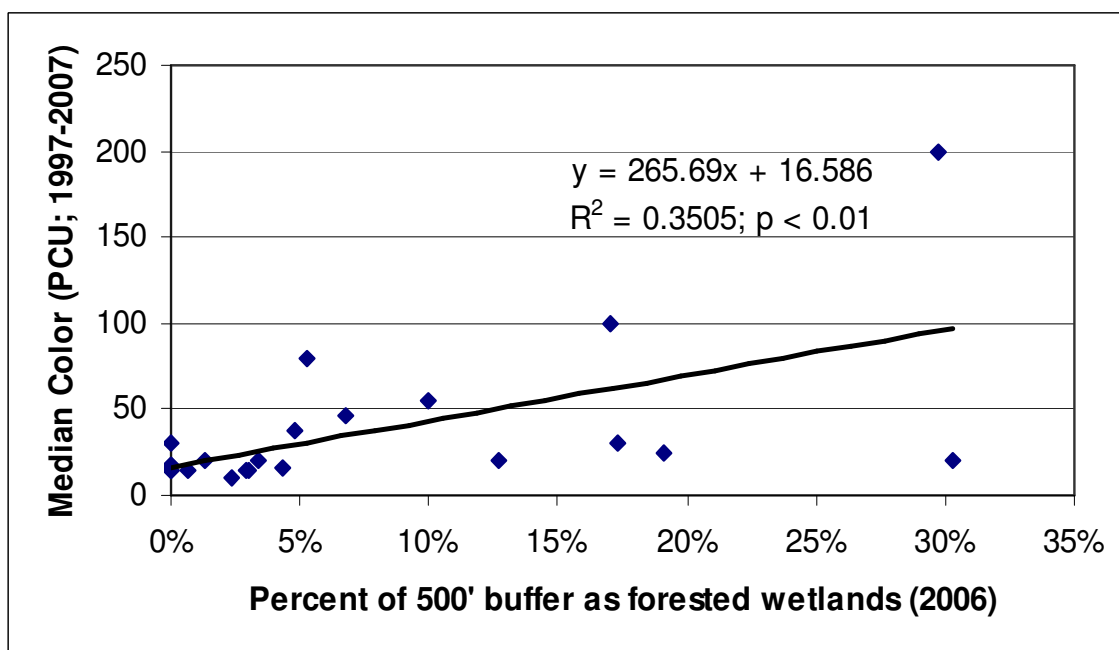


Figure 13
Lake Color (PCU) vs. Percentage of 500-foot Buffer as Forested Wetlands



Combined, these results indicated that the amount of color (i.e., tannins) within lakes of the WHCL system varies mostly as a function of the amount of forested wetlands within 500 feet of the lake's shoreline. Forested wetlands, rather than marshes, appear to be the major sources of tannins to these lakes.

As tannin levels have been shown to moderate the influence of nutrients on phytoplankton levels (Figure 11), it thus follows that swamp shorelines play an important role in moderating the influence of nutrients on phytoplankton growth by increasing the amount of tannins (i.e., color) in adjacent lakes.

3.3. TMDL Findings

The existing TMDL for the WHCL system, while noting the importance of nitrogen as having a role in limiting phytoplankton biomass, nonetheless presents load reduction goals for phosphorus alone. The topic of nutrient limitation is obviously an important one, in that reductions in the concentration of the most-limiting nutrient are required to reduce phytoplankton biomass. However, the goal of the TMDL report is not just to reduce phytoplankton levels, it is to reduce phytoplankton levels such that they fall below a particular threshold. The appropriate threshold for TMDL purposes is a chlorophyll-a concentration of 20 μg / liter, which equates to a TSI_{CHLA} value of 60.

To determine the nutrient that needs to be addressed for load reduction purposes, the State of Florida mostly relies upon the ratio between TN and TP, by weight. If this ratio is less than 10, the water body is assumed to be limited by nitrogen. If this ratio is greater than 30, then the lake is assumed to be limited by phosphorus. If this ratio is between 10 and 30, the water body is assumed to be co-limited by both nitrogen and phosphorus. However, problems with an overly simplistic application of the TN:TP ratio have been the topic of much debate (see summary in Schelske et al. 1999). A more direct approach to determining the most likely nutrient of concern for any given lake is to determine the relationship between levels of TN vs. phytoplankton biomass, in contrast to the relationship between levels of TP vs. phytoplankton biomass. Table 11 summarizes the results of an assessment wherein water quality data were compared for all lakes for the period of 1997 to 2007. Highlighted boxes are where the relationship between either TP and chlorophyll-a or TN and chlorophyll-a were statistically significant ($p < 0.05$). Also shown is the r^2 value, and indication of the “strength” of the relationship (if found).

Table 11
Results from regression analyses (data from 1997 to 2007) of TP vs. chlorophyll-a and TN vs. chlorophyll-a in Winter Haven Chain of Lakes

Lake	Total Phosphorus		Total Nitrogen	
	p	r ²	p	r ²
Blue	0.173	0.070	<0.0001	0.593
Cannon	0.309	0.004	<0.0001	0.208
Conine	<0.0001	0.362	<0.0001	0.220
Eloise	0.650	0.005	0.005	0.160
Fannie	0.042	0.049	0.0003	0.140
Haines	<0.0001	0.231	<0.0001	0.347
Hamilton	0.626	0.010	0.128	0.081
Hartridge	0.659	0.003	<0.0001	0.415
Henry	0.063	0.027	0.554	0.003
Howard	0.625	0.006	0.0002	0.282
Idylwild	0.019	0.065	0.006	0.083
Jessie	0.008	0.070	<0.0001	0.293
Little Hamilton	0.748	0.005	0.001	0.356
Lulu	0.012	0.029	<0.0001	0.110
Mariana	0.056	0.090	<0.0001	0.503
May	0.000	0.140	0.0001	0.138
Middle Hamilton	0.018	0.263	0.628	0.010
Mirror	0.151	0.068	<0.0001	0.646
Rochelle	<0.0001	0.220	<0.0001	0.277
Roy	0.323	0.241	0.001	0.948
Shipp	<0.0001	0.145	<0.0001	0.203
Smart	0.017	0.108	0.039	0.088
Spring	0.110	0.095	0.0001	0.392
Summit	0.444	0.017	0.002	0.222
Winterset	0.911	0.000	<0.0001	0.306

Note: Shading = p < 0.05

The results shown in Table 11 show that only 11 of 25 lakes in the WHCL show evidence of a statistically significant empirical relationship between the abundance of total phosphorus and chlorophyll-a. In contrast, 22 of 25 lakes show evidence of a statistically significant empirical relationship between the abundance of total nitrogen and chlorophyll-a. Additionally, the average r² value for lakes with a significant relationship between TP and chlorophyll-a is 0.15, suggesting that even for those lakes with empirical evidence of a relationship between TP and phytoplankton, levels of TP account for only 15 percent of the variability in phytoplankton

abundance. The average r^2 value for lakes with a significant relationship between TN and chlorophyll-a is 0.33, suggesting that levels of TN account for 33 percent of the variability in phytoplankton abundance for those lakes with empirical evidence of a relationship between TN and chlorophyll-a.

As important as the findings shown in Table 11 are, they may not actually be sufficient for setting goals to shift “impaired” lakes to an unimpaired condition. For example, water quality data for the severely impaired lakes do not include data during which these lakes were ever “unimpaired”. To determine the nutrient concentration(s) required to shift impaired lakes to unimpaired conditions usually requires an extrapolation of data beyond the boundaries of the data set collected.

An alternative approach to setting target nutrient concentrations is to compare impaired lakes to unimpaired lakes and to look for relationships that explain the difference between the two. This approach is known as a “space for time” substitution, wherein different locations (i.e., space) are used as a surrogate for a different “time” (i.e., when the lake wasn’t impaired). Based on results already discussed, space for time analysis for WHCL was further subdivided such that Ridge lakes would be compared against each other, and Valley lakes would be compared against each other.

As Ridge and Valley lakes have different susceptibility to nutrient enrichment, different shorelines and differing levels of color, potential water quality targets were calculated using empirically derived relationships between nutrients and chlorophyll-a. These relationships were separately derived for Ridge and Valley lakes, using the classifications assigned in Table 5.

Figures 14 and 15 illustrate the relationships between TP versus chlorophyll-a and TN versus chlorophyll-a, respectively, for Ridge lakes in the WHCL.

Figure 14
Relationship between Total Phosphorus and Chlorophyll-a for Ridge Lakes

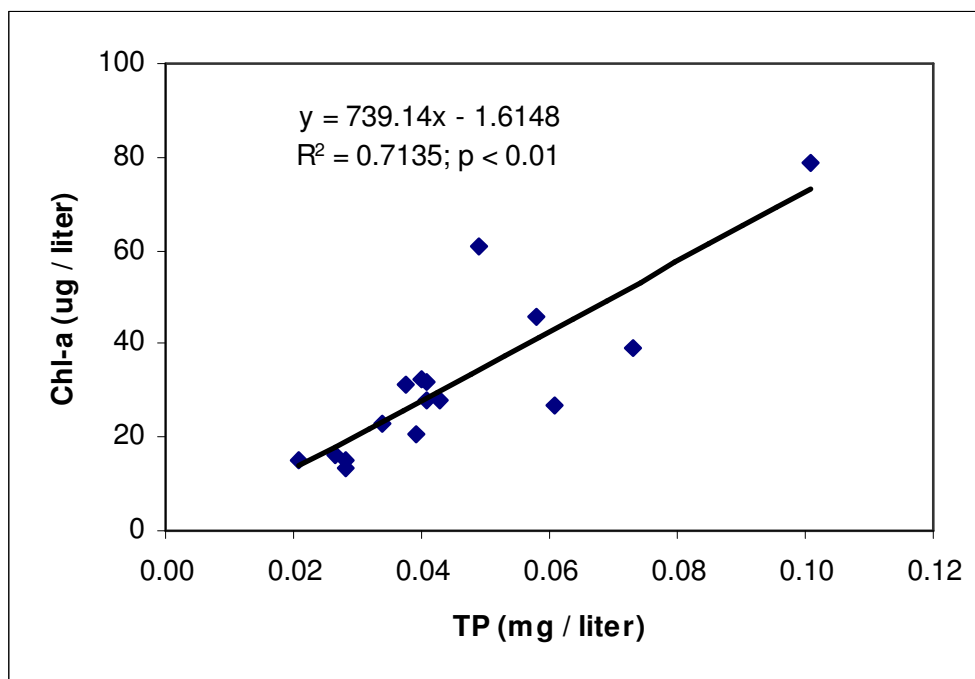
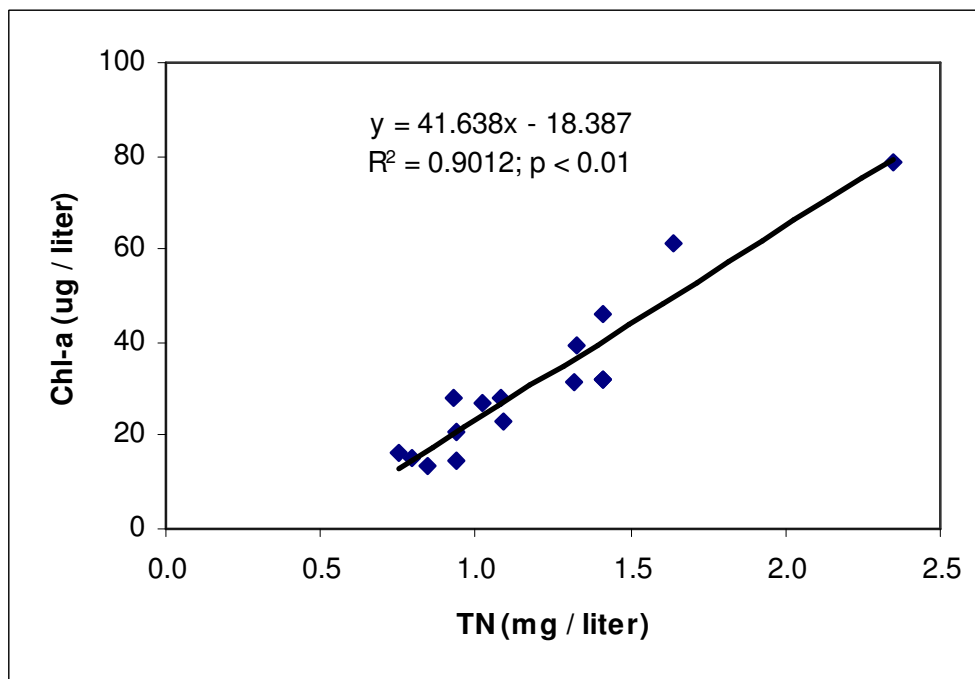


Figure 15
Relationship between Total Nitrogen and Chlorophyll-a for Ridge Lakes



Combined, these results indicate strong relationships between levels of both phosphorus and nitrogen, when compared to chlorophyll-a, for Ridge lakes in the WHCL system. The higher r-squared value for the TN vs. chlorophyll-a relationship, compared to phosphorus, suggests that nitrogen concentrations might be equally, if not more, important in controlling phytoplankton growth in these lakes. For the most part, nitrogen concentrations are within the range of values that can be explained by stormwater runoff (i.e., less than 1.5 to 2.5 mg TN / liter). In contrast, in-lake concentrations of TN from lakes with very high levels of TN (i.e., greater than 3 mg TN / liter) such as Lakes Jesup and Hancock have been found to have significant amounts of nitrogen-fixing blue-green algae, and nitrogen fixation has been measured. While the results from the Ridge Lakes are not complete enough to conclude no nitrogen fixation is occurring, it appears as if the appropriate way to interpret Figure 15 is that nitrogen concentrations play a role in limiting phytoplankton biomass, rather than blue-green algae are controlling nitrogen concentrations via nitrogen fixation.

Figures 16 and 17 illustrate the relationships between TP versus chlorophyll-a and TN versus chlorophyll-a, respectively, for Valley lakes in the WHCL.

Figure 16
Relationship between Total Phosphorus and Chlorophyll-a for Valley Lakes

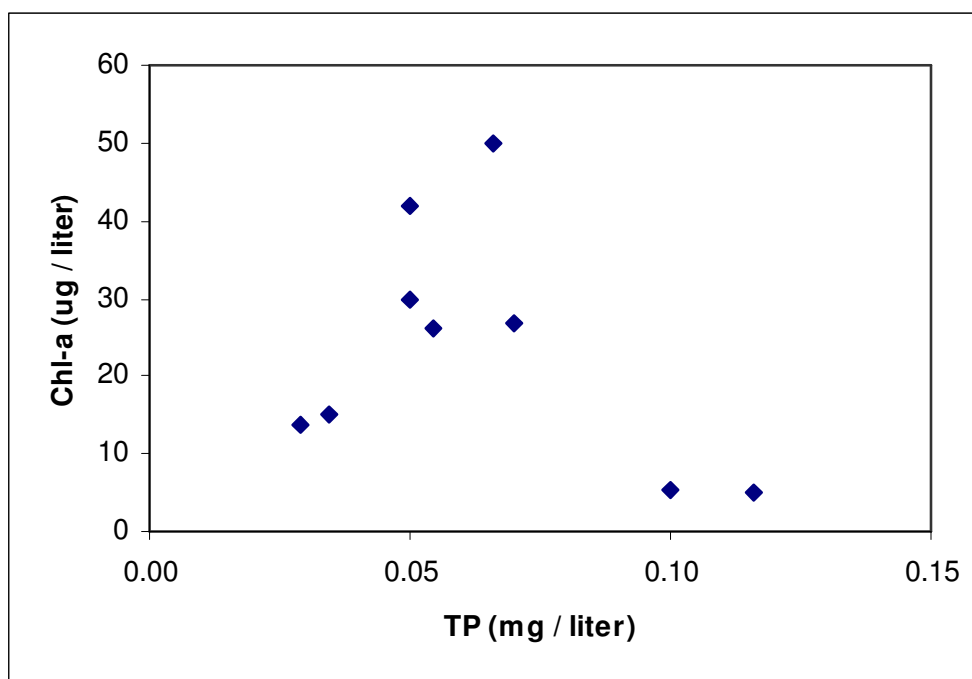
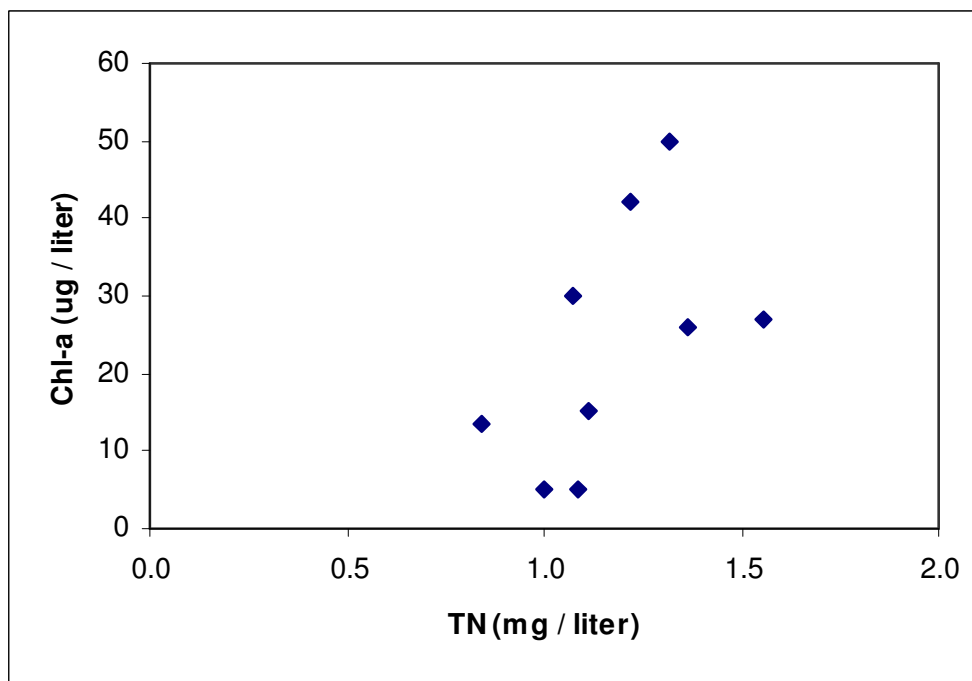


Figure 17
Relationship between Total Nitrogen and Chlorophyll-a for Valley Lakes



In contrast to the Ridge lakes, there does not appear to be any evidence of an empirical relationship between levels of either phosphorus or nitrogen and chlorophyll-a in Valley lakes.

Consequently, it may be premature to make predictions as to the response of chlorophyll-a to nutrient levels for Valley lakes. In contrast, there is strong evidence of such relationships for Ridge lakes.

Based on the strong empirical relationships in Ridge lakes between TN and chlorophyll-a and TP and chlorophyll-a, an attempt was made to develop locally-derived water quality goals for the WHCL. Specifically, nitrogen and phosphorus “goals” were established for the Ridge lakes in the WHCL system, based on goal setting for chlorophyll-a.

For the State of Florida, water quality goals in lakes are typically set based on an agreed upon and appropriate TSI goal. As an initial step in this process, FDEP gives guidance on how TSI values are to be separately calculated for chlorophyll-a, TN, and TP, using the following equations:

For chlorophyll-a:

$$CHLA_{TSI} = 16.8 + 14.4 * \ln(\text{Chl } a), \text{ with Chlorophyll } a \text{ in } \mu\text{g/L}$$

For nitrogen:

$$TN_{TSI} = 56 + 19.8 * \ln(N), \text{ with Nitrogen in mg/L}$$

For phosphorus:

$$TP_{TSI} = 18.6 * \ln(P * 1000) - 18.4, \text{ with Phosphorus in mg/L}$$

Once these separately calculated TSI values are calculated, then the overall TSI value for a given lake is derived dependent upon the ratio between TN and TP. The nutrient-related TSI calculation can vary between one relevant for TN, one relevant for TP, or one relevant for a co-limited system. The relevant nutrient-related TSI value (referred to as the $NUTR_{TSI}$ value) is then used in combination with the TSI calculation specific to chlorophyll-a (referred to as the $CHLA_{TSI}$ value) as outlined below:

$$\begin{aligned} \text{If } TN/TP > 30, \text{ then } NUTR_{TSI} &= TP_{TSI} \\ \text{If } TN/TP < 10, \text{ then } NUTR_{TSI} &= TN_{TSI} \\ \text{If } 10 < TN/TP < 30, \text{ then } NUTR_{TSI} &= (TP_{TSI} + TN_{TSI})/2 \end{aligned}$$

$$TSI = (CHLA_{TSI} + NUTR_{TSI})/2$$

The TMDL for the WHCL, adopted for the Southern Chain of Lakes, is for phosphorus reduction only (FDEP 2007), which is applicable for phosphorus-limited lakes. Determination of the limiting nutrient, based on FDEP protocol, is dependent upon the ratio between levels of nitrogen and phosphorus.

When TN:TP ratios are less than 10, lakes are considered to be nitrogen limited. At TN:TP ratios in excess of 30, lakes are considered to be phosphorus limited. Between 10 and 30, lakes are considered to be “balanced” or co-limited by both nitrogen and phosphorus. For those lakes requiring TMDLs to be developed (see Table 1) only Lakes Howard, Mirror and Shipp have TN:TP ratios higher than 30 (Table 12). The other ten lakes have TN:TP ratios between 10 and 30, and would thus be classified by FDEP as being co-limited by both nitrogen and phosphorus.

However, both the PLRG report prepared for the District (USF 2005) and the subsequent TMDL report (FDEP 2007) only calculate phosphorus load reduction goals for impaired lakes in the WHCL system.

Table 12
TN:TP ratios and TSI values by Year for WHCL System (from FDEP 2007)

WBID	Waterbody Segment	Chain	IWR Assessment Status Based on TSI for Nutrients	TMDL Year	TN/TP Ratio Median	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	Average TSI 1992-2003
1521Q	Lake Blue	Southern	Planning List		20.0	68.5	64.3	64.2										65.7
1521H	Lake Cannon	Southern	Impaired	2004	22.0	63.0	62.2	59.5	66.7	65.1	62.3	62.7	56.9	60.8	62.2	59.0		61.9
1521B	Lake Eloise	Southern	Not Impaired	2004	38.3				63.7		55.6							59.7
1521I	Lake Hartridge	Southern	Not Impaired	2009	26.6						51.4		45.5					48.5
1521F	Lake Howard	Southern	Impaired	2004	45.6	67.5	63.4	62.5	65.2	63.3	65.5		57.3					63.5
1521J	Lake Idylwild	Southern	Impaired	2009	22.4						58.9	61.8	58.8					59.8
1521K	Lake Jessie	Southern	Impaired	2004	19.4	63.6			64.6	62.2	61.1	62.9	59.0					62.2
1521	Lake Lulu	Southern	Impaired	2004	24.0	48.7	54.7	47.4	53.8	48.9	47.1	54.6	57.2	65.0	66.2	64.8		55.3
1521L	Lake Marianna	Southern	Not Impaired		35.5		55.5											55.5
1521E	Lake May	Southern	Impaired	2004	23.0						64.1	67.0	59.1					63.4
1521G	Lake Mirror	Southern	Impaired	2004	43.0												69.4	69.4
1521O	Lake Roy	Southern	Insufficient Data		38.7													
1521D	Lake Shipp	Southern	Impaired	2004	40.2						70.4		64.9	75.6	72.0	71.1	68.2	70.4
1521M	Lake Summit	Southern	Insufficient Data		23.1													
1521A	Lake Winterset	Southern	Not Impaired	2009	36.9								45.9					45.9
1521G	Spring Lake	Southern	Insufficient Data		25.6													
1488U	Lake Conine	Northern	Impaired	2009	16.9		75.6	78.6	68.3	71.0	66.5	63.3	58.4	58.6	63.8			67.1
14882	Lake Fannie	Northern	Not Impaired	2009	25.7	58.4				59.1			49.0					55.5
1488C	Lake Haines	Northern	Impaired	2004	21.5	71.0	75.5	76.3	69.1	75.4	70.2	65.8	65.5	62.2	59.9		68.1	69.0
1488B	Lake Rochelle	Northern	Impaired	2009	24.0	62.5			62.2	63.4	61.6	62.3	58.1	58.5			63.1	61.5
1488A	Lake Smart	Northern	Impaired	2004	24.7						64.9	66.6	59.3	60.0				62.7

Based on TN:TP ratios, the TSI goal for 9 of the 12 impaired lakes within the WHCL should be calculated using values for nitrogen, phosphorus, and chlorophyll-a, as outlined below:

The nutrient-related TSI goal would be calculated as

$$(TP_{TSI} + TN_{TSI}) / 2,$$

and the multi-parameter TSI value would be calculated as

$$(CHLA_{TSI} + NUTR_{TSI}) / 2.$$

Based on these goals, an overall TSI goal of 60 would equate to the following conditions:

Chl-a of 20 µg / liter,

TN of 1.2 mg / liter, and

TP of 0.07 mg / liter

These numbers are equivalent to those used for the classification of water quality in Florida lakes and estuaries for a TSI of 60, as illustrated below in Table 13.

Table 13
TSI values for Chl-a, TN and TP (from FDEP 1996)

For lakes: 0-59 is good, 60-69 is fair, 70-100 is poor.
For estuaries: 0-49 is good, 50-59 is fair, 60-100 is poor.

Trophic State Index	Chlorophyll CHLA/ micrograms per liter ($\mu\text{g}/\text{l}$)	Total Phosphorus TP/ milligrams of phosphorus per liter (mgP/l)	Total Nitrogen TN/ milligrams of nitrogen per liter (mgN/l)
0	0.3	0.003	0.06
10	0.6	0.005	0.10
20	1.3	0.009	0.16
30	2.5	0.01	0.27
40	5.0	0.02	0.45
50	10.0	0.04	0.70
60	20.0	0.07	1.2
70	40	0.12	2.0
80	80	0.20	3.4
90	160	0.34	5.6
100	320	0.58	9.3

For the management of the WHCL system, a TSI goal of 60 would be expected to require a chlorophyll-a (Chl-a) goal of 20 μg / liter. Using the state-wide data set summarized in Table 13, achievement of that Chl-a goal would be expected to occur if TP and TN concentrations were reduced to levels of 0.07 and 1.2 mg / liter, respectively.

However, the relationships between TP and Chl-a and between TN and Chl-a which were used to derive TSI values on a state-wide level do not appear valid within the WHCL system.

For Valley lakes, there is no empirical evidence of any relationship between nutrient availability and Chl-a levels, when comparing these lakes against each other (see Figures 16 and 17). Thus, it does not appear to be appropriate, at this time, to make predictions as to the responses of Chl-a to variation in nutrient levels for Valley lakes. For those Valley lakes with Chl-a impairments (Lakes Haines, Lulu, Smart, and Rochelle) and based upon the available data, it is difficult to determine if a cause and effect relationship exists between nutrients and phytoplankton, perhaps due to the “masking” effects of tannins moderating water clarity. Consequently, the development of nutrient targets, and thus nutrient reduction targets, is not feasible at this time.

Ridge lakes are more susceptible to nutrient enrichment than Valley lakes (see Figure 11). They also appear to be more susceptible to nutrient enrichment than would be indicated by the use of the nutrient and chlorophyll-a relationships shown in Table 13.

Thus for Valley lakes, nutrient goals developed by both the District’s PLRG study (USF 2005) and FDEP’s TMDL report (FDEP 2007) may not result in expected levels of chlorophyll-a, as there is no clear empirical relationship between nutrients and chlorophyll-a for those lakes. The PLRG study conducted for Lakes Haines and Shipp by PBS&J (2004) also found no relationship between nutrients and chlorophyll-a, and the phosphorus reduction goals outlined in that report

were explicitly limited to those levels of TP that would result in a TSI_{TP} value of 60 (not a TSI_{CHLA} value of 60).

In contrast, Ridge lakes appear to be more sensitive to nutrient enrichment, due to their lower levels of tannins than the “typical” Florida lake.

To develop site-specific (for the WHCL) nutrient guidance for chlorophyll-a, the equations developed between phosphorous and chlorophyll-a and between nitrogen and chlorophyll-a (Figures 14 and 15, respectively) were used to determine the phosphorus and nitrogen concentrations that would result in a chlorophyll-a concentration of 20 μg / liter. The value of 20 μg / liter was chosen as it corresponds to a TSI_{CHLA} value of 60 (see Table 13).

For phosphorus, the equation that relates Chl-a to phosphorus is:

$$\text{Chl-a} = 739.14(\text{TP}) - 1.6148$$

For nitrogen, the equation that relates Chl-a to nitrogen is:

$$\text{Chl-a} = 41.638(\text{TN}) - 18.387$$

Using these equations, the site-specific TP goal for Ridge lakes in the WHCL system would be 0.029 mg / liter. The site-specific TN goal for Ridge lakes in the WHCL system would be 0.93 mg / liter. These values are lower than the default TSI values for both TP and TN shown in Table 14, as they reflect the greater susceptibility of Ridge lakes to nutrient enrichment, due to their lower than typical levels of tannins.

For Ridge lakes, the TP and TN goals described above were compared to the median TP and TN values for the 1997 to 2007 time period. The reduction in concentration required to get median values to the TP and TN goals of 0.029 and 0.93 mg / liter, respectively, were then compared to the TMDL goals developed by FDEP (2007). This approach allows for the development of a “space for time” substitution, wherein the nutrient characteristics of Ridge lakes with low levels of chlorophyll-a are used to develop guidance for lakes with high levels of chlorophyll-a. A more ideal situation would be to have nutrient and chlorophyll-a data from individual lakes in both impaired and unimpaired conditions, but this is not possible, as impaired lakes have only been “impaired” during the time period during which water quality data are available.

Table 14
Comparison of Empirically-derived TN and TP Concentration Reductions with
FDEP (2007) TMDL Load Reduction Goals

Lake	TN reduction (%) for 0.93 mg / liter	TP reduction (%) for 0.029 mg / liter	TP load reduction (%) from TMDL report
Blue	60.4	71.3	
Cannon	13.9	32.6	49.0
Conine	29.8	60.3	
Eloise	29.4	23.2	
Howard	34.0	29.3	57.5
Idylwild	0.0	29.3	38.0
Jessie	8.8	52.5	45.0
Mariana	14.8	14.7	
May	34.0	50.0	52.5
Mirror	34.0	27.5	22.5
Roy	0.9		
Shipp	43.3	40.8	60.0
Spring	0.5	25.6	

The results shown in Table 12 suggest that the concentration reductions derived using the site-specific empirical relationships for Ridge lakes in the WHCL system are not much different from the load reductions developed in the FDEP (2007) TMDL report. The range of phosphorus load reductions listed in the TMDL report are from 22.5 to 60 percent, while the percent reductions in phosphorus concentrations shown in Table 12 (for the same lakes with TMDLs reported) range from 27.5 to 52.5 percent. However, the load reductions for impaired lakes should also include nitrogen reduction for most of these lakes, as the TN:TP ratios for all impaired lakes except Lakes Howard, Mirror and Shipp fall within the range of being classified as co-limited by both phosphorus and nitrogen. Even for Lakes Howard, Mirror and Shipp, empirically-derived nutrient reduction goals (Table 12) suggest reductions in nitrogen are also needed for chlorophyll-a levels to meet a TSI_{CHLA} goal of 60 (equivalent to a chlorophyll-a value of 20 µg / liter). The conclusion drawn here that nitrogen can be a limiting nutrient for phytoplankton is consistent with the findings of Canfield (1983), who summarized nutrient and phytoplankton relationships from 223 Florida lakes.

3.4. Influence of Lake Levels on Water Quality

An additional assessment for purposes of this report involved the investigation of the effects, if any, of lake levels – that is water levels – on water quality. As described above (Section 2.3) lake level data were queried to determine if there were any apparent relationships between lake levels and water quality. In most lakes, lake level data were much more numerous than water quality data. Consequently, the amount of data available for analysis was limited by the amount of water quality data. However, not all lakes had an adequate data set on lake levels for analysis of the interaction between lake levels and water quality. For this assessment, the relationship

between lake levels and water quality was evaluated if there were sufficient lake level data for at least ten (10) continuous years, to be consistent with the water quality analysis conducted here.

Additionally, not all lakes appear to have separate lake level gages (Mike Britt and Roger Griffith, personal communication). Since canals connect these lakes to each other, it is assumed that by knowing the lake level for lakes connected by a canal, the water level in one lake is consistent with the water level in connected lakes (although lakes separated by a water control structure need to be separately measured). However, it was apparent during the course of this study (fall of 2007 to summer of 2008) that a number of lakes assumed to be at similar levels due to their connecting canals were actually isolated from each other. Perhaps associated with reduced rainfall during the 2007 to 2008 time period, no evidence was found of any hydrologic connection between Lakes Conine and Smart, as the bottom of the canal was higher than the top of the lake surfaces of both Lake Conine and Lake Smart. There also appeared to be very little flow between Lakes Eloise and Lulu and also between Lakes Shipp and Lulu, although there was certainly some degree of connection between these lakes. A berm across the canal between Lakes Haines and Rochelle precludes any direct connection. It is not known how many other inter-connecting canals were dry during this study period, nor is it known how often such connections are severed. However, it does appear reasonable to collect lake level data for more lakes, as the assumption that lake levels are the same for adjacent lakes with inter-connected canals does not appear to be consistent with the observations made during this study. That is, many of these lakes appear to be somewhat hydrologically isolated from each other, at least during low rainfall conditions.

With this as background, the lake level : water quality relationship was derived for all lakes with sufficient data sets for both lake levels and water quality. Further, it was assumed for this effort (Mike Britt, personal communication) that lake levels in Lakes Mirror, Shipp and Lulu would be the same as those reported for Lake Shipp.

As an example of the results from this assessment, Figures 18, 19, and 20 illustrate the relationships found between lake level and chlorophyll-a, TP and TN, respectively, for Lake Blue.

Figure 18
Relationship between Lake Level, in feet (NGVD) and Chlorophyll-a (μg / liter) for Lake Blue

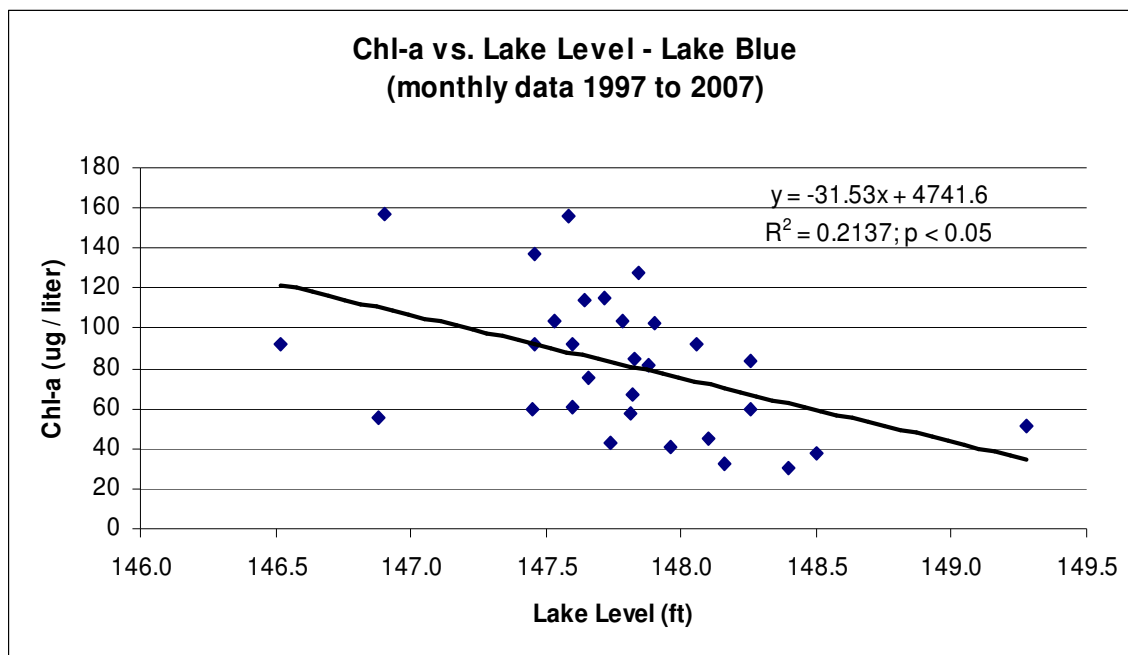


Figure 19
Relationship between Lake Level, in feet (NGVD) and Total Phosphorus (mg / liter) for Lake Blue

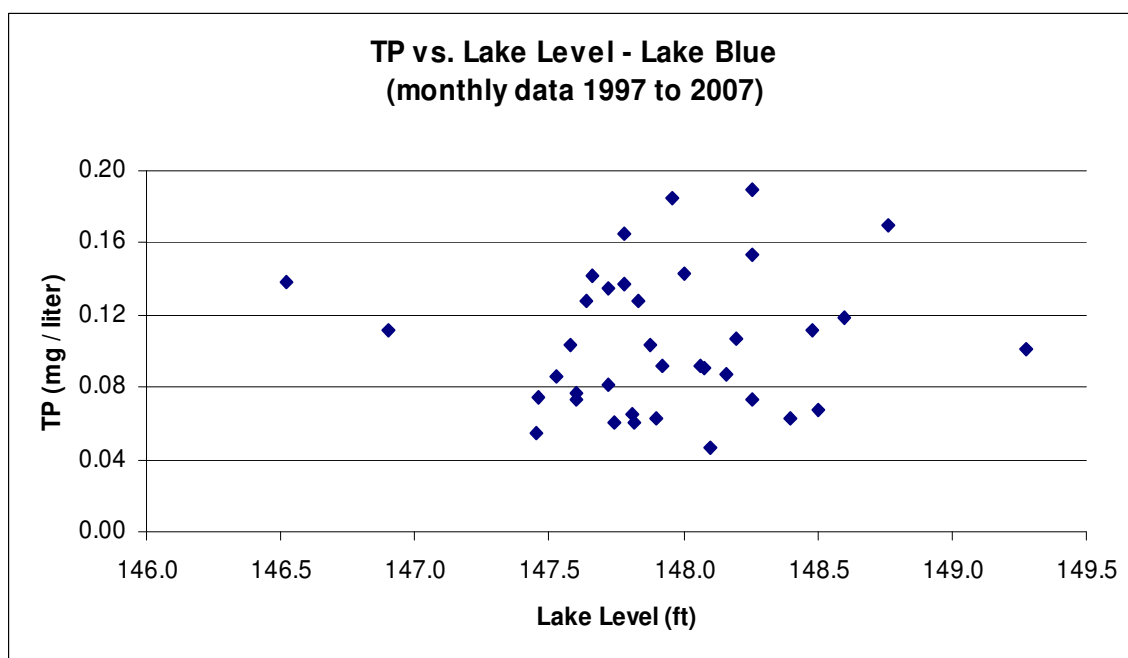
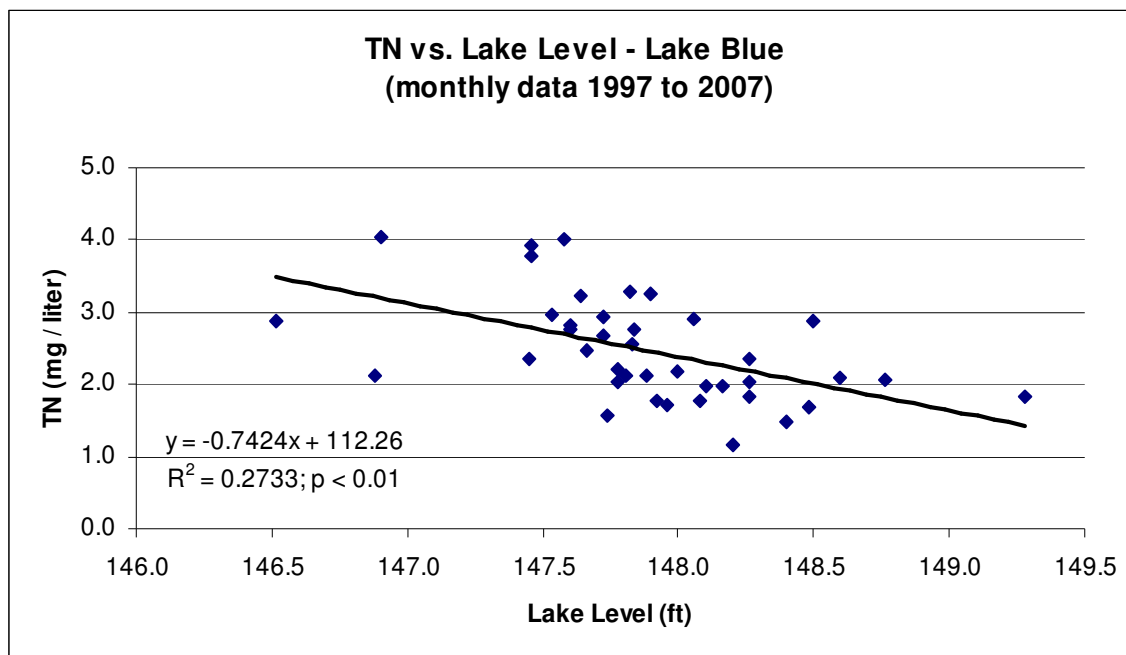


Figure 20
Relationship between Lake Level, in feet (NGVD) and Total Nitrogen (mg / liter) for Lake Blue



These data need to be carefully examined to prevent incorrect interpretations of findings. For example, the data shown in Figure 18 clearly show an inverse and statistically significant relationship between lake levels and chlorophyll-a. That is, the highest levels of chlorophyll-a are usually associated with low lake levels, and vice versa. However, no relationship was found between lake levels and phosphorus concentrations. The inverse relationship between nitrogen and lake levels (Figure 20) could be interpreted as indicating concentrations of nitrogen increase with low lake levels, and in combination with the information shown in Figure 18, this could be interpreted as indicating that increased nitrogen availability (rather than phosphorus) was the limiting nutrient allowing phytoplankton growth to occur.

However, the nitrogen concentration levels shown in Figure 20 include values in excess of 3 and even 4 mg TN / liter. These levels are substantially higher than event median concentration (EMC) values used in the stormwater loading models used by PBS&J (2004), USF (2005) and FDEP (2007). Instead, it is possible, or even likely, that the correlation shown between nitrogen and chlorophyll-a in Figure 20 is due to elevated levels of blue-green algae (common under conditions of high levels of chlorophyll-a) capable of nitrogen fixation. That is, rather than nutrient levels “explaining” phytoplankton abundance, it is possible and/or probable that in this case phytoplankton levels “explain” elevated levels of nitrogen.

With these caveats in mind, the relationships between lake levels and chlorophyll-a, total nitrogen, and total phosphorus were examined for all lakes where sufficient data existed for both lake levels and water quality. The results of these analyses are summarized in Table 15.

Table 15
Results from Analysis of Lake Levels and Chlorophyll-a, total Nitrogen
and Total Phosphorus

“NEG” = inverse relationship found. “NEG*” = inverse relationship found with evidence of nitrogen fixation. “POS” = positive relationship found. “NONE” = no significant relationship found. “ID” = insufficient data for analysis

Lake	Chl-a	TP	TN
Blue	NEG	NONE	NEG*
Cannon	ID	ID	ID
Conine	POS	POS	NONE
Eloise	ID	ID	ID
Fannie	ID	ID	ID
Haines	NONE	POS	POS
Hamilton	NONE	NONE	NONE
Hartridge	ID	ID	ID
Henry	NEG	POS	NONE
Howard	NEG	NONE	NEG*
Idylwild	ID	ID	ID
Jessie	ID	ID	ID
Lulu	NONE	NEG	NEG
Mariana	ID	ID	ID
May	NONE	NEG	NEG
Mirror	NONE	NONE	NONE
Rochelle	NONE	NONE	NONE
Roy	ID	ID	ID
Smart	NONE	POS	NONE
Shipp	NEG	NEG	NEG
Spring	ID	ID	ID
Summit	ID	ID	ID
Winterset	ID	ID	ID

These results show that insufficient data exist for most lakes to determine the relationships, if any, between lake levels and water quality. For those lakes where sufficient data exist for both lake levels and water quality, the pattern of relationships between lake level and water quality varied by the parameter examined and are summarized below.

- For chlorophyll, twelve lakes had sufficient data to examine these relationships. Seven of these twelve lakes showed no relationship between lake levels and chlorophyll-a, while four lakes had negative relationships. Only one lake, Lake Conine, had a positive relationship between lake levels and chlorophyll-a.
- For phosphorus, twelve lakes had sufficient data to examine these relationships. Five of these twelve lakes showed no relationship between lake levels and phosphorus, while three lakes had negative relationships. Four lakes had positive relationships between lake

levels and phosphorus. Three of the four lakes with positive relationships were Valley lakes. Lake Conine was the only Ridge lake showing a positive relationship between lake levels and phosphorus.

- For nitrogen, twelve lakes had sufficient data to examine these relationships. Six of these twelve lakes showed no relationship between lake levels and nitrogen, while five lakes had negative relationships. Only one lake, the Valley lake of Lake Haines, had a positive relationship between lake levels and nitrogen.
- Lake Conine was unique as the only lake to exhibit a trend of higher levels of chlorophyll-a with higher lake levels. In contrast, Lakes Blue, Henry, Howard and Shipp had trends of higher chlorophyll-a with lower lake levels.
- Of the four lakes with positive correlations between lake levels and phosphorus, three of the four were Valley lakes; Lakes Haines, Henry and Smart. Lake Conine was the only Ridge lake with such a pattern. For nitrogen, only Lake Haines, a Valley lake, had a positive relationship between lake levels and nitrogen.

High lake levels reflect recent inflow events, both short and long-term. Those inflows can come from direct runoff, groundwater seepage, between-lake flow via connecting canals, and atmospheric deposition. These elevated inflows would be accompanied by elevated nutrient loadings. Thus, when lakes have elevated lake levels, they exhibit water quality reflective of elevated antecedent nutrient loading. Despite this, only one lake, Lake Conine, had a pattern of higher levels of chlorophyll-a at higher lake levels.

In contrast, four lakes - Lakes Blue, Henry, Howard and Shipp – had trends of higher levels of chlorophyll-a at lower lake levels. For these lakes, it seems likely that internal processes, such as sediment resuspension and re-mineralization, are more important process controlling phytoplankton production than the influences of external nutrient loads.

Patterns of nitrogen and lake levels are complicated by the probable relationship between chlorophyll-a and nitrogen for lakes with nitrogen-fixing blue-green algae. As shown for Lake Blue (Figure 20) nitrogen may reflect the increasing influence of blue-green algae at higher phytoplankton levels, and thus these relationships may not be overly useful for examining the effects of lake levels on nutrient availability.

Combined, these results suggest that Lake Conine is perhaps unique, at least for Ridge lakes, in that nutrient concentrations and phytoplankton levels appear to be related to antecedent external loadings. In contrast, lakes more commonly exhibit a pattern of higher phytoplankton levels at lower lake levels. For lakes such as these, internal processes related to sediments might be more important to controlling phytoplankton levels than external loads.

Findings such as these are highly relevant for designing resource management strategies for the WHCL system. Therefore, a more detailed data set is needed for both lake levels and water quality, to allow for the detection of the presence or absence of trends, either positive or negative, between lake levels and water quality.

4.0 Recommendations

4.1. Ridge Lakes

A major recommendation of this report is that the lakes of the WHCL system should not be managed by defaulting to state-wide TSI and nutrient – phytoplankton algorithms. More specifically, lakes within the WHCL are quite different from the “typical” lake in Florida. Lakes located within the Lake Wales Ridge physiographic region tend to have sandy lake bottoms and shorelines, with low levels of tannins. These lakes are more susceptible to nutrient enrichment than the typical Florida lake, and therefore using the default state-wide algorithms for phytoplankton responses to nutrient availability would result in higher levels of chlorophyll-a than the typical Florida lake. For the WHCL, FDEP (2007) used a TSI threshold of 60 to develop nutrient TMDLs for listed lakes. This approach was considered to be appropriate, as prior investigations of the paleolimnology of the WHCL system indicated that these lakes were considered to be naturally mesotrophic, with historical TSI values probably in excess of 40, regardless of having color values lower than 40 PCU (Whitmore and Brenner 1995). Managing these lakes for a TSI_{CHLA} goal of 60 would require TP and TN concentrations to be lower than their respective TSI_{TN} 60 and TSI_{TP} 60 values.

For Ridge lakes, it is recommended that a resource management goal based on chlorophyll-a alone be used, and that a TSI_{CHLA} goal of 60 appears consistent with allowable degradation guidance outlined in FDEP (2007). Achievement of such a TSI goal would result in a chlorophyll-a goal of 20 µg / liter. Based on the empirical relationships derived in this study, achievement of this chlorophyll-a goal would in turn require adoption of a TP goal of 0.029 mg / liter, and a TN goal of 0.93 mg / liter for Ridge lakes.

The concentration reductions needed to achieve these water quality standards are outlined in Table 14. The goal of the ongoing City of Winter Haven – District Watershed Management Plan effort should be development of projects that are likely to achieve these nutrient concentration goals. Based on past experience, it seems likely that projects such as point source abatement (if such opportunities exist), sediment removal and inactivation, and whole-lake alum treatment ought to be implemented where possible, as they have been shown to be capable of improving in-lake water quality within the WHCL system. In contrast, there is little direct evidence that large-scale stormwater treatment projects have been able to reduce nutrient loads to a sufficient degree as to have a documented affect on water quality within their receiving water bodies.

These recommendations are that load reduction goals should be based on a WHCL system site-specific TSI_{CHLA} goal of 60. Further, it is recommended that nutrient load reductions should be based on achieving in-lake water column concentrations of 0.029 and 0.93 mg / liter of total phosphorus and total nitrogen, respectively. Based on these recommendations, it would be prudent to pursue load reduction strategies for these proposed water quality goals, rather than the default state-wide TSI goal used in the PLRG study (USF 2005) and the TMDL study (FDEP 2007).

The City of Winter Haven and its partners have already implemented a number of water quality improvement projects within the WHCL system. These projects and their impacts related to the TMDL report (FDEP 2007) are summarized below in Table 16.

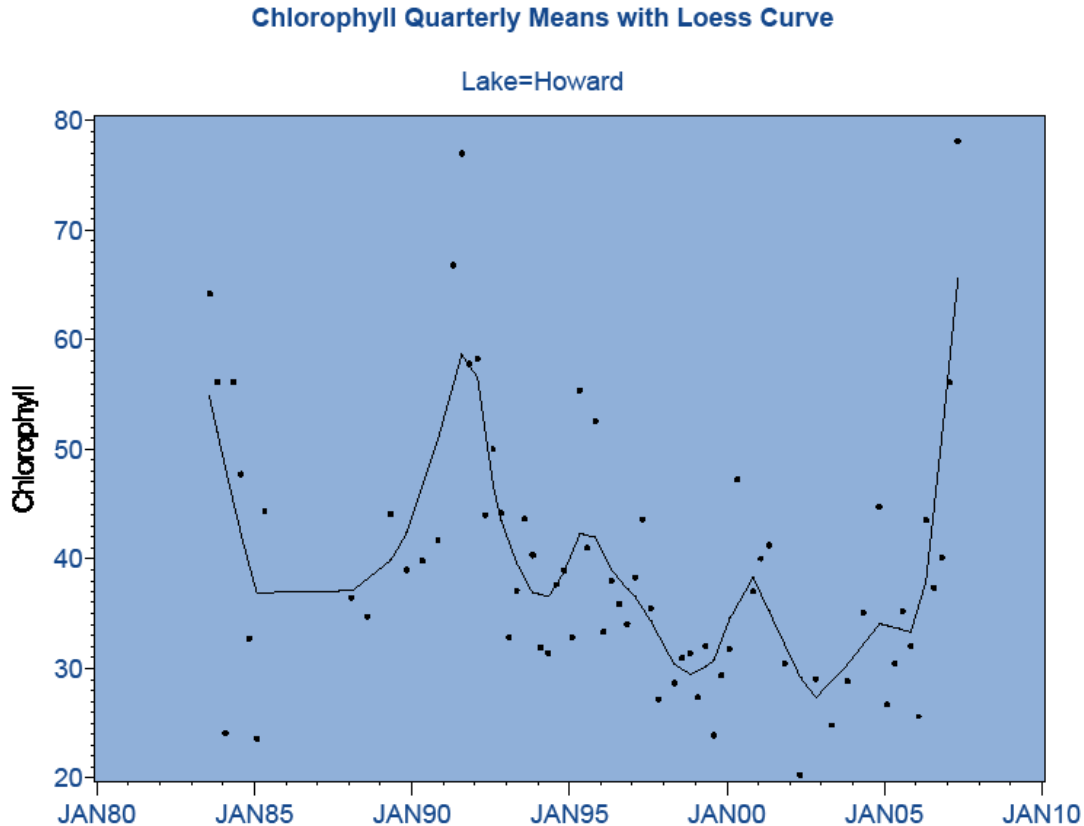
Table 16
Estimated TP load Reductions (kg TP / yr) for Various WHCL Projects and
Required TP Reductions (kg TP / yr) to meet a TSI goal of 60 as derived from
Table 5.2 in FDEP (2007) TMDL report

No.	Project Name	Year Completed	Contributing Drainage Area (ac.)	BMPs Used	Estimated Phosphorus Reduction (kg / yr)	TMDL Phosphorus Reduction Required (kg / yr)
1	Lake Howard Habitat/Stormwater Retrofit Project	2001	578	Wetland Treatment / Wet Detention	181	
2	Lake Howard Alum Injection Project	2000	175	Alum Injection	82	
	Lake Howard Total Projects		753		263	193
3	Lake May Stormwater/Alum Injection Project	2005	343	Alum Injection	357	97
4	Lake Lulu Stormwater/Alum Injection Project	2005	275	Alum Injection	193	84
5	Lake Hartridge Stormwater Treatment Pond	2007	105	Wet Detention	39	NA

The information displayed in Table 16 allows for a comparison of water quality data in individual lakes where projects designed to meet TMDL obligations have already been completed. Based on TP load reduction estimates for projects constructed on Lakes Howard, May, and Lulu, it appears that required TP load reductions have already been accomplished for those same lakes. As such, if the intent of the projects was accomplished, the reduction in TP loads sufficient to meet water quality goals of the TMDL, then water quality data should show evidence of such.

For Lake Howard, unfortunately, there is no clear evidence of an improvement in water quality, as illustrated by levels of chlorophyll-a following the completion of stormwater retrofits in 2000 and 2001 (Figure 21).

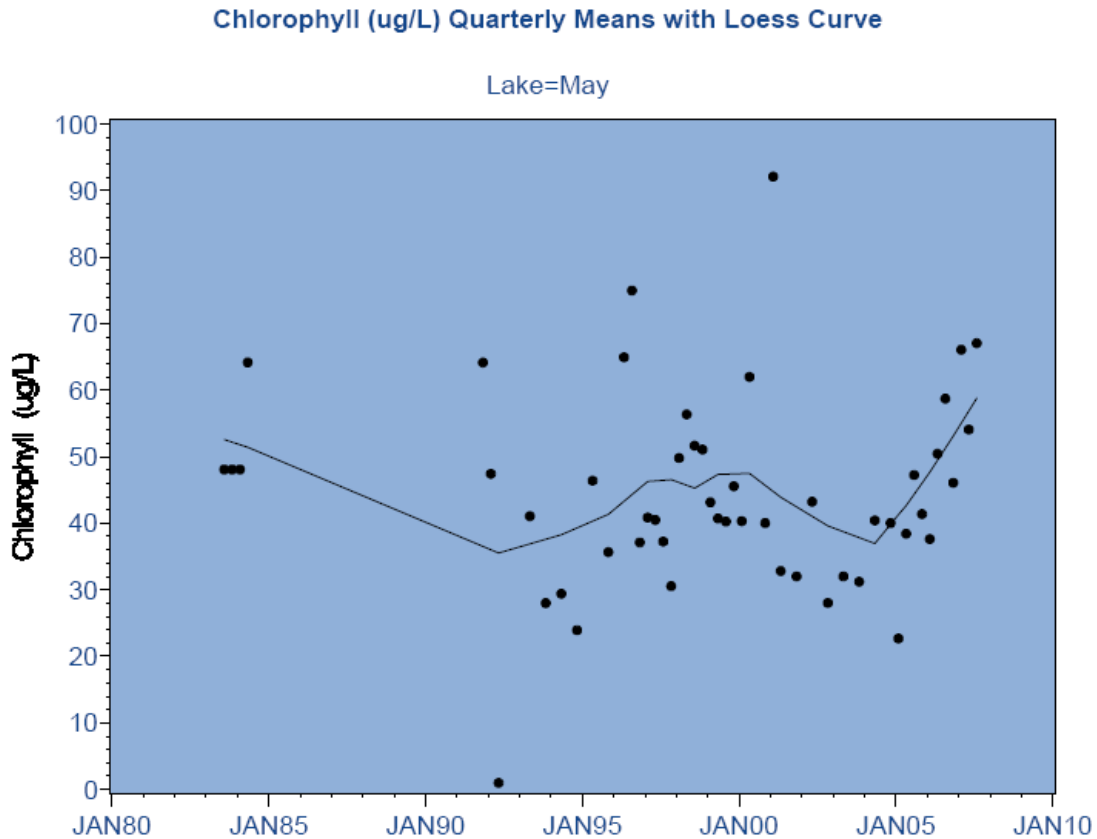
Figure 21
Chlorophyll-a levels in Lake Howard over time. Line is Loess best-fit curve of quarterly means



Chlorophyll-a levels in Lake Howard show a pattern that seems to reflect a delayed, but actual, response to point source load reductions in the 1980s. However, chlorophyll-a levels do not show a similarly significant reduction in levels after 2000 and 2001. As the scale on the y-axis starts at 20 $\mu\text{g} / \text{liter}$, it is clearly evident that chlorophyll-a levels did not decrease down to TSI_{CHLA} values of 60 or less (which would require chlorophyll-a levels to be below 20 $\mu\text{g} / \text{liter}$).

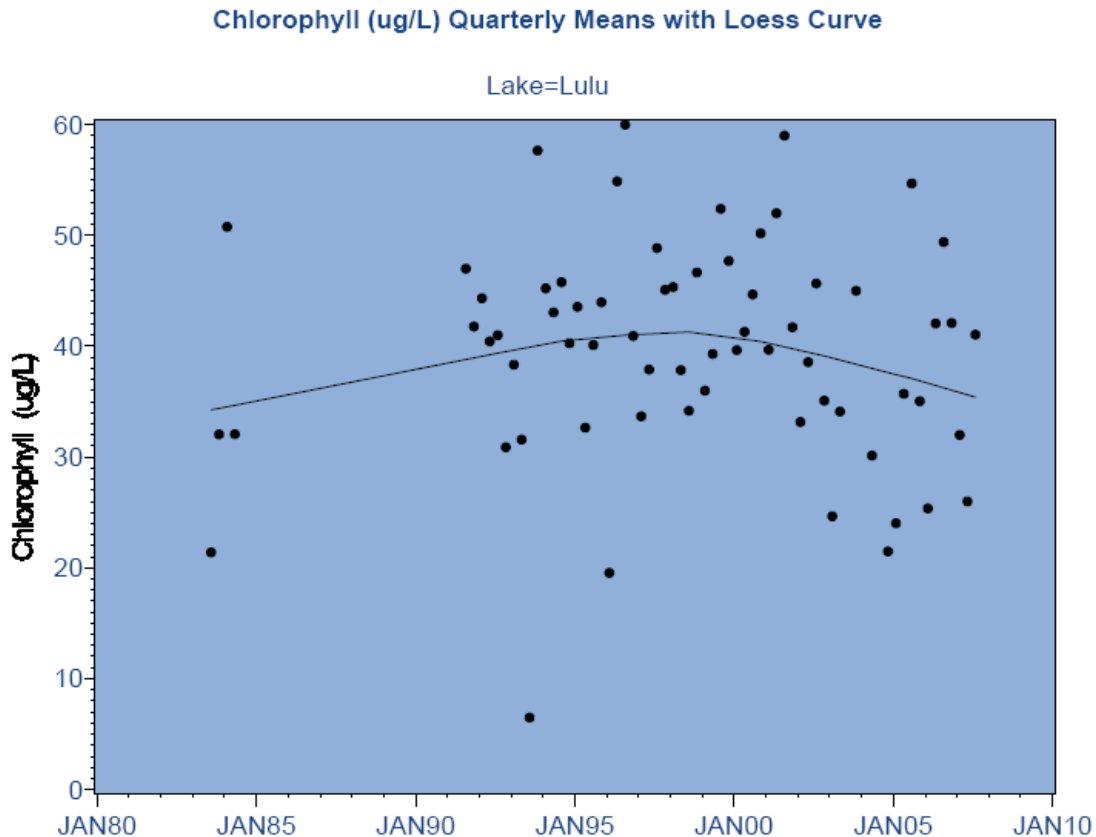
Similar to Lake Howard, Lake May also does not appear to exhibit a water quality response sufficient in magnitude to suggest that the attainment of the TP reduction goals (achieved via completion of stormwater retrofit projects in 2005) and outlined in the WHCL TMDL (FDEP 2007) have significantly improved water quality in a way that could be appreciated by the general public (Figure 22).

Figure 22
Chlorophyll-a levels in Lake May over time. Line is Loess best-fit curve of quarterly means



Finally, Lake Lulu appears to be a third example of a lake where achievement of load reduction goals outlined in the TMDL report (FDEP 2007) does not appear to offer evidence of the achievement of TSI goals for chlorophyll-a (i.e., 20 μg / liter) after the implementation of load reductions, significant enough to meet TMDL requirements, in the year 2005 (Figure 23).

Figure 23
Chlorophyll-a levels in Lake Lulu over time. Line is Loess best-fit curve of quarterly means



While it is likely that the TP load reductions outlined in the TMDL report (FDEP 2007) underestimate the TP concentration reductions required to manage these lakes to a TSI_{CHLA} goal of 60, due to the lower than “typical” amounts of color in Ridge lakes, it should also be noted that the City of Winter Haven and its funding partners appear to have already implemented stormwater retrofit projects in *excess* of TMDL load reduction goals (FDEP 2007) listed for Lakes Howard, May and Lulu. It is the response of the lakes to such reductions that is the topic of this discussion, not the interest or intent of the parties involved in these projects to meet their TMDL obligations.

In addition to their nutrient removal functions, large-scale stormwater treatment systems can play an important role in improving the aesthetic appeal of many of these lakes, as they can capture large amounts of floatable debris. This intercepted stream of garbage would otherwise degrade the recreational and habitat value of these lakes (see Figures 24 and 25). These regional stormwater projects also have an important function as a means to educate the public about the issues of habitat loss and water quality degradation within the WHCL watershed.

Figure 24
Trash Collected by Stormwater Project on Lake Hartridge



Figure 25
Trash Collected by Stormwater Project on Lake Jessie



However, predicted load reductions with such efforts, even if implemented on a much more massive scale than is currently the case, do not seem to be capable of producing the quantity of load reduction required to achieve the proposed water quality targets for Ridge lakes.

The load reduction efficiencies for typical wet detention ponds, as summarized by FDEP in its report on the District's Melburne Pond project (2006), are 30 and 70 percent, respectively, for TN and TP.

The TP load reductions required for impaired lakes of the WHCL, as outlined in FDEP (2007) range from 23 to 60 %. With a presumed 70 percent load reduction efficiency for permitted wet detention ponds, achieving such reductions on a watershed-wide level would require retrofitting from a third to nearly the entirety of the contributing drainage basin for impaired lakes. This poses significant challenges. Even if enhanced TP removal efficiencies are achieved via the use of alum injection technologies, the challenge of treating enough of the watershed are obvious. Alum treatment also involves ongoing operation and maintenance requirements not associated with more traditional wet detention systems.

Existing wet detention pond stormwater treatment requirements used by the District (for most instances) are that the first inch of stormwater runoff must be captured and kept within the treatment system for a minimum wet season residence time of 14 days. Based on these criteria, it is assumed (see above) that incoming TP loads will be reduced by 70%, and incoming TN loads will be reduced by 30%.

Recent work by Harper (2005) found that higher removal rates of TP and TN can be achieved by significantly increasing the residence time of treatment ponds used for regional stormwater treatment systems, as shown in Figures 26 and 27.

Figure 26
Phosphorus Removal Efficiency vs. Residence Time (figure from Harper [2005])

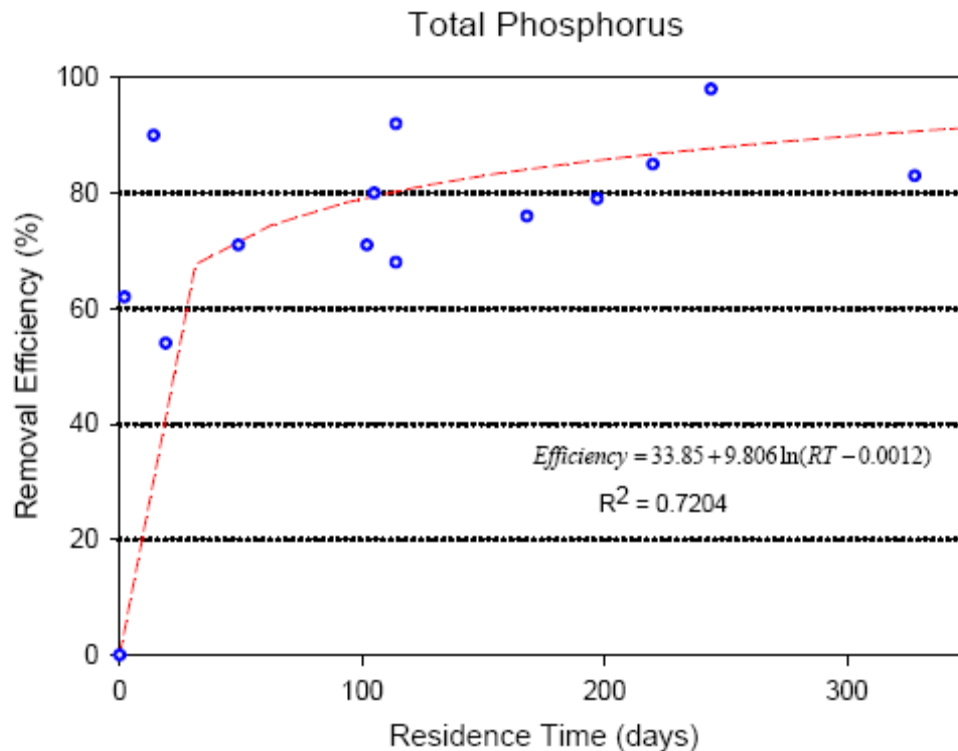
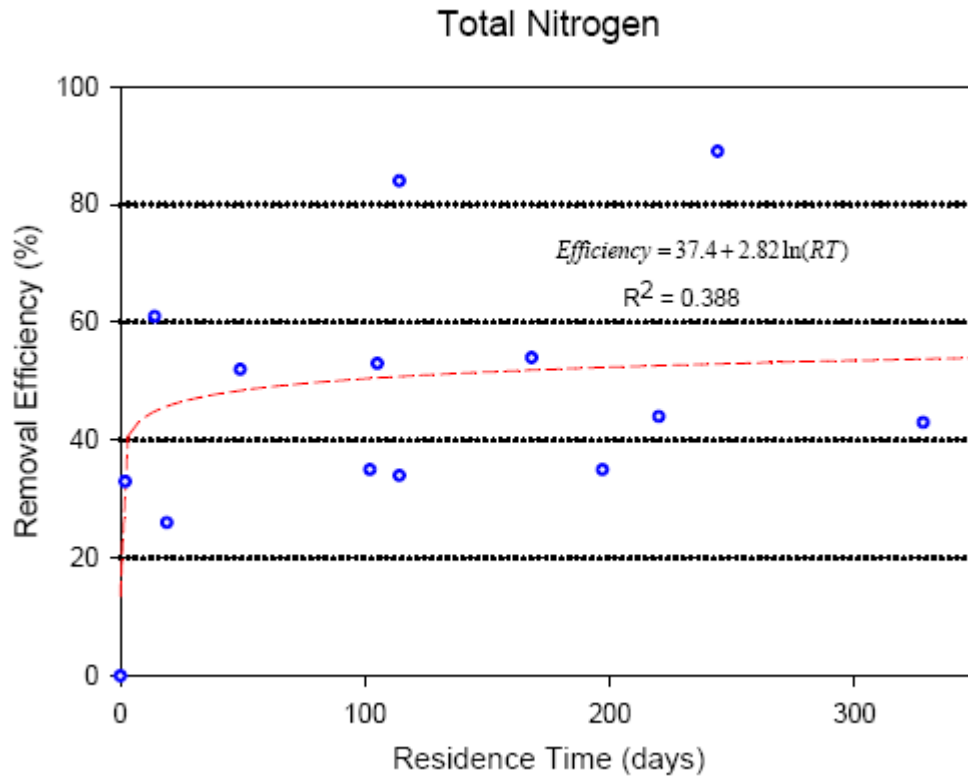


Figure 27
Nitrogen Removal Efficiency vs. Residence Time (figure from Harper [2005])



As summarized in Harper (2005) the majority of nutrient removal that occurs in wet detention treatment systems occurs in the permanent pool, rather than the vegetated fringe. The recommendation from Harper (2005) was that stormwater treatment ponds should be constructed as deep as possible (without breaching the aquitard) to take advantage of the increased treatment efficiencies achievable at high residence times (i.e., above 100 days).

Based on a review of water quality for all lakes within the WHCL system, the two lakes with the most pronounced improvements in water quality were Lakes Conine and Smart (Figures 28 and 29).

Figure 28
Period of Record for Chlorophyll-a for Lake Conine

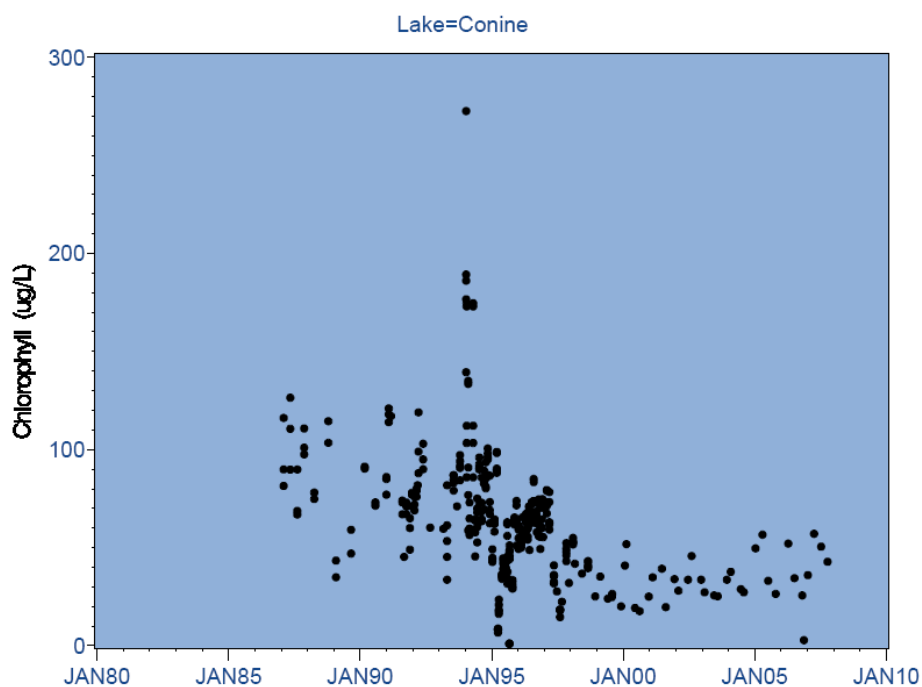
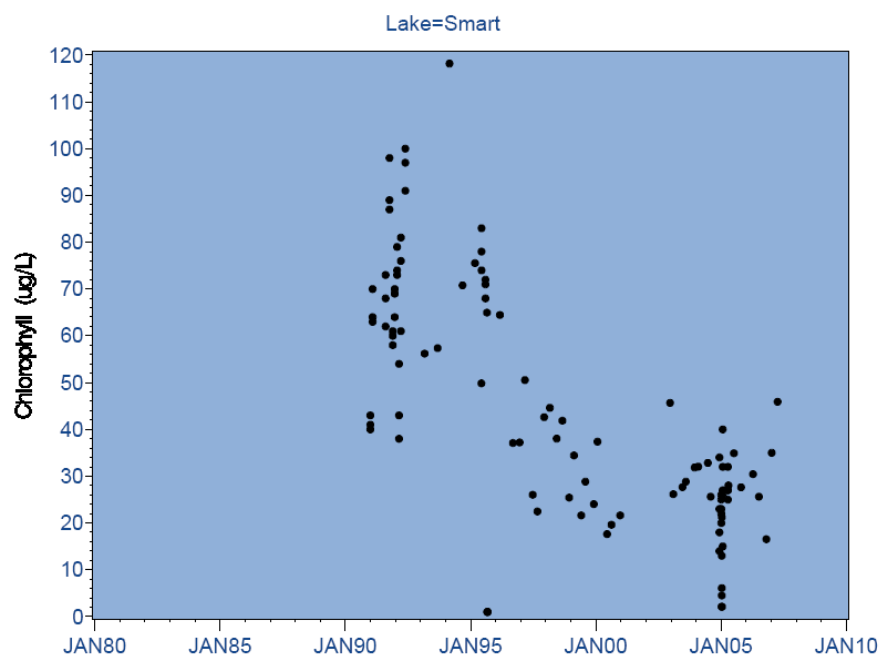


Figure 29
Period of Record for chlorophyll-a for Lake Smart



Improvements in water quality in these two lakes appear to be due mostly to the following actions:

- The removal of domestic wastewater treatment plant loads into Lake Conine in 1992.
- Whole-lake alum treatment of Lake Conine in 1995.
- Benefits to Lake Smart appear to have been mostly due to upstream (via connecting canal) improvements in Lake Conine.

These results suggest that water quality improvements for Ridge lakes can be achieved via non-traditional techniques such as whole-lake alum treatment. However point source loads (if any still exist) should be removed prior to such activities. Also, should regional stormwater treatment ponds be used for reducing phosphorus and nitrogen loads, efforts should be made to maximize the residence time of such systems, via maximizing either the area or depth of these ponds. Otherwise, nutrient load reductions, even with large regional stormwater treatment systems, are unlikely to be able to reduce loads sufficiently to result in observable and/or measurable improvements in water quality in the lakes themselves.

4.2. Valley Lakes

For Valley lakes, the lack of statistically significant relationships between nutrient concentrations (both TP and TN) and chlorophyll-a indicate factors other than nutrients might be more important for controlling phytoplankton growth in these tannin-rich lakes. Rather than focusing on nutrient reduction strategies alone, it appears that a more promising plan of action would be to focus on reestablishing the historic swamp and lake hydrologic connections for these lakes. In many locations, the canals between adjacent Valley lakes have been cut through the swamp and marsh slough systems that historically allowed surface flow between them at high water levels. In some instances, these canals appear to have dried up and/or hydrologically isolated these swamps, thus potentially reducing their tannin loads to these lakes. Whitmore and Brenner (1995) in their study of Lakes Conine, Haines, Hartridge, Howard, and May, concluded that, “In all five study lakes, pre-disturbance samples show that the study lakes previously had substantially greater input from adjacent swamps or marshes.”

These findings do not reduce the need to successfully manage stormwater loads to receiving water bodies, especially for new construction activities. Instead, the intent is to highlight the need for additional activities, above and beyond the traditional retrofit-driven approaches to lake management that have been designed and implemented for many systems, without evidence of a concurrent improvement in water quality in the targeted water bodies.

Figure 30 shows a view looking toward Lake Haines taken within the canal that connects Lake Haines to Lake Rochelle.

Figure 30
Canal between Lake Haines and Lake Rochelle



The canal that connects these two lakes has drained, to a presently unknown extent, the swamp that was the historic flow-way through which wet season flows moved between Lakes Haines and Rochelle. To effectively reestablish the water quality and habitat value of these important wetland systems, it may be necessary to minimize these canal influences. To do this, the following actions could be implemented:

- Use of sheet piling or other techniques to prevent the “dewatering” effect of these canals on adjacent swamps.
- Use of locks to maintain wet season water levels high enough to create an effective swamp-lake hydrologic connection.
- Where found, filling in of swamp drainage canals that aren’t necessary for flood protection. Drainage canals that do not appear to be needed for flood control purposes of adjacent property can be found within the swamps on the north shore of Lake Haines and the south shore of Lake Lulu - and may be present in other locations as well.

In addition, several historic herbaceous wetlands have apparently transitioned to willow swamps, such as the wetland located at the southeast corner of Lake Lulu. By restoring these areas to their historic herbaceous wetland conditions, enhanced nutrient uptake and wildlife benefits could both be realized.

In terms of ongoing lake management efforts, the following recommendations are proposed:

- The current Watershed Management Plan (WMP) being overseen by the City of Winter Haven should be used to refine loading estimates from stormwater and groundwater sources.
- Ground water load estimates should be refined, if necessary, based on results from the ongoing FDEP-sponsored groundwater seepage study.
- The WMP should use the hydrologic modeling tools to evaluate the influence of lake levels on residence time and between-lake load estimates.
- The WMP should use the empirically-derived TP and TN goals described within this report for Ridge lakes as target nutrient concentrations.
- The WMP should be used to identify load reduction strategies to meet these proposed TP and TN targets for Ridge lakes.

Additionally, ongoing and future lake management efforts should be open to being refined and/or significantly revised via adaptive management, should additional information suggest our understanding of lake processes needs to be modified.

5.0 References

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