Lake & Watershed Management Plan
Lakes Rippowam, Oscaleta & Waccabuc

Town of Lewisboro, Westchester County, NY

Prepared for:

Three Lakes Council

Attn: Jan Andersen, President
PO Box 241
South Salem, NY 10590

Prepared by:

Cedar Eden Environmental, LLC

1519 State Route 86
Saranac Lake, NY 12983
518.304.3697 • mmartin@cedareden.com

http://cedareden.com
Established 2001

November 9, 2019

Table of Contents

List of Tables

List of Figures

Executive Summary

Background

The Three Lakes Council contracted with Cedar Eden Environmental in 2003 to conduct a diagnostic-feasibility study of Lake Rippowam, Lake Oscaleta and Lake Waccabuc located in the Town of Lewisboro, Westchester County, NY (Figure 1). That study resulted in the publication of a lake and watershed management plan for the Three Lakes (Martin 2004). Since that time, the Three Lakes Council has been implementing the recommendations of that management plan, including outreach & education and an extensive water quality monitoring program on the lakes. The lakes, however, continue to experience water quality problems, including an excess of nutrients, a loss of hypolimnetic oxygen, harmful algae blooms and excessive growth of aquatic plants. The Three Lakes Council contracted with Cedar Eden Environmental in 2018 to create an updated lake and watershed management plan for the Three Lakes. This document is the result of that study.

The Watershed

Extremely steep terrain exists along the northern watershed along the south-facings shores of Lake Waccabuc and Lake Rippowam. Steep slopes also above the southern shores of Lake Oscaleta and throughout the CT portion of the watershed. The only relatively flat portions of the watershed exist in the basin plains surrounding the Three Lakes and in the southwest corner of the Lake Waccabuc watershed. Most of the watershed is forested with little to no medium and high density residential development. Most of the low intensity residential development exists in the Lake Waccabuc watershed, along the northeastern shore and in the southwest corner of the watershed. There has been very little change in land use since 2001.

Watershed soils are dominated by hydrologic group B soils with moderate infiltration rates (797 acres), followed by hydrologic group D soils with very slow infiltration rates (569 acres) and hydrologic group C soils with slow infiltration rates (256 acres). Most of the watershed soils are only slightly to moderately fragile (susceptible to degradation). However, much of the watershed soils are very limited for conveying surface water and for infiltration. Steep areas and wetland areas in the watershed contain soils which are very limited for subsurface wastewater disposal. The rest of the soils in the watershed tend to be somewhat limited (NY) or have low potential (CT).

Soils in the areas of the primary dirt and gravel roads – Tarry-A-Bit, East Ridge and Old Pond – are in areas with soils that are primarily moderately suited for natural surface roads, have moderate to severe erosion hazard ratings, and are moderately to poorly suited for unpaved local roads.

Water Quality

Lake Rippowam and Lake Oscaleta are mesotrophic lakes while Lake Waccabuc is meso-eutrophic. Lake Oscaleta and Lake Waccabuc experience considerable loss of oxygen in their hypolimnia during the summer stratified period, resulting in the release of phosphorus from the lake sediments into the overlying water. There appears to be a trend for a decrease in the depth at which anoxia occurs in both of those lakes over the past fifteen years.

Internal loading of phosphorus in Lake Oscaleta and Lake Waccabuc was significant and there is evidence that some of that phosphorus become available in the upper waters, fueling cyanobacteria blooms.

In Lake Rippowam, transparency was not correlated with climate and weakly correlated to water quality. Chlorophyll *a* was correlated to summer minimum and maximum air temperatures, particularly the average summer maximum air temperature. In Lake Oscaleta, transparency was not correlated to water quality or climate. Chlorophyll *a* was best predicted by total nitrogen although this may be the other way around due to presence of nitrogen-fixing bacteria in the lake. Summer total phosphorus was not related to climate. In Lake Waccabuc, summer total phosphorus predicts chlorophyll a in Lake Waccabuc, chlorophyll a predicts transparency. Climate and water quality parameters failed to predict summer total phosphorus in Lake Waccabuc.

Pollutant Loading & Reductions

Lake Rippowam receives an annual load of 27.3 kg of phosphorus per year and 303.0 kg of nitrogen per year. The watershed is small and relatively undeveloped. As a result, the total phosphorus load is small, making the percent contribution from precipitation (24.9%) and the water supply (25.2%) quite significant and the water supply orthophosphorus buffer by far the largest controllable source of phosphorus within the watershed. Using the selected model, total phosphorus would have to be reduced by 30 percent (8.3 kg/year) to achieve an in-lake total phosphorus of 0.020. This could be achieved by switching the water supply to alternative anti-corrosion measures (25.2 percent direct reduction) and modest changes in stormwater management, primarily addressing runoff from impervious surfaces (roads, roofs, driveways) and lawns.

Lake Oscaleta receives an annual load of 128.5 kg of phosphorus per year and 1,256.7 kg of nitrogen per year. Internal loading accounted for nearly 21% of the annual phosphorus loading while the water supply accounted for 5 percent. Using the selected model, total phosphorus would have to be reduced by 33.9 percent (43.5 kg/year) to achieve an in-lake (weighted) total phosphorus of 0.020. This could be achieved by switching the water supply to alternative anti-corrosion measures (5 percent direct reduction plus an 12.6 percent reduction in load from Lake Rippowam), modest changes in stormwater management, primarily addressing runoff from impervious surfaces (roads, roofs, driveways) and lawns and reducing internal loading through aeration or phosphorus inactivation (21 percent).

Lake Waccabuc receives an annual load of 989.3 kg of phosphorus per year and 2,011.7 kg of nitrogen per year. Internal loading accounted for 76 percent of the annual phosphorus load. Using the selected model, total phosphorus would have to be reduced by 94 percent (929 kg/year) to achieve an in-lake (weighted) total phosphorus of 0.020. This could be achieved by addressing the internal loading of phosphorus within the lake through hypolimnetic aeration or phosphorus inactivation (76 percent) and moderately aggressive changes in stormwater management, including addressing dirt and gravel roads, runoff from impervious surfaces and lawns, and untreated runoff from paved roads.

Nonpoint Source Problem Areas

Significant nonpoint source problem areas in the watershed were the three dirt and gravel roads, uncontrolled stormwater runoff from private properties and stormwater runoff in a few locations along paved roads.

Management Recommendations

Watershed Management

- ☆ Hire an engineering firm to design corrective stormwater management measures for the Post Office parking lot and Mead Street in the area of the Post Office
- ☆ Hire an engineering firm design stormwater management measures along Tarry-A-Bit Road and Old Pond Road for reducing nutrient runoff.
- ☆ Hire an engineering firm to design stormwater management measures to control runoff from the lawns and driveways that contribute to erosion problems on Tarry-A-Bit Road.
- ☆ Hire an engineering firm to design and resurface Tarry-A-Bit Road and Old Pond Road with Driving Surface Aggregate
- ☆ Homeowners with bare soils, construction sites, or dirt piles on their properties should be encouraged to re-vegetate the areas in order to reduce the erosion potential. Silt fences and other erosion and sedimentation controls should be implemented at all construction sites, large or small.
- ☆ Homeowners should test their soil for phosphorus and nitrogen concentrations so that they can minimize the amount of fertilizer that they add to their lawns.
- ☆ Homeowners should plant vegetative buffers along the lake shore. Shoreline homeowners should be discouraged from mowing their lawns up to the edge of the lake. A minimum of a five foot vegetative buffer should be left along the lake shore or streambank to provide erosion control and to filter nonpoint source pollution from entering the water.
- ☆ Homeowners should be encouraged to wash cars and trucks on grassy areas, if possible, or use commercial car washes.
- ☆ Homeowners should be encouraged to clean up any pet waste that has the potential to be washed into the Three Lakes during rain events.
- ☆ Institute and provide assistance and support for mandatory septic system pumping.

- ☆ Encourage and seek funding support for the replacement of septic systems near lakes and streams with advanced treatment technologies.
- ☆ Encourage the use of small community systems with advanced nutrient removal in areas where home density, lot size and closeness to lake shore is problematic.
- ☆ Institute a program to install rain barrels and rain gardens throughout the watershed by offering education and incentives
- ☆ Provide education and support for the creation of riparian buffers around streams and lake shorelines.

Lake Management

Lake Rippowam

- ☆ Hire an engineering firm to develop alternative water treatment to reduce corrosivity in the water without the use of orthophosphorus.

Lake Oscaleta

- ☆ Hire an engineering firm to develop alternative water treatment to reduce corrosivity in the water without the use of orthophosphorus.
- ☆ Encourage NYS DEC to approve the use of alum in New York lakes for the long-term management of internal phosphorus loading
- ☆ Hire a qualified engineering firm to design and implement a hypolimnetic oxygenation system or long-term nutrient inactivation treatment.
- ☆ Develop a comprehensive aquatic plant management plan, including rapid response protocol for new invasive species, and institute lake-wide management of aquatic plants rather than leaving it up to individual homeowners or local associations.

Lake Waccabuc

- ☆ Encourage NYS DEC to approve the use of alum in New York lakes for the long-term management of internal phosphorus loading
- ☆ Hire a qualified engineering firm to design and implement a hypolimnetic oxygenation long-term nutrient inactivation treatment.
- ☆ Develop a comprehensive aquatic plant management plan, including rapid response protocol for new invasive species, and institute lake-wide management of aquatic plants rather than leaving it up to individual homeowners or local associations.

Monitoring

- ☆ Continue an annual lake monitoring program using CSLAP or equivalent to provide data needed to assess water quality trends and evaluate the effectiveness of management activities.

- Map aquatic plant distribution and abundance on an annual basis if possible. Alternately, map entire littoral zone every two to five years and institute volunteer monitoring to identify new aquatic invasive plant species and new colonies of existing invasive plant species before they become established
- Continue to test cyanobacteria blooms for toxins and provide advisories to residents when toxins are present.
- Conduct a fisheries study to assess the health of the fisheries in the lakes and to provide scientifically-based recommendations for stocking

Education

- Institute an education and outreach campaign in support of the watershed management plan with all stakeholders
- Incorporate lake user surveys into the educational campaign

Introduction

The Three Lakes Council contracted with Cedar Eden Environmental in 2003 to conduct a diagnostic-feasibility study of Lake Rippowam, Lake Oscaleta and Lake Waccabuc located in the Town of Lewisboro, Westchester County, NY (Figure 1). That study resulted in the publication of a lake and watershed management plan for the Three Lakes (Martin 2004). Since that time, the Three Lakes Council has been implementing the recommendations of that management plan, including outreach & education and an extensive water quality monitoring program on the lakes. The lakes, however, continue to experience water quality problems, including an excess of nutrients, a loss of hypolimnetic oxygen, harmful algae blooms and excessive growth of aquatic plants. The Three Lakes Council contracted with Cedar Eden Environmental in 2018 to create an updated lake and watershed management plan for the Three Lakes. This document is the result of that study.

The Three Lakes Council conducted a survey of its membership in 2016 regarding lake concerns and impressions. The survey showed that respondents used the lakes for non-motorized boating (96%), scenic enjoyment (95%) and swimming or wading (89%). Respondents indicated that the most important criteria for judging lake quality by lake residents were water clarity (62%), amount of “weeds” (55%), frequency of algal blooms (40%) and swimming conditions (38%). The top three conditions identified as a serious problem on the lakes were invasive aquatic plants (38%), algae blooms (37%) and harmful algal blooms (34%). Issues identified as “some problem” on the lakes were algae blooms (53%), invasive aquatic plants (51%), waterfowl droppings (51%), native aquatic plants (43%), nutrients from inadequate septic systems (39%) and chemicals from lawn herbicides and pesticides (37%). Respondents identified privacy, beauty, tranquility, recreation and wildlife as what the liked best about their lake and algae, weeds, beavers and motorboats as what they liked least.

The survey included a section about management actions. Among actions respondents wanted to take were protecting undeveloped shoreline (66%), goose egg oiling (59%), education on alternative septic system technologies (51%), education on boat operation and rules (48%), education on lakeside buffer planting (45%) and weed control through hand or suction harvesting (41%). Among actions respondents would consider were weed control through benthic barriers (46%) and weed control through hand or suction harvesting (44%). Actions that respondents did not want to take were weed and algae control using chemicals (52% and 44%, respectively).

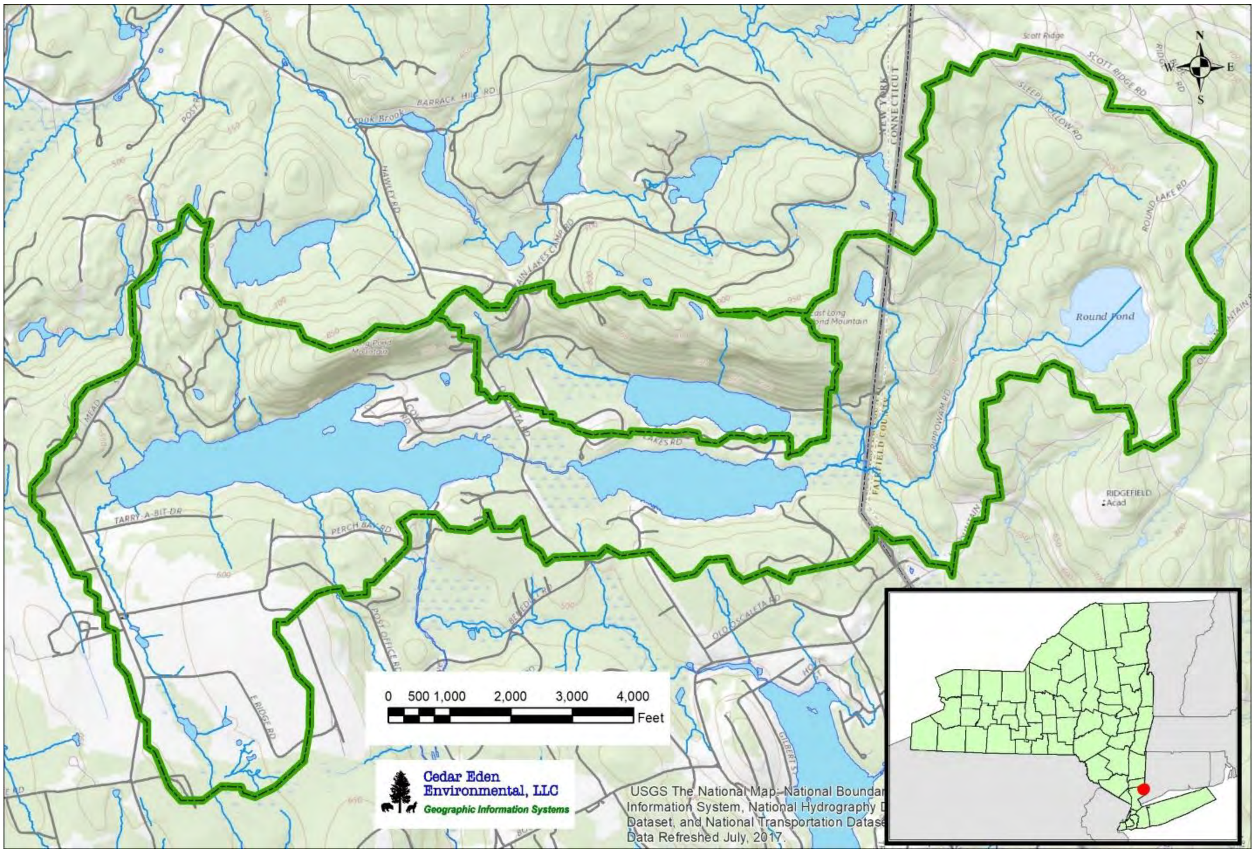

Figure 1 Location of Three Lakes watershed in New York State

9 Elements of Watershed Plans

The U.S Environmental Protection Agency has provided a guidance document containing the 9 elements of watershed plans (USEPA 2008). This guidance has been adopted by the NYS Department of Environmental Conservation and will be used to guide future funding for State grants.

a. Identification of causes of impairment and pollutant sources that need to be controlled to achieve needed load reductions
b. Estimate of the load reductions expected from management measures
c. Description of the Nonpoint Source pollution (NPS) management measures that need to be implemented to achieve load reductions and description of the critical areas in which those measures will be needed
d. Estimate of the amounts of technical and financial assistance needed, associated costs, and sources and authorities that will be relied upon to implement this plan
e. Information and education component to enhance public understanding of the project and encourage early and continued participation in selecting, designing and implementing NPS measures

f. Schedule for implementing the NPS management measures identified in the plan
g. Description of interim measurable milestones for determining whether NPS measures are being implemented
h. Set of criteria that can be used to determine whether loading reductions are being achieved over time and substantial progress is being made toward attaining water quality standards
i. Monitoring component to evaluate the effectiveness of the implementation efforts measured against criteria (item h)

Lake Characteristics

The morphological characteristics of the three lakes are presented in the following table (modified from Martin, 2004).

Table 1 Selected morphological characteristics of the Three Lakes

Lake Characteristic	Lake Rippowam	Lake Oscaleta	Lake Waccabuc
Surface Area	33.9 ac 13.7 ha	65.2 ac 26.4 ha	138.0 ac 55.9 ha
Maximum Depth	20 ft 5.8 m	36 ft 10.8 m	44 ft 14.2 m
Mean Depth	13.5 ft 4.1 m	19.4 ft 5.9 m	23.3 ft 7.1 m
Lake Volume	150 million gallons 566,536.1 m^3	412 million gallons 1,557,959.9 m^3	3696 million gallons 13,990,063.4 m^3
Hypolimnion Volume	0.1 million gallons 456 m^3	61 million gallons 230,898 m^3	369 million gallons 1,398,107 m^3
Flushing Rate	4.7 times/year	3.2 times/year	1.4 times/year
Phosphorus Retention Coefficient	0.48 percent	0.48 percent	0.55 percent

Watershed Characteristics

The Three Lakes watershed is located in the Town of Lewisboro, Westchester County, NY within the Lower Hudson drainage (Figure 1). A portion of the watershed is also located in Ridgefield, Fairfield County, CT.

Watershed boundaries for the Three Lakes were recreated using StreamStats (USGS, 2016a). The watershed for Lake Rippowam is 278.8 acres. The percent of the watershed area storage for storage (lakes, ponds, reservoirs, wetlands) is 20.2 percent. The watershed for Lake Oscaleta, which includes the watershed of Lake Rippowam, is 1,281.7 acres. The percent of the watershed area storage for storage (lakes, ponds, reservoirs, wetlands) is 16.5 percent. The watershed for Lake Waccabuc is approximately 2,195.6 acres and includes the watersheds of Lake Rippowam and Lake Oscaleta. The percent of the watershed area storage for storage (lakes, ponds, reservoirs, wetlands) is 16.7 percent.

Topography and Slope

Watershed topography was examined using GIS analysis of 1/3 arc-second resolution National Elevation Dataset (NED) digital elevation data (USGS, 2016b). The topographic contours for the Three Lakes watersheds are shown in Figure 2. The Three Lakes watershed has a maximum elevation of 304.5 meters (998.9 feet) at East Long Pond Mountain on the east edge of the ridge north of Lake Rippowam and a minimum elevation of 143.4 meters (470.4 feet) at the lake plains between the lakes. The Lake Rippowam watershed is the steepest, with a mean basin slope is 1,240 feet per mile, followed by the Lake Oscaleta watershed with a mean basin slope is 778 feet per mile and the Lake Waccabuc watershed with a mean basin slope is 703 feet per mile.

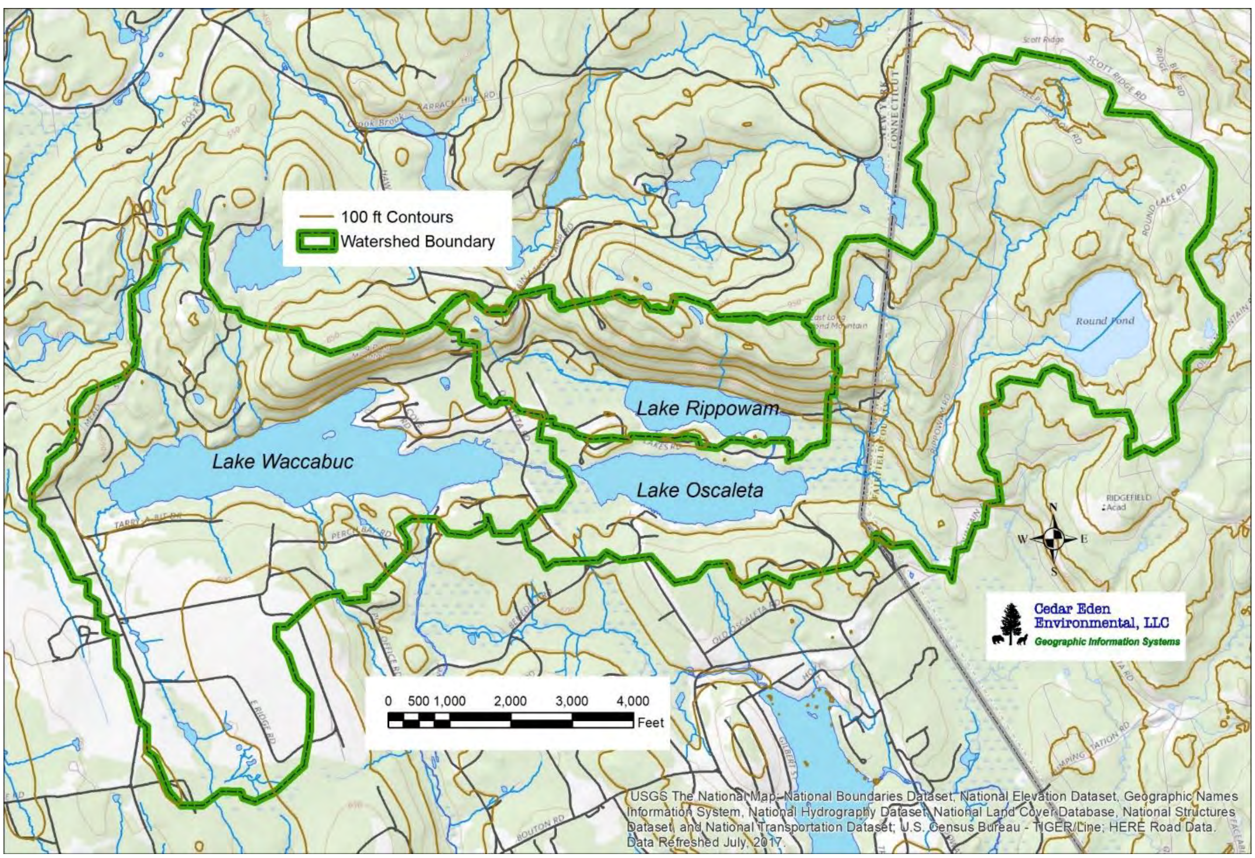

Figure 2 Topography of the Three Lakes watersheds

Percent slope within the Three Lakes watersheds are shown in Figure 3. Extremely steep terrain exists along the northern watershed along the south-facings shores of Lake Waccabuc and Lake

Rippowam. Steep slopes also above the southern shores of Lake Oscaleta and throughout the CT portion of the watershed. The only relatively flat portions of the watershed exist in the basin plains surrounding the Three Lakes and in the southwest corner of the Lake Waccabuc watershed.

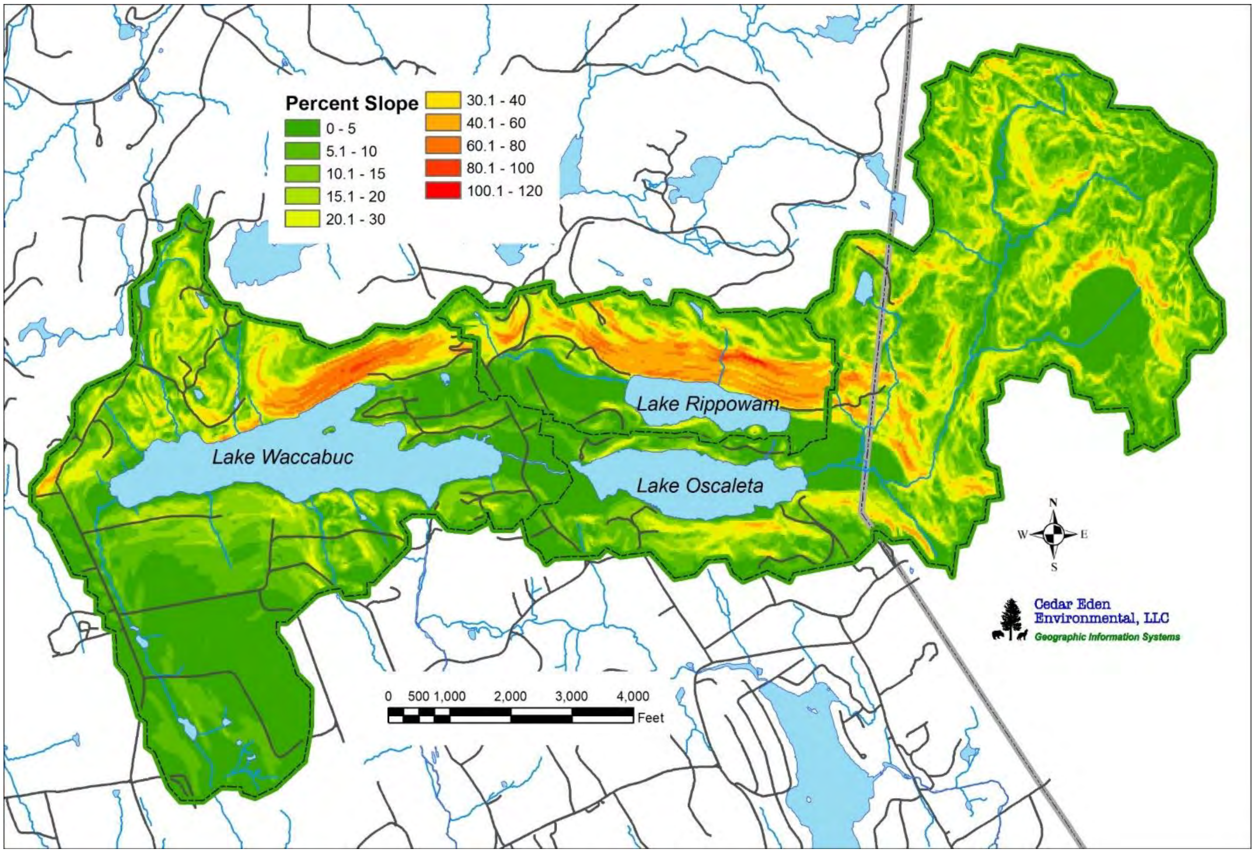

Figure 3 Percent slope within the Three Lakes watersheds

Land Use

Land use in the Three Lakes watershed was determined by GIS analysis of the 2011 National Land Cover Data (NLCD) dataset (2011 Edition, amended 2014) and the NLCD 2001 to 2011 Land Cover Change dataset. Land cover class descriptions are presented in Table 2.

Table 2 NLCD Land Cover Classification System Land Cover Class Definitions	
Land Cover Class	**Description**
Open Water	areas of open water, generally with less than 25% cover of vegetation or soil.
Developed, Open Space	areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.

Developed, Low Intensity	areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.
Developed, Medium Intensity	areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.
Developed High Intensity	highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.
Deciduous Forest	areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.
Evergreen Forest	areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.
Mixed Forest	areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.
Shrub/Scrub	areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.
Grassland/Herbaceous	areas dominated by graminoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling but can be utilized for grazing.
Pasture/Hay	areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation
Woody Wetlands	areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
Emergent Herbaceous Wetlands	Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

Current Land Use

Current (2011) land use in the Three Lakes watersheds is presented in Figure 4 and summarized in Table 3 and Figure 5. Most of the watershed is forested with little to no medium and high density residential development. Most of the low intensity residential development exists in the Lake Waccabuc watershed, along the northeastern shore and in the southwest corner of the watershed.

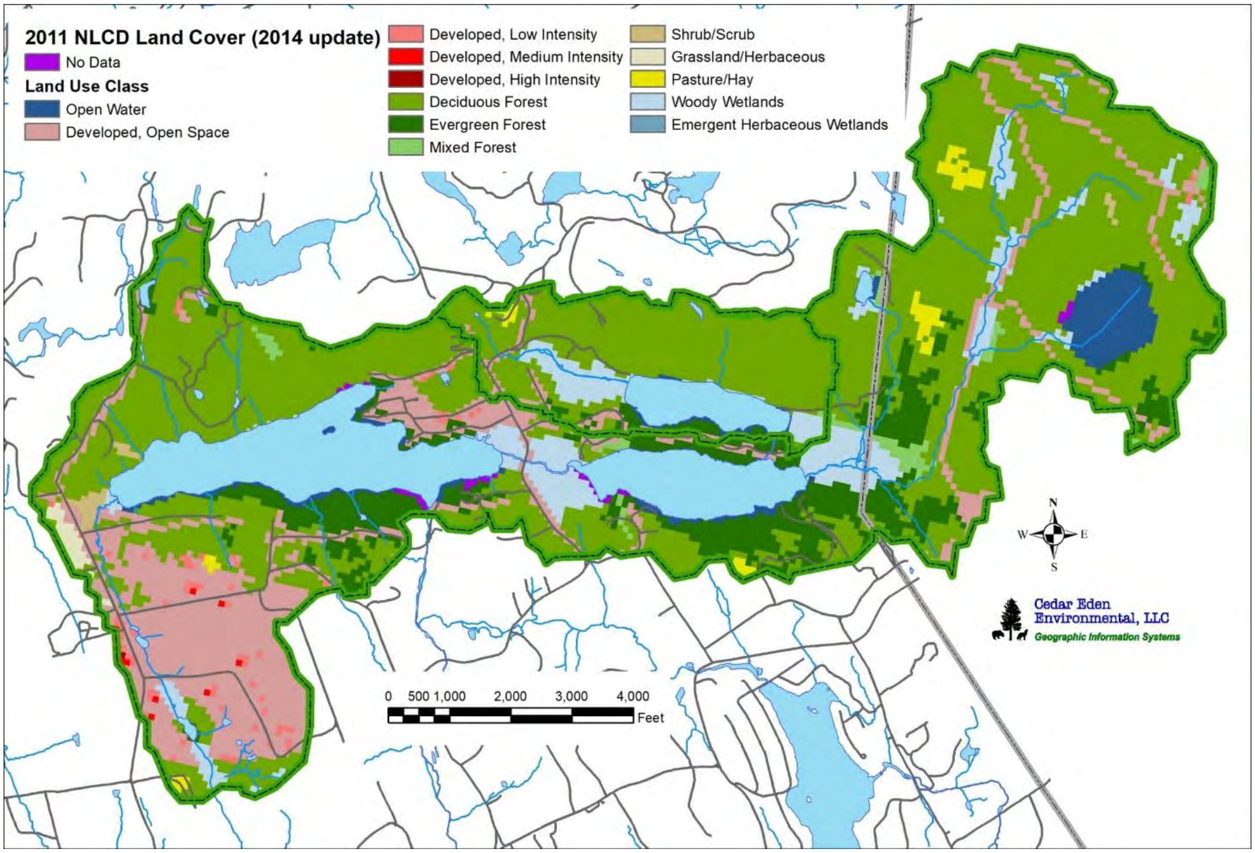

Figure 4 NLCD Land Cover in the Three Lakes watersheds

Table 3 Summary of land cover in the Three Lakes watersheds

	Waccabuc		Oscaleta		Rippowam	
Land Cover	**Percent**	**Acreage**	**Percent**	**Acreage**	**Percent**	**Acreage**
Open Water	12.7%	278.3	11.1%	142.4	12.8%	35.7
Developed, Open Space	15.5%	341.4	6.3%	80.6	4.9%	13.7
Developed, Low Intensity	0.8%	17.8	0.2%	2.0	0.1%	0.2
Developed, Medium Intensity	0.1%	2.4	0.0%	0.0	0.0%	0.0
Developed, High Intensity	0.0%	0.2	0.0%	0.0	0.0%	0.0
Deciduous Forest	51.7%	1135.5	59.5%	763.0	66.3%	184.8
Evergreen Forest	9.3%	205.0	11.1%	142.4	3.7%	10.3
Mixed Forest	1.0%	22.4	1.6%	20.0	0.2%	0.7
Shrub/Scrub	0.4%	7.8	0.1%	1.3	0.0%	0.0
Grassland/Herbaceous	0.4%	8.7	0.0%	0.0	0.0%	0.0
Pasture/Hay	1.0%	20.9	1.4%	17.5	0.9%	2.5
Woody Wetlands	6.7%	146.8	8.4%	108.2	11.1%	31.0
Emergent Herbaceous Wetlands	0.4%	8.4	0.3%	4.2	0.0%	0.0
	100.0%	**2195.6**	**100.0%**	**1281.7**	**100.0%**	**278.9**

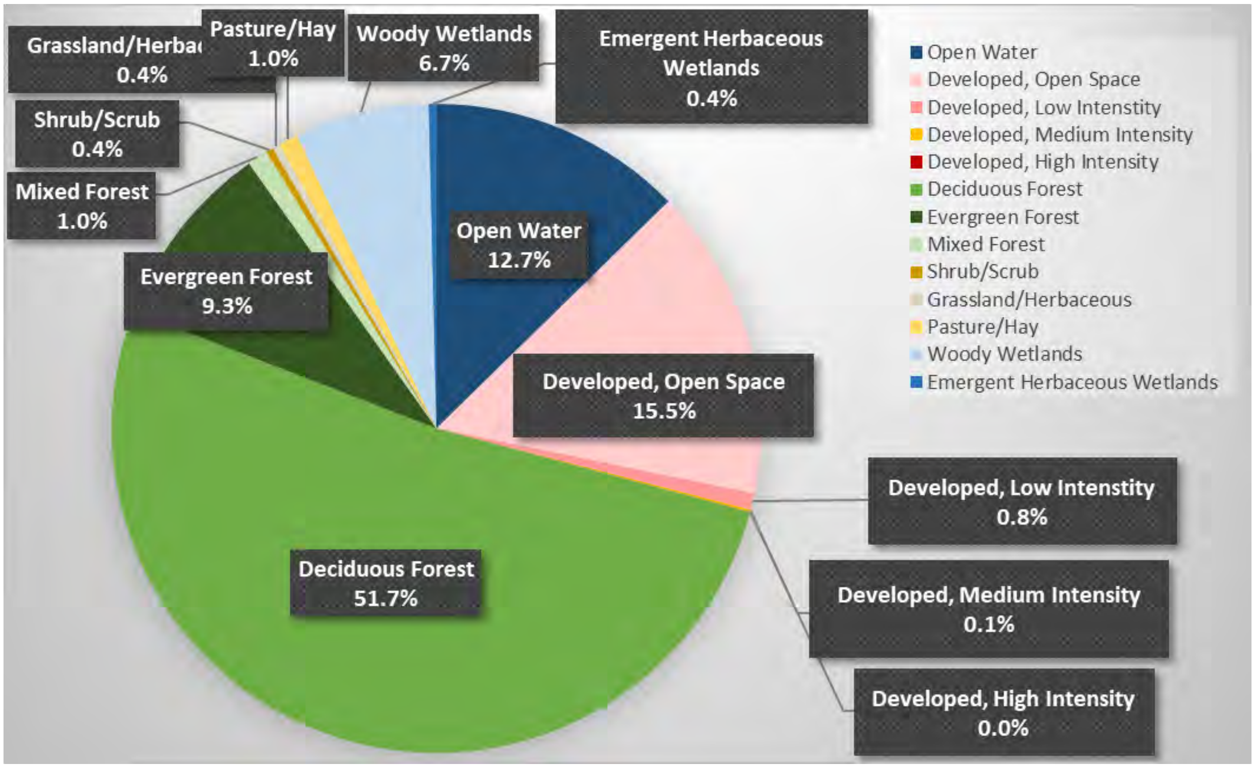

Figure 5 Percent Land Cover in the Three Lakes watershed

Land Use Change

Figure 6 and Figure 7 presents the change in land cover in the Three Lakes watersheds between 2011 and 2011. These changes are summarized in Table 4. Approximately 13 acres of land experienced a change in land cover between 2001 and 2011, less than 1 percent of the entire watershed. These changes were located in the southwest portion of the Lake Waccabuc watershed and consisted primarily of conversion of Deciduous Forest to Developed Open Space (7.1 acres) with about 1.3 acres converted from Developed Open Space to Low, Medium or High Density Development.

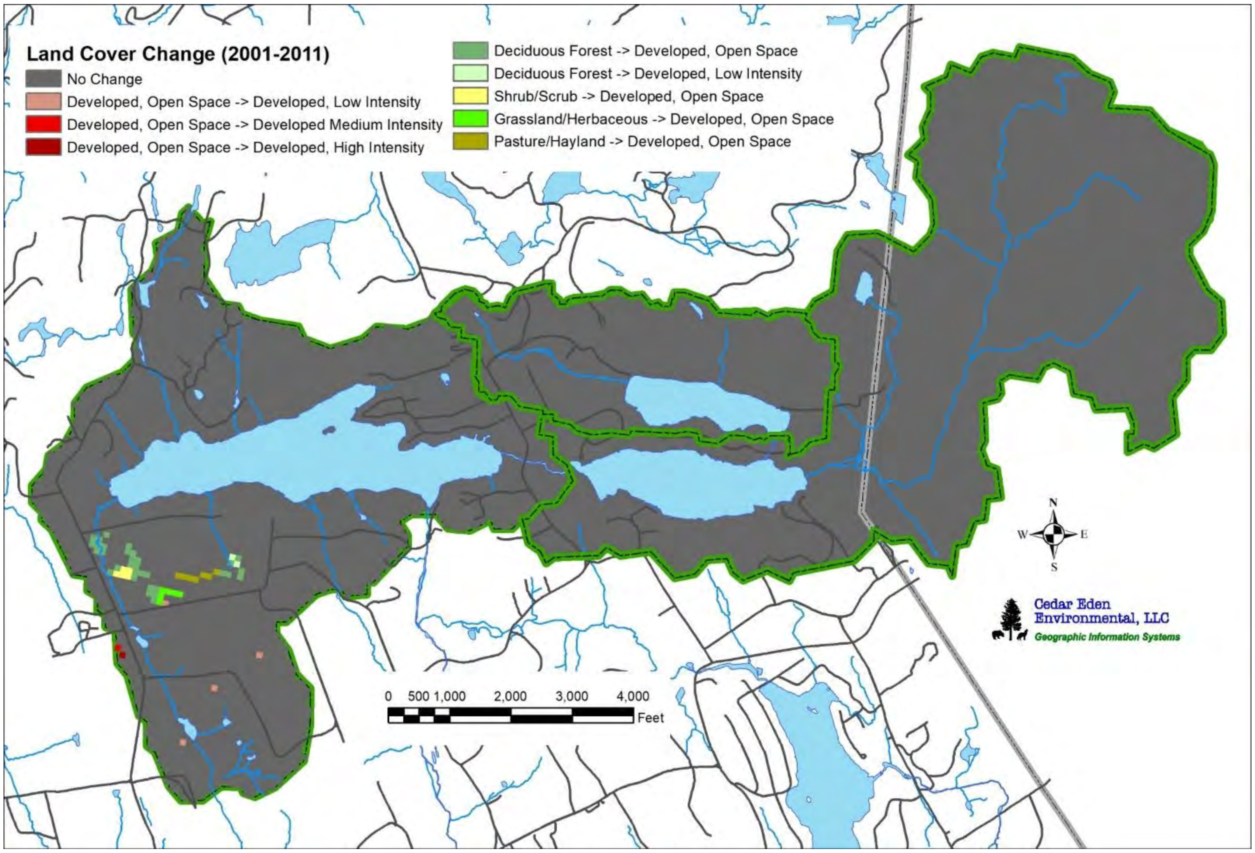

Figure 6 Change in Land Cover between 2001 and 2011 in the Three Lakes watersheds

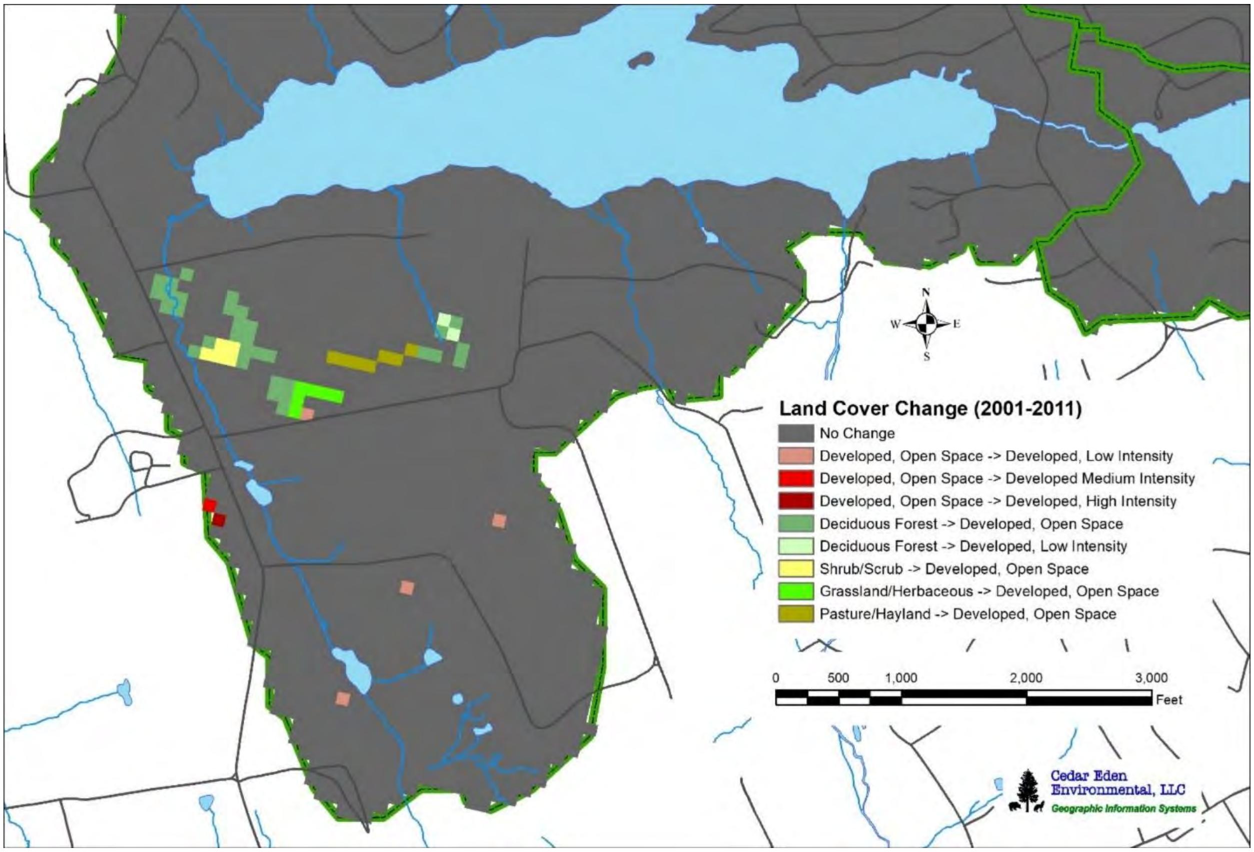

Figure 7 Close-up of Land Cover changes between 2001 and 2011 in the Three Lakes watershed

Table 4 Summary of Land Cover changes in Three Lakes watershed between 2001 and 2011		
Land Use	Percent	Acreage
Developed, Open Space ⇨ Developed, Low Intensity	0.0%	0.89
Developed, Open Space ⇨ Developed, Medium Intensity	0.0%	0.22
Developed, Open Space ⇨ Developed, High Intensity	0.0%	0.22
Dec Forest ⇨ Developed, Open Space	0.3%	7.11
Dec Forest ⇨ Developed, Low Intensity	0.0%	0.44
Shrub/Scrub ⇨ Developed, Open Space	0.1%	1.11
Grass/Herb ⇨ Developed, Open Space	0.1%	1.33
Pasture/Hay ⇨ Developed, Open Space	0.1%	1.55
	0.6%	**12.88**

Discussion

The Three Lakes' watersheds are largely undeveloped, with only about one percent of the watershed containing any development, which is predominantly low intensity development.

There has also been little change in land use over at least the past 20 years or so. As a result, there are not a lot of opportunities for managing lake water quality through watershed management programs. Watershed management should therefore focus on protecting undeveloped lands; managing runoff quality and quantity from developed lands through the use of buffers, fertilizer and pet waste management; capturing and treating runoff from impervious surfaces such as roofs and driveways (and basement sump pumps); and addressing those areas of NPS pollution along paved roads and dirt and gravel roads identified in this report.

Soils

Watershed soils information was obtained using the online Web Soil Survey along with GIS and Access database analyses of the Soil Survey Geographic (SSURGO) database for State of Connecticut and Westchester County, NY (NRCS 2017).

Watershed Soils

A map of the watershed soils by map unit are presented in Figure 8 along with soil names in Table 5. The majority of the watershed soils are the Charlton-Chatfield complex of varying slopes, comprising 499.8 acres or 26 percent of the watershed soils (excluding water) and a mix of Chatfield-Hollis-Rock outcrop, Hollis-Chatfield-Rock outcrop and Holis-Rock outcrop complexes of varying slopes, comprising 576.1 acres or 30 percent of the watershed soils (excluding water). Each map unit is described in more detail below (USDA NRCS 2018).

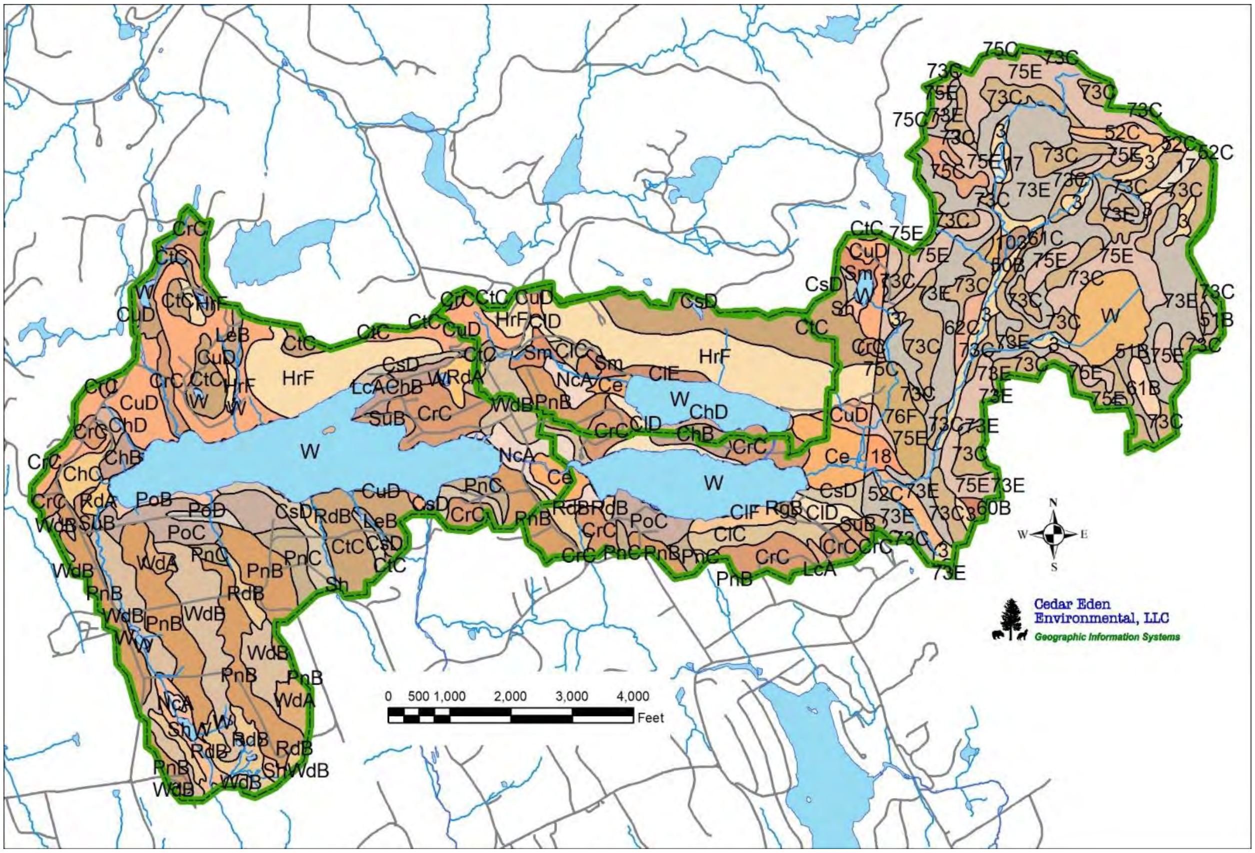

Figure 8 Soil types in the Three Lakes watersheds

Table 5 Summary of soil types in the Three Lakes watersheds

Map Unit	Soil Name	Acreage	Percent
103	Rippowam fine sandy loam	3.8	0.2%
17	Timakwa and Natchaug soils, 0 to 2 percent slopes	7.0	0.3%
18	Catden and Freetown soils, 0 to 2 percent slopes	6.0	0.3%
3	Ridgebury, Leicester, and Whitman soils, 0 to 8 percent slopes, extremely stony	41.5	1.9%
50B	Sutton fine sandy loam, 3 to 8 percent slopes	2.2	0.1%
51B	Sutton fine sandy loam, 0 to 8 percent slopes, very stony	9.2	0.4%
52C	Sutton fine sandy loam, 2 to 15 percent slopes, extremely stony	18.8	0.9%
60B	Canton and Charlton fine sandy loams, 3 to 8 percent slopes	2.6	0.1%
61B	Canton and Charlton fine sandy loams, 0 to 8 percent slopes, very stony	6.3	0.3%
61C	Canton and Charlton fine sandy loams, 8 to 15 percent slopes, very stony	2.6	0.1%
62C	Canton and Charlton fine sandy loams, 3 to 15 percent slopes, extremely stony	6.6	0.3%
73C	Charlton-Chatfield complex, 0 to 15 percent slopes, very rocky	192.9	8.8%
73E	Charlton-Chatfield complex, 15 to 45 percent slopes, very rocky	180.3	8.2%
75C	Hollis-Chatfield-Rock outcrop complex, 3 to 15 percent slopes	12.2	0.6%
75E	Hollis-Chatfield-Rock outcrop complex, 15 to 45 percent slopes	140.9	6.4%
76F	Rock outcrop-Hollis complex, 45 to 60 percent slopes	23.1	1.1%
Ce	Catden muck, 0 to 2 percent slopes	38.2	1.7%
ChB	Charlton fine sandy loam, 3 to 8 percent slopes	26.6	1.2%
ChC	Charlton fine sandy loam, 8 to 15 percent slopes	10.1	0.5%
ChD	Charlton fine sandy loam, 15 to 25 percent slopes	7.0	0.3%
ClC	Charlton fine sandy loam, 8 to 15 percent slopes, very stony	20.0	0.9%
ClD	Charlton loam, 15 to 25 percent slopes, very stony	20.9	1.0%
ClE	Charlton loam, 25 to 35 percent slopes, very stony	5.6	0.3%
ClF	Charlton loam, 35 to 45 percent slopes, very stony	8.5	0.4%
CrC	Charlton-Chatfield complex, 0 to 15 percent slopes, very rocky	126.7	5.8%
CsD	Chatfield-Charlton complex, 15 to 35 percent slopes, very rocky	41.4	1.9%
CtC	Chatfield-Hollis-Rock outcrop complex, 0 to 15 percent slopes	138.9	6.3%
CuD	Chatfield-Hollis-Rock outcrop complex, 15 to 35 percent slopes	141.2	6.4%
HrF	Hollis-Rock outcrop complex, 35 to 60 percent slopes	155.1	7.1%
LcA	Leicester loam, 0 to 3 percent slopes, stony	3.4	0.2%
LeB	Leicester loam, 2 to 8 percent slopes, very stony	8.0	0.4%
NcA	Natchaug muck, 0 to 2 percent slopes	28.3	1.3%
PnB	Paxton fine sandy loam, 3 to 8 percent slopes	169.9	7.7%
PnC	Paxton fine sandy loam, 8 to 15 percent slopes	27.1	1.2%
PoB	Paxton fine sandy loam, 0 to 8 percent slopes, very stony	6.4	0.3%
PoC	Paxton fine sandy loam, 8 to 15 percent slopes, very stony	48.0	2.2%
PoD	Paxton fine sandy loam, 15 to 25 percent slopes, very stony	4.6	0.2%
RdA	Ridgebury complex, 0 to 3 percent slopes	11.3	0.5%
RdB	Ridgebury complex, 3 to 8 percent slopes	42.5	1.9%
RgB	Ridgebury complex, 0 to 8 percent slopes, very stony	1.4	0.1%
Sh	Sun loam	16.7	0.8%
Sm	Sun loam, extremely stony	13.3	0.6%
SuB	Sutton loam, 3 to 8 percent slopes	9.4	0.4%
W	Water	276.4	12.6%
WdA	Woodbridge loam, 0 to 3 percent slopes	13.2	0.6%
WdB	Woodbridge loam, 3 to 8 percent slopes	119.6	5.4%
		2195.6	**100.0%**

Map unit: 73C/CrC - Charlton-Chatfield complex, 0 to 15 percent slopes, very rocky

Component: Charlton, very stony (50%)

The Charlton, very stony component makes up 50 percent of the map unit. Slopes are 3 to 15 percent. This component is on bedrock-controlled hills on glaciated uplands. The parent material consists of coarse-loamy melt- out till derived from granite, gneiss, and/or schist. Depth to a root restrictive layer is greater than 60 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is moderately high. Available water to a depth of 60 inches (or restricted depth) is moderate. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 95 percent. Below this thin organic horizon the organic matter content is about 10 percent. Nonirrigated land capability classification is 6s. This soil does not meet hydric criteria.

Component: Chatfield, very stony (30%)

The Chatfield, very stony component makes up 30 percent of the map unit. Slopes are 3 to 15 percent. This component is on bedrock-controlled ridges on glaciated uplands. The parent material consists of coarse-loamy melt-out till derived from granite, gneiss, and/or schist. Depth to a root restrictive layer, bedrock, lithic, is 20 to 41 inches (depth from the mineral surface is 20 to 35 inches). The natural drainage class is well drained. Water movement in the most restrictive layer is very low. Available water to a depth of 60 inches (or restricted depth) is low. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 95 percent. Below this thin organic horizon the organic matter content is about 10 percent. Nonirrigated land capability classification is 6s. This soil does not meet hydric criteria.

Map unit: 73E - Charlton-Chatfield complex, 15 to 45 percent slopes, very rocky

Component: Charlton (45%)

The Charlton component makes up 45 percent of the map unit. Slopes are 15 to 45 percent. This component is on hills, uplands. The parent material consists of coarse-loamy melt-out till derived from granite and/or schist and/or gneiss. Depth to a root restrictive layer is greater than 60 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is moderately high. Available water to a depth of 60 inches (or restricted depth) is moderate. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter *content in the surface horizon is about 4 percent. Non-irrigated land capability classification is 7s. This soil does not meet hydric criteria.*

Component: Chatfield (30%)

The Chatfield component makes up 30 percent of the map unit. Slopes are 15 to 45 percent. This component is on bedrock controlled hills, bedrock controlled ridges, uplands. The parent material consists of coarse-loamy melt out till derived from granite and/or schist and/or gneiss. Depth to a root restrictive layer, bedrock, lithic, is 20 to 40 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is low. Available water to a depth of 60 inches (or restricted depth) is low. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 75 percent. Below this thin organic horizon the organic matter content is about 4 percent. Nonirrigated land capability classification is 7s. This soil does not meet hydric criteria.

Map unit: 75E - Hollis-Chatfield-Rock outcrop complex, 15 to 45 percent slopes

Component: Hollis (35%)

The Hollis component makes up 35 percent of the map unit. Slopes are 15 to 45 percent. This component is on bedrock controlled hills, bedrock controlled ridges, uplands. The parent material consists of loamy melt-out till derived from granite and/or schist and/or gneiss. Depth to a root restrictive layer, bedrock, lithic, is 10 to 20 inches. The natural drainage class is somewhat excessively drained. Water movement in the most restrictive layer is low. Available water to a depth of 60 inches (or restricted depth) is very low. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 40 percent. Below this thin organic horizon the organic matter content is about 3 percent. Nonirrigated land capability classification is 7s. This soil does not meet hydric criteria.

Component: Chatfield (30%)

The Chatfield component makes up 30 percent of the map unit. Slopes are 15 to 45 percent. This component is on bedrock controlled hills, bedrock controlled ridges, uplands. The parent material consists of coarse-loamy melt out till derived from granite and/or schist and/or gneiss. Depth to a root restrictive layer, bedrock, lithic, is 20 to 40 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is low. Available water to a depth of 60 inches (or restricted depth) is low. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is *about 75 percent. Below this thin organic horizon the organic matter content is about 4 percent. Nonirrigated land capability classification is 7s. This soil does not meet hydric criteria.*

Component: Rock outcrop (15%)

Generated brief soil descriptions are created for major soil components. The Rock outcrop is a miscellaneous area.

Map unit: CuD - Chatfield-Hollis-Rock outcrop complex, 15 to 35 percent slopes

Component: Chatfield, extremely stony (35%)

The Chatfield, extremely stony component makes up 35 percent of the map unit. Slopes are 15 to 35 percent. This component is on bedrock-controlled ridges on glaciated uplands. The parent material consists of coarse- loamy melt-out till derived from granite, gneiss, and/or schist. Depth to a root restrictive layer, bedrock, lithic, is 20 to 41 inches (depth from the mineral surface is 20 to 35 inches). The natural drainage class is well drained. Water movement in the most restrictive layer is very low. Available water to a depth of 60 inches (or restricted depth) is low. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 95 percent. Below this thin organic horizon the organic matter content is about 10 percent. Nonirrigated land capability classification is 7s. This soil does not meet hydric criteria.

Component: Hollis, extremely stony (30%)

The Hollis, extremely stony component makes up 30 percent of the map unit. Slopes are 15 to 35 percent. This component is on bedrock-controlled ridges on glaciated uplands. The parent material consists of coarse-loamy melt-out till derived from granite, gneiss, and/or schist. Depth to a root restrictive layer, bedrock, lithic, is 8 to 23 inches (depth from the mineral surface is 8 to 18 inches). The natural drainage class is somewhat excessively drained. Water movement in the most restrictive layer is very low. Available water to a depth of 60 inches (or restricted depth) is very low. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 95 percent. Below this thin organic horizon the organic matter content is about 10 percent. Nonirrigated land capability classification is 7s. This soil does not meet hydric criteria.

Component: Rock outcrop (20%)

Generated brief soil descriptions are created for major soil components. The Rock outcrop is a miscellaneous area.

Map unit: HrF - Hollis-Rock outcrop complex, 35 to 60 percent slopes

Component: Hollis, very stony (60%)

The Hollis, very stony component makes up 60 percent of the map unit. Slopes are 35 to 60 percent. This component is on bedrock-controlled ridges on glaciated uplands. The parent material consists of coarse-loamy melt-out till derived from granite, gneiss, and/or schist. Depth to a root restrictive layer, bedrock, lithic, is 8 to 23 inches (depth from the mineral surface is 8 to 18 inches). The natural drainage class is somewhat excessively drained. Water movement in the most restrictive layer is very low. Available water to a depth of 60 inches (or restricted depth) is very low. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 95 percent. Below this thin organic horizon the organic matter content is about 10 percent. Nonirrigated land capability classification is 7s. This soil does not meet hydric criteria.

Component: Rock outcrop (20%)

Generated brief soil descriptions are created for major soil components. The Rock outcrop is a miscellaneous area.

Map unit: CtC - Chatfield-Hollis-Rock outcrop complex, 0 to 15 percent slopes

Component: Chatfield, extremely stony (39%)

The Chatfield, extremely stony component makes up 39 percent of the map unit. Slopes are 0 to 15 percent. This component is on bedrock-controlled ridges on uplands. The parent material consists of coarse-loamy melt-out till derived from granite, gneiss, and/or schist. Depth to a root restrictive layer, bedrock, lithic, is 20 to 41 inches (depth from the mineral surface is 20 to 35 inches). The natural drainage class is well drained. Water movement in the most restrictive layer is very low. Available water to a depth of 60 inches (or restricted depth) is low. Shrink swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 95 percent. Below this thin organic horizon the organic matter content is about 10 percent. Nonirrigated land capability classification is 7s. This soil does not meet hydric criteria.

Component: Hollis, extremely stony (26%)

The Hollis, extremely stony component makes up 26 percent of the map unit. Slopes are 0 to 15 percent. This component is on bedrock-controlled ridges on uplands. The parent *material consists of coarse-loamy melt-out till derived from granite, gneiss, and/or schist. Depth to a root restrictive layer, bedrock, lithic, is 8 to 23 inches (depth from the mineral surface is 8 to 18 inches). The natural drainage class is somewhat excessively drained. Water movement in the most restrictive layer is very low. Available water to a depth of 60 inches (or restricted depth) is very low. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 95 percent. Below this thin organic horizon the organic matter content is about 10 percent. Nonirrigated land capability classification is 7s. This soil does not meet hydric criteria.*

Component: Rock outcrop (17%)

Generated brief soil descriptions are created for major soil components. The Rock outcrop is a miscellaneous area.

Hydrologic Soil Group

Hydric soils are defined by the National Technical Committee for Hydric Soils (NTCHS) as soils that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part (Federal Register, 1994). Under natural conditions, these soils are either saturated or inundated long enough during the growing season to support the growth and reproduction of hydrophytic vegetation.

Hydrologic soil groups are based on estimates of runoff potential. Soils are assigned to one of four groups according to the rate of water infiltration when the soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms.

The soils in the United States are assigned to four groups (A, B, C, and D) and three dual classes (A/D, B/D, and C/D). The groups are defined as follows:

Group A. Soils having a high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well drained to excessively drained sands or gravelly sands. These soils have a high rate of water transmission.

Group B. Soils having a moderate infiltration rate when thoroughly wet. These consist chiefly of moderately deep or deep, moderately well drained or well drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission.

Group C. Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.

Group D. Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

If a soil is assigned to a dual hydrologic group (A/D, B/D, or C/D), the first letter is for drained areas and the second is for undrained areas. Only the soils that in their natural condition are in group D are assigned to dual classes.

A summary of soils in the Three Lakes watershed by hydrologic soil group is presented in Table 6. Watershed soils are dominated by hydrologic group B soils (797 acres), followed by hydrologic group D soils (569 acres) and hydrologic group C soils (256 acres).

Table 6 Summary of soils by hydrologic soil group in the Three Lakes watersheds

Hydro Soil Group	Acres	Percentage
A/D	11.4	0.6%
B	797.0	41.5%
B/D	122.8	6.4%
C	256.1	13.3%
C/D	162.8	8.5%
D	569.2	29.7%
	1919.2	**100.0%**

Figure 9 presents the hydric rating of soils by soil map unit in the Three Lakes watersheds. This rating indicates the percentage of map units that meets the criteria for hydric soils. Map units are composed of one or more map unit components or soil types, each of which is rated as hydric soil or not hydric. Map units that are made up dominantly of hydric soils may have small areas of minor nonhydric components in the higher positions on the landform, and map units that are made up dominantly of nonhydric soils may have small areas of minor hydric components in the lower positions on the landform. Each map unit is rated based on its respective components and the percentage of each component within the map unit.

The thematic map is color coded based on the composition of hydric components. The five color classes are separated as 100 percent hydric components, 66 to 99 percent hydric components, 33 to 65 percent hydric components, 1 to 32 percent hydric components, and less than one percent hydric components.

Most of the Three Lakes watersheds consist of soils with less than 32% hydric components. Predominantly hydric soils were present in the lacustrine wetlands associated with the three lakes and riparian wetlands along major tributaries within the watersheds.

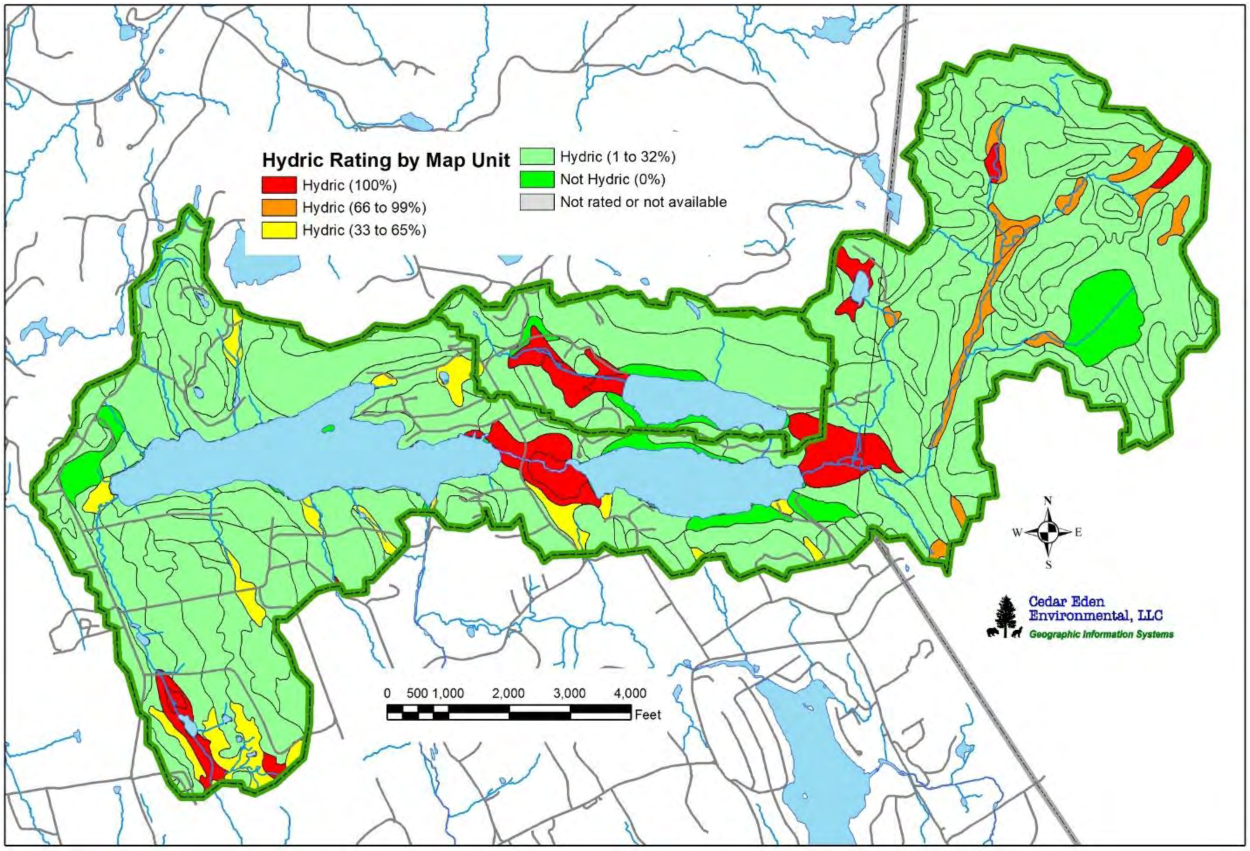

Figure 9 Hydric soil rating by soil map unit in the Three Lakes watersheds

Fragile Soil Index

Soils can be rated based on their susceptibility to degradation in the "Fragile Soil Index" interpretation. Fragile soils are those that are most vulnerable to degradation. In other words, they can be easily degraded and they have a low resistance to degradation processes. They tend to be highly susceptible to erosion and can have a low capacity to recover after degradation has occurred (low resilience). Fragile soils are generally characterized by a low content of organic matter, low aggregate stability, and weak soil structure. They are generally located on sloping ground, have sparse plant cover, and tend to be in arid or semiarid regions. The index can be used for conservation and watershed planning to assist in identifying soils and areas highly vulnerable to degradation.

Depending on inherent soil characteristics and the climate, soils can vary from highly resistant, or stable, to vulnerable and extremely sensitive to degradation. Under stress, fragile soils can degrade to a new altered state, which may be less favorable or unfavorable for plant growth and less capable of performing soil functions. To assess the fragility of the soil, indicators of vulnerability to degradation processes are used. They include organic matter, soil structure, rooting depth, vegetative cover, slope, and aridity.

The organic matter content indicates the capacity of the soil to resist and/or recover from degradation processes. Organic matter improves the soil pore structure, increases water infiltration, and reduces soil compaction and soil erosion. Soil structure indicates the capacity of the soil to resist degradation from accelerated water erosion (by increasing the amount of infiltration). Pore structure is the most important aspect of soil structure as pores provide habitat for organism. Shallow soils are more vulnerable to degradation processes because they have limited rooting depth and have a reduced amount of material from which to form new soil. As erosion removes the upper soil profile, productivity will decline if the subsoil is limiting for crop growth. Vegetative cover is very important as uncovered soil is most vulnerable to the processes of soil erosion, both by wind and water. Slope (a measure of the steepness or the degree of inclination) indicates the degree of vulnerability to erosion and mass movement. Aridity is defined by the shortage of moisture. Lack of water is a main factor limiting biological processes and the ability of the soil to resist and/or recover from degradation.

The Fragile Soil Index for soils within the Three Lakes watersheds is presented in Figure 10. Most of the watershed soils are only slightly to moderately fragile.

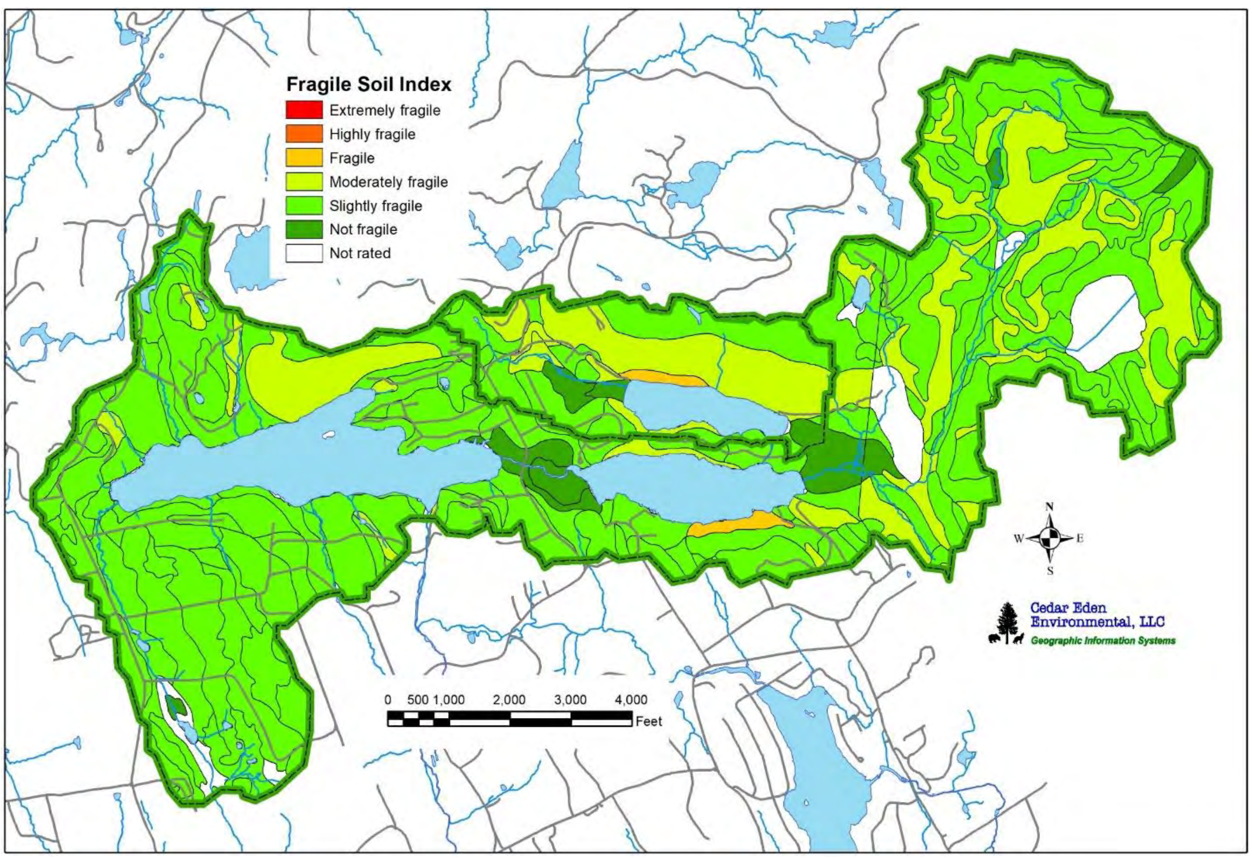

Figure 10 Fragile Soil Index in the Three Lakes watersheds

Soils are placed into interpretive classes based on their index rating, which ranges from 0 to 1. An index rating of 1 is the most fragile, while a rating of zero is the least fragile. Interpretative classes are as follows:

Not Fragile (index rating less than or equal to 0.009) – These soils have a very high potential to resist degradation and be highly resilient. They are highly structured with an organic matter content greater than 5.7%, are nearly level, are deep or very deep, have greater than 85% vegetative cover, and are in a climate that is wet or very wet.

Slightly Fragile (index rating less than 0.009 and less than or equal to 0.209) – These soils have a high potential to resist degradation and be resilient. They are:

- Poorly structured to weakly structured soils that have an extremely low to moderate content of organic matter, are very deep, have high vegetative cover, occur on nearly level ground, and are in wet or very wet climates;
- Highly structured soils that have a very high content of organic matter, are very shallow to moderately deep, have high vegetative cover, occur on nearly level ground, and are in wet or very wet climates;
- Highly structured soils that have a very high content of organic matter, are very deep, have low to moderately high vegetative cover, occur on nearly level ground, and are in wet or very wet climates;
- Highly structured soils that have a very high content of organic matter, are very deep, have high vegetative cover; are on slopes greater than 3%, and are in wet or very wet climates; or
- Highly structured soils that have a very high content of organic matter, are very deep, have high vegetative cover; occur on nearly level ground, and in semi-dry to mildly wet climates;

Moderately Fragile (index rating greater than 0.209 and less than or equal to 0.409) – These soils have a moderate potential to resist degradation and be moderately resilient. They are:

- Highly structured soils that have a very high content of organic matter, are very shallow, have high vegetative cover, occur in nearly level to moderately sloping areas, and are in semi-dry climates;
- Poorly structured soils that have an extremely low content of organic matter, are deep, have low vegetative cover, occur in nearly level areas, and are in wet or very wet climates;
- Poorly structured soils that have an extremely low content of organic matter, occur on gentle to very steep slopes, have high vegetative cover, and are in wet or very wet climates;
- Weakly structured soils that have a very low content of organic matter, are deep, occur in nearly level to gently sloping areas, have high vegetative cover, and are in semi-dry climates; or

- Weakly structured soils that have a very low content of organic matter, are very shallow to very deep, occur in nearly level to strongly sloping areas, have high vegetative cover, and are in mildly wet climates.

Fragile (index rating greater than 0.409 and less than or equal to 0.609). These soils have a low potential to resist degradation and low resilience. They are:

- Well structured soils that have a low content of organic matter, are shallow to very deep, have moderate to moderately high vegetative cover, occur on steep slopes, and are in dry climates;
- Well structured soils that have a low content of organic matter, are shallow to very deep, have a low vegetative cover, occur in nearly level to gently sloping areas, and are in dry climates;
- Well structured soils that have a low content of organic matter, are deep, have low vegetative cover, occur on nearly level to very steep slopes, and are in a semi-dry climate;
- Moderately structured soils that have a very low content of organic matter, are deep, have moderately high vegetative cover, occur on moderately steep to very steep slopes, and are in semi-dry climates; or
- Weakly structured soils that have a low content of organic matter, occur on moderately steep to very steep slopes, have low vegetative cover, and are in wet or very wet climates.

Very Fragile (index rating greater than 0.609 and less than or equal to 0.809) ΓÇô These soils have a very low potential to resist degradation and very low resilience. They are:

- Weakly structured soils that have an extremely low content of organic matter, are deep, have low vegetative cover, occur on nearly level to very steep slopes, and are in dry climates;
- Weakly structured soils that have an extremely low content of organic matter, are shallow to very deep, have low vegetative cover, occur on nearly level to very steep slopes, and are in very dry climates; or
- Poorly structured soils that have an extremely low content of organic matter, are very shallow, have no vegetative cover, occur on steep slopes, and are in mildly wet to wet climates.

Extremely Fragile (index rating greater than 0.809 and less than or equal to 1.0) ΓÇô These soils can have no potential to resist degradation and no resilience. They are:

- Poorly structured soils that have an extremely low content of organic matter, are very shallow, have low vegetative cover, occur on very steep slopes, and are in dry or very dry climates;
- Weakly structured soils that have a very low content of organic matter, are nearly level to very deep, have low vegetative cover, occur on very steep slopes, and are in dry climates; or

- Very shallow soils on steep slopes.

The interpretive rating is based on soils that occur in the dominant land use for the map unit component and may not represent soils that occur in site-specific land uses.

Surface Water Management

The ratings for Surface Water Management, System are based on the soil properties that affect the capacity of the soil to convey surface water across the landscape. Factors affecting the system installation and performance are considered. Water conveyances include graded ditches, grassed waterways, terraces, and diversions. The ratings are for soils in their natural condition and do not consider present land use. The properties that affect the surface system performance include depth to bedrock, saturated hydraulic conductivity, depth to cemented pan, slope, flooding, ponding, large stone content, sodicity, surface water erosion, and gypsum content.

The ratings are both verbal and numerical. Rating class terms indicate the extent to which the soils are limited by all of the soil features that affect the specified use. "Not limited" indicates that the soil has features that are very favorable for the specified use. Good performance and very low maintenance can be expected. "Somewhat limited" indicates that the soil has features that are moderately favorable for the specified use. The limitations can be overcome or minimized by special planning, design, or installation. Fair performance and moderate maintenance can be expected. "Very limited" indicates that the soil has one or more features that are unfavorable for the specified use. The limitations generally cannot be overcome without major soil reclamation, special design, or expensive installation procedures.

A map of the suitability of soils in the Three Lakes watersheds for surface water management systems is presented in Figure 11. Nearly all of the soils are very limited. This indicates the soils in the watershed are not well-suited for surface water conveyance structures such as ditches and waterways.

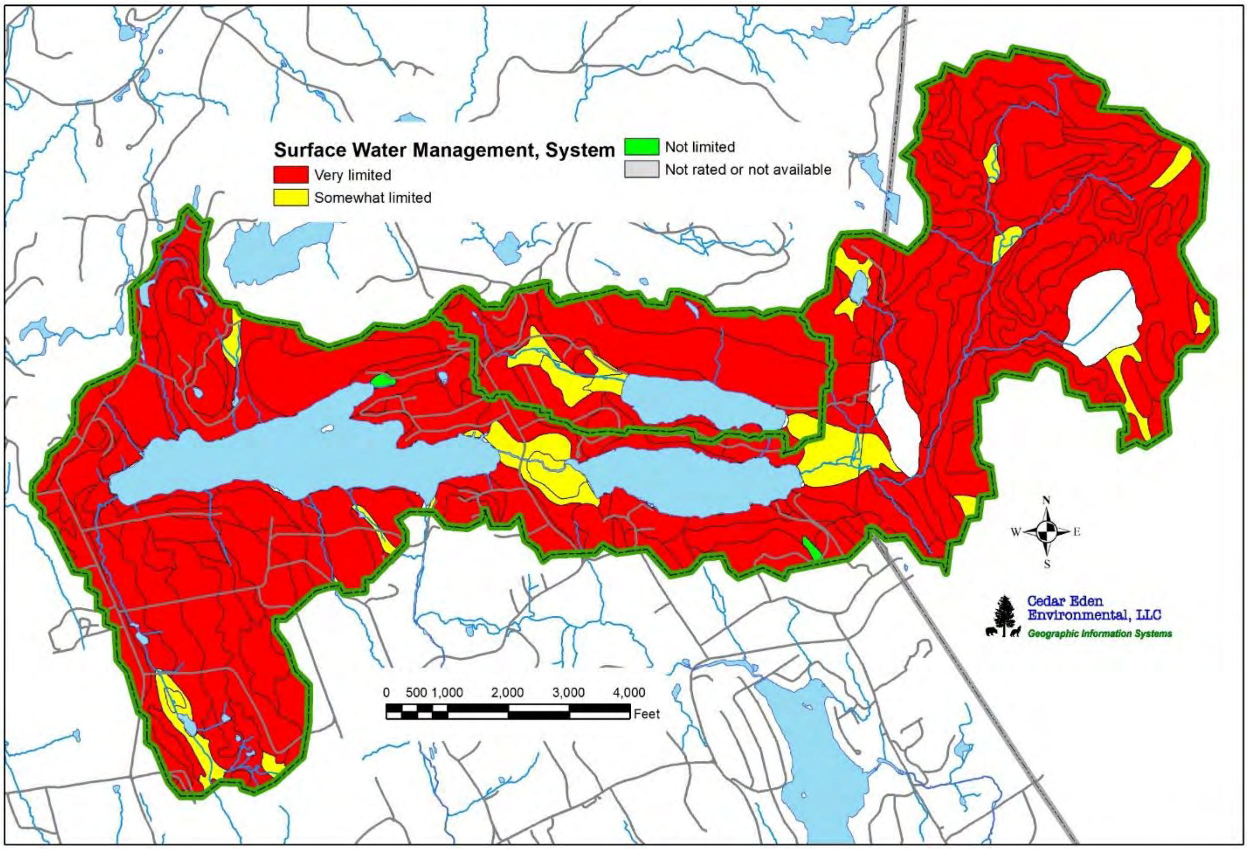

Figure 11 Suitability of soils for surface water management systems in the Three Lakes watersheds

Subsurface Water Management Performance

The ratings for Subsurface Water Management, System Performance are based on the soil properties that affect the capacity of the soil to be drained. The properties that affect the subsurface system performance include depth to a water table, salinity, flooding, sodicity, sand content, soil reaction, hydraulic conductivity, soil density, gypsum content, and subsidence.

The ratings are both verbal and numerical. Rating class terms indicate the extent to which the soils are limited by all of the soil features that affect the specified use. "Not limited" indicates that the soil has features that are very favorable for the specified use. Good performance and very low maintenance can be expected. "Somewhat limited" indicates that the soil has features that are moderately favorable for the specified use. The limitations can be overcome or minimized by special planning, design, or installation. Fair performance and moderate maintenance can be expected. "Very limited" indicates that the soil has one or more features that are unfavorable for the specified use. The limitations generally cannot be overcome without major soil reclamation, special design, or expensive installation procedures. Poor performance can be expected.

A map of the suitability of soils in the Three Lakes watersheds for subsurface water management system performance is presented in Figure 12. Nearly all the soils are very limited. This indicates the soils in the watershed may not be well-suited for subsurface water management systems such as infiltration structures.

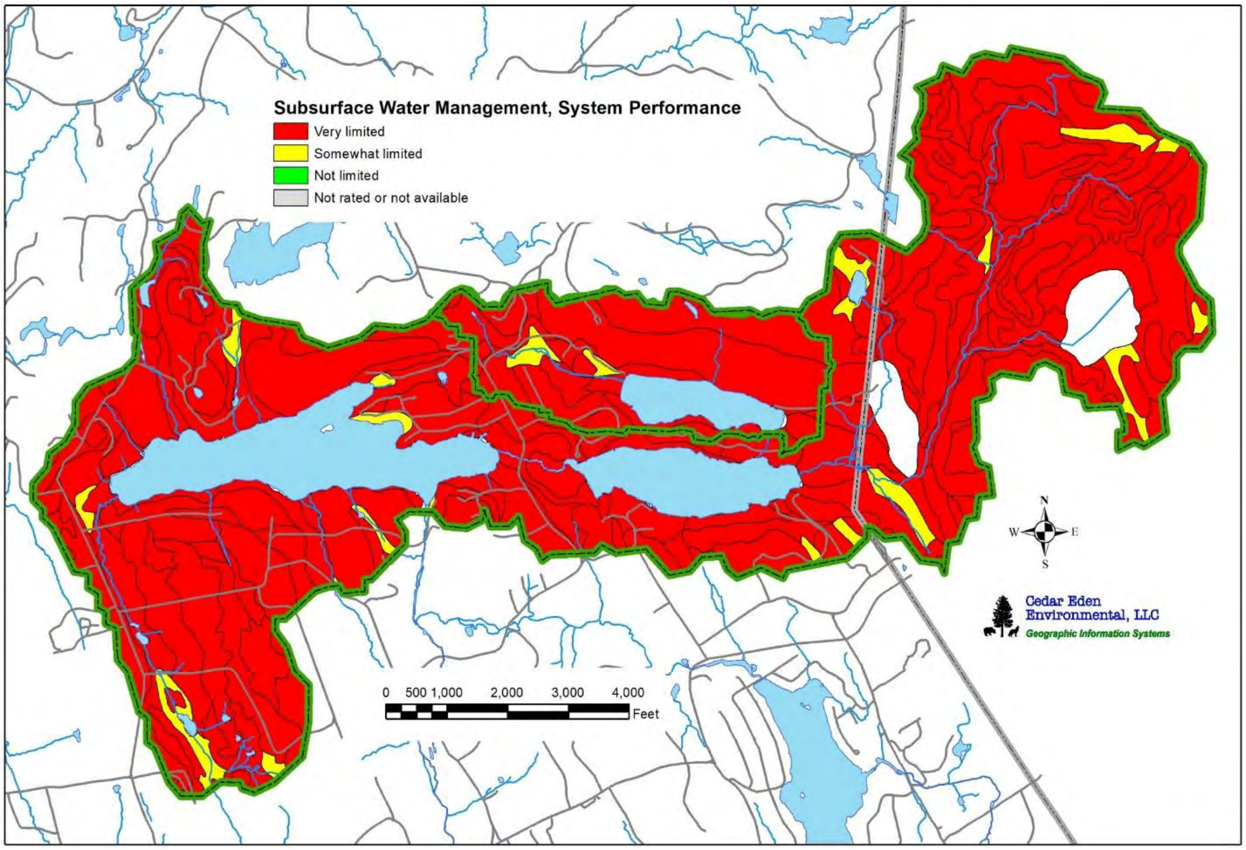

Figure 12 Soil performance ratings of Subsurface Water Management systems in the Three Lakes watersheds

Stormwater Management via Infiltration (NY)

Proper management of stormwater runoff from construction sites and developed areas is an issue of growing importance in New York State. During construction, exposed soil is subject to a greater risk of erosion, resulting in a greater potential for sedimentation in waterways. Stormwater runoff increases on the rooftops of buildings, paved parking lots, and other impervious surfaces, and thus increases the potential for flooding and discharge of polluted runoff into open water. Management of stormwater runoff can prevent or reduce the availability, release, or transport of substances that can degrade surface and ground waters. Guidelines and design criteria for stormwater management practices have been established by the New York State Department of Environmental Conservation (2008).

This interpretation is designed to evaluate the limitations of soils for stormwater management practices. The purpose of the interpretation is to help decision makers use soil survey information in the selection and implementation of the stormwater management practices best suited to a particular location. The information in the interpretations is intended for planning purposes and does not eliminate the need for on-site investigation of the soil.

Rating class terms indicate the extent to which the soils are limited by the soil features that influence the design, construction, and performance of stormwater management practices. "Least limited" indicates that the soil has features that are very favorable for this practice. Good performance and low maintenance can be expected. "Somewhat limited" indicates that the soil has features that are moderately favorable for the practice. The limitations can be overcome or minimized by special planning, design, or construction. Fair performance and moderate maintenance can be expected. "Most limited" indicates that the soil has one or more features that are unfavorable for the practice. The limitations generally cannot be overcome without major soil reclamation, special design, or expensive construction procedures. Poor performance and high maintenance can be expected.

Limitation of watershed soils for soil infiltration stormwater management for the New York portion of the Three Lakes watersheds is presented in Figure 13. Nearly all the soils are most limited. This indicates the soils in the watershed may not be well-suited for stormwater management structures. Such structures constructed in the watershed would require extra planning and design to overcome these limitations.

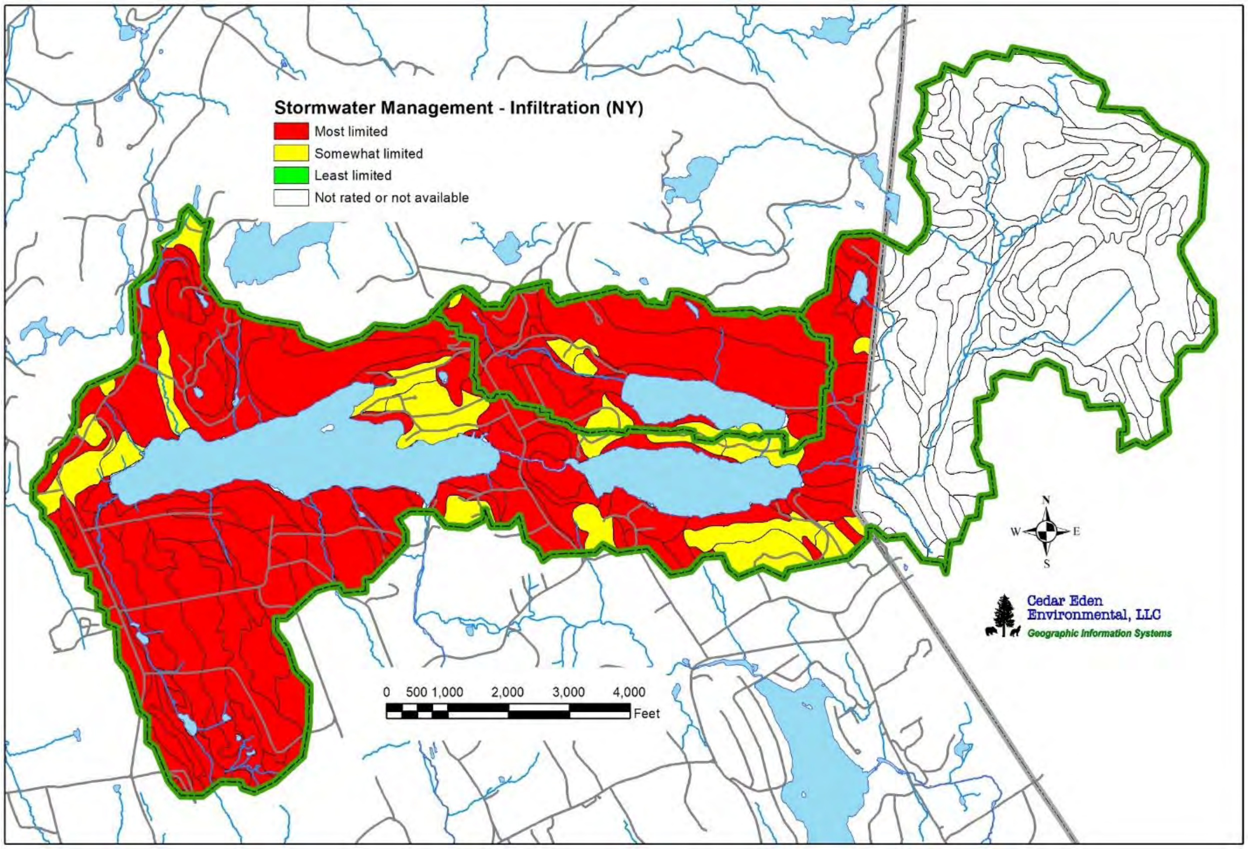

Figure 13 Limitations of soils for infiltration stormwater management in the Three Lakes watersheds (NY)

Subsurface Wastewater Disposal

Soil limitation for subsurface water disposal in the Three Lakes watersheds is presented in Figure 14. These are ranked for Septic Tank Absorption Fields in the NY portion of the watershed and Subsurface Sewage Disposal Systems in the CT portion of the watershed. Steep areas and wetland areas in the watershed are indicated by soils which are very limited for subsurface wastewater disposal. The rest of the soils tend to be somewhat limited (NY) or have low potential (CT). The rating systems are described in the sections below.

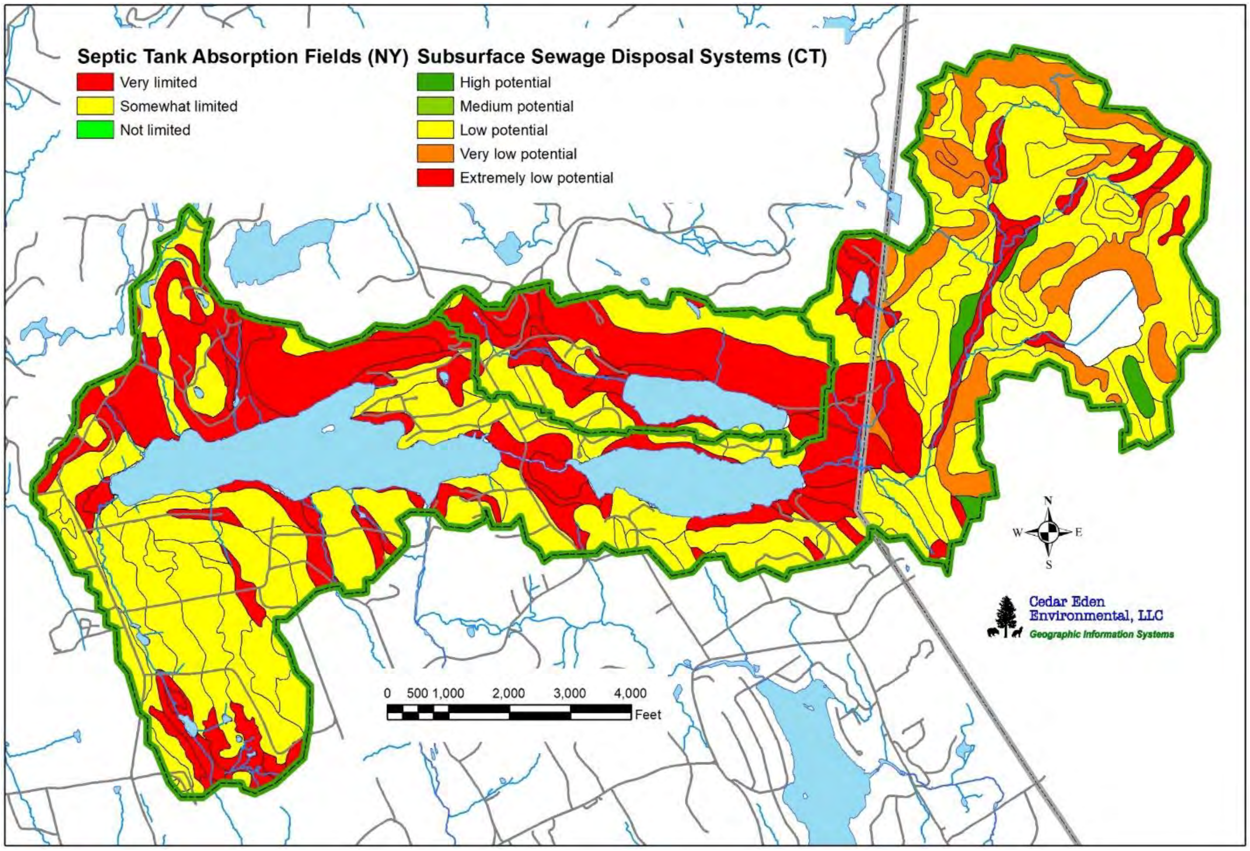

Figure 14 Soil limitations for subsurface wastewater disposal in the Three Lakes watersheds

Septic Tank Absorption Fields (NY)

Septic tank absorption fields are subsurface systems of perforated pipe or similar devices that distribute effluent from a septic tank into the soil. New York State Department of Health regulations allow installation of septic system absorption fields of varying designs, depending upon the depth of suitable soil material above any limitation in the natural soil at a site (New York State Department of Health, 1990). Where necessary, imported fill material may be used to elevate absorption trenches to at least the minimum distance of 24 inches above limiting soil horizons. The depth ranges of suitable material and corresponding types of absorption systems allowed are as follows:

- Less than 12 inches-no system allowed
- 12 to 24 inches-alternative raised trench
- 24 to 48 inches-conventional shallow trench
- More than 48 inches-conventional system

The ratings in this interpretation are based on evaluation of the soil between depths of 12 and 48 inches. In addition, the bottom layer of the soil is evaluated for risk of seepage. This interpretation does not evaluate bedrock below the soil. The soil properties and site features considered are those that affect absorption of the effluent, construction and maintenance of the system, and public health.

The soil properties and qualities that affect the absorption and effective treatment of wastewater effluent are saturated hydraulic conductivity (Ksat), depth to a seasonal high water table, depth to bedrock, depth to dense material, and susceptibility to flooding. Stones and boulders and a shallow depth to bedrock or dense material interfere with installation. Excessive slope may cause lateral seepage and surfacing of the effluent in downslope areas. In addition, the hazards of erosion and sedimentation increase as slope increases.

Some soils are underlain by loose sand and gravel or fractured bedrock at a depth of less than 2 feet below the distribution lines. In these soils the absorption field may not adequately filter the effluent, particularly when the system is new. As a result, ground water may be contaminated.

The ratings are both verbal and numerical. Rating class terms indicate the extent to which the soils are limited by all of the soil features that affect the specified use. "Not limited" indicates that the soil has features that are very favorable for the specified use. Good performance and very low maintenance can be expected. "Somewhat limited" indicates that the soil has features that are moderately favorable for the specified use. The limitations can be overcome or minimized by special planning, design, or installation. Fair performance and moderate maintenance can be expected. "Very limited" indicates that the soil has one or more features that are unfavorable for the specified use. The limitations generally cannot be overcome without major soil reclamation, special design, or expensive installation procedures. Poor performance and high maintenance can be expected.

Subsurface Sewage Disposal Systems (CT)

Subsurface sewage disposal systems (SSDS) consist of a house sewer, a septic tank followed by a leaching system, any necessary pumps and siphons, and a groundwater control system upon which the operation of the leaching system depends. This interpretation focuses mainly on the septic tank leaching field and groundwater control system.

Soil Potential Ratings

Soil potential ratings indicate the relative quality of a soil for a particular use compared to other soils in a given area, in this case the State of Connecticut. The rating criteria were developed by a committee of State and local sanitarians, engineers, and installers. The soils data was provided by the USDA Natural Resources Conservation Service (NRCS), and the performance and site conditions for a typical system were defined. This information provided a standard against which various combinations of properties of soils within Connecticut could be compared.

The engineering and installation practices used to overcome various soil limitations were listed, and their costs estimated. This information was used to identify limitations and costs associated with installing an SSDS on each soil in Connecticut. Soils with no or minor limitations for the installation of an SSDS were rated the highest. Conversely, soils requiring extensive site modification and design were rated the lowest. The ease of system installation, and therefore cost, formed the basis of the rating scheme.

Rating Classes

The rating class definitions refer to installation of an SSDS that meets State and local health code regulations. Soils with high potential have characteristics that meet the performance standard. A typical system can be installed at a cost of "x", which represents the going rate for installing an SSDS. The actual value of x varies depending upon many factors unrelated to soil properties.

The cost of installing a leaching field is expressed as a multiple of x and called the cost factor. For example, a cost factor of 3x to and 3.5x means that the estimated cost of installing a leaching field in the particular soil ranges from 3 to 3.5 times more than that of installing a field in a soil with high potential. The cost factors provide relative estimates of the costs of installing an SSDS.

The soil potential ratings and associated cost factors, assuming a typical system, are defined below.

- High Potential – These soils have the best combination of characteristics or have limitations that can be easily overcome using standard installation practices. The cost factor is 1x to 2.0x.
- Medium Potential – These soils have significant limitations, such as low percolation rate, that generally can be overcome using commonly applied designs. The cost factor ranges from 2.0x to 2.5x.
- Low Potential – These soils have one or more limitations, such as low percolation rate and depth to seasonal high water table, that require extensive design and site preparation to overcome. The cost factor ranges from 2.5x to 3.5x.
- Very Low Potential – These soils have major soil limitations, such as depth to bedrock, that require extensive design and site preparation to overcome. A permit for an SSDS may not be issued unless the naturally occurring soils meet the minimal requirements outlined in the State health code. It is unlikely that these soils can be improved sufficiently to meet State health code regulations. The cost factor ranges from 4.25x to 6.0x.
- Extremely Low Potential – These soils have multiple major limitations, such as flooding and depth to seasonal high water table, which are extremely difficult to overcome. A permit for an SSDS may not be issued unless the naturally occurring soils meet the minimal requirements outlined in the State health code. It is unlikely that these soils can be improved sufficiently to meet State health code regulations.
- Not Rated – Areas labeled Not Rated have soil characteristics that show extreme variability from one location to another. The work needed to overcome adverse soil

properties cannot be estimated. These areas commonly are urban land complexes or miscellaneous areas. An on-site investigation is required to determine soil conditions at the site.

Dirt Road Management

A number of roads within the Three Lakes watersheds have dirt and gravel surfaces. This section describes soil ratings relevant to dirt road management.

Suitability for Roads (Natural Surface)

The ratings in this interpretation indicate the suitability for using the natural surface of the soil for roads. The ratings are based on slope, rock fragments on the surface, plasticity index, content of sand, the Unified classification of the soil, depth to a water table, ponding, flooding, and the hazard of soil slippage.

The ratings are both verbal and numerical. The soils are described as "well suited," "moderately suited," or "poorly suited" to this use. "Well suited" indicates that the soil has features that are favorable for the specified kind of roads and has no limitations. Good performance can be expected, and little or no maintenance is needed. "Moderately suited" indicates that the soil has features that are moderately favorable for the specified kind of roads. One or more soil properties are less than desirable, and fair performance can be expected. Some maintenance is needed. "Poorly suited" indicates that the soil has one or more properties that are unfavorable for the specified kind of roads. Overcoming the unfavorable properties requires special design, extra maintenance, and costly alteration.

Soil suitability for natural surface roads in the Three Lakes watersheds is presented in Figure 15. The main dirt roads – Tarry-A-Bit, East Ridge and Old Pond – are in areas with soils that are primarily moderately suited for natural surface roads. The soils at the upper (eastern) end of Tarry-A-Bit Road are poorly suited for natural surface roads, as is the eastern and western portions of Old Pond Road.

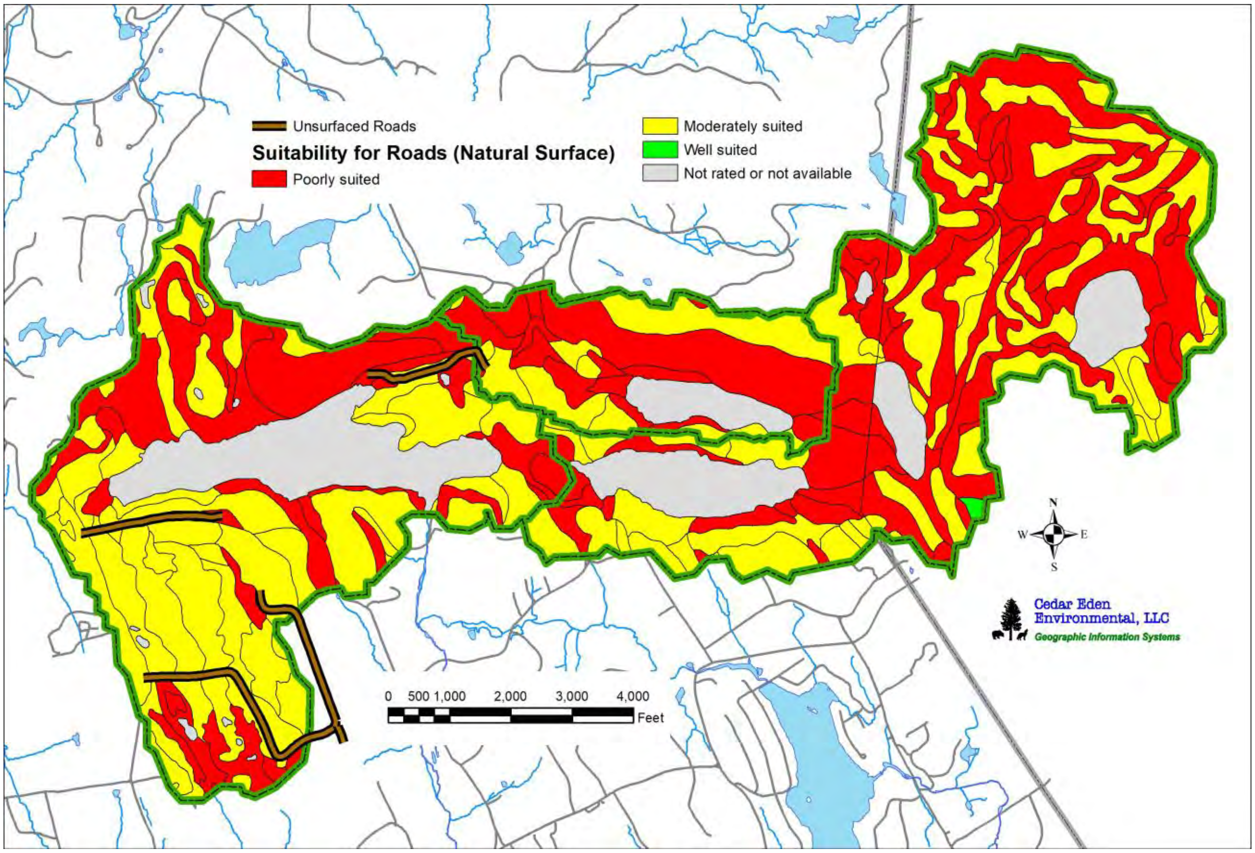

Figure 15 Suitability of soils for natural surface roads in the Three Lakes watersheds

Erosion Hazard for Unsurfaced Roads and Trails

The ratings in this interpretation indicate the hazard of soil loss from unsurfaced roads and trails. The ratings are based on soil erosion factor K, slope, and content of rock fragments.

The ratings are both verbal and numerical. The hazard is described as "slight," "moderate," or "severe." A rating of "slight" indicates that little or no erosion is likely; "moderate" indicates that some erosion is likely, that the roads or trails may require occasional maintenance, and that simple erosion-control measures are needed; and "severe" indicates that significant erosion is expected, that the roads or trails require frequent maintenance, and that costly erosion-control measures are needed.

The erosion hazard for unsurfaced roads in the Three Lakes watersheds is presented in Figure 16. Tarry-A-Bit Road is located in soils that have a severe erosion hazard rating. East Ridge Road is located in soils that have a moderate erosion hazard rating. Old Pond Road is primarily located in soils that have a moderate erosion hazard, although the beginning and end of the roadway are in soils with a severe erosion hazard rating.

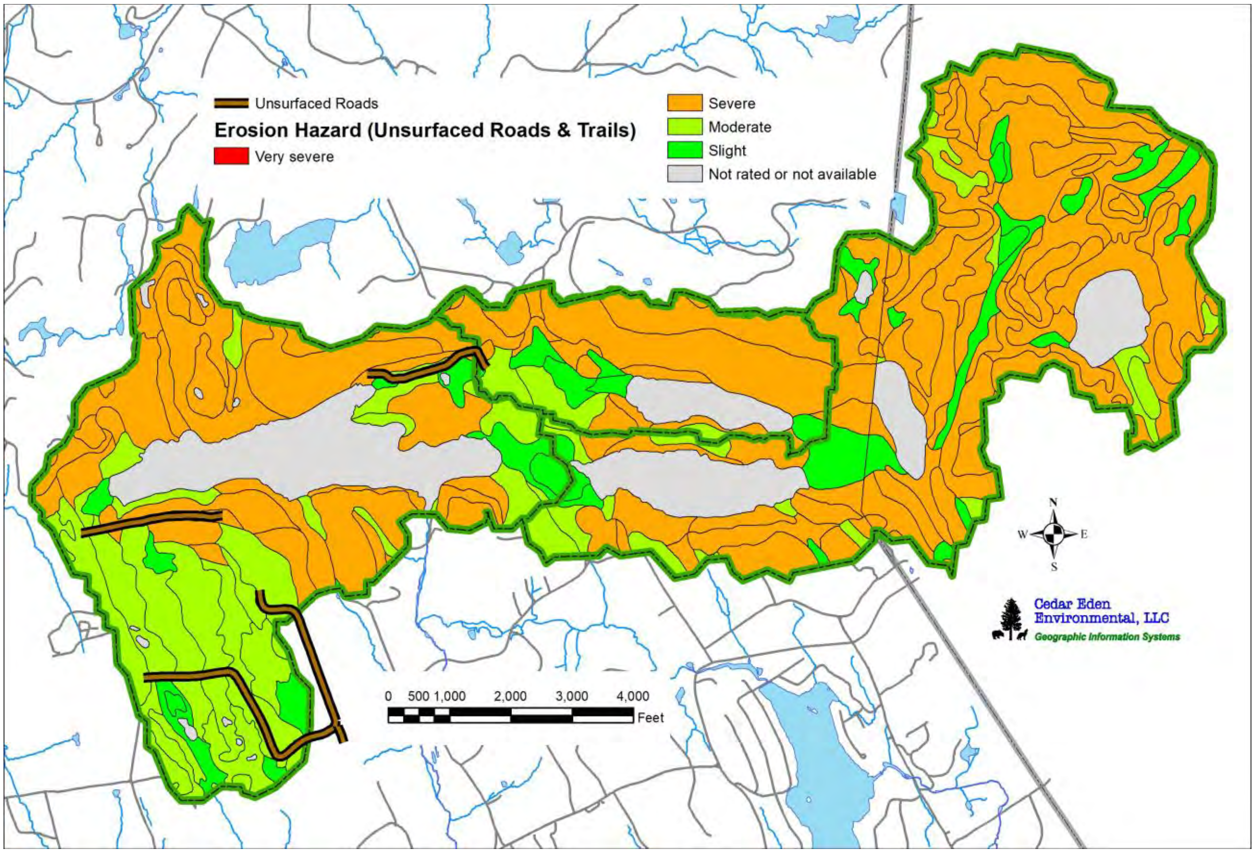

Figure 16 Soil erosion hazard for unsurfaced roads and trails in the Three Lakes watersheds

Unpaved Local Roads

Unpaved local roads and streets are those roads and streets that carry traffic year round but have a graded surface of local soil material or aggregate.

The roads and streets consist of:

1. the underlying local soil material, either cut or fill, which is called "the sub-grade";
2. the surface, which may be the same as the subgrade or may have aggerate such as crushed limestone added.

Unpaved local roads are graded to shed water, and conventional drainage measures are provided. These roads and streets are built mainly from the soil at the site. Soil interpretations for local roads and streets are used as a tool in evaluating soil suitability and identifying soil limitations for the practice. The rating is for soils in their present condition and does not consider present land use. Soil properties and qualities that affect local roads and streets are those that influence the ease of excavation and grading and the traffic-supporting capacity. The properties and qualities that affect the ease of excavation and grading are hardness of bedrock or a cemented pan, depth to bedrock or a cemented pan, depth to a water table, flooding, the amount of large stones, and slope. The properties that affect traffic-supporting capacity are soil strength as inferred from the AASHTO group index and the Unified classification, subsidence, shrink-swell behavior, potential frost action, and depth to the seasonal high water table. The dust generating tendency of the soil is also considered.

Soil suitability for unpaved local roads in the Three Lakes watersheds is presented in Figure 17. The main dirt roads – Tarry-A-Bit, East Ridge and Old Pond – are in areas with soils that are primarily moderately suited for natural surface roads. The soils at the upper (eastern) end of Tarry-A-Bit Road are poorly suited for natural surface roads, as is the eastern and western portions of Old Pond Road.

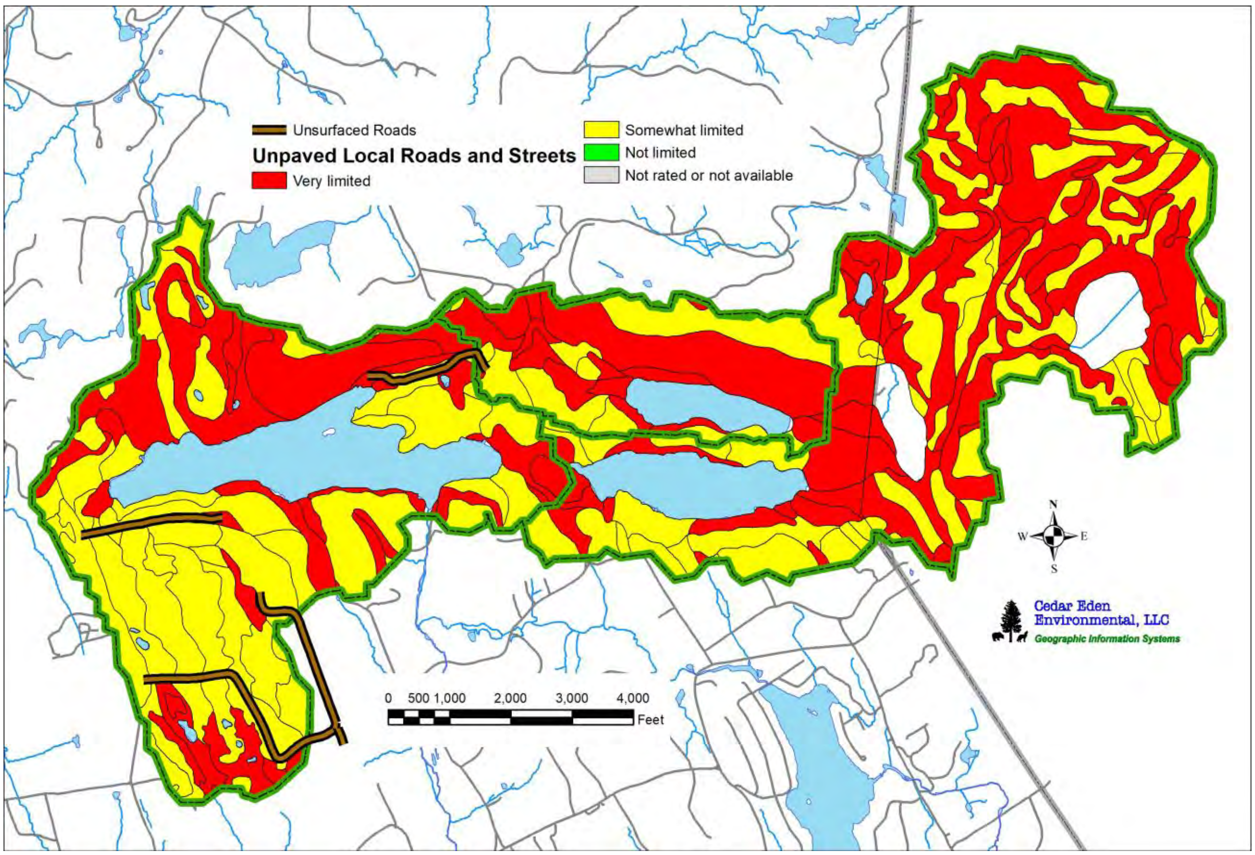

Figure 17 Limitations of soils for unpaved roadways in the Three Lakes watersheds

Discussion

Soils within the Three Lakes' watersheds are not well suited for septic systems or the infiltration of stormwater. This means that these types of systems need to be appropriately designed so that they are sized properly for treating wastewater and stormwater. The soils are also not well suited for dirt and gravel and unpaved road surfaces, exacerbating the erosion and runoff from existing dirt and gravel roads and in ditches along paved road surfaces.

Climate

Mean annual runoff, mean annual rainfall and peak flow statistics for each watershed were determined using StreamStats.

The watershed for Lake Rippowam has a mean annual runoff of 26.3 inches with a mean annual precipitation of 48.4 inches and a summer average mean precipitation of 13.3 inches. The watershed for Lake Oscaleta, which includes the watershed of Lake Rippowam, has a mean annual runoff of 26.4 inches with a mean annual precipitation of 48.5 inches and a summer average mean precipitation of 13.3 inches. The watershed for Lake Waccabuc has a mean annual runoff of 26.3 inches with a mean annual precipitation of 48.4 inches and a summer average mean precipitation of 13.3 inches. Watershed Peak Flow Statistics (Lumia et al 2006) are shown in Table 7.

Table 7 Peak flow statistics for the Three Lakes watersheds

Statistic (CFS)*	Rippowam	Oscaleta	Waccabuc
1.25 Year Peak Flood	4.76 cfs	23.4 cfs	37.3 cfs
1.5 Year Peak Flood	5.98 cfs	29.1 cfs	46.3 cfs
2 Year Peak Flood	7.83 cfs	37.8 cfs	59.7 cfs
5 Year Peak Flood	14 cfs	66.3 cfs	103 cfs
10 Year Peak Flood	19.5 cfs	92 cfs	143 cfs
25 Year Peak Flood	28.4 cfs	133 cfs	204 cfs
50 Year Peak Flood	36.7 cfs	170 cfs	261 cfs
100 Year Peak Flood	46.5 cfs	215 cfs	329 cfs
200 Year Peak Flood	58.3 cfs	268 cfs	408 cfs
500 Year Peak Flood	77.7 cfs	354 cfs	538 cfs

**cubic feet per second (ft^3/s)*

There are several long-term climate data stations in the vicinity of the Three Lakes watershed. The South Salem station, located within the watershed itself, and the Yorktown Heights station collect daily precipitation data only. Full daily temperature and precipitation collection takes place at Danbury and Ridgefield CT stations. Figure 18 presents a comparison of precipitation data between South Salem and the Danbury and Yorktown Heights stations. The best correlation for local precipitation measured at South Salem was from Yorktown Heights with an r^2 of 0.8338.

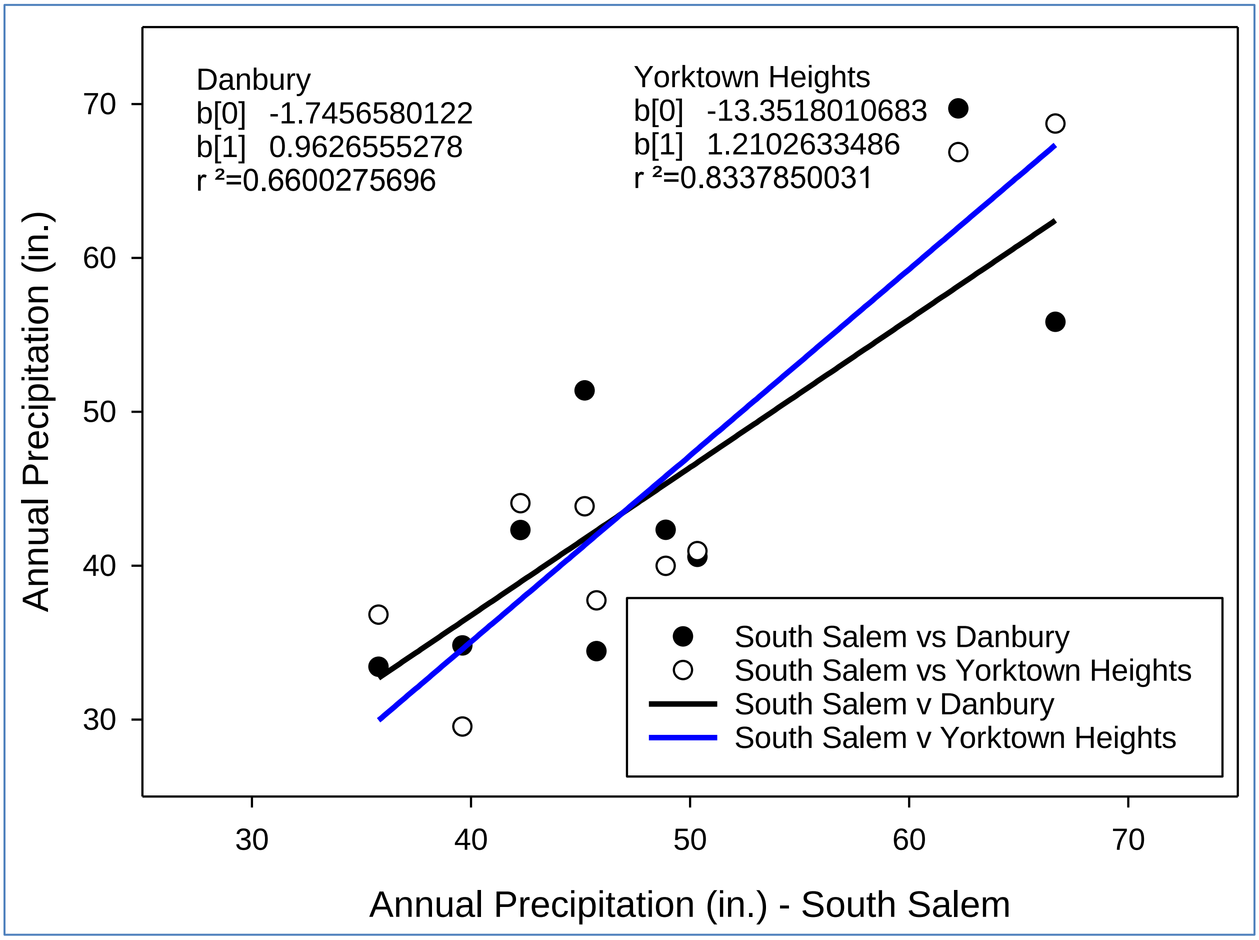

Figure 18 Comparison of precipitation data between South Salem, Danbury and Yorktown Heights weather stations

Weather conditions (daily minimum temperature, daily maximum temperature, precipitation) for the period of 1998 through 2018 and for 2018 using data from the Danbury CT station are presented in Figure 19 and Figure 20, respectively. Annual weather conditions are summarized in Table 8.

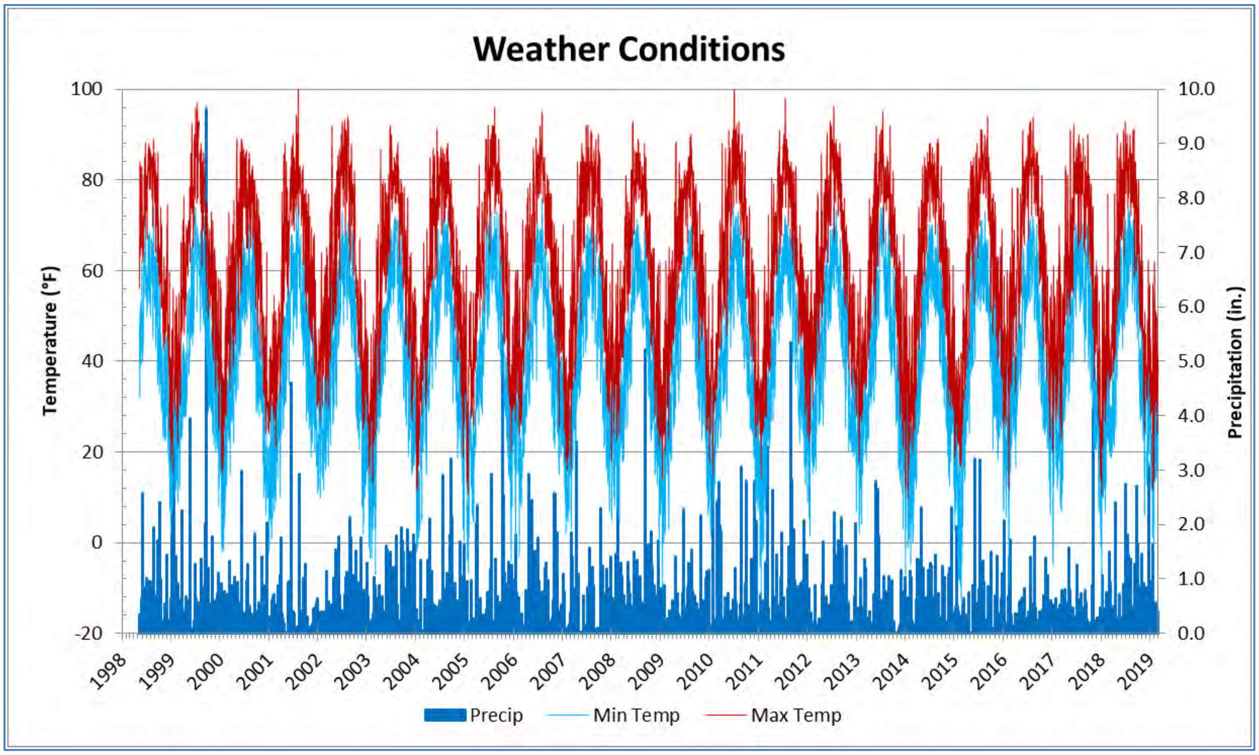

Figure 19 Weather conditions (daily minimum and maximum temperatures, daily precipitation) for 1998-2018 (Danbury, CT)

Table 8 Summary of Annual Climate Conditions (Danbury, CT)			
Year	**Annual Precip (in)**	**Mean Max Temp (°F)**	**Mean Min Temp (°F)**
1999	60.9	60.7	39.8
2000	40.7	58.5	38.3
2001	41.1	60.1	38.8
2002	47.3	60.7	40.2
2003	57.7	58.0	39.4
2004	44.8	59.8	40.7
2005	54.4	59.9	38.9
2006	54.3	61.3	40.7
2007	40.4	59.8	39.1
2008	57.2	59.8	39.2
2009	45.8	58.5	39.0
2010	51.4	61.2	40.8
2011	69.7	61.0	41.0
2012	42.3	62.3	42.7
2013	40.6	59.7	39.9
2014	42.3	58.5	38.5

2015	34.4	60.8	39.1
2016	34.8	62.2	40.4
2017	33.4	60.9	41.2
2018	55.8	60.0	41.7

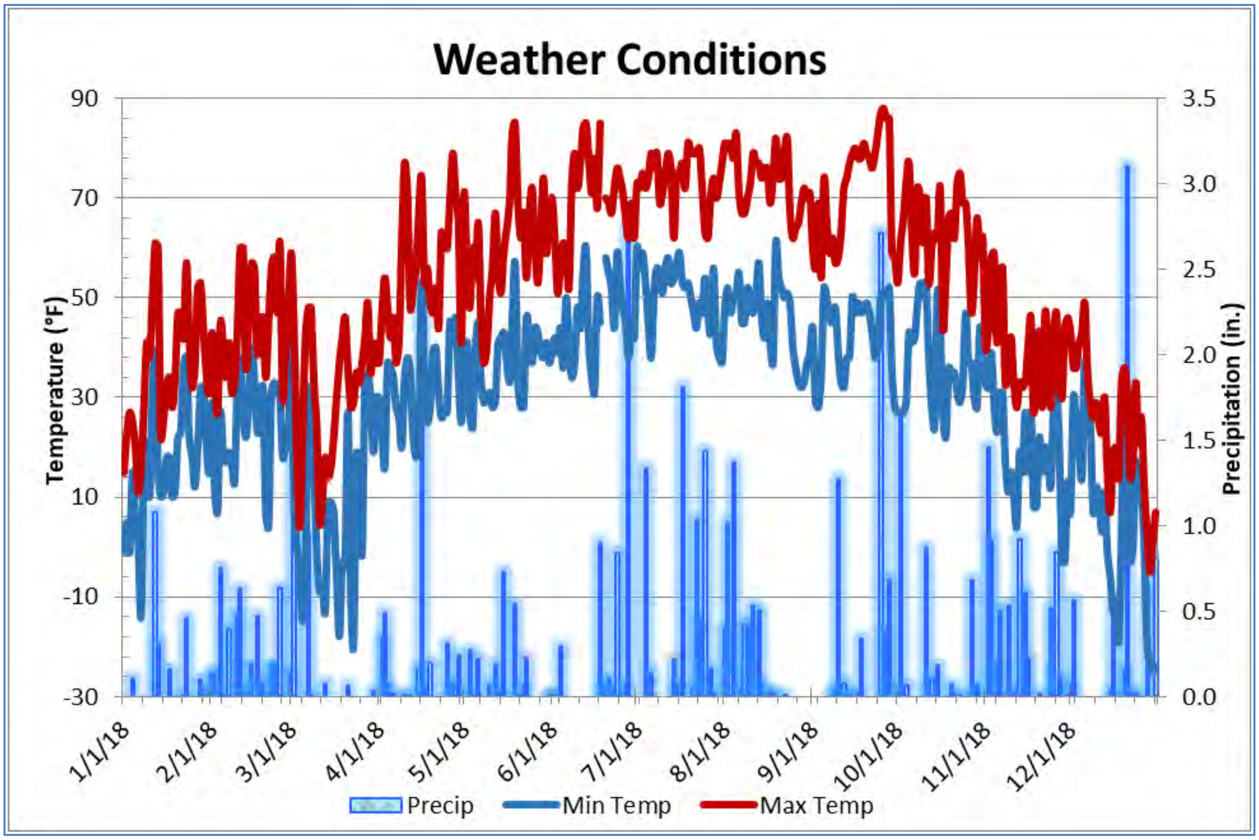

Figure 20 Weather conditions (daily minimum and maximum temperatures, daily precipitation) for 2018 (Danbury, CT)

Discussion

Climatic conditions within the Three Lake's watersheds have remained relatively stable over the past twenty years or so. The average maximum and minimum daily temperature show little variation over the period of study. Annual precipitation was low from 2012 through 2017. Although not shown in the figures or tables, the maximum annual daily maximum temperature has also been relatively stable over the period of record, while the minimum annual daily minimum temperature has decreased somewhat over the period of record.

Water Quality

The following sections present water quality results for the primary trophic state parameters (water quality parameters that define lake productivity) using Three Lakes Council data from 2018. Growing season in the following figures and discussions refers to May through September while summer season refers to June through August.

Dissolved Oxygen and Temperature

Vertical mixing within the water column of a lake is a function of the water's temperature dependent density gradient. Cold water is denser than warm water. In the spring and fall lakes generally become isothermal (entirely the same temperature) and lake water circulates freely from top to bottom. As the surface water heats up in late spring/early summer, this water becomes less dense. When a lake is deep enough, and/or sheltered from the wind, the water at the bottom of the lake remains cold throughout the summer and does not mix with the warm, low density surface water. The lake is then essentially divided into three different compartments. The cold bottom waters make up the hypolimnion, and the warm surface water is called the epilimnion. The transition zone where temperatures change rapidly with depth is termed the metalimnion. The thermocline lies within the metalimnion and is the horizontal plane where the maximum change in temperature with depth occurs.

The amount of oxygen dissolved in a lake plays an important part in its ecosystem. EPA guidelines for dissolved oxygen concentrations for adult life stages of fish are 5.0 mg/L for warm water species and 6.5 mg/L for cold water species (US EPA 1986). EPA also established minimum dissolved oxygen concentrations at different levels of fish impairment. The levels of production impairment for adult salmonids (cold water fish such as trout and salmon) are: none at 8 mg/L, slight at 6 mg/L, moderate at 5 mg/L, severe at 4 mg/L, and acute mortality at 3 mg/L.

Lakes receive most of their oxygen from the atmosphere through gas exchange at the water's surface. In deeper lakes that stratify, the colder bottom water (hypolimnion) is isolated from the oxygen entering the upper water (epilimnion). If the lake sediments are rich in organic matter, bacterial decomposition uses up the oxygen in the bottom waters and the hypolimnion becomes hypoxic (less than 2.0 mg/L of oxygen) or anoxic (without oxygen). If this occurs, cold water fish habitat is lost, and phosphorus bound within the lake bottom sediments is released into the overlying water.

A dissolved oxygen and temperature profile graph presents a vertical profile of these two parameters on a given sampling date. Another way to examine dissolved oxygen and temperature within lakes throughout a monitoring season is to generate isopleths – lines of equal value – from the collected dissolved oxygen and temperature data and plot those on axes of depth versus date. This yields graphs that visually show a cross-section of the lake from surface to bottom spread across the sampling season. In any such isopleth graph, if you trace a line vertically from the top to the bottom, you will see the values at every depth for the particular date you are tracing.

Lake Rippowam

Temperature and dissolved oxygen isopleths for Lake Rippowam in 2018 are presented in Figure 21 and Figure 22, respectively. Stratification began to become established in mid- to late May and ended with lake mixing in early October. Much of the lower waters below 4 meters in depth contained less than 4 mg/L of oxygen throughout the stratification period. A portion of the deeper waters were hypoxic from June into September. Low dissolved oxygen concentrations can be seen to extend to the lake surface in early October, when the lake mixed. Examining the temperature isopleth for Lake Rippowam, you can see that temperatures were 18°C or less – the maximum temperature for some coldwater fish – during spring and fall mixing but waters warmed in the summer with 18°C temperatures or less below 4 meters. The 18°C temperature isopleth sloped down and reached the lake bottom by late August. Therefore, during the summer of 2018, conditions were not ideal for coldwater fish (DO > 5 mg/L, Temp < 18°C).

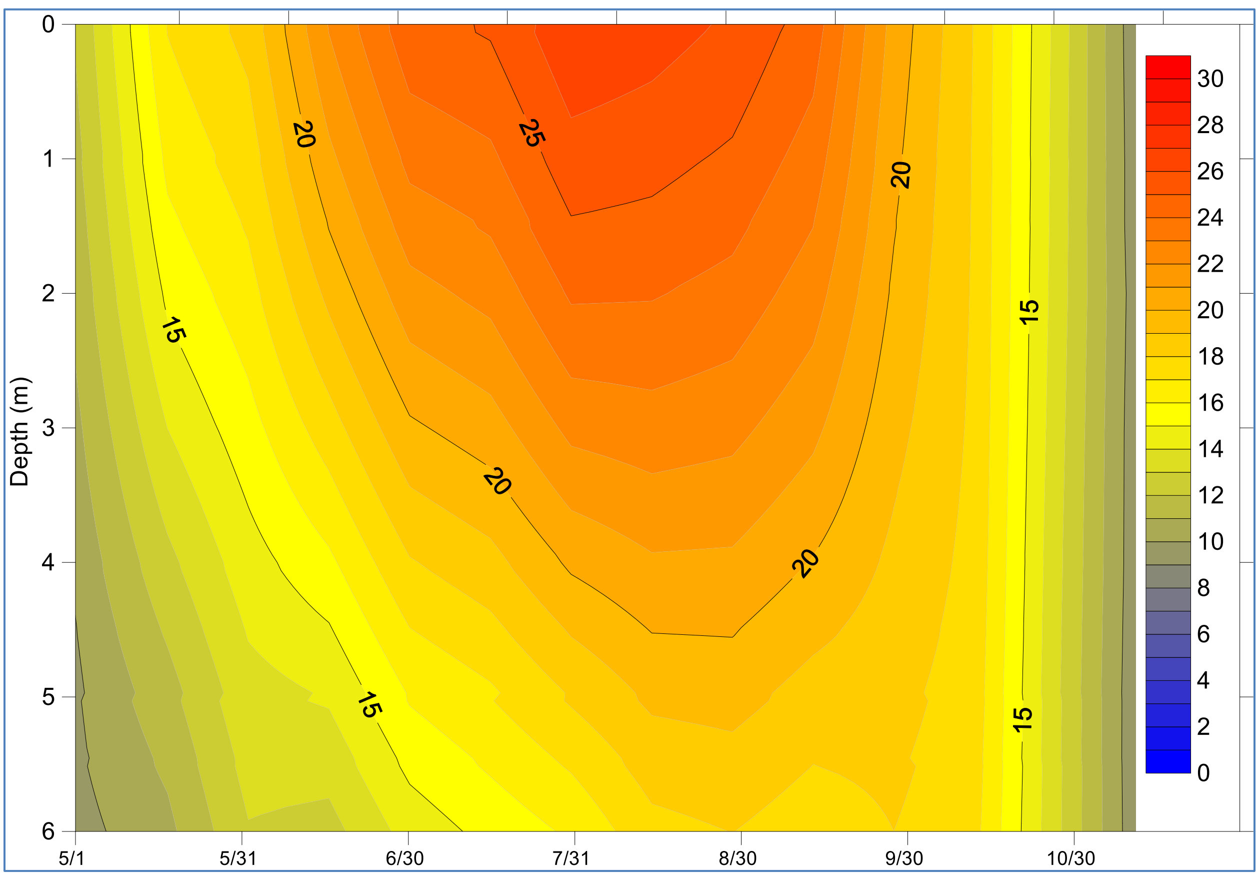

Figure 21 Temperature isopleths for 2018 in Lake Rippowam

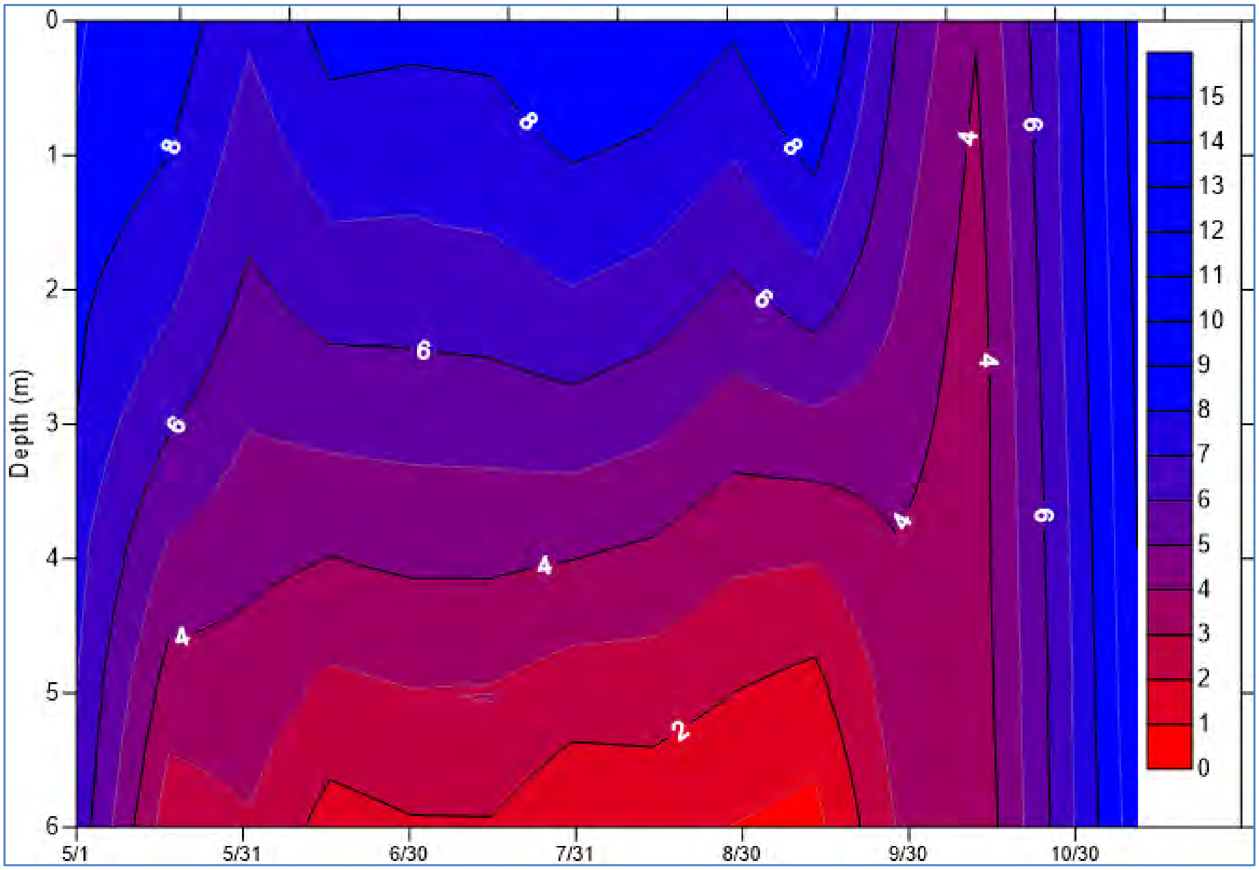

Figure 22 Dissolved oxygen isopleths for 2018 in Lake Rippowam

Lake Oscaleta

Temperature and dissolved oxygen isopleths for Lake Oscaleta in 2018 are presented in Figure 23 and Figure 24, respectively. Stratification began to become established in mid- May and ended with lake mixing in late October. Most of the hypolimnion contained less than 4 mg/L of oxygen throughout the stratification period below depths of 5 to 6 meters, with 5 mg/L or less extending to 3.5 meters. A portion of the deeper waters were anoxic from early June through September. Lower dissolved oxygen concentrations can be seen to extend to the lake surface in October, when the lake mixed. Examining the temperature isopleth for Lake Oscaleta, you can see that temperatures were 18°C or less – the maximum temperature for some coldwater fish – below a depth of 4 to 5 meters. Therefore, during the summer of 2018, conditions were not ideal for coldwater fish (DO > 5 mg/L, Temp < 18°C), with only a limited range of depth with suitable conditions and no suitable depths in August.

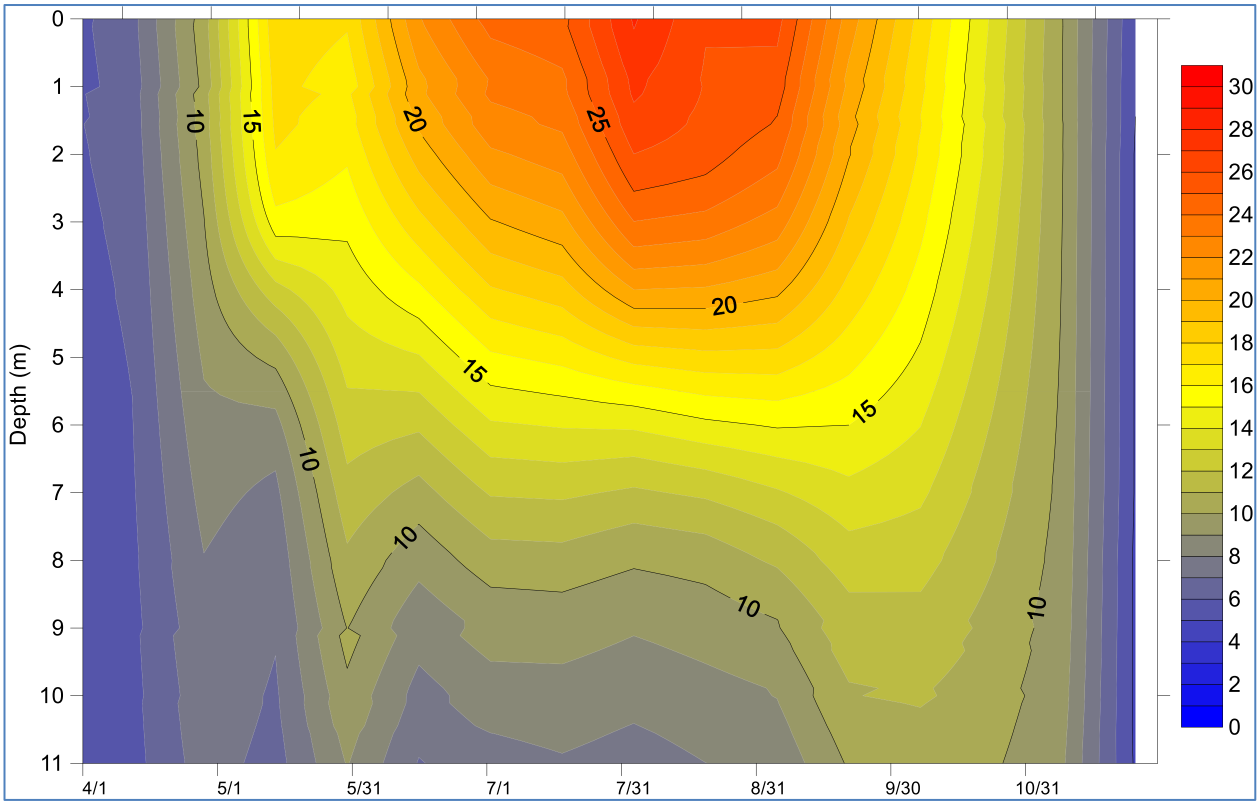

Figure 23 Temperature isopleths for 2018 in Lake Oscaleta

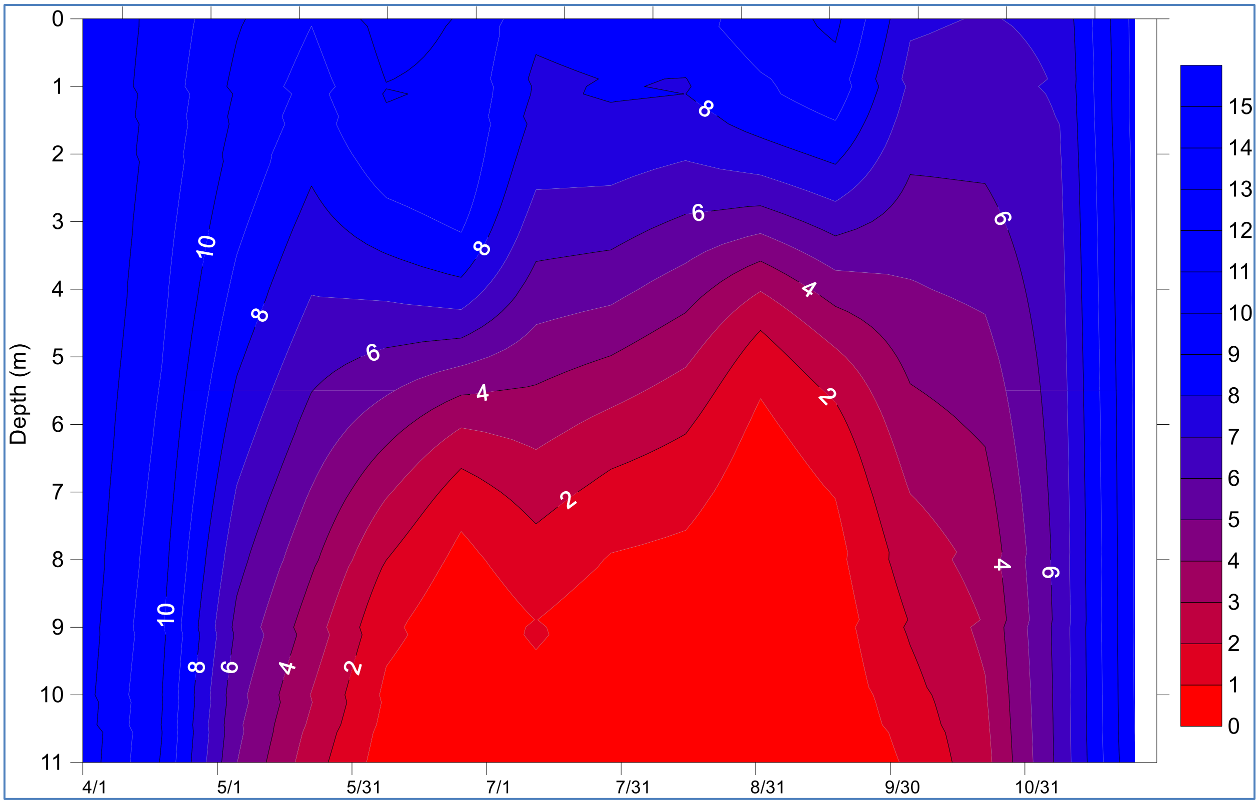

Figure 24 Dissolved oxygen isopleths for 2018 in Lake Oscaleta

Lake Waccabuc

Temperature and dissolved oxygen isopleths for Lake Waccabuc in 2018 are presented in Figure 25 and Figure 26, respectively. Stratification began to become established in mid- May and ended with lake mixing in early November. Most of the hypolimnion contained less than 4 mg/L of oxygen throughout the stratification period, extending to depths of 4 meters. The hypolimnion was hypoxic or anoxic from early June through October. These lower dissolved oxygen concentrations can be seen to extend into the epilimnion from August until lake mixing. Examining the temperature isopleth for Lake Waccabuc, you can see that temperatures were 18°C or less – the maximum temperature for some coldwater fish – below a depth of 5 to 6 meters. Therefore, during the summer of 2018, conditions were not ideal for coldwater fish (DO > 5 mg/L, Temp < 18°C).

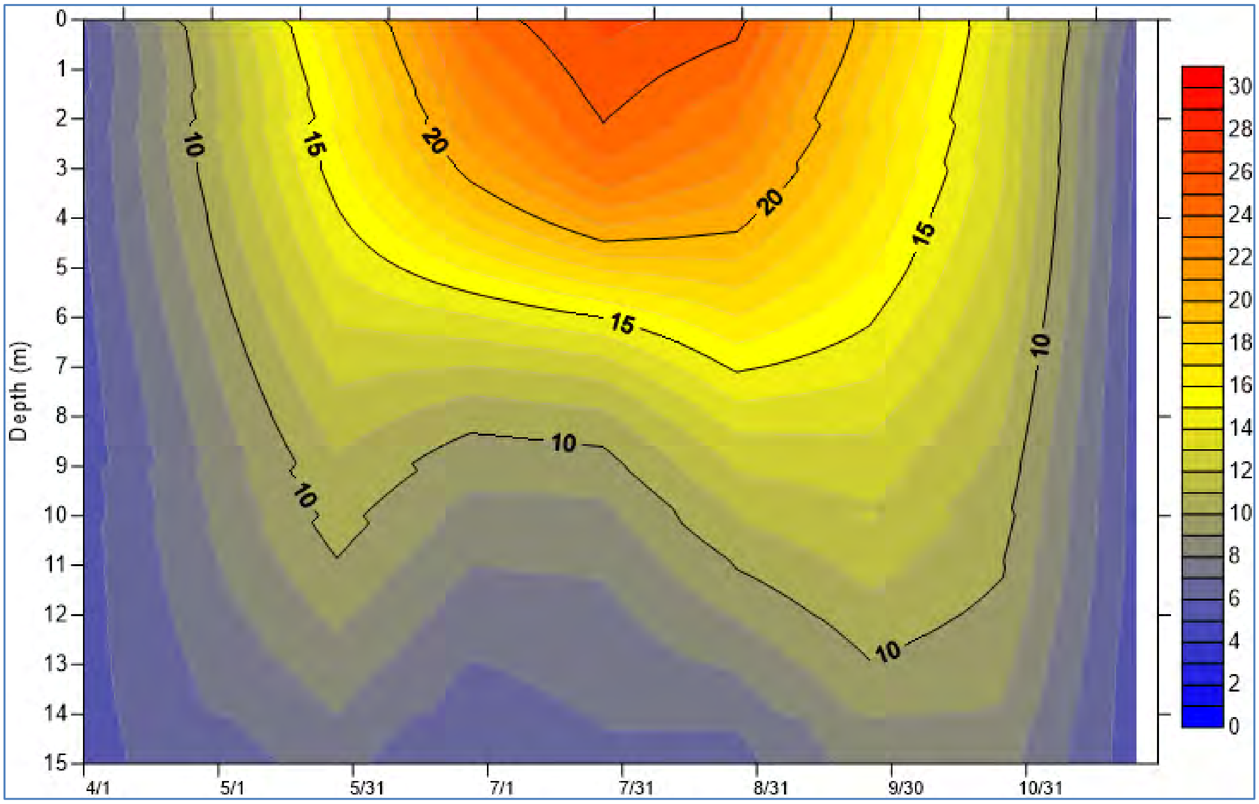

Figure 25 Temperature isopleths for 2018 in Lake Waccabuc

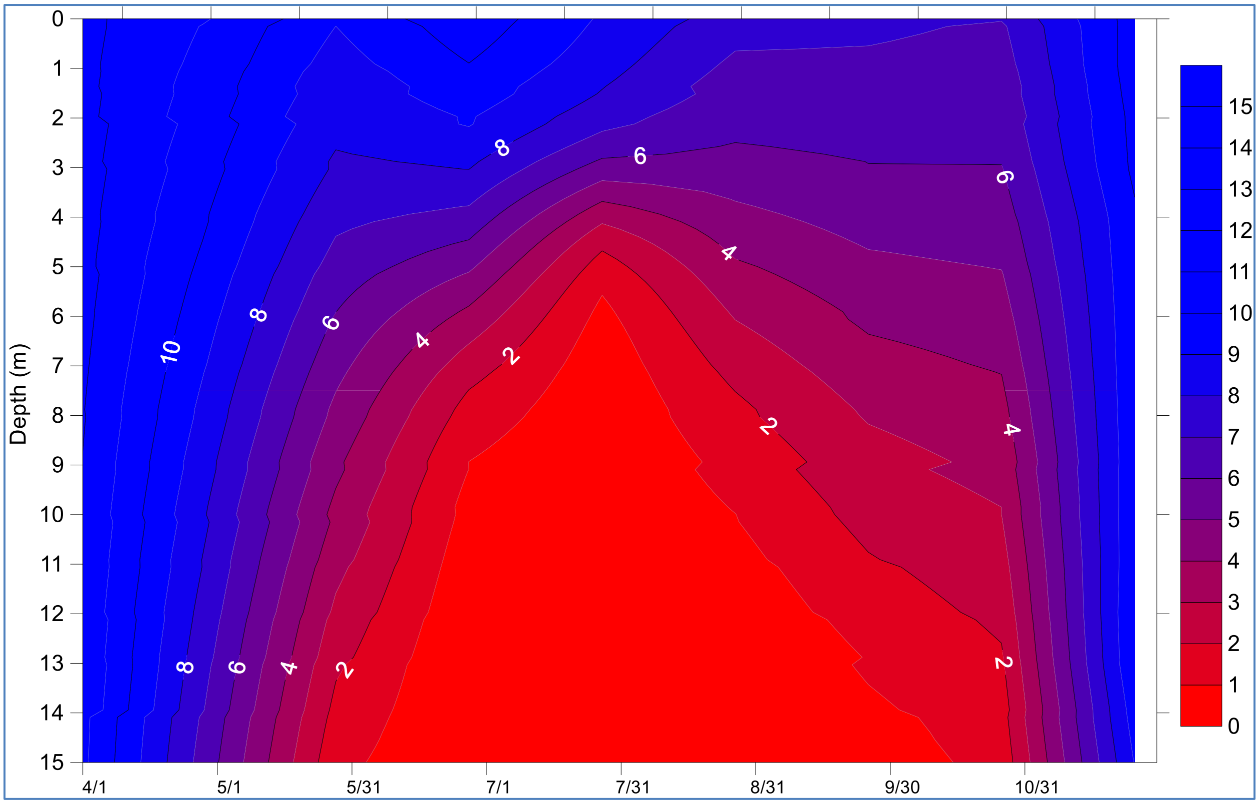

Figure 26 Dissolved oxygen isopleths for 2018 in Lake Waccabuc

Total Phosphorus

Phosphorus is the nutrient that most often controls algal productivity (growth) in lakes. Total phosphorus is a measure of all forms of phosphorus, both organic and inorganic. Total phosphorus concentrations are directly related to the trophic condition of a lake. Epilimnetic (surface) total phosphorus concentrations less than 0.010 mg/L are associated with oligotrophic conditions and concentrations greater than 0.020 mg/L are associated with eutrophic conditions (NYSFOLA 2009).

Epilimnetic total phosphorus in the Three Lakes in 2018 is presented in Figure 27. All three lakes started out the season with phosphorus concentrations in the eutrophic range. Phosphorus dropped into the mesotrophic range in June in Lake Oscaleta and Lake Rippowam and in August in Lake Waccabuc. An increase in phosphorus occurred in July in Lake Waccabuc and in September in Lake Rippowam when that lake mixed.

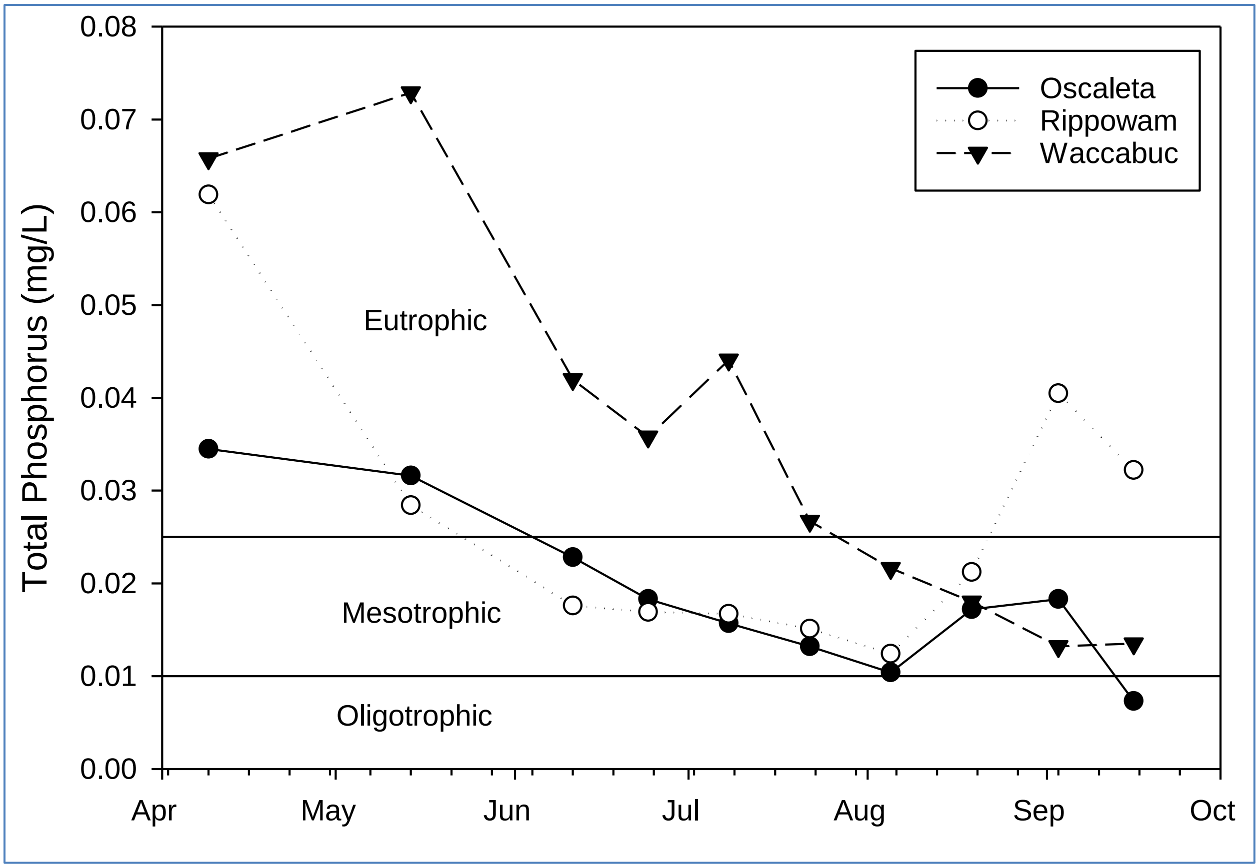

Figure 27 Epilimnetic total phosphorus concentrations in 2018 in the Three Lakes

Hypolimnetic total phosphorus in the Three Lakes in 2018 is presented in Figure 28. Hypolimnetic phosphorus increased considerably in Lake Waccabuc throughout the season and slightly in Lake Rippowam and Lake Oscaleta.

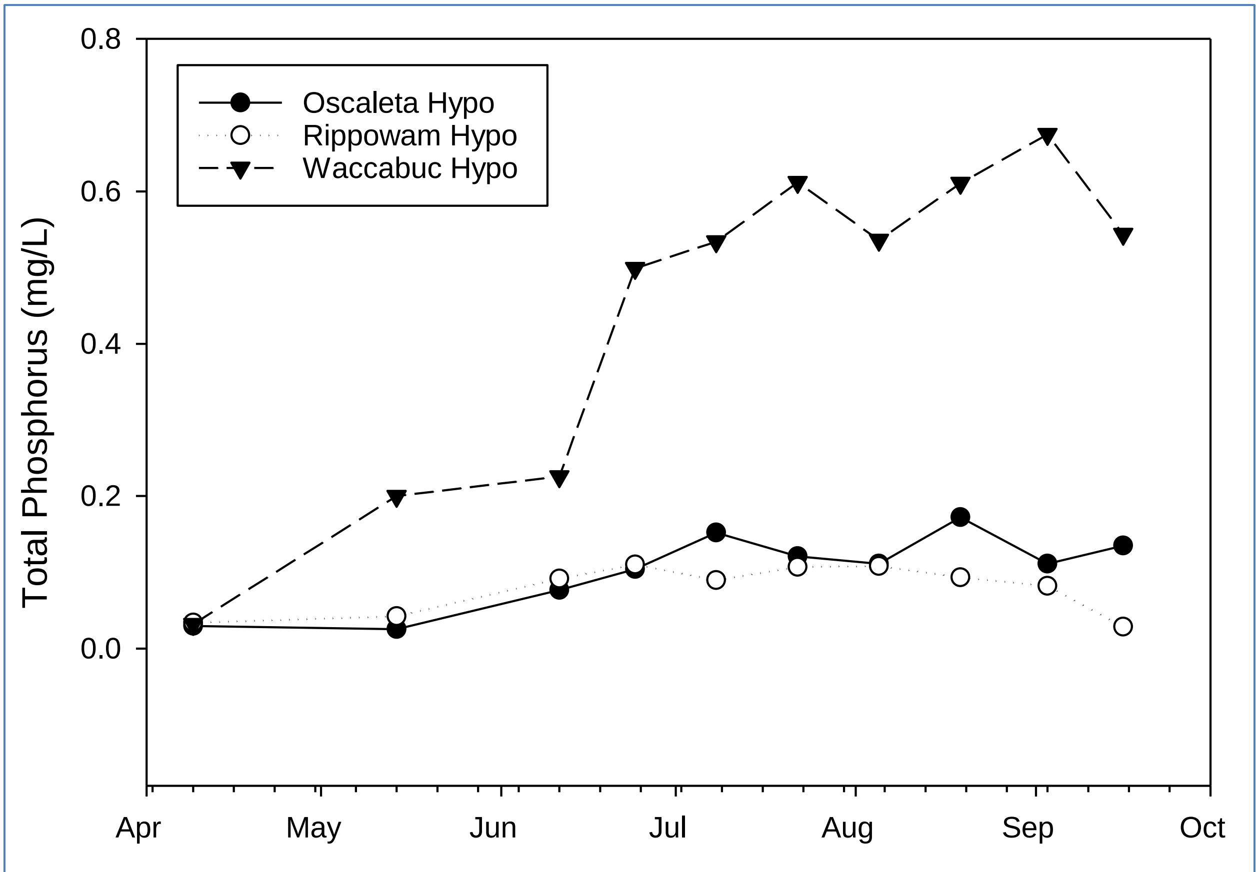

Figure 28 Hypolimnetic total phosphorus concentrations in 2018 in the Three Lakes

Chlorophyll *a*

Chlorophyll a is a green pigment used by plants in photosynthesis. The measurement of chlorophyll a provides an indication of the amount of phytoplankton growing in a lake and therefore can be used to classify lake trophic state. Chlorophyll a concentrations less than 2 micrograms per liter (µg/L) are associated with oligotrophic conditions, while concentrations greater than 8 µg/L are associated with eutrophic conditions (DEC & FOLA 1990).

Chlorophyll *a* in the Three Lakes in 2018 is presented in Figure 29. Chlorophyll *a* concentrations were in the eutrophic range in all lakes at the start of the season. Chlorophyll *a* dropped into the mesotrophic range in Lake Rippowam in May but climbed back into the eutrophic range in July, when it continued to increase throughout the rest of the season. Chlorophyll *a* dropped into the mesotrophic range in Lake Oscaleta in June where it remained until early August, after which it increased into the eutrophic range. Chlorophyll *a* also dropped into the mesotrophic range in Lake Waccabuc in June but it returned well into the eutrophic range in mid-June until early August.

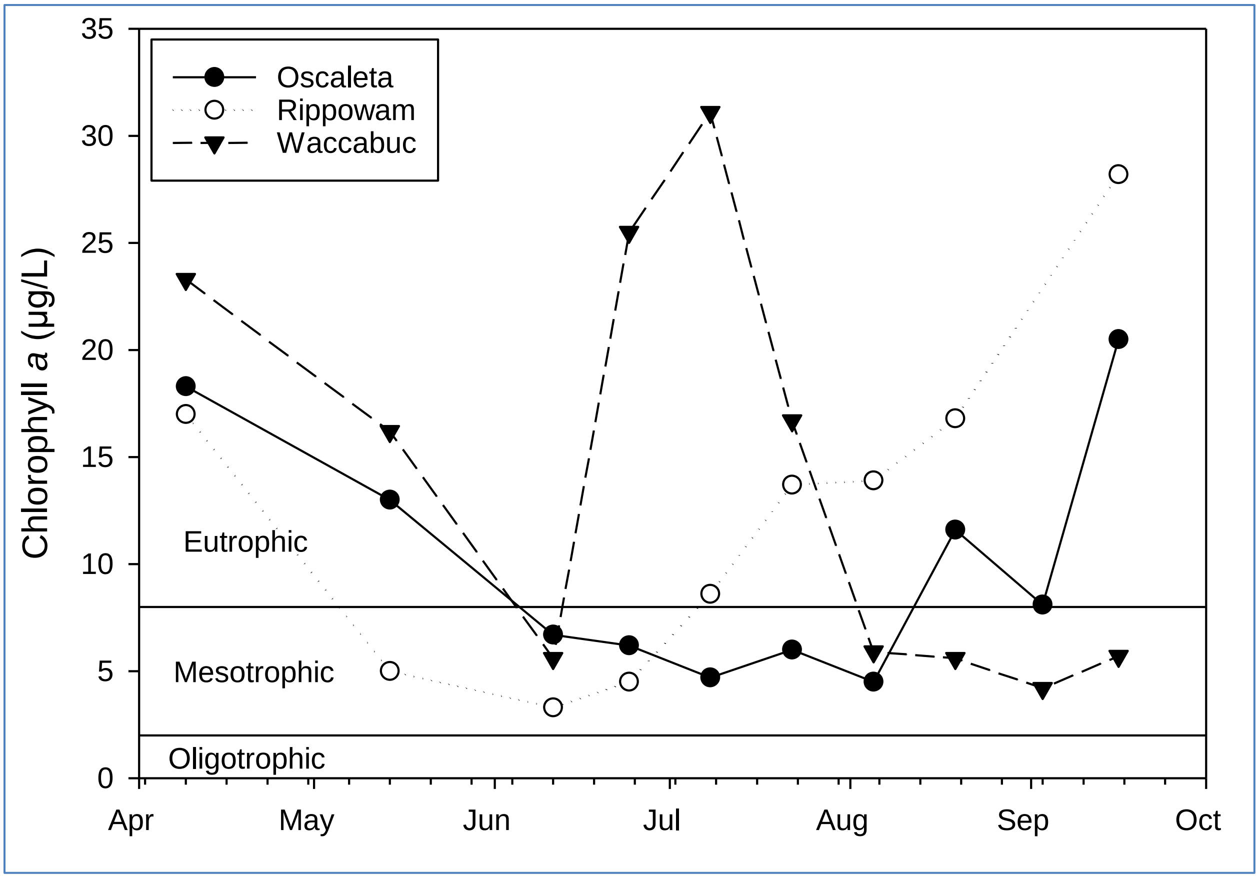

Figure 29 Chlorophyll a concentrations in 2018 in the Three Lakes

Transparency

Transparency is a measure of water clarity in lakes and ponds. It is determined by lowering a 20 cm black and white disk, otherwise known as a Secchi disk, into a lake to the depth where it is no longer visible from the surface. Since algae are the main determinant of water clarity in non-stained lakes that lack excessive amounts of inorganic turbidity (suspended silt), transparency is used as an indicator of lake trophic state. Transparencies greater than 5 meters are associated with oligotrophic conditions, while transparencies less than 2 meters are associated with eutrophic conditions (NYSFOLA 2009).

Transparency in the Three Lakes in 2018 is presented in Figure 30. Transparency in Lake Oscaleta and Lake Waccabuc was in the mesotrophic range throughout much of the season. Lake Waccabuc experienced eutrophic transparency from mid-June to the end of June. Transparency was mostly in the eutrophic range in Lake Rippowam starting in late June.

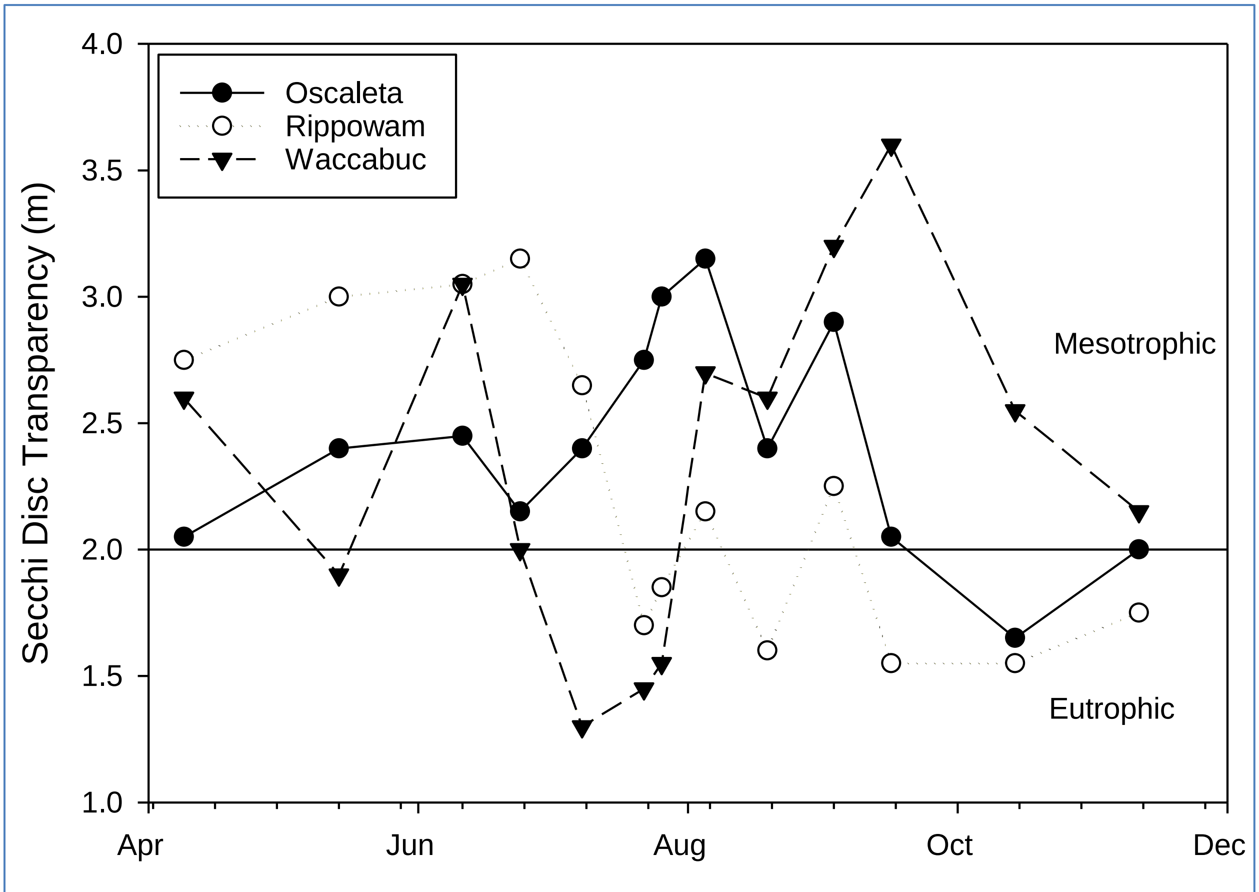

Figure 30 Transparency in 2018 in the Three Lakes

Trophic State

Trophic state is a key term used in limnology to describe the amount of algae and macrophytes (aquatic plants) found in a lake. Oligotrophic lakes have few algae and macrophytes and appear clean and clear, while eutrophic lakes show an overabundance of growth and often have a pronounced green color due to algae. Eutrophication is a natural process whereby lakes increase in trophic state over long periods of time. However, the process of eutrophication can be greatly accelerated by human activities (such as watershed development and sewage disposal) which introduce additional nutrients, organic matter and silt into the lake system. This cultural eutrophication can be slowed and even reversed by controlling human inputs, but in many cases additional in-lake treatments are required in order to accelerate this rehabilitation process.

The Carlson (1977) Trophic State Index (TSI) is an extremely valuable tool for the evaluation of lakes. This index should be calculated using summer averages for total phosphorus, chlorophyll a, and/or transparency (Secchi depth) data. To calculate this index each seasonal average is logarithmically converted to a scale of relative trophic state ranging from 1 to 100. This index was constructed such that an increase in ten units represents a doubling in algal biomass. For example, a lake with a chlorophyll TSI of 40 has twice as much algae as a lake with a TSI value of 30. Generally, TSI values less than 37 are considered oligotrophic, while TSI values greater than 51 are considered eutrophic (DEC & FOLA 1990).

The Trophic State Indices for the Three Lakes in 2018 are presented in Figure 31. Lake Rippowam was mesotrophic based on transparency TSI and phosphorus TSI and eutrophic based on chlorophyll TSI. Lake Oscaleta was mesotrophic based on all three TSI. Lake Waccabuc was mesotrophic based on transparency TSI and eutrophic based on phosphorus TSI and chlorophyll TSI.

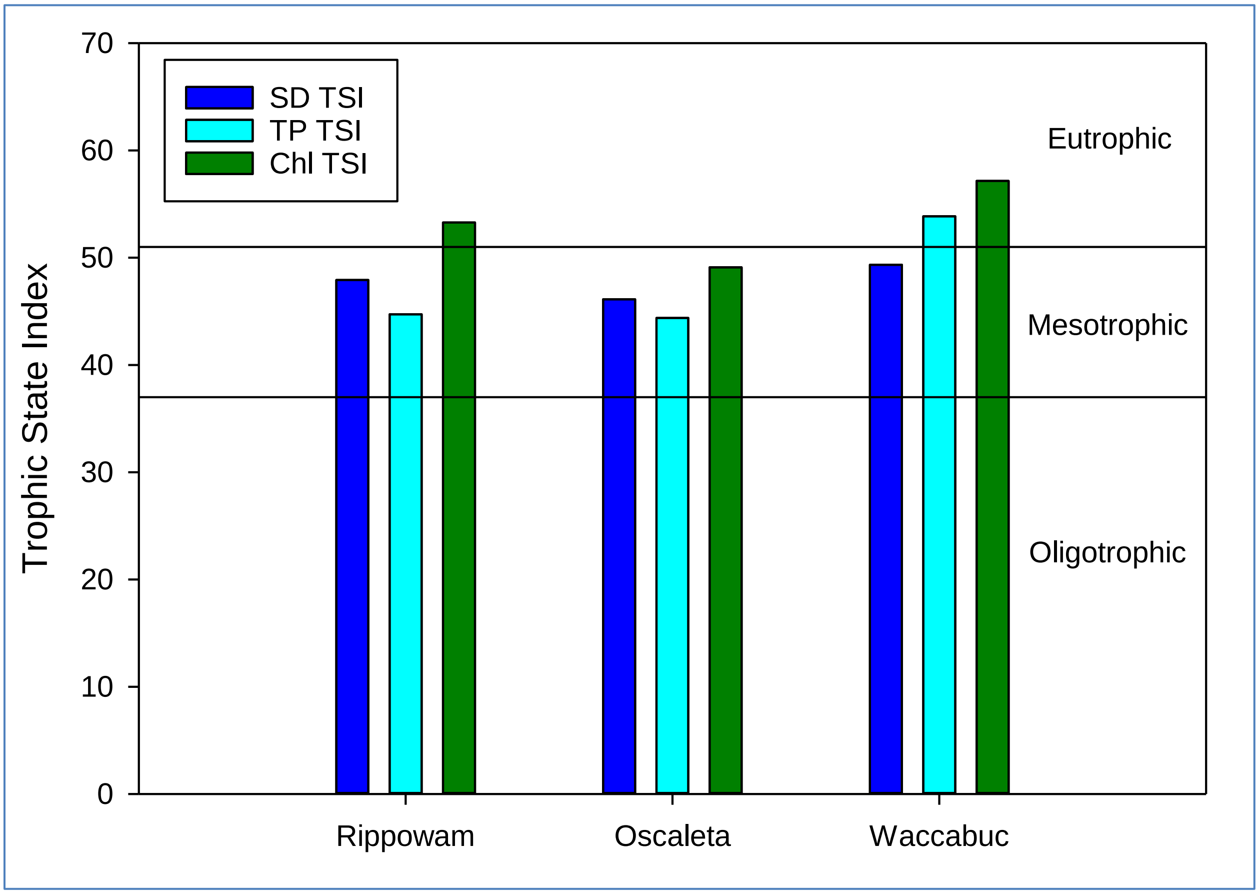

Figure 31 Trophic State Indices in 2018 in the Three Lakes

Limiting Nutrient

Phytoplankton growth depends on a variety of nutrients, including macronutrients such as phosphorus, nitrogen, and carbon, along with trace nutrients, such as iron, manganese, and other minerals. According to Liebig's Law of the Minimum, biological growth is limited by the substance that is present in the minimum quantity with respect to the needs of the organism. Nitrogen and phosphorus are usually the nutrients limiting algal growth in most natural waters. Controlling the concentration of the limited nutrient in a lake may help to improve water quality.

Depending on the species, algae require approximately 15 to 26 atoms of nitrogen for every atom of phosphorus. This ratio converts to 7 to 12 mg of nitrogen per 1 mg of phosphorus on a mass basis. A ratio of total nitrogen to total phosphorus of 15:1 is generally regarded as the dividing point between nitrogen and phosphorus limitation (Downing and McCauley, 1992). Identification of the limiting nutrient becomes more certain as the total nitrogen to total phosphorus ratio moves farther away from the dividing point, with ratios of 10:1 or less providing a strong indication of nitrogen limitation and ratios of 20:1 or more strongly indicating phosphorus limitation.

The total phosphorus to total nitrogen ratio (TN:TP) was calculated using the 2018 data for each lake and is presented in Figure 32. All three lakes were phosphorus limited throughout the growing season.

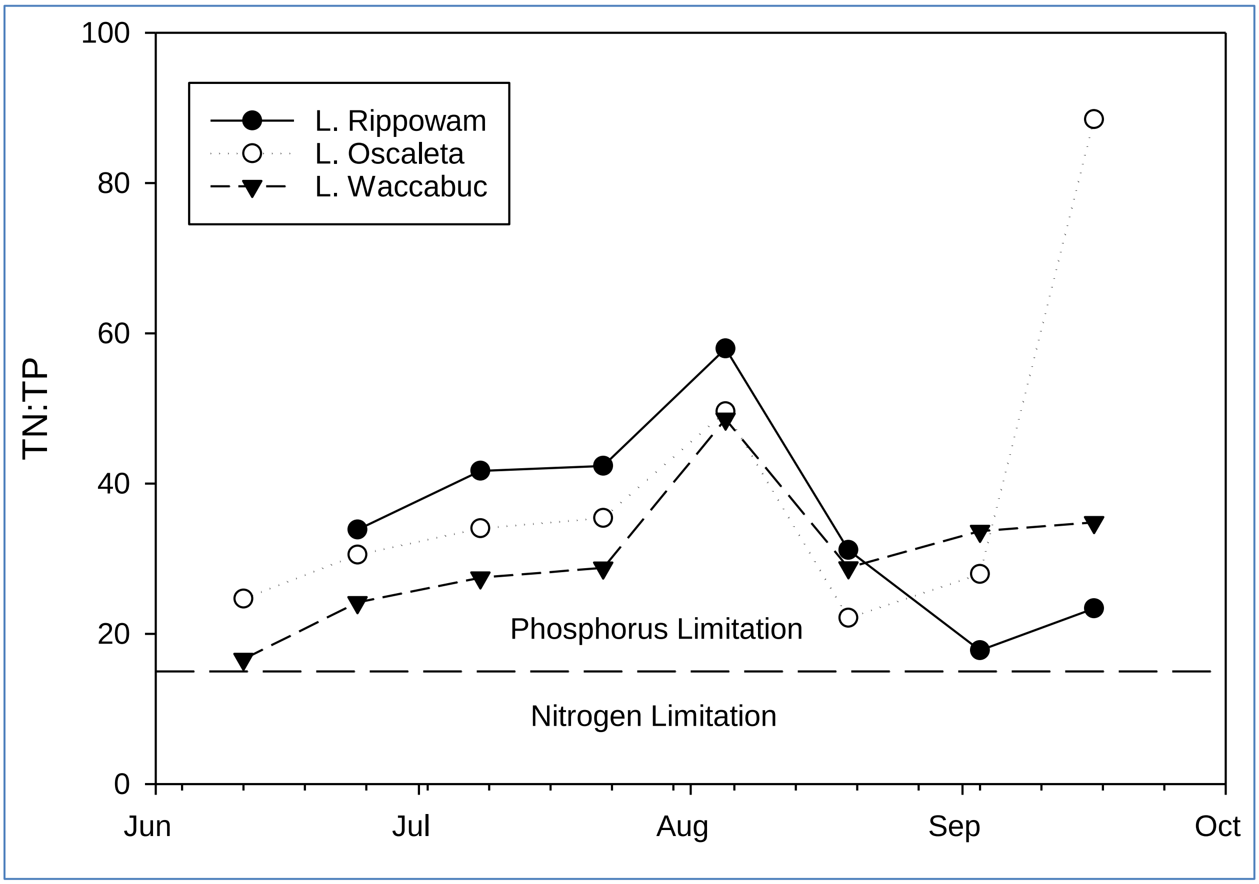

Figure 32 TN:TP Ratio for 2018 in the Three Lakes

Water Quality Trends

The following sections present water quality trends for the primary trophic state parameters, based upon the CSLAP data from 2004 through 2018. Growing season in the following figures and discussions refers to May through September while summer season refers to June through August. Error bars on graphs represent 95 percent confidence intervals.

Dissolved Oxygen

Lake Rippowam

Temperature isopleths from 2004 through 2018 are presented in Figure 33. Surface water temperatures from 2004 through 2018 are presented in Figure 34. Maximum surface temperature was fairly consistent across the period of record.

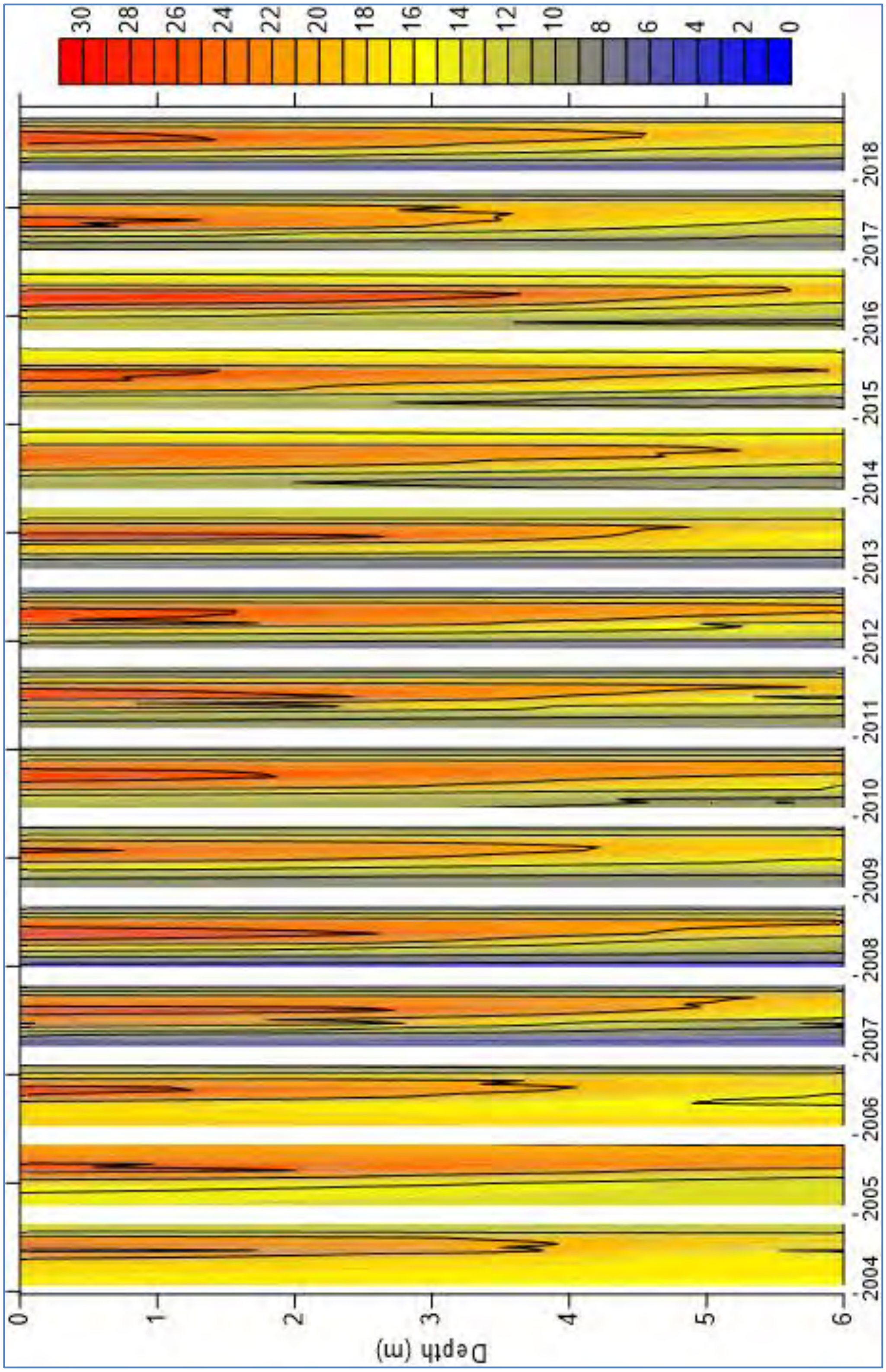

Figure 33 Temperature isopleths for 2004-2018 in Lake Rippowam

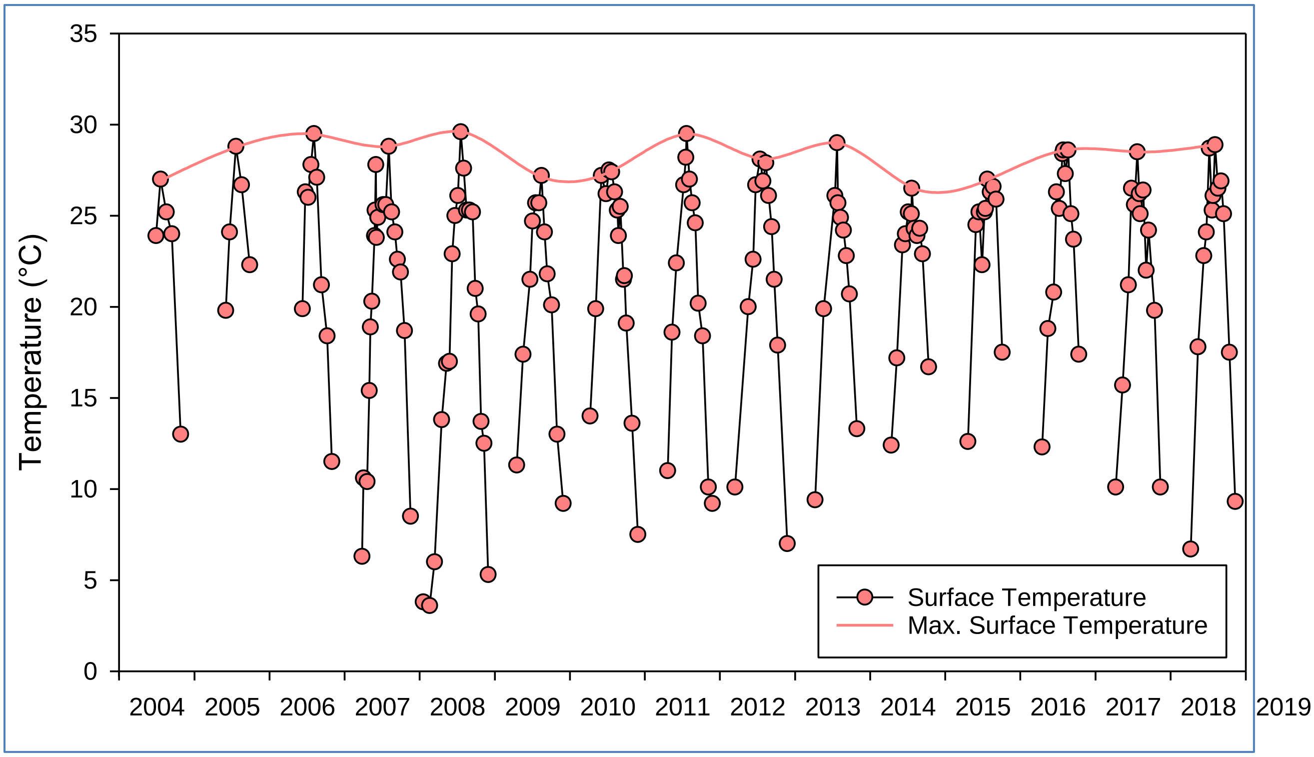

Figure 34 Surface water temperatures in Lake Rippowam (2004-2018)

The depth of the top of the anoxic zone from 2004 through 2018 is presented in Figure 35. There appears to be a slight decrease in the depth at which anoxia occurs in Lake Rippowam over the period of record, decreasing from 4.9 meters in 2004 to 4.4 meters in 2018.

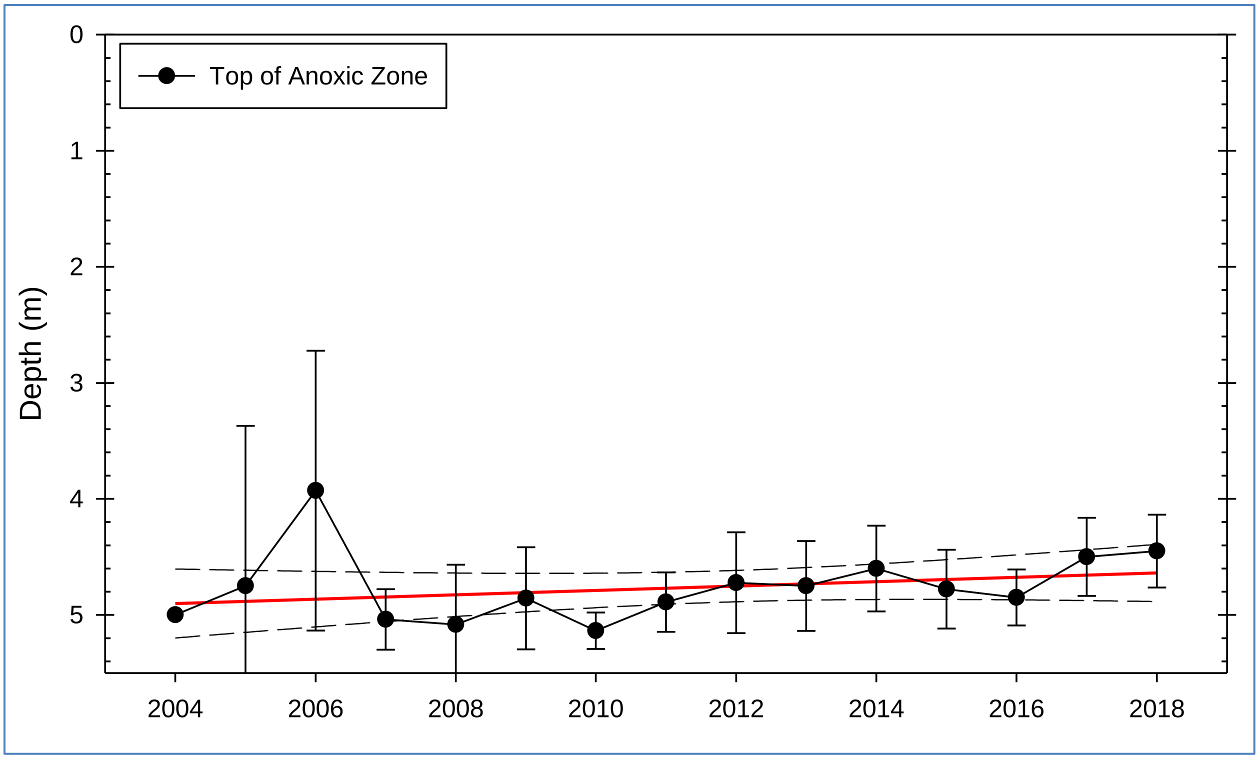

Figure 35 Depth of the top of the anoxic zone in Lake Rippowam (2004-2018)

Lake Oscaleta

Temperature isopleths from 2004 through 2018 are presented in Figure 36. Surface water temperatures from 2004 through 2018 are presented in Figure 37. Maximum surface temperature was fairly consistent across the period of record.

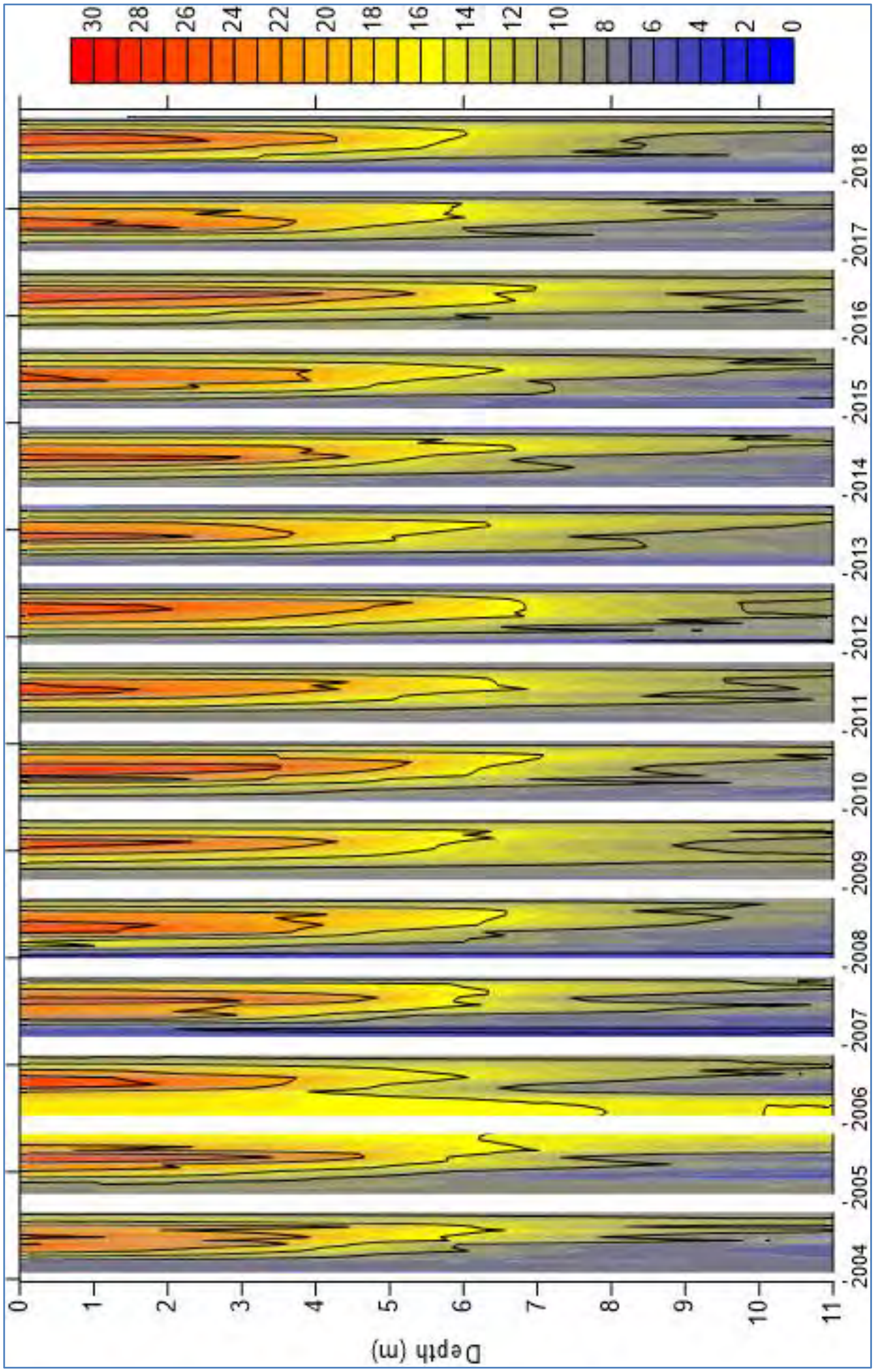

Figure 36 Temperature isopleths for 2004-2018 in Lake Oscaleta

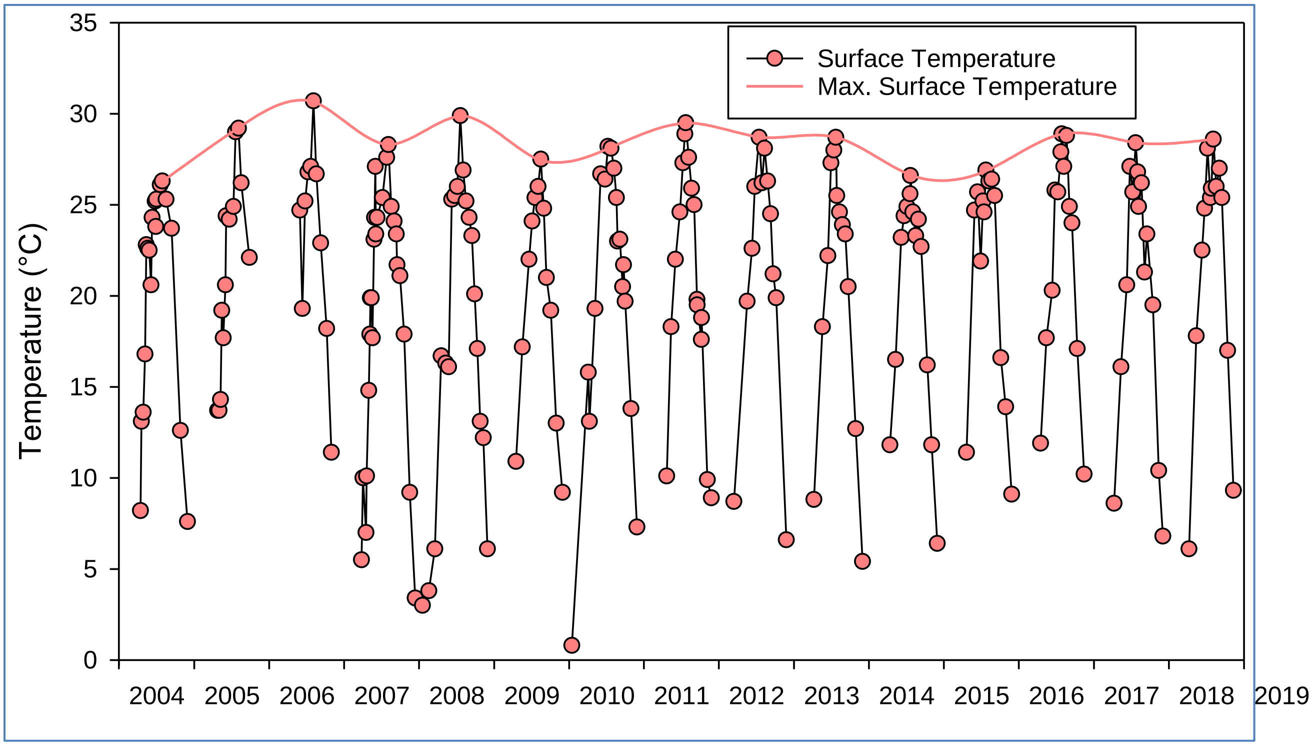

Figure 37 Surface water temperatures in Lake Oscaleta (2004-2018)

The depth of the top of the anoxic zone from 2004 through 2018 is presented in Figure 38. There appears to be a significant decrease in the depth at which anoxia occurs in Lake Oscaleta over the period of record, decreasing from 8.6 meters in 2004 to 6.3 meters in 2018.

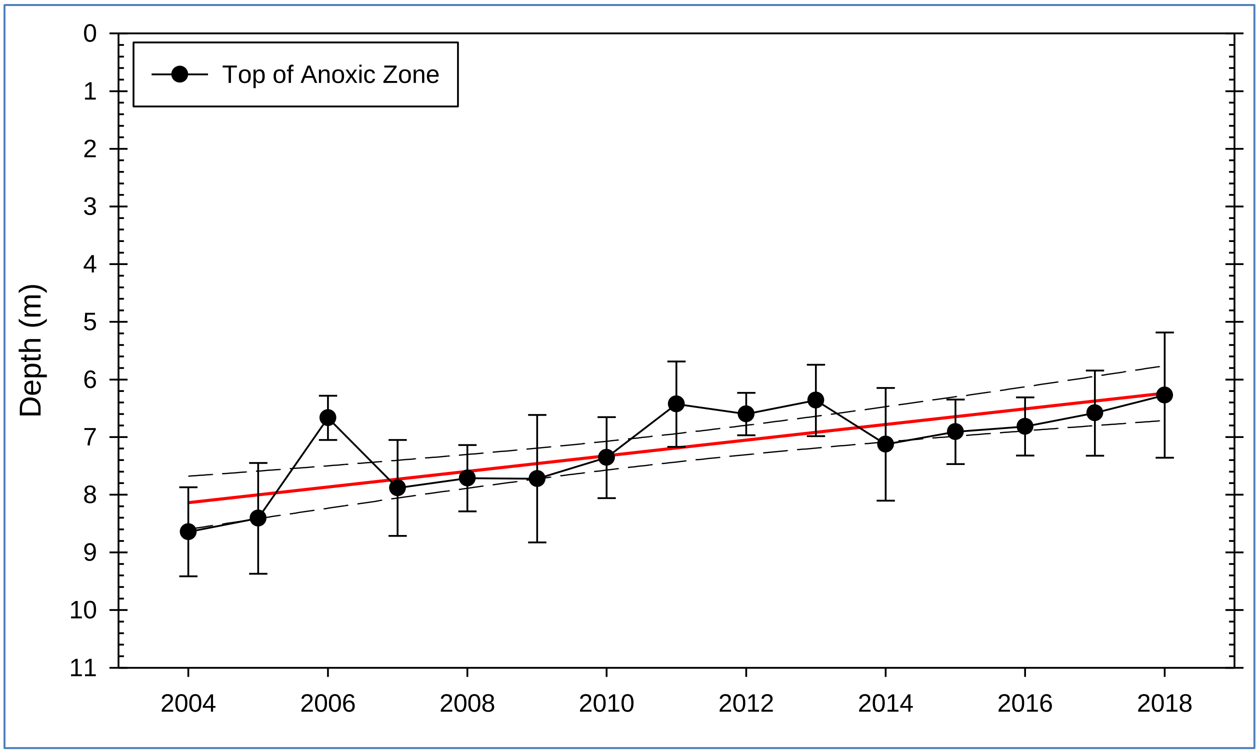

Figure 38 Depth of the top of the anoxic zone in Lake Oscaleta

Lake Waccabuc

Temperature isopleths from 2004 through 2018 are presented in Figure 39. Surface water temperatures from 2004 through 2018 are presented in Figure 40. Maximum surface temperature was fairly consistent across the period of record.

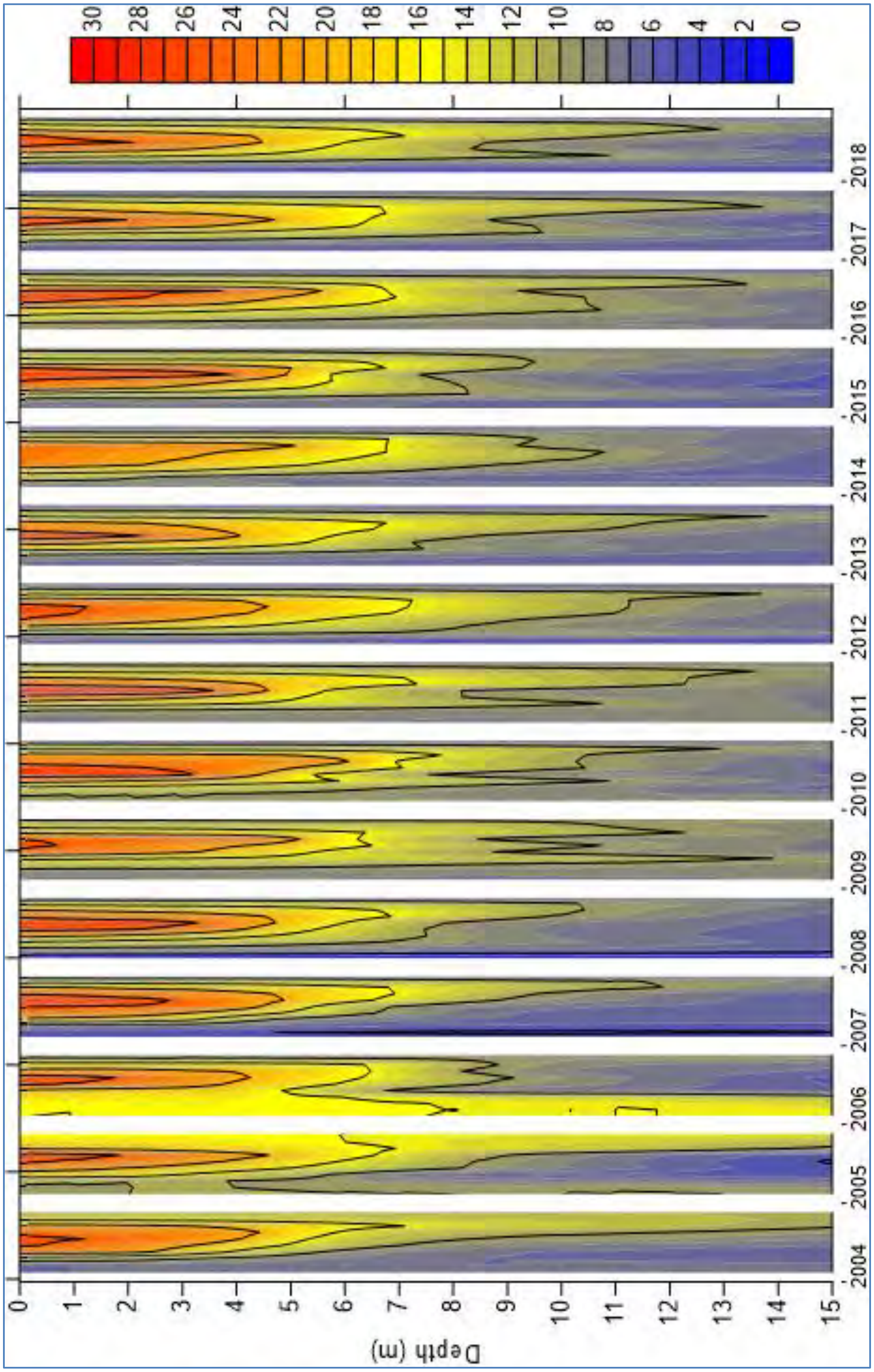

Figure 39 Temperature isopleths for 2004-2018 in Lake Waccabuc

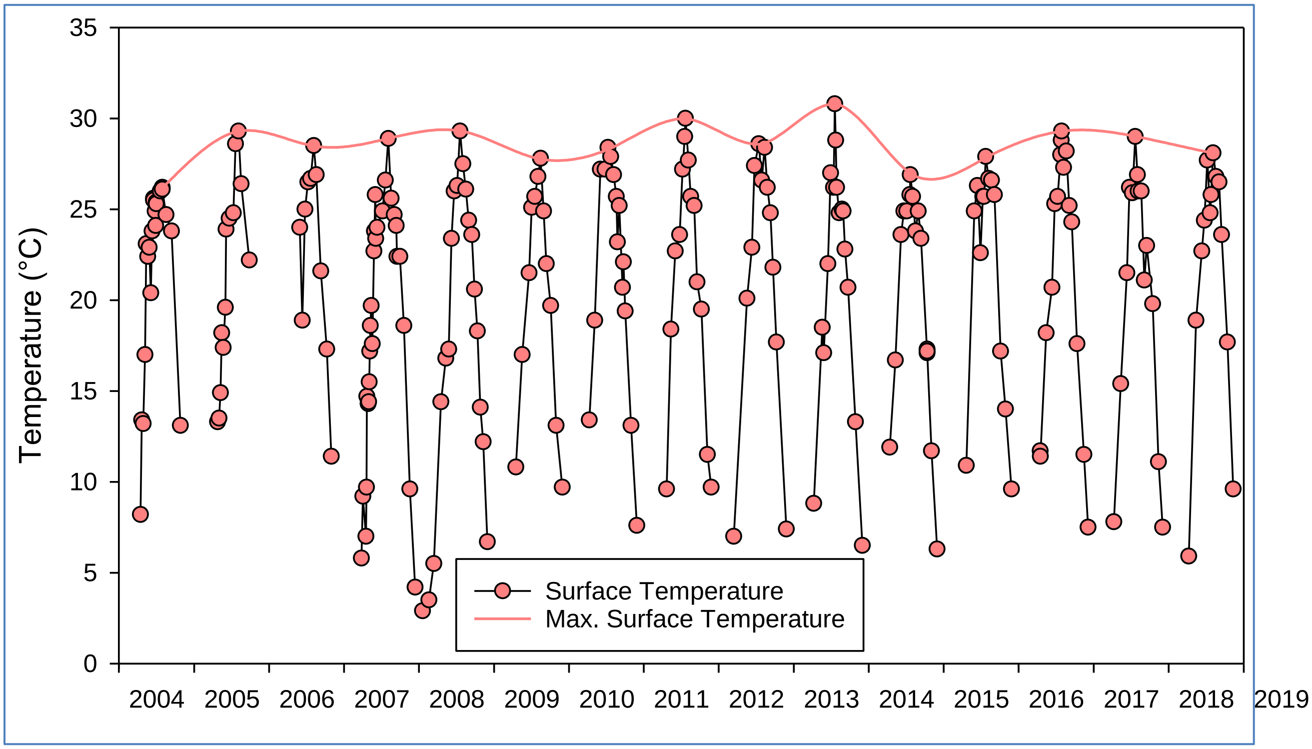

Figure 40 Surface water temperatures in Lake Waccabuc (2004-2018)

The depth of the top of the anoxic zone from 2004 through 2018 is presented in Figure 41. There appears to be a slight decrease in the depth at which anoxia occurs in Lake Waccabuc over the period of record, decreasing from 9.1 meters in 2004 to 7.3 meters in 2018.

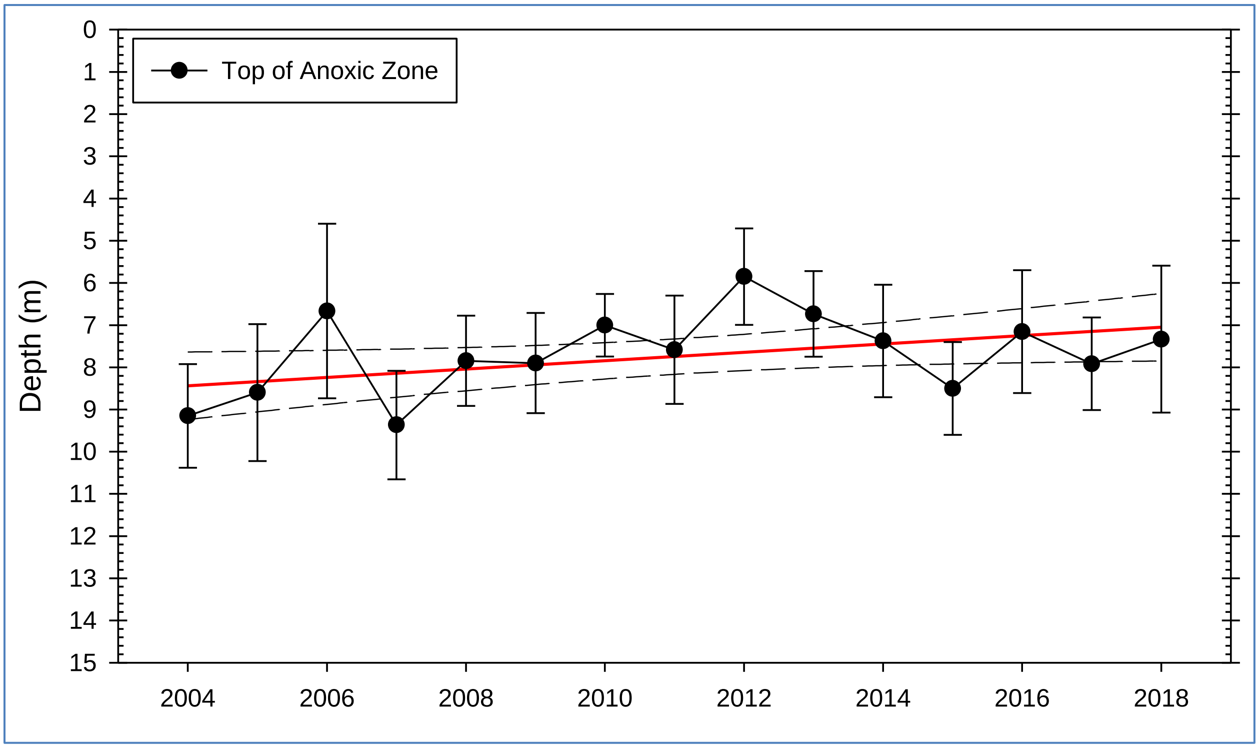

Figure 41 Depth of the top of the anoxic zone in Lake Waccabuc (2004-2018)

Total Phosphorus

Lake Rippowam

Growing season mean epilimnetic total phosphorus for 2004 through 2018 is presented in Figure 42. There does not appear to be any significant trend.

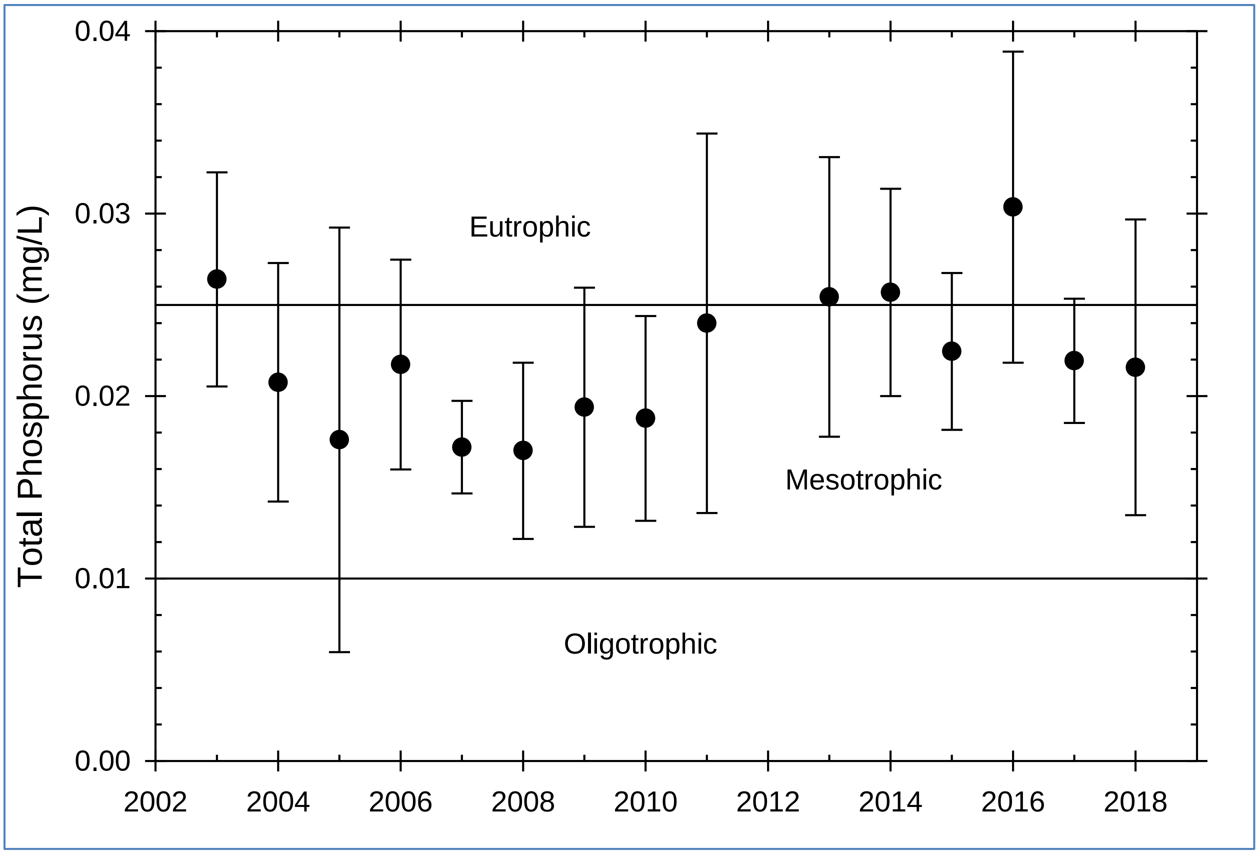

Figure 42 Growing season mean Epilimnetic total phosphorus in Lake Rippowam (2003-2018)

Growing season mean hypolimnetic total phosphorus for 2004 through 2018 is presented in Figure 43. It appears that hypolimnetic phosphorus concentrations have been steadily increasing since 2010.

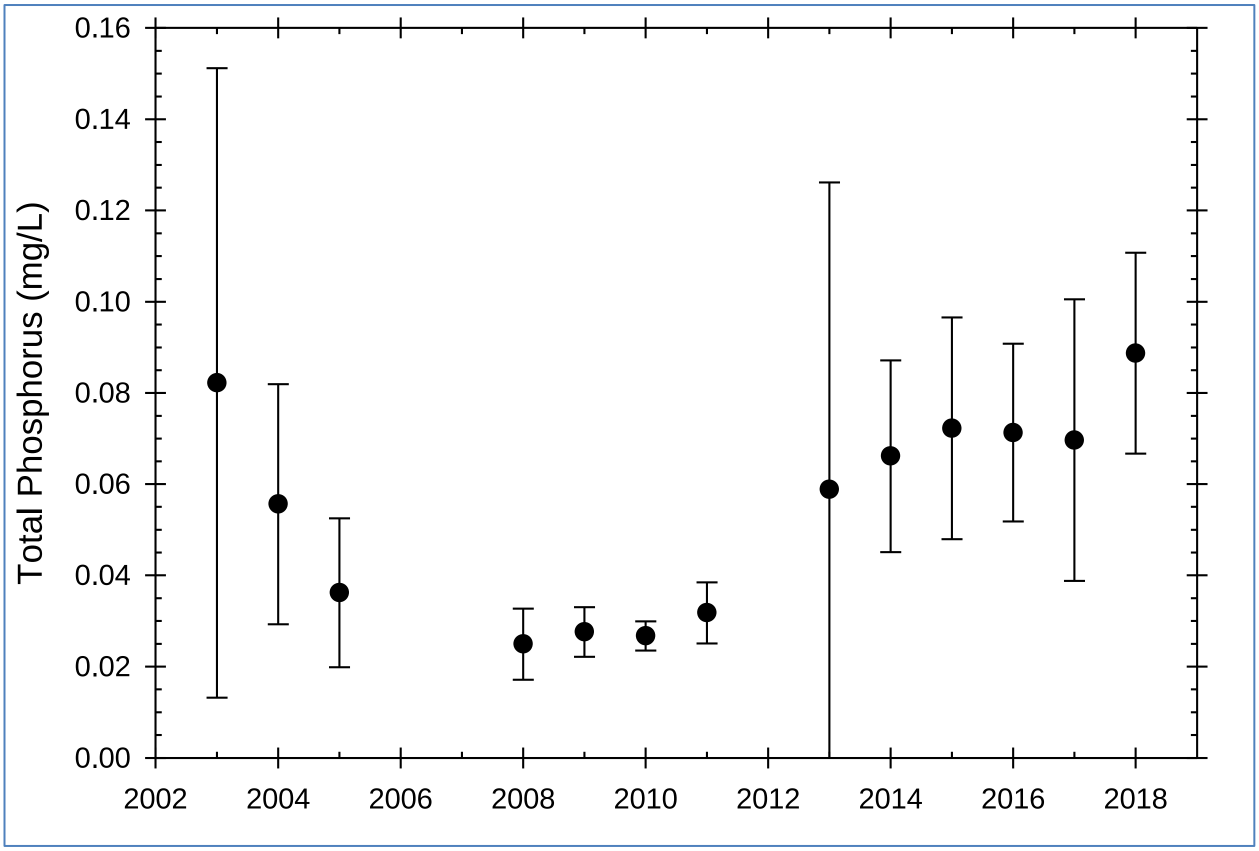

Figure 43 Growing season mean hypolimnetic total phosphorus in Lake Rippowam (2003-2018)

Lake Oscaleta

Growing season mean epilimnetic total phosphorus for 2004 through 2018 is presented in Figure 44. There does not appear to be any significant trend.

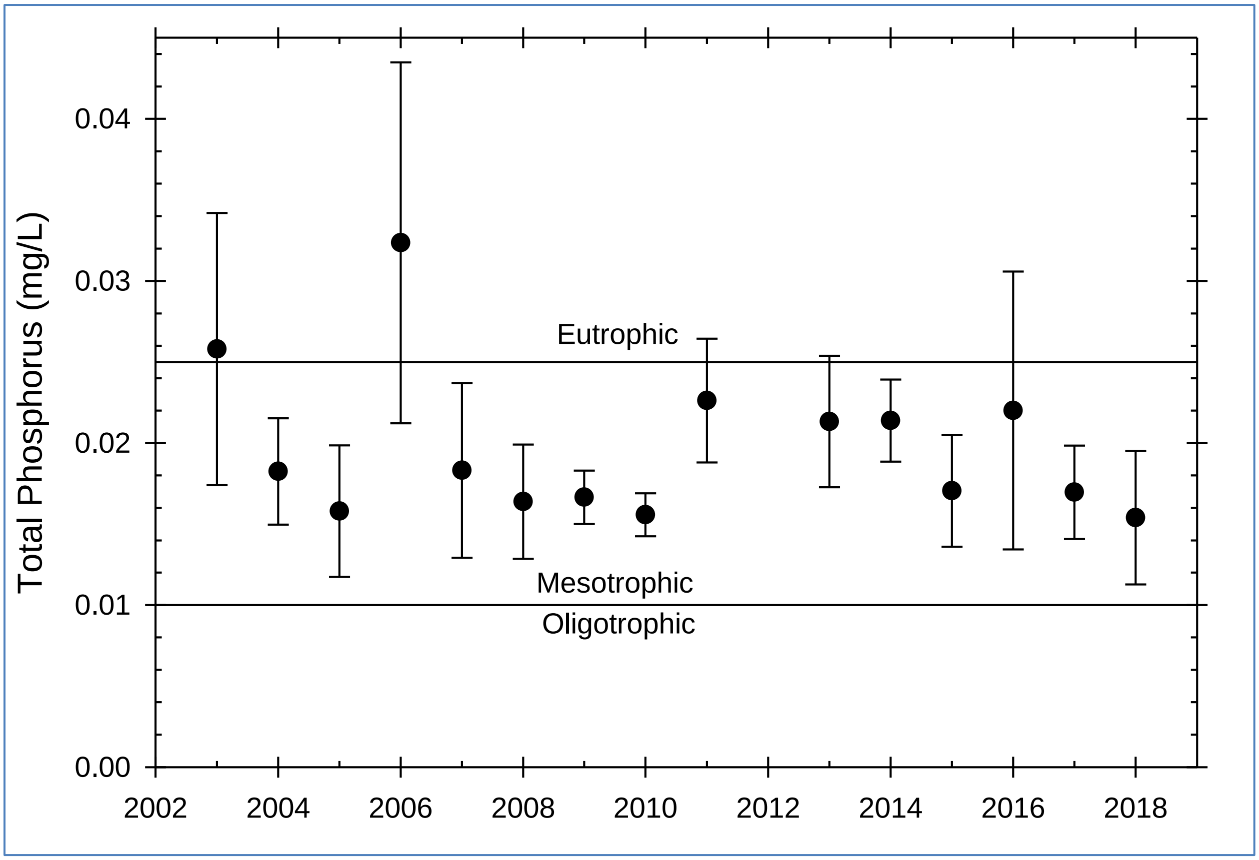

Figure 44 Growing season mean epilimnetic total phosphorus in Lake Oscaleta (2003-2018)

Growing season mean hypolimnetic total phosphorus for 2004 through 2018 is presented in Figure 42. There appears to be a slight trend of increasing hypolimnetic total phosphorus since 2013.

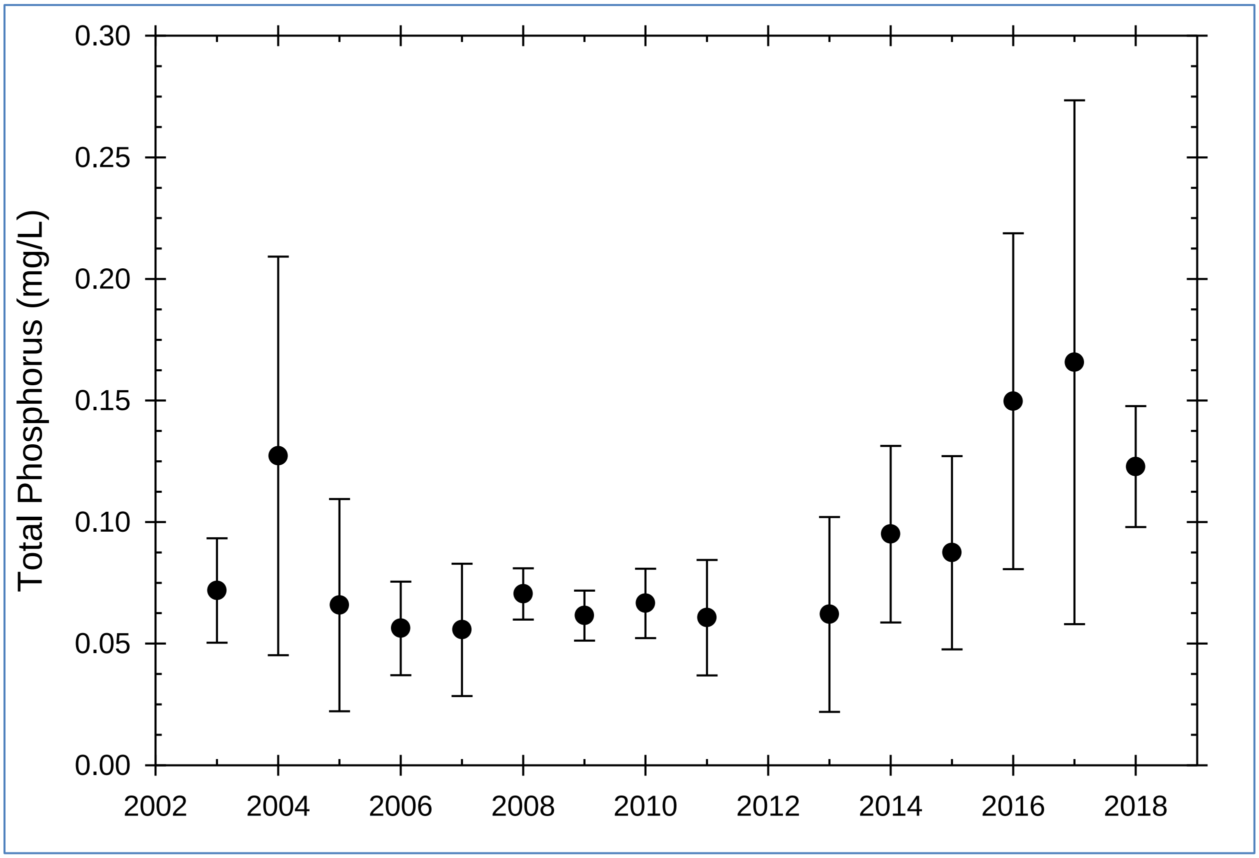

Figure 45 Growing season mean hypolimnetic total phosphorus in Lake Oscaleta (2003-2018)

Lake Waccabuc

Growing season mean epilimnetic total phosphorus for 1986 through 1995 and 2004 through 2018 is presented in Figure 46. There does not appear to be any significant trend, although epilimnetic total phosphorus appears to be somewhat higher in later years compared to the earlier data.

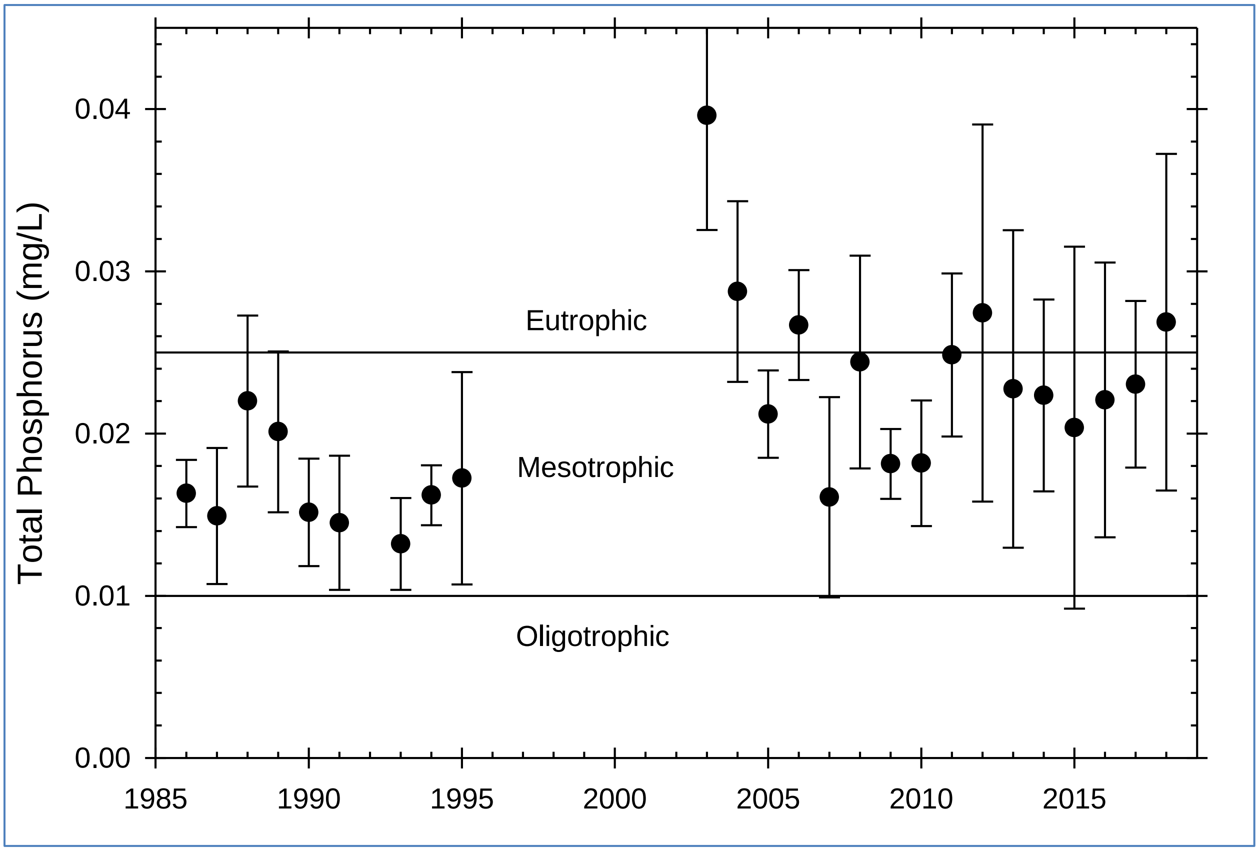

Figure 46 Growing season mean epilimnetic total phosphorus in Lake Waccabuc (1986-2018)

Growing season mean epilimnetic total phosphorus for 2003 through 2018 is presented in Figure 42. There appears to be a significant trend for increasing hypolimnetic total phosphorus concentrations from 2004 through 2007/2008. Hypolimnetic total phosphorus remained steady for several years and then decreased somewhat from 2011 to 2013 after which it increased again through 2017.

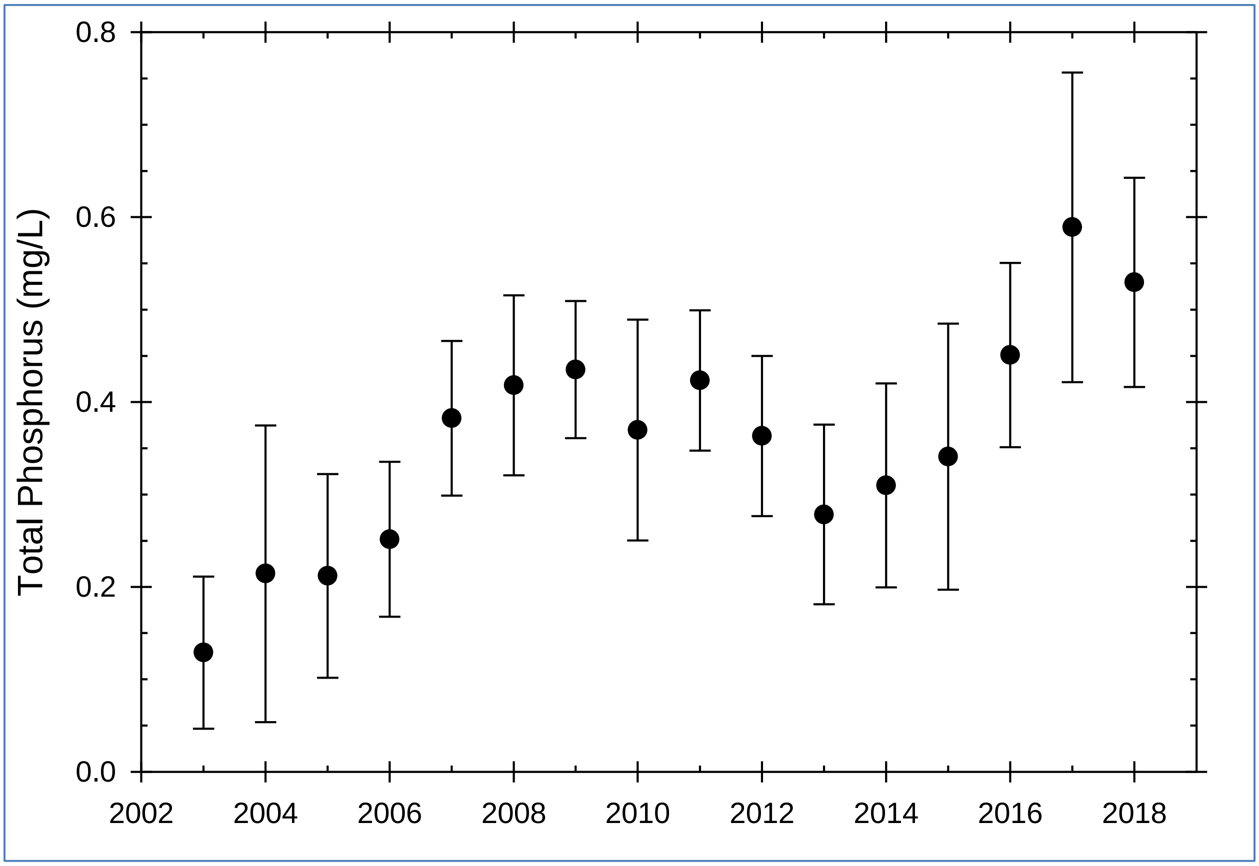

Figure 47 Growing season mean hypolimnetic total phosphorus in Lake Waccabuc (2003-2018)

While the overall trend in hypolimnetic total phosphorus appears to be increasing concentrations over time, there is annual variability that may preclude significance to this trend at a statistically relevant (significant) level. To test the statistical significance of apparent differences in growing season mean hypolimnetic total phosphorus over time, a Kruskal-Wallis (H Test) One Way Analysis of Variance on Ranks was conducted on hypolimnetic total phosphorus results for 200 through 2018. The number of data points per year ranged from 5 to 13. The Kruskal-Wallis H test showed that there was a statistically significant difference (greater than would be expected by chance) in median hypolimnetic total phosphorus concentrations between the different years, with an H value of 50.385 and 15 degrees of freedom at a $P < 0.0041$. A pairwise multiple comparison (Dunn's Method) was conducted to determine which years were statistically different from one another. Hypolimnetic total phosphorus in 2017 and 2018 were significantly higher than 2003 and 2005 ($P < 0.05$).

A comparison of monthly mean hypolimnetic total phosphorus in Lake Waccabuc is presented in Figure 48 for the period of 2006 through 2018. These data were fitted with a fifth order polynomial linear regression (r^2=0.4856). These data show that hypolimnetic total phosphorus in Lake Waccabuc starts out low in late spring and increases steadily until late-September, after which they start to decline as the lake mixes.

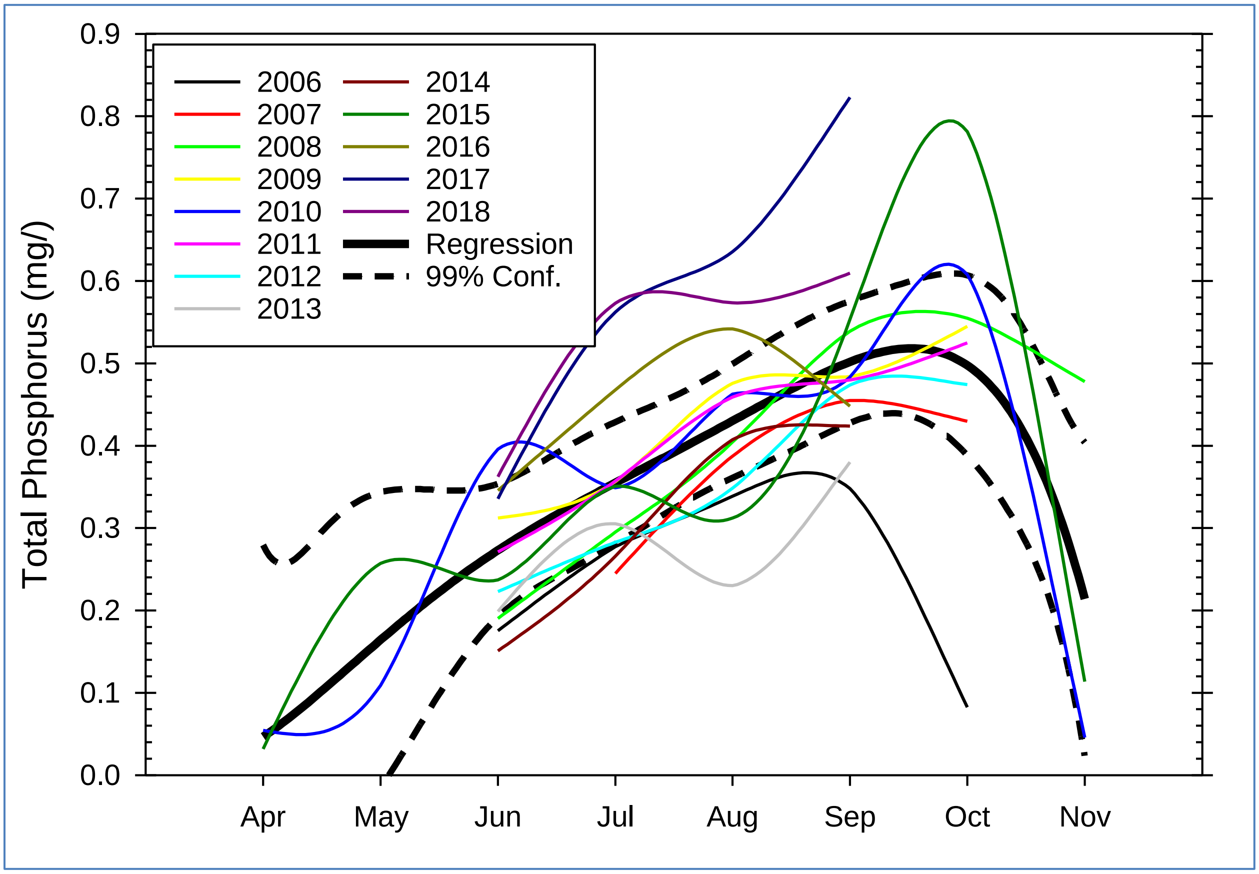

Figure 48 Comparison of monthly mean hypolimnetic total phosphorus in Lake Waccabuc (2006-2018)

Chlorophyll *a*

Lake Rippowam

Growing season mean chlorophyll *a* for 2003 through 2018 is presented in Figure 49. Growing season mean chlorophyll *a* was in the eutrophic range in most years, with significant intra-annual variability as demonstrated by the large confidence intervals.

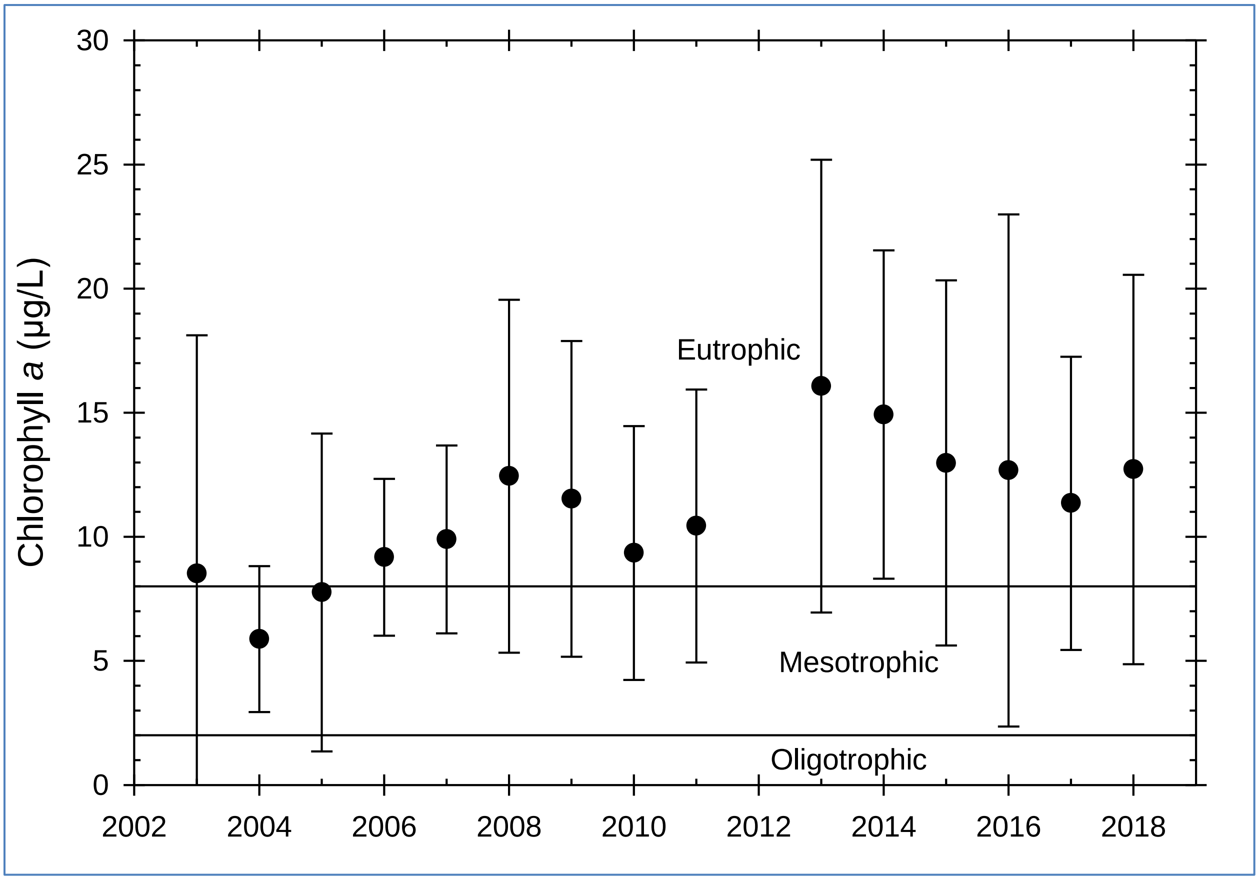

Figure 49 Growing season mean chlorophyll a in Lake Rippowam (2003-2018)

Lake Oscaleta

Growing season mean chlorophyll *a* for 2003 through 2018 is presented in Figure 50. Growing season mean chlorophyll *a* was in the mesotrophic range in most years, with significant intra-annual variability as demonstrated by the large confidence intervals.

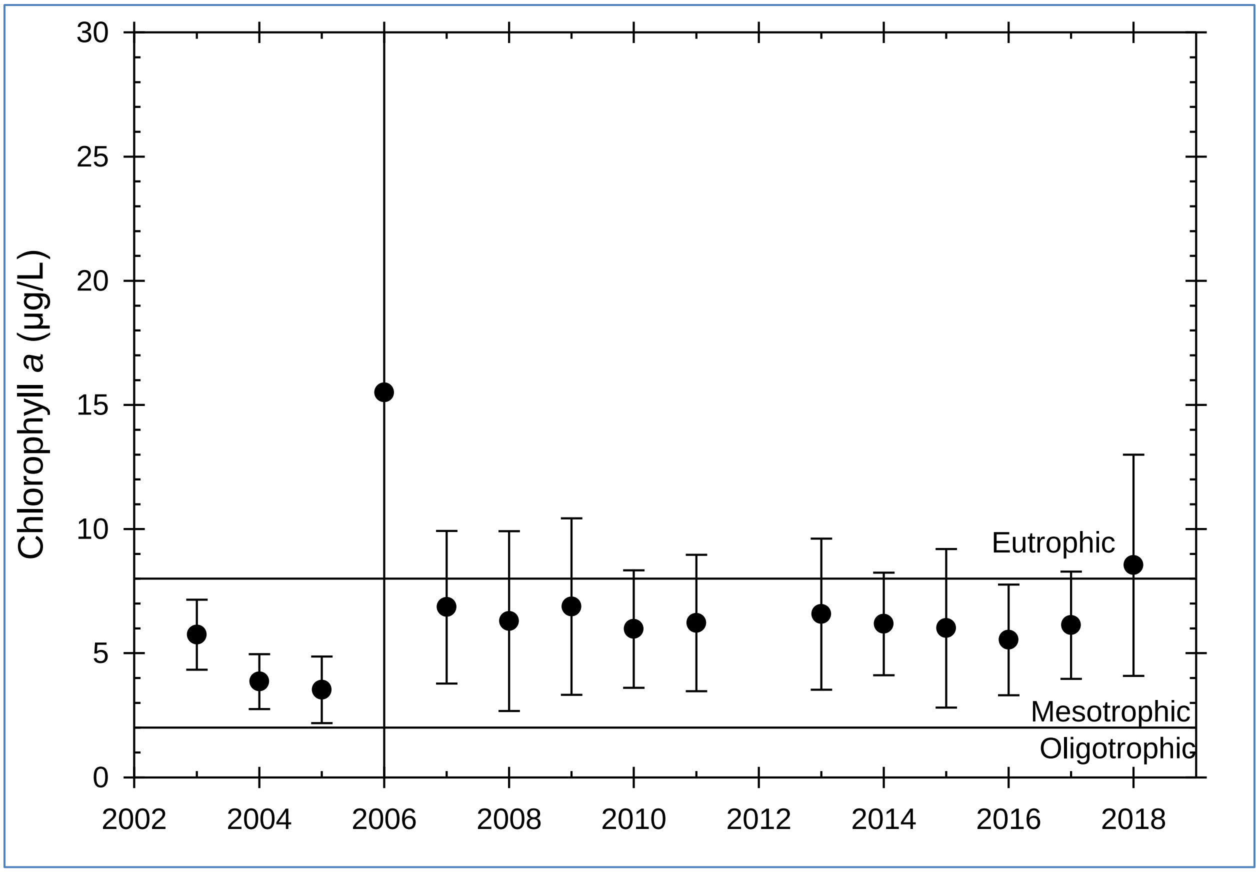

Figure 50 Growing season mean chlorophyll a in Lake Oscaleta (2003-2018)

Lake Waccabuc

Growing season mean chlorophyll *a* for 1996 through 1995 and 2003 through 2018 is presented in Figure 51. Growing season mean chlorophyll *a* was in the eutrophic range in most of the earlier years and bounced around between mesotrophic and eutrophic in the later years, with significant intra-annual variability as demonstrated by the extremely large confidence intervals. This is an indication of frequent algae bloom occurrence.

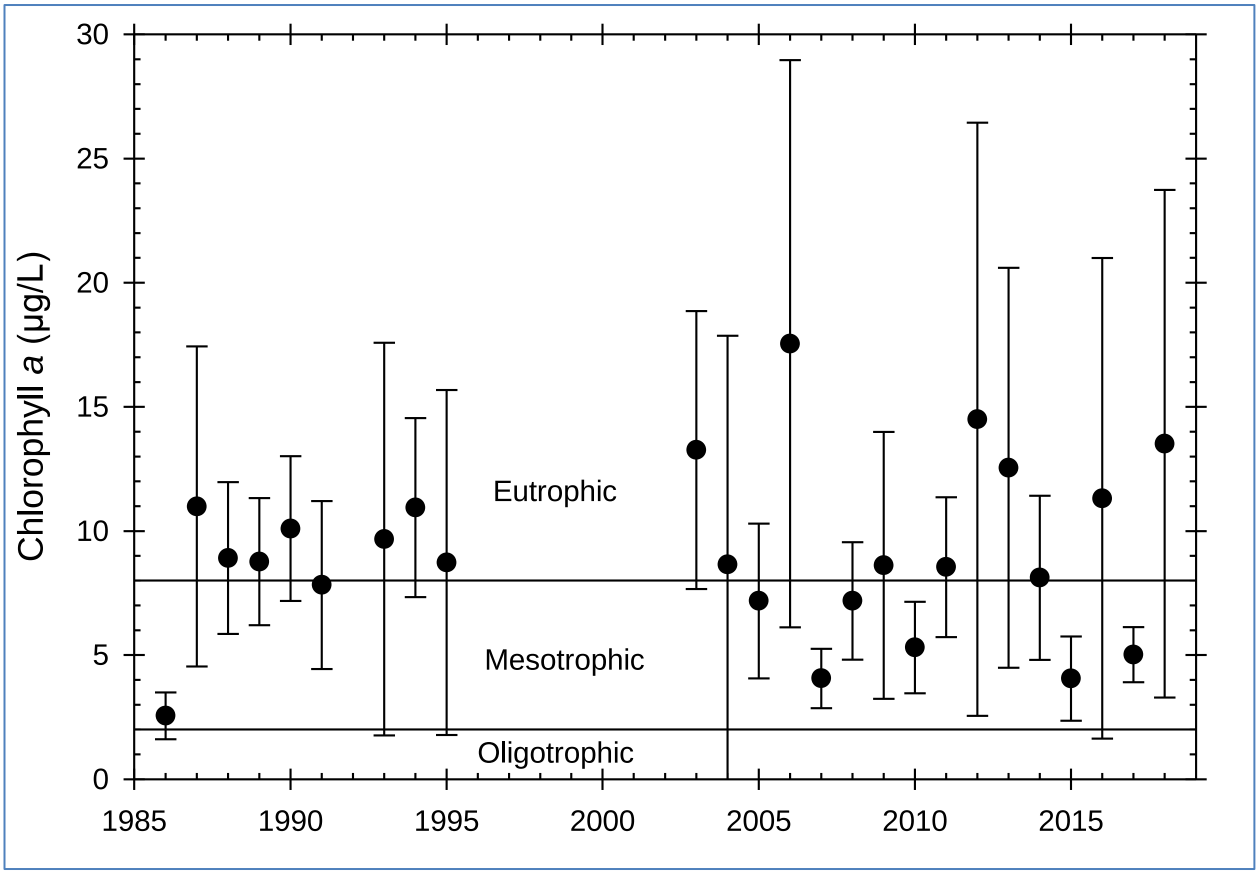

Figure 51 Growing season mean chlorophyll a in Lake Waccabuc (1986-2018)

Transparency

Growing season mean transparency for 2003 through 2018 is presented in Figure 52. Transparency was in the eutrophic range in most years with no significant trend.

Lake Rippowam

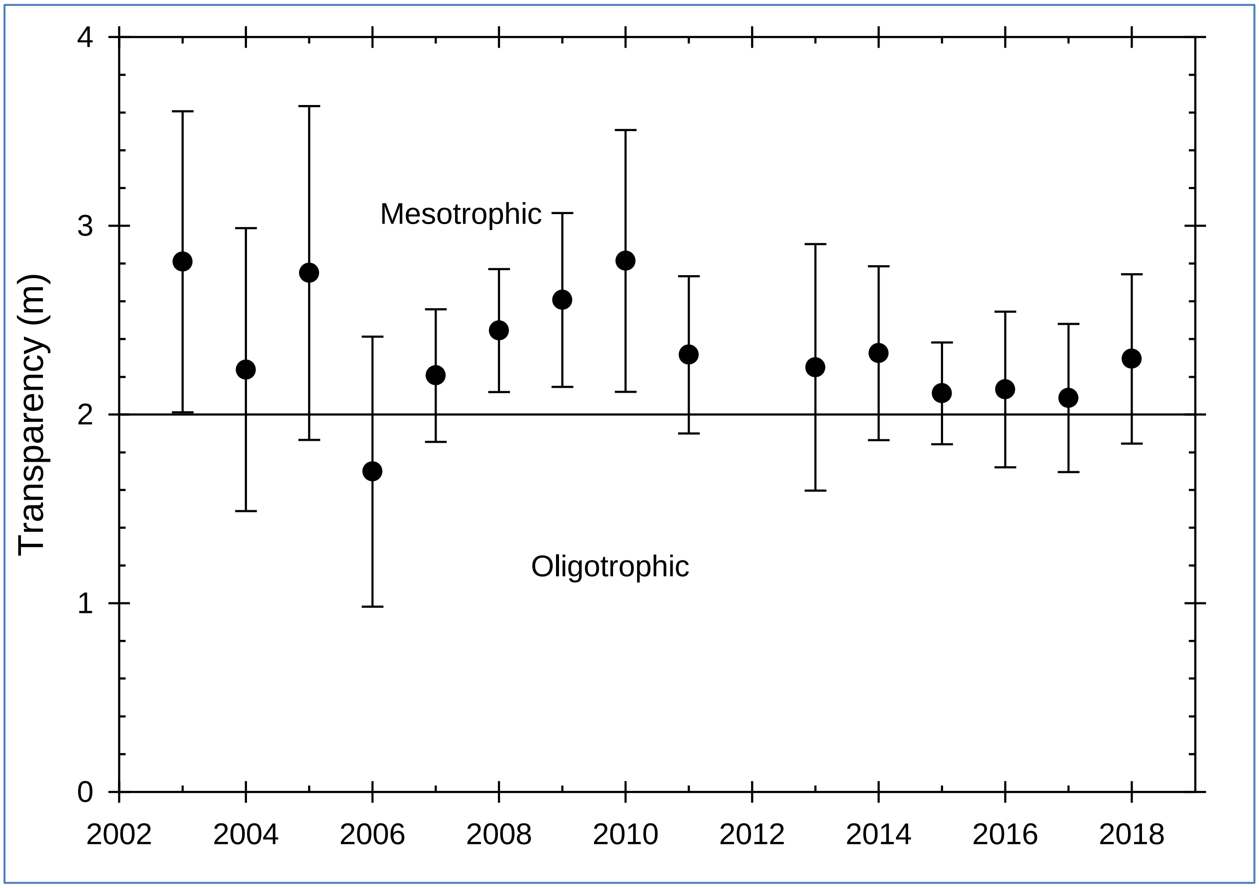

Figure 52 Growing season mean transparency in Lake Rippowam (2003-2018)

Lake Oscaleta

Growing season mean transparency for 2003 through 2018 is presented in Figure 53. Transparency was in the mesotrophic range throughout the period of record with no significant trend.

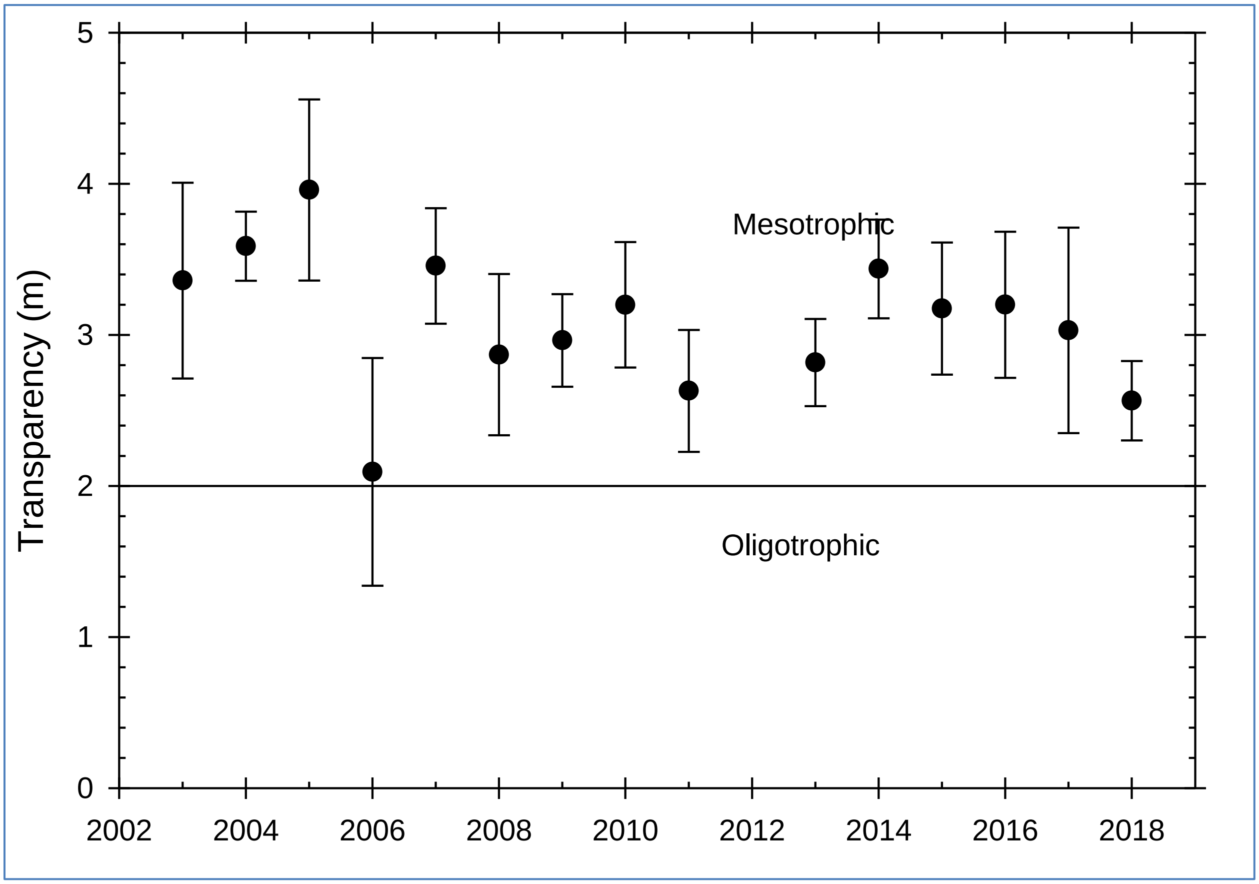

Figure 53 Growing season mean transparency in Lake Oscaleta (2003-2018)

Lake Waccabuc

Growing season mean transparency for 1986 through 1995 and 2003 through 2018 is presented in Figure 52. Transparency was in the eutrophic range in most years with no significant trend.

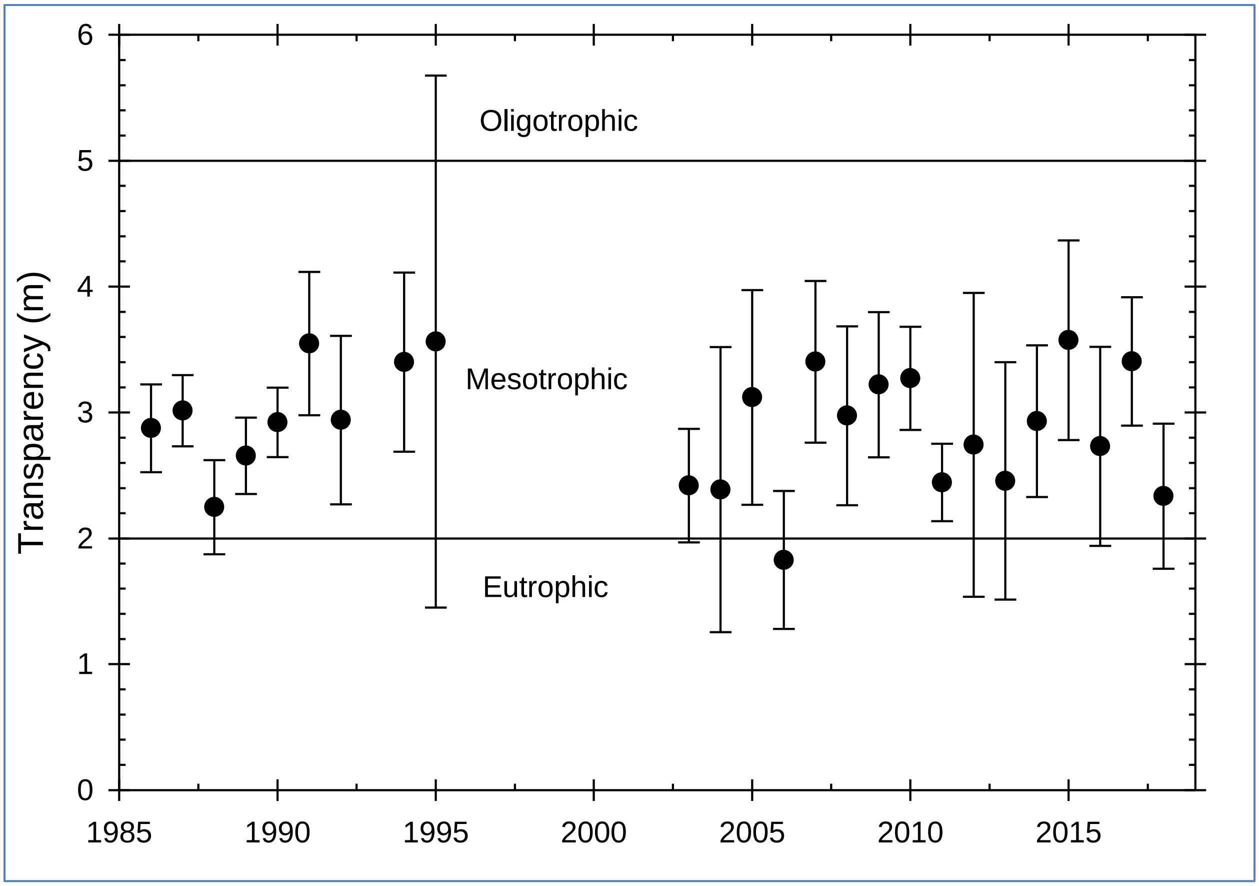

Figure 54 Growing season mean transparency in Lake Waccabuc (1986-2018)

Trophic State Index

Lake Rippowam

The Trophic State Indices for 2003 through 2018 are presented in Figure 55. Chlorophyll TSI was often in the eutrophic range while transparency TSI and phosphorus TSI were in the mesotrophic range.

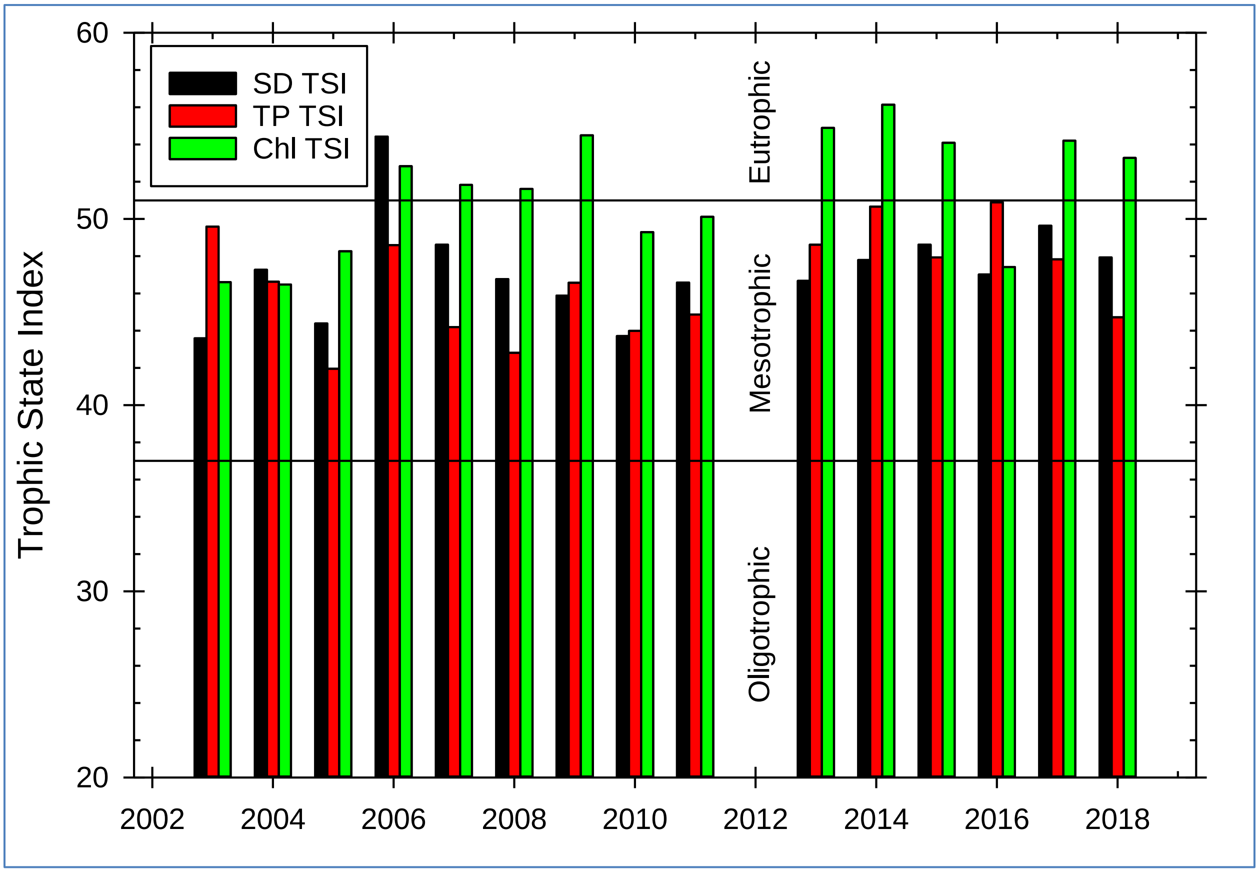

Figure 55 Trophic State Indices in Lake Rippowam (2003-2018)

Lake Oscaleta

The Trophic State Indices for 2003 through 2018 are presented in Figure 56. All TSIs were in the mesotrophic range throughout the period of record with the exception of 2006 when both phosphorus TSI and chlorophyll TSI were in the eutrophic range.

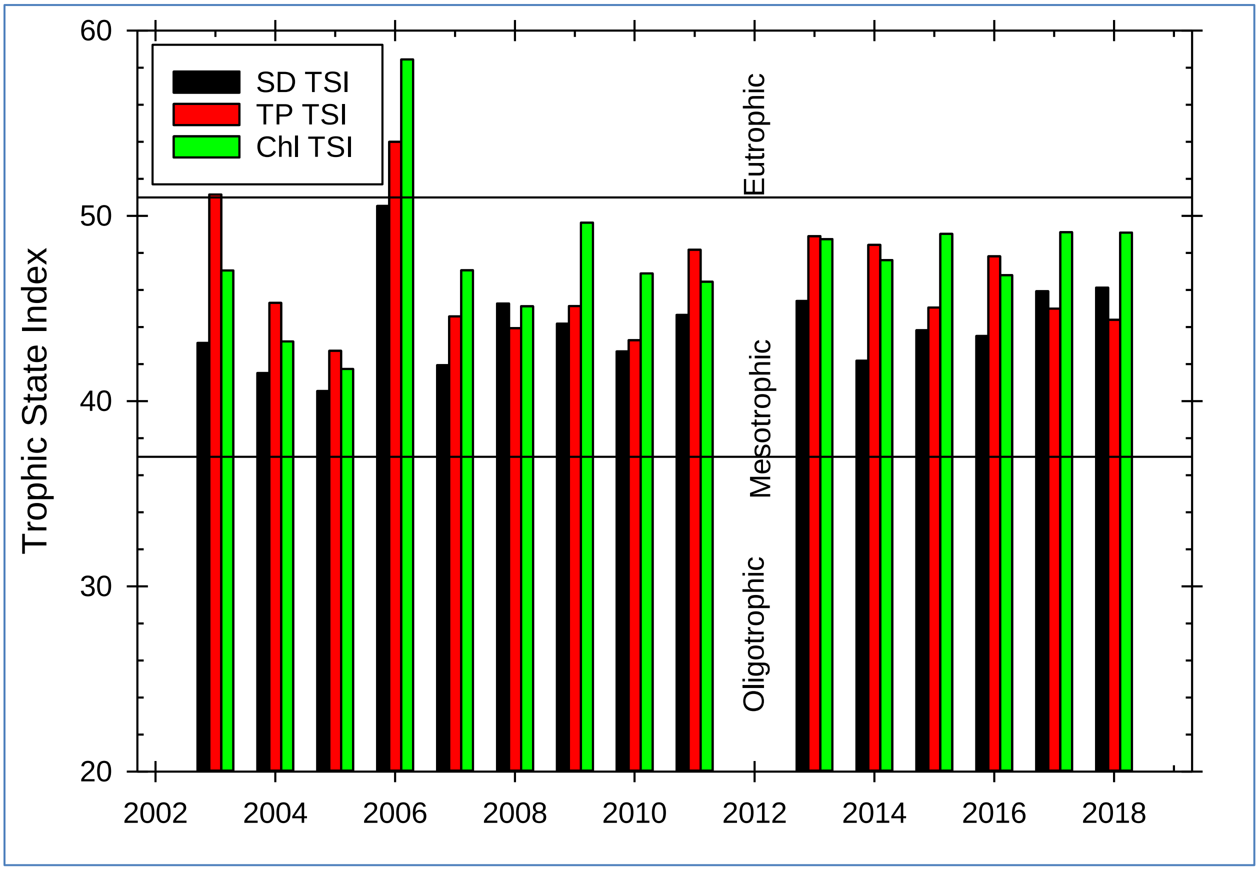

Figure 56 Trophic State Indices in Lake Oscaleta (2003-2018)

Lake Waccabuc

The Trophic State Indices for 1986 through 1995 and 2003 through 2018 are presented in Figure 57. Chlorophyll TSI was often in the eutrophic range while transparency TSI and phosphorus TSI were in the mesotrophic range. Transparency TSI was in the mesotrophic range throughout the period of record (exception 2006). Chlorophyll TSI was in the eutrophic range in more years than the other two TSIs. Phosphorus TSI was generally in the mesotrophic range, although it approached and entered the eutrophic range more frequently since 2003.

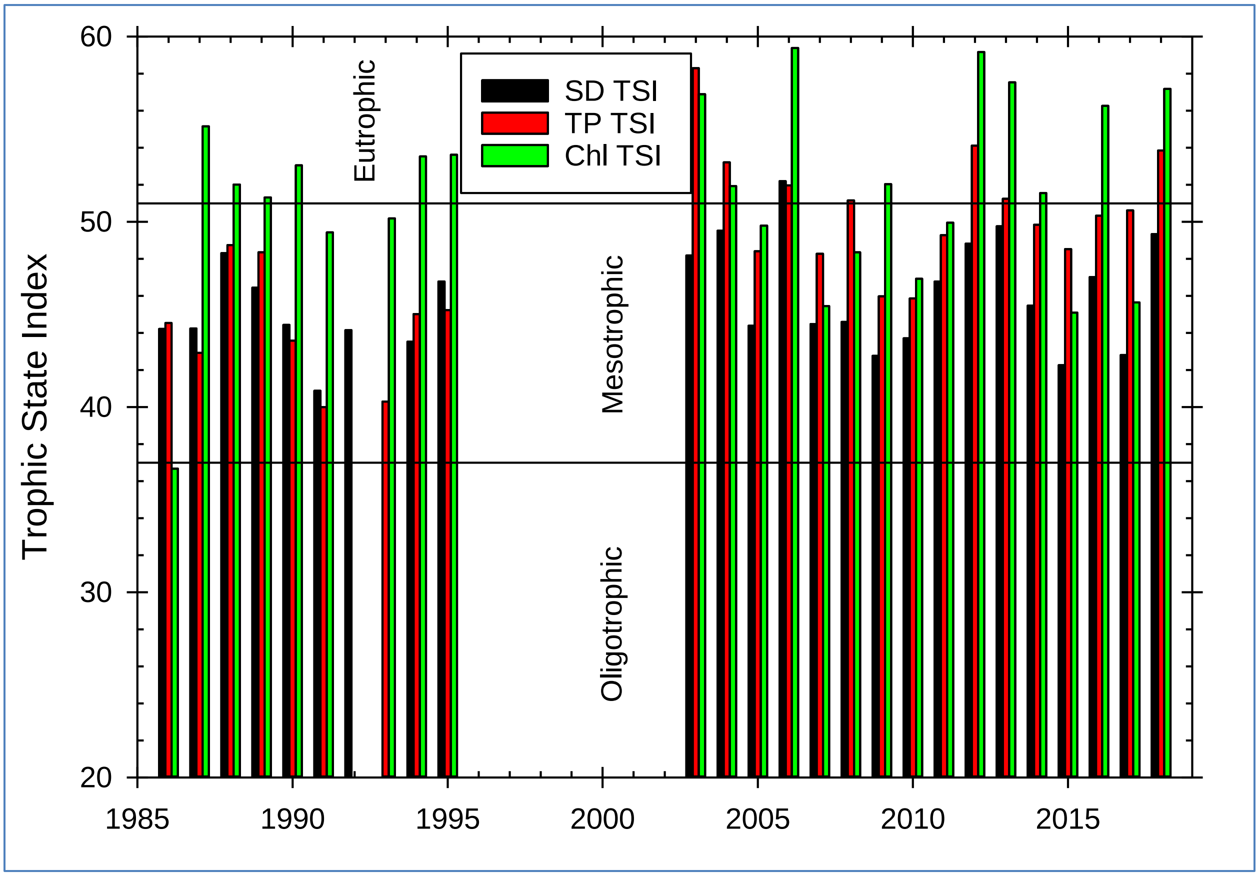

Figure 57 Trophic State Indices in Lake Waccabuc (1986-2018)

Predicting Water Quality

Statistical analyses were run for various water quality and climatic parameters to determine the factors that control water quality in the Three Lakes. These analyses looked at 2010 through 2018 data using CSLAP water quality data, precipitation data from the local weather station and temperature data from the NOAA station at Danbury, CT (nearest station with consistent temperature data). Water quality and climate data were summarized for the summer season (June through August) and the growing season (May through September). Local precipitation data were not available prior to 2010 and correlations were worse using temperature data prior to 2010, perhaps due to climate change.

Lake Rippowam

Transparency in Lake Rippowam was not correlated with climate and weakly correlated to water quality. Chlorophyll a correlated to summer minimum and maximum air temperatures, particularly the average summer maximum air temperature.

Transparency

Summer transparency was not correlated to summer total phosphorus or summer chlorophyll *a*. Summer transparency was not correlated to spring precipitation, summer precipitation, or summer maximum air temperature. This lack of relationship may perhaps be due to staining of water and shading from surrounding hillside that results in lower transparency without the presence of algae.

Summer transparency was compared to summer total phosphorus, summer chlorophyll *a*, summer nitrate/nitrite, summer ammonia and summer total dissolved nitrogen, resulting in the following multiple linear regression equation:

Summer SD = 4.150 - (30.633 * Summer TP) - (0.000236 * Summer Chl) + (0.782 * Summer Nox) + (4.705 * Summer NH4) - (2.246 * Summer TDN)
N = 8; R = 0.931; R^2 = 0.866; Adj R^2 = 0.531

While this multiple linear regression equation yields an R^2 of 0.866, none of the independent variables account for the ability to predict Summer SD ($P<0.05$). Therefore, growing season transparency was not correlated to any water quality or climate parameters.

Chlorophyll *a*

We examined the relationship between summer chlorophyll *a* and summer TP, nitrate/nitrite, ammonia and total nitrogen, none of which were able to predict chlorophyll separately or in combination. A linear regression of summer chlorophyll with total phosphorus yielded an R^2 = 0.186 and an Adj R^2 = 0.0503.

A multiple linear regression of chlorophyll *a* versus various climatic parameters yielded that summer chlorophyll *a* can best be predicted from a linear combination of the independent variables: Summer Precipitation ($P=0.013$), Summer Average Maximum Air Temperature ($P<0.001$), and Summer Average Minimum Air Temperature ($P=0.009$). This yielded the following multiple linear regression equation:

Summer Chl = 129.554 - (0.478 * Summer Precip) - (3.785 * Summer Ave Max) + (3.214 * Summer Ave Min)
N = 8; R = 0.985; R^2 = 0.970; Adj R^2 = 0.948
Standard Error of Estimate = 0.643

A further analysis of the parameters yielded that summer average minimum and maximum temperature accounted for the greatest correlation with summer chlorophyll *a*, with summer average maximum temperature accounting for the ability to predict summer chlorophyll *a* ($P < 0.05$). Those regression equations are:

Summer Chl = 153.775 - (2.268 * Summer Ave Max) + (0.652 * Summer Ave Min)
N = 8; R = 0.914; R^2 = 0.836; Adj R^2 = 0.770
Standard Error of Estimate = 1.347

Summer Chl = 169.842 - (1.983 * Summer Ave Max)
N = 8 ; R = 0.894; R^2 = 0.798; Adj R^2 = 0.765
Standard Error of Estimate = 1.361

Total Phosphorus

Climate and water quality parameters failed to predict summer total phosphorus in Lake Rippowam.

Lake Oscaleta

Summer transparency was not correlated to water quality or climate. Summer chlorophyll *a* was best predicted by summer total nitrogen although this may be the other way around due to presence of nitrogen-fixing bacteria in the lake. Summer total phosphorus was not related to climate.

Transparency

Summer transparency was not correlated to summer total phosphorus, summer chlorophyll *a* or spring and summer climatic conditions.

Chlorophyll *a*

Summer chlorophyll *a* was most correlated to summer total nitrogen (could be an artifact of nitrogen-fixing bacteria – with chlorophyll *a* the cause rather than an effect). That linear regression equation is:

Summer Chl = 2.354 + (8.229 * Summer TDN)
N = 8; R = 0.916; R^2 = 0.839; Adj R^2 = 0.812
Standard Error of Estimate = 0.298
Normality Test (Shapiro-Wilk): Failed (P = 0.025)

Summer chlorophyll *a* was not correlated to summer total phosphorus. Summer chlorophyll was not correlated to spring or summer climate conditions.

Total Phosphorus

Summer total phosphorus was not predicted by climate.

Lake Waccabuc

Summer total phosphorus predicts chlorophyll *a* in Lake Waccabuc, chlorophyll *a* predicts transparency. Climate and water quality parameters failed to predict summer total phosphorus in Lake Waccabuc.

Transparency

Transparency

A multiple linear regression of transparency with summer total phosphorus and summer chlorophyll *a* yielded a strong correlation with an R^2 of 0.833. However, not all of the independent variables appeared necessary. Summer chlorophyll *a* appeared to account for the ability to predict summer transparency ($P < 0.05$). The resultant linear regression equation is:

Summer SD = 3.551 - (0.0879 * Summer Chl)
N = 9; R = 0.910; R^2 = 0.828; Adj R^2 = 0.804
Standard Error of Estimate = 0.231

The result of this regression analysis showing the relationship between summer mean transparency and summer mean chlorophyll a in Lake Waccabuc is presented in Figure 58.

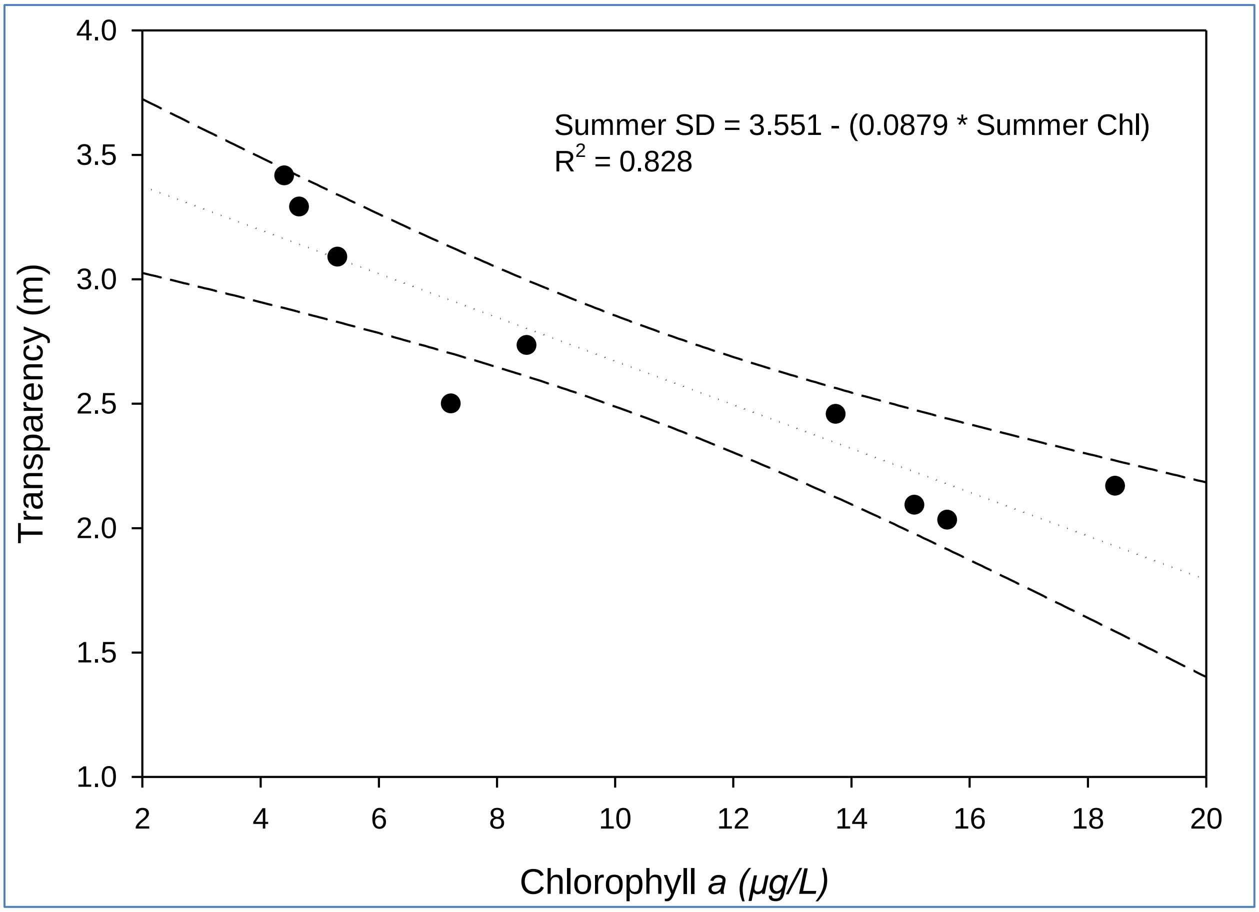

Figure 58 Relationship between summer mean transparency and chlorophyll a in Lake Waccabuc

Summer transparency was compared to summer total phosphorus, summer chlorophyll *a*, summer nitrate/nitrite, summer ammonia and summer total dissolved nitrogen, resulting in the following multiple linear regression equation:

> **Summer SD = 2.461 + (109.271 * Summer TP) - (0.132 * Summer Chl) - (57.060 * Summer Nox) - (30.693 * Summer NH4) - (4.007 * Summer TDN) + (0.109 * Summer TN/TP)**
> N = 9; R = 0.981; R^2 = 0.961; Adj R^2 = 0.846

While this multiple linear regression equation yields an R^2 of 0.961, none of the independent variables account for the ability to predict Summer SD (P<0.05). Therefore, growing season transparency was not correlated to any water quality or climate parameters.

Summer transparency was also not related to spring precipitation or temperature or to summer precipitation or temperature.

Chlorophyll *a*

We examined the relationship between summer chlorophyll *a* and summer TP, nitrate/nitrite, ammonia and TN. Summer chlorophyll *a* can be predicted from summer TP, using the following linear regression equation:

Summer Chl = -14.492 + (991.087 * Summer TP)
N = 9; R = 0.810; R^2 = 0.657; Adj R^2 = 0.607
Standard Error of Estimate = 3.388

Climate conditions (spring precipitation, summer precipitation or summer maximum air temperature) did not account for the ability to predict summer chlorophyll *a*.

Total Phosphorus

Neither climate conditions nor water quality parameters accounted for ability to predict summer total phosphorus in Lake Waccabuc.

Aquatic Plants

Figure 59 Photo of macrophyte beds near Lake Oscaleta outlet

Three Lakes Council conducts periodic professional macrophyte mapping on the lakes using the rake toss method. The resultant data is comprised of relative densities of each identified macrophyte for each rake toss site. These data were analyzed to determine the number of sites where each species was present. Relative abundance was calculated by normalizing each species site presence to the sum of all species site presence expressed as 100 percent. In this instance, relative abundance is the percent composition of an aquatic plant species relative to the total number of aquatic plant species in the lake. So, for example, Eurasian milfoil may have been present in 66 rake toss sites. White waterlily may have been present at 63 sites. The total sites with macrophytes present was 129. The relative abundance of Eurasian milfoil is therefore 51 percent (66/129*100). Relative abundance allows comparison between lakes regardless of the number of rake toss sites in use by normalizing all values to 100 percent.

Lake Rippowam

In 2016, 60 rake toss sites were sampled on Lake Rippowam. Eurasian watermilfoil was the most dominant macrophyte, present in 48.3 percent of all sites with a relative abundance of 39.2 percent, followed by white water lily present at 35 percent of the sites with a relative abundance of 38.4 percent and yellow water lily present at 13.3 percent of the sites with a relative abundance of 10.8 percent. A total of 10 species were identified. Submersed macrophytes were present at 48.3 percent of the sites (relative abundance of 55.8%) and floating macrophytes were present at 38.3 percent of the sites (relative abundance of 44.2%). The Lake Rippowam macrophyte results are summarized in Table 9.

Table 9 Macrophyte relative abundance in Lake Rippowam (2016)		
Species	Presence	Relative Abundance
Eurasian Water Milfoil	48.3%	39.2%
White Water Lily	35.0%	28.4%
Spatterdock	13.3%	10.8%
Benthic Filamentous Algae	8.3%	6.8%
Coontail	5.0%	4.1%
Bass Weed	3.3%	2.7%
Floating Filamentous Algae	3.3%	2.7%
Watermoss	3.3%	2.7%
Arrowhead	1.7%	1.4%
Small Duckweed	1.7%	1.4%

Lake Oscaleta

In 2016, 87 rake toss sites were sampled on Lake Oscaleta. Eurasian watermilfoil was the most dominant macrophyte, present in 75.9 percent of all sites with a relative abundance of 16.3 percent, followed by white water lily present at 72.4 percent of the sites with a relative abundance of 15.5 percent, bassweed present at 49.4 percent of the sites with a relative abundance of 10.6 percent and coontail present at 47.1 percent of the sites with a relative abundance of 10.1 percent. A total of 20 species were identified. Submersed macrophytes were present at 85.1 percent of the sites (relative abundance of 50.7%) and floating macrophytes were present at 82.8 percent of the sites (relative abundance of 49.3%). The Lake Oscaleta macrophyte results are summarized in Table 10.

Table 10 Macrophyte relative abundance in Lake Oscaleta (2016)		
Species	Presence	Relative Abundance
Eurasian Water Milfoil	75.9%	16.3%
White Water Lily	72.4%	15.5%
Bass Weed	49.4%	10.6%
Coontail	47.1%	10.1%
Spatterdock	37.9%	8.1%
Watershield	37.9%	8.1%
Robbin's Pondweed	36.8%	7.9%
Creeping Bladderwort	34.5%	7.4%
Benthic Filamentous Algae	19.5%	4.2%
Arrowhead	10.3%	2.2%
Floating Filamentous Algae	10.3%	2.2%
Common Waterweed	9.2%	2.0%
Small Duckweed	6.9%	1.5%
Leafy Pondweed	5.7%	1.2%
Ribbon-Leaf Pondweed	4.6%	1.0%
Brittle Naiad	2.3%	0.5%
Wild Celery	2.3%	0.5%
Bur-reed	1.1%	0.2%
Southern Naiad	1.1%	0.2%
Waterthread Pondweed	1.1%	0.2%

Lake Waccabuc

In 2017, 116 rake toss sites were sampled on Lake Waccabuc. Eurasian watermilfoil was the most dominant macrophyte, present in 82.8 percent of all sites with a relative abundance of 22.4 percent, followed by white water lily present at 38.8 percent of the sites with a relative abundance of 10.5 percent, benthic filamentous algae present at 35.3 percent of all sites with a relative abundance of 9.6 percent and coontail present at 33.6 percent of the sites with a relative abundance of 9.1 percent. A total of 23 species were identified. Submersed macrophytes were present at 87.9 percent of the sites (relative abundance of 61.8%) and floating macrophytes were present at 54.3 percent of the sites (relative abundance of 38.2%). The Lake Waccabuc macrophyte results are summarized in Table 11.

Table 11 Macrophyte relative abundance in Lake Waccabuc (2017)		
Species	Presence	Rel. Abundance
Eurasian Water Milfoil	82.8%	22.4%
White Water Lily	38.8%	10.5%
Benthic Filamentous Algae	35.3%	9.6%
Coontail	33.6%	9.1%
Watershield	30.2%	8.2%
Bass Weed	29.3%	7.9%
Water Stargrass	25.9%	7.0%
Floating Filamentous Algae	24.1%	6.5%
Pondweed sp.	19.0%	5.1%
Spatterdock	15.5%	4.2%
Common Waterweed	9.5%	2.6%
Arrowhead	6.0%	1.6%
Robbin's Pondweed	6.0%	1.6%
Common Bladderwort	5.2%	1.4%
Brittle Naiad	2.6%	0.7%
Leafy Pondweed	1.7%	0.5%
Curly-Leaf Pondweed	0.9%	0.2%
Dwarf Milfoil	0.9%	0.2%
Quillwort	0.9%	0.2%
Slender Naiad	0.9%	0.2%
Small Duckweed	0.9%	0.2%
Bur Reed	0.0%	0.0%
Ribbon-Leaf Pondweed	0.0%	0.0%

Watershed Investigation

CEE conducted a watershed investigation on October 2 and 3, 2018. Each road within the watershed was driven and areas of interest (NPS problem areas, etc.) were geo-located, examined and photographed. A map of the traveled roads, GPS sites and photograph locations is presented in Figure 60. An index map of the watershed investigation sites is presented in Figure 61. Maps of the watershed sites in the western portion of the watershed and central and eastern portion of the watershed are shown in Figure 62 and Figure 63, respectively. A description of the watershed investigation sites is shown in Table 12.

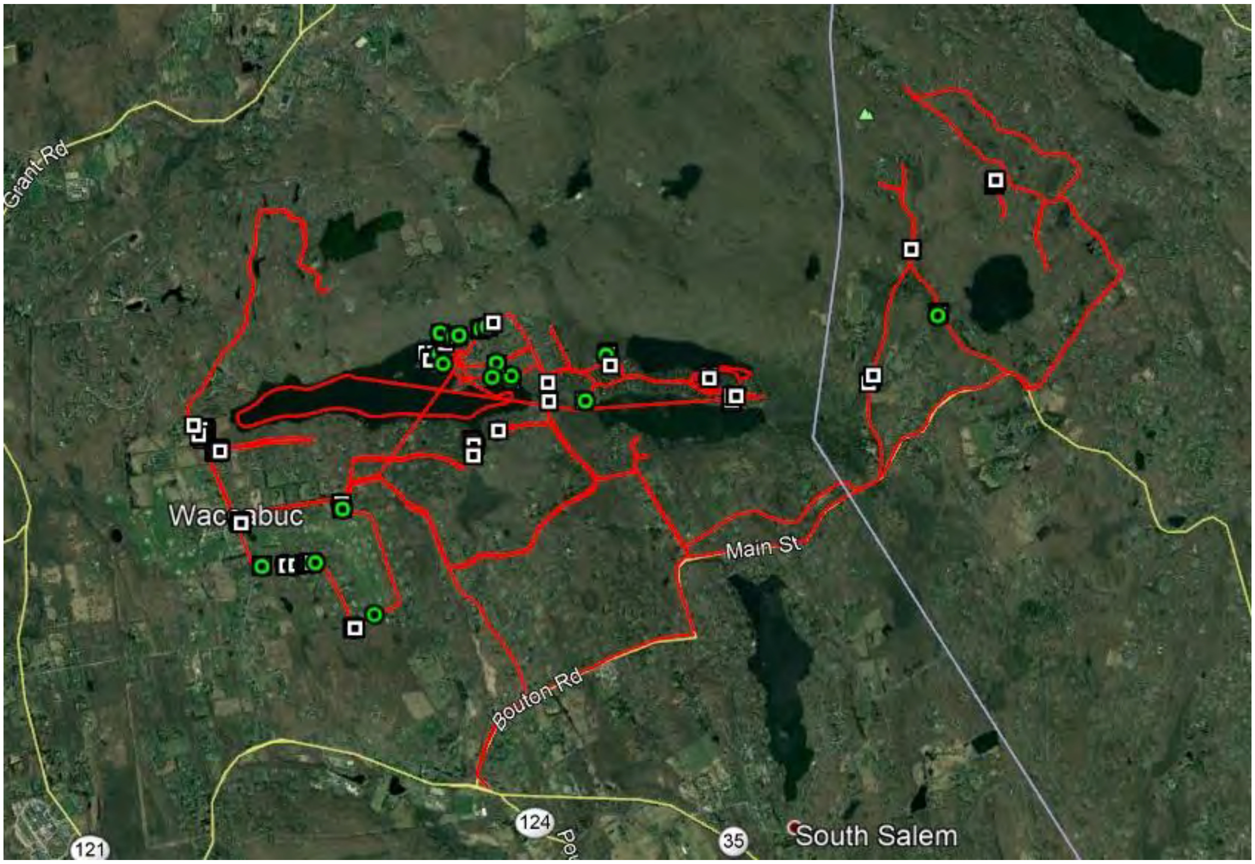

Figure 60 Aerial map of watershed investigation showing roads traveled (red line), GPS sites (green circles) and photograph locations (white squares)

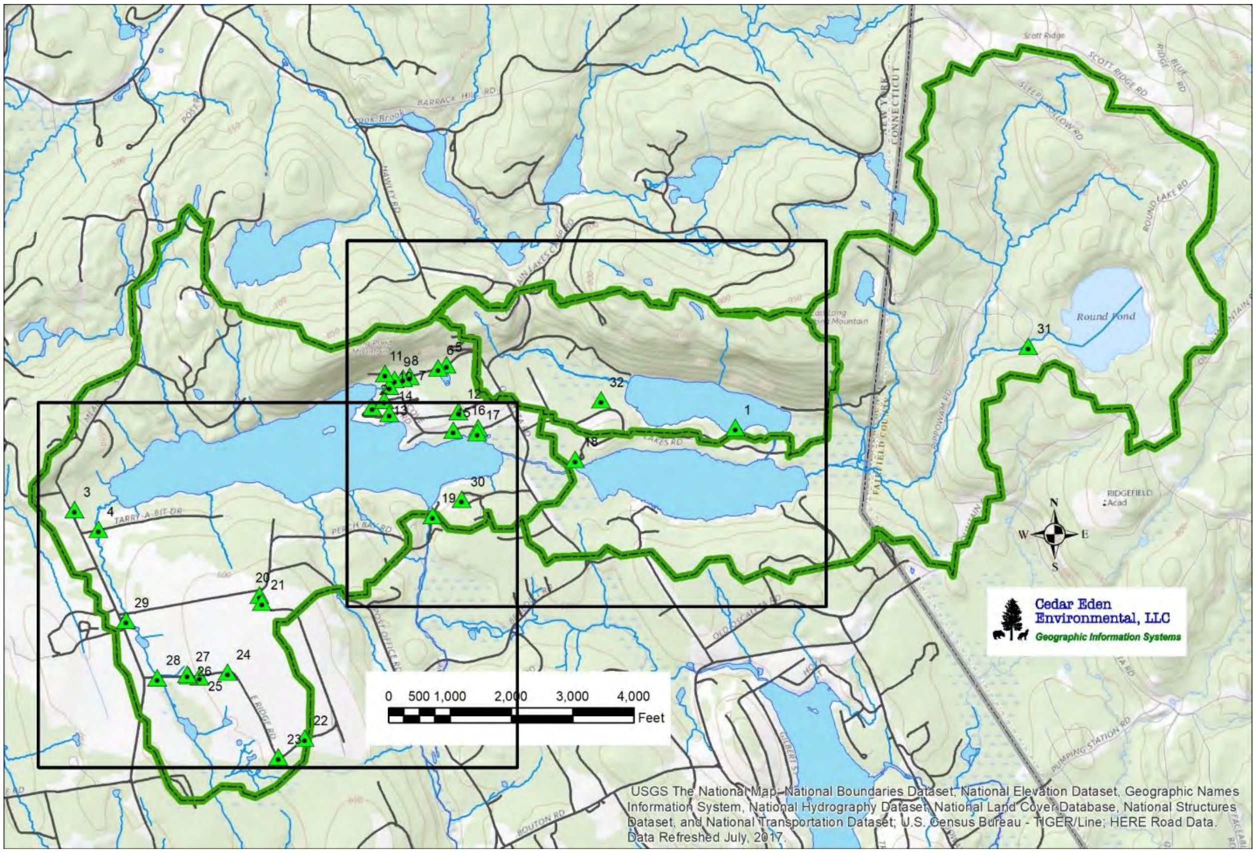

Figure 61 Index map of watershed investigation sites

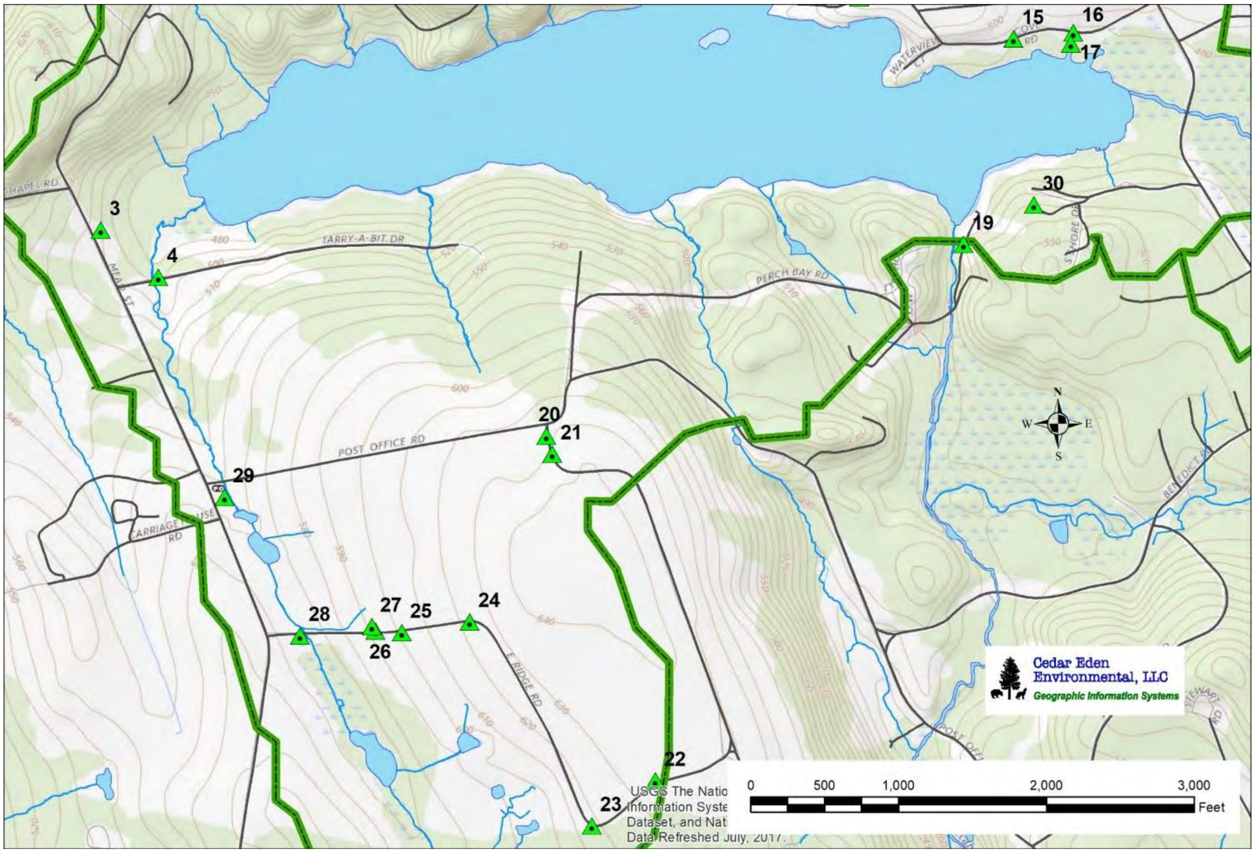

Figure 62 Map of watershed investigation sites in the western watershed

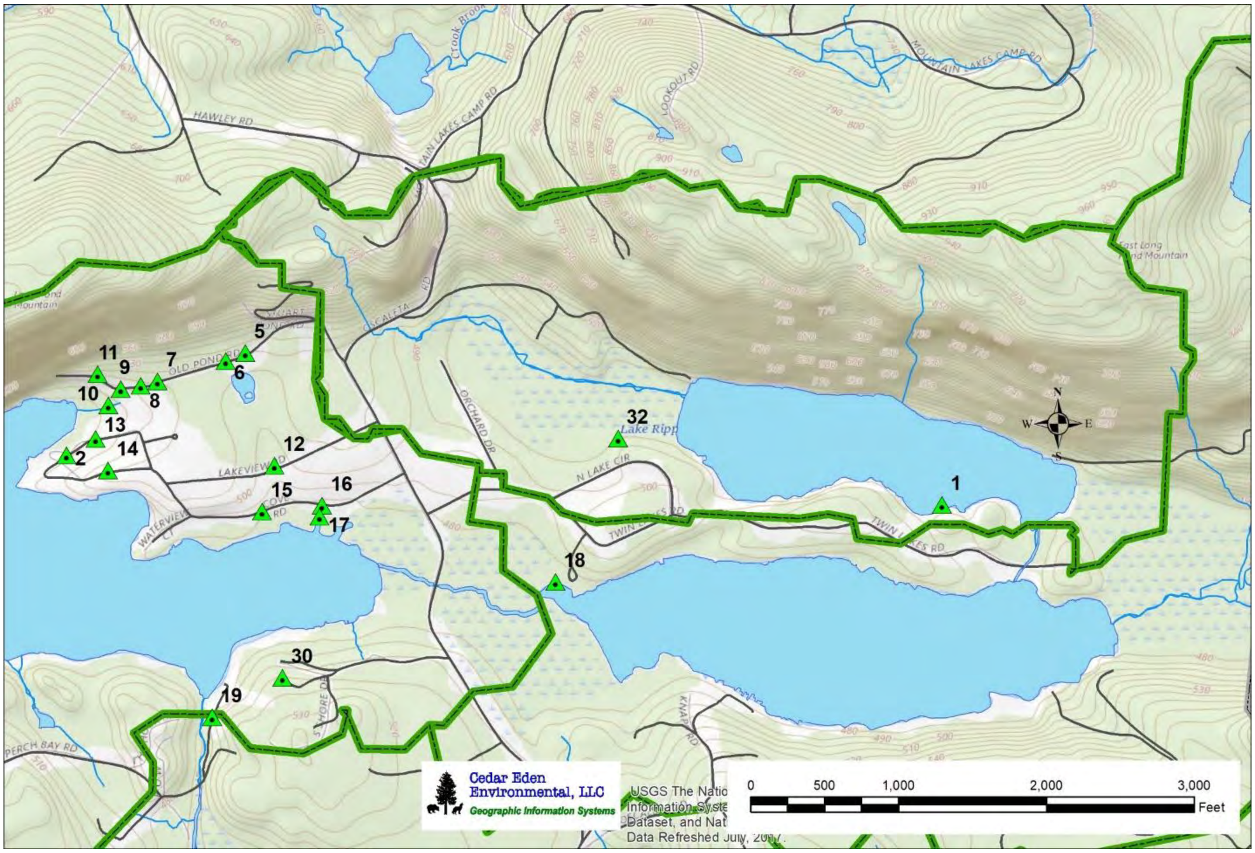

Figure 63 Map of watershed investigation sites in the central and eastern watershed

Table 12 Watershed Investigation Sites			
ID	**Type**	**Description**	**Location**
1	lake buffer	shoreline, bare earth, steep bank, undergrowth removed	Twin Lakes Road
	channel	channel between Rippowam & Oscaleta (also lake gage)	Twin Lakes Road
	channel	Channel between Oscaleta & Waccabuc (at culvert)	
2	storm drain	broken storm drain to lake, runoff down access road	
3	BMP	storm basin outlet level spreader doesn't work	Mead Street
4	dirt road	road runoff into gulley, woods & stream; long erosion slope; all that material dumps along bank of inlet; upslope paved drives and lawns rain into road, contributing to problem	Tarry-A-Bit
	dirt road	erosion	Old Pond Road
5	dirt road	full of gravel nearly to top of drain pipes due to gulley erosion	Old Pond Road
6	dirt road	erosion	Old Pond Road
7	dirt road	steeper slope, gulley erosion in gravel @ 29 OPR, crosses road and into woods at #182	Old Pond Road
8	dirt road	gulley erosion, into woods	Old Pond Road

9	dirt road	40 OPR, gravel into woods, into wetland and stream at #185	Old Pond Road
10	dirt road	gravel into wetland and stream	Old Pond Road
11	dirt road	private launch into Waccabuc	Old Pond Road
12	Homeowner practices	pumping muddy lawn water into road and stream channel @ 17 Lakeview and into lake	near 12 Lakeview
13		Bottom of Cove Road loop ROW (forested w/power lines)	Cove Road
14		Top of Cove Road loop ROW	Cove Road
15	access	Lake Waccabuc Association Lake Access	
16 & 17	lake gage	Waccabuc lake gage - at road and at lake	
18	lake gage	Oscaleta lake gage	
19	outlet	Waccabuc outlet/River - good riparian habitat, vernal pools between River and Perch Bay Beach Road	
20	dirt road	flat, poorly crowned, lower than grass edges so rainfall runs down road & scours channels, near eastern entrance at PO Rd	East Ridge Road
21	dirt road	erosion	East Ridge Road
22	dirt road	apparent watershed boundary, slope same as 194	East Ridge Road
23	dirt road	erosion but it just moves down road and into grass field	East Ridge Road
24	dirt road	scoured ditches both sides of road	East Ridge Road
25	dirt road	heavy gulley scour	East Ridge Road
26	dirt road	gulley directed into woods, finer material deposits in woods in wide fan, into wetland & maybe main Waccabuc inlet	East Ridge Road
27	dirt road	same as above	East Ridge Road
28	dirt road	silt into wetlands uphill side of road, near stream	East Ridge Road
29	erosion	overflow from USPS parking lot and runs into stream; sheet flow from road runs down "picnic" area and erodes soil into stream; area NOT picked up by Mead Street SW BMP	Mead Street
30		drainage ditch from upper road to lower road	South Shore Drive
30A	road crossing	driveway and streambank (Round Pond outlet road crossing)	Rippowam Rd, CT
30B		little stream in the woods	Rippowam Rd, CT
31	erosion	Round Pond outlet road crossing; erosion into stream at base of paved hill	Oreneca Road, CT
31B		headwater stream	Harrison Ct, CT
32		water treatment plant	North Lake Circle

Unique and Special Habitat

Waccabuc outlet/Waccabuc River

While not technically in the watershed, the riparian habitat along the Waccabuc River just below the Lake Waccabuc dam is a unique and special habitat with numerous vernal pools (Figure 64).

Figure 64 Photo of riparian habitat with vernal pools along Waccabuc River (Site 19)

Beaver Activity

Evidence of beaver activity was observed in the road culvert between Lake Oscaleta and Lake Waccabuc (Figure 65). This was reported to be a frequent occurrence and drastically alters the flow of water between all three lakes.

Figure 65 Photo of plugged culvert due to beaver activity (Oscaleta-Waccabuc channel)

Stormwater Management

Dirt and Gravel Roads

There are three significant unsurfaced (dirt and gravel) roads within the Three Lakes watershed, all located with the Lake Waccabuc watershed – Tarry-A-Bit Road, Old Pond Road and East Ridge Road. Significant erosion and movement of road surface materials off of the road surface into surrounding lands, streams and wetlands were observed.

Tarry-A-Bit Road

Gully and ditch erosion near the stream crossing on Tarry-A-Bit Road is shown in Figure 66. Note that the properties to the upper left of this photograph contain steep lawns and paved driveways that direct stormwater flow onto the road surface, contributing to excessive erosion during storm events. Significant amounts of road bed material at this location are transported into and along the main southwestern tributary to Lake Waccabuc, as shown in Figure 67.

Figure 66 Photo of erosion on Tarry-A-Bit Road (Site 4)

Figure 67 Photo of road material accumulating along Waccabuc inlet stream (Site 4)

Old Pond Road

There were numerous locations along Old Pond Road where gulley erosion resulted into the transport of material into storm drains and adjacent lands, streams and wetlands. These can be seen in Figures 68 through 74.

Figure 68 Gulley erosion and runoff entering storm drain on Old Pond Road (Sites 5 & 6)

Figure 69 Clogged storm drain and road material washing into drainage ditch on Old Pond Road (Sites 5 & 6)

Figure 70 Gulley erosion on Old Pond Road (Sites 7 & 8)

Figure 71 Gulley erosion and runoff of materials on Old Pond Road (Sites 7 & 8)

Figure 72 Clogged storm drain and runoff of road material on Old Pond Road (Sites 9 & 10)

Figure 73 Long distance transport of road material into wetland and stream on Old Pond Road (Sites 9 & 10)

Figure 74 Gulley erosion on private launch off Old Pond Road (Site 11)

East Ridge Road

There were numerous locations along East Ridge Road where gulley erosion resulted into the transport of material into storm drains and adjacent lands, streams and wetlands. These can be seen in Figures 75 through 81.

Figure 75 Photo of road scour and erosion on East Ridge Road (Site 20)

Figure 76 Photo of road scour and erosion on East Ridge Road (Site 20)

Figure 77 Photo of road scour and erosion on East Ridge Road (Sites 21 & 24)

Figure 78 Photo of road scour and erosion on East Ridge Road (Site 24)

Figure 79 Photo of road scour and erosion on East Ridge Road (Sites 25 & 26)

Figure 80 Photo of material runoff from erosion on East Ridge Road (Sites 26 & 27)

Figure 81 Photo of erosion materials being deposited in wetland and stream on East Ridge Road (Site 28)

Lakeshore Buffers

Figure 82 shows a particularly good example of poorly managed lakefront property with bare steep slopes and little to no shoreline buffer vegetation.

Figure 82 Photo of bare earth and lack of lakeshore buffer on steep slope (Site 1)

Stormwater Runoff

Roof/Lawn Runoff

One of the best ways to control stormwater as with all non-point source pollution is to deal with it as close to the source as possible. Many properties around the lake and within the watershed do not manage stormwater wisely but instead allow it to run quickly off the property. Figure 83 shows an example where a homeowner was pumping accumulated stormwater/basement groundwater off their property and into the road, where it ran down the road and entered a storm drain where it was discharged into a stream channel.

Figure 83 Runoff from roof/lawn carrying silt along road into storm drain and stream channel (Site 12)

Cove Road

Figure 84 shows a site where a storm drain pipe has collapsed, forcing storm water to run directly into the lake down a small paved drive rather than directly into the lake within a pipe. Neither situation is ideal from a lake management perspective as storm runoff contains excess nutrients and bacteria. This particular storm drain drains a significant area of the lower Cover Road loop.

Figure 84 Collapsed storm drain and overland flow into Lake Waccabuc on Cove Road (Site 2)

Mead Street/USPS Parking Lot

Stormwater runoff along upper Mead Street overflows from the road and through the USPS parking lot and yard, resulting in erosion and movement of material from the parking lot and yard and into the nearby southwest tributary to Lake Waccabuc. This area is not picked up by the stormwater BMP at the base of Mead Street hill. This can be seen in Figure 85 and Figure 86.

Figure 85 Runoff and erosion from Post Office parking lot and Mead Street (Site 29)

Figure 86 Runoff and erosion from Mead Street into stream (Site 29)

Oreneca Road

Figure 87 shows roadside erosion into a headwater stream in the upper Lake Oscaleta watershed.

Figure 87 Photo of roadside erosion into stream on Oreneca Road (Site 31)

Pollutant Budgets

The pollutant budgets for a lake are similar to the hydrologic budget in that they are calculated by balancing inputs and outputs to the waterbody. A pollutant budget can be summarized as:

external load = outflow + sedimentation - internal load + change in storage

Developing a pollutant budget based on such a mass balance equation requires a considerable amount of watershed monitoring and is beyond the scope of this project. However, these budgets can also be estimated by using land use information for a given watershed and literature values of expected pollutant contributions for each of the various land uses. These values are called export coefficients and describe the amount of a pollutant contributed for a given area of land use. The Three Lakes phosphorus budgets were calculated using this methodology. Land Use was obtained using the 2011 NLCD Land Use/Land Cover dataset. The watershed was digitized using existing topographic data. Pollutant concentrations and impervious cover data for each land use were determined using several references, including the NLCD LULC dataset, NHDES Simple Method EMC Guidance, IDEM Pollutant Load Model Documentation for Critical Areas, and the Stormwater Management Resource Center.

Land use categories were combined into more general groups and export coefficients were selected from Reckhow (1980) that might best represent conditions found in Westchester County. Median values provided by Reckhow 1980 were selected, since these might be more appropriate in a developed area where much of the stormwater is discharged to surface waters untreated. Export coefficients were updated based on recent literature (Sharma et al., 2012; Harmel et al., 2006; McCarthy 2008).

Additional Nutrient Sources

Upstream Waterbodies

Pollutant budgets were calculated for each lake based on their direct watershed, excluding drainage from upstream lake watersheds. Upstream lake contributions were then added based on the pollutant load of that upstream lake attenuated by the lakes' phosphorus retention coefficient.

Twin Lakes Water Supply

The Twin Lakes water district supplies water to residents of Lake Rippowam and Oscaleta at a rate of approximately 3.7 million gallons per year (average of last three years). Phosphorus is added at a concentration of 3.02 ppm. This adds a potential additional load of 13.75 kg P per year to the watershed, which, for the purposes of modeling, was split equally between Rippowam and Oscaleta.

Internal Loading

Each of the lakes exhibited a build-up of phosphorus within the hypolimnion, indicating internal loading. This is an additional source of phosphorus that needs to be taken into account. The amount of internal phosphorus loading was calculated as the change in phosphorus mass within the hypolimnion over time.

Internal loading is discussed in detail in the "Internal Phosphorus Loading" section of this report.

Lake Rippowam

Results of the nutrient budget modeling for Lake Rippowam are summarized in Table 13 and Figure 88. Lake Rippowam receives an annual load of 27.3 kg of phosphorus per year and 303.0 kg of nitrogen per year. The watershed is small and relatively undeveloped. As a result, the total phosphorus load is small, making the percent contribution from precipitation (24.9%) and the water supply (25.2%) quite significant and the water supply orthophosphorus buffer by far the largest controllable source of phosphorus within the watershed.

Table 13 Nutrient Budget Calculations and Results for Lake Rippowam Watershed								
Land Use	Area (ha)	Loading Coefficients (kg/ha/yr)		Annual Load (kg/year)		Annual Load (Percent)	
		TP	TN	TP	TN	TP	TN
Open Water	14.45			0.0	0.0	0.0%	0.0%
Open Lands	6.54	1.1	5.5	7.2	36.0	26.3%	11.9%
Mod./High Dens. Residential	0.00	1.1	5.5	0.0	0.0	0.0%	0.0%
Forest	91.77	0.0685	2.0	6.3	183.5	23.0%	60.6%
Low Dens. Residential	0.00	0.725	4.335	0.1	0.4	0.2%	0.1%
Water Supply				6.9		25.2%	0.0%
Internal Loading				0.1		0.3%	0.0%
Precipitation	14.45	0.4715	5.75	6.8	83.1	24.9%	27.4%
Totals				27.3	303.0	100%	100%

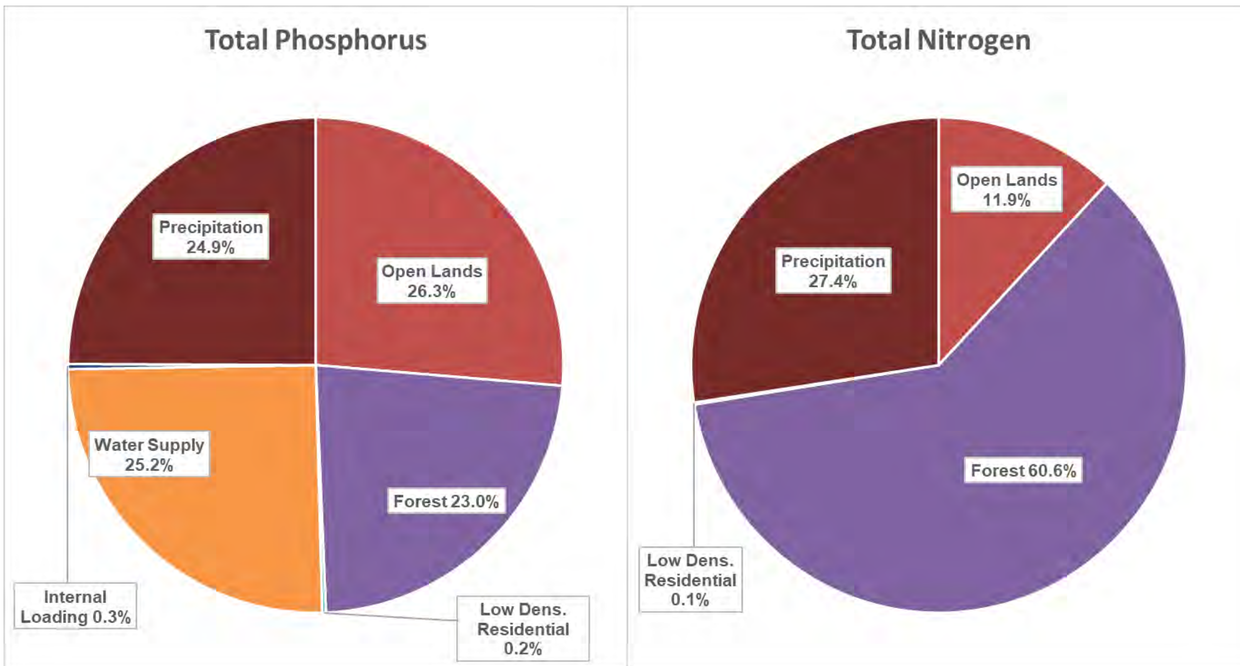

Figure 88 Lake Rippowam nutrient budgets, percent contribution from all sources

Lake Oscaleta

Results of the nutrient budget modeling for Lake Oscaleta are summarized in Table 14 and Figure 89. Lake Oscaleta receives an annual load of 128.5 kg of phosphorus per year and 1,256.7 kg of nitrogen per year. Internal loading accounted for nearly 21% of the annual phosphorus loading while the water supply accounted for 5 percent.

Table 14 Nutrient Budget Calculations and Results for Lake Oscaleta Watershed							
		Loading Coefficients (kg/ha/yr)		Annual Load (kg/year)		Annual Load (Percent)	
Land Use	Area (ha)	TP	TN	TP	TN	TP	TN
Open Water	44.87			0.0	0.0	0.0%	0.0%
Open Lands	33.22	1.1	5.5	36.5	182.7	28.4%	14.5%
Mod./High Dens. Residential	0.00	1.1	5.5	0.0	0.0	0.0%	0.0%
Forest	327.68	0.0685	2.0	22.4	655.4	17.5%	52.1%
Low Dens. Residential	0.72	0.725	4.335	0.5	3.1	0.4%	0.2%
Water Supply				6.9		5.3%	0.0%
Internal Loading				26.8		20.8%	0.0%
Precipitation	44.87	0.4715	5.75	21.2	258.0	16.5%	20.5%
Upstream Watershed				14.2	157.6	11.1%	12.5%
Totals				**128.5**	**1256.7**	**100%**	**100%**

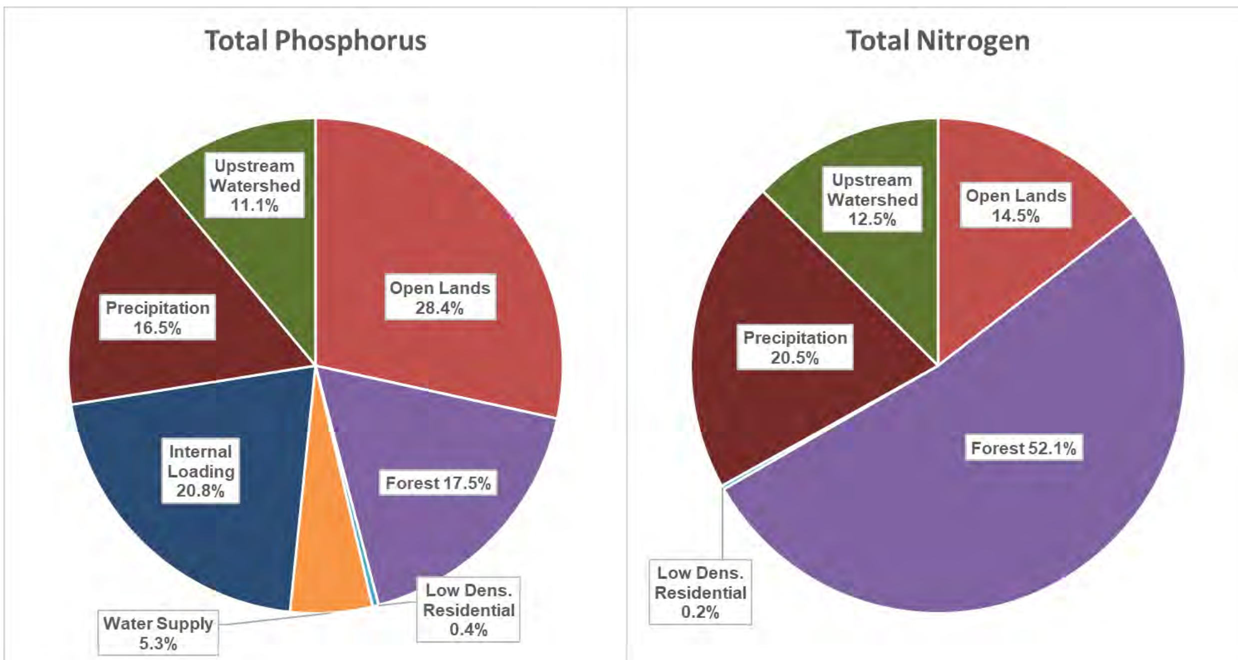

Figure 89 Lake Oscaleta nutrient budgets, percent contribution from all sources

Lake Waccabuc

Results of the nutrient budget modeling for Lake Waccabuc are summarized in Table 15 and Figure 90. Lake Waccabuc receives an annual load of 989.3 kg of phosphorus per year and 2,011.7 kg of nitrogen per year. Internal loading accounted for 76 percent of the annual phosphorus load.

Table 15 Nutrient Budget Calculations and Results for Lake Waccabuc Watershed								
		Loading Coefficients (kg/ha/yr)		Annual Load (kg/year)		Annual Load (Percent)	
Land Use	**Area (ha)**	**TP**	**TN**	**TP**	**TN**	**TP**	**TN**
Open Water	56.74			0.0	0.0	0.0%	0.0%
Open Lands	110.44	1.1	5.5	121.5	607.4	12.3%	30.2%
Mod./High Dens. Residential	1.09	1.1	5.5	1.2	6.0	0.1%	0.3%
Forest	195.44	0.0685	2.0	13.4	390.9	1.4%	19.4%
Low Dens. Residential	6.39	0.725	4.335	4.6	27.7	0.5%	1.4%
Water Supply						0.0%	0.0%
Internal Loading				755.0		76.3%	0.0%
Precipitation	56.74	0.4715	5.75	26.8	326.2	2.7%	16.2%
Upstream Watershed				66.8	653.5	6.8%	32.5%
Totals				**989.3**	**2011.7**	**100%**	**100%**

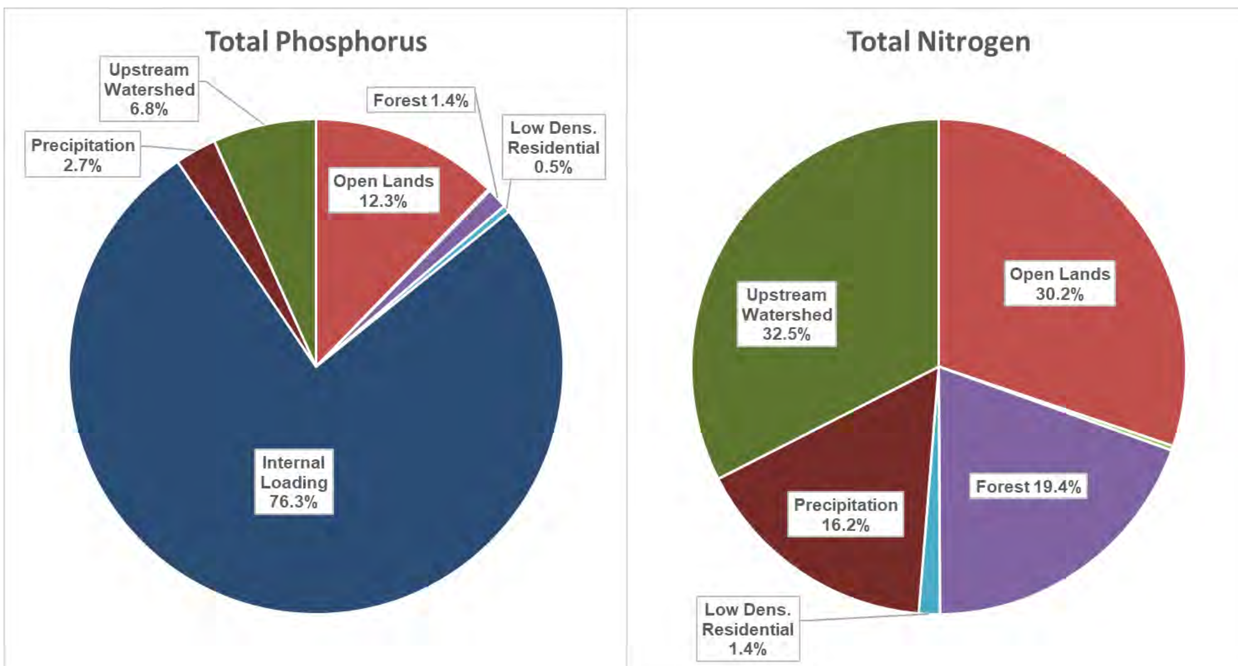

Figure 90 Lake Waccabuc nutrient budgets budget, percent contribution from all sources

Internal Loading of Phosphorus

Internal loading of phosphorus is a result of sediment-bound phosphorus being released into the hypolimnion under reducing (anoxic) conditions. In most lakes that become anoxic under summer stratification, total phosphorus is released from the sediments and builds up within the hypolimnion. Some of this phosphorus may migrate into the epilimnion and support algal blooms, while most of it typically causes fall algal blooms when the lake destratifies and mixes.

Net accumulation or loss of phosphorus within the hypolimnia of Lake Oscaleta and Lake Waccabuc were calculated using the CSLAP data from 2006 through 2018 and the bathymetric maps produced in 2003. The average depth of the thermocline (mid-thermocline) was determined using temperature and dissolved oxygen profiles. Mid-thermocline depth was determined to be the area of greatest temperature change and declining dissolved oxygen concentrations within the water column. The hypolimnetic volume was determined as the volume of the lake at a depth greater than the mid-thermocline depth using the bathymetric survey. This volume was 230,898 cubic meters for Lake Oscaleta and 1,398,107 for Lake Waccabuc. For each sampling date, the hypolimnetic volume (in Liters) was multiplied by the hypolimnetic phosphorus concentration (in mg/L) to yield an estimate of the mass of phosphorus within the hypolimnion on that date. Net change in hypolimnetic phosphorus mass for each sampling date (generally twice per month from June through September) was calculated by subtracting the previous date from the current date. A positive net change would indicate an increase in phosphorus within the hypolimnion that could be associated with internal loading while a negative net change would indicate a decrease in phosphorus within the hypolimnion that might be associated with sedimentation processes or release into the epilimnion. Net change in hypolimnetic phosphorus mass over the growing season was computed by summing up the calculations from each sample date.

Lake Oscaleta

Change in hypolimnetic total phosphorus mass for 2006 through 2018 is presented in Figure 91. Average daily increase in hypolimnetic phosphorus for the period of record was 0.2 kg (median 0.14 kg/day). The average annual hypolimnetic phosphorus contribution was 39.7 kg (median 26.9 kg/year).

In many years, the net change in phosphorus would switch from a net gain to a net loss from one sample date to the next. This could indicate that the hypolimnetic phosphorus was somehow migrating out of the hypolimnion between sample dates during the growing season. High net mass decreases in the fall months indicate the released of accumulated hypolimnetic phosphorus when the lake mixes.

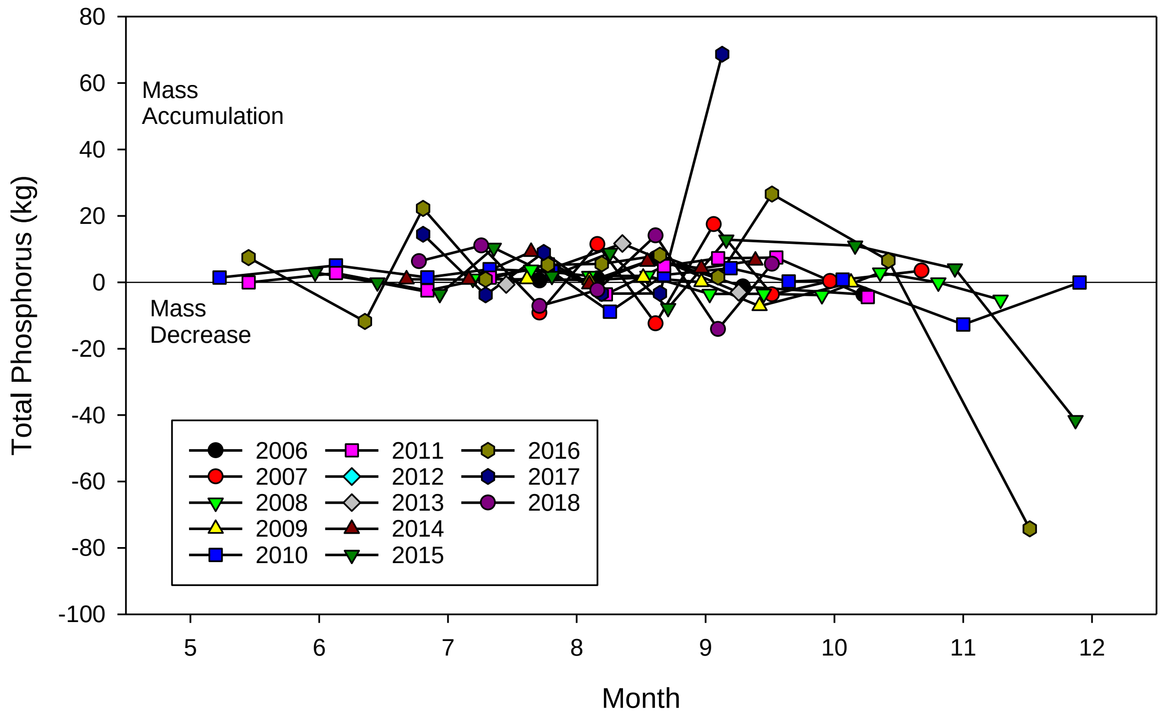

Figure 91 Change in hypolimnetic total phosphorus mass between sample dates in Lake Oscaleta (2006-2018)

Lake Waccabuc

Change in hypolimnetic total phosphorus mass for 2006 through 2018 is presented in Figure 92. Note the size of the y-axis scale compared to Lake Oscaleta (Figure 911) due to the much greater release and accumulation of phosphorus by lake sediments into the hypolimnion. Average daily increase in hypolimnetic phosphorus for the period of record was 4.8 kg (median 4.6 kg/day). The average annual hypolimnetic phosphorus contribution was 883 kg (median 847 kg/year).

In many years, the net change in phosphorus would switch from a net gain to a net loss from one sample date to the next. This could indicate that the hypolimnetic phosphorus was migrating out of the hypolimnion between sample dates during the growing season. High net mass decreases in the fall months indicate the released of accumulated hypolimnetic phosphorus when the lake mixes.

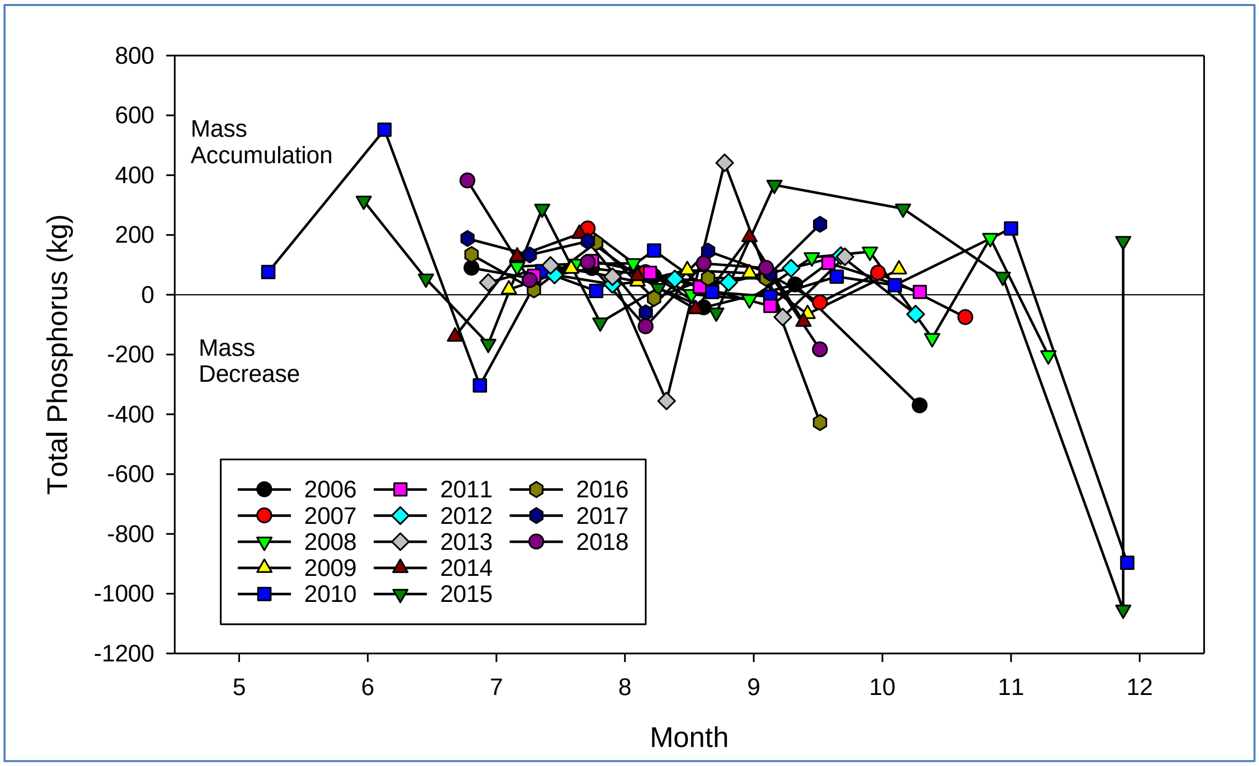

Figure 92 Change in hypolimnetic total phosphorus mass between sample dates in Lake Waccabuc (2006-2018)

Lake Response Modeling – Total Phosphorus Load Reductions

Evaluation of Models and Model Results

There are a number of empirical models that have been developed to predict in-lake phosphorus concentrations based upon a number of input parameters primarily relating to lake morphometry, hydrology and total phosphorus loading. These models can also be used to predict the required reduction in watershed phosphorus load to reach a target in-lake concentration. Sixteen of those models were examined to see how well they predicted weighted average total phosphorus concentrations in the Three Lakes. An appropriate model was selected for each lake based upon how closely it was able to predict the weighted average total phosphorus concentration using 2018 data. The weighted average total phosphorus was calculated using the following formula:

Weighted Mean TP = (Mean epi TP * percent epi volume) + (Mean hypo TP * percent hypo volume)

Lake Rippowam

The Vollenweider and Kerekes (1982) model best predicted the weighted total phosphorus in Lake Rippowam (0.025 mg/L) with a result of 0.027 mg/L (105% of target value). All other models grossly underestimated in-lake total phosphorus in the lake. The Vollenweider and Kerekes (1982) model is described by the following equation:

$$TP = 1.55\left(\frac{TPi}{1+SQRT(T)}\right)^{0.82}$$

Where:

TPi = mean annual inflow TP concentration
(areal P load*residence time)/mean depth
T = Lake Residence Time (length of time water spends in lake, inverse of flushing rate)

Lake Oscaleta

The Canfield and Bachman (1981) model best predicted the weighted total phosphorus in Lake Oscaleta (0.031 mg/L) with a result of 0.025 mg/L (81% of target value). A correction to 100% was made to the model results while calculating loading reductions (result x 1.19). The Canfield and Bachman (1981) model is described by the following equation:

$$TP = \left(\frac{L}{Z*(RHO+GAMMA)}\right)$$

Where:

L = areal P load
Z = mean depth
RHO = flushing rate
Gamma = $0.162*(L/Z)^{0.458}$

Lake Waccabuc

The Vollenweider and Kerekes (1982) model best predicted the weighted total phosphorus in Lake Waccabuc (0.203 mg/L) with a result of 0.228 mg/L (112% of target value). A correction to 100% was added to the model results while calculating loading reductions (result x 0.88). The Vollenweider and Kerekes (1982) model is described by the following equation:

$$TP = 1.55\left(\frac{TPi}{1+SQRT(T)}\right)^{0.82}$$

Where:

TPi = mean annual inflow TP concentration
(areal P load*residence time)/mean depth
T = Lake Residence Time (length of time water spends in lake, inverse of flushing rate)

Phosphorus Reduction Requirements

Iterative runs of the selected models for each lake were conducted with reduced phosphorus loading values to yield the percent reduction in the phosphorus budget required to reduce the weighted average total phosphorus the NYS standard for lakes of 0.020 mg/L. Any reductions in phosphorus loading are limited to controllable sources of phosphorus, which includes internal loading of phosphorus and human sources relating to land use conditions, although controllable sources may also include soil erosion on undeveloped lands and stream bank erosion.

Lake Rippowam

In 2018, Lake Rippowam had an average epilimnetic total phosphorus of 0.022 mg/L and a weighted mean total phosphorus of 0.025 mg/L. Using the selected model, total phosphorus would have to be reduced by 30.4 percent (8.3 kg/year) to achieve an in-lake total phosphorus of 0.020. This could be achieved by switching the water supply to alternative anti-corrosion measures (25 percent direct reduction) and modest changes in stormwater management, primarily addressing runoff from impervious surfaces (roads, roofs, driveways) and lawns.

Lake Oscaleta

In 2018, Lake Oscaleta had an average epilimnetic total phosphorus of 0.015 mg/L and a weighted mean total phosphorus of 0.031 mg/L. The discrepancy between the average epilimnetic total phosphorus and weighted total phosphorus is due to the contribution of phosphorus in the hypolimnion due to internal loading. Using the selected model, total phosphorus would have to be reduced by 33.9 percent (43.5 kg/year) to achieve an in-lake (weighted) total phosphorus of 0.020. This could be achieved by switching the water supply to alternative anti-corrosion measures (5 percent direct reduction plus an 12.6 percent reduction in load from Lake Rippowam), modest changes in stormwater management, primarily addressing runoff from impervious surfaces (roads, roofs, driveways) and lawns and reducing internal loading through hypolimnetic aeration or phosphorus inactivation (21 percent).

Lake Waccabuc

In 2018, Lake Waccabuc had an average epilimnetic total phosphorus of 0.027 mg/L and a weighted mean total phosphorus of 0.203 mg/L. The discrepancy between the average epilimnetic total phosphorus and weighted total phosphorus is due to the contribution of phosphorus in the hypolimnion due to internal loading. Using the selected model, total phosphorus would have to be reduced by 94 percent (929 kg/year) to achieve an in-lake (weighted) total phosphorus of 0.020. This could be achieved by addressing the internal loading of phosphorus within the lake through hypolimnetic aeration or phosphorus inactivation (76 percent) and aggressive changes in stormwater management, including addressing dirt and gravel roads, runoff from impervious surfaces and lawns, and untreated runoff from paved roads.

Lake & Watershed Management Recommendations and Strategies

Watershed Management Alternatives

Paved Roads

Roads can have a negative impact on the natural community in watersheds. Roads change the hydrology of the watershed by redirecting water from its otherwise natural flow patterns. Roads increase nonpoint source pollution by increasing the amount of impervious surfaces, thereby preventing infiltration of stormwater into the ground. Roads also create an unnatural disturbance that promotes the growth of invasive plant species.

Traditional thinking in road maintenance has been to get water off of the roads and into low-lying areas such as streams by the quickest means possible. However, this results in excess nutrients and sediment entering streams. Inadequate drainage structures such as culverts can cause downstream erosion. All watershed roads should be graded and the road edges well vegetated.

Roadside erosion sites should be repaired using methods such as grassed swales, riprap swales, bank stabilization, bioengineering techniques, level spreaders, and other methods. Roadside swales should be properly maintained and should always be immediately stabilized if they are disturbed. Properly sized culverts at stream crossings and under driveways and cross streets are imperative, as well as adequate roadside drainage structures. Emergency procedures should be established to handle accidental spills such as cargo fuel or other materials. The use of ice melting materials, such as sodium chloride and calcium chloride, is necessary on occasion to ensure safe driving conditions. These chemicals should be used only when necessary and only in amounts required to provide effective results.

- ☆ An engineering firm should be hired to design corrective stormwater management measures for the Post Office parking lot and Mead Street in the area of the Post Office

Dirt and Gravel Roads

One of the main causes of erosion on gravel roads is an improper gradation of the gravel itself. The responsible party has the option to resurface the entire road, or just particular sections of the road with a Driving Surface Aggregate (DSA) designed specifically for use as an unbound wearing surface aggregate for roads. The DSA, designed by Penn State's Center for Dirt and

Gravel Road Studies (PSU), has been used on hundreds of miles of public roadways in Pennsylvania and has become the standard for dirt and gravel roads due to its long-wearing ability, low erosion and low maintenance. Penn State's studies have shown an 80-90% reduction in sediment runoff from DSA compared to existing road surfaces, even after 3 years of exposure and use. Since DSA is so densely packed, less loose material is available to generate dust and the generation of dust and sediment pollution is reduced by a lengthening of the road maintenance cycles which would loosen the aggregate surface, resulting in periods of sediment loss. DSA consists of specifications for aggregate formulation, road preparation, placement, compaction and maintenance. More detailed information and specifications can be found in the DSA Information Bulletin (PSU 2014).

Material costs for DSA ranges from $15-25 per ton compared to about $10-$20 per ton for a variety of stone or mixed aggregate. Equipment needed for installation are typical for projects applying a permanent roadway, and may include dozers, graders, excavators, backhoes, loaders, trucks, pavers and rollers.

- ☆ Priority targets for road resurfacing with DSA are Tarry-A-Bit Road and Old Pond Road.
- ☆ An engineering firm should be hired to design stormwater management measures along Tarry-A-Bit Road and Old Pond Road for reducing nutrient runoff.
- ☆ An engineering firm should be hired to design stormwater management measures to control runoff from the lawns and driveways that contribute to erosion problems on Tarry-A-Bit Road.

Homeowner Management Activities

Watershed education and public participation are important aspects of any watershed management or NPDES Phase II stormwater program. The development of environmental education programs designed for school-aged children and adults is an effective watershed management approach. Citizen involvement and practices benefiting the watershed should be publicized and encouraged. Positive practices include stormwater management, recycling of yard wastes, safe storage and disposal of toxic materials, environmentally sound recreation behavior, and proper lawn and yard maintenance. Citizens should also be discouraged from using invasive plant species in their yard or garden landscaping. Training citizens to recognize and remove non-native invasive species in the watershed can have a positive impact on the spread of noxious weeds.

Residential areas can be important sources of nutrient and sediment loading within a watershed. Although homeowners and residential landowners often care about preserving natural areas, they may not always know the best ways to do so. Homeowners in the Three Lakes watershed should be made aware of ways they can help protect their lakes and the surrounding watershed from water quality degradation. Several homeowner practices are listed below that can be implemented as part of a public education program.

- ☆ Homeowners with bare soils, construction sites, or dirt piles on their properties should be encouraged to re-vegetate the areas in order to reduce the erosion potential. Silt fences and other erosion and sedimentation controls should be implemented at all construction sites, large or small.
- ☆ Lawn fertilizer can be a significant source of nutrients to lakes and streams, especially in suburban areas where nice green lawns are desirable. Homeowners should test their soil for phosphorus and nitrogen concentrations so that they can minimize the amount of fertilizer that they add to their lawns. Homeowners can contact the Cornell Cooperative Extension Westchester County office (http://westchester.cce.cornell.edu/) to obtain information on soil testing.
- ☆ Shoreline homeowners should be discouraged from mowing their lawns up to the edge of the lake. A minimum of a five foot vegetative buffer should be left along the lake shore or streambank to provide erosion control and to filter nonpoint source pollution from entering the water. Planting the water's edge with native wildflowers and rushes has the added benefit of providing a habitat for wildlife and discouraging nuisance waterfowl congregation.
- ☆ Homeowners should be encouraged to wash cars and trucks on grassy areas, if possible, or use commercial car washes. This practice will reduce the amount of phosphorus and detergent that runs into the Three Lakes and their tributaries.
- ☆ Homeowners should be encouraged to clean up any pet waste that has the potential to be washed into the Three Lakes during rain events. Animal wastes are very high in nutrients and bacteria.

Septic System Maintenance

Septic systems have the potential to contribute a substantial amount of bioavailable phosphorus to a lake. Therefore, it is always a good idea to promote regular (once every three years) pumping, on-going maintenance, and system upgrade and replacement programs.

- ☆ Institute and provide assistance and support for mandatory septic system pumping.
- ☆ Encourage and seek funding support for the replacement of septic systems near lakes and streams with advanced treatment technologies.
- ☆ Encourage the use of small community systems with advanced nutrient removal in areas where home density, lot size and closeness to lake shore is problematic.

Residential Stormwater Management Recommendations

Stormwater runoff increases the transport of nutrients from a watershed into receiving streams and ultimately (sometimes directly) into the lakes. Measures that reduce runoff volume and velocity reduce pollutant loads downstream. It is best to deal with stormwater with smaller best management practices at its individual sources, such as roofs, driveways and lawns, rather than trying to create large BMPs downstream.

There are several stormwater management opportunities for the areas in the watershed that are already developed with housing units. Rain barrels and rain gardens are options that individual homeowners can install on their property to help improve stormwater runoff quality, and at the same time improve the aesthetics of their property.

Rain barrels collect stormwater runoff from rooftops. The stored water can then be used to water flower and vegetable gardens when it is not raining. During larger rain events, discharges from rain barrels should be directed to a grassed area, a rain garden, or possibly a dry well. This way the stormwater is used and infiltrated into the ground rather than running directly into the swales and the lakes. The cost of rain barrels can range from $50 to over $300, but a standard 55 gallon rain barrel typically costs about $100. If the Association bought rain barrels in bulk, they may get a better price that they could pass along to the homeowners.

Figure 93 Photo of rain barrel

A rain garden (bioretention basin) is a shallow surface depression planted with native vegetation to capture and treat stormwater runoff. The purpose of this BMP is to capture, treat and infiltrate stormwater. Rain gardens store and infiltrate stormwater runoff, which increases groundwater recharge and may decrease downstream erosion and flooding. Stormwater runoff water quality is improved by filtration through the soil media and biological and biochemical reactions with the soil and around the root zones of plants. Rain gardens improve water quality, reduce stormwater runoff and peak volumes, increase groundwater recharge, provide wildlife habitat and are aesthetically pleasing. Rain gardens can be installed by individual homeowners to treat stormwater runoff from their rooftop and driveways. Rain gardens can be an aesthetically pleasing way for homeowners to combine stormwater management and landscaping to their property. Stormwater is directed to the rain garden and provides water and nutrients for the plants. Excess stormwater is stored in this area and can continue to be used by the plants days after a rain event.

A flourishing rain garden.

This rain garden is two years old. Weeds have a hard time growing. Birds and butterflies are regular visitors to the garden.

Figure 94 Photos of rain gardens

☆ Institute a program to install rain barrels and rain gardens throughout the watershed by offering education and incentives

Protect and Restore Riparian and Wetland Areas

A riparian buffer is the area adjacent to streams, lakes, ponds and wetlands. This area is extremely important to the health of a water body, as it intercepts, slows and filters stormwater before it reaches the water. A wooded riparian buffer with a shrub and herbaceous layer is the most effective riparian buffer, while the least effective riparian buffer consists of mowed grass or no vegetation. The wider a riparian buffer is, the better it is for the health of a stream.

Riparian buffer restoration consists of removing invasive species and/or undesirable vegetation and replanting with native trees, shrubs and herbaceous species. Among the benefits of these buffers is improved water quality, reduced soil erosion and stormwater runoff and improved wildlife habitat. Figure 6.1 illustrates the inputs and outputs of nutrients in a riparian buffer, and Figure 6.2 describes the recommended minimum buffer widths to achieve specific objectives.

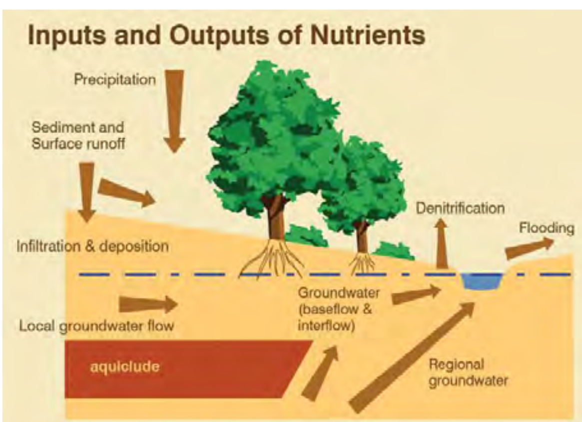

Figure 95 Riparian Buffer Nutrient Inputs and Outputs Source: Virginia Dept of Forestry

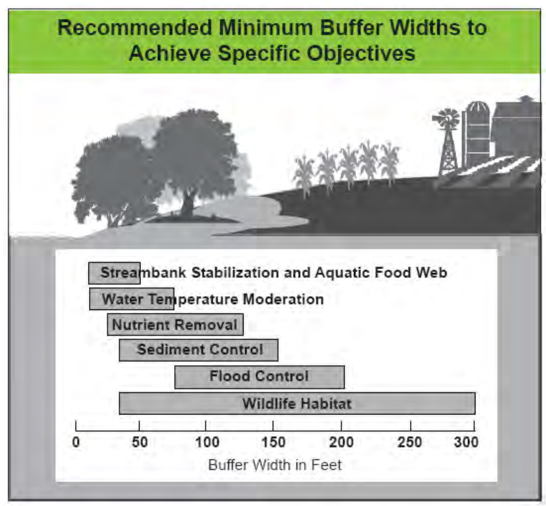

Figure 96 Buffer Widths and Objectives Source: Virginia Department of Forestry

☆ Provide education and support for the creation of riparian buffers around streams and lake shorelines.

In-Lake Management Alternatives

Lake Aeration

Aeration has been widely used as a restoration measure for lakes and ponds where summer hypolimnetic oxygen depletion and/or winter-kill are of major concern. Aeration can be divided into two categories: those methods which destratify the lake water column and circulate the entire lake, and those methods which aerate the hypolimnion (deep water layer) without destratifying the lake. Both methods are based on the principle that if the dissolved oxygen concentration in a lake is increased, additional fish habitat will be provided and the release of phosphorus from the sediments that can occur under anoxic (low dissolved oxygen) conditions will be decreased or eliminated.

Since Lake Waccabuc and Lake Oscaleta are stratified lakes, aeration systems that do not destratify the lake water column and ensure that dissolved oxygen is evenly distributed throughout the hypolimnia are recommended. Options include atmospheric air, oxygen generators and liquid oxygen distributed into the hypolimnion through chambered systems or microbubble diffusion systems. The aeration systems should be operated from mid-April through the end of the stratification period each year.

Note that the use of lake aeration is likely not the most-cost effective way of obtaining a long-term reduction of internal loading once you take into consideration initial equipment and installation costs and annual costs for utilities and maintenance.

Whole-lake aeration would provide limited benefit to Lake Rippowam since there is little evidence of internal loading within the lake. Lake circulation – lateral movement of the upper waters – may provide some aesthetic benefits but do little to effect water quality.

Bubble Diffusion Oxygenation

Bubble plume diffusers use micropore injection systems to introduce atmospheric or pure oxygen into the lake bottom where it is absorbed, resulting in an increase in oxygen levels. Installation costs range from $0.5M to $2.5M ($40 to $800 per hectare meter) while annual operating costs run from $30,000 to $140,000 ($5 to $36 per hectare meter) (Mobley et al. 2019).

Cost Estimates for Bubble Plume Diffusion Oxygenation

Lake Waccabuc
Lake Volume: 14M m^3 or 1,399 ha m
Installation Cost: $55,960 to $1,119,200
Annual Operating Cost: $7,000 to $50,400

Lake Oscaleta
Lake Volume: 1.6M m^3 or 156 ha m
Installation Cost: $6,240 to $124,800
Annual Operating Cost: $780 to $5,600

- ☆ Hire an engineering firm to design and install an aeration system for Lake Waccabuc and Lake Oscaleta

Nutrient Inactivation

Lake sediments contain the accumulated detritus of hundreds of years. Sediments in lakes that have received an excessive nutrient loading from the watershed due to agricultural runoff or wastewater disposal contain higher amounts of phosphorus. Under the right conditions, this phosphorus can be released from the sediments into the overlying water, resulting in an internal phosphorus load that continues to foster cyanobacteria blooms many decades after outside nutrient sources have been addressed.

Sediment phosphorus inactivation is the use of phosphorus-binding chemicals within a lake to trap the phosphorus within the sediments and preventing their release into the water column. Sediment phosphorus inactivation can result in rapid, dramatic improvements in water quality when the sediment phosphorus is the major source of phosphorus fueling algae blooms. Sediment phosphorus inactivation would be used after all outside sources of phosphorus have been reduced as much as possible.

There are several chemicals that can be used to seal sediments, but aluminum salts (sodium aluminate and aluminum sulfate) are the most common. However, the NYS DEC has banned the use of alum in lakes for this purpose. An acceptable, DEC-permitted alternative is PhosLock®, a mineral compound consisting of bentonite clay and lanthanum. Although alum is not currently a permittable treatment option in New York state, it is less expensive and more effective than PhosLock® (Palli, 2015). PhosLock is 10-15 times more to as much as 100 times more than alum on a per treatment basis and may not be as effective as alum in binding phosphorus within sediments at equivalent dosages.

Aluminum Salts

The use of aluminum salts as a lake best management practice (BMP) began in the early 1980s and has since become an effective and efficient method of phosphorus inactivation (Connor and Martin, 1989). Aluminum sulfate (alum) and sodium aluminate are the most prevalent compounds used in sediment phosphorus inactivation treatments. The alum combines with the phosphorus in the lake water, settles to the bottom of the lake, and "seals" the bottom sediments. Once the sediments are "sealed," phosphorus cannot be released and resuspended during anoxic lake conditions. The objective is to reduce the amount of phosphorus available in the lake for algal growth. A number of salts have been used for lake phosphorus inactivation, including aluminum, calcium and iron. The application of aluminum salts has been the most effective method, in terms of long-term effectiveness. Therefore, the treatment is often referred to by the generic term "Alum Treatment."

Batch alum treatment are used when watershed phosphorus loading is low relative to internal loading and involves adding a large batch of alum at a given time to bind phosphorus in a lake. Alum is added to the water column to precipitate suspended phosphorus, or directly to the hypolimnion to inhibit phosphorus release from the sediments, or both. This method typically helps to improve water quality in the lake immediately and over a long time period as long as additional phosphorus inputs to the lake are minimized prior to treatment. Batch alum treatment is generally used in lakes that exhibit long retention times with little flushing. This method should be used only when phosphorus loads to the lake (via stormwater or other point or nonpoint sources) are addressed and minimized.

The costs for alum applications for Lake Waccabuc and Lake Oscaleta were calculated[1] with the following assumptions:

1. Assumed that the use of application buffer (sodium aluminate) along with alum would ensure a safe pH during treatment
2. Assumed a dose of 70 g Al/m2 for both lakes. This is a reasonable dose based on the amount of internal loading. However, some doses in area lakes were in the 40-50 g Al/m2 range. Ideally, the precise dose would be determined based on an analysis of P-fractions from sediments cores collected prior to the applications. Two to three deep-water cores should be adequate for lakes of this size.
3. Assumed that the entire lake will receive alum. The actual application zone could be slightly smaller if only the area that goes anoxic is treated.

Doses and Cost Estimates for Alum:

Lake Waccabuc
76,705 gallons of alum
38,352 gallons of sodium aluminate
$391,000

Lake Oscaleta
36,129 gallons of alum
18,064 gallons of sodium aluminate
$193,000

[1] Source: John C. Holz, Ph.D. Limnologist/Principal. HAB Aquatics, Lincoln, NE

- ☆ Encourage NYS DEC to approve the use of alum in New York lakes for the long-term management of internal phosphorus loading
- ☆ Hire a consulting firm to conduct required testing, design and implement a long-term alum treatment for Lake Waccabuc and Lake Oscaleta.

PhosLock®

At the present time, the use of aluminum salts such as sodium aluminate and aluminum sulfate are not registered for use in New York. Non-alum alternatives, such as Phoslock ®, may be allowed by NYSDC; however, it is not known how extensive the permitting process would be for these products. Determining the cost of a PhosLock treatment requires information on the amount of sediment to be treated and the amount of bioavailable phosphorus within that sediment. Without that information, a comparison was made using the known treatment costs or cost estimates where PhosLock was used or evaluated for use. Costs for example lakes varied widely, depending on the size of the lake, the amount of phosphorus within the sediments and the amount of PhosLock applied to the lake. Case study costs were then scaled for the relative difference in size between example lakes and Lake Waccabuc and Lake Oscaleta. The entire lake area was used in order to allow for a more direct comparison with estimated alum costs. Keep in mind that this analysis cannot account for any differences in the amount of bioavailable phosphorus in these lakes. Lake Waccabuc and Lake Oscaleta sediments may be higher in bioavailable phosphorus that the case study lakes.

In the case examples examined (Heart Lake and Black Lake, Washington State), the cost of PhosLock ranged from $90 to $200 for each pound of phosphorus in the sediment, including material and application costs. The amount of phosphorus in the sediments of the case examples ranged from 1,292 pounds to 2,380 pounds. For Lake Waccabuc, this yields a range of costs for a PhosLock treatment from $447,873 to $995,273. For Lake Oscaleta, this yields a range of costs for a PhosLock treatment from $210,944 to $468,7878. Data from a third case example (Elk Lake, Victoria BC) yielded a cost of $659,855 for Lake Waccabuc and $310,801 for Lake Oscaleta. Therefore, $1,194,327 (highest estimate plus 20% for testing, design and contingencies) is a good figure to use as a rough cost estimate to treat Lake Waccabuc with PhosLock and $562,545 is a good figure to use as a rough estimate to treat Lake Oscaleta.

Cost Estimates for PhosLock

Lake Waccabuc
$1,194,327

Lake Oscaleta
$562,545

- ☆ Hire a consulting firm to conduct required testing, design and implement a long-term PhosLock® treatment for Lake Waccabuc.

Waterfowl Control

Geese droppings can be a significant source of phosphorus, nitrogen and bacteria to lakes. One goose can be responsible for contributing up to 0.5 pounds of phosphorus per year to a lake. Geese and other waterfowl are part of the natural ecosystem surrounding lakes, ponds and wetlands and if populations are not excessive, their contribution to the nutrient loading of a lake is relatively insignificant.

A few facts that are important to note regarding resident Canada geese populations include:

1. Their life expectancy is very long in comparison to most bird species.
2. The move-in rate by new members of the population is not well documented; however, it is believed to be quite high.
3. There are few natural predatory species for the geese. The populations of the predatory species which do exist have been virtually eliminated in many areas due to intense urban development.
4. Hunting is nearly impossible in areas of urban and suburban development, so it no longer serves as a population check for the geese.

There are two basic solutions to the problem: on-site management techniques and removal of the geese from the site. These two solutions may be integrated to form a more effective geese control management plan.

Removal is a guaranteed option for eliminating the geese population. However, this is the costliest method and requires substantial permitting which takes a great deal of time and added expense. Also, there is no guarantee that permit applications (and all included terms) will be approved by the regulatory agencies. Removal is most easily conducted during molting when the geese are unable to fly and may be driven to a specified fenced-in area for capture. A major problem in removal and relocation of geese is that there are very few areas left to take the geese, since their presence is so undesirable.

On-site management of the geese is the other basic option for controlling the populations of resident Canada geese at a given location. Several on-site management techniques have been developed, tested, and found successful by the US Fish and Wildlife Service, and are described below.

Controlled Landscaping Practices

Controlled landscaping practices and physical barriers will help deter the geese from residing in many areas. Studies have found that the geese do not feed in areas where the grass has been allowed to grow naturally. Also, preventing easy access to and from bodies of water greatly reduces the number of escape routes for the geese and therefore significantly decreases their level of security. This may be accomplished by allowing emergent wetland plants and shoreline vegetation such as shrubs and grasses to grow, or by erecting physical barriers such as snow fences. It is important to note that the use of controlled landscaping practices and physical barriers may not be acceptable for certain land uses where open space and access to waterbodies is essential or desirable.

Egg Inactivation

Egg inactivation has been found successful in preventing the addition of new, young Canada geese into the local population and is being used successfully by the Three Lakes Council. Geese are capable of laying eggs for an approximated 28 days. However, the gestation period is greater than 28 days. Therefore, by the time that the female realizes that the eggs will never hatch, she is no longer capable of producing another clutch during that season. The eggs may be inactivated by several methods, including shaking, puncturing, replacing eggs with plastic substitutes, or coating the eggs with oil. The eggs must appear to be intact so that the female will not realize their impotency and lay more eggs.

Visual Deterrents

Visual deterrents such as special filaments, tape, balloons, flashing lights, and scarecrows may be useful in many areas where the geese like to congregate. The disadvantage of visual deterrents is that in many cases they are unsightly to humans, they are not acceptable in every land use, and they may lose their effectiveness as the geese become conditioned to their presence.

Chemical Deterrents

Chemical deterrents have also been developed by certain companies. These chemicals are applied directly to the vegetation in the areas where the geese feed and congregate, causing the geese to feel either discomfort or nausea. The use of certain visual deterrents (i.e. paint) in conjunction with the chemical deterrents may condition the geese to associate the visual deterrent with the discomfort or nausea. Therefore, over time, only the visual deterrent may be necessary to control the geese and the use of chemical deterrents may either be reduced or eliminated. The disadvantages of this method are that the chemical deterrent needs to be applied many times during the season, and it is very costly.

Scare Tactics

Scare tactics such as trained dogs manually chasing geese from areas of congregation, and explosive charges and other loud devices may be effective in driving the geese from a given area. Such methods may not be appropriate or safe, depending on the surrounding land use. And in many cases, the geese may become conditioned to and very tolerant of these scare tactics. Recently, some wildlife officials have begun using special lasers to scare off the geese by shining them in their eyes. This method shows some promise, although it is not yet well documented and the equipment is expensive.

Most often, no single geese management tactic is effective by itself. The use of several techniques in an integrated approach is usually necessary. Discouraging geese congregation by not mowing vegetation to the edge of the lake, and not feeding the geese are the simplest and most effective first steps in keeping nuisance waterfowl populations to a minimum and preventing population overload. The Three Lakes Council should try various options for reducing the Canada Geese population at the lake. After a year or so of trying to get rid of the geese, the Three Lakes Council can contact the US Fish and Wildlife service to determine if they will remove the geese from the lake for a fee.

- ☆ Continue goose management program on the Three Lakes.

Conclusions and Recommendations

Conclusions

Lake Rippowam and Lake Oscaleta are mesotrophic lakes while Lake Waccabuc is meso-eutrophic. Lake Oscaleta and Lake Waccabuc experience considerable loss of oxygen in their hypolimnia during the summer stratified period, resulting in the release of phosphorus from the lake sediments into the overlying water. There appears to be a trend for a decrease in the depth at which anoxia occurs in both of those lakes over the past fifteen years.

Internal loading of phosphorus in Lake Oscaleta and Lake Waccabuc was significant and there is evidence that some of that phosphorus become available in the upper waters, fueling cyanobacteria blooms.

Lake Rippowam receives an annual load of 27.3 kg of phosphorus per year and 303.0 kg of nitrogen per year. The watershed is small and relatively undeveloped. As a result, the total phosphorus load is small, making the percent contribution from precipitation (24.9%) and the water supply (25.2%) quite significant and the water supply orthophosphorus buffer by far the largest controllable source of phosphorus within the watershed. Using the selected model, total phosphorus would have to be reduced by 30 percent (8.3 kg/year) to achieve an in-lake total phosphorus of 0.020. This could be achieved by switching the water supply to alternative anti-corrosion measures (25 percent direct reduction) and modest changes in stormwater management, primarily addressing runoff from impervious surfaces (roads, roofs, driveways) and lawns.

Lake Oscaleta receives an annual load of 128.5 kg of phosphorus per year and 1,256.7 kg of nitrogen per year. Internal loading accounted for nearly 21% of the annual phosphorus loading while the water supply accounted for 5.3 percent. Using the selected model, total phosphorus would have to be reduced by 34 percent (43.5 kg/year) to achieve an in-lake (weighted) total phosphorus of 0.020. This could be achieved by switching the water supply to alternative anti-corrosion measures (5 percent direct reduction plus an 12.5 percent reduction in load from Lake

Rippowam), modest changes in stormwater management, primarily addressing runoff from impervious surfaces (roads, roofs, driveways) and lawns and reducing internal loading through aeration or phosphorus inactivation (21 percent).

Lake Waccabuc receives an annual load of 989.3 kg of phosphorus per year and 2,011.7 kg of nitrogen per year. Internal loading accounted for 76 percent of the annual phosphorus load. Using the selected model, total phosphorus would have to be reduced by 94 percent (929 kg/year) to achieve an in-lake (weighted) total phosphorus of 0.020. This could be achieved by addressing the internal loading of phosphorus within the lake through hypolimnetic aeration or phosphorus inactivation (76 percent) and aggressive changes in stormwater management, including addressing dirt and gravel roads, runoff from impervious surfaces and lawns, and untreated runoff from paved roads.

Significant nonpoint source problem areas in the watershed were the three dirt and gravel roads, uncontrolled stormwater runoff from private properties and stormwater runoff in a few locations along paved roads.

Recommendations

Watershed Management

- ☆ Hire an engineering firm to design corrective stormwater management measures for the Post Office parking lot and Mead Street in the area of the Post Office
- ☆ Hire an engineering firm design stormwater management measures along Tarry-A-Bit Road and Old Pond Road for reducing nutrient runoff.
- ☆ Hire an engineering firm to design stormwater management measures to control runoff from the lawns and driveways that contribute to erosion problems on Tarry-A-Bit Road.
- ☆ Hire an engineering firm to design and resurface Tarry-A-Bit Road and Old Pond Road with DSA
- ☆ Homeowners with bare soils, construction sites, or dirt piles on their properties should be encouraged to re-vegetate the areas in order to reduce the erosion potential. Silt fences and other erosion and sedimentation controls should be implemented at all construction sites, large or small.
- ☆ Homeowners should test their soil for phosphorus and nitrogen concentrations so that they can minimize the amount of fertilizer that they add to their lawns.
- ☆ Homeowners should plant vegetative buffers along the lake shore. Shoreline homeowners should be discouraged from mowing their lawns up to the edge of the lake. A minimum of a five foot vegetative buffer should be left along the lake shore or streambank to provide erosion control and to filter nonpoint source pollution from entering the water.
- ☆ Homeowners should be encouraged to wash cars and trucks on grassy areas, if possible, or use commercial car washes.

- ☆ Homeowners should be encouraged to clean up any pet waste that has the potential to be washed into the Three Lakes during rain events.
- ☆ Institute and provide assistance and support for mandatory septic system pumping.
- ☆ Encourage and seek funding support for the replacement of septic systems near lakes and streams with advanced treatment technologies.
- ☆ Encourage the use of small community systems with advanced nutrient removal in areas where home density, lot size and closeness to lake shore is problematic.
- ☆ Institute a program to install rain barrels and rain gardens throughout the watershed by offering education and incentives
- ☆ Provide education and support for the creation of riparian buffers around streams and lake shorelines.

Lake Management

Lake Rippowam

- ☆ Hire an engineering firm to develop alternative water treatment to reduce corrosivity in the water without the use of orthophosphorus.

Lake Oscaleta

- ☆ Hire an engineering firm to develop alternative water treatment to reduce corrosivity in the water without the use of orthophosphorus.
- ☆ Encourage NYS DEC to approve the use of alum in New York lakes for the long-term management of internal phosphorus loading
- ☆ Hire an engineering firm to design and install a hypolimnetic aeration system or a long-term nutrient inactivation treatment. Nutrient inactivation through the use of alum is the recommended alternative due to cost-effectiveness and the immediacy and degree of expected improvement.

Lake Waccabuc

- ☆ Encourage NYS DEC to approve the use of alum in New York lakes for the long-term management of internal phosphorus loading
- ☆ Hire an engineering firm to design and install a hypolimnetic aeration system or a long-term nutrient inactivation treatment. Nutrient inactivation through the use of alum is the recommended alternative due to cost-effectiveness and the immediacy and degree of expected improvement.

Monitoring

- ✰ Continue an annual lake monitoring program using CSLAP or equivalent to provide data needed to assess water quality trends and evaluate the effectiveness of management activities.
- ✰ Map aquatic plant distribution and abundance on an annual basis if possible. Alternately, map entire littoral zone every two to five years and institute volunteer monitoring to identify new aquatic invasive plant species and new colonies of existing invasive plant species before they become established
- ✰ Continue to test cyanobacteria blooms for toxins and provide advisories to residents when toxins are present.
- ✰ Conduct a fisheries study to assess the health of the fisheries in the lakes and to provide scientifically-based recommendations for stocking

Public Education

Public outreach is an important component to the success of any long-term watershed management plan (WMP). The key focus of the public outreach component of the Three Lakes Management Plan is to ensure that stakeholders are informed as to its scope and findings. Potential stakeholders include Three Lakes residents and Council members, municipal officials from Lewisboro, the Westchester County Soil and Water Conservation District, and the general public. Outreach will be accomplished through meetings, dissemination of the report and/or summaries via a web page and distributing the plan and plan summaries to stakeholders for dissemination among their constituents.

- ✰ Institute an education and outreach campaign in support of the watershed management plan with all stakeholders
- ✰ Incorporate lake user surveys into the educational campaign

Summary Documents

Create summary documents and fact sheets containing major findings and recommendations of WMP.

Stakeholder Meetings

Meet with various stakeholder groups (SWCD, Municipalities, Three Lakes Council/residents) to present plan.

WMP Website

Create a page describing WMP and hosting fact sheets and WMP document for download by interested parties.

Public Meetings

Host meetings for general public within the watershed to present findings and recommendations of WMP.

Three Lakes Community Lectures

Host educational lectures for the Three Lakes Community on aspects relating to lake and watershed management, including:

- Creating Lakefront Buffers
- Homeowner Best Management Practices
- Rain Gardens and Rain Barrels
- Aquatic Plant Identification & Management

Implementation Plan

Priority for Implementation

The priorities for implementation are:

- ☆ Addressing internal loading in Lake Waccabuc (#1) and Lake Oscaleta
- ☆ Addressing erosion and runoff on Tarry-a-Bit Road and Old Pond Road
- ☆ Addressing erosion and runoff from Mead Street near the Post Office
- ☆ Addressing runoff from impervious surfaces and basement drains
- ☆ Public education about stormwater management

Timetable for Implementation

The timetable for implementation should be developed by the Three Lakes Council based on internal and external funding availability.

Measuring Success

Interim Milestones

Interim milestones include:

- ☆ Board meeting discussion to review recommendations and develop specific implementation targets

- ☆ Public outreach and education regarding management plan findings and recommendations
- ☆ Contractual arrangements with engineering/lake management firms to implement recommended NPS and in-lake management activities

Criteria

The criteria for measuring success include:

- ☆ Miles of dirt & gravel roads that have been corrected
- ☆ Improvement in dissolved oxygen levels in Lake Waccabuc and Lake Oscaleta
- ☆ Improvement (reduction) in total phosphorus concentrations within the lakes
- ☆ Reduction in the number, frequency and duration of cyanobacteria blooms

Funding Sources and Responsible Parties

Funding Sources

Clean Water State Revolving Fund

Since its inception, the CWSRF program has served as the nation's largest water quality financing source, helping communities across the country meet the goals of the Clean Water Act by improving water quality, protecting aquatic wildlife, protecting and restoring drinking water sources, and preserving our nation's waters for recreational use.

In New York State, the CWSRF is jointly administered by the NYS Environmental Facilities Corporation (nysefc.org) and the New York State Department of Environmental Conservation (DEC). Since 1990, the program has provided more than $14 billion in low-cost financing under this program.

The CWSRF provides low-interest rate financing to municipalities to construct water quality protection projects such as sewers and wastewater treatment facilities. A variety of publicly-owned water quality improvement projects are eligible for financing. Eligible projects include point source projects such as municipally-owned wastewater treatment facilities and nonpoint source projects such as stormwater management projects (green infrastructure, streambank stabilization, drainage erosion and sediment control, restoration of riparian vegetation/wetlands) and landfill closures, as well as certain habitat restoration and protection projects in national estuary program areas.

Municipal applicants may apply for financing for any CWSRF-eligible project. A municipality means any county, city, town, village, district corporation, county or town improvement district, Indian reservation wholly within New York State, any public benefit corporation or public authority established pursuant to the laws of New York, or any agency of New York State which is empowered to construct and operate a project, or any two or more of the foregoing which are acting jointly in connection with a project. Any municipality or not-for-profit entity which is authorized to acquire land for water quality protection purposes under Article 49 of the NYS Environmental Conservation Law may apply for CWSRF financing for land acquisition to protect water quality. Non-municipal entities may apply for financing CWSRF-eligible nonpoint source projects in Category E of the IUP for projects including, but not limited to: brownfield remediation, landfill leachate collection, storage and treatment, landfill gas collection, landfill capping, stormwater management, water body restoration (including streambank stabilization and drainage erosion and sediment control), and failing decentralized septic systems.

The CWSRF has an open enrollment, so application for funding can be made at any time.

Hudson River Estuary Program

The Hudson River Estuary Grant Program, managed by the NYS DEC, routinely offers grants for projects within the Hudson River Estuary, which includes the Three Lakes. In 2017, they released grant notice for Tributary Restoration and Resiliency (Round 20) with approximately $1,000,000 in available funding. This particular round of funding was focused on conserving and restoring habitat connectivity for river herring and/or the American eel within tributaries of the Hudson River Estuary watershed. Past grant funding initiatives have included local stewardship planning and river access & education. Additional rounds of funding for various projects become available each year.

New York City Department of Environmental Protection

The NYC DEP funds and implements a comprehensive Long-Term Watershed Protection Program which focuses on both protective and corrective initiatives to ensure that the source of water for nearly half of New York State’s population remains of extraordinary high quality for current consumers and future generations.

NYS DEC Aquatic Invasive Species Eradication Grant Program

The Aquatic Invasive Species (AIS) Spread Prevention Program supports projects that foster public education and outreach in water bodies with multiple AIS that can easily spread to uninvaded areas. Other eligible projects include decontamination stations and boat steward training programs in high priority areas. DEC awarded nearly $2.1 million from the New York State Environmental Protection Fund to 24 projects across the state. Applications are generally due around the beginning of the year. Grants range from $25,000 to $100,000 and must include a 25% project match. Eligible applicants include municipalities, not-for-profit organizations and academic institutions. DEC makes an effort to distribute grant funds based on the strategic importance of proposed projects and local waterbodies' vulnerability based on ecological characteristics, level and type of recreational boating access, and proximity to major travel corridors and waters colonized by small-bodied AIS and/or high priority plant AIS.

NYS DOS Water Quality Planning and Implementation Grants

The Water Quality Planning and Implementation Grants (PIGs) are administered by the NYS Department of State. The PIGs program is designed to assist watershed communities in preparing or updating comprehensive plans, establishing or revising community development tools and local laws, and creating strategic plans for hamlets, villages, and other potentially developable areas within the New York City Watershed. This program is open to East- and West-of-Hudson Watershed municipalities and is administered by the Albany Office staff. There are currently no rounds open.

NYS State Aid to Localities

Senate/Assembly Budget Bill requesting Aid to Localities. Appropriations of general fund for specific, dedicated funds can be earmarked within this bill by local representatives. Various municipalities and county SWCDs have used this to get funding for invasive species control, dredging and other environmental projects (Chapter 53, section 1). Moneys for specific lakes have ranged from $25,000 to $200,000

Regional Economic Development Council

Certain economic development and environmental funding programs are now administered by the 10 Regional Economic Development Council's within New York State under the Consolidated Funding Application. These grant/funding programs include NYS DEC's Wastewater Infrastructure Engineering Planning, the Water Quality Improvement Project and Aquatic Invasive Species Eradication grant programs. In 2016, Governor Cuomo announced funding for the Regional Economic Development Council initiative that included nearly $28 million dollars for 46 projects from the WQIP program (round 13). Funding for Round 14 of WQIP funding has not yet been announced.

Three Lakes Council

The Three Lakes Council has a history of self-funding a number of management issues, including monitoring and aquatic plant management. Leveraging Three Lakes Council funds against grants would increase the amount of environmental work that can take place within the watershed.

US Army Corps Aquatic Ecosystem Restoration

Under the authority provided by Section 206 of the Water Resources Development Act of 1996, the Army Corps of Engineers may plan, design and build projects to restore aquatic ecosystems for fish and wildlife. Such projects generally include manipulation of the hydrology in and along bodies of water, including wetlands and riparian areas. A project is adopted for construction only after a detailed investigation determines that the project will improve the quality of the environment and is in the best interest of the public. Projects must improve the quality of the environment, be in the public interest, demonstrate cost effectiveness and be no more than $5.0 million in total cost. ACOE provides technical assistance and project management. There is a required 35% local match.

WQIP

Administered by the NYS DEC, the Water Quality Improvement Program (WQIP) is a competitive, statewide reimbursement grant program open to municipalities and SWCDs for projects that directly address documented water quality impairments. The WQIP program is funded primarily by the Environmental Protection Fund (EPF) and NY Works II for projects that reduce polluted runoff, improve water quality and restore habitat in New York's waterbodies. Grants awarded through the WQIP program can fund up to 85 percent of the project cost for Wastewater Treatment Improvement projects. Grant recipients may receive up to 75 percent of the project cost for Non-agricultural Nonpoint Source Abatement and Control, Aquatic Habitat Restoration, Municipal Separate Storm Sewer System projects. Examples of fundable projects from the 2016 grant announcement included stream stabilization/restoration, green infrastructure, stormwater retrofits, riparian buffers and in-lake controls for nutrients (hypolimnetic aeration, hypolimnetic withdrawal, dredging).

CT DEEP

Much like NYS DEC, the Connecticut Department of Energy and Environmental Protection (CT DEEP) offers a number of opportunities for grants and financial assistance. Their Section 319 Nonpoint Source Grant Program funds implementation projects that target waterbodies on the State’s List of Impaired Waterbodies. Unfortunately, the Three Lakes are located in New York, with only a portion of the watershed in Connecticut. Also it does not appear that the lakes’ primary tributaries are listed on the CTDEEP’s impaired waterbodies list.

Responsible Parties

This section details the roles of stakeholders in the implementation of the WMP.

Three Lakes Council

- Review Draft WMP
- Coordinate WMP implementation
- Public Outreach (summary documents, website, coordinate stakeholder/public meetings)
- Fund Water Quality Monitoring & Plant Mapping
- Fund algal and macrophyte control programs
- Coordinate applications for funding

- Provide up-front funding to match grant funds
- Evaluate Success

Local Municipality and SWCD

- Public Outreach (participate in and help facilitate public outreach)
- Serve as project sponsors for grants that require recipients to be municipality or SWCD
- Serve as project lead for projects outside of Three Lakes Council property

Literature Cited and Reference Materials

Canfield, Daniel & W. Bachmann, Roger. (1981). Prediction of Total Phosphorus Concentrations, Chlorophyll a, and Secchi Depths in Natural and Artificial Lakes. Canadian Journal of Fisheries and Aquatic Sciences - CAN J FISHERIES AQUAT SCI. 38. 414-423.

Caraco, D. 2013. Watershed Treatment Model (WTM) 2013. Center for Watershed Protection, Ellicott City, MD.

Carlson, R.E. 1977. A trophic state index for lakes. Limnology and Oceanography. 22(2): 361-369

Chapin, F.S. III, P.A. Matson and H.A. Mooney. Principles of Terrestrial Ecosystem Ecology. New York, NY: Springer Science & Business Media. p. 218. Retrieved from http://books.google.com

Connor, J. N. and M. R. Martin. 1989. An assessment of sediment phosphorus inactivation, Kezar Lake, New Hampshire. Water Res. Bull. 25:4, pp. 845 853.

Downing, J.A and E. McCauley, 1992. The nitrogen:phosphorus relationship in lakes. Limnol. Oceanogr. 37(5), 936-945.

Edzwald, J.K, D.C. Toensing and M.C. Leung. 1976. Phosphate Adsorption Reactions with Clay Minerals. Environ. Sci. Technol.. 10(5): 485-490.

Harmel, D., S. Potter, P. Casebolt, K. Reckhow, C. Green and R. Haney. 2006. Compilation of measured nutrient load data for agricultural land uses in the United States. J Amer Water Res Assoc (JAWRA). 42(5): 1163-1178.

Homer, C.G., Dewitz, J., Yang, L., Jin, S., Danielson, P., Xian, Coulston, J., Herold, N., Wickham, J. and K. Megown. 2015. Completion of the 2011 National Land Cover Database for the conterminous United States – representing a decade of land cover change information, Photogrammetric Engineering and Remote Sensing, Vol. 81, 345-353.

Lumia, Richard, D.A. Freehafter and M.J. Smith. 2006. Magnitude and Frequency of Floods in New York: U.S. Geological Survey Scientific Investigations Report 2006-5112, 152 p. (http://pubs.usgs.gov/sir/2006/5112/)

Martin, M.R. 2004. Diagnostic-Feasibility Study and Lake & Watershed Management Plan for Lake Rippowam, Lake Oscaleta & Lake Waccabuc. Cedar Eden Environmental, LLC. Saranac Lake, NY. 88 pp. plus Appendices.

McCarthy, L. 2008. New Hampshire Stormwater Manual, Volume 1: Stormwater and Antidegradation, Appendix D: Typical Stormwater Pollutant EMCs. December 2008. NH Department of Environmental Services. Concord, NH.

MEDEP. 2010. Gravel Road Maintenance Manual: A Guideline for Landowners on Camp and Other Gravel Roads. Maine Dept. of Environmental Protection & Kennebec County Soil & Water Conservation District. April 2010.

Mobley, M., P. Gantzer, P. Benskin, I. Hannoun, S. McMahon, D. Austin and R. Scharf. 2019. Hypolimnetic oxygenation of water supply reservoirs using bubble plume diffusers. Lake and Reservoir Management. Vol 35, No 3: 247-265.

NHDEP & NHDOT. 2001. Best Management Practices for Routine Roadway Maintenance Activities in New Hampshire. NH Dept. of Environmental Services and NH Dept. of Transportation. August 2001.

NRCS. 2017. Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at the following link: https://websoilsurvey.sc.egov.usda.gov/. Accessed [2018/2019].

NYSFOLA. 2009. Diet for a Small Lake: The Expanded Guide to New York State Lake and Watershed Management. New York State Federation of Lake Associations, Inc.

PADEP. 2012. Erosion and Sediment Pollution Control Program Manual: Final. Technical Guidance Number 363-2134-008. PA Dept. of Environmental Protection. March 2012.

Palli, Natalia Blazquez. 2015. A comparison of two methods to reduce internal phosphorus cycling in lakes: Aluminium versus Phoslock. Masters Thesis. Department of Aquatic Sciences and Assessment. Swedish University of Agricultural Sciences.

PSU. Center for Dirt and Gravel Road Studies. The Pennsylvania State University. http://www.dirtandgravel.psu.edu/

PSU. 2014. Information Bulletin: Driving Surface Aggregate. 3/2014. Penn State Center for Dirt and Gravel Roads. The University of Pennsylvania.

http://www.dirtandgravel.psu.edu/sites/default/files/General%20Resources/DSA/DSA_Informational_Bulletin.pdf

Schueler, T. 1987. Controlling urban runoff: a practical manual for planning and designing urban BMPs. Metropolitan Washington Council of Governments. Washington, DC

Sharma, D., R. Gupta, R.K. Singh and A. Kansal. Characteristics of the event mean concentration (EMCs) from rainfall runoff on mixed agricultural land use in the shoreline zone of the Yamuna River in Delhi, India. Appl Water Sci (2012) 2:55-62.

USDA. 2012. Environmentally Sensitive Maintenance for Dirt and Gravel Roads. US Dept. of Agriculture, Forest Service. April 2012.

USDA NRCS. 2018. Map Unit Description (Brief, Generated). Westchester County, NY. Survey Area Version: 14. Survey Area Version Date: 09/03/2018. Natural Resource Conservation Service.

USDA NRCS. 2018. Map Unit Description (Brief, Generated). Connecticut. Survey Area Version: 18. Survey Area Version Date: 12/06/2018. Natural Resource Conservation Service.

USEPA. 2006. Environmentally Sensitive Maintenance for Dirt and Gravel Roads. USEPA-PA-2005-. US Environmental Protection Agency. February 2006.

US EPA. 2008. Handbook for Developing Watershed Plans to Restore and Protect Our Waters. EPA 841-B-08-002. US Environmental Protection Agency. Washington, DC.

USGS. 2016a. The StreamStats program, online at http://streamstats.usgs.gov, accessed on 03/10/2019. U.S. Geological Survey. Reston, VA.

USGS. 2016b. USGS NED 1/3 arc-second n42w074 1 x 1 degree ArcGrid 2016. U.S. Geological Survey. Reston, VA.

Veley, R.J. and Moran, M.J., 2012, Evaluating lake stratification and temporal trends by using near-continuous water-quality data from automated profiling systems for water years 2005–09, Lake Mead, Arizona and Nevada: U.S. Geo-logical Survey Scientific Investigation Report 2012–5080, 25 p. Available at http://pubs.usgs.gov/sir/2012/5080/.

Vollenweider, R.A. and J. Kerekes 1982. Eutrophication of waters. Monitoring, assessment and control. Paris (France): OECD Cooperative programme on monitoring of inland waters (eutrophication control); Environment Directorate. Paris. p.156

Glossary of Lake and Watershed Terms[†]

Acid neutralizing capacity (ANC): the equivalent capacity of a solution to neutralize strong acids. The components of ANC include weak bases (carbonate species, dissociated organic acids, alumino-hydroxides, borates, and silicates) and strong bases (primarily, OH-). In the National Surface Water Survey, as well as in most other recent studies of acid-base chemistry of surface waters, ANC was measured by the Gran titration procedure.

Acidic deposition: transfer of acids and acidifying compounds from the atmosphere to terrestrial and aquatic environments via rain, snow, sleet, hail, cloud droplets, particles, and gas exchange.

Adsorption: The adhesion of one substance to the surface of another: clays, for example, can adsorb phosphorus and organic molecules

Aerobic: Describes life or processes that require the presence of molecular oxygen.

Algae: Small aquatic plants that occur as single cells, colonies, or filaments. Planktonic algae float freely in the open water. Filamentous algae form long threads and are often seen as mats on the surface in shallow areas of the lake.

Alkalinity: (see *acid neutralizing capacity*).

Allochthonous: Materials (e.g., organic matter and sediment) that enter a lake from atmosphere or drainage basin (see *autochthonous*).

Anaerobic: Describes processes that occur in the absence of molecular oxygen.

Anoxia: A condition of no oxygen in the water. Often occurs near the bottom of fertile stratified lakes in the summer and under ice in late winter.

Anoxic: "Without oxygen." (see *anoxia*).

Autochthonous: Materials produced within a lake e.g., autochthonous organic matter from plankton versus allochthonous organic matter from terrestrial vegetation.

Bathymetric map: A map showing the bottom contours and depth of a lake; can be used to calculate lake volume.

Benthic: Macroscopic (seen without aid of a microscope) organisms living in and on the bottom sediments of lakes and streams. Originally, the term meant the lake bottom, but it is now applied almost uniformly to the animals associated with the substrate. Also referred to as *benthos*.

Biochemical oxygen demand (BOD): The rate of oxygen consumption by organisms during the decomposition (respiration) of organic matter, expressed as grams oxygen per cubic meter of water per hour.

Biomass: The weight of biological matter. Standing crop is the amount of biomass (e.g., fish or algae) in a body of water at a given time. Often measured in terms of grams per square meter of surface.

Biota: All plant and animal species occurring in a specified area.

[†] adapted from: *The Lake and Reservoir Restoration Guidance Manual* (US EPA 1990)

Chemical oxygen demand (COD): Non-biological uptake of molecular oxygen by organic and inorganic compounds in water.

Chlorophyll: A green pigment in algae and other green plants that is essential for the conversion of sunlight, carbon dioxide and water to sugar (photosynthesis). Sugar is then converted to starch, proteins, fats and other organic molecules.

Chlorophyll a: A type of chlorophyll present in all types of algae, sometimes in direct proportion to the biomass of algae.

Cluster development: Placement of housing and other buildings of a development in groups to provide larger areas of open space

Consumers: Animals that cannot produce their own food through photosynthesis and must consume plants or animals for energy (see *producers*).

Decomposition: The transformation of organic molecules (e.g., sugar) to inorganic molecules (e.g., carbon dioxide and water) through biological and non-biological processes.

Delphi: A technique that solicits potential solutions to a problem situation from a group of experts and then asks the experts to rank the full list of alternatives.

Density flows: A flow of water of one density (determined by temperature or salinity) over or under water of another density (e.g. flow of cold river water under warm reservoir surface water).

Detritus: Non-living dissolved and particulate organic material from the metabolic activities and deaths of terrestrial and aquatic organisms.

Drainage basin: Land area from which water flows into a stream or lake (see *watershed*).

Drainage lakes: Lakes having a defined surface inlet and outlet.

Ecology: Scientific study of relationships between organisms and their environment: also defined as the study of the structure and function of nature.

Ecosystem: A system of interrelated organisms and their physical-chemical environment. In limnology, the ecosystem is usually considered to include the lake and its watershed.

Effluent: Liquid wastes from sewage treatment, septic systems or industrial sources that are released to a surface water.

Environment: Collectively, the surrounding conditions, influences and living and inert matter that affect a particular organism or biological community.

Epilimnion: Uppermost, warmest, well-mixed layer of a lake during summertime thermal stratification. The epilimnion extends from the surface to the thermocline.

Erosion: Breakdown and movement of land surface which is often intensified by human disturbances.

Eutrophic: From Greek for well-nourished; describes a lake of high photosynthetic activity (plants and/or algae), high nutrient concentration and low transparency.

Eutrophication: The process of physical, chemical, and biological changes associated with nutrients, organic matter, silt enrichment, and sedimentation of a lake or reservoir. If the process is accelerated by man-made influences it is termed cultural eutrophication.

Fall overturn: The autumn mixing, top to bottom, of lake water caused by cooling and wind-derived energy.

Fecal coliform test: Most common test for the presence of fecal material from warm-blooded animals. Fecal coliforms are measured because of convenience; they are not necessarily harmful but indicate the potential presence of other disease-causing organisms.

Floodplain: Land adjacent to lakes or rivers that is covered as water levels rise and overflow the normal water channels.

Flushing rate: The rate at which water enters and leaves a lake relative to lake volume, usually expressed as time needed to replace the lake volume with inflowing water.

Flux: The rate at which a measurable amount of a material flows past a designated point in a given amount of time.

Food chain: The general progression of feeding levels from primary producers, to herbivores, to planktivores, to the larger predators.

Food web: The complex of feeding interactions existing among the lake's organisms.

Forage fish: Fish, including a variety of panfish and minnows, that are prey for game fish.

Groundwater: Water found beneath the soil surface; saturates the stratum at which it is located; often connected to lakes.

Hard water: Water with relatively high levels of dissolved minerals such as calcium, iron, and magnesium.

Hydrographic map: A map showing the location of areas or objects within a lake.

Hydrologic cycle: The circular flow or cycling of water from the atmosphere to the earth (precipitation) and back to the atmosphere (evaporation and plant transpiration). Runoff, surface water, groundwater, and water infiltrated in soils are all part of the hydrologic cycle.

Hypolimnion: Lower, cooler layer of a lake during summertime thermal stratification.

Hypoxia: A condition of low oxygen in the water (< 2.0 mg/L). Often occurs near the bottom of fertile stratified lakes in the summer and under ice in late winter.

Influent: A tributary stream.

Internal nutrient cycling: Transformation of nutrients such as nitrogen or phosphorus from biological to inorganic forms through decomposition, occurring within the lake itself. Also refers to the release of sediment-bound nutrients into the overlying water that typically occurs within the anoxic hypolimnion of stratified, mesotrophic and eutrophic lakes.

Isothermal: The same temperature throughout the water column of a lake.

Lake: A considerable inland body of standing water, either naturally formed or manmade.

Lake district: A special purpose unit of government with authority to manage a lake(s) and with financial powers to raise funds through mill levy, user charge, special assessment, bonding, and borrowing. May or may not have police power to inspect septic systems, regulate surface water use, or zone land.

Lake management: The practice of keeping lake quality in a state such that attainable uses can be achieved and maintained.

Lake protection: The act of preventing degradation or deterioration of attainable lake uses.

Lake restoration: The act of bringing a lake back to its attainable uses.

Lentic: Relating to standing water (versus lotic, running water).

Limnologist: One who studies limnology.

Limnology: Scientific study of fresh water, especially the history, geology, biology, physics, and chemistry of lakes. Also termed freshwater ecology.

Littoral zone: That portion of a waterbody extending from the shoreline lakeward to the greatest depth occupied by rooted plants.

Loading: The total amount of material (sediment, nutrients, oxygen-demanding material) brought into the lake by inflowing streams, runoff, direct discharge through pipes, groundwater, the air, and other sources over a specific period of time (often annually).

Macroinvertebrates: Aquatic insects, worms, clams, snails, and other animals visible without the aid of a microscope, that may be associated with or live on substrates such as sediments and macrophytes. They supply a major portion of fish diets and consume detritus and algae.

Macrophytes: Rooted and floating aquatic plants, commonly referred to as waterweeds. These plants may flower and bear seed. Some forms, such as duckweed and coontail (*Ceratophyllum*), are free-floating forms without roots in the sediment.

Mandatory property owners association: Organization of property owners in a subdivision or development with membership and annual fee required by covenants on the property deed. The association will often enforce deed restrictions on members' property and may have common facilities such as bathhouse, clubhouse, golf course, etc.

Marginal zone: Area where land and water meet at the perimeter of a lake. Includes plant species, insects and animals that thrive in this narrow, specialized ecological system.

Mesotrophic: Describes a lake of moderate plant productivity and transparency; a trophic state between oligotrophic and eutrophic.

Metalimnion: Layer of rapid temperature and density change in a thermally stratified lake. Resistance to mixing is high in this region.

Morphometry: Relating to a lake's physical structure (e.g., depth, shoreline length).

Nekton: Large aquatic organisms whose mobility is not determined by water movement -- for example, fish and amphibians.

Nominal group process: A process of soliciting concerns/issues/ideas from members of a group and ranking the resulting list to ascertain group priorities. Designed to neutralize dominant personalities.

Nutrient: An element or chemical essential to life, such as carbon, oxygen, nitrogen, and phosphorus.

Nutrient budget: Quantitative assessment of nutrients (e.g., nitrogen or phosphorus) moving into, being retained in, and moving out of an ecosystem; commonly constructed for phosphorus because of its tendency to control lake trophic state.

Nutrient cycling: The flow of nutrients from one component of an ecosystem to another, as when macrophytes die and release nutrients that become available to algae (organic to inorganic phase and return).

Oligotrophic: "Poorly nourished," from the Greek. Describes a lake of low plant productivity and high transparency.

Ooze: Lake bottom accumulation of inorganic sediments and the partially decomposed remains of algae, weeds, fish, and aquatic insects. Sometimes called muck (see *sediment*).

Ordinary high water mark: Physical demarcation line, indicating the highest point that water level reaches and maintains for some time. Line is visible on rocks, or shoreline, and by the location of certain types of vegetation.

Organic matter: Molecules manufactured by plants and animals and containing linked carbon atoms and elements such as hydrogen, oxygen, nitrogen, sulfur, and phosphorus.

Paleolimnology: The study of the fossil record within lake sediments.

Pathogen: A microorganism capable of producing disease. They are of great concern to human health relative to drinking water and swimming beaches.

Pelagic zone: This is the open area of a lake, from the edge of the littoral zone to the center of the lake.

Perched: A condition where the lake water is isolated from the groundwater table by impermeable material such as clay.

pH: A measure of the concentration of hydrogen ions of a substance, which ranges from very acid (pH = 1) to very alkaline (pH = 14). pH 7 is neutral and most lake waters range between 6 and 9. pH values less than 6 are considered acidic, and most life forms can not survive at pH of 4.0 or lower.

Photic zone: The lighted region of a lake where photosynthesis takes place. Extends down to a depth where plant growth and respiration are balanced by the amount of light available.

Phytoplankton: Microscopic algae and microbes that float freely in open water of lakes and oceans.

Plankton: Microscopic plants, microbes and animals floating or swimmng freely about in lakes and oceans.

Primary productivity: The rate at which algae and macrophytes fix or convert light, water and carbon dioxide to sugar in plant cells (through photosynthesis). Commonly measured as milligrams of carbon per square meter per hour.

Primary producers: Green plants that manufacture their own food through photosynthesis.

Profundal zone: Area of lake water and sediment occurring on the lake bottom below the depth of light penetration.

Reservoir: A manmade lake where water is collected and kept in quantity for a variety of uses, including flood control, water supply, recreation and hydroelectric power.

Residence time: Commonly called the hydraulic residence time -- the amount of time required to completely replace the lake's current volume of water with an equal volume of new water.

Respiration: Process by which organic matter is oxidized by organisms, including plants, animals, and bacteria. The process releases energy, carbon dioxide, and water.

Secchi depth: A measure of transparency of water obtained by lowering a black and white, or all white, disk (Secchi disk, 20 cm in diameter) into water until it is no longer visible. Measured in units of meters or feet.

Sediment: Bottom material in a lake that has been deposited after the formation of a lake basin. It originates from remains of aquatic organisms, chemical precipitation of dissolved minerals, and erosion of surrounding lands (see *ooze* and *detritus*).

Seepage lakes: Lakes having either an inlet or outlet (but not both) and generally obtaining their water from groundwater and rain or snow.

Soil retention capacity: The ability of a given soil type to adsorb substances such as phosphorus, thus retarding their movement to the water.

Stratification: Layering of water caused by differences in water density. Thermal stratification is typical of most deep lakes during summer. Chemical stratification can also occur.

Swimmers itch: A rash caused by penetration into the skin of the immature stage (cercaria) of a flatworm (not easily controlled due to complex life cycle). A shower or alcohol rubdown should minimize penetration.

Thermal stratification: Lake stratification caused by temperature-created differences in water density.

Thermocline: A horizontal plane across a lake at the depth of the most rapid vertical change in temperature and density in a stratified lake (see *metalimnion*.).

Topographic map: A map showing the elevation of the landscape at specified contour intervals (typically 10 or 20 foot intervals, may be expressed in feet or meters). Can be used to delineate the watershed.

Trophic state: The degree of eutrophication of a lake. Transparency, chlorophyll a levels, phosphorus concentrations, amount of macrophytes, and quantity of dissolved oxygen in the hypolimnion can be used to assess state.

Voluntary lake property owners association: Organization of property owners in an area around a lake that members join at their option.

Water column: Water in the lake between the interface with the atmosphere at the surface and the interface with the sediment layer at the bottom. Idea derives from vertical series of measurements (oxygen, temperature, phosphorus) used to characterize lake water.

Water table: The upper surface of groundwater; below this point, the soil is saturated with water.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

Zooplankton: Microscopic animals that float or swim freely in lake water, graze on detritus particles, bacteria, and algae, and may be consumed by fish.