NEW YORK STATE OF OPPORTUNITY | Department of Environmental Conservation

2017 FINGER LAKES WATER QUALITY REPORT

Summary of Historic Finger Lakes Data and the 2017 Citizens Statewide Lake Assessment Program

September 2018

Division of Water (DOW)

Finger Lakes Watershed Hub (FLWH)

615 Erie Boulevard, Syracuse, NY

Lake Monitoring and Assessment Section (LMAS)

625 Broadway, Albany, NY

www.dec.ny.gov

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Acknowledgements

The New York State Department of Environmental Conservation's (NYSDEC) Citizens Statewide Lake Assessment Program's (CSLAP's) expansion into the Finger Lakes was made possible by funding from the NYS Environmental Protection Fund-Ocean and Great Lakes Program. This funding allowed 22 sites on the 11 Finger Lakes to be added to the program in the spring of 2017. Although many of the Finger Lakes had participated in CSLAP historically, this represented the first time all 11 Finger Lakes were part of CSLAP during the same field season. This incredible opportunity allowed NYSDEC to: (1) collect critical water quality data on these important natural resources, (2) assess contemporary water quality in the Finger Lakes in the context of recent and continuing water quality concerns, (3) make comparisons of the water quality between the lakes in 2017, and (4) make preliminary trend determinations for individual lakes over time.

A program as comprehensive as CSLAP does not function without the efforts of many hardworking and dedicated individuals. Many thanks to the NYS Federation of Lake Associations, Inc. (NYSFOLA), including manager of NYSFOLA and co-coordinator of CSLAP, Nancy Mueller. Since 2000, Nancy has served as the Assistant Program Coordinator and ensured day-to-day operation of the program. Also, the authors would like to express our appreciation to the entire NYSFOLA board of directors, Lou Feeney, Jan Andersen, and others for working with NYSDEC over the past three decades to shape CSLAP into one of the most successful citizen science programs in the country.

All the chemical analyses for CSLAP have been conducted at Upstate Freshwater Institute (UFI) since 2000. UFI has been incredibly accommodating during their tenure as the CSLAP laboratory, especially in its expansion to the Finger Lakes in 2017.

All the contemporary data presented in this report was collected by volunteers. The CSLAP program would not exist if it weren't for the hundreds of volunteers that generously and tirelessly donate their time and resources in efforts to improve and preserve their lakes. The authors would like to thank the lake associations of the Finger Lakes (below) for working with us in 2017 as we quickly brought the program to the region.

- Conesus Lake Association
- City of Rochester (Hemlock and Canadice Lakes)
- Honeoye Valley Association and the Honeoye Lake Watershed Taskforce
- Canandaigua Lake Watershed Association
- Keuka Lake Association
- Seneca Lake Pure Waters Association
- Cayuga Lake Watershed Network
- Owasco Watershed Lake Association
- Skaneateles Lake Association
- Otisco Lake Preservation Association

Lastly, thank you to the NYSDEC Lake Management and Assessment Section (LMAS) and the Section Chief, Scott Kishbaugh, who has worked as the CSLAP program manager since 1986. CSLAP would not be the premier citizen science monitoring program that it is today without his hard work and dedication to improving the water quality of NYS lakes.

2017 CSLAP Volunteers by Lake

Conesus Lake	Chris Willoughby, Mike Parker, Ellen Hanafin, Karl Hanafin
Hemlock Lake	John Maier, Kathy Witzel, Britt Vanno, Dave Rowley, Greg Whitney
Canadice Lake	John Maier, Kathy Witzel, Britt Vanno, Dave Rowley, Greg Whitney
Honeoye Lake	Terry Gronwall, Dorothy Gronwall
Canandaigua Lake	E.H. Carman IV, Ruby Hagrey, Susan Carman, Ted Carman, Albert Crofton, Deirdre Crofton, Lindsay McMillan, Nadia Harvieux
Keuka Lake	Maria Hudson, Scott Drake, Stan Martin, Thom Love
Seneca Lake	Dan Corbett, Larry Martin, Laurie Corbett, Sue Martin, Addison Mason
Cayuga Lake	Tom Casella, William Ebert, Don Sargent, Michelle Henry, Shannon Barrett
Owasco Lake	Mark Plis, Michele Plis, Brian Brundage, Jeff Calkins
Skaneateles Lake	Barbara Delmonico, Bill Dean, Bob Dean, Jed Delmonico, Buzz Roberts, Deb Hole, Gretchen Roberts, Rich Hole
Otisco Lake	Benjamin Hardwick

Executive Summary

NYSDEC is responsible for reporting on the condition of water resources in New York State (NYS), including more than 16,000 lakes, ponds, and reservoirs, to meet state and federal monitoring requirements and address multiple data needs. With such a vast number of freshwater resources, NSYDEC acknowledges that more information is needed than can be collected by staff resources alone. Most lake management activities are locally-led initiatives in NYS, but require collaboration between engaged lake residents and government officials to effectively evaluate and manage water quality problems.

The Citizens Statewide Lake Assessment Program (CSLAP) is a partnership between NYSDEC, NYSFOLA, and lake residents who help monitor and collect critical lake data in a manner consistent with other NYS programs. This information is used to understand lake conditions, to develop lake management plans, and to meet monitoring requirements mandated by the Federal Clean Water Act (CWA) and NYS Environmental Conservation Law (ECL).

Through a new initiative, CSLAP volunteers monitored twenty-two locations on the eleven Finger Lakes in the summer of 2017, representing the first synoptic look into the water quality of all the Finger Lakes since the late 1990s. Combined, the dataset collected in 2017 was large and comprehensive (as an example, 340 observations of total phosphorus were successfully collected and analyzed). Field data and user perception observations, as well as, water quality samples and indicators of harmful algal blooms (HABs), including algal toxin samples were collected. Lake trophic state was evaluated and specialized forms of dissolved nutrients were successfully piloted. Quality control results with paired field duplicate samples showed acceptable comparability between volunteers and NYSDEC staff, providing assurance that the data collected through CSLAP is of sufficient quality to aid NYSDEC in making accurate assessments and important management decisions to protect the water quality of these valuable natural resources.

In 2017, the Finger Lakes represented a moderate cross-section of the range of water quality conditions in NYS. The eleven Finger Lakes tended to have better water quality, compared with smaller lakes in the Finger Lakes region. Compared with other NYS lakes, the Finger Lakes tended to have:

1. average to low concentrations for total phosphorus, chlorophyll-a, and color;
2. average to high clarity (Secchi depth);
3. low nitrogen concentrations in the western Finger Lakes and high nitrogen concentrations in the eastern Finger Lakes;
4. high chloride, calcium, pH, and specific conductivity; and
5. more susceptibly to HABs than other lakes with similar water quality conditions.

Phosphorus exhibited a strong, positive correlation with chlorophyll-a and an inverse correlation with Secchi disk depth in 2017. The relationship between these two metrics of water quality was similar to the relationship developed with NYSDEC data in the late 1990s for these lakes. Nitrogen to phosphorus ratios were high (> 20) for the mesotrophic and oligotrophic lakes for most observations, although there were times, seasonally, for several lakes in which the ratio dropped below the threshold for N and/or P limitation. The N:P ratio for the eutrophic lakes suggested that either N or P could limit algal growth in these systems.

Comparison of the Finger Lakes Relative to NYS Median Values for Key Water Quality Indicators

Lake	Current Trophic State	Total Phosphorus TP	Chlorophyll-a Chl-a	Secchi Disk Depth SD	Total Nitrogen TN	Oxidized Dissolved N NO_X	Ammonia NH_3	Calcium Ca^{2+}	Chloride Cl^-	pH	Color
Conesus	Mesotrophic	HIGH	HIGH	HIGH	LOW	LOW	LOW	HIGH	HIGH	HIGH	LOW
Hemlock	Mesotrophic	LOW	LOW	HIGH	LOW	HIGH	LOW	HIGH	HIGH	HIGH	LOW
Canadice	Oligotrophic	LOW	LOW	HIGH	LOW	LOW	HIGH	LOW	HIGH	LOW	LOW
Honeoye	Eutrophic	HIGH	HIGH	LOW	HIGH	LOW	HIGH	HIGH	LOW	HIGH	HIGH
Canandaigua	Oligotrophic	LOW	LOW	HIGH	LOW	HIGH	LOW	HIGH	HIGH	HIGH	LOW
Keuka	Oligotrophic	LOW	LOW	HIGH	LOW	HIGH	HIGH	HIGH	HIGH	HIGH	LOW
Seneca	Mesotrophic	HIGH	HIGH	HIGH	HIGH	HIGH	LOW	HIGH	HIGH	HIGH	LOW
Cayuga	Mesotrophic	HIGH	HIGH	LOW	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	LOW
Owasco	Mesotrophic	LOW	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	LOW	HIGH	LOW
Skaneateles	Oligotrophic	LOW	LOW	HIGH	HIGH	HIGH	LOW	HIGH	LOW	HIGH	LOW
Otisco	Mesotrophic	HIGH	HIGH	LOW	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	LOW

HIGH = higher than the NYS average; LOW = lower than the NYS average

Nitrogen was not strongly correlated with summer average chlorophyll-a in the Finger Lakes in 2017, reinforcing the paradigm that P mostly limits algal growth in these systems for most of the time during the growing season. An interesting geographical pattern was observed for total nitrogen and NO_X concentrations, in which values of these indicators were statistically lower in the western Finger Lakes compared with the eastern Finger Lakes. The geology, large size and volumes, and key watershed management practices all play roles in influencing water quality of the Finger Lakes.

Chlorophyll-a in most lakes have improved or remained stable since the 1970s but have declined in water quality (i.e., chlorophyll-a has increased) since the 1990s. Clarity trends have been mixed as well, but since the early 1900s clarity has decreased for most lakes. However, long term trends cannot yet be evaluated in these lakes, since most continuous data from these lakes does not conform with NYSDEC's quality assurance standards. It is anticipated that the initiation of CSLAP sampling on all eleven Finger Lakes, and continuation of this program in future years, will provide data to support more robust long-term trend analyses.

The Finger Lakes were variable with regards to dissolved nutrients in 2017. These water quality metrics will be expanded to all the lakes in 2018 so that comparisons can be made between lakes and more definitive conclusions can be made to determine their effect on water quality. A summary of individual lake results is presented below.

Conesus

Conesus Lake is a small Finger Lake with a surface area of 13.7 km^2 and volume of 157 million m^3. The 2017 data suggests that Conesus Lake remains *meso-eutrophic (moderately-highly productive)*. Major trophic state indicators were intermediate for total phosphorus (0.020 mg/L), chlorophyll-a (5.9 µg/L), and water clarity (Secchi disk depth of 3.1 m). Conesus Lake has low levels of total nitrogen and NO_X (0.36 and 0.01 mg/L, respectively). Lake productivity increased in early-July as indicated by an increase in chlorophyll-a and a drop in Secchi depth. Productivity then declined for the remainder of the summer with a slight increase at the end of September. Using current chlorophyll-a as metric of lake quality, Conesus's water quality has improved slightly since the 1990s.

Hemlock

Hemlock Lake is a small Finger Lake serving as a drinking water supply for the City of Rochester. It has a surface area of 7.2 km^2 and volume of 105 million m^3. The 2017 data suggests that Hemlock Lake remains *meso-oligotrophic (low-moderate levels of productivity)*. Major trophic state indicators were intermediate to low for total phosphorus (0.011 mg/L) and for chlorophyll-a (2.9 µg/L), and intermediate for water clarity (Secchi disk depth of 3.8 m). Hemlock Lake has low levels of total nitrogen and NO_X (0.27 and 0.07 mg/L, respectively). Lake productivity increased in mid-July as indicated by an increase in chlorophyll-a and a drop in water clarity. Productivity then declined for the remainder of the summer with a slight increase in chlorophyll-a in mid-September. The City of Rochester reported algal blooms in the summer of 2017, although these were small and ephemeral, with no measured impact on drinking water quality. Using current chlorophyll-a as metric of lake quality, Hemlock's water quality has improved since the 1970s but degraded slightly since the 1990s.

Canadice

Canadice Lake is a small Finger Lake that also provides drinking water to the City of Rochester, with a surface area of 2.6 km^2 and volume of 42 million m^3. The 2017 data suggests that Hemlock Lake is *oligotrophic (low levels of productivity)*. Major trophic state indicators were low for total phosphorus (0.009 mg/L) and chlorophyll-a (1.8 µg/L), and high for water clarity (Secchi disk depth of 5.7 m). Canadice Lake has low levels of total nitrogen and NO_X (0.19 and 0.01 mg/L, respectively). Lake productivity was consistent throughout the summer with slight increases in July and the end of September. Water clarity was also seasonally consistent with slight decreases coinciding with the increases in lake productivity. The City of Rochester reported algal blooms in the summer of 2017, but as with Hemlock Lake, these were short-lived and covered only a very small area. Using current chlorophyll-a as metric of lake quality, Canadice's water quality has continued to improve since the 1970s.

Honeoye

Honeoye Lake is a small Finger Lake with a surface area of 7.1 km^2 and volume of 34 million m^3, but does not provide public drinking water. The 2017 data suggests that Honeoye Lake remains *eutrophic (highly productive)*. Major trophic state indicators were high for total phosphorus (0.036 mg/L) and for chlorophyll-a (22.2µg/L) and low for water clarity (Secchi disk depth of 1.7 m). Honeoye Lake has low levels of total nitrogen and NO_X (0.73 and 0.01 mg/L, respectively). Lake productivity increased in August, then declined in mid-September with slight increase at the end of September. Honeoye experienced numerous harmful algal blooms in 2017 as reported by the Honeoye Lake Watershed Taskforce, and these blooms have been well documented over much of the last decade. Using current chlorophyll-a as metric of lake quality, Honeoye's water quality has declined since the 1990s.

Canandaigua

Canandaigua Lake is a large Finger Lake with a surface area of 42.3 km^2 and volume of 1,600 million m^3. Despite recent harmful algal blooms (HABs), the 2017 data suggests that Canandaigua Lake remains *meso-oligotrophic (low-moderate levels of productivity)*. Major trophic state indicators were low for total phosphorus (TP) (0.008 mg/L) and chlorophyll-a (2 µg/L) and high for water clarity (Secchi disk depth of 5 m). Canandaigua Lake has low levels of total nitrogen and NO_X (0.33 and 0.05 mg/L, respectively). Lake productivity increased modestly through early summer and water clarity dropped slightly, likely due to rising algae levels and/or from runoff events in July. Algal growth decreased in August and then increased in September. Canandaigua Lake had several reports of cyanobacteria blooms at numerous locations in the lake in the late summer as reported by the Canandaigua Lake Watershed Association and Watershed Council. Canandaigua has had periodic blooms since a large HAB affected the north end of the lake in 2015. Using current chlorophyll-a as metric of lake quality, Canandaigua's water quality has improved since the 1970s, but has degraded slightly since the late 1990s.

Keuka

Keuka Lake is the only branched Finger Lake. It has a surface area of 47 km^2 and volume of 1,400 million m^3. The 2017 data suggests that Keuka Lake is *meso-oligotrophic (low-moderate productivity)*. Major trophic state indicators were low total phosphorus levels (0.008 mg/L), low to intermediate chlorophyll-a levels (2.7 µg/L) and high water clarity (Secchi disk depth of 5.6 m). Keuka Lake has the lowest levels of total nitrogen (TN) of the eleven Finger Lakes and has low NO$_X$ (0.25 and 0.04 mg/L, respectively). Interestingly, the ratio of TN to TP dropped from ~ 60 in the late spring to ~ 5 in late August indicating potential N-limitation. The Keuka Lake Association reported small and ephemeral shoreline cyanobacteria blooms on the lake in 2017; blooms had not been reported to NYSDEC prior to 2017. Using current chlorophyll-a as metric of lake quality, Keuka's water quality has improved continually since the 1970s.

Seneca

Seneca Lake is one of the largest Finger Lakes with a surface area of 175.4 km^2 and volume of 15,500 million m^3. The 2017 data suggests that Seneca Lake is *mesotrophic (moderately productive)*. Major trophic state indicators were intermediate for total phosphorus (0.015 mg/L), chlorophyll-a (4.6 µg/L), and water clarity (Secchi disk depth of 3.6 m). Seneca Lake has low levels of total nitrogen and NO$_X$ (0.5 and 0.18 mg/L, respectively). Lake productivity increased in mid-September of 2017, as manifested by a slight drop in water clarity and conductivity and an increase in algae levels, coinciding with harmful algal blooms as reported by the Seneca Lake Pure Waters Association. Blooms had also been reported on the lake in recent years. Using current chlorophyll-a as metric of lake quality, Seneca's water quality has improved since the 1970s, but degraded since the late 1990s and early 2000s.

Cayuga

Cayuga Lake is one of the largest Finger Lakes with a surface area of 172 km^2 and volume of over 9,300 million m^3. It is the longest Finger Lake (61.4 km) and has ~ 155 km of shoreline. The 2017 data suggests that Cayuga Lake remains *meso-eutrophic (moderately-highly productive)*. Major trophic state indicators were intermediate for total phosphorus (0.018 mg/L), chlorophyll-a (6.1 µg/L), and water clarity (Secchi disk depth of 2.9 m). Cayuga Lake was the Finger Lake with the highest summer average total nitrogen and NO$_X$ concentrations (1.09 and 0.71 mg/L, respectively). Lake productivity increased through early summer and water clarity dropped in response to rising algae levels and/or from runoff events in early July. Algal growth then decreased and stabilized for the remainder of the season. In July and September, Cayuga Lake had numerous reports of cyanobacteria blooms at numerous locations in the lake, although blooms had not been well documented prior to 2017. Using current chlorophyll-a as metric of lake quality, Cayuga's water quality has degraded relative to several key historical reference points: the 1970s, the late 1990s, and the mid-2000s.

Owasco

Owasco Lake is a medium-sized Finger Lake with a surface area of 26.7 km^2 and volume of 781 million m^3. The 2017 data suggests that Owasco Lake remains *mesotrophic (moderately productive)*. Major trophic state indicators were intermediate for total phosphorus (0.014 mg/L), chlorophyll-a (5.4 µg/L), and for water clarity (Secchi disk depth of 3.4 m). Owasco Lake has elevated summer average total nitrogen and NO_X concentrations (0.94 and 0.61 mg/L, respectively). Lake productivity increased through early summer and water clarity dropped in response to rising algae levels and/or from runoff events in early July. Algal growth then decreased and stabilized for the remainder of the season. From July through September, the Owasco Lake Watershed Association and Owasco Lake Watershed Inspection Program reported numerous cyanobacteria blooms throughout the lake, following an increasing frequency in bloom reports in recent years. Using current chlorophyll-a as metric of lake quality, Owasco's water quality in the open water has remained stable relative to several key historical reference points: the 1970s, and the late 1990s. However, 2017 was slightly higher in chlorophyll-a than the mid-2000s.

Skaneateles

Skaneateles Lake is a large Finger Lake with a surface area of 35.9 km^2 and volume of over 1,500 million m^3. Despite the large algal bloom in 2017, Skaneateles Lake remains *oligotrophic (low levels of productivity)*. Major trophic state indicators were low for total phosphorus (0.006 mg/L), chlorophyll-a (1.2 µg/L), and high for water clarity (Secchi disk depth > 6.5 m). Skaneateles Lake has low levels of total nitrogen and NO_X (0.46 and 0.3 mg/L, respectively). Lake productivity increased in mid-September of 2017, as manifested by a slight drop in water clarity and conductivity and an increase in algae levels. The first confirmed harmful algal bloom on Skaneateles was recorded in September and affected the northern third of the lake. Phosphorus readings spiked, and Secchi disk readings declined in July due to extremely heavy rain storms. Using current chlorophyll-a as metric of lake quality, Skaneateles's water quality has improved since the 1970s, but degraded slightly since the late 1990s.

Otisco

Otisco Lake is a small Finger Lake with a surface area of 7.6 km^2 and volume of over 78 million m^3. The 2017 data suggests that Otisco Lake remains *meso-eutrophic (moderately to highly productive)*. Major trophic state indicators were intermediate-high for total phosphorus (0.021 mg/L), high for chlorophyll-a (7.2 µg/L), and intermediate for water clarity (Secchi disk depth of 2.9 m). Otisco Lake has intermediate levels of total nitrogen and NO_X (0.7 and 0.26 mg/L, respectively). Lake productivity increased in mid-July and at the end of August, as manifested by a slight drop in water clarity and an increase in algae levels. HABs were only sporadically reported in the lake in 2017, and have not been well documented in recent years. Using current chlorophyll-a as metric of lake quality, Otisco's water quality has degraded since the 1970s and 1990s.

The Finger Lakes exhibited good to high water quality, however, all eleven lakes experienced harmful algal blooms in 2017 of varying extents, duration, and toxicity. Recent research and the Governor's 2018 HAB Initiative have shown that the Finger Lakes represent ecological systems which provide conditions favorable for these blooms. While more research is needed to properly predict bloom triggers and forecast blooms, the underlying chemistry and water quality observations provided by CSLAP in the Finger Lakes is providing invaluable data to understand the nature of biological dynamics in the region and provide information to assess future monitoring technologies. This data can and will be used in the development of HABs mitigation and nutrient reduction strategies as well as targeted best management practice implementation.

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Acronym List

9EP	Nine Element Plan
ALSC	Adirondack Lake Survey Corporation
BG	Blue Green
C	Confirmed
Ca	Calcium
CALM	Consolidated Assessment and Listing Methodology
CDC	Centers for Disease Control
Chl-a	Chlorophyll a
Cl	Chloride
CSLAP	Citizens Statewide Lake Assessment Program
CWA	Clean Water Act
DBPs	Disinfection By-Products
DOC	Dissolved Organic Carbon
ECL	Environmental Conservation Law
ELAP	Environmental Laboratory Approval Program
HABS	Harmful Algal Blooms
HT	High Toxins
LCI	Lake Classification and Inventory
LCMS/MS	Liquid Chromatography-Mass Spectrometry
LN	Natural Logarithm
LOD	Level of Detection
LOQ	Level of Quantification
NH_3	Ammonia
NOx	Oxidized Nitrogen
NYS	New York State
NYSDEC	New York State Department of Environmental Conservation
NYSDEC	New York State Department of Environmental Conservation Finger Lakes Water Hub – a section of four
NYSDEC	New York State Department of Environmental Conservation Lake Management and Assessment Section
NYSDOH	NYS Department on Health
NYSFOLA	New York State Federation of Lakes Association, Inc.
OPRHP	Office of Parks, Recreation and Historic Preservation
QAPP	Quality Assurance Project Plans
QC	Quality Control
RPD	Relative Percent Difference
S	Suspicious
SC	Specific Conductance
SD	Secchi Disk
SM	Standard Method
SOP	Standard Operating Procedures
SUNY ESF	SUNY College of Environmental Science and Forestry
TDN	Total Dissolved Nitrogen
TDP	Total Dissolved Phosphorus
TMDL	Total Maximum Daily Load
TN	Total Nitrogen

Acronym List Continued

TP	Total Phosphorus
TSI	Trophic State Index
UFI	Upstate Freshwater Institute
USEPA	United States Environmental Protection Agency
WHO	World Health Organization
WI/PWL	Waterbody Inventory/Priority Waterbodies List

Section 1: The Citizens Statewide Lake Assessment Program (CSLAP)

CSLAP Background

There is a long history of water quality monitoring programs in New York State (NYS), starting with the State Conservation Department (predecessor to the NYS Department of Environmental Conservation, or NYSDEC) biological surveys from the 1920s and 1930s. The Adirondack Lake Survey Corporation (ALSC) conducted a study of more than 1,500 lakes in the Adirondacks, Catskills and surrounding areas primarily for evaluation of lake acidification in the 1980s. The NYSDEC Lake Classification and Inventory (LCI) survey has sampled more than 600 lakes since the early 1980s, and the NYSDEC Division of Fish and Wildlife conducts sampling of many lakes in support of fisheries managementactions, including fish stocking. In addition to NYS programs, there have also been a myriad of academic and private studies of lakes throughout the state by various stakeholder groups ranging from infrequently sampled lakes to individual, high-profile lakes that are sampled year after year.

However, very few of these programs have been conducted consistently over multiple years, sampling at a frequency or duration capable of evaluating intra-(within) or inter-(between) annual trends in water quality on many lakes. Because most private or academic studies were narrowly focused on a particular waterbody prioritizing a specific issue, there has not been a holistic monitoring and assessment program dedicated to evaluating the health of the more than 16,000 lakes in NYS. Perhaps most importantly, very few of these programs were directed toward the large number of small lakes used daily by active lake communities and only a few of the professional programs took advantage of the local knowledge and experience of lake residents observing first-hand the daily and generational changes in their lakes. Including local stakeholders is vitally important to gaining an understanding of many individual lakes and, by extension, NYS lakes.

In 1983, NYS Federation of Lake Associations, Inc. (NYSFOLA) was organized to lobby NYS for a volunteer monitoring program to monitor and assess the water quality of NYS lakes like those in Wisconsin, Vermont, and Maine. In the mid-1980s, NYSDEC staff and the NYS Federation of Lake Associations, Inc. (NYSFOLA) proposed the development of a volunteer monitoring program to be used to supplement existing, professional monitoring efforts. NYSDEC Commissioner Henry Williams committed full support for the Citizens Statewide Lake Assessment Program (CSLAP), but initial efforts to secure funding for the program were unsuccessful.

In his 1986 State of the State address, NYS Governor Mario M. Cuomo provided his endorsement:

> *“I propose creating a program within the Department of Environmental Conservation to use trained volunteers to collect information on the State's water bodies. With this information, the Department can more effectively manage and protect our invaluable water resources.”   -Governor Mario M Cuomo*

With this endorsement and the support of several other organizations, CSLAP was established in 1986 by Jim Sutherland and Jay Bloomfield from the NYSDEC as a cooperative program between the NYSDEC and NYSFOLA, a non-profit coalition of lake associations, individual citizens, park districts, lake managers, and consultants dedicated to the preservation and restoration of lakes and their watersheds. This program has expanded significantly over the last 30 years, and now serves as the primary long-term water quality monitoring network in NYS. CSLAP was codified in the state Environmental Conservation Law (ECL, in Article 17-0305) in 1988 to require NYSDEC to conduct the program.

Why Does NYS Have CSLAP?

Information about the state of lakes, ponds and reservoirs in NYS is gathered in several ways. There are many lake sampling programs conducted throughout NYS by government agencies, academic institutions, consultants, and citizen scientists. Some of this data is collected to identify a specific water quality problem, in support of fish stocking, beach operation, or other resource management activity, or to support student or public education, ***while a primary use of lake data by the NYSDEC is to assess whether these lakes are meeting their best intended use***. The data generated from many of these programs are important, but there are enormous challenges in evaluating this information in a standardized way which is why the quality and consistency of the CSLAP program has been an invaluable and integral part of NYS efforts to monitor and assess water quality.

NYSDEC has two major lake monitoring programs: CSLAP and the Lake Classification and Inventory (LCI). These programs differ from each other, but both are unique among the various lake water quality monitoring programs conducted in NYS. These monitoring programs follow the NYSDEC requirements to use an ELAP certified lab and adhere to a strict state-approved Quality Assurance Project Plan (QAPP) or Quality Assurance Management Plan (QAMP) for the use of water quality data for several regulatory purposes, including lake assessments. For more information on LCI: https://www.dec.ny.gov/chemical/31411.html.

In addition to providing NYSDEC with monitoring and assessment data, CSLAP provides participating lake associations with the necessary data to develop lake and watershed management plans, gather information necessary to obtain lake management permits, and monitor the success of both in-lake and watershed based management activities. CSLAP is a partnership between NYSDEC, in collaboration with NYSFOLA, and lake residents who help monitor and collect critical lake data in a manner consistent with other NYS programs. This information is used to understand lake conditions, to develop lake management plans, and to meet monitoring requirements mandated by the Federal Clean Water Act (CWA) and NYS Environmental Conservation Law (ECL).

What Does CSLAP Do?

The Citizens Statewide Lake Assessment Program (CSLAP) has three major objectives:

(1) **collect** lake data for representative lakes throughout NYS,
(2) **identify** lake problems and changes in water quality over time, and
(3) **educate** the public about lake preservation, management and restoration.

(1) Collect – Trained CSLAP volunteers collect lake field data and collect water chemistry samples following approved methods. NYSDEC and NYSFOLA train volunteers from participating lake associations to collect water samples for several parameters designed to help evaluate nutrient enrichment conditions leading to excessive weed and algae growth. Every other week for 15 weeks, volunteers collect water samples at the deepest part of the lake, or at multiple sites on larger lakes, for lab analysis at a NYS Department of Health (NYSDOH) Environmental Laboratory Approval Program (ELAP) laboratory which allows them to be used in a variety of NYSDEC monitoring and assessment programs and management tools (including Total Maximum Daily Load [TMDL] analysis and Nine Element [9EP] planning). CSLAP lab sample analysis was conducted by the NYSDOH from 1986 to 2002, and by Upstate Freshwater Institute (UFI) starting in 2002.

Citizen scientists also record weather conditions, water temperature, water transparency, lake depth, and assessments of recreation and water quality of the lake and algal conditions based on the user's perception (Kishbaugh 1994). This snapshot of water quality based on “how the water looks” is extremely important in assessing water quality. Although subjective, visual assessments can be a very powerful tool for determining improvements or declines in water quality. In addition to water quality sampling, CSLAP volunteers collect information on freshwater harmful algal blooms (HABs), invasive species distribution, and aquatic plant surveys. HABs sampling through CSLAP forms the basis for one of the most extensive HABs surveillance and monitoring programs in the country, in support of a robust public education, outreach and notification system conducted by NYSDEC. Some CSLAP volunteers with access to multi-probe electronic meters also conduct depth profiles of field parameters.

(2) Identify – All CSLAP data and user perception information are added to the statewide lake database to help detect changes in water quality over time. The data also increases the total number of lakes that are sampled statewide and improves NYSDEC’s understanding of the overall water quality of NYS lakes. The data are used to report water quality information to federal, state, and local governments and to develop long term management/protection strategies and to monitor/propose management activities.

Regular lake monitoring keeps track of existing problems, detects threats to lakes before they become a problem, and helps evaluate lake condition patterns throughout NYS. Lake residents and trained volunteers can observe lake changes and compare them to "normal" conditions to detect emerging problems. The perspective of lakefront residents is even more important in documenting and tracking shoreline HABs and early introductions of invasive species.

HABs can be very ephemeral in many NYS lakes, with extreme variability in time and space. Finding and documenting these blooms, critically important to informing lake residents and visitors about public health threats, are extremely challenging in routine monitoring programs. Trained samplers look for blooms along the shoreline and respond to bloom reports from neighbors, which dramatically improves the ability of NYSDEC to understand bloom formation and protect public users of these lakes.

In addition, invasive species (plants and animals) are more easily managed, and in some cases eradicated, through a robust early detection program. CSLAP volunteers frequently report infestations of aquatic invasive species (AIS) in waterbodies that have not been previously seen in the lake. This significantly improves the ability for local lake managers including lake associations and other watershed partners to initiate local responses. A significant portion of the NYSDEC iMapInvasives inventory of AIS, documented in http://www.nyimapinvasives.org/, is derived from CSLAP samplers.

(3) Educate – Volunteers who participate in CSLAP gain a better understanding of lake ecology and the consequences of specific lake management practices. CSLAP volunteers have a strong commitment to conserve and protect lake resources, an important attribute since lake management in NYS is largely conducted at the local level. Volunteers help local communities better understand what is happening in the lake by sharing their knowledge and enthusiasm. Lake data collected by CSLAP volunteers educates lakefront property owners, lake users, and citizens, NYSDEC, contributes to water quality management plans and reports for CSLAP lakes, and supports many NYSDEC and local community programs and activities. For more information about CSLAP: https://www.dec.ny.gov/chemical/81576.html.

Section 2: CSLAP in the Finger Lakes

CSLAP 2017 Overview

All water quality measures used in CSLAP are documented in NYSDEC-approved Quality Assurance Management Plan (QAMP). A detailed summary of these measures can be found at http://www.dec.ny.gov /chemical/81849.html.

Training

All CSLAP samplers are trained in standardized methods for collecting accurate and representative samples, consistent with the NYSDEC Lake Monitoring Standard Operating Procedures (http://www.dec.ny.gov /docs/water_pdf/sop20314.pdf). Specific sampling instructions are provided to the trained CSLAP samplers through several methods, including sampling training sessions conducted by NYSDEC and NYFOLA, written sampling protocols (http://www.nysfola.org/cslap), instructional videos (http://www.dec.ny.gov/chemical/81849.html), sampling protocol quizzes (http://www.dec.ny.gov/docs/water_pdf/cslapquiz2.pdf) and in-season "OOPS" sheets outlining specific problem areas to avoid sampling anomalies. In addition, NYSFOLA and the laboratory staff communicate directly with volunteers whenever issues with sample transport or field data occur. These training procedures are applied to all CSLAP lakes, not just the Finger Lakes, to provide standardization across all program lakes and to facilitate inter-lake comparisons.

Additionally, Finger Lakes Watershed Hub staff conducted field visits on the Finger Lakes during the 2017 sampling season. Staff audited with CSLAP volunteers one site per lake. Staff performed visual assessments, collected field observations, and collected field duplicate samples using the volunteer's equipment. The results of these quality assurance audits are available in Section 4.

Data and sample collection

CSLAP volunteer's complete user perception surveys on each trip which is very important for assessing "how does the water look?". Evaluated through field perception forms (four question surveys completed during each sampling session), use impairment surveys link recreational lake use assessments to water quality data.

In all thermally stratified CSLAP lakes, surface and deep samples are collected in the deepest portion of the lake (open water). Since 1986, CSLAP samplers have used Kemmerer bottles to collect surface samples at a depth of 1.5 meters, and deeper water column samples. In most CSLAP lakes, deepwater samples are collected from 1.5 meters above the lake bottom in the deepest part of the lake. In the Finger Lakes, deepwater samplers were collected at shallower, metalimnetic depths to evaluate other important lake conditions. Surface and deep samples are transferred from the Kemmerer to collapsible containers in the field.

Open water HAB samples collected through CSLAP even in the absence of any bloom conditions. This provides a long-term dataset to evaluate cyanobacterial abundance and levels of toxins throughout the spectrum of water quality conditions, including open water conditions with no visual evidence of blooms. If conditions at the site are consistent with a HAB (for example, appearing to resemble spilled paint, pea soup, green streaks, or dense concentrations of green dots), then surface skim samples are collected from the most intense part of the bloom. CSLAP volunteers also collect shoreline samples if a bloom is present.

Field measurements include water clarity and temperature. Secchi disk transparency readings in CSLAP are measured using a standard limnological (black and white quartered, 20cm diameter) disk, with the Secchi disk transparency defined as the average of the depths of Secchi disk disappearance and reappearance in the watercolumn. Water and air temperature are measured using a field thermometer, measured from the collapsible containers.

Instructions for completing standardized field forms are provided during all training sessions. Most CSLAP volunteers enter data on-line through a NYSFOLA-hosted web page (https://www.cslapdata.org/index.php). Field data not entered by volunteers is entered into the database by the NYSFOLA program coordinator.

Sample processing and preservation methods

Water samples are collected in the field and transferred to pre-labeled bottles provided by NYSDEC, NYSFOLA and UFI. Samples are identified using a standardized format:

XX-YYY-(B)ZZ; where

- XX = last two digits of the year of sample collection (17 in 2017)
- YYY = unique lake ID assigned to all CSLAP lakes prior to initiation of sampling
- (B)= letter preceding unique sample ID for those shoreline scum samples ("B" represents a bloom sample)
- ZZ = consecutive number pre-assigned to each CSLAP sampling session, starting with 01 for surface grab samples (open water or bloom), 11 for deep-water grab samples, and 99 for QA samples.

Chlorophyll-a (Chl-a), (true) color, and cyanotoxins are field filtered in open water CSLAP samples, although cyanotoxins are analyzed from raw water samples when collected from concentrated shoreline blooms in CSLAP. Filters are placed in labeled vials, and Chl-a vials are wrapped in aluminum foil to prevent additional algae growth.

All CSLAP samples, except the raw water sample used for unextracted Chl-a measurements at SUNY ESF and cyanotoxins (field filter or raw water sample), are frozen overnight for next day shipping. All samples are accompanied by Request for Analysis/Chain of Custody forms signed by the samplers and laboratory staff receiving the sampling bottles.

Sample shipping

Open water CSLAP sample bottles and filter vials are shipped to the contract lab inside Styrofoam coolers with ice packs using pre-paid shipping labels. Shoreline bloom samples from CSLAP samplers are shipped as whole water samples with ice packs and coolers directly to SUNY ESF, also using pre-paid shipping labels.

Analytical methods

The field indicators measured through CSLAP or HABs programs are measured through standard limnological methods as governed by NYSDEC SOP 203-18 (Lake Monitoring Standard Operating Procedures); parameters with a laboratory equivalent are measured using methods approved by USEPA, Standard Methods, or some modification thereof. The laboratory water quality indicators measured through CSLAP are analyzed using accepted methodologies, as outlined in Table 1. Each of these laboratory analyses for which ELAP certification is available is analyzed using an ELAP approved method, and are outlined in the CSLAP QAMP. The locations monitored in 2017 and the analytical program are presented in Table 2. Tables 3-4 describe the number of samples collected at the near-surface (1.5m) and deep sampling depths, respectively.

Quality Control

Several quality control measures have been instituted in the field and/or laboratory through these monitoring programs, including:

- Training and procedure checks- as described above, a number of training techniques are used to assure sampling data accuracy. Each of these techniques involve feedback mechanisms- routine checks by CSLAP program staff, review of field and laboratory procedures to verify training techniques, sampler feedback, and periodic review of instructions
- Field measures- field duplicate samples were collected by Finger Lakes Watershed Hub staff at the surface of all eleven Finger Lakes in 2017. Differences in volunteer samples and Hub staff are presented in subsequent sections and have led to program improvements to assure quality data.
- Laboratory measures- UFI routinely conducts quality checks and deploy several quality measures outlined in the program QAMP, including enhanced staff training, data documentation, equipment calibration logs and checks, matrix duplicate and spike sampling, and laboratory control samples.
- Data review- laboratory staff and project managers review program data to assure the collection, transport, analysis and reporting of high quality data in support of the NYSDEC program objectives and compliance with the approved QAPPs.

Table 1. Laboratory methods and other analytical method information for CSLAP parameters

CSLAP Sample Type	Method	ELAP Certified?	Precision	Accuracy	LOD	LOQ
FIELD PARAMETERS						
Secchi disk transparency	SOP #203-14	NA	± 0.1m	± 0.1m	0.1 m	same
Water temperature	SM 2550B	Yes	± 1°C	± 1°C	-5C	same
Lake perception	SOP #203-14	NA	NA	NA	NA	NA
WATER CHEMISTRY PARAMETERS						
Total phosphorus; TP (and Total Dissolved P; TDP)	SM 18-20 4500-P E	Yes	±20% RPD	±20%	0.001 mg P/L	0.0038 mg P/L
Nitrate+Nitrite; NOx	USEPA 353.2 Rev 2.0	Yes	±20% RPD	±20%	0.007 mg N/L	0.029 mg N/L
Ammonia; NH_3	USEPA 350.1 Rev 2.0	Yes	±20% RPD	±20%	0.015 mg N/L	0.056 mg N/L
Total nitrogen; TN (and Total Dissolved N)	SM 20 4500-N C	Yes	±20% RPD	±20%	0.09 mg N/L	0.307 mg N/L
Chlorophyll-a-extracted; Chl-a	USEPA 445.0 Rev. 1.2	NA	±20% RPD	±20%	0.1 µg Chl/L	0.3 µg Chl/L
pH	SM 18-20 4500 H+ B	Yes	±20% RPD	±20%	exempt	exempt
Specific conductance; SC	SM 18-20 2510 B	Yes	±20% RPD	±20%	10 umho/cm	10 umho/cm
True color	SM 18-20 2120 B	Yes	±20% RPD	±20%	1 pCU	5 pCU
Calcium; Ca^{2+}	USEPA 200.7	Yes	±20% RPD	±20%	0.2 mg/L	0.7 mg/L
Chloride; Cl^-	SM 4500-Cl-97, -11	Yes	±20% RPD	±20%	100 µg/l Cl/L	100 µg/l Cl/L

Table 1 (cont.). Laboratory methods and other analytical method information for CSLAP parameters

CSLAP Sample Type	Method	ELAP Certified?	Precision	Accuracy	LOD	LOQ
HAB PARAMETERS						
Chlorophyll-a-unextracted	Bbe Moldaenke, 2014	NA	± 0.01 µg/L	± 0.01 µg/L	0.05 µg/L	same
Bluegreen chlorophyll-a unextracted	Bbe Moldaenke, 2014	NA	± 0.01 µg/L	± 0.01 µg/L	0.05 µg/L	same
Microcystin	USEPA 544-LCMS	NA in 2017, will be a certified method in 2018 (ELISA, EPA method 546)			0.3 µg/l	same
Anatoxin-a	USEPA 545 – LCMS/MS	NA			0.027 µg/l	same
Cylindrospermopsin	USEPA 545 – LCMS/MS	NA			0.318 µg/l	same

ELAP Certified? = certified through the Environmental Laboratory Approval Program as per 40 CFR Part 136; SM = Standard Methods; EPA = EPA approved methods

Table 2. 2017 CSLAP Finger Lakes monitoring locations and descriptions

Lake	Site	Lake Depth (m)	Lat. (°)	Lon. (°)	Surface Indicators (1.5m depth)	Secondary Sampling Depth (m)	Secondary Sampling Indicators
Conesus Lake	N	12	42.812	-77.712	A	9m	C
	S	18	42.755	-77.712	A	12m	C
Hemlock Lake	N	11	42.773	-77.615	B	9m	D
	Mid	27	42.720	-77.611	B	18m	D
	S	11	42.682	-77.600	B	9m	D
Canadice Lake	Mid	24	42.717	-77.568	B	18m	D
Honeoye Lake	N	7	42.765	-77.512	B	5.5m	D
	S	9	42.751	-77.509	B	7.5m	D
Canandaigua Lake	N	54	42.821	-77.276	B	15m	E
	S	78	42.719	-77.313	B	15m	E
Keuka Lake	N	51	42.550	-77.150	A	18m	E
	S	55	42.489	-77.155	A	18m	E
Seneca Lake	N	35	42.771	-76.950	A	18m	E
	S	17	42.585	-76.898	A	18m	E
Cayuga Lake	N	18	42.818	-76.726	A	9m	C
	S	50	42.555	-76.598	A	18m	C
Owasco Lake	N	34	42.845	-76.516	A	9m	C
	S	48	42.795	-76.493	A	9m	C
Skaneateles Lake	N	35	42.918	-76.415	A	15m	C
	S	83	42.802	-76.292	A	18m	C
Otisco Lake	N	19	42.875	-76.296	B	9m	E
	S	19	42.856	-76.274	B	9m	E

A Air and water temperature, Secchi depth, Chl-a, TP, TN, NO_x, NH_3, SC, pH, Color, Ca^{2+}, Cl^-, algal ID, algal toxins + TDP, TDN
B Air and water temperature, Secchi depth, Chl-a, TP, TN, NO_x, NH3, SC, pH, Color, Ca^{2+}, Cl-, algal ID, algal toxins
C Water temperature, TP, TDP, TN, TDN, DOC, algal ID, algal toxins
D Water temperature, TP, TN, DOC, algal ID, algal toxins
E Water temperature, TP, TN

Table 3. Summary (Number of Samples) of surface water quality and assessment data collected in 2017

Lake	Temp.[1]	Clarity	Chl-a	TP	TDP	TN	TDN	NO_X	NH_3	SC	pH	Color	Cl^-	Ca^{2+}	Algal ID	Algal Toxins[2]	User Perception
Conesus	16	16	16	16	16	15	15	16	16	14	15	16	3	4	16	16	16
Hemlock	24	24	24	24	-	23	-	24	24	24	24	24	6	6	24	24	24
Canadice	7	7	7	7	-	6	-	7	7	7	7	7	2	2	7	7	7
Honeoye	16	16	16	16	-	16	-	16	16	15	16	16	4	4	16	16	16
Canandaigua	16	16	15	16	-	15	-	16	16	16	16	16	4	4	16	16	15
Keuka	15	16	16	16	16	16	16	16	16	16	16	16	4	4	16	16	16
Seneca	16	16	16	16	16	16	16	16	15	16	16	16	4	4	16	16	16
Cayuga	16	16	16	16	16	16	16	15	16	16	16	16	4	4	16	16	16
Owasco	15	15	14	15	15	15	15	15	15	15	15	15	4	4	15	15	14
Skaneateles	16	16	15	16	14	16	16	16	16	15	16	16	4	4	16	16	15
Otisco	16	16	16	16		16		16	16	16	16	16	4	4	16	16	16
Total	**173**	**174**	**171**	**174**	**93**	**170**	**94**	**173**	**173**	**170**	**173**	**174**	**43**	**44**	**174**	**174**	**171**

[1] Air and water temperature; [2] Microcystin, Anatoxin, Cylindrospermopsin as well as congener analysis at SUNY ESF in 2017

Table 4. Summary (Number of Samples) of deep sample water quality data collected in 2017

Lake	Temp.	TP	TDP	TN	TDN	Algal ID	Algal Toxins[1]
Conesus	16	16	16	16	16	16	16
Hemlock	24	23	-	24	--	24	24
Canadice	7	7	-	7	-	7	7
Honeoye	16	16	-	16	-	14	14
Canandaigua	14	15	-	15	-	-	--
Keuka	15	15	-	16	-	-	-
Seneca	16	16	--	16	-	-	-
Cayuga	16	16	16	16	16	16	16
Owasco	15	15	15	15	15	15	15
Skaneateles	16	15	-	16	-	-	-
Otisco	16	16	-	16	-	-	-
Total	**171**	**170**	**47**	**173**	**47**	**92**	**92**

[1] Microcystin, Anatoxin, Cylindrospermopsin as well as congener analysis at SUNY ESF in 2017

Section 3: Background of the Finger Lakes

Introduction

The Finger Lakes of Central New York (Figure 1) have many similarities, but are different and unique in several important ways. They share a similar climate (cold snowy winters, a brief spring and a warm summer), geology (mostly shale, with some sandstone and limestone bands), shape and orientation (elongated, in the N-S direction with the exception of Y-shaped Keuka). They all drain from the south to the north and are in the Great Lakes watershed. The lakes vary significantly in maximum depth (~ 9m for Honeoye vs ~ 200 m for Seneca; Table 5), surface area (Canadice Lake at 2.7 square kilometers [km^2] to Seneca Lake at 176 km^2), and volume – Seneca Lake has 400 times the volume of Honeoye. These differences in size and morphology (shape) influence fundamental limnological properties such as thermal stratification, light penetration, water column interaction with the sediments, water chemistry, and biology and therefore, play critical roles in influencing individual lake ecology.

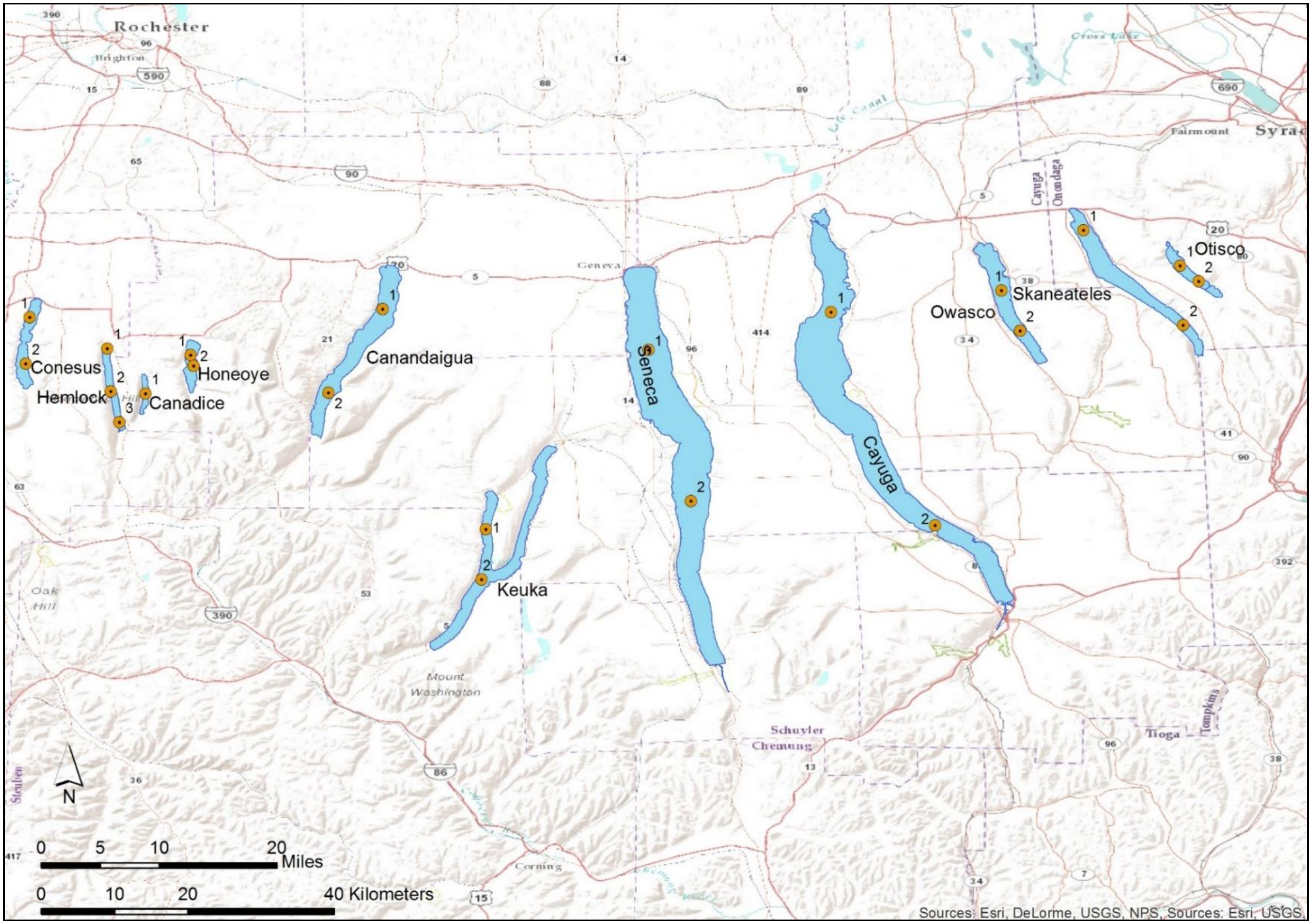
Some lakes have watersheds that are predominately forested, which is not markedly different from a century ago, others have watersheds dominated by agriculture. Industry and urban development varies throughout the Finger Lakes basin. Except for Hemlock and Canadice, all Finger Lakes have at least partially developed shorelines. They support a variety of uses, ranging from drinking water sources (except Honeoye), fishing, swimming, and other forms of recreation, although the Rochester drinking water supplies (Canadice and Hemlock Lakes) experience less recreational pressure due to protective watershed restrictions.

Table 5. Physical characteristics of the Finger Lakes

Lake	Mean Depth (m)	Max Depth (m)	Length (km)	Shoreline Length (km)	Surface Area (LA) (km^2)	Watershed Area (WA) (km^2)	WA:LA$^+$	Volume (10^6 m^3)	Elevation above MSL^{++} (m)
Conesus	11.5	18.0	12.6	29	13.0	182	14.0	149	249
Hemlock	13.6	27.5	10.8	27	8.4	111	13.2	114	276
Canadice	16.4	25.4	5.1	12	2.7	32	11.9	44	334
Honeoye	4.9	9.2	6.6	17	7.3	104	14.3	36	245
Canandaigua	38.8	83.5	24.9	66	42.6	482	11.3	1,653	210
Keuka	30.5	55.8	31.6	96	47.3	464	9.8	1,441	218
***Seneca**	88.6	198	56.6	127	175.6	1,838	10.5	15,556	136
****Cayuga**	54.5	133	61.4	170	172.5	1,870	10.8	9,399	116
Owasco	29.3	54	17.9	43	27.5	515	18.7	806	217
Skaneateles	43.5	90.5	24.2	55	35.3	189	5.3	1,535	263
Otisco	10.2	20.1	8.7	24	8.9	110	12.3	91	240

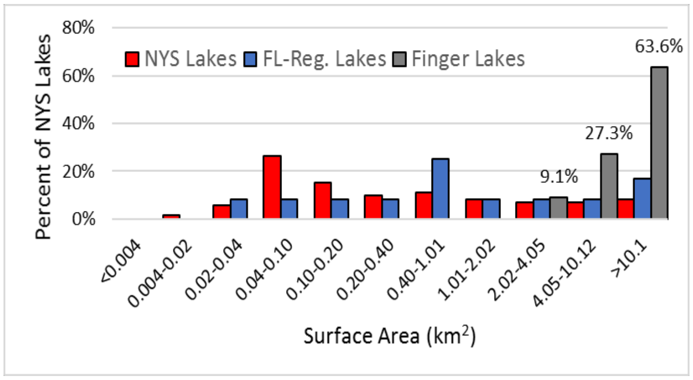
* excluding Keuka Lake watershed; ** excludes Seneca River watershed; + watershed to lake surface area ratio; ++ mean sea level

As with much of the northeast in the last 250 years, the region experienced industrialization, alterations to land use and changes to its hydrology. Most of the original forests were felled, wastewater was discharged into the lakes, increased development led to more runoff, and soil loss from agricultural practices found its way into the lakes. Cultural eutrophication – the increase in lake productivity produced by an unnatural input of nutrients – was apparent in all the lakes by the 1970s, when nuisance algal blooms were documented by the USEPA, although it is not known if these blooms produced toxins. Water quality improved in the late part of the 20th century, in large part due to implementation of Clean Water Act requirements, and the resulting improvements to wastewater treatment. Today, most Finger Lakes have good or very good water quality.



Sources: Esri, DeLorme, USGS, NPS, Sources: Esri, USGS

Figure 1 . Map of the Finger Lakes Region in Central New York including 2017 Finger Lake CSLAP sites.



The lakes and rivers of the region supply drinking water to more than 2 million people. Groundwater is only a minor component of municipal public water supply, due to the low porosity and permeability of most of the region's Silurian and Devonian bedrock. Groundwater does serve private wells in much of the rural parts of the region. Except for Honeoye Lake, all the Finger Lakes are used as public drinking water supplies, serving 1.5 million customers. The lakes are also used extensively for private water supplies, via individual lake intakes or shoreline wells, although NYS DOH does not recommend this practice.

The eleven Finger lakes represent some of the largest lakes in New York in term of surface area, depth, and volume, which plays an important role in the water quality of these systems (inset). A lake's morphology (size and shape) and orientation determines thermal stratification and the degree to which the photic zone (the part of the upper waters where light is available to algae and plants) interacts with the bottom sediments. Assimilative capacity, the ability of a waterbody to receive nutrient inputs and maintain water quality, is heavily influenced by lake morphology and nutrient inputs. In the 1960s, researchers determined that water quality and trophic state in lakes is a result of external loading inputs relative to the lake's depth, surface area and residence time (Vollenweider 1970). Nutrient inputs are directly influenced by watershed characteristics such as slopes, soil types, land use, cultural practices, population density, and the size of the watershed relative to the size of the receiving lake. In addition, legacy nutrient loading has led to phosphorus accumulation in the bottom sediments, which are released into the water during the summer in some lakes. In the Finger Lakes, Schaffner and Olgesby (1978) found that the water quality of the Finger Lakes was driven by phosphorus inputs relative to the size of the epilimnion of lakes. They also described the statistical relationships between phosphorus loading, lake TP concentration, chlorophyll concentrations, and Secchi disk clarity.

Water Quality Classifications

All waters in NYS are assigned a letter classification that denotes their best uses. Letter classes such as AA, A, B, C, and D are assigned to fresh surface waters, and SA, SB, SC, I, and SD to saline (marine) surface waters. Best uses include: source of drinking water, swimming, boating, fishing, and shell fishing. The letter classifications and their best uses are described in Table 6.

Table 6. Water quality classifications on NYS and the designated best use

Classification	Best Use
Class AA	The best usages are a source of water supply for drinking, culinary or food processing purposes; primary and secondary contact recreation; and fishing. The waters shall be suitable for fish, shellfish and wildlife propagation and survival. This classification may be given to those waters that, if subjected to approved disinfection treatment, with additional treatment if necessary to remove naturally present impurities, meet or will meet NYSDOH drinking water standards and are or will be considered safe and satisfactory for drinking water purposes.
Class A	The best usages are a source of water supply for drinking, culinary or food processing purposes; primary and secondary contact recreation; and fishing. The waters shall be suitable for fish, shellfish and wildlife propagation and survival. This classification may be given to those waters that, if subjected to approved treatment equal to coagulation, sedimentation, filtration and disinfection, with additional treatment if necessary to reduce naturally present impurities, meet or will meet NYSDOH drinking water standards and are or will be considered safe and satisfactory for drinking water purposes.
Class B	Best usage is primary and secondary contact recreation and fishing. These waters shall be suitable for fish, shellfish and wildlife propagation and survival.
Class C	Best usage is fishing. These waters shall be suitable for fish, shellfish and wildlife propagation and survival. The water quality shall be suitable for primary and secondary contact recreation, although other factors may limit the use for these purposes.
Class D	Best usage is fishing. Due to such natural conditions as intermittency of flow, water conditions not conducive to propagation of game fishery, or stream bed conditions, the waters will not support fish propagation. These waters shall be suitable for fish, shellfish and wildlife survival. The water quality shall be suitable for primary and secondary contact recreation, although other factors may limit the use for these purposes.

**The *symbol (T),* appearing in an entry in the classification means that the classified waters are trout waters. The *symbol (TS),* appearing in an entry in classification means that the classified waters in that specific item are trout spawning waters.

The Waterbody Inventory/Priority Waterbodies List (WI/PWL) is an inventory of water quality assessments that characterize known/and or suspected water quality issues and determine the extent of designated use support in a waterbody. It is instrumental in directing water quality management efforts to address water quality impacts and in tracking progress toward their resolution. In addition, the WI/PWL provides the foundation for the development of the state Section 303(d) List of Impaired Waters, a USEPA program that dictates the development of nutrient budgets and proposed actions to reduce specific inputs or impacts, and restore and protect designated uses.

> CSLAP data, collected under a standardized quality control program, provides current and valuable data to properly assess and update WI/PWLs for NYS Lakes.

The WI/PWL assessments reflect data and information drawn from numerous NYSDEC programs (e.g. CSLAP) as well as other federal, state and local government agencies, and other partners. All data and information used in these assessments has been evaluated for adequacy and quality as per the NYSDEC Consolidated Assessment and Listing Methodology (CALM; https://www.dec.ny.gov/ chemical/36730.htm). The NYSDEC CALM provides a "rulebook" for conducting assessments and impaired water listing decisions. These rules are based on assessing designated uses against existing water quality standards and guidance values indicating "how much is too much?" of a water quality indicator before designated uses are impacted. For more information on NYSDEC CALM see http://www.dec.ny.gov/docs/water_pdf/asmtmeth09.pdf

WI/PWLs for Conesus, Hemlock, Canadice and Honeoye Lakes can be found in the Lower Genesee River Sub-Basin listing at http://www.dec.ny.gov/chemical/36744.html. WI/PWLs for Canandaigua, Keuka, Seneca, Cayuga, Owasco, Skaneateles, and Otisco Lakes can be found in the Oswego River/Finger Lakes Basin (West) listing at http://www.dec.ny.gov/chemical/36737.html. Table 7 provides the most recent PWL information for each of the Finger Lakes.

Table 7. Water quality classifications and current status of the Finger Lakes

Lake	Segment	Classification	WI/PWL Status	Management Status	Primary Impairment	Primary Pollutant
Conesus (2018)	Entire Lake	AA	Impaired	Strategy underway	Primary and secondary recreation	Elevated nutrient loads, aquatic vegetation growth
Hemlock (2015)	Entire Lake	AA(T)	No Known Impacts	No action needed*	N/A	N/A
Canadice (2016)	Entire Lake	AA(TS)	Impaired	Strategy underway	Fish consumption	PCBs
Honeoye (2018)	Entire Lake	AA	Impaired	Strategy underway	Primary and secondary recreation	Nutrients (phosphorus)
Canandaigua (2007)	Entire Lake	AA(TS)	Threatened	Strategy underway	Water supply Threatened	N/A
Keuka (2015)	Entire Lake	AA(TS)	No Known Impacts	No action needed*	N/A	N/A
Seneca (2016)	North	B(T)	No Known Impacts	No action needed*	N/A	N/A
	Middle	AA(TS)	Threatened	Protection Strategy Needed	Water supply Threatened	N/A
	South	B(T)	Threatened	Strategy underway	Water supply Threatened	N/A
Cayuga (2018)	Northern End	B(T)	Minor Impacts	Strategy underway	Primary and secondary recreation	Algal/plant growth and invasive species
	Mid-North	A(T)	Minor Impacts	Strategy underway	Primary and secondary recreation	Algal/plant growth and invasive species
	Mid-South	AA(T)	Minor Impacts	Strategy underway	Primary and secondary recreation	Algal/plant growth and invasive species
	Southern End	A	Impaired	Strategy underway	Primary and secondary recreation	Nutrients (phosphorus), silt/sediment
Owasco (2018)	Entire Lake	AA(T)	Impaired	Strategy underway	Primary and secondary recreation	Pathogens
Skaneateles (2018)	Entire Lake	AA	Minor Impacts	Strategy underway	Primary and secondary recreation	Harmful Algal Blooms
Otisco (2007)	Entire Lake	AA	Minor Impacts	Protection Strategy Needed	Aquatic life	Low dissolved oxygen levels

**Although no actions are required by USEPA to address water quality impacts, local communities may have developed protection strategies to maintain high quality conditions.*

Emerging Threat: Harmful Algal Blooms

Like other NYS lakes, the Finger Lakes have good water quality but continue to face water quality challenges from climate change, agricultural run-off, emerging contaminants in wastewater effluents, stormwater flows, aging infrastructure, septic impacts, and the effects of cyanobacterial blooms (often called Harmful Algal Blooms, or "HABs").

Several Finger Lakes have experienced HABs periodically since at least 2012, the first year of a formal process for NYSDEC bloom documentation (https://www.dec.ny.gov/chemical/77118.html). HABs were detected in all 11 Finger Lakes in 2017. More details about HABs occurrenences in the Finger Lakes are provided in Section 6. However, since CSLAP reestablished in 2017 and surveillance networks have been only established in a few of these lakes in recent years, it is likely that the frequency, extent and duration of HABs in the Finger Lakes have not been well documented, historically.

In his 2018 State of the State address, Governor Andrew M. Cuomo announced a $65 million, four-point initiative to aggressively combat HABs in New York, with the goal of identifying contributing factors fueling HABs, and implementing innovative strategies to address their causes and protect water quality. Under this initiative, the Governor's Water Quality Rapid Response Team focused strategic planning efforts on 12 priority lakes across New York that have experienced or are vulnerable to HABs. The five Finger Lakes identified as priority lakes as part of this Initiative were Conesus, Honeoye, Cayuga, Owasco and Skaneateles Lakes.

The Governor's Team brought together national, state, and local experts at four regional summits which focused on conditions that were affecting the waters and contributing to HABs formation, and immediate and long-range actions to reduce the frequency and/or treat HABs. Although the 12 selected lakes are unique and represent a wide range of conditions, the goal was to identify factors that lead to HABs in specific water bodies, and apply the information learned to assist other lakes facing similar threats. The Rapid Response Team, national stakeholders, and local steering committees worked together collaboratively to develop science-driven HAB Action Plans for each of the 12 lakes to reduce the sources of pollution that spark algal blooms. The HAB Action Plans for these five Finger Lakes (and each of the 12 priority lakes) document water quality conditions, bloom extent, and factors that contribute to these blooms (https://on.ny.gov/HABsAction).

Previous Investigations

The eleven Finger Lakes have been intensively studied by numerous researchers for well over a century. In early twentieth century, Birge and Juday published their study "A Limnological Study of the Finger Lakes of New York" (Birge and Juday 1914). Their famous quote regarding the uniqueness and complexity of the lakes still holds true today with the emergence of new problems and challenges, including HABs.

> *"It is probable that there is no group of lakes in the world which offer the limnologist [lake scientist] such opportunities for working out the problems of his science"*
> *- E.A. Birge and C. Juday, 1914*

Since Birge and Juday, there have been numerous scientific studies, biological assessments, ecological process studies, and monitoring programs of the Finger Lakes from storied limnologists and world renowned academic researchers to local stakeholder groups. To date the most comprehensive look at the Finger Lakes remains Bloomfield's compilation, "The Lakes of New York State: The Ecology of the Finger Lakes" published in 1978. Anyone interested in the history of the Finger Lakes basin should review this publication. There are too many water quality studies to mention in this report, but the Finger Lakes Watershed Hub (NYSDEC FLWH) is currently compiling sources (post 1980) of Finger Lake data and reports to consolidate these important resources in one central location.

This report refers to several previous investigations or monitoring by NYS directly whereby the water quality of all eleven Finger Lakes were monitored consistently and systematically. The studies referenced here provide historical context and comparison to the 2017 CSLAP data are:

(1) **Bloomfield 1978 –** Historic review of the history, geology, and ecology of the Finger Lakes. The water quality component referenced in this volume relied heavily on the work of Schaffner and Oglesby (1978), and includes a mix of academic and government studies,
(2) **Callinan 2001 –** the Water Quality of the Finger Lakes conducted in the late 1990s by NYSDEC which comprehensively monitored and assessed the surface and hypolimnion (deep portion) of the Finger Lakes for metrics of trophic state (total phosphorus, chlorophyll-a, Secchi disk clarity), nitrogen, alkalinity, metals, chloride, temperature, and dissolved oxygen,
(3) **Callinan et al. 2013** – a regional study of trophic state metrics, dissolved organic carbon and drinking water quality of 21 NYS lakes by NYSDEC, including all Finger Lakes, conducted over the 2004-2007 interval, for the purpose of evaluating drinking water threats, and
(4) **2017 Finger Lakes Region Lakes Report –** a comprehensive review of CSLAP and LCI data from the Finger Lakes region. This report contains lake results from smaller lakes, ponds and reservoirs (not the eleven Finger Lakes) in the Finger Lakes basin, to provide some geographic context for evaluating water quality conditions in the Finger Lakes.

Section 4: Major Water Quality Indicators

The water quality and overall health of a lake ecosystem can be assessed visually, determined with field measurements, or evaluated through chemical analyses. CSLAP employs all three techniques in monitoring and assessment of lake health. The individual lake chapters in Section 9 of this report provide the all assessment results for all 22 sites monitored in the Finger Lakes in 2017. As indicated in Tables 2-4, the programs were slightly different between lakes, so the results described in this report will be limited to lake average-summer average values (defined as June through September) for the surface waters among indicators common to all lakes.

This approach provides consistency, not only for these lakes in 2017, but for the traditional approach for evaluating NYS surface waters and trophic state (Section 5). It is also important to note that although this look into contemporary water quality of the Finger Lakes is based on one year only. The individual lake chapters contain a summary of historic NYSDEC data available for these lakes. ***While this report refers to several investigations of water quality for comparison to 2017, the authors would like to qualify any apparent changes described here should be viewed cautiously – with large lake systems like the Finger Lakes, multiple years of data are required for accurate assessments of trend.*** The 2017 data set presented in this report is a snapshot, highly dependent on the environmental conditions specific to 2017 and any apparent changes in water quality over time will become clearer with the addition of subsequent data. Summer average lake values for all water quality indicators are presented in Table 8.

Several additional indicators were included in 2017 at some sites as pilot projects. It is anticipated that some of these metrics will be routinely incorporated into CSLAP as standard indicators for all program lakes after the data is evaluated. The Finger Lakes will be considered for additional future pilot projects to evaluate additional or emerging technologies or water quality indicators. 2017 represents the first year of CSLAP on the Finger Lakes, and the cumulative dataset from multiple years of sampling at multiple sites on these lakes will provide valuable long-term datasets to evaluate water quality trends, identify contemporary and emerging problems, and assess the success of in-lake and watershed based mitigation actions (e.g., TMDLs and 9EPs).

Summer Average Conditions: Major Water Quality Parameters

Total Phosphorus (TP)

In most temperate freshwater systems, including the Finger Lakes, **phosphorus** is the nutrient most often limiting algal growth

Trophic status is driven primarily by phosphorus, since phosphorus usually limits the amount of algae growth in temperate freshwater lakes. There are multiple forms of phosphorus, and the amount of soluble, “available” phosphorus often dictates additional growth of algae. However, these other forms are difficult to monitor and can vary significantly between the water, algal cells, and sediment, often within very short timeframes. The primary measure of phosphorus is referred to as “total” phosphorus (TP), which measures all forms and states of phosphorus. It is recorded as milligrams per liter (mg/L), or parts per million (ppm). Readings less than 0.010 mg/L are generally indicative of oligotrophic lakes, and low susceptibility for excessive algae growth and harmful algal blooms, at least within large portions of the lake. Readings above 0.020 mg/L indicate an increasing susceptibility to widespread or frequent shoreline blooms, and are typical of eutrophic lakes. Measurements between these thresholds are generally typical of mesotrophic lakes.

In 1993, NYSDEC designated a TP threshold of 0.020 mg/L as the state guidance value associated with poor aesthetic quality; a comparable threshold to protect against excessive (toxic) algae blooms and poor water clarity has not yet been adopted. NYSDEC is also working to update this guidance value to better reflect impacts to recreational uses, but it is likely that this guidance will take the form of a "response variable" (a response to this excessive eutrophication, such as chlorophyll-a, reduced water clarity, or the presence of open water or shoreline blooms) rather than a "stressor" (such as phosphorus or nitrogen levels triggering this response).

In 2017, 161 NYS CSLAP lake sites were analyzed for TP. The summer average TP ranged from 0.005 to 0.374 mg/L (Figure 2a). The interquartile range (range between the 25th and 75th percentiles) was 0.009 to 0.025 mg/L with a median statewide concentration of 0.015 mg/L (mean = 0.028 mg/L).

Summer average TP concentrations in the eleven Finger Lakes (Figure 2b) varied between 0.006 (Skaneateles) and 0.036 mg/L (Honeoye), meaning that the minimum and maximum concentrations in the Finger Lakes were outside the NYS interquartile range. Skaneateles, Canandaigua, Keuka, and Canadice were at or below the 25th percentile of NYS lakes in 2017. Conesus, Cayuga, and Otisco summer average TP exceeded the NYS median (greater than 0.015 mg/L) but were lower than average. In addition, three lakes (Otisco, Conesus and Honeoye) reached or exceeded NYS guidance value for TP (0.020 mg/L) and Honeoye exceeded the 75th percentile of NYS lakes in 2017. Figure 3 shows the geographical distribution of TP in the Finger Lakes.

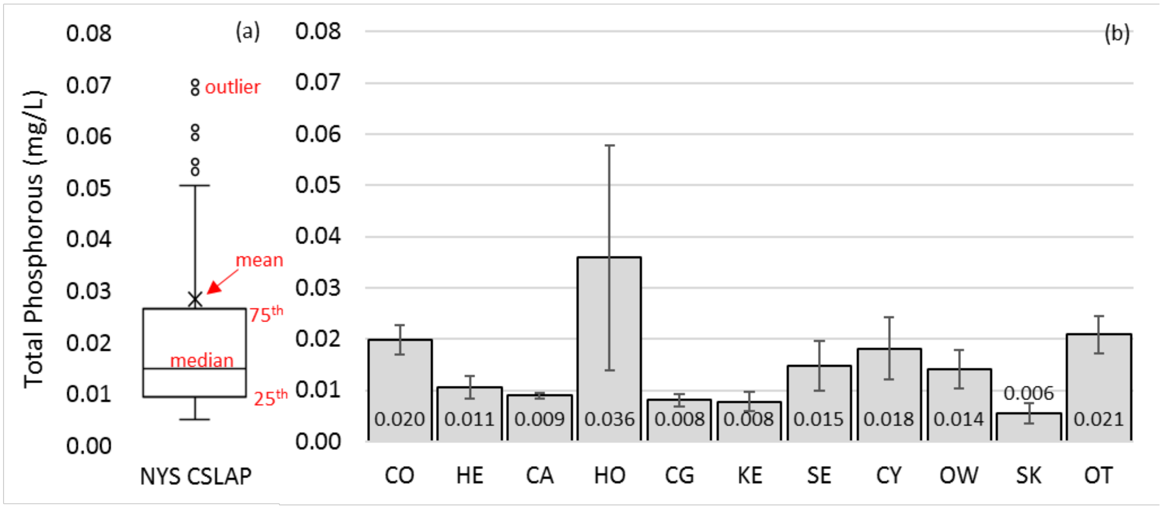


Figure 2. Summer average TP concentrations (mg/L) in 2017: (a) in all NYS CSLAP lakes and (b) in the 11 Finger Lakes (the X axis is ordered from left to right proceeding from west to east). In panel (a) the upper and lower edges of the box show 3rd and 1st quartile ranges, upper and lower whiskers show 1st and 4th quartile, central line is the median, "X" marks the mean, and circles represent outliers for all NYS lakes. In panel (b), bar height and numbers show the average for each lake, error bars are ±1 standard deviation for each of the Finger Lakes.

Table 8. 2017 Summer average (June 1 through September 30) conditions of surface samples by lake with variability statistics

Lake	Temperature (°C)	Clarity (m)	Chl-a (µg/L)	TP (mg/L)	TDP (mg/L)	TN (mg/L)	TDN (mg/L)	NO_X (mg/L)	NH_3 (mg/L)	SC (µS/cm)	pH^+	Color (CU)	Cl^- (mg/L)	Ca^{2+} (mg/L)
Conesus	24.0	3.1	5.9	0.020	0.008	0.363	0.255	0.009	0.021	337.6	7.8	4.9	51.8	27.1
	(1.9)*	(0.9)	(2.4)	(0.003)	(0.002)	(0.104)	(0.109)	(0.006)	(0.015)	(58.4)	(0.4)	(0.3)	(6.5)	(4.7)
Hemlock	23.0	3.9	2.9	0.011	-	0.270	-	0.069	0.023	254.8	7.6	5.3	34.0	22.3
	(1.8)	(0.9)	(1.3)	(0.002)	-	(0.089)	-	(0.059)	(0.018)	(11.4)	(0.2)	(1.2)	(2.1)	(2.0)
Canadice	22.7	5.7	1.8	0.009	-	0.192	-	0.007	0.045	191.1	7.5	5.6	34.7	13.7
	(1.0)	(0.9)	(0.4)	(0.000)	-	(0.052)	-	(0.000)	(0.056)	(41.6)	(0.3)	(1.1)	(2.0)	(1.0)
Honeoye	23.2	1.7	22.2	0.036	-	0.734	-	0.009	0.048	208.2	7.6	11.4	30.1	16.2
	(1.7)	(0.6)	(17.7)	(0.022)	-	(0.844)	-	(0.005)	(0.035)	(20.7)	(0.5)	(7.2)	(4.5)	(4.0)
Canandaigua	22.6	5.2	2.0	0.008	-	0.327	-	0.045	0.023	326.0	7.7	4.0	45.1	32.1
	(1.9)	(1.2)	(1.6)	(0.001)	-	(0.089)	-	(0.039)	(0.010)	(50.1)	(0.4)	(1.2)	(1.3)	(4.7)
Keuka	22.5	6.5	2.7	0.008	0.004	0.251	0.173	0.037	0.057	260.9	8.0	3.6	41.9	23.2
	(1.8)	(2.8)	(2.0)	(0.002)	(0.001)	(0.117)	(0.085)	(0.032)	(0.038)	(47.7)	(0.4)	(1.2)	(10.7)	(3.5)
Seneca	21.0	3.3	4.6	0.015	0.006	0.499	0.439	0.179	0.041	599.0	7.6	3.1	112.5	29.3
	(2.2)	(1.2)	(2.4)	(0.005)	(0.002)	(0.101)	(0.082)	(0.103)	(0.037)	(47.1)	(0.4)	(1.4)	(65.0)	(2.5)
Cayuga	22.0	2.9	6.1	0.018	0.007	1.094	1.007	0.712	0.046	386.7	7.6	3.7	46.4	31.9
	(2.8)	(0.7)	(3.3)	(0.006)	(0.003)	(0.213)	(0.198)	(0.181)	(0.043)	(16.9)	(0.3)	(1.6)	(4.0)	(7.6)
Owasco	22.1	3.4	5.4	0.014	0.006	0.936	0.833	0.608	0.048	251.5	7.6	5.7	24.7	30.0
	(1.9)	(1.1)	(4.4)	(0.004)	(0.002)	(0.178)	(0.174)	(0.133)	(0.038)	(27.5)	(0.3)	(1.3)	(5.1)	(1.8)
Skaneateles	22.1	6.7	1.2	0.006	0.003	0.460	0.323	0.305	0.021	246.0	7.6	2.1	21.8	28.4
	(1.6)	(2.0)	(0.5)	(0.002)	(0.001)	(0.156)	(0.115)	(0.093)	(0.013)	(14.8)	(0.2)	(1.1)	(1.0)	(4.8)
Otisco	23.2	2.9	7.2	0.021	-	0.703	-	0.259	0.055	338.7	7.9	6.1	47.2	31.2
	(2.3)	(0.8)	(4.0)	(0.004)	-	(0.255)	-	(0.122)	(0.029)	(31.6)	(0.4)	(1.1)	(12.1)	(3.0)

* all parenthetic values represent one standard deviation difference from the summer average

\+ average of individual pH values

The eleven Finger Lakes were very low in TP, compared with smaller lakes and ponds in the broader Finger Lakes basin. In the “2017 Finger Lakes Regional Lakes Report” (NYSDEC 2017) the average TP for all the lakes in the region was 0.075 mg/L and ranged from 0.013 to ~ 0.150 mg/L.

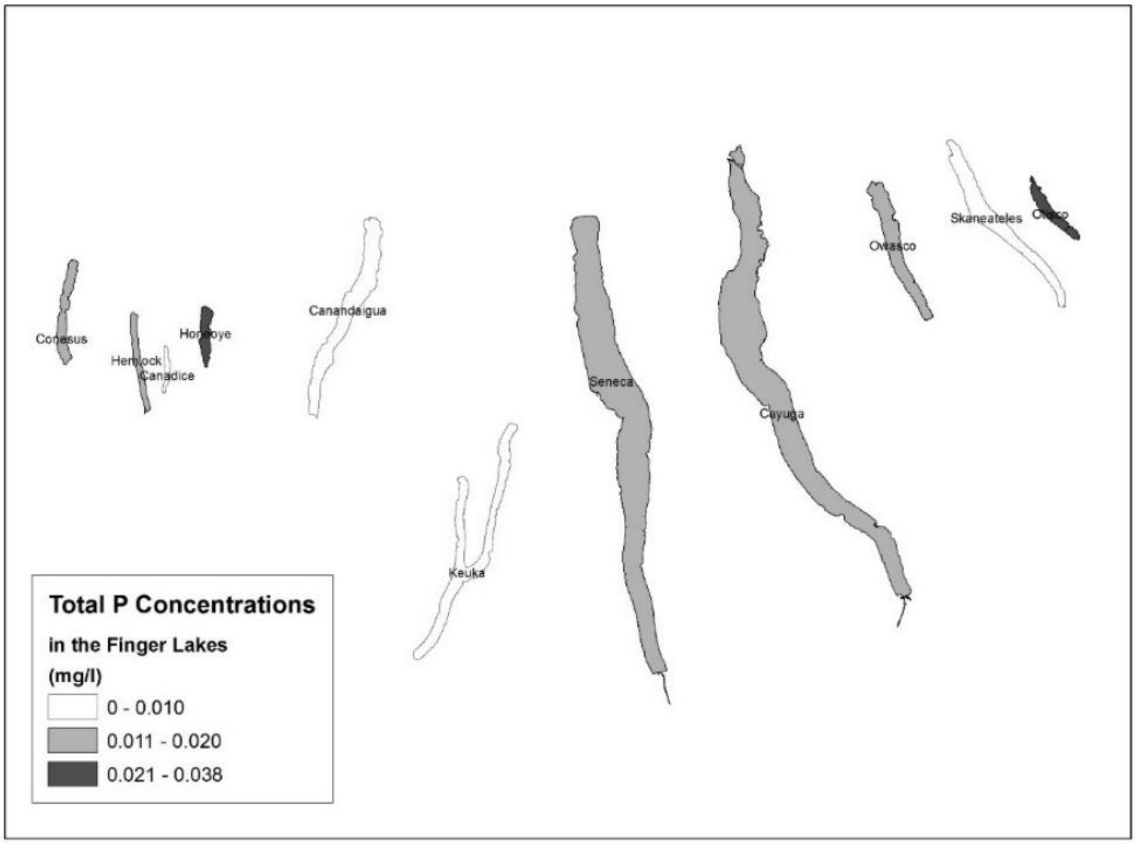


Figure 3. Distribution in lake average TP concentration in the Finger Lakes in 2017. Shading corresponds to NYSDEC trophic criteria for TP.

Previous investigations of TP in the Finger Lakes are presented in Figures 4a and 4b. Hemlock, Canadice, Owasco and Skaneateles Lakes have seen little change in their TP concentrations since the 1970s. In contrast, Honeoye and Otisco Lakes have experienced notable increases since the 1970s. Honeoye TP has increased from 0.019 mg/L to ~ 0.040 mg/L in 2017 (approximate 100% increase) while Otisco Lake summer average TP has increased approximately 120% since the 1970s. Some lakes, notably Canandaigua, Keuka, Seneca, and Cayuga, exhibited decreases in TP from the 1970s to the late 1990s. For Cayuga and Seneca, 2017 TP concentrations have increased to near 1970’s concentrations. Skaneateles, Keuka, Hemlock and Canadice Lake TP concentrations have remained relatively stable since the late 1990s. The TP concentration in Owasco Lake has increased slightly since the 1990s but current TP values are within 0.002 mg/L of the data presented in Bloomfield 1978.

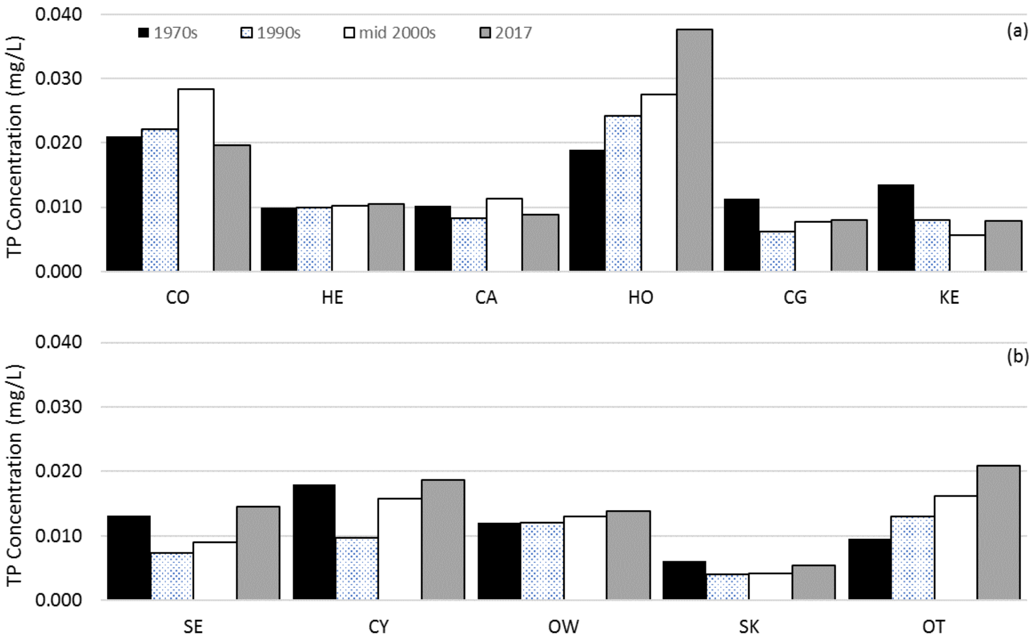


Figure 4. TP concentrations (mg/L) in the Finger Lakes from the 1970s (Bloomfield 1978), 1990s (Callinan 2001), mid 2000s (Callinan et al. 2013) and 2017 for: (a) the western lakes and (b) the eastern lakes. Note that the TP values from the 1970s were from winter samples.

Chlorophyll-*a* (Chl-a)

What most people refer to as "algae" is actually a highly diverse group of photosynthetic microscopic organisms referred to broadly as "phytoplankton" that include floating, suspended, and benthic forms. The broader term also includes photosynthesizing cyanobacteria that were once referred to as blue-green algae, but generally does not include macroalgae, more frequently (and mistakenly) considered to be "weeds." The amount of algae, or biomass, in a lake or pond can appear to be dominated by any of these forms, but suspended phytoplankton usually represents much of the biomass, and thus serves as the base for the overall aquatic food chain. This is also the form most commonly analyzed in monitoring programs.

As with TP, trophic status can be assessed by measurements of suspended phytoplankton. This can be achieved in several ways, such as cell count, but is most frequently quantified by the measurement of chlorophyll *a* (Chl-a), a photosynthetic pigment found in all freshwater phytoplankton, including cyanobacteria. Chl-a readings less than 2 parts per billion (or micrograms per liter; µg/L) are generally indicative of oligotrophic lakes. Readings above 8 parts per billion are typical of eutrophic lakes that are susceptible to persistent water quality problems. Readings between these thresholds are generally typical of mesotrophic lakes.


Filamentous Green Algae

NYSDEC has not formally adopted a target Chl-a threshold (water quality standard or guidance value) for lakes and ponds, but NYS research has identified that Chl-a concentrations greater than 10 µg/L can result in reduced water clarity, degradations in aesthetic and recreational water quality, and increased frequency of open water and shoreline algal blooms.

Chl-a is highly variable in NYS lakes with summer average values ranging from less than 1 to greater than 60 µg/L (Figure 5a). The interquartile range was 2.5 to 8.6 µg/L with a median statewide concentration of 4.6 µg/L (mean = 9.1 µg/L).

Skaneateles, Canandaigua and Canadice Lakes had the lowest Chl-a concentrations, averaging at or below 2 µg/L in 2017 (i.e., less than the 25th percentile of NYS lakes). Honeoye had the highest average concentration, of ~22 µg/L, significantly higher than the next most productive Finger Lake, Otisco (7.2 µg/L; Figure 5b). Conesus, Honeoye, Cayuga, Owasco, and Otisco all had Chl-a values greater than the NYS median (4.6 µg/L). The discussion of historical changes in Chl-a will be reserved for the Trophic State discussion in Section 5. These values fall in the expected range given the TP levels for these lakes, as expected given the strong relationship between phosphorus and chlorophyll in most NYS lakes (see the section "Relationships Between Major Trophic Indicators" later in this document).

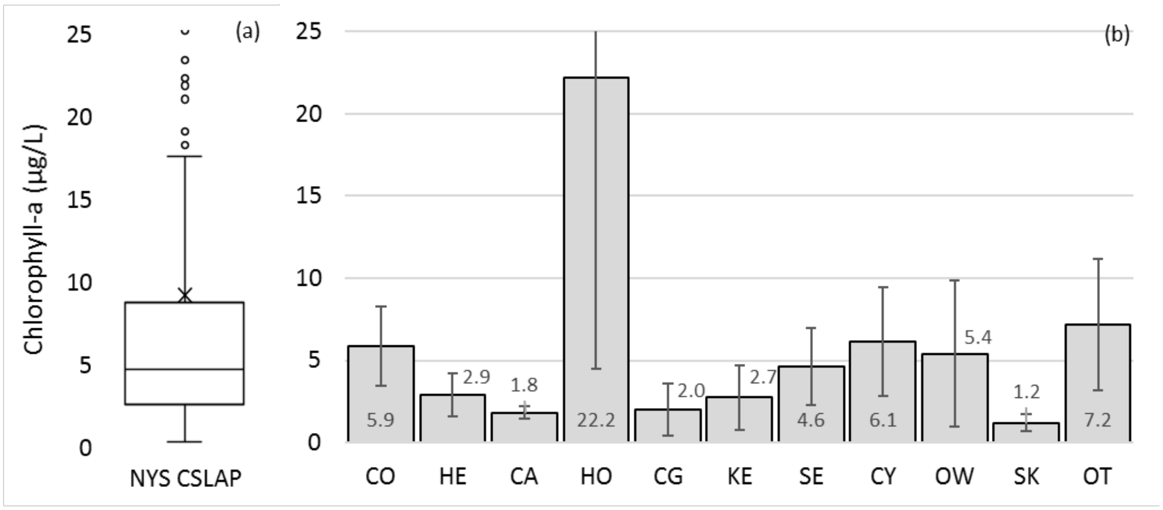


Figure 5. Chl-a concentrations (µg/L) in 2017: (a) in NYS CSLAP lakes and (b) in the 11 Finger Lakes (from left to right proceeding from west to east).

Average Chl-a for the lakes in the Finger Lakes region listed in the 2017 Finger Lakes Region Lakes Report (CSLAP and LCI lakes from 2012-2016) was 32 µg/L and ranged in summer average Chl-a from 3 to 160 µg/L (NYSDEC 2017). Other than Honeoye Lake, Chl-a levels in the Finger Lakes were substantially lower than the smaller lakes and ponds in the region.

Secchi Disk Clarity

Secchi disk

The Secchi disk was invented by Angelo Secchi, the Director of the Vatican Observatory, to measure the clarity of the water in the Mediterranean Sea. For freshwater use, the Secchi disk is a black and white quadrant disk, 20 cm in diameter affixed to a tape measure. The disk is lowered through the water column to estimate the depth of water clarity. This simple and economical design has been used since 1865 as an indirect method of measuring the clarity of water in lakes all over the world. The device was also used in the Finger Lakes by the earliest researchers (Birge and Juday) in 1910. The transparency of the water- "how clear is it?"- is one of the fundamental measures of water quality, due to its relationship with other limnological indicators such as algal production, and the connection between water transparency and public use. Water transparency, also referred to as water clarity, is closely connected to the amount of suspended and dissolved material in the water. The suspended material is comprised of both phytoplankton and suspended particles, and the dissolved material relates to brownish color imparted by dissolved organic matter. In most deep lakes, like the Finger Lakes, water clarity is very closely related to phytoplankton, while in shallower lakes, water clarity is influenced by algae, suspended sediment, and natural brownness.

As with TP and Chl-a, trophic status can be assessed by measurements of water clarity. Water clarity readings greater than about 5 meters are generally indicative of oligotrophic lakes. Readings less than 2 meters indicate eutrophic conditions. Readings between these thresholds are generally typical of mesotrophic lakes. NYSDEC has not formally adopted a target water clarity threshold (water quality standard or guidance value) for lakes and ponds, although NYSDOH will not site a new swimming beach unless water clarity exceeds 4 feet (or about 1.2 meters).

As with TP and Chl-a, Secchi disk transparency measurements were also highly variable in 2017 CSLAP lakes. Summer average clarity ranged from less than 1 to 9.1 m with an interquartile range of 1.8 to 4.1 m. The median statewide Secchi depth was 3.1 m (mean = 3.3 m; Figure 6a). The Secchi depth measurement range for the Finger Lakes varied between 1.7 m (Honeoye) and 6.7 m (Skaneateles). Skaneateles and Keuka Lakes had the greatest average lake clarity, with both having Secchi disk depths greater than 6 m (Figure 6b).

Honeoye, Cayuga, and Otisco Lakes had SD lower than the state's median value of 3.1 m (1.7 m, 2.9 m, and 2.9 m, respectively). Water clarity in Conesus and Seneca were approximately at the NYS CSLAP median value and Canandaigua and Canadice had clarity values greater than the state's 75th percentile (> 4.1 m).

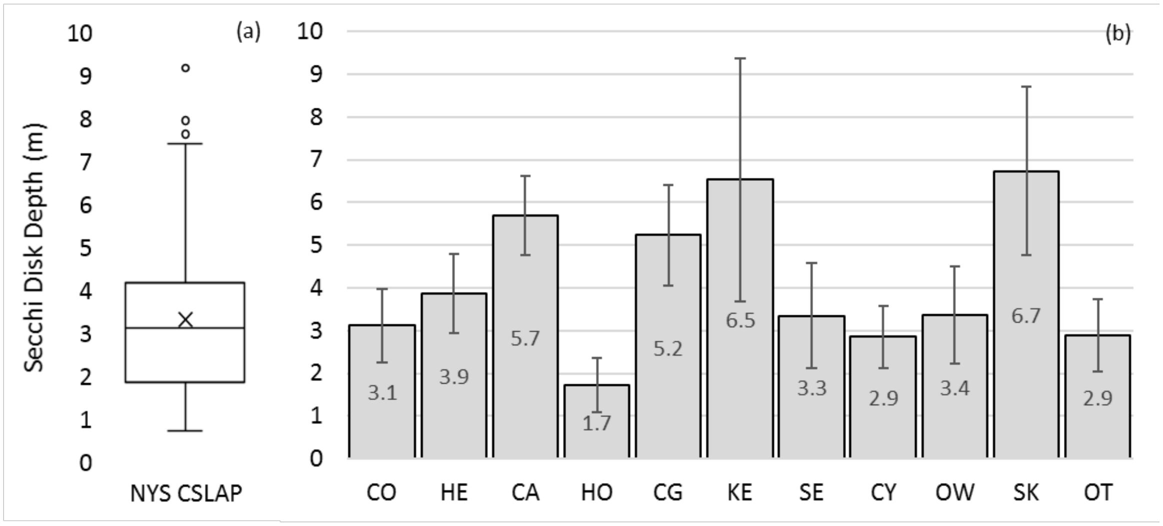


Figure 6. Secchi Disk depth (m) in 2017: (a) in NYS CSLAP lakes and (b) in the 11 Finger Lakes (from left to right proceeding from west to east).

The eleven Finger Lakes generally had much higher clarity compared with smaller lakes and ponds in the Finger Lakes region (NYSDEC 2017). Average Secchi disk depth in the smaller lakes was 1.8 m with a range between 0.4 and 3.5 m.

The Finger Lakes have a long history of Secchi disk measurements, starting in the early 1900's with the classic limnological investigations of Birge and Juday (1914). Patterns in water clarity have varied between lakes: some lakes have severely degraded in clarity, while others had higher clarity in 2017 compared with the early 20th century (Figure 7). Despite differences in magnitude of changes, most lakes have experienced the same general trend since the turn of the last century: (1) water clarity degradation from 1910 to the 1970s, (2) improvements in clarity from the 1970s to the late 1990s – but with the 1990s rarely being clearer than 1910, (3) minor changes (both positive or negative) from the late 1990s to the mid-2000s and to 2017.

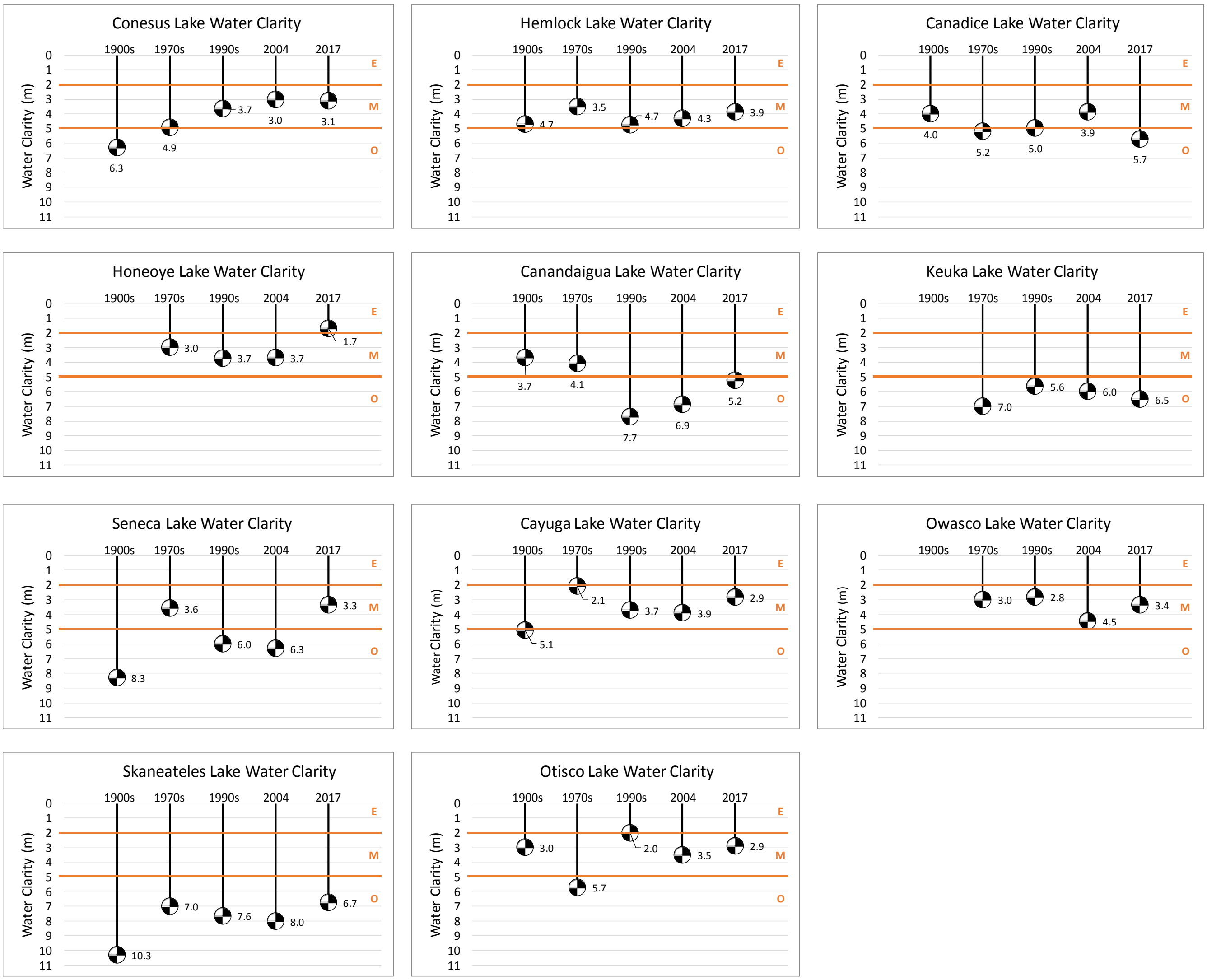


Figure 7. Summer average SD (m) for the Finger Lakes from 1910 (Birge and Juday 1914 [if available], Bloomfield 1978, Callinan 2001, 2013) to 2017. The panels are arranged from west to east, starting the upper left. Note the letters correspond to trophic state boundaries for SD; E – eutrophic, M – mesotrophic, and O – oligotrophic.

Relationships Between Major Trophic Indicators

Surface Chl-a observations were positively correlated with TP concentrations in NYS lakes in 2017. That is as TP concentrations increased, Chl-a concentrations also increased. The relationship was highly variable with summer average TP explaining 55% (R^2, also called the coefficient of determination, a metric of statistical fit-see box on the right) of the variability in summer average Chl-a for individual observations (Figure 8). At TP concentrations near the NYS guidance value (0.020 mg/L), Chl-a concentrations ranged from ~ 1 µg/L to > 10 µg/L indicating that while TP is an important in promoting algal growth: (1) TP is a composite measurement that includes dissolved forms and non-algal particles such as resuspended sediment and (2) factors other than TP (e.g., light, temperature, and grazing pressure) are important in determining Chl-a concentrations in NYS lakes. The relationship between TP-Chl-a for the Finger Lakes was consistent with the NYS TP-Chl-a relationship as all the Finger Lakes values were within the scatter of the larger pool of NYS lakes (Figure 8-symbols). Skaneateles and Canadice observations were slightly below the best-fit NYS line indicating that these lakes had less Chl-a for a given TP concentration on average. Three lakes: Owasco, Otisco, and Honeoye had observations above the best-fit line indicating that these lakes had higher Chl-a levels for their respective TP concentrations in 2017 compared with other NYS lakes.

The R^2 is also called the coefficient of determination. The R^2 can range from 0 to 1 with a 0 indicating the predictor (for example, TP) explains 0 percent of the variation in the response variable (for example, Chl-a). An R^2 of 1 would mean that the predictor explains 100% of the variability in the response. R^2 values of greater than 0.7 typically indicate a strong relationship.

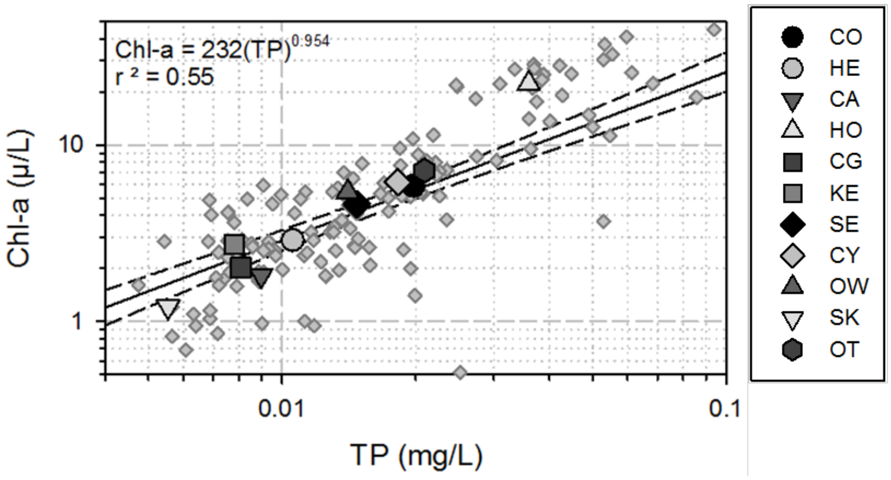


Figure 8. Relationship between summer average TP concentrations (mg/L) and Chl-a concentrations (µg/L) for the 2017 NYS CSLAP dataset (gray diamonds) with the Finger Lakes as symbols (legend). NYS statistical best-fit relationship (solid line) with 95% confidence intervals (dashed line).

Chl-a concentrations were negatively correlated with Secchi disk clarity (Figure 9). That is, as Chl-a increased, Secchi disk clarity generally decreased. The relationship for all CSLAP observations was also moderate with Chl-a only explaining 61% of the variability in clarity. Secchi disk depth was highly variable at all levels of Chl-a concentration. At Chl-a concentrations of 4 µg/L, clarity measurements less than ~2 m (eutrophic) and greater than 9 m (oligotrophic) were observed. This is not unexpected given that many factors regulate water clarity in a lake, including: (1) type of algal community, (2) water color and dissolved organic matter, (3) sediment laden runoff from the watershed following intense rain storms, (4) resuspended nearshore sediments transported to the open water during wind events, and (5) internal production of calcium carbonate (i.e., whiting events). In addition, these relationships are less robust when Chl-a measurements are very low and within the range of variability in the analytical tests. Like TP-Chl-a, the relationship between Chl-a-SD for the Finger Lakes was consistent with the NYS Chl-a-SD relationship (Figure 9). All the Finger Lakes had slightly better clarity for a given Chl-a concentration in 2017 compared with other NYS lakes.

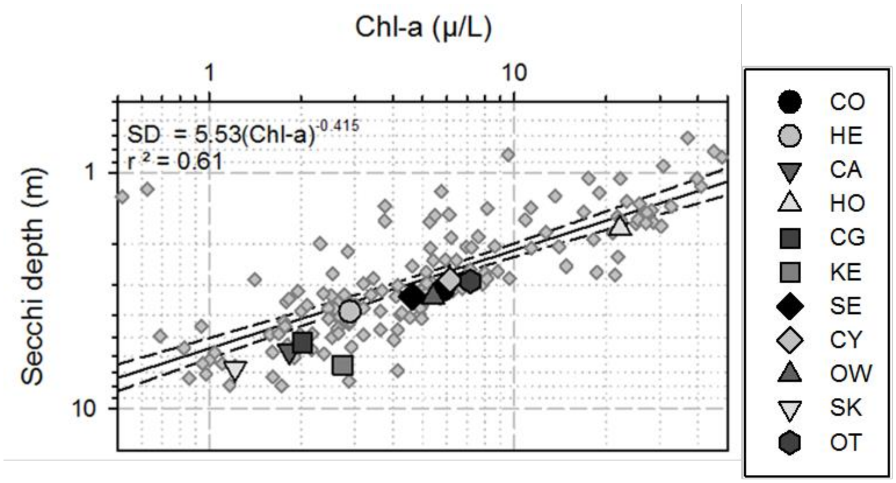


Figure 9. Relationship between Chl-a concentrations (µg/L) and Secchi disk clarity (m) for all paired observations in the 2017 Finger Lakes CSLAP dataset (gray diamonds) with the Finger Lakes as symbols (legend). NYS statistical best-fit relationship (solid line) with 95% confidence intervals (dashed line).

TP was a good predictor of Secchi disk clarity in all 2017 NYS lakes with the overall relationship similar to Chl-a-SD (Figure 10). Because TP includes all types of P in the sample (algal and suspended sediment), it is not unexpected that TP by itself would be a good predictor of clarity, especially in moderate to low biological production ecosystems (since, as noted above, chlorophyll levels in these ecosystems are close to the analytical detection limit and therefore difficult to accurately measure). In NYS lakes in 2017, TP explained 59% of the variability in Secchi depth. The relationship between TP-SD for the Finger Lakes was consistent with the NYS TP-SD.

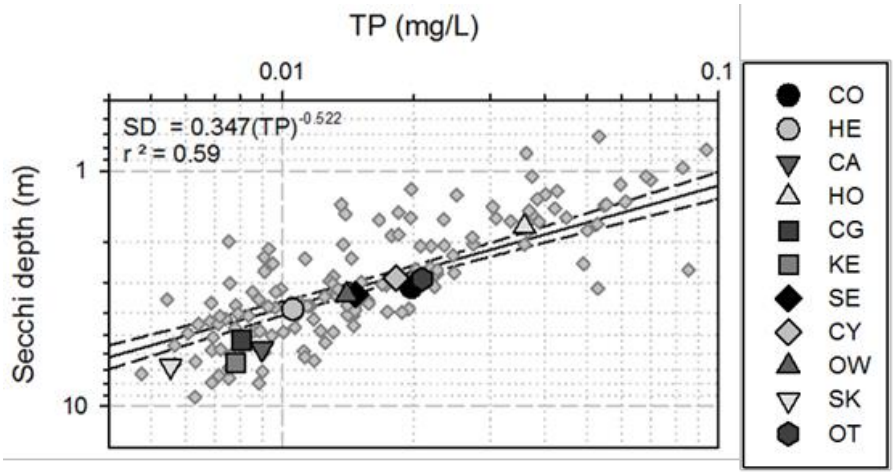


Figure 10. Relationship between TP concentrations (mg/L) and Secchi disk clarity (m) for all paired observations in the 2017 Finger Lakes CSLAP dataset (gray diamonds) with the Finger Lakes as symbols (legend). NYS statistical best-fit relationship (solid line) with 95% confidence intervals (dashed line).

Figure 11a shows the relationships between the summer average values of TP and Chl-a for the Finger Lakes in 2017 (Note that Honeoye was an outlier compared with the other lake averages and were not included in development of the statistical relationships). On a summer average basis, open water TP explained 92% of the variability in open water Chl-a. The relationship between phosphorus and algae has been well established, going back to at least the 1950s. The P-limitation mechanism was elegantly highlighted in the pioneering work by Dr. David Schindler in the Canadian Experimental Lakes Area in the 1970s (Schindler 1977). This research, confirmed by many studies in the following decades, formed the basis for the foundational principle of lake management linking phosphorus limitation with algae control. In many lakes, phosphorus serves as the primary limiting factor controlling algae growth during the summer growing season- increasing phosphorus, particularly soluble phosphorus, will increase algae levels. Interestingly, the 2017 relationship between TP-Chl-a for the Finger Lakes appears to have changed very little since the late 1990s (Callinan 2001).

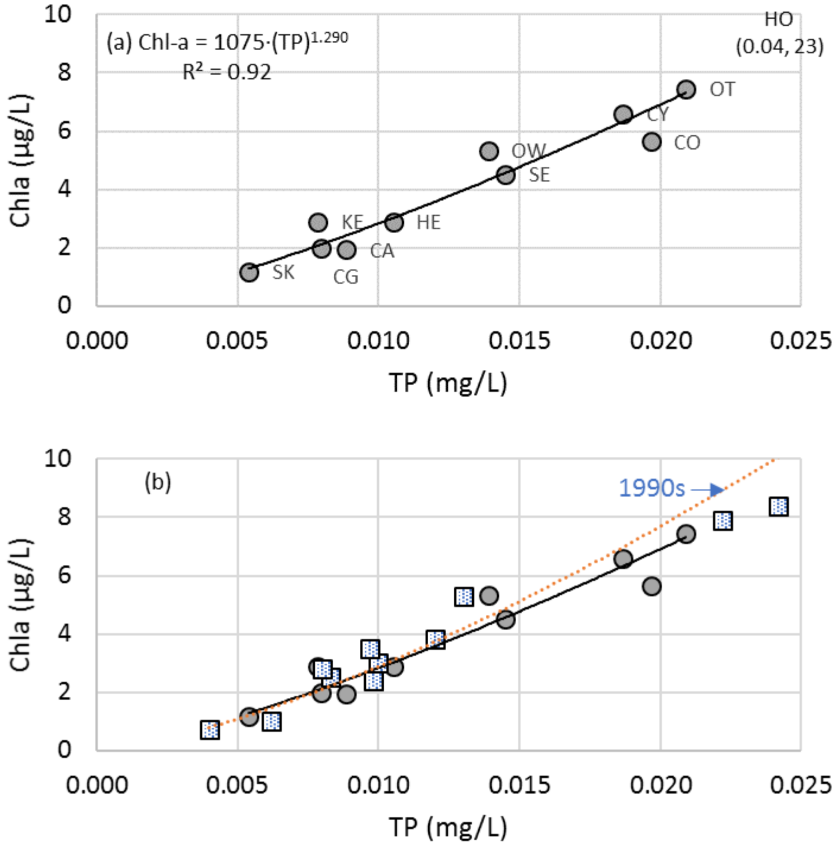


Figure 11. Relationships between major trophic state metrics for lake summer average values for: (a) TP (mg/L) – Chl-a (µg/L) in 2017, (b) TP (mg/L) – Chl-a (µg/L) in 2017 (solid line) with the best-fit line from the late 1990s (dotted line).

The relationship between summer average Chl-a and Secchi depth was strong in 2017 with open water Chl-a explaining more than 80% of the variation in clarity (Figure 12a). Interestingly, despite having similar summer average Chl-a values (~ 3 µg/L), Keuka and Hemlock Lakes had substantially different summer average Secchi depths (6.5 m and 3.9 m respectively). As with TP-Chl-a, the relationship between Chl-a-SD appears to have changed very little since the late 1990s (Callinan 2001; Figure 12b), indicating the influence of algal growth on clarity in these lakes on a seasonal scale.

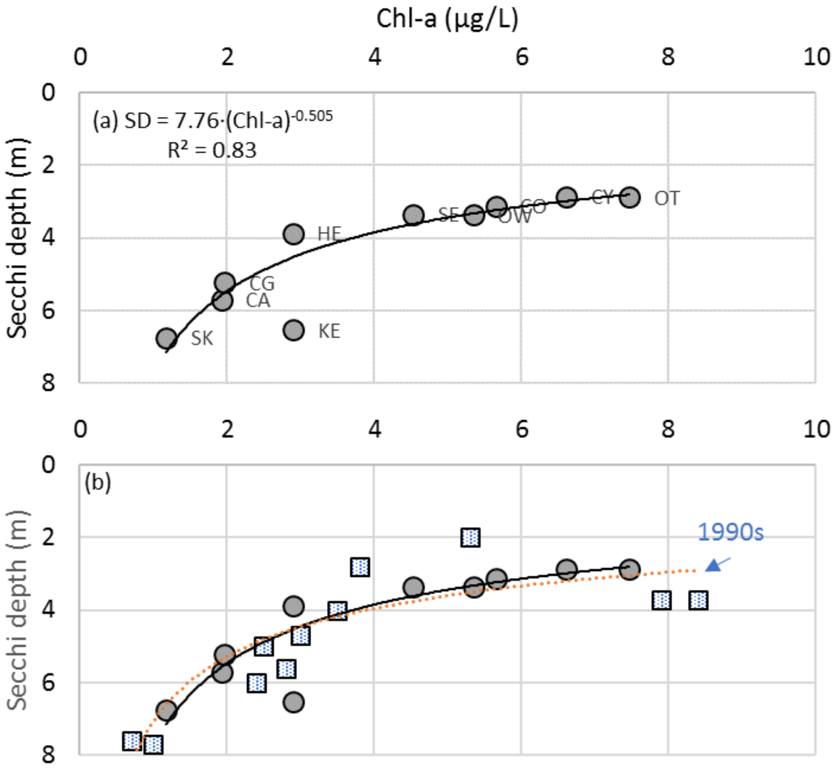


Figure 12. Relationships between major trophic state metrics for lake summer average values for: (a) Chl-a (µg/L) – SD (m) in 2017, (b) Chl-a (µg/L) – SD (m) in 2017 (solid line) with the best-fit line from the late 1990s (dotted line).

Summer average TP explained more than 91% of the variation in clarity in the Finger Lakes in 2017 (Figure 13a). As with, the other major trophic indicator relationships, the contemporary relationship between TP-SD was very similar to the late 1990s (Callinan 2001; Figure 13b), indicating: (1) the role of TP influencing algal growth and therefore, clarity in the Finger Lakes and (2) the effect of the inorganic TP forms, like suspended sediment, on Secchi depth.

Total Nitrogen

Several forms of nitrogen are included in the CSLAP program. These forms include nitrate + nitrite (NOx), ammonia (NH_3) and total nitrogen (TN). The role of nitrogen in cyanobacteria biomass and cyanotoxins has come under intensive study in recent years. The empirical relationship between any specific nitrogen form and Chl-a is not as strong as the relationship between TP and Chl-a in most NYS lakes. A preliminary investigation of the 2012-2017 CSLAP dataset as part of the Governor Cuomo's HABs Initiative in 2018, showed a strong relationship between HABs production and phosphorus rather than nitrogen. However, the specific role of nitrogen, phosphorus, and other bloom "triggers" for any individual lake may be specific to that lake.

Nitrate (NO_3) is a form of nitrogen that is available for biological uptake, including uptake by algae. It is more easily analyzed as NO_X, or nitrate + nitrite. Nitrite (NO_2) is rarely found in surface waters, and can be created as an intermediate step in denitrification; the conversion of nitrate into nitrogen gas in the absence of oxygen. Nitrite can be toxic to aquatic life, though it readily converts to nitrate (or other forms of nitrogen) in the presence of oxygen. Toxic levels of nitrite are rarely found in surface waters, although elevated nitrite levels may be found in highly anoxic waters near the bottom of some lakes. Nitrate can be a limiting nutrient for some forms of green algae and may be an important nutrient in some regions of the state, such as Long Island. Nitrate can be an important component of wastewater, stormwater, fertilizers, and soil erosion. Therefore, it can be an indirect surrogate for pollutant loading to lakes, although elevated nitrate readings may be natural in some parts of the state. The oxidized forms of nitrogen NO_3, NO_2, NO and N_2O are collectively referred to as NO_X.

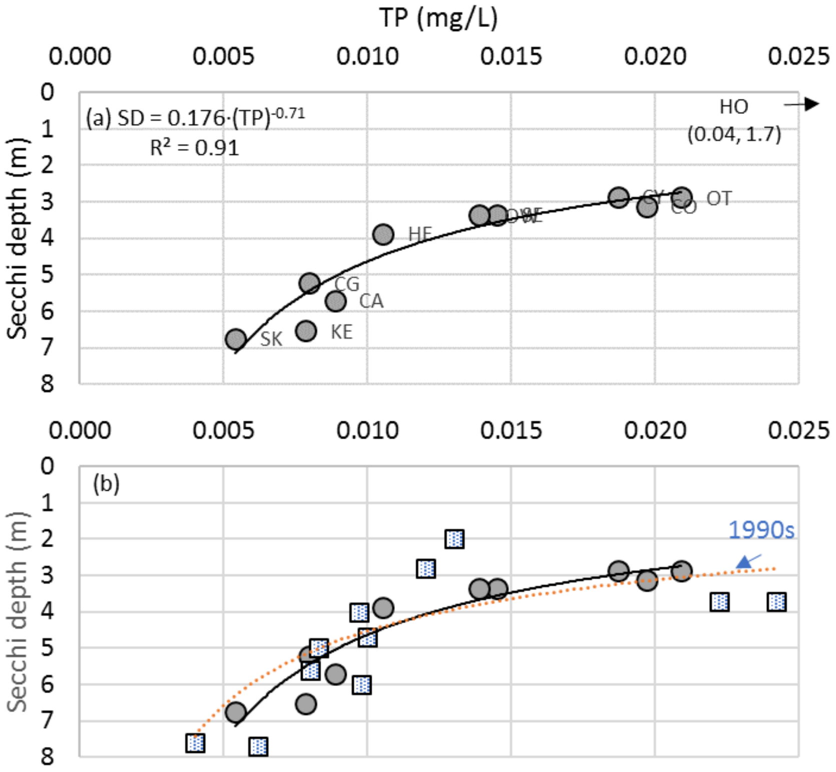


Figure 13. Relationships between major trophic state metrics for lake summer average values for: (a) TP (mg/L) – SD (m) in 2017, (b) TP (mg/L) – SD (m) in 2017 (solid line) with the best-fit line from the late 1990s (dotted line).

Ammonia is a form of nitrogen produced from nitrogen gas by nitrogen fixation and through the degradation of organic matter generated through several biological processes. It is toxic to aquatic organisms and (to a much lesser extent) humans at concentrations occasionally found in lake water, particularly at high pH or in the absence of oxygen (such as occasionally found in the bottom waters of productive lakes). High ammonia readings may also be a sign of pollution such as stormwater runoff, wastewater treatment plant effluent, or may indicate persistent problems with deoxygenated water.

Total nitrogen is the sum of all component forms of nitrogen—NOx + total Kjeldahl nitrogen (or TKN, which is equal to total ammonia + organic nitrogen). It can also be computed as an independent laboratory analysis, without first analyzing the nitrogen components, as is done by UFI through CSLAP.

There are no water quality standards for total nitrogen, although in some lakes, TN levels above 0.6 mg/L may indicate eutrophic conditions (NYSDEC 2017). The NYS water quality standard for ammonia is 2 mg/L adopted to protect aquatic life (although lower standards for pH dependent forms of ammonia are applied to trout waters), but this is very rarely reached in surface water samples. Elevated ammonia in bottom waters may be an indication of deoxygenation, often in response to excessive algae or other eutrophication measures. The NO_3 drinking water standard in NYS is 10 mg/L; this is well above the readings found in NYS lakes. For both NOx and ammonia, readings above 0.300 mg/L could be considered elevated, although elevated nitrogen levels in some lakes may be associated with natural conditions and therefore, not necessarily indicative of water quality problems.

Summer average TN values were extremely variable in NYS ranging from 0.133 to 1.710 mg/L (Figure 14a). The interquartile range was 0.343 to 0.636 mg/L with a median statewide concentration of 0.446 mg/L (mean = 0.544 mg/L). TN concentrations in the eleven Finger Lakes were also highly variable, ranging between 0.192 mg/L (Canadice) and 1.094 mg/L (Cayuga) as presented in Figure 14b.

With regards to TN, an interesting geographical pattern was observed, not seen with TP, Chl-a, or SD. Except for Honeoye Lake, all lakes from Keuka – west had summer average TN values less than the NYS median (< 0.446 mg/L; Figure 14b). The five eastern lakes (Seneca to Otisco) had elevated TN values when compared to the NYS lakes (Figure 14a) and the western Finger Lakes, ranging from greater than 0.460 mg/L to ~1.000 mg/L.

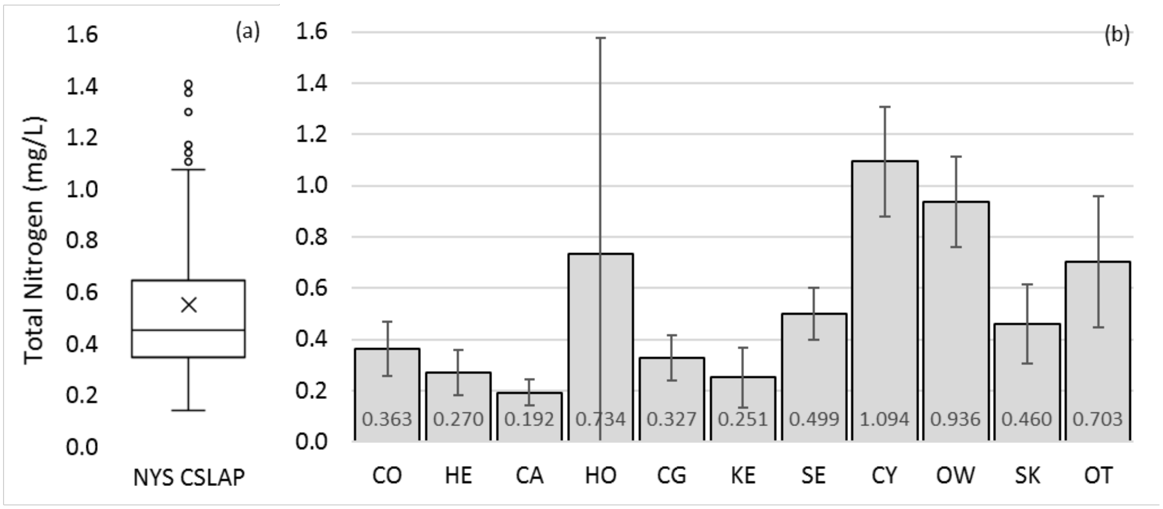


Figure 14. Summer average TN concentrations (mg/L) in 2017: (a) in NYS CSLAP lakes and (b) in the 11 Finger Lakes (from left to right proceeding from west to east). * Honeoye Lake recorded a 3.83 mg/L value on June 26. Excluding that observation, the summer average value decreased to 0.53 mg/L.

Relationships Between TN, Chl-a, and Clarity

Surface Chl-a observations were positively correlated with TN concentrations in NYS lakes in 2017, although the relationship was weak and extremely variable with TN only explaining 38% of the variability in Chl-a for NYS lakes (Figure 15). The relationship between TN-Chl-a for the Finger Lakes was consistent with the NYS TN-Chl-a relationship as all the Finger Lakes values were within the scatter of the larger pool of NYS lakes (Figure 15). Cayuga, Owasco, and Skaneateles had observations well below the best-fit line indicating that these lakes had lower Chl-a levels for their respective TN concentrations in 2017 compared with other NYS lakes.

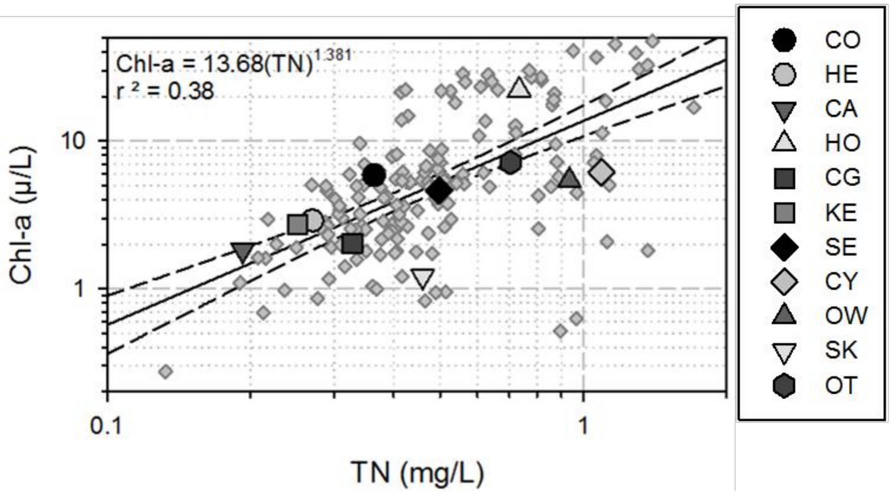


Figure 15. Relationship between summer average TN concentrations (mg/L) and Chl-a concentrations (µg/L) for the 2017 NYS CSLAP dataset (gray diamonds) with the Finger Lakes as symbols (legend). NYS statistical best-fit relationship (solid line) with 95% confidence intervals (dashed line).

Figure 16a shows the relationships between summer average TN and Chl-a in the Finger Lakes in 2017 (note that Honeoye was an outlier compared with the other lake averages and was not included in development of the statistical relationships). TN was positively correlated with algal growth in the Finger Lakes in 2017, although TN was a poor predictor of summer average Chl-a in these lakes (R^2=0.39). The relationship between TN and Chl-a was much weaker than the relationship between TP and Chl-a (R^2=0.92; Figure 11a). These observations support the current paradigm of P promoting algal growth in the Finger Lakes. In fact, as will be discussed subsequently, most of the TN in the Finger Lakes is in soluble forms and therefore would be expected to be somewhat disconnected to primary production and water clarity, since it has not been taken up by algae. As noted earlier, atmospheric nitrogen may be providing a constant source of nitrogen for algal communities dominated by nitrogen-fixing cyanobacteria such as *Dolichospermum* and *Aphanizomenon.*

Figure 16b shows the relationships between the summer average values of TN and Secchi disk clarity in the Finger Lakes in 2017. Generally, TN was negatively correlated with algal growth in the Finger Lakes, but was a poor predictor of clarity (R^2=0.43). The relationship between TN and SD was much weaker than the relationship between TP and SD (Figure 13a; R^2=0.91). TN, unlike TP does not have a strong particulate mineral phase.

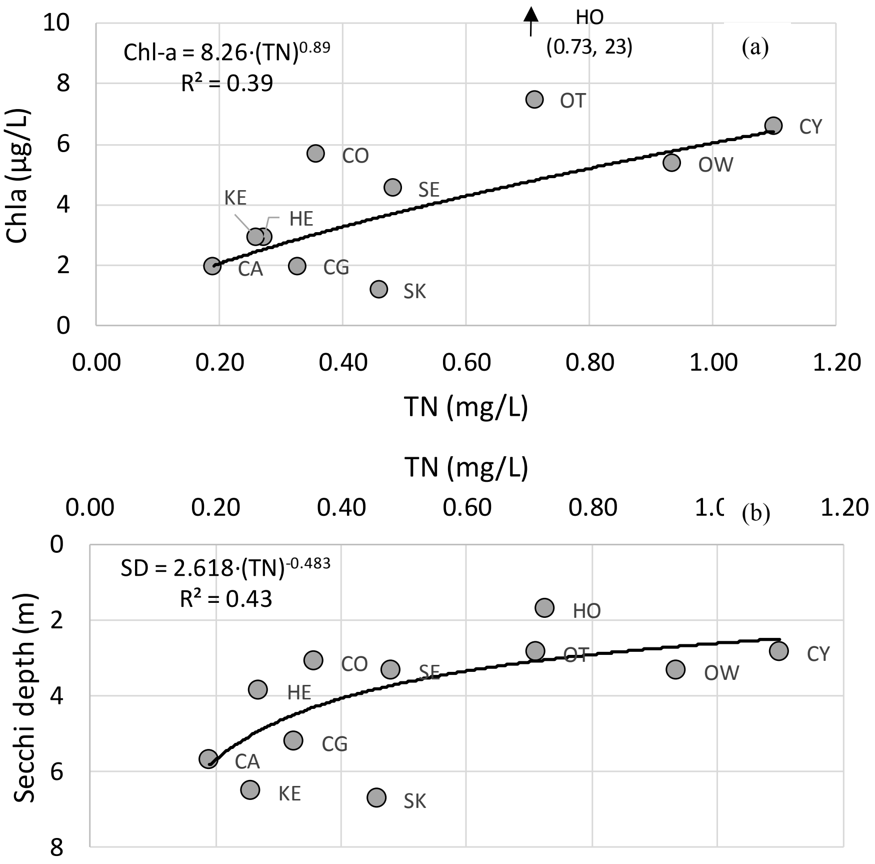


Figure 16. Relationships between: (a) summer average TN (mg/L) – Chl-a (µg/L) and (b) TN (mg/L) – Secchi disk clarity (m) in the Finger Lakes in 2017.

Seasonal Patterns in Major Indicators

Surface TP and Chl-a observations were seasonally variable within and between the Finger Lakes in 2017 (Figures 17 and 18). Despite the variability, the patterns in Chl-a generally tracked the patterns in TP. Hemlock and Canadice Lakes displayed very little seasonality for TP and Chl-a (Figure 17b,c and Figure 18b). The highest individual TP observation was on Honeoye Lake on Aug. 28 at the southern site (0.091 mg/L) which was coincident with the highest Chl-a observation in 2017 (~ 67 µg/L).

Like the patterns in TP and Chl-a, the patterns in Chl-a and water clarity (Secchi depth) were highly variable between lakes and seasonally within individual lakes (Figures 19 and 20). Also, the patterns in water clarity generally tracked (inversely) the patterns in algal growth. There were some exceptions which may have been caused by non-algal particulates from intense rains influencing clarity in July for a few lakes such as Skaneateles, Seneca, and Keuka.

Patterns in TN and Chl-a were variable in 2017 (Figures 21 and 22), however, the patterns were more disconnected than for TP and Chl-a. This may be expected given the role of P in regulating algal growth in most of the Finger Lakes for most of the season. This will be discussed in more detail in subsequent sections.

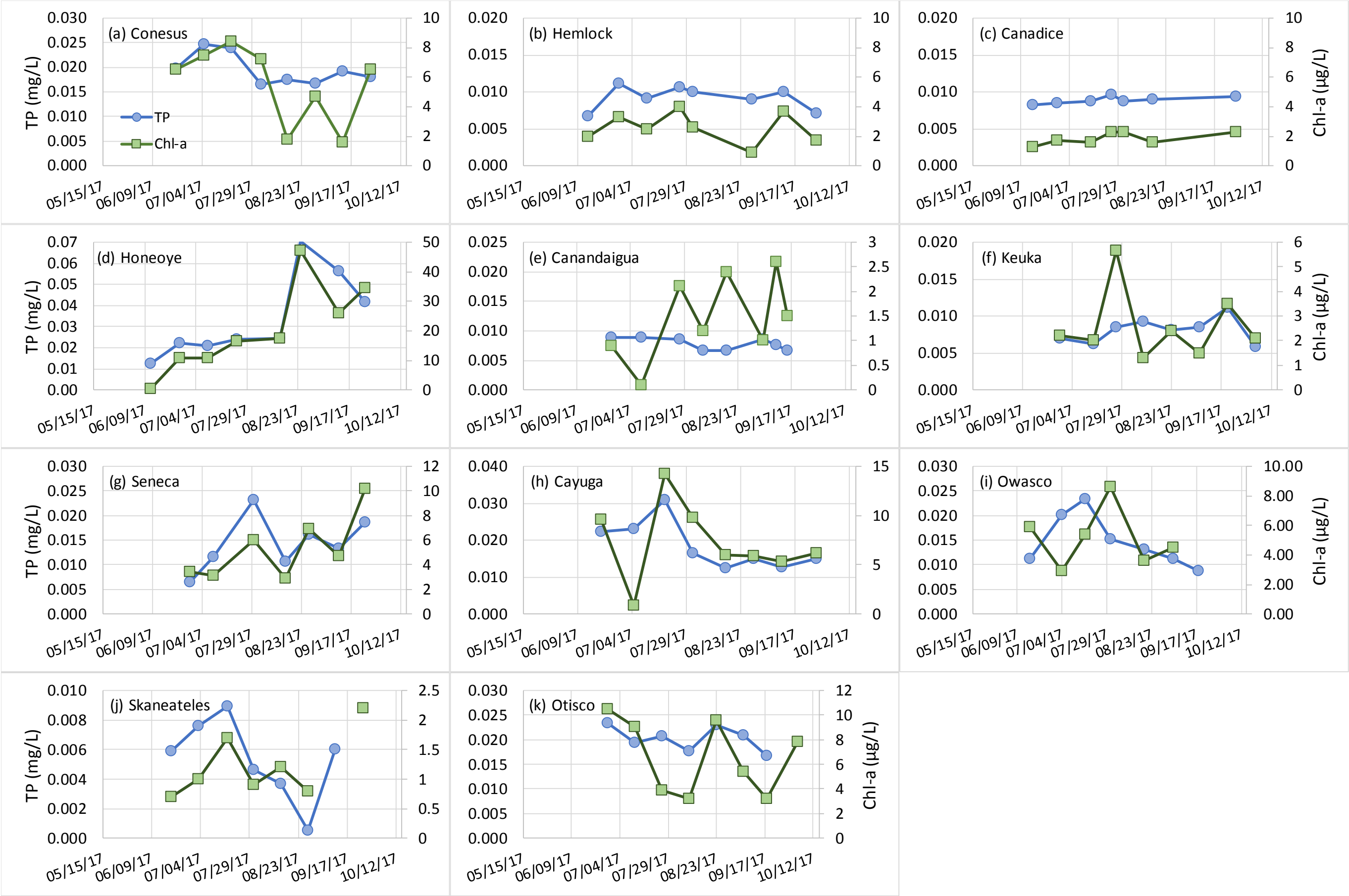


Figure 17. Patterns in TP (µg/L) in blue and Chl-a (µg/L) in green in the Finger Lakes in 2017 from the **northern** site locations. Note that Canadice has one mid-lake location. Please note the scale differences between the panels.

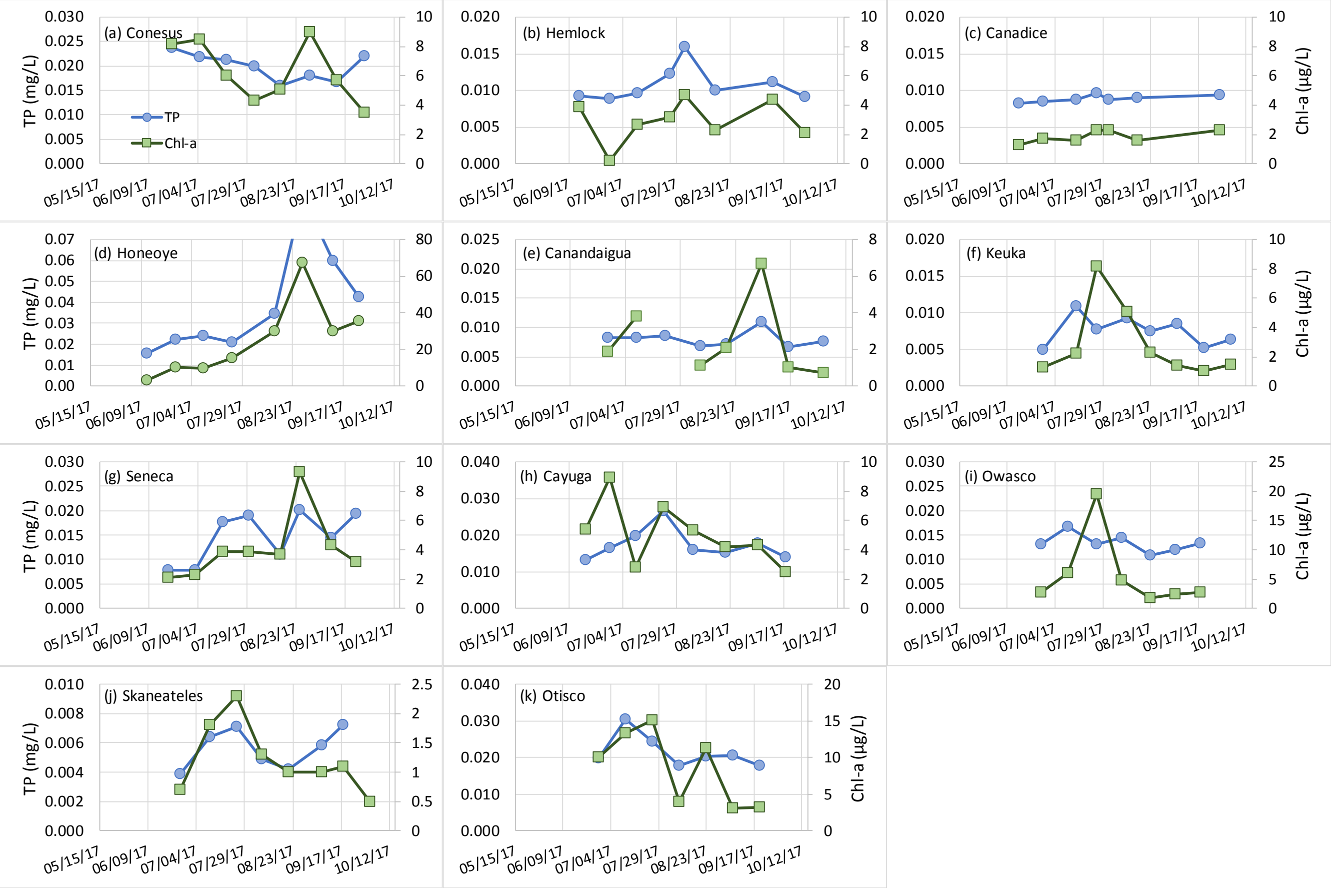


Figure 18. Patterns in TP (µg/L) in blue and Chl-a (µg/L) in green in the Finger Lakes in 2017 from the **southern** site locations. Note that Canadice has one mid-lake location. Please note the scale differences between the panels.

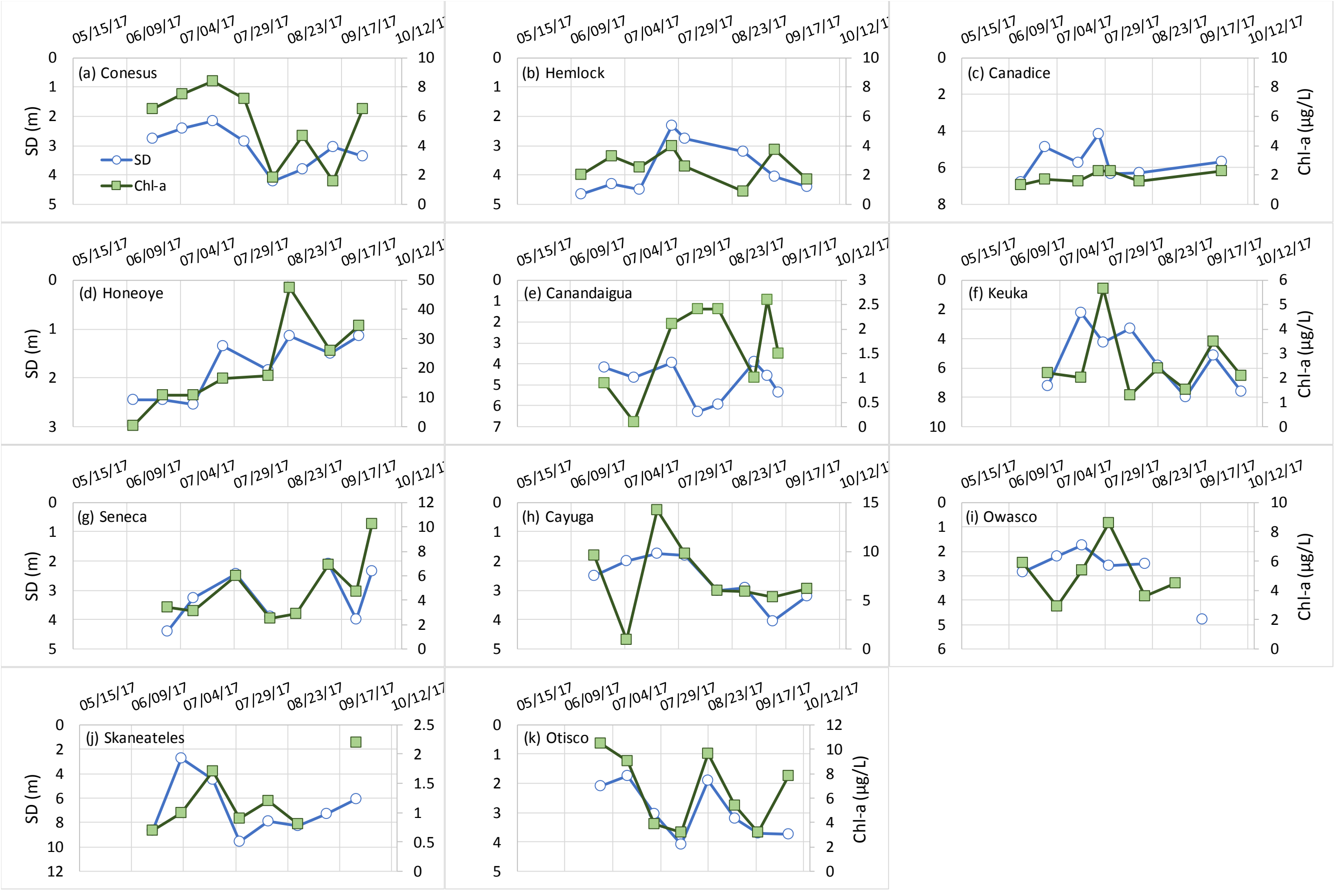


Figure 19. Patterns in Chl-a (µg/L) in green and SD (m) in blue in the Finger Lakes in 2017 from the **northern** site locations. Note that Canadice has one mid-lake location. Please note the scale differences between the panels.

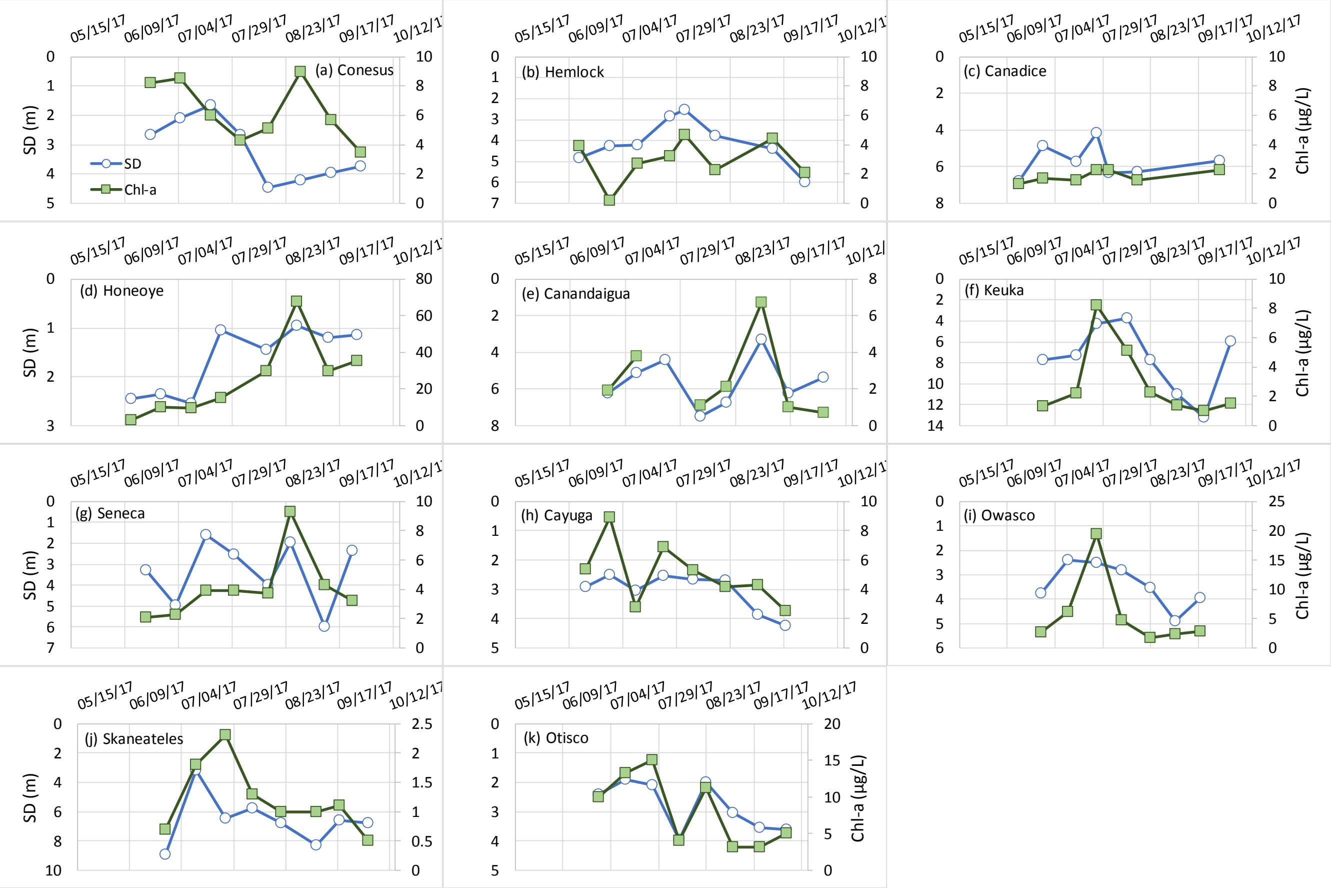


Figure 20. Patterns in Chl-a (µg/L) in green and SD (m) in blue in the Finger Lakes in 2017 from the **southern** site locations. Note that Canadice has one mid-lake location. Please note the scale differences between the panels.

Figure 21. Patterns in TN (mg/L) in blue and Chl-a (µg/L) in green in the Finger Lakes in 2017 from the **northern** site locations. Note that Canadice has one mid-lake location. Please note the scale differences between the panels.

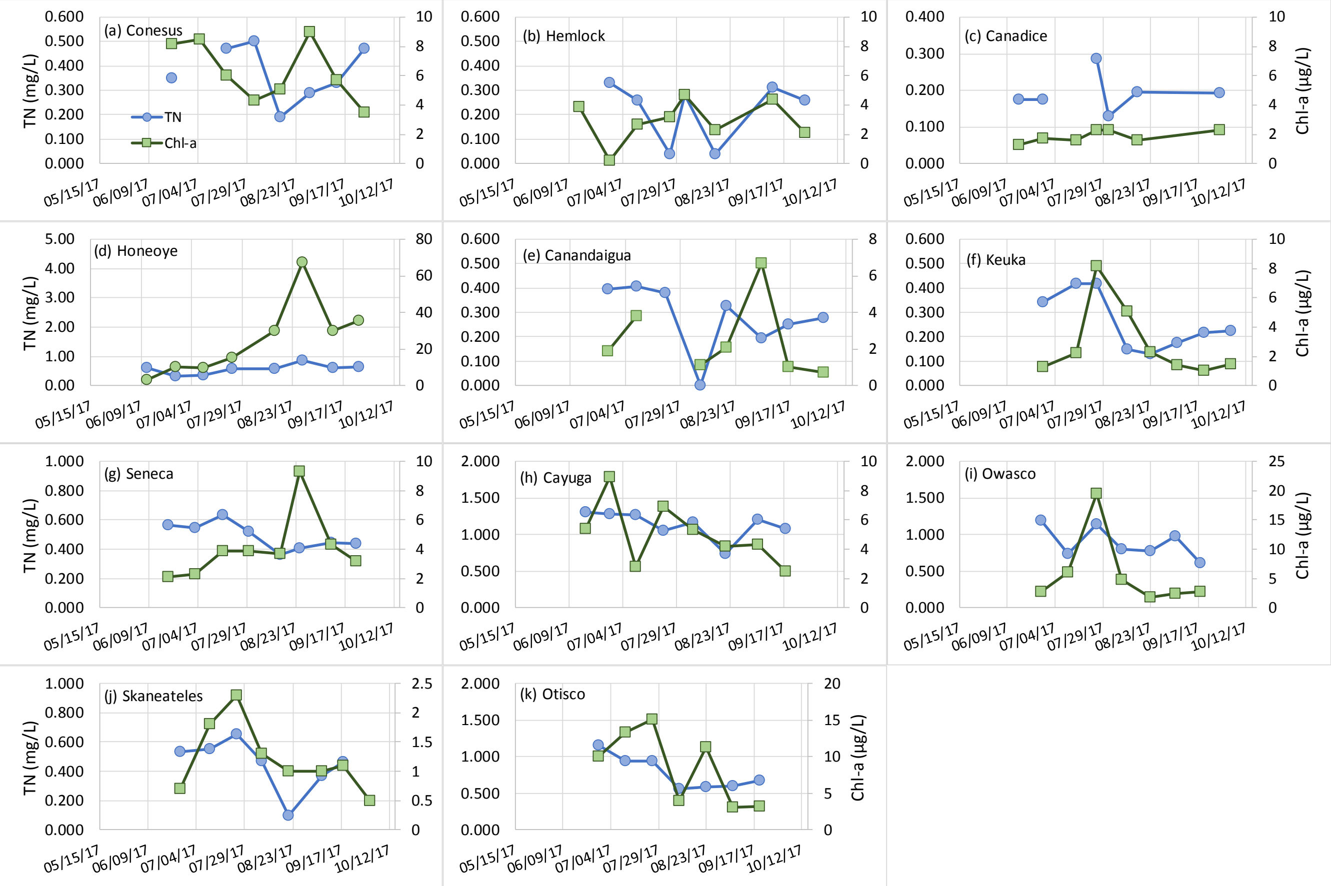


Figure 22. Patterns in TN (mg/L) in blue and Chl-a (µg/L) in green in the Finger Lakes in 2017 from the **southern** site locations. Note that Canadice has one mid-lake location. Please note the scale differences between the panels.

TN:TP Ratios

The ratio between TN and TP, referred to as the N:P ratio, may influence the extent and type of algae growth, and may have relevance for the production of both cyanobacteria biomass and cyanotoxins. For example, a low N:P ratio provides a selective advantage to nitrogen-fixing types of cyanobacteria such as *Dolichospermum*. The ratio of N:P also is an important limnological analysis that can lend insight to whether N or P are limiting algal growth. On a weight basis, the ratio of carbon (C), nitrogen (N), and phosphorus (P) in typical aquatic plant material (algae and macrophytes) is approximately 40:7:1 (Wetzel, 2001). These ratios often referred to as the Redfield ratios named after the scientist that pioneered this work in the 1930s. Thus, from a physiological perspective, aquatic plants (algae) require significantly less phosphorus than carbon and/or nitrogen.

Previous empirical investigations have found that freshwater ecosystems with N:P ratios > 20 – phosphorus is most likely the limiting nutrient. Lakes with N:P < 10 – nitrogen is most likely the limiting nutrient and when N:P is between 10-20 it is difficult to determine the limiting nutrient. When N:P is between 10-20 limitation depends upon other factors such as light availability, presence/absence of nitrogen-fixing algae (cyanobacteria), and the forms of nutrients present (Thomann and Mueller, 1987).

N:P ratio values for the 2017 observations were seasonally variable (within a lake) and between lakes, consistent with the levels of variability observed for TN and TP (Figures 17-18 and 21-22). Conesus, Honeoye, and Canadice Lakes had relatively low N:P ratios (~20) in the spring which decreased throughout the season to ~ 10, indicating that these lakes, due to elevated P and N concentrations likely experience periods of both N and P limitation. Interestingly, Honeoye-south and Hemlock-south both observed N:P less than 10 (likely indicates N-limitation), while the northern sites did not.

The larger lakes generally had seasonally high N:P ratios (> 40) in the spring, followed by decreases in N:P into the summer. In some cases, the N:P ratio dropped below 20, indicating that N or P could be limiting algal growth at those times in those lakes. This pattern was most prevalent in Seneca (Figure 24g,k) and Otisco Lakes (Figure 23g,k). A N:P ratio at Skaneateles Lake-south approached 20 on August 21. Keuka Lake-north had a N:P value less than 10 in August, indicating likely N-limitation.

Average Cayuga and Owasco Lakes N:P values were 64 and 69, respectively in 2017. These lakes had N:P values remain above 30 all season, due to the high levels of N in these lakes indicating that these lakes are P-limited.

There was a weak negative correlation between individual paired N:P ratios and Chl-a measurements (r=-0.25), and a slightly stronger negative relationship between summer average N:P ratio and summer average Chl-a (r=-0.31). These results indicate that in the eleven Finger Lakes, decreasing N:P is loosely correlated with increasing Chl-a. A more detailed evaluation of the onset of blooms (and their associated toxins) and N:P ratios will help to better evaluate the role of nitrogen in bloom formation in the Finger Lakes. It should also be noted that this only addresses relationships between open water algae levels and N:P ratios, not the piling of bloom materials along the shoreline.

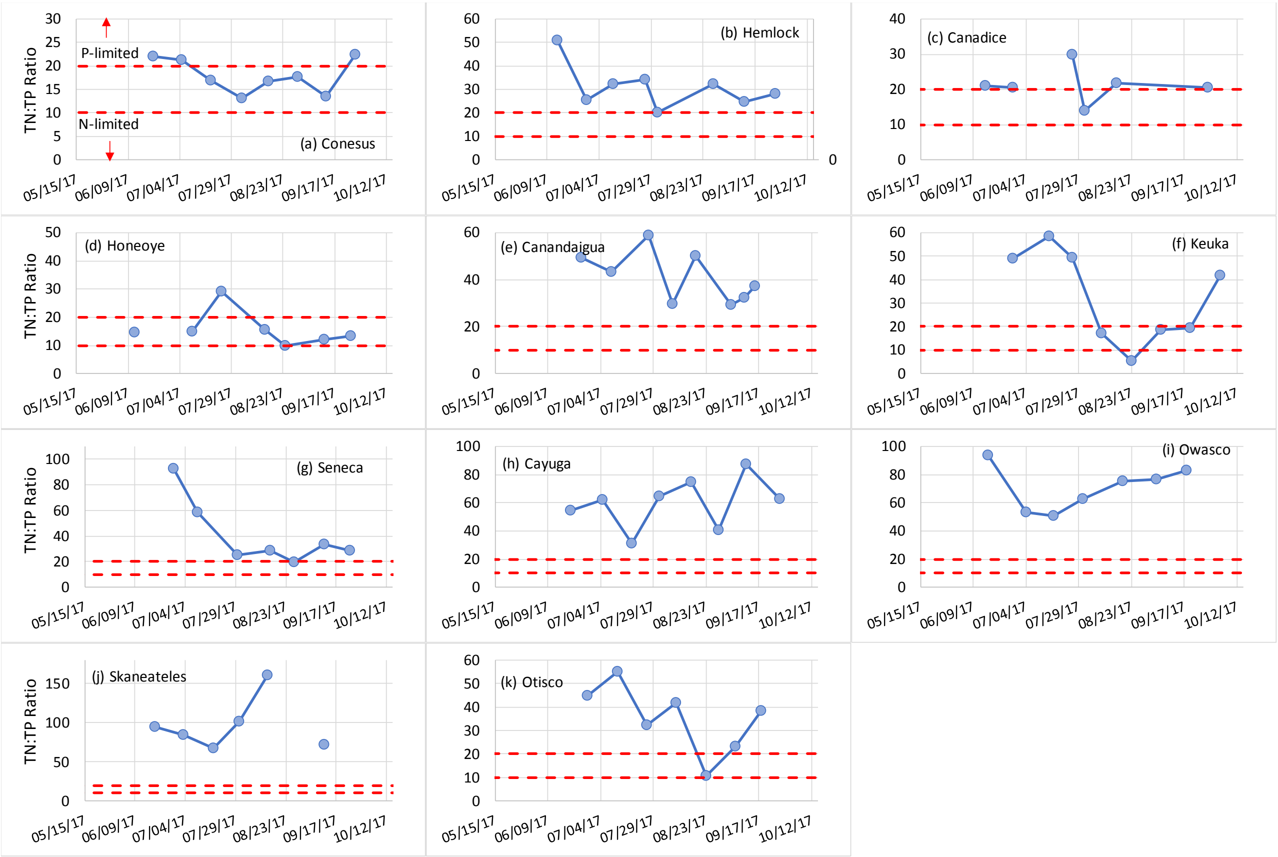


Figure 23. Patterns in N:P in the Finger Lakes in 2017 from the **northern** site locations. Note that Canadice has one mid-lake location. Please note the scale differences between the panels.

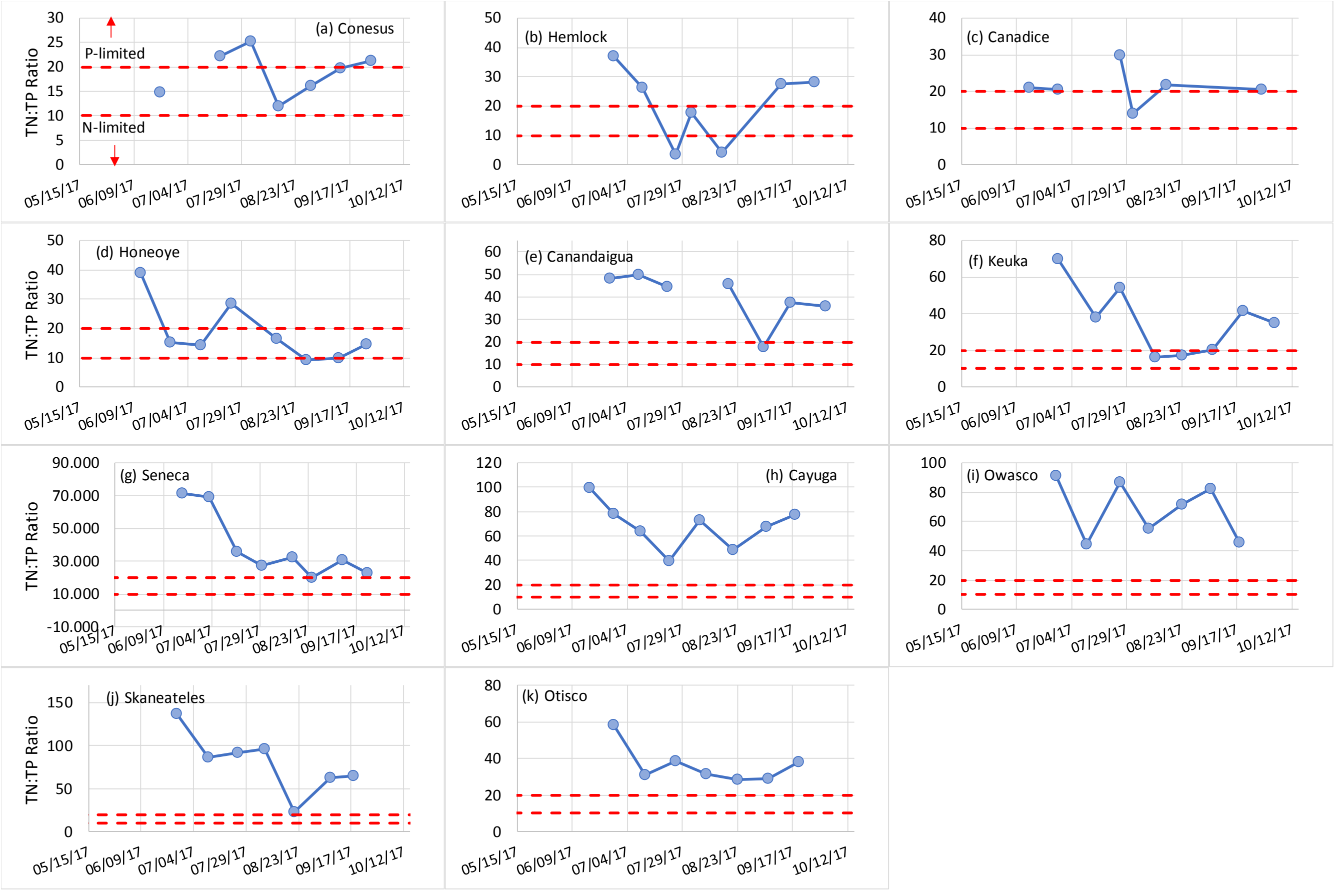


Figure 24. Patterns in N:P ratio in the Finger Lakes in 2017 from the **southern** site locations. Note that Canadice has one mid-lake location. Please note the scale differences between the panels.

Other Water Quality Parameters

Total Dissolved Phosphorus

Total dissolved phosphorus, or TDP, is measured as the component of phosphorus that passes through a 0.45µm filter, and includes both biologically available phosphorus and phosphorus that is not readily available for phytoplankton growth. TDP was first analyzed through CSLAP in several Finger Lakes in 2017. TDP and soluble reactive P (SRP – a form of P that is completely, readily available for algal growth) sampling through CSLAP will be piloted in all Finger Lakes in 2018. The relationship between TDP and Chl-a can be complicated by timing- the available portion of TDP may peak immediately before uptake by phytoplankton at a frequency out of sync with lake sampling- biological degradation of phosphorus, and other factors that influence lake productivity. This is even more pronounced for SRP, which is often not detectable in lake samples due to rapid uptake by primary producers.

In 2017, six Finger Lakes were analyzed for TDP. Overall, summer average TDP concentrations were low compared with TP values but varied between 0.003 mg/L (Skaneateles) and 0.008 mg/L (Conesus). Seneca, Cayuga, and Owasco Lakes had summer average TDP concentrations of 0.006, 0.007, and 0.006 mg/L, respectively. Keuka Lake also had low summer average TDP concentrations (0.004 mg/L).

Figure 25 shows the seasonal time series of TP and TDP observations for the northern sites on the six lakes. In Conesus Lake, the proportion of TP that was TDP ranged from 40% to 55%, but the relationship between the two forms was relatively stable. For Seneca (Figure 25c), Cayuga (Figure 25d), and Owasco Lakes (Figure 25e), the proportion of TP that was TDP varied substantially throughout the 2017 season ranging from as little as 12% (Cayuga on July 19) to as high as 80% (Owasco on Sep. 5). The variability in the relationship between TP and TDP varied in Keuka and Skaneateles Lake as well, but the overall concentrations of both P forms were lower in these two oligotrophic lakes than the other lakes.

In the case of Cayuga Lake (Figure 25d), the proportion of TP that was dissolved in June and early July was between 40-44% (TDP ranged from 0.009-0.1000 mg/L). In mid-July, TDP concentration was 0.004 mg/L and the fraction of TDP:TP dropped to 12% of TP. This drop in TDP corresponded with a mid-season algal bloom and highest individual Chl-a measurement on Cayuga Lake in 2017 on July 19th (14.3 µg/L; Figure 26d) and was likely due to algal uptake. After the bloom in July, the Chl-a dropped to ~ 10 µg/L and the TDP increased to 0.01 mg/L. In August, both the TDP and Chl-a values decreased and remained relatively stable, with TDP values remaining 0.006 mg/L and Chl-a values ranging between 5-6 into late September.

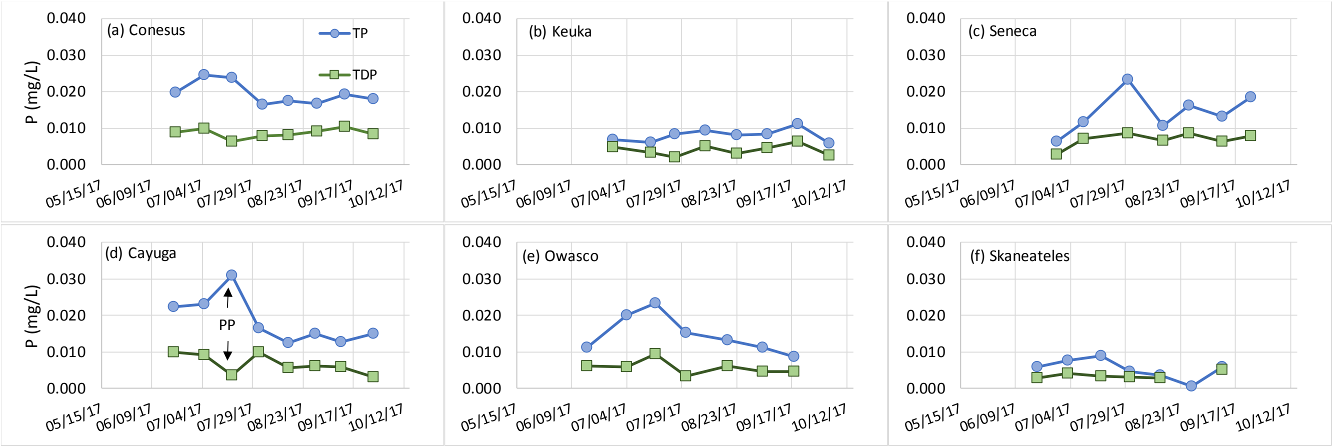


Figure 25. 2017-time series of TP (mg/L) in blue and TDP (mg/L) in green in six Finger Lakes' **northern** sites: (a) Conesus, (b) Keuka, (c) Seneca, (d) Cayuga, (e) Owasco, and (f) Skaneateles.

The TP, TDP, and Chl-a patterns for Owasco Lake (Figure 26e) were like those described for Cayuga. During the late July bloom on Owasco, Chl-a levels increased to 8.9 µg/L which was accompanied by a 3-fold reduction in TDP (from 0.009 to 0.003 mg/L). Post bloom, Chl-a concentrations fell to 3.6 µg/L and remained less than 5 µg/L for the remainder of the season. In the same time interval, TDP concentrations increased to ~ 0.005 mg/L and remained stable until October.

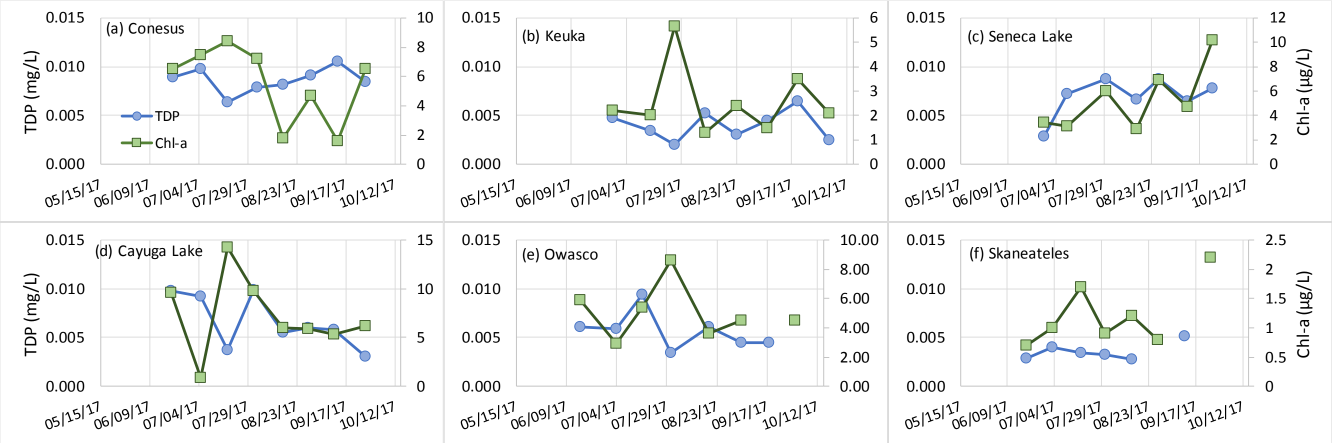


Figure 26. 2017-time series of TDP (mg/L) in blue and Chl-a (µg/L) in green in six Finger Lakes' **northern** sites: (a) Conesus, (b) Keuka, (c) Seneca, (d) Cayuga, (e) Owasco, and (f) Skaneateles.

Dissolved Forms of Nitrogen; TDN, NO_X, NH_3

As with TDP, dissolved nitrogen (TDN) can be comprised of both available and unavailable types. Other forms of nitrogen previously discussed also vary during the summer in response to biological uptake, conversion between various forms, and movement into and out of the lake. These forms were routinely monitored through CSLAP on the Finger Lakes in all surface samples, and in some of the lakes in deep water samples.

Summer average TDN concentrations in the six Finger Lakes varied between 0.173 (Keuka) and 1.007 mg/L (Cayuga). Owasco Lake had a summer average TDN concentration of 0.833 mg/L and Seneca Lake averaged 0.439 mg/L. Skaneateles and Conesus Lakes had concentrations of 0.323 and 0.255 mg/L, respectively.

As with the other water quality indicators, NO_X observations were also highly variable in 2017 NYS lakes. NO_X ranged from 0.007 mg/L to ~0.08 mg/L with an interquartile range of 0.008 to 0.041 mg/L. The median statewide NO_X concentration was 0.013 mg/L (mean = 0.069 mg/L; Figure 27a). NOx concentrations in the eleven Finger Lakes varied between 0.007 and 0.713 mg/L (Figure 27b). All the Finger Lakes to the west of Seneca Lake had average NOx concentrations less than half the State's median concentration (Figure 28; 0.013 mg/L), whereas Seneca Lake had a summer average concentrations slightly greater than state's mean value (0.017 mg/L). All of the eastern Finger Lakes had NOx concentrations more than double the NYS mean concentration, consistent with patterns in TN (Figure 14).

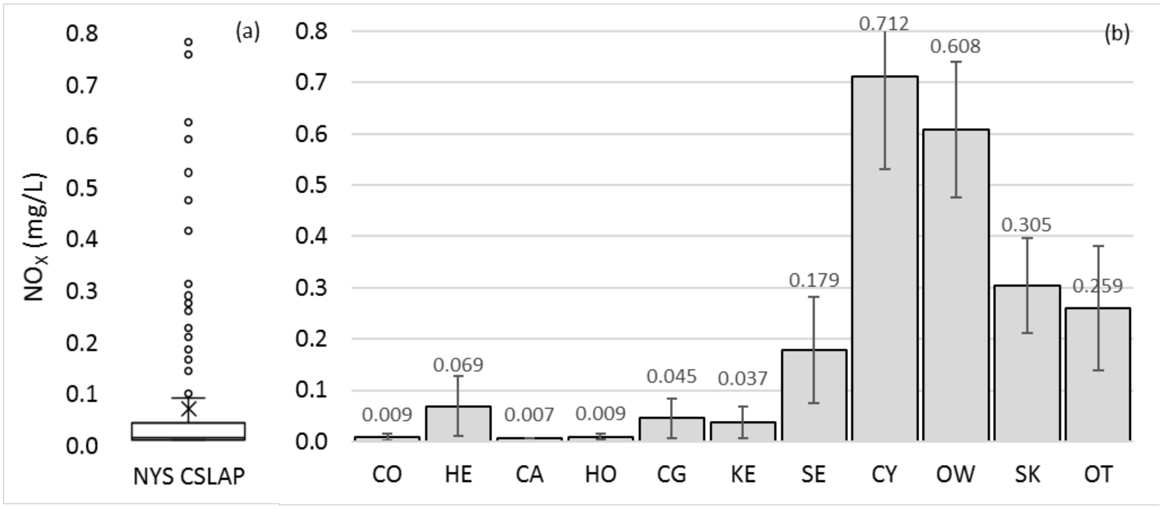


Figure 27. NO_X concentrations (mg/L) in 2017: (a) in NYS CSLAP lakes and (b) in the 11 Finger Lakes (from left to right proceeding from west to east).

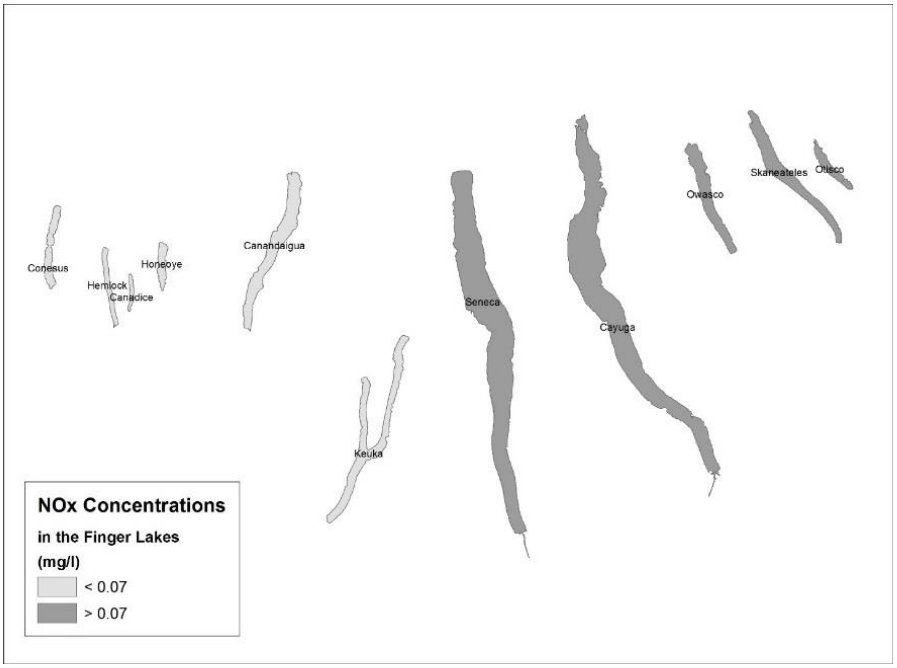


Figure 28. Oxidized Nitrogen (NOx) concentrations (mg/L) in the Finger Lakes in 2017.

The reduced (i.e. oxygen deficient) form of nitrogen, NH_3 (ammonia), was analyzed in CSLAP lakes in 2017. In NYS, the range in ammonia was 0.011 to 0.800 mg/L (Figure 29a). The mean statewide concentration was 0.058 mg/L (median = 0.042 mg/L).

Conesus, Hemlock, Canandaigua and Skaneateles had the lowest average NH_3 concentrations, all below 0.030 mg/L in 2017 (Figure 29b). The remaining lakes had NH_3 concentrations clustered around 0.050 mg/L, with Keuka lake having the highest average concentration at 0.057 mg/L. Unlike for NO_X and TN, there were no apparent geographic patterns in NH_3 in 2017.

The relative proportion of NH_3 and NO_X varied geographically in the Finger Lakes (Figure 30), consistent with the similar NH_3 concentration in all lakes and the much higher concentrations in NO_X observed in the east.

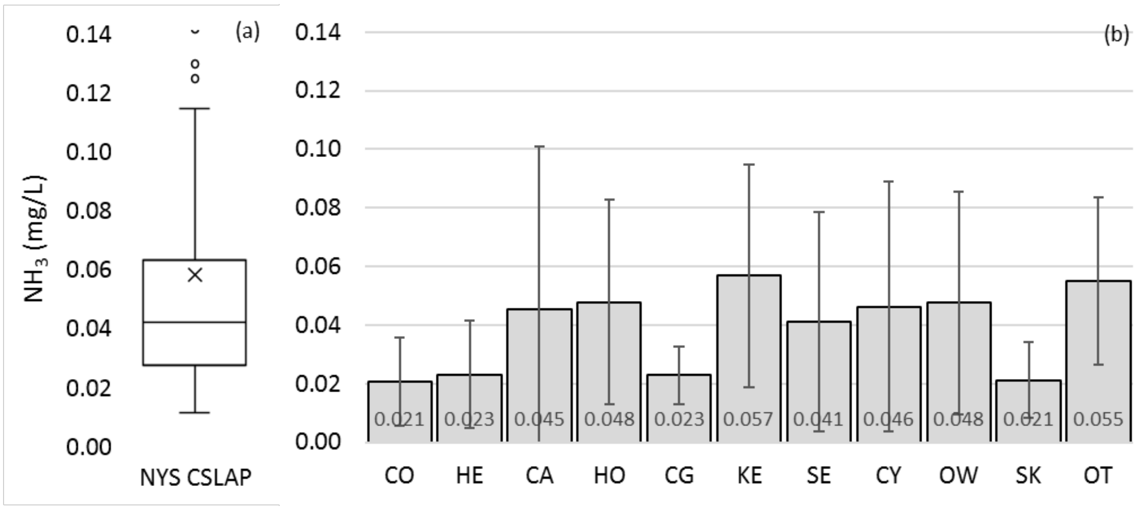


Figure 29. NH_3 concentrations (mg/L) in 2017: (a) in NYS CSLAP lakes and (b) in the 11 Finger Lakes (from left to right proceeding from west to east).

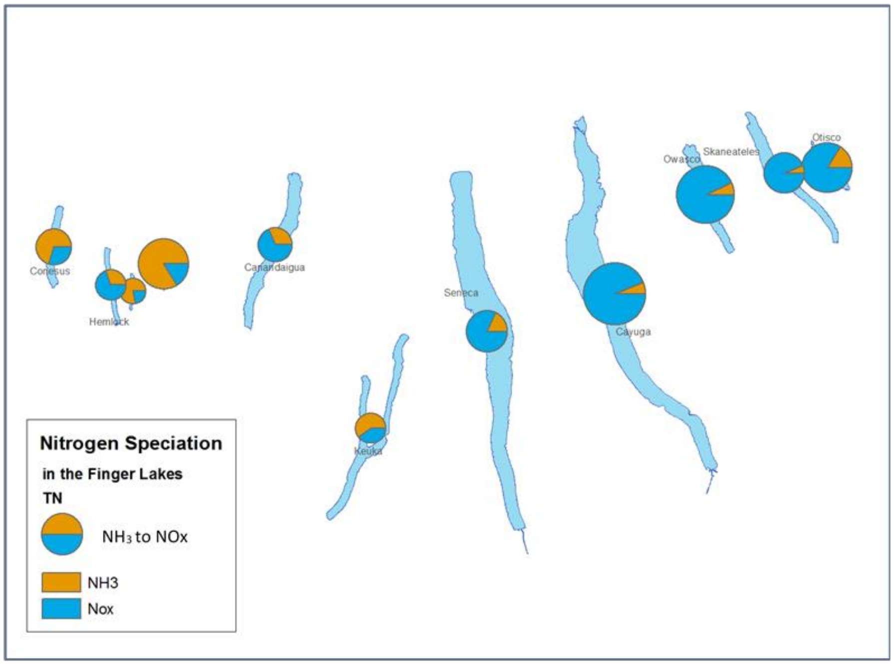


Figure 30. Proportions Charts of average summer oxidized (NO_X) to reduced (NH_3) nitrogen species in the surface waters of the Finger Lakes in 2017. Pie chart size is proportional to the total concentration of N species in each lake.

Geographical Distribution of Nitrogen

Lakes west of Seneca Lake (Keuka – Conesus) and the eastern lakes (Seneca – Otisco) had substantially different concentrations for both TN and NO_X. Figure 31a and b are distribution plots of all TN and NO_X observations partitioned into the two geographic groups of lakes: western and eastern. The TN observations from the western lakes (N = 90) were right-skewed with an average concentration of 0.33 mg/L (median = 0.31 mg/L). The interquartile range for these lakes was 0.22 to 0.40 mg/L. The eastern lakes had much higher TN concentrations, averaging 0.74 mg/L (median = 0.65 mg/L), more than 2-times the average concentration of the western lakes. The interquartile range of the eastern lakes was 0.48 to 0.99 mg/L. Note that the 75th percentile of the TN observations in western lakes was less than the 25th percentile of the eastern lakes. A Mann-Whitney U-test was performed on these groups and the difference in TN between the lakes was statistically significant ($p <<< 0.01$).

The Mann-Whitney U-test is a statistical test that determines if the differences between two groups of data are statistically significant (more than just random chance). The p-value represents the likelihood of making an incorrect conclusion with a p-value of 0.01 indicating a 1% chance of making an incorrect conclusion.

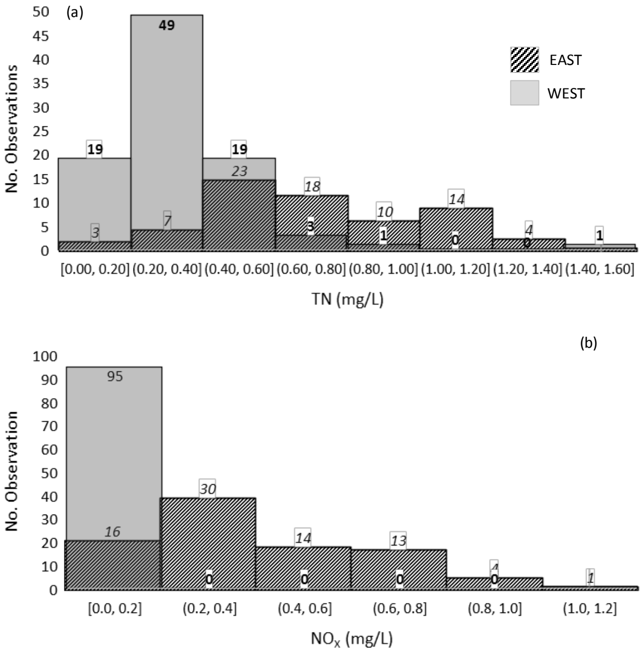


Figure 31. Distribution plots of: (a) TN (mg/L) and (b) NO_X (mg/L) observations for western lakes (light gray) and eastern lakes (dark gray cross-hatched).

The statistical differences between the western and eastern lakes were strong for NO_X as well (Figure 31b). All NO_X observations (N = 95) in the western lakes were less than 0.2 mg/L averaging 0.03 mg/L (median = 0.007 mg/L), while the observations from the eastern lakes ranged from 0.007 to 1.0 mg/L. The eastern lakes averaged 0.41 mg/L of NO_X (median = 0.40 mg/L), more than 10-times the average concentration of the western lakes. The 90th percentile of NO_X in the western lakes was less than the 25th percentile of the eastern lakes. A Mann-Whitney U-test was performed on these groups and the difference in TN between the lakes was statistically significant (p <<< 0.01). The same statistical treatment was applied to summer average TP and Chl-a observations portioned into the west and east groups, but geographic differences were not found for these parameters (see Figures 2 and 5).

The geographical pattern in TN in the Finger Lakes was preliminarily investigated to assess potential watershed factors that correlated with the distribution of TN in these lakes. Each lake's watershed boundary was determined in ArcGIS and the watershed area was overlaid with the National Land Cover Data (NLCD 2011) to determine the area (and overall percentage) of various land cover in each of the 11 watersheds. The number of septic systems used seasonally (summer) within 250 ft of a watercourse in each Finger Lake watershed were determined in ArcGIS (http://www.dec.ny.gov/docs/water_pdf/dowvision.pdf). Wastewater treatment plant effluent inputs as sources of TN were not considered for this analysis but likely contributes to TN levels in some watersheds.

While correlation can be insightful, it should not be confused with causation. **Correlation** implies there is a statistical relationship between two variables. **Causation** implies that one variable determines the response of another.

Summer average TN concentration was inversely related to percent of the watershed as forested in the Finger Lakes in 2017 (Figure 32a); that is a forested land percent decreased, lake TN concentrations increased. Percent land as pasture and cultivated crops (i.e., row crops such as corn and soybeans) was positively correlated with TN concentrations in the Finger Lakes (Figure 32b,c) explaining 46% and 88% of the variability in TN, respectively. The septic system analysis (Figure 32d) showed a positive correlation with TN concentration as well. Similar analyses will be expanded to other parameters in subsequent years as more data becomes available.

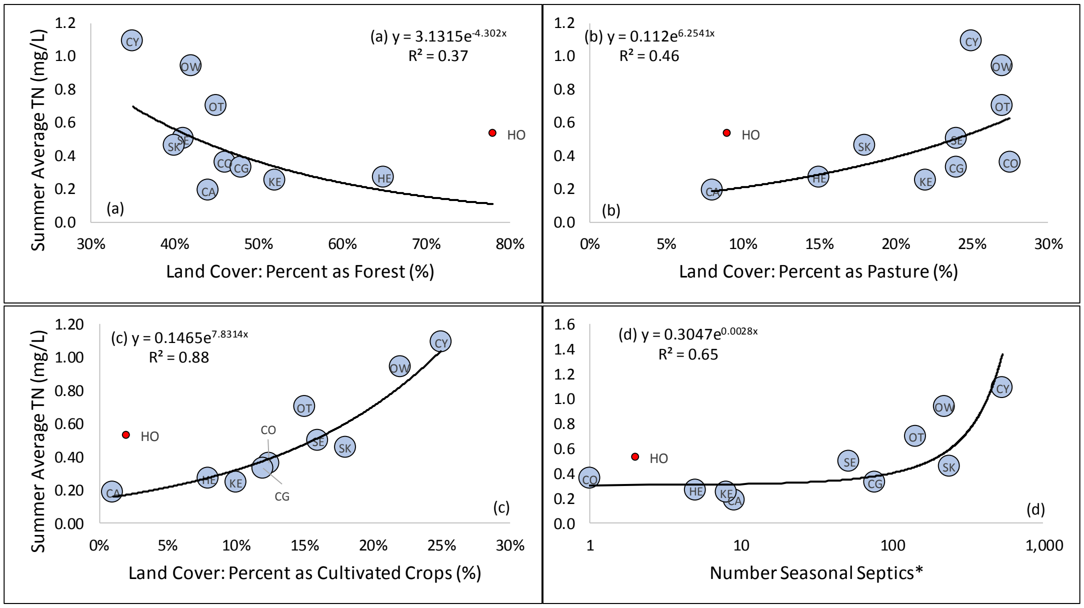


Figure 32. Relationship between TN (mg/L) and NCLD (2011) land use patterns in the Finger Lakes for: (a) percent forest, (b) percent pasture, (c) percent cultivated crops, and (d) number of seasonal septic systems (*within 250 ft of a watercourse). Note: the red symbol represents Honeoye lake and was excluded from the analysis. The Statistical best-fit relationship is shown (solid line).

Neither NO_X nor NH_3 were good predictors of Chl-a in 2017 NYS lakes (Figures 33 and 34). The relationships between NO_X-Chl-a and NH_3-Chl-a for the Finger Lakes were also weak but consistent with the respective relationships for all NYS lakes.

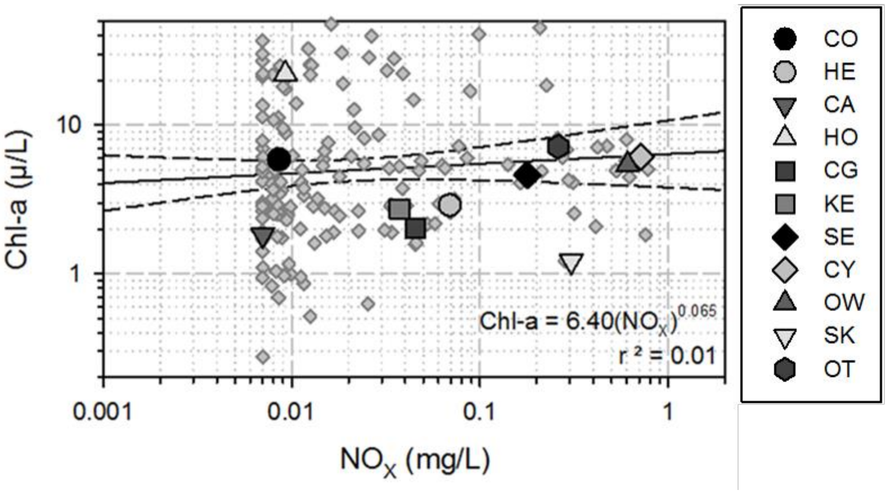


Figure 33. Relationship between summer average NO_X concentrations (mg/L) and Chl-a concentrations (µg/L) for the 2017 NYS CSLAP dataset (gray diamonds) with the Finger Lakes as symbols (legend). NYS statistical best-fit relationship (solid line) with 95% confidence intervals (dashed line).

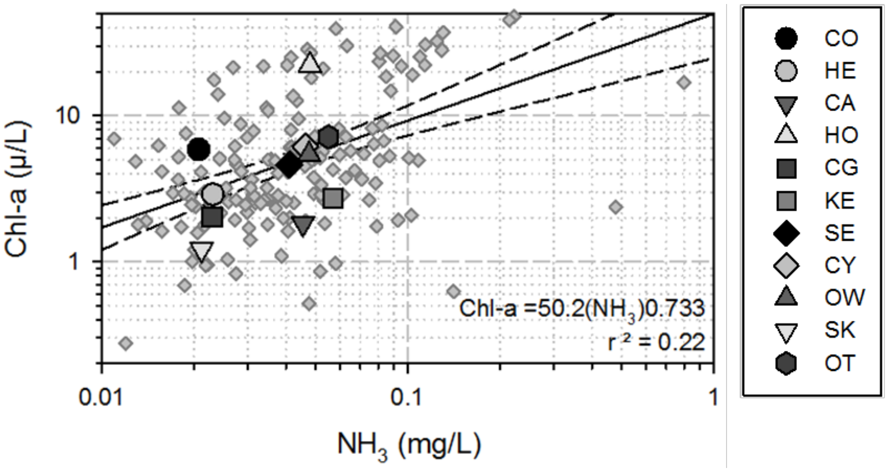


Figure 34. Relationship between summer average NH_3 concentrations (mg/L) and Chl-a concentrations (µg/L) for the 2017 NYS CSLAP dataset (gray diamonds) with the Finger Lakes as symbols (legend). NYS statistical best-fit relationship (solid line) with 95% confidence intervals (dashed line).

Calcium

Calcium is a trace metal closely associated with limestone geology and hardwater lakes. It can be considered a surrogate for alkalinity, or buffering capacity—lakes with high calcium levels are generally less susceptible to swings in pH associated with acid rain or other acidic inputs to lakes. Calcium is also a micronutrient required by freshwater mussels to grow their shells, and may be one of the most significant limiting factors to colonization by invasive mussels. Calcium is usually stable in most lake systems, so it is analyzed in only two samples per year through CSLAP. Calcium levels may vary spatially within a lake, due to inputs from concrete, limestone leaching, or tributary inputs. Open water calcium levels may be significantly lower than those measured near developed shorelines, thus underestimating the potential for "microhabitats" for dreissenid mussels.

In 2017, CSLAP lakes analyzed for calcium (Ca^{2+}, N=157) ranged from 1 to 54 mg/L (Figure 35a). The quartile range was 7.2 to 25.1 mg/L with a median statewide concentration of 16.1 mg/L (mean = 17.1 mg/L). Calcium concentrations in the eleven Finger Lakes were all higher than the statewide median except for Canadice Lake (Figure 35b). In fact, most had average concentrations above the NYS 75th percentile for Ca^{2+} (25.1 mg/L). Honeoye Lake had the second lowest calcium concentration, averaging 16.2 mg/L in 2017. Six Finger Lakes had Ca^{2+} concentrations between 20 and 30 mg/L: Hemlock (22.3), Keuka (23.2), Conesus (27.1), Skaneateles (28.4), Seneca (29.3), and Owasco (30). Otisco, Cayuga, and Canandaigua Lakes had calcium concentrations greater than 30 mg/L. All Finger Lakes had calcium concentrations high enough to support colonization and growth of invasive dreissenid mussels with estimates of critical growth thresholds ranging from as low as 10 mg/L (Bootsma and Lia 2013) to 20 mg/L (Hincks and Mackie 1997). Zebra mussels have been confirmed in each of the Finger Lakes except Canadice Lake (the Finger Lake with the lowest calcium levels), and quagga mussels have been found in Canandaigua, Cayuga, Keuka, Owasco, Seneca, and Skaneateles Lakes. Not coincidentally, these are the deepest of the Finger Lakes.

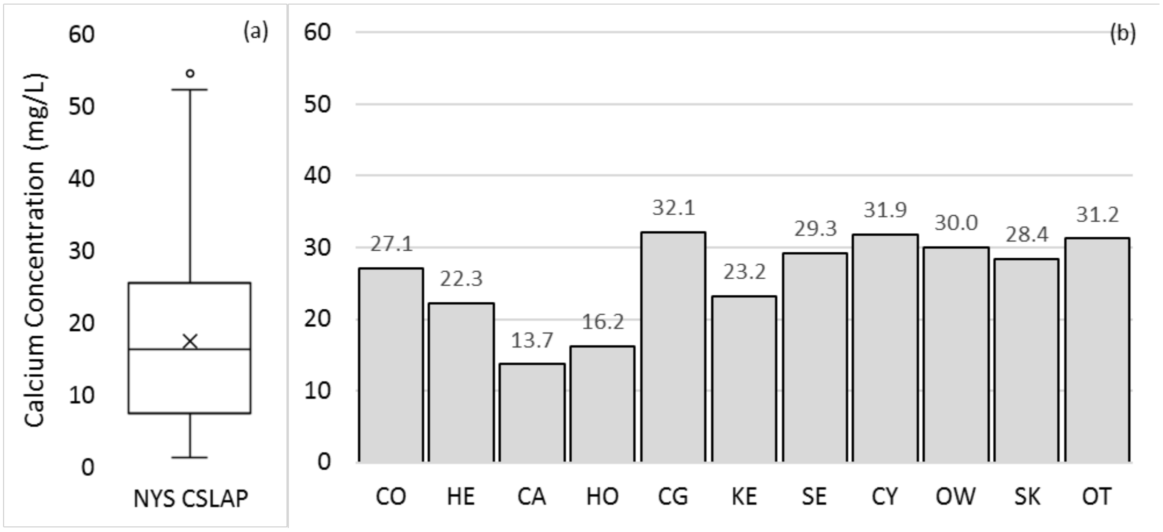


Figure 35. Ca^{2+} concentrations (mg/L) in 2017: (a) in NYS CSLAP lakes and (b) in the 11 Finger Lakes (from left to right proceeding from west to east).

The surface water calcium concentrations were substantially lower in 2017 compared with the NYSDEC Synoptic Survey in the late 1990s (Callinan 2001; Figure 36). Calcium concentrations decreased by more than 20% in all lakes, except Keuka (< 2% change). The exact mechanism for this is unclear but maybe due to uptake and sequestration into the shells of invasive zebra and quagga mussels.

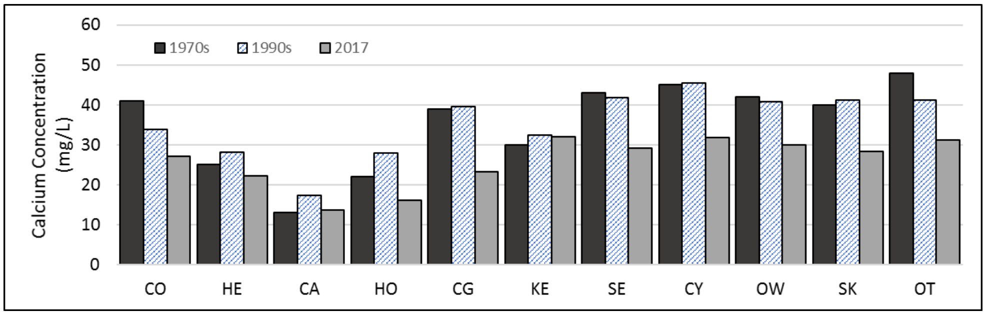


Figure 36. Current and historical (late-1990's) surface water calcium (mg/L) concentrations.

Chloride

Chloride concentrations vary in freshwater lakes due to natural conditions (e.g., geology and soils) but is also a constituent of road deicing agents (road salt), and can enter lakes from to stormwater runoff, intrusion from salt water, wastewater and industrial discharges. The NYS drinking water standard for chloride is 250 mg/L, a value rarely seen in NYS lakes. No standards exist for protection of aquatic life, although this is an active area of research in the northeastern United States.

Chloride (Cl^-) concentrations varied substantially between CSLAP lakes in 2017. Cl^- concentrations (N=160) ranged from 5 to 271 mg/L (Figure 37a; outlier was a non-drinking water lake). The interquartile range was 20.3 to 44.4 mg/L with a median statewide concentration of 31 mg/L (mean = 40 mg/L). Summer average Cl^- concentrations were also highly variable between the Finger Lakes in 2017 (Figure 37b). Skaneateles Lake had the lowest chloride concentration (21.8 mg/L), followed by Owasco Lake (24.7 mg/L). Three lakes had Cl^- between 30-40 mg/L: Honeoye (30. 1mg/L), Hemlock (34.0 mg/L), and Canadice (34.7 mg/L). Four lakes had chloride concentrations between 40 and 50 mg/L: Keuka (41.9 mg/L), Canandaigua (45.1 mg/L), Cayuga (46.4 mg/L), and Otisco (47.2 mg/L). Seneca Lake had the highest concentration of Cl^- in the Finger Lakes (112 mg/L), substantially more than the next highest (Conesus Lake; 51.8 mg/L).

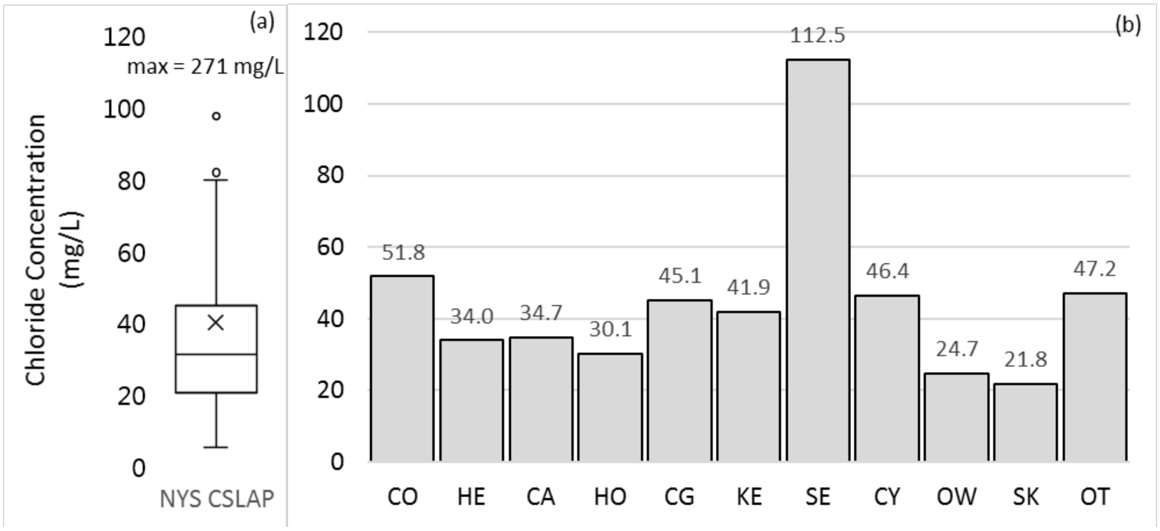


Figure 37. Cl^- concentrations (mg/L) in 2017: (a) in NYS CSLAP lakes and (b) in the 11 Finger Lakes (from left to right proceeding from west to east).

Cl^- concentrations have increased in nine of the eleven Finger Lakes since the 1970's and increased in ten of the eleven lakes since the late-1990's (Callinan 2001). Honeoye and Keuka chloride concentrations have increased approximately 150% since the late 1990's and seven other lakes have increased by more than 50% (Conesus, Hemlock, Canadice, Canandaigua, Owasco, Skaneateles, and Otisco). Seneca Lake Cl^- concentrations have decreased ~37% since the 1970's and 14% since the late-1990s due to reductions in industrial discharge and natural flushing and dilution (Figure 38). Cayuga Lake Cl^- has increased by 13% since Callinan's study (2001) but has decreased ~ 40% since compared with the values reported in Bloomfield (1978).

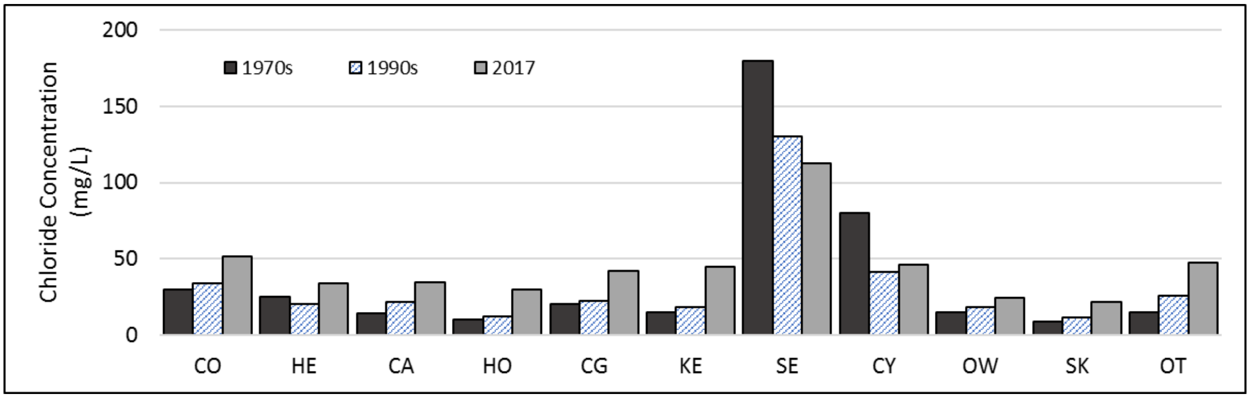


Figure 38. Current and historical (1970s [Bloomfield 1978] and late-1990's, [Callinan 2001]) surface water chloride (mg/L) concentrations.

pH, Specific Conductivity, and Color

pH is the abbreviation for "powers of hydrogen," and is a mathematical construct that characterizes the acidity of water on a simple scale. It is the negative logarithm of the hydrogen ion concentration, and is measured on a 14-point scale, from 0 (very highly acidic) to 14 (very highly basic) with 7 being neutral (equal concentrations of hydrogen and hydroxide ions). This means that a pH of 5 is 10-times more acidic than a pH of 6. It should be noted that the pH of uncontaminated rainwater is 5.6, due to the dissolution of carbon dioxide, a slightly acidic gaseous compound, although most lakes exhibit higher pH due to the buffering of runoff water (the primary source of water inputs) from limestone and soil particles.

The survival of most aquatic organisms is strongly dependent on pH. Many aquatic organisms do not properly function in water with pH below 6.5 or above 8.5, corresponding to NYS water quality standards. However, aquatic organisms in some lakes have adapted to naturally depressed pH- between 6 and 6.5- associated with dissolved organic matter ("brownness"), and periodic high pH readings may be managed by other aquatic organisms. Aquatic life impacts from low pH are well understood. However, high pH from strongly alkaline inputs or algae blooms (drawing CO_2 out of the water through respiration) can also stress aquatic life. This sensitivity of aquatic organisms to pH also reflects the sensitivity of some chemical compounds to pH—the sensitivity of fish to low pH water is a function of aluminum compounds, which can clog gills once certain forms of aluminum predominate at lower pH values. Other compounds, such as ammonia, are more highly toxic at elevated pH. pH is an important water quality indicator as it determines the level of acidity or alkalinity of a water body and is influences all important chemical transformations in a lake ecosystem. In most freshwater lakes, pH ranges from 6 to 9 (Wetzel 2001). Historical NYSDEC data, particularly collected as part of the Adirondack Lake Survey Corporation (ALSC) study of more than 1600 lakes in the mid- 1980s, demonstrated that the lowest pH- often well below a pH of 5, can be found in small, high elevation lakes, particularly in the Adirondacks. pH in many of these lakes has slowly increased in response to the federal Clean Air Act amendments from the 1990s which reduced the levels of NOx and SOx (oxidized sulfur compounds) in acidic rainfall.

The eleven Finger Lakes are classified as neutral to slightly alkaline lakes (Table 9), consistent with the hardwater, high calcium levels as discussed earlier. Summer average pH values ranged from 7.49 (Canadice) to 7.93 (Keuka). While no observations were less than 6.5 in 2017, three lakes had individual pH values exceed 8.5. During an algal bloom, pH can increase as algae or cyanobacteria remove inorganic carbon (an acid) from the water column, although some of these lakes naturally have elevated pH levels due to significant underlying limestone geology. For Honeoye and Otisco Lakes, exceedances of the NYS water quality standard coincided with increases in Chl-a suggesting an algal bloom as the mechanism for the high pH. The reason for the exceedance in Keuka Lake in late August is unknown but was not coincident with high Chl-a levels.

Table 9. Summary of pH (standard units) conditions in the Finger Lakes in 2017.

Lake	Summer Average pH	Minimum pH	Maximum pH	Notes
Conesus	7.78	6.92	8.47	
Hemlock	7.54	7.10	7.99	
Canadice	7.49	6.85	7.69	
Honeoye	7.65	6.52	**8.70**	Coincident with fall Chl-a peak
Canandaigua	7.71	7.03	8.44	
Keuka	7.93	7.11	**8.65**	Aug. 2017 – no apparent increase in Chl-a
Seneca	7.60	6.96	8.10	
Cayuga	7.63	7.14	8.34	
Owasco	7.60	7.09	8.23	
Skaneateles	7.56	6.83	8.08	
Otisco	7.83	7.14	**8.70**	Coincident with early spring Chl-a peak

Specific Conductance

Conductivity, reported as specific conductance (SC; and corrected to 25°C), measures the amount of current that can be carried through water (and "conduct" electricity). The current is carried by ions such as sodium, potassium, and calcium, so the conductivity is a rough measure of the concentrations of these ions. It is also closely related to water hardness and alkalinity (buffering capacity), and is usually a characteristic of the geology of the basin surrounding the lake. However, while conductivity itself is not a strong indicator of water quality, changes in conductivity can: (1) indicate changes in pollutant inputs to lakes, (2) change biological habitat, (3) change the way nutrients remain in the water. NYS and Finger Lake patterns in SC were similar to those discussed for Ca^{2+}.

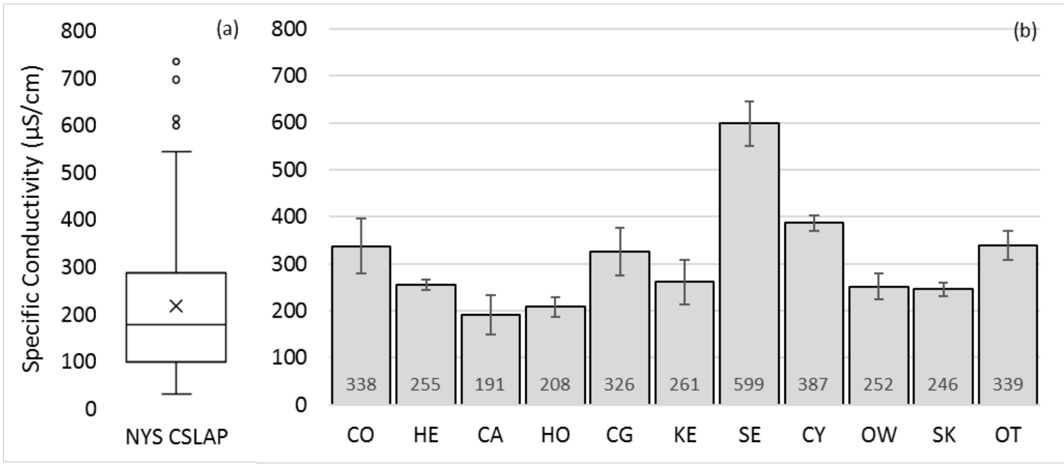


Figure 39. SC concentrations (µS/cm) in 2017: (a) in NYS CSLAP lakes and (b) in the 11 Finger Lakes (from left to right proceeding from west to east).

Color

Water color is a surrogate for dissolved organic carbon, and is manifested in a brownness in the water associated with weak organic (tannic and fluvic) acids. These weak acids are derived from organic soils, or heavily vegetated wetlands or littoral areas in the lake, and can result in slightly depressed pH. However, these are most apparent when elevated brownness limits the transparency of the water. When lakes have high levels of dissolved organic matter, they are often referred to as dystrophic, indicating that this condition influences the evaluation of trophic state (since phosphorus readings, chlorophyll-a values, and water clarity are not as balanced as in other clear water- or even greenish- lakes).

Strong water color is not strongly linked to public water quality perception, since dissolved color is often "natural" in many lakes. However, changes in color can indicate changes in runoff patterns to lakes, and may be considered a problem. High color can be negatively correlated to conductivity, since dissolved organic matter is often comprised of neutrally charged particles that do not carry current. The ALSC dataset demonstrated that tea-colored lakes are most common in the western Adirondacks, but they can be found in other regions.

NYS lakes are extremely variable with regards to color, ranging from 2 to 63 CU (Figure 40a). The interquartile range was 5.5 to 17.5 CU with a median statewide value of 9.1 CU (mean = 14 CU). The Finger Lakes have very low color compared to NYS lakes generally and lakes in the Adirondack region specifically (Figure 40b). Summer average color values were between 2 (Skaneateles) and 11 (Honeoye) CU, all less than the NYS average in 2017.

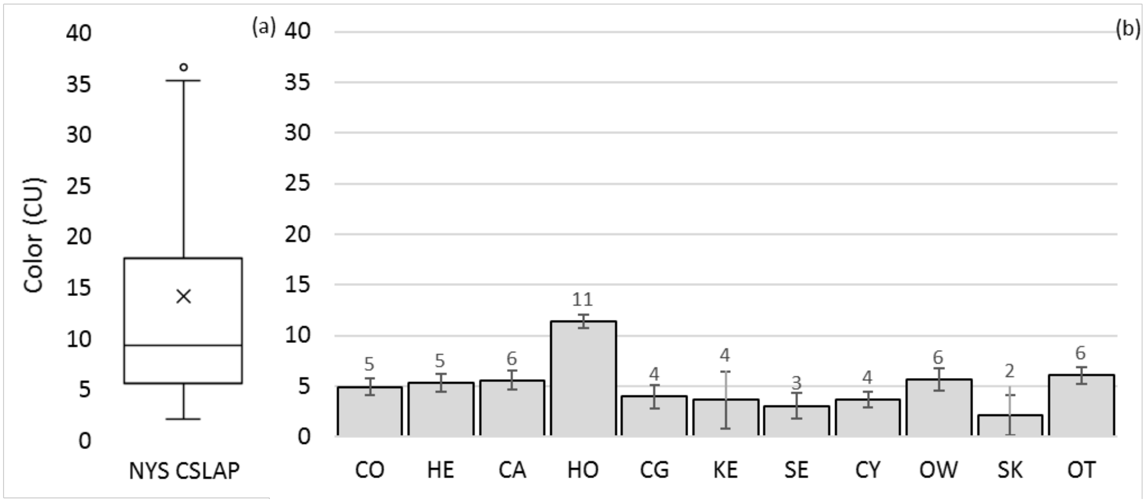


Figure 40. Color (CU) in 2017 (a) in NYS CSLAP lakes and (b) in the 11 Finger Lakes (from left to right proceeding from west to east).

In NYS lakes, color was moderately inversely related to clarity (as color increased, clarity decreased; Figure 41) with the relationship R^2 equal to 0.41. The color-SD relationship for the Finger Lakes was consistent with the pattern observed in NYS lakes. However, color was not a strong driver of clarity in the Finger Lakes in 2017, with color only explaining a small amount of the variability in Secchi depth for these lakes (relationship not shown). This is not unexpected given the relatively low color of the Finger Lakes.

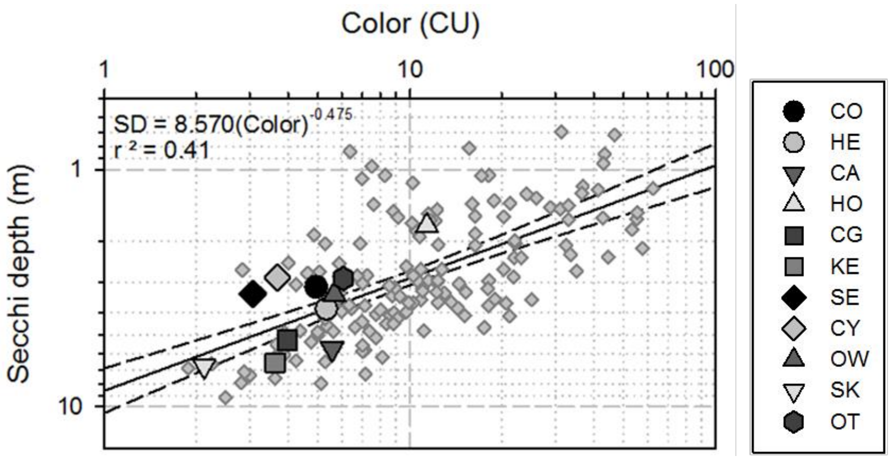


Figure 41. Relationship between summer average Color (CU) and Secchi disk depth (m) for the 2017 NYS CSLAP dataset (gray diamonds) with the Finger Lakes as symbols (legend). NYS statistical best-fit relationship (solid line) with 95% confidence intervals (dashed line).

Quality Control Performance

NYSDEC FLWH staff collected quality control (QC) samples with volunteer scientists in the summer of 2017 to assess the precision and representativeness of the CSLAP Finger Lakes program. The QC samples were essentially field duplicates of the surface (1.5m below surface) samples that were collected at the same time, with the same equipment, and processed in the same manner as the volunteer samples. Therefore, this sampling evaluated each component of the sampling related to sampler performance- sample collection, transfer of samples from collection to storage devices, sample processing (sample transfer to individual aliquot bottles and filtration), and sample transport to the laboratories. The Hub staff also used the opportunity to answer other limnological questions posed by CSLAP sampler and to learn more about each of the lakes. One site was chosen at each Finger Lake to conduct these quality control visits. After processing, the QC samples were relinquished to the analytical laboratory for analysis (Table 10).

Table 10. Summary of CSLAP and QC Samples Collected in the Finger Lakes in 2017.

Lake	Site	Date	Parameters
Conesus Lake	North (S1)	09/13/17	Site conditions, user perception, algal bloom conditions, temperature, Secchi depth, pH, SC, Chl-a, Color, NO_X, NH_3, TN, TP,
Hemlock Lake	North (S1)	08/01/17	
Canadice Lake	North (S1)	08/01/17	
Honeoye Lake	North (S1)	09/12/17	
Canandaigua Lake	South (S2)	08/07/17	
Keuka Lake	South (S2)	07/26/17	
Seneca Lake	South (S2)	08/15/17	
Cayuga Lake	North (S1)	07/19/17	
Owasco Lake	South (S2)	09/05/17	
Skaneateles Lake	South (S2)	08/21/17	
Otisco Lake	North (S1)	07/12/17	

The QC samples generally performed well with volunteer samples as determined by low absolute differences relative to the concentrations and examination of paired scatterplots (Figure 42). The one exception to the overall good performance of the paired samples was Honeoye Lake on September 12. It is not unusual for field duplicates from Honeoye Lake yield different results, due the heterogeneous conditions in this shallow, polymictic (mixing multiple times annually), productive lake (T. Gronwall, personal communication).

The volunteer and QC TP samples showed a very high level of performance (Figure 42a). The difference between all but two of the paired samples were within the Level of Quantification (LOQ) for TP (0.0038 mg/L) and most differences were less than or equal to the TP Level of Detection (LOD = 0.001 mg/L). The differences were also not unidirectional- that is, some volunteer samples had higher TP readings, and others had lower TP readings that the QC TP samples. This suggests that the majority of the differences fall within the normal range of variability associated with environmental sampling. The average TP concentration of NYSDEC QC samples (across 10 lakes) was 0.012 mg/L and the average TP concentration of the volunteer samples was 0.014 mg/L (excluding Honeoye Lake).

Chl-a measurements generally performed well (Figure 42b), although not as well as TP which is understandable given the level of processing involved with collection and filtering of the Chl-a samples for CSLAP. This also reflects an expected larger variability in indicators that are highly heterogeneous. Most of the differences between samples and QC samples were moderate (between 0.5-2 µg/L) but several of the samples had large discrepancies (greater than 2 µg/L). The average Chl-a concentration of QC samples (across 10 lakes) was 4.9 µg/L and the average Chl-a concentration of the volunteer samples was 4.2 mg/L (excluding Honeoye Lake).

Most paired Secchi depth measurements were within 0.2 m and all but one QC measurement was within 10% of the associated volunteer sample (Figure 42c). Through the course of the protocol evaluation it was determined that the volunteer was not determining the SD to the nearest 0.1 m as specified in the CSLAP protocol (which was corrected after the discovery of the error). The average Secchi depth of QC samples (across all 11 lakes) was 4.2 m and the average Secchi depth of the volunteer samples was 4.1 m.

There was a range in performance for other water quality indicators (Figure 42d-i). Most notably, SC and TN performed well, whereas, pH, Color, NO_X, and NH_3 had varying degrees of differences between the volunteer samples and QC samples. Potential sampler-related sources of differences between the volunteer sample and the NYSDEC samples include: (1) insufficient rinsing of the collapsible container in the field, (2) skin contact contamination of the sample water, (3) insufficient mixing of the sample prior to processing, (4) improper seating of the filter paper for Chl-a, and (5) contamination of the filtration apparatus. To help improve quality of the collected data the NYSDEC had retrained many of the volunteers and provided each volunteer group with an updated procedural checklist for field and on-shore processing. NYSDEC and NYSFOLA will also continue to evaluate sampling and training procedures to minimize opportunities for error and improve (the already high) confidence in results generated from this program. However, it is acknowledged that some of the differences represent environmental variability inherent in defining representative conditions with a single sample in space and time.

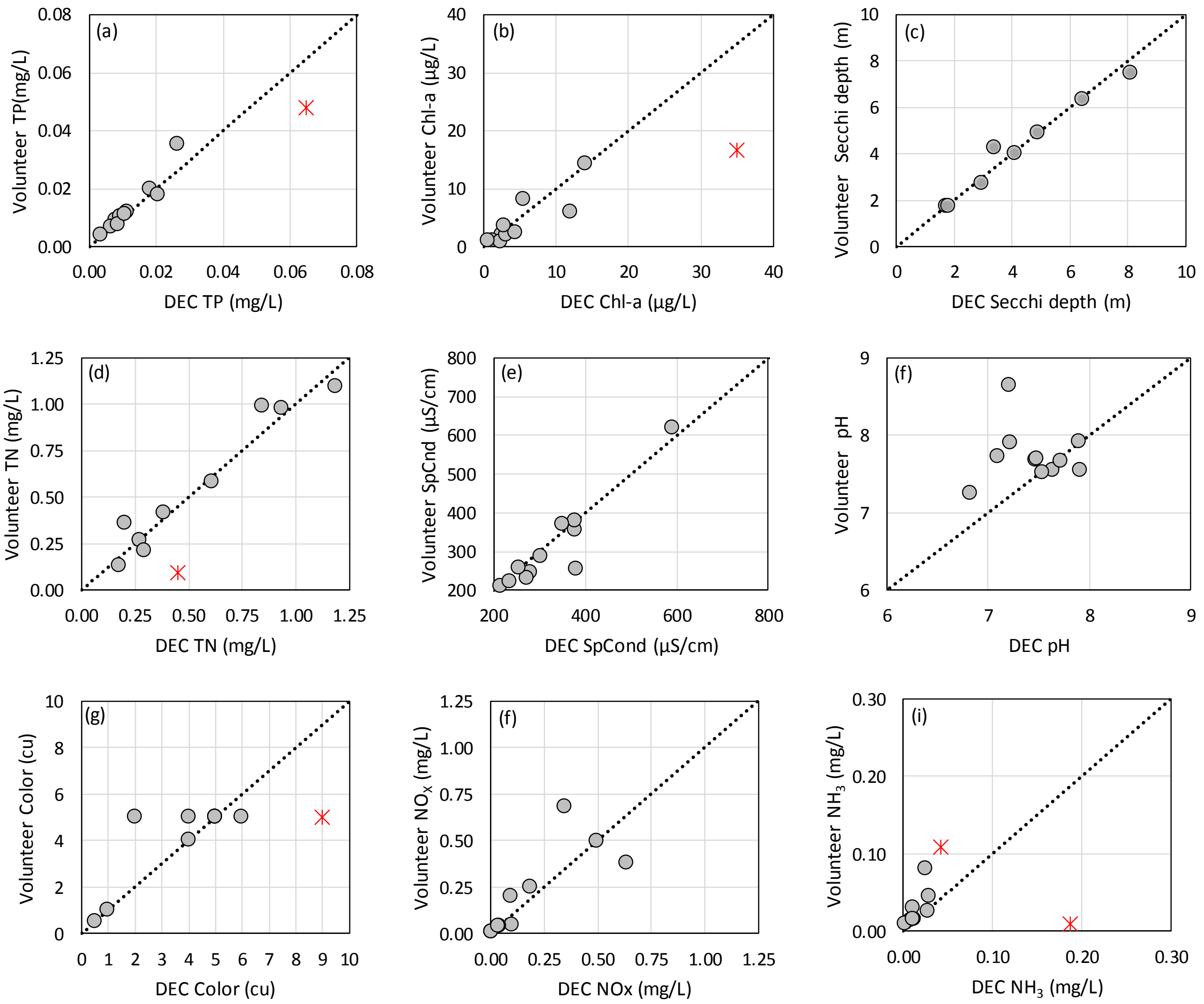


Figure 42. Comparison of NYSDEC staff QC samples with volunteer samples in the Finger Lakes in 2017. Circle points represent individual lake results, red Xs represent outliers and the dashed line represents the 1:1 line of equality.

Section 5. Evaluation of Trophic State

Context

Trophic state refers to the level of biomass production, specifically primary (biological) productivity for a given water body. Primary productivity, defined as the mass of algae produced within a water body, is usually estimated by measurements of Chl-a, the main photosynthetic pigment in algal cells. Trophic state is a common metric to assess the health of a waterbody and has explicitly defined criteria in NYS (Table 11 for: (1) Chl-a—a common surrogate of algal biomass, (2) TP—the primary nutrient that limits algae growth, and (3) SD—a measure of water clarity which is commonly influenced by primary production.

The term trophic refers to nutrition, and originates from the Greek word trophikos, or food. In an ecological setting, it refers to the relationships among different organisms in the food chain. In a lake setting, the food chain, or more properly the food web, is based on phytoplankton, or algae. The amount of algae produced in a lake dictates the production of other organisms; hence, algae are referred to as the primary producers. Lakes with large amounts of algae (and other plants and animals), excessive nutrients and reduced water clarity are called *eutrophic*, literally "well-nourished", and lakes with little biological production, few nutrients and very clear water are called *oligotrophic*, or "scant(ly) nourished." Lakes with intermediate nourishment are called *mesotrophic*. Eutrophication is the process in which lakes become overly nourished, whether naturally or induced by human activities (cultural eutrophication).

These definitions are not synonymous with water quality conditions or an indication of supporting lake use—many eutrophic lakes are highly productive sports fisheries, and many oligotrophic lakes do not support aquatic life, often due to high lake acidity imparted by acid rain. However, higher trophic states result in not only reduced water clarity and higher algae levels, but also declines in drinking water quality, reduced oxygen in the lakes lower waters, greater susceptibility to nuisance and harmful algal blooms, and dominance by invasive aquatic plants. In many waterbodies, the trophic status dictates both the support of designated uses and serves as a surrogate for water quality conditions. For the Finger Lakes, supporting drinking water use for thousands of residents and swimming opportunities for countless visitors, lake management objectives will largely point to attaining or maintaining a lower trophic status.

Table 11. NYS Trophic State Criteria

Trophic State	Meaning	TP (mg/L)	Chl-a (µg/L)	SD (m)
Oligotrophic	Poorly nourished, low algal production	< 0.010	< 2	> 5
Mesotrophic		0.010 – 0.020	2 – 8	2 – 5
Eutrophic	Well nourished, high levels of algal production	> 0.020	> 8	< 2

Dr. Robert Carlson from Kent State University (Carlson 1977) established empirical relationships between TP, Chl-a, SD and used the resulting equations to define the Trophic State Index (TSI) for a set of mid-western US lakes in the mid-1970s. This allows each of these indicators to be used to define the trophic state of any lake, and to compare these indicators in a way that might provide some additional insights about the algal dynamics in lakes.

- ➢ Eq.1: $TSI(Chla) = 9.81 - LN(Chla) + 30.6; where\ Chla = chlorophylla\ concentration\ in\ \mu g/L$
- ➢ Eq.2: $TSI(TP) = 14.42 * LN(TP) + 4.15; where\ TP = TP\ concentration\ in\ \mu g/L$
- ➢ Eq.3: $TSI(SD) = 60 - 14.41 * LN(SD); where\ SD = Secchi\ clarity\ depth\ in\ meters$

Carlson developed these trophic state indices on a logarithmic scale from 0 (extremely unproductive) to 100 (extremely productive) so that every increase of 10 TSI units indicates a doubling of algal biomass. TSI values in a range between 40 and 50 correspond to mesotrophic conditions for each of these trophic indicators, with values higher than 50 corresponding to eutrophic conditions, and TSI values lower than 40 attributed to oligotrophic conditions. These original TSI values have been adjusted for NYS to align with the boundaries of mesotrophy (NYSDEC 2017; Table 12). All subsequent discussions of trophic state will use the NYS criteria.

Table 12. Carlson and NYS Trophic State Criteria

Trophic State	**Oligotrophic**		**Mesotrophic**		**Eutrophic**	
	Carlson (1977)	**NYS**	Carlson (1977)	**NYS**	Carlson (1977)	**NYS**
Total Phosphorus	<40	**<37**	40-50	**37-47**	>50	**>47**
Chlorophyll-a	<40	**<37**	40-50	**37-51**	>50	**>51**
Secchi Disc Clarity	<40	**<37**	40-50	**37-50**	>50	**>50**

The Finger Lakes varied significantly in 2017, ranging from oligotrophic in Skaneateles and Keuka Lakes to eutrophic conditions in Honeoye Lake. The remainder of the Finger Lakes are currently classified as mesotrophic, although Otisco, Cayuga, and Conesus were in the range of upper mesotrophy, corresponding to a TSI greater than 45. Differences between TSI(Chl-a), TSI(TP) and TSI(SD) were generally small within each lake (Table 13). Figure 43 shows the distribution of trophic state in the Finger Lakes in 2017 as based on TSI(Chl-a).

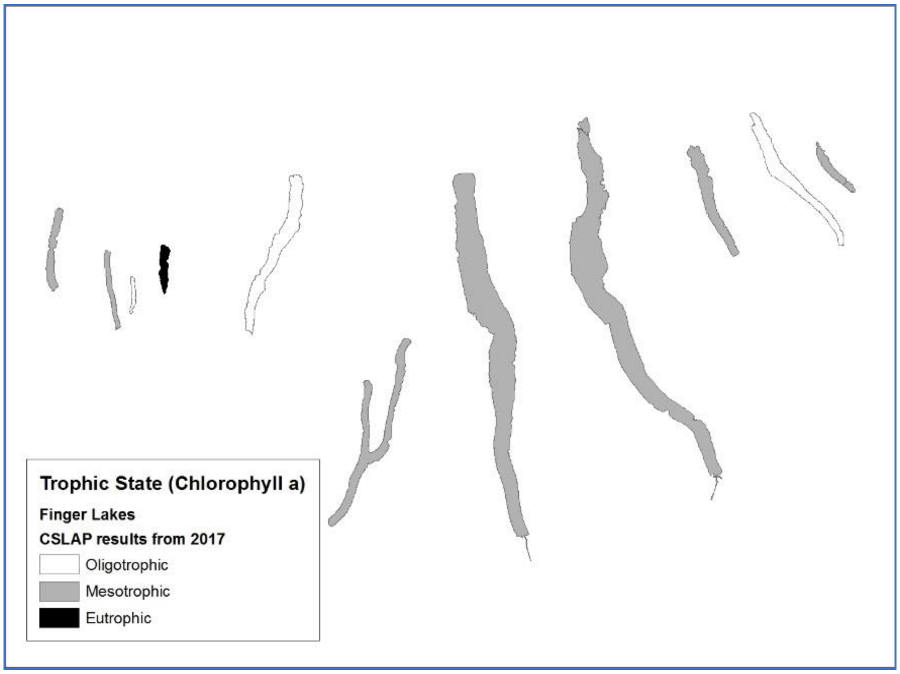


Figure 43. Geographic distribution of Chl-a trophic state assessments in the Finger Lakes in 2017.

Carlson TSI values derived from trophic indicator measurements from the 1970s (Bloomfield 1978), the late 1990s (Callinan 2001), the mid-2000s (Callinan 2013), and 2017 CSLAP results are presented in Table 13. Earlier researchers noted substantial interannual variability for individual lakes within each specified period. For example, Callinan noted that even for oligotrophic Skaneateles Lake (TSI(Chl-a) of 37 during the late 1990s), individual summer TSI(Chl-a) values ranged from 32-40 during that timeframe due to year-to-year differences in algal growth, grazing by zooplankton, and timing of sample collection. In some lakes, Chl-a can also vary in response to active management of algae and water clarity with the use of algaecides.

Table 13. Carlson TSI for the Eleven Finger Lakes from the 1970, late 1990s, and 2017 CSLAP.

	TSI(SD)				**TSI(TP)**				**TSI(Chl-a)**			
Lake	**1970s**	**late 1990s**	**mid-2000s**	**2017**	**1970s**	**late 1990s**	**mid-2000s**	**2017**	**1970s**	**late 1990s**	**mid-2000s**	**2017**
Otisco	36	49	42	**45**	37	41	44	**48**	36	47	49	**50**
Skaneateles	35	31	30	**33**	30	24	25	**29**	37	27	27	**32**
Owasco	44	45	38	**43**	42	40	41	**42**	47	44	48	**47**
Cayuga	42	40	40	**45**	46	37	44	**46**	45	43	47	**49**
Seneca	45	33	33	**43**	44	37	36	**43**	52	39	41	**45**
Keuka	38	34	34	**33**	42	34	29	**34**	46	41	40	**41**
Canandaigua	39	30	32	**36**	39	30	34	**34**	37	31	39	**37**
Honeoye	44	50	56	**52**	42	50	52	**56**	62	51	62	**61**
Canadice	36	35	40	**35**	38	35	39	**36**	37	40	40	**37**
Hemlock	43	37	39	**40**	37	37	38	**38**	48	41	47	**41**
Conesus	37	42	44	**44**	48	49	52	**47**	27	51	50	**48**

Modest differences were observed between the three TSI scores within lakes. As an example, in Canadice Lake, all three TSI scores were between 37-35 (Table 13). However slight, some TSI differences were observed across the Finger Lakes. For all lakes, TSI(Chl-a) was greater than TSI(SD) and TSI(TP). As an example, Honeoye Lake TSI(SD) was 52, TSI(TP) was 56 but TSI(Chl-a) was 61. Differences between a lake's TSI scores can be insightful in determining relative degrees of nutrient and/or light limitation (Carlson 1977, Wetzel 2001).

Figure 44 is an adaptation of Figure 13-16 in Wetzel (2001), depicting the relationship between the three TSI scores. All lakes had TSI(Chl-a) greater than TSI(TP), suggesting that these lakes are phosphorus limited, consistent with results for TP, TN, N:P, and Chl-a presented previously (Section 4). 2017 lake scores for TSI(Chl-a) minus TSI(SD) were positive in all lakes (except Skaneateles) which indicates that transparency in these lakes is greater than predicted by the TSI(Chl-a) score alone. This pattern is caused by light attenuation (reduction) being dominated by large particles, cyanobacterial colonies, or the removal of small inorganic particles from the water column from zooplankton grazing (Wetzel 2001) or perhaps dreissenid mussel filter feeding.

The Finger Lakes were all in the upper-right quadrant of Figure 44, indicating a similarity in the eleven Finger Lakes. Conversely, the 2017 NYS CSLAP data set were scattered throughout the matrix which shows that a diverse number of factors determine productivity and clarity in NYS, consistent with previous NYS research.

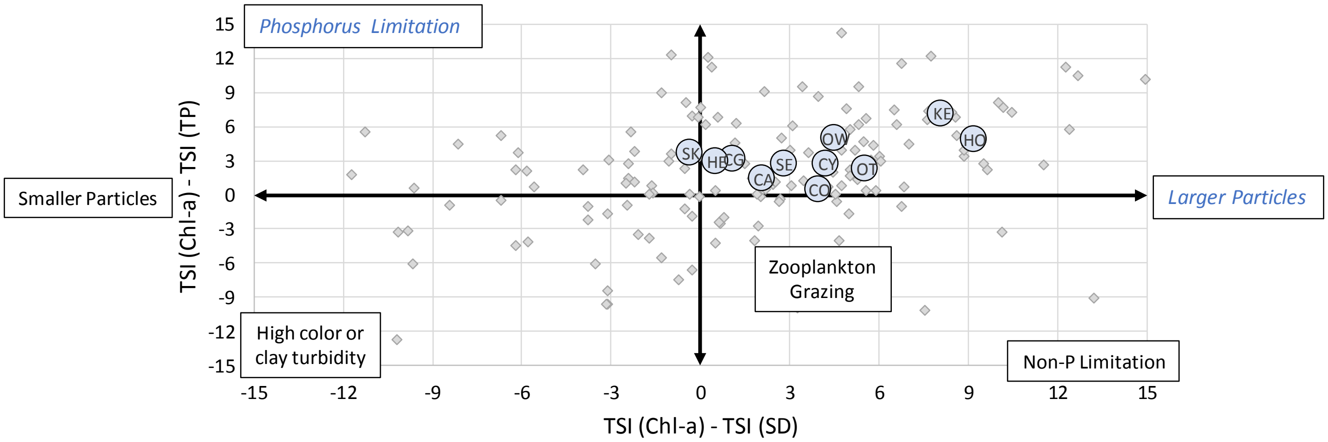


Figure 44. Matrix plot between [TSI(Chl-a) minus TSI(SD)] versus [TSI(Chl-a) minus TSI(TP)] for all NYS lakes (gray diamonds) and the Finger Lakes (circles). Possible mechanisms causing lake orientation on the matrix is provided.

Section 6: Harmful Algal Blooms

Background

Algal blooms have been observed and reported on NYS lakes for at least several centuries. Blooms comprised of cyanobacteria, have been around for at least that time period, though most likely longer. Cyanobacteria are among the oldest organisms on earth, dating back several billion years. In recent years, however, these blooms have attracted significant interest around the world and in New York due to very high-profile blooms in the Great Lakes, all Finger Lakes, and hundreds of smaller lakes and ponds throughout NYS. Blooms have also been identified in other waterbodies in the Finger Lakes region, including some flowing waters.

NYSDEC and NYSDOH began the process of developing a procedure to formally document cyanobacteria blooms through a Centers for Disease Control (CDC) grant in 2008. NYSDEC established a HABs Program which includes surveillance and many monitoring partnerships, particularly through CSLAP and SUNY College of Environmental Science and Forestry (SUNY ESF) beginning in the early 2010s. This is comprised of a robust CSLAP open water monitoring program, and collections of suspected shoreline bloom samples observed by or reported by volunteers on all CSLAP lakes. Additionally, NYSDEC worked collaboratively to develop shoreline surveillance and monitoring networks on Honeoye Lake in 2013, Owasco Lake in 2014, Seneca Lake in 2015, and Otisco Lake in 2017. Additional shoreline networks will be established on Skaneateles, Cayuga, and Canandaigua Lakes in 2018.

What is a HAB?

Harmful algae blooms are dense concentrations of cyanobacteria (blue green algae) that can produce liver, nerve and dermal toxins, or other harmful substances. Exposure to blooms can result in health impacts through skin exposure, ingestion or inhalation.

NYSDEC established a relationship with SUNY ESF to analyze HABs samples. SUNY ESF generates reports based on the analytical results, which are interpreted by NYSDEC HABs Program staff in Albany, and then sent to lake stakeholders including water purveyors, regional NYSDEC staff, state and local DOHs, lake associations and other partners. The NYSDEC HABs Program has additional partnerships with other laboratories for analyzing HABs parameters, including Stony Brook University, Upstate Freshwater Institute, and the Finger Lakes Institute.

What is a Bloom?

Bloom reports can take the form of visual observations, collected samples with associated analytical results, digital pictures, beach operational decisions, and other data or information. Reports come into the NYSDEC, with most reports coming in mid- to late-week in late summer when the largest number of lakes are surveyed, public observations and lake use peaks, and when cyanobacteria blooms are most likely to occur. Most bloom reports fit the following two categories:

- **Visual –** cyanobacteria blooms usually look like spilled paint, pea soup, or green streaks on the water surface, or large concentrations of green dots on or within the water column. They can also exhibit heavy green discoloration throughout the water column. In many cases, bloom reports don't fit cleanly in one of these categories, but will share many visual characteristics. Beach operators may make closure decisions based on visual observations of blooms.
- **Sampling results** – when a bloom is suspected, samples are often collected and submitted to one of the laboratories cited above. Upon receipt at the laboratory, samples are run through a fluoroprobe (bbe Moldanke) and analyzed for total and fractional Chl-a, including measurements of cyanobacteria (blue

green algae or BG Chl-a) content. The chlorophyll pigment is not extracted from the cells, so this measurement is not as accurate as the extracted chlorophyll measurement (Table 1). However, fluoroprobe measurements can be generated quickly, require little analyst time or cost (once the equipment is purchased), and unlike extracted samples, can distinguish between potentially harmful blooms (comprised of cyanobacteria) and blooms of other algae. Samples with total Chl-a levels above 10 µg/l are inspected (qualitatively) microscopically for the dominant algal taxa with cyanobacteria generally reported to genus. All samples, including those with little evidence of blooms, are run for cyanobacteria toxins.

Bloom reports are characterized by the NYSDEC HABs Program using the following categories, recognizing that the status of each report can change based on additional information:

- **Not a Bloom** represents a low likelihood that a cyanobacteria bloom is present. The following criteria must be met: (1) in the absence of a sample, visual evidence is not consistent with a cyanobacteria bloom; samples show (2) BG Chl-a < 25 µg/L; (3) a microscopic scan without dominance by cyanobacteria and bloom-like densities; or (4) only in absence of the previous criteria being met: microcystin ≤ 4 µg/L.

- **Suspicious Bloom** fulfills either of the following criteria: (1) characterized by NYSDEC HABs Program or NYSDOH staff from surveillance reports or digital photographs from visual evidence of a bloom is likely to be cyanobacteria. In absence of digital photographs, a descriptive field report from professional staff or trained volunteer may indicate suspicious conditions; (2) staff from NYSDOH, NYSDEC or NYSOPRHP close a regulated swimming beach due to the visual observation of a bloom.

- **Confirmed Bloom** fulfills at least one of the following criteria: (1) BG Chl-a levels ≥ 25 µg/L (as measured with a fluoroprobe); (2) microscopic confirmation that majority of sample is cyanobacteria and present in bloom-like densities; or (3) only in absence of the previous criteria being met: microcystin ≥ 4 µg/L but less than high toxin thresholds and accompanied by ancillary visual evidence of the presence or recent history of a bloom. These BG Chl-a thresholds were developed from the NYSDEC interpretation of the World Health Organization (WHO) thresholds between moderate and high probability of acute health effects, as described in detail in the NYSDEC program guide (http://www.dec.ny.gov/docs/water_pdf/habsprogramguide.pdf).

- **Confirmed with High Toxins Bloom** are Confirmed Blooms with laboratory analytical results meeting one of the following criteria: (1) total microcystin ≥ 20 µg/L from shoreline bloom samples; (2) total microcystin ≥ 10 µg/L from open water bloom samples; or (3) known risk of exposure to anatoxin or another cyanotoxins, based on evaluation of these cyanotoxin testing results and consultation between NYSDEC HABs Program or NYSDOH staff.

Bloom status designations form the basis of the NYSDEC HAB Notification program, in which Suspicious, Confirmed, and Confirmed with High Toxin Blooms are cited in notification emails sent to samplers, and NYSDEC and NYSDOH staff in Albany, and the county agencies corresponding to the bloom location. These emails are generally sent within 24 hours of receipt of a bloom report, usually within the same day, and include bloom descriptive information (including provided images) and data for regional staff to assess needs for site visits or additional actions. In addition, the NYSDEC HAB web page is updated every Friday afternoon with the most recent bloom status for these waterbodies. The cited information includes name and location of the waterbody (in tabular form and on a NYS map), status date, extent of the bloom, the source of information, and any change in status since the last weekly web update.

It should be assumed that harmful algal blooms may occur on any waterbody, particularly those identified as mesotrophic or eutrophic. Any lake resident, visitor, or recreational user should follow the advice provided by the NYSDEC and the NYSDOH:

- Avoid contact with any surface scums or heavily discolored water,
- If exposed to the bloom, rinse with clean water, and seek medical assistance if experiencing nausea, vomiting, rashes, or difficulty breathing,
- Report all health symptoms and exposure information to the local health department, and
- Report bloom information to the NYSDEC at HABsInfo@dec.ny.gov

Statewide Distribution of HABs

The distribution of HABs is provided in Figure 45 showing the 2012-17 cumulative summary of Suspicious, Confirmed and Confirmed with High Toxin Blooms locations throughout NYS. This map shows the "peak" occurrence in each waterbody- Confirmed with High Toxin Blooms supersede Confirmed Blooms, which supersede Suspicious Blooms. The small black dots on Figure 45 indicate sampled waterbodies with no bloom reports. It should be noted that some waterbodies bloom in some years, but not others.

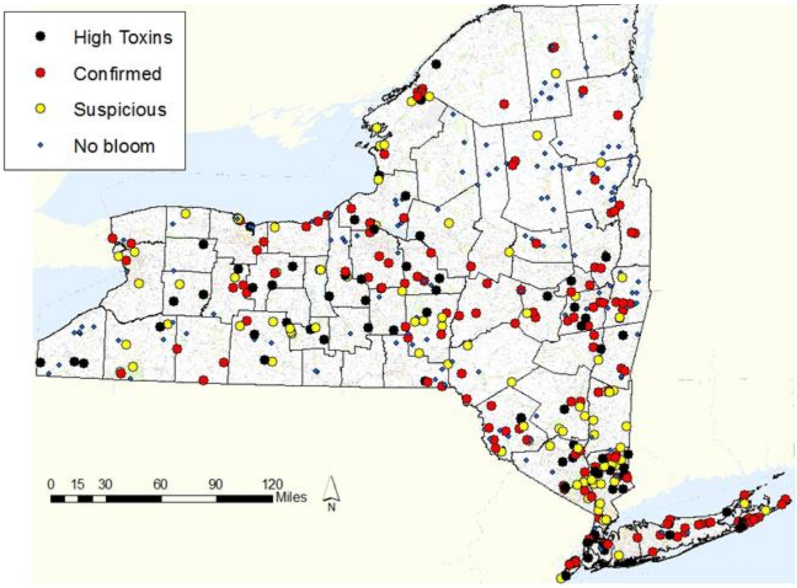


Figure 45. HABs Distribution 2012-2017

Table 14 shows the number of NYS waterbodies that have had documented Suspicious, Confirmed and Confirmed with High Toxin Blooms in each year since 2012. A part of the increase in blooms can be attributed to increasing numbers of surveillance and monitoring partnerships and greater public attention to the issue, although the actual occurrence of HABs may have increased, particularly in the Finger Lakes and other large waterbodies. The 2012-17 cumulative row on the bottom of the table reflects the total number of waterbodies in each category; many individual lakes were cited each year but are only counted once in the cumulative totals.

Table 14. HABs Reports in NYS Lakes

Year	Suspicious	Confirmed	High Toxins	Total
2012	20	29	9	58
2013	17	37	22	76
2014	19	51	23	93
2015	40	62	35	137
2016	41	95	38	174
2017	48	85	35	168
2012-17	75	133	77	340

Finger Lakes Distribution of HABs

The table inset to the right, shows the Suspicious, Confirmed, and Confirmed with High Toxins Blooms in the Finger Lakes. Information about open water and shoreline bloom reports from CSLAP can be found in the Individual Lake Chapters (Section 9). This table should not be considered a definitive assessment of blooms in these lakes; this only represents the extent to which credible bloom reports were provided to NYSDEC and its partners. The information documented by NYSDEC likely does not reflect the true extent, duration, or intensity of blooms on these waterbodies. The extent of blooms in each lake is documented in the Individual Lake Chapters, particularly those with active surveillance networks.

Lake	2012	2013	2014	2015	2016	2017
Otisco				S		C
Skaneateles						HT
Owasco		HT	HT	HT	HT	HT
Cayuga			C		C	HT
Seneca				HT	HT	HT
Keuka						HT
Canandaigua				HT	C	HT
Honeoye	S	HT	HT	HT	C	C
Canadice						C
Hemlock						C
Conesus			S		C	C

Bloom reports in some lakes (or in some years) are primarily a function of vigilant surveillance- blooms are observed and reported when surveyors look for blooms, particularly when this surveillance includes large portions of the shoreline. For the Finger Lakes and some waterbodies elsewhere in NYS in general, blooms may have been present in each year since 2012, but were not reported or observed due to the lack of complete surveillance (and some lakes were not sampled each year). This may particularly be the case in very large lakes, where blooms can often escape detection unless the lakes are closely surveyed.

Potential Factors Influencing HABs in the Finger Lakes

As demonstrated in Figure 45, HABs occur in many waterbodies throughout New York. In 2017, HABs were observed on all 11 Finger Lakes for the first time since the NYSDEC began the HAB Program. While it is known that excessive nutrient levels, particularly phosphorus, can trigger the formation of algal blooms generally, and HABs specifically, an increasing number of blooms have been documented on mesotrophic (moderate nutrient lakes) to oligotrophic lakes (low nutrient lakes). The frequency, duration, and intensity of blooms are influenced by many factors. Research over the last few decades has documented several factors that trigger HABs, although it is likely that the reasons for blooms on any lake could be unique to that lake (NYSDEC 2017). Furthermore, there may be additional, unidentified factors that influence HABs that are not discussed in this report. Some factors, as illustrated in the scientific literature (below), that appear to affect bloom formation include: elevated algae levels, elevated nutrient levels, food web changes (zebra and quagga mussels), and lake geometry and orientation. Localized nutrient sources, nitrogen to phosphorus ratios, nutrient fractions (dissolved or suspended), and seasonal nutrient inputs may be the proximate cause of some blooms in some lakes (Andersen et al. 2002).

Other factors, including flow and stratification characteristics, buoyancy concentration in deep photic (algae-growing) zones, wind concentration due to fetch length, food web interactions, and temperature or flash runoff increases from climate change may play an important role in bloom formation and toxin production. The data-water quality, biological condition, morphometry, and physical characteristics- from these lakes and from lakes with little to no evidence of blooms continues to be closely evaluated by the NYSDEC to gain a greater understanding of the causes of blooms. Future research and detailed evaluations are occurring as part of the 2018 Governor's HABs initiative, and will continue with extensive reviews of the Finger Lakes and NYS HABs dataset.

Climate: The temperate climate in NYS allows for the growth and development of HABs. Warm summer temperatures, high light intensity and calm wind conditions in the late summer offer an ideal environment for cyanobacterial growth. The effects of climate change will likely have a positive effect on HABs in NYS lakes. More intense, frequent rain events which deliver nutrients to lakes followed by periods of warm, stagnant conditions with high light intensity will allow for cyanobacteria to thrive in the future (Pearl and Otten 2013, Pearl et al. 2016, Chapra et al. 2017). Additional elements of climate change that may increase bloom frequency and duration, including longer growing seasons, earlier ice-out and later ice-in periods, changes in thermal stratification patterns, and selectivity for cyanobacteria relative to other phytoplankton.

Elevated Algal Levels and Lake Productivity: The frequency of shoreline blooms increases as open water algal levels (extracted Chl-a) increase, due to the greater likelihood that there is sufficient algal material in the water to concentrate into bloom quantities along the shoreline. In NYS more than half of all lakes with open water Chl-a levels above 10-15 µg/L report shoreline blooms. It should be recognized, however, that blooms can occur throughout a waterbody, along the shoreline only, or as patchy growth at any location in a lake, although densest concentrations tend to accumulate on the shoreline. This is a concern since this corresponds to the area where people recreate or the location of domestic (individual) water intakes.

Elevated Nutrient Levels: The relationship between nutrients and HABs has been well documented for decades (Heisler et al. 2008). In NYS, the frequency of open water and shoreline cyanobacteria blooms increases as open water total phosphorus (TP) readings increase. Open water blooms are uncommon when open water phosphorus levels are less than 0.030 mg/L, but steadily increase when TP rises from 0.030-0.050 mg/L (and above 0.100 mg/L). Shoreline cyanobacteria blooms, however, occur in nearly 30% of the lakes even at TP levels < 0.020 mg/L, and steadily increase until TP levels reach approximately 0.060 mg/L. At elevated phosphorus levels, cyanobacteria blooms occur in nearly three-quarters of all lakes. However, as noted above, even in low nutrient lakes, large bloom "patches" can be found near the center of the lake, due to surface accumulation of large quantities of HABs associated with the buoyancy of some cyanobacteria.

Lake Geometry and Orientation: The physical configuration of some lakes renders them susceptible to blooms. Several lakes exhibiting cyanobacteria blooms despite relatively low nutrient levels appear to be polymictic. Phosphorus levels may build up near the lake bottom. During frequent summer mixing events, these nutrients can migrate to the lake surface and trigger algae growth. In addition, some cyanobacteria can extract nutrients from deeper water or bottom sediments in these lakes with intermediate depths, and then migrate to the surface.

Lake Depth Categories

Shallow - Lakes that are less than about 6 meters deep, defined thermal layers are not established. Typically, the entire water column can be well-mixed

Polymictic - Lakes that are about 6-15 meters deep, in which thermal layers are often weakly established. Lake mixing periods can occur during high wind events, alternating with periods of thermal stratification and nutrient release from bottom sediments

Deep - Lakes that are deeper than 15 meters form strong thermal stratification layers that remain intact throughout the growing season. Deepwater nutrients generally don't migrate to the water surface until fall turnover. However, even deep lakes may have shallower sections that exhibit some of the "shallow" or "polymictic" characteristics described above.

Fetch length is the distance over water across which wind can blow unabated. Bloom frequency increases as the Maximum Fetch Length/Shoreline Length ratio increases for lakes with relatively low open water phosphorus readings, if the maximum fetch is frequently oriented with wind direction, but that the relationship is not as well defined for higher TP levels. This suggests that the physical configuration of the lake may play a role in triggering shoreline blooms in waterbodies with relatively low nutrient levels. The Maximum Fetch Length to Shoreline Length (FL:SL) ratios range from 0.33 (Keuka) to 0.44 (Skaneateles and Cayuga). FL:SL ratios in the Finger Lakes would fall in the upper half of the more than 425 NYS lakes surveyed for HABs in the last six years, and the maximum fetch for these lakes would fall in the highest 10th percentile for NYS lakes. The Finger Lakes all have elongated N-S orientations with large shoreline distances which can allow surface accumulations of wind-blown HABs from a very large open area of the lake to be concentrated (Chorus and Bertram 1999). Shoreline blooms are far more common than open water blooms in lakes. These blooms- either originating near the shoreline or concentrated by wind or water movement along the lake shore- may be reported by lake residents or visitors.

Zebra/Quagga Mussels: Dreissenid mussels (zebra and quagga mussels) can significantly alter the biological condition of lakes. While dreissenids will filter phytoplankton out of the water column, thereby increasing water clarity, they selectively remove green algae, diatoms, and other algae, leaving cyanobacteria at relatively higher concentrations in the lake. This results in less competition for nutrients, further exacerbating cyanobacteria growth. The frequency of shoreline and open water blooms in lakes with dreissenid mussels is consistently higher than in lakes without zebra mussels. There has been substantial research of the complex influence of dreissenid mussels on algal bloom development in the Great Lakes (Hecky et al. 2004) and lakes in Michigan. Sarnelle et al. 2012 demonstrated that low phosphorus (TP ~ 0.01 mg/L – the lower bounds of mesotrophy in NYS trophic determination), low productivity lakes are at a greater risk for HABs in the presence of zebra mussels compared to low phosphorus lakes without these invasive bivalves. NYS HABs data collected over the last six years indicate that low nutrient lakes with dreissenid mussels are 3-5 times more likely to experience HABs than those without these mussels (NYSDEC 2018).

Algal Indicators and Toxins

Each of the shoreline and open water HABs samples submitted to SUNY ESF are analyzed for different algal toxins. These include several congeners of microcystin (a liver toxin that is the most common cyanotoxin in New York waterbodies), anatoxin-a (a neurotoxin), cylindrospermopsin (a liver toxin), and BMAA (β-Methylamino-L-alanine, a neurotoxin that may be associated with several neurological disorders). To date, neither cylindrospermopsin nor BMAA have been detected in any NYS samples.

USEPA has developed total microcystin guidance values for treated drinking water and draft guidance values for recreation. In 2015, USEPA issued a 10-day drinking water health advisory of 0.3 μg/L for children (less than six years old), and 1.6 μg/L for older children (>6 years of age) and adults. This advisory was intended to apply to treated drinking water, not "raw" lake water, and the lower 0.3 μg/L advisory level has been adopted by NYSDOH as a health advisory for local health departments.

Draft human health recreational ambient water quality criteria for microcystin released by USEPA in 2016 suggest a swimming advisory threshold of 4 µg/L, not to be exceeded on any day or more than 10% of days per recreation season. This has been adopted by NYSDOH as a health advisory for local health departments.

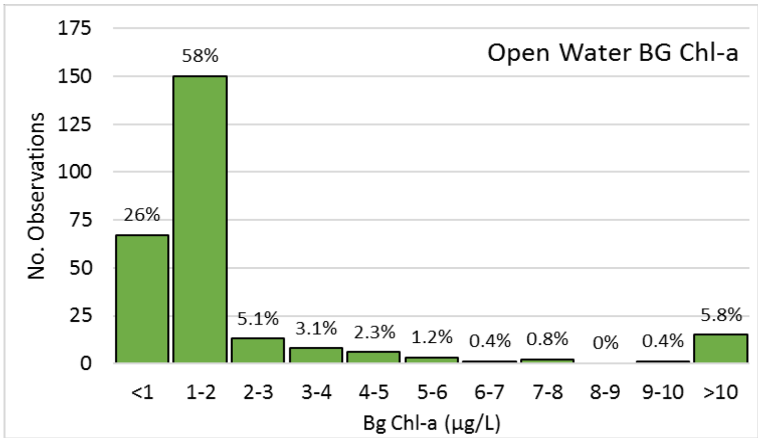
Exposure to any cyanobacteria HABs can cause health effects in people and animals when water with blooms is touched, swallowed, or when airborne droplets are inhaled. This is true regardless of toxin levels; some blue-green algae produce toxins, while others do not. Exposure to blooms and toxins can cause symptoms such as diarrhea, nausea or vomiting, skin, eye or throat irritation, allergic reactions, or breathing difficulties. For more information go to www.health.ny.gov/harmfulalgae. However, although the presence of cyanobacteria blooms is considered a risk even if cyanotoxins levels are undetectable, toxin levels will continue to be closely evaluated through CSLAP and other HAB surveillance and monitoring programs in the Finger Lakes and in NYS.

NYSDEC research has shown that the frequency of Confirmed with High Toxin Blooms increases with increasing open water TP and TN (NYSDEC 2017). The frequency of these blooms increased significantly as TP levels exceed 0.035 mg/l (= 35 µg/l), but increases steadily as TN levels rise. Recent research indicates a potential relationship between nitrogen enrichment and toxin levels - these datasets will continue to be evaluated to determine if these relationships are present in NYS lakes (Davis et al. 2008). This will include a detailed evaluation of differences in lakes dominated by N-fixing taxa (e.g., *Dolichospermum*) and those dominated by taxa that do not fix atmospheric nitrogen (such as *Microcystis*).

Multiple HABs indicators are sampled routinely as part of the CSLAP program at the designated open- water locations. They include visual assessments and water sample collection for BG Chl-a and HABs toxin analysis. These open-water samples allow for the assessment of the primary lake body and will be compared with near-shore bloom characteristics (subsequently). However, as noted earlier, cyanobacteria growth and distribution is very heterogeneous- not uniformly distributed within and throughout the water column- so individual open water or shoreline sampling results may not be highly representative of lake conditions. NYSDEC and other researchers continue to evaluate other tools, including satellite imagery, to improve the evaluation of bloom conditions on these lakes.

Algal Indicators and Toxins in the Finger Lakes in 2017

The majority of open-water samples in the Finger Lakes collected in 2017 had very low concentrations of BG Chl-a (inset). Only three samples exceeded the NYSDEC's Confirmed Bloom threshold (25 µg/L for BG Chl-a; Table 15). These three open water samples were restricted to the most eutrophic Finger Lakes; Conesus and Honeoye Lakes. Among all observations, 26% of BG Chl-a concentrations were less than 1 µg/L and approximately 90% of all observations were less than 3 µg/L.



Concentrations of microcystin were also low in the open water (Table 15). Only one observation (Keuka Lake Site 1 on 9/20/17 = 0.67 µg/L) was above the limit of detection (> 0.3 µg/L) but the concentration was well below both the NYSDEC Confirmed with High Toxins Bloom threshold for an open water sample.

The nearshore results discussed here were highly variable both between and within lakes (as well as spatially and temporally) with regards to the number of samples collected and concentrations (Figures 46 and 47). Some of the variability is no doubt due to the differences in the types of established HABs monitoring programs between the lakes and the variability associated with sampling the densest scum material. Therefore, these results will be discussed qualitatively.

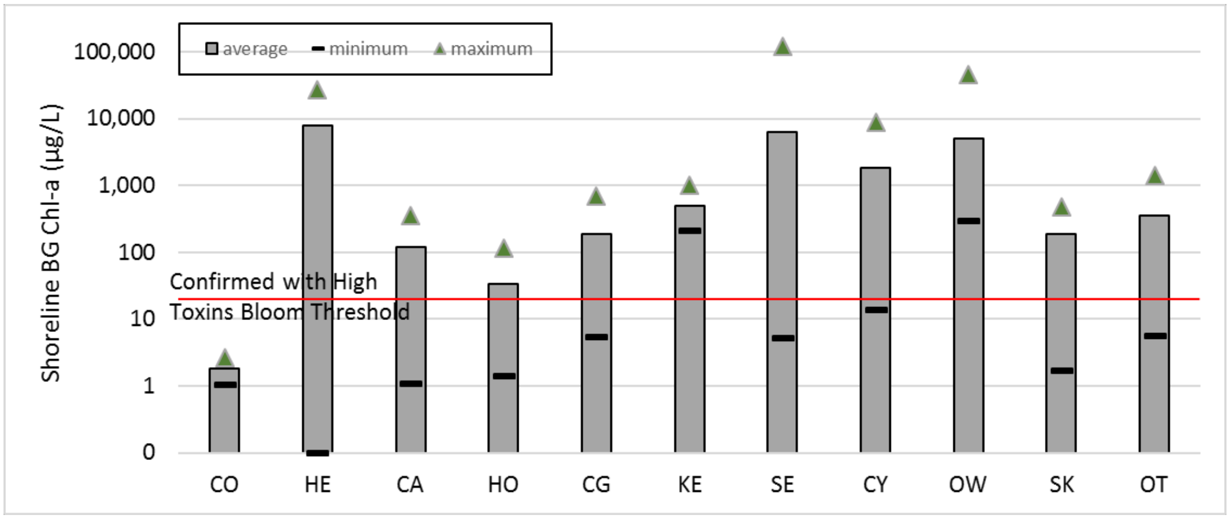


Figure 46. Nearshore BG Chl-a (µg/L) concentrations in the Finger Lakes (from west to east) presented on a log-scale.

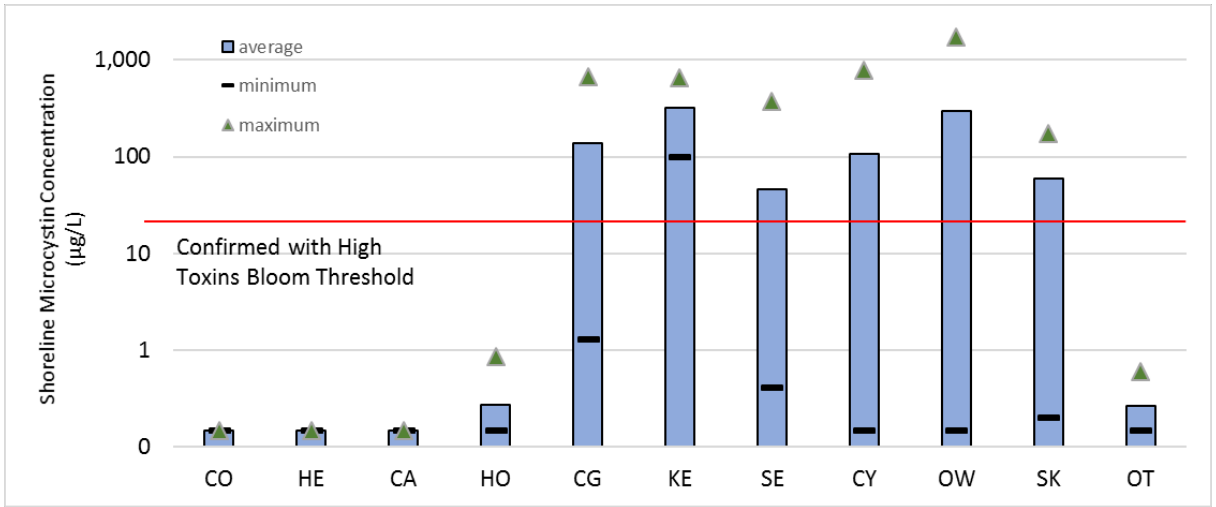


Figure 47. Nearshore microcystin (µg/L) concentrations in the Finger Lakes (from west to east) presented on a log-scale.

The nearshore concentrations of both BG Chl-a and the microcystin toxin were generally higher compared with the open water concentrations but extremely variable within and between lakes. Values of BG Chl-a often exceeded the NYSDEC Confirmed Bloom threshold (Figure 46 and Tables 16-18) with some samples reaching concentrations 100-1,000-times the threshold. This is expected as nearshore samples are collected: (1) only if a bloom is present and (2) these samples reflect the skim sampling methodology designed to capture the worst-case values of a bloom and concentrate the bloom material for analysis. Concentrations of microcystin were highly variable in nearshore samples as well, with many samples exceeding the Confirmed with High Toxins Bloom threshold (Figure 47 and Tables 16-18).

Table 15. Open Water HABs Results CSLAP Finger Lakes in 2017

Lake Site	Position	Maximum BG Chl-a (µg/L)*	No. Samples with Detectable Microcystin (MC) +	Date(s) Detectable MC	MC Concentration (µg/L) †
Conesus-S1	Surface	3	1 (8)	09/13/17	0.06 ††
	Deep	25[a]	0 (7)	-	-
Conesus-S2	Surface	1.45	0 (8)	-	-
	Deep	3.65	0 (8)	-	-
Hemlock S1	Surface	0.67	0 (8)	-	-
	Deep	0.98	0 (8)	-	-
Hemlock S2	Surface	0.66	0 (8)	-	-
	Deep	0.88	0 (8)	-	-
Hemlock S3	Surface	0.25	0 (8)	-	-
	Deep	0.86	0 (8)	-	-
Canadice S1	Surface	0.82	0 (8)	-	-
	Deep	0.8	1 (8)	06/28/17	0.19 ††
Honeoye S1	Surface	27	0 (7)	-	-
	Deep	16	0 (7)	-	-
Honeoye S2	Surface	42	0 (7)	-	-
	Deep	4.04	0 (7)	-	-
Canandaigua S1	Surface	0.87	0 (7)	-	-
Canandaigua S2	Surface	0.58	0 (8)	-	-
Keuka S1	Surface	0.7	1 (8)	9/20/17	0.67
Keuka S2	Surface	0.92	0 (8)	-	-
Seneca S1	Surface	1.89	0 (8)	-	-
Seneca S2	Surface	1.48	0 (8)	-	-
Cayuga S1	Surface	0.23	0 (8)	-	-
	Deep	0.58	0 (8)	-	-
Cayuga S2	Surface	0.87	0 (8)	-	-
	Deep	0.51	0 (8)	-	-
Owasco S1	Surface	0.49	0 (8)	-	-
	Deep	0.87	0 (7)	-	-
Owasco S2	Surface	1.87	0 (7)	-	-
	Deep	2.43	0 (7)	-	-
Skaneateles S1	Surface	2.06	0 (8)	-	-
Skaneateles S2	Surface	0.76	0 (8)	-	-
Otisco S1	Surface	1.62	0 (8)	-	-
Otisco S2	Surface	1.42	0 (8)	-	-

* **red bold** - above NYSDEC threshold for Confirmed Bloom (25 µg/L)
+ total number of samples collected parenthetically
† MC detection limit 0.3 µg/L; **red bold** - High toxins designation is greater than 10 µg/L in the open water
†† between method detection limit and reporting limit
[a] This was a deep sample that might have indicated a metalimnetic bloom that did not appear on the surface or otherwise trigger any water quality problems

A few interesting patterns emerged from 2017 dataset. Despite high shoreline bloom BG Chl-a values, associated microcystin concentrations in the four western Finger Lakes were low, often less than detection (Table 16) and the maximum microcystin shoreline concentration was ~ 1µg/L on Honeoye Lake (August 28). The shoreline microcystin concentrations for these lakes were generally lower than the seven larger Finger Lakes to the east (Figure 48).

Cayuga and Owasco Lake microcystin concentrations demonstrated some seasonality (Table 18). Both lakes had high shoreline BG Chl-a concentrations in July but microcystin concentrations were all less than detection limit (0.3 µg/L). Conversely, in September both BG Chl-a and microcystin concentrations were high and all exceeded the Confirmed with High Toxins Bloom threshold, except for one sample on Cayuga Lake (September 26).

Table 16. Shoreline HABs Results CSLAP Finger Lakes in 2017

Lake	Collection Dates [1]	BG Chl-a (µg/L) *	MC Concentration (µg/L) +	Anatoxin Concentration (µg/L) †
Conesus	27-Sep	1	<DL	<DL
	27-Sep	3	<DL	<DL
Hemlock	12-Jul	**26,781**	<DL	<DL
	13-Jul	**4,290**	<DL	<DL
	27-Sep	0	<DL	<DL
	27-Sep	1	<DL	<DL
Canadice	1-Aug	**351**	<DL	<DL
	28-Sep	1	<DL	<DL
	28-Sep	3	<DL	<DL
Honeoye	24-Jul	3	<DL	<DL
	28-Aug	**34**	<DL	<DL
	18-Sep	**116**	1	<DL
	18-Sep	**39**	<DL	<DL
	27-Sep	1	<DL	<DL
	27-Sep	7	0.2	<DL
Canandaigua	22-Aug	8	2	<DL
	18-Sep	**130**	**118**	<DL
	18-Sep	**701**	**663**	<DL
	18-Sep	**364**	**387**	<DL
	25-Sep	**381**	**30**	<DL
	25-Sep	5	1	<DL
	25-Sep	**45**	**22**	<DL
	26-Sep	13	5	<DL
	26-Sep	**32**	14	<DL
Keuka	14-Sep	**293**	**197**	<DL
	14-Sep	**1,010**	**654**	<DL
	26-Sep	**210**	**98**	<DL

[1] Multiple collections on one date are from different shoreline areas

* **Red bold** - above NYSDEC threshold for Confirmed Bloom (25 µg/L)

\+ MC detection limit 0.3 µg/L; **red bold** - high toxins designation is greater than 20 µg/L in the open water

† No current threshold or guidance value for Anatoxin

Table 17. Shoreline HABs Results CSLAP Finger Lakes in 2017

Lake	Collection Dates [1]	BG Chl-a (µg/L) *	MC Concentration (µg/L) +	Anatoxin Concentration (µg/L) †
Seneca	15-Sep	**132**	**66.4**	<DL
	15-Sep	**132**	**66.4**	<DL
	15-Sep	**165**	**126.4**	<DL
	15-Sep	**161**	**117.8**	<DL
	15-Sep	**225**	**58.2**	0.1
	15-Sep	**251**	**100.1**	<DL
	15-Sep	**146**	**186.5**	0.3
	16-Sep	**378**	**58.8**	<DL
	17-Sep	5	8.9	<DL
	17-Sep	**384**	**49.3**	0.1
	18-Sep	**456**	**40.2**	<DL
	20-Sep	**477**	**47.2**	<DL
	20-Sep	**9,539**	16.1	<DL
	20-Sep	**13,119**	**61.9**	1.5
	20-Sep	**31,500**	**164.4**	<DL
	21-Sep	**1,282**	**35.6**	0.2
	21-Sep	**1,369**	10.1	<DL
	21-Sep	**1,414**	17.2	<DL
	21-Sep	**1,617**	**93.1**	<DL
	21-Sep	**2,033**	13.8	0.2
	21-Sep	**5,014**	**166.4**	<DL
	21-Sep	**8,830**	**113.0**	<DL
	21-Sep	**29,125**	**368.7**	<DL
	21-Sep	**42,800**	**127.1**	0.4
	22-Sep	**134**	0.4	<DL
	22-Sep	**361**	4.2	0.1
	22-Sep	**450**	3.4	<DL
	22-Sep	**1,072**	2.9	0.4
	22-Sep	**1,221**	1.1	0.2
	22-Sep	**1,565**	9.1	0.2
	22-Sep	**23,669**	**40.8**	<DL
	23-Sep	**289**	0.9	<DL
	23-Sep	**382**	1.0	<DL
	23-Sep	**655**	2.2	0.1
	23-Sep	**826**	0.5	<DL
	23-Sep	**3,971**	1.0	<DL
	23-Sep	**9,890**	8.4	0.5
	24-Sep	**118**	<DL	0.1
	24-Sep	**130**	7.0	<DL
	24-Sep	**406**	2.2	<DL
	24-Sep	**457**	0.7	<DL
	24-Sep	**881**	3.3	3.7
	24-Sep	**994**	4.4	<DL
	24-Sep	**1,189**	5.6	<DL
	24-Sep	**118,356**	**49.0**	<DL
	25-Sep	**953**	7.7	0.3
	25-Sep	**973**	6.4	<DL
	25-Sep	**940**	2.5	0.2
	25-Sep	**2,237**	**35.3**	0.2
	26-Sep	**477**	5.7	<DL
	26-Sep	**774**	3.9	0.1
	26-Sep	**1,091**	4.7	<DL

[1] Multiple collections on one date are from different shoreline areas

* **Red bold** - above NYSDEC threshold for Confirmed Bloom (25 µg/L)

\+ MC detection limit 0.3 µg/L; **red bold** - high toxins designation is greater than 20 µg/L in the open water

† No current threshold or guidance value for Anatoxin

Table 18. Shoreline HABs Results CSLAP Finger Lakes in 2017

Lake	Collection Dates [1]	BG Chl-a (µg/L)*	MC Concentration (µg/L)+	Anatoxin Concentration (µg/L) †
Cayuga	18-Jul	**876**	<DL	<DL
	26-Jul	**152**	<DL	<DL
	26-Jul	**3,440**	<DL	<DL
	31-Jul	14	<DL	<DL
	31-Jul	**8,756**	<DL	<DL
	14-Sep	**330**	**36**	<DL
	20-Sep	**996**	**241**	<DL
	26-Sep	**3,978**	**783**	<DL
	26-Sep	21	5	<DL
Owasco	27-Jul	**8,128**	<DL	<DL
	28-Jul	**7,556**	<DL	<DL
	30-Jul	**1,677**	<DL	<DL
	31-Jul	**2,926**	<DL	<DL
	31-Jul	**680**	<DL	<DL
	31-Jul	**3,292**	<DL	<DL
	11-Sep	**716**	**236**	<DL
	11-Sep	**511**	**55**	<DL
	11-Sep	**556**	**118**	0.1
	11-Sep	**638**	**189**	0.8
	12-Sep	**2,206**	**591**	18.6
	12-Sep	**297**	**118**	0.3
	12-Sep	**988**	**82**	<DL
	17-Sep	**45,463**	**1,123**	<DL
	18-Sep	**1,258**	**319**	<DL
	18-Sep	**4,578**	**332**	<DL
	18-Sep	**2,081**	**297**	0.1
	18-Sep	**20,813**	**1,705**	0.6
	25-Sep	**4,381**	**618**	8.9
	25-Sep	**1,301**	**317**	0.5
	29-Sep	**1,192**	**259**	0.1
	29-Sep	**1,106**	**112**	1.8
	29-Sep	**1,596**	**362**	0.2
Skaneateles	16-Sep	**449**	**126**	<DL
	16-Sep	**331**	**108**	<DL
	16-Sep	**470**	**172**	<DL
	25-Sep	**46**	7	<DL
	25-Sep	13	1	<DL
	27-Sep	2	0	<DL
	27-Sep	3	3	<DL
Otisco	12-Jul	**1,401**	<DL	<DL
	21-Aug	20	<DL	<DL
	26-Sep	7	1	2.3
	26-Sep	6	<DL	<DL

[1] Multiple collections on one date are from different shoreline areas

* **Red bold** - above NYSDEC threshold for Confirmed Bloom (25 µg/L)

\+ MC detection limit 0.3 µg/L; **red bold** - high toxins designation is greater than 20 µg/L in the open water

† No current threshold or guidance value for Anatoxin

The three Case Studies below represent an evaluation of some potential causes of blooms in the Finger Lakes in 2017. This review is not intended to reach specific conclusions about each bloom, but to present the 2017 HABs dataset in the context of potential bloom drivers.

Case Study: Skaneateles Lake

Although the causes of HABs are not fully understood and vary from lake to lake, elevated nutrients are known to be a major contributor (Smith 1982; Paerl and Otten 2013). Other factors known to contribute to HABs include higher temperatures, increased episodic precipitation events and associated nutrient loading followed by calm, warm conditions (Pearl and Otten 2013). Skaneateles Lake, with low average TP, had a widespread and sustained HAB in the fall of 2017. HABs were documented, for the first time ever, in Skaneateles Lake with samples collected on September 16, 25, and October 2. Although these observations were documented as individual events, it appeared to be a sustained or continuous HAB for the span of several weeks across a large portion of the lake.

Skaneateles Lake is an oligotrophic lake with low TP, although average concentrations in 2017 (at 0.006 mg/L) were slightly above concentrations from the late-1990s and mid-2000s (Callinan 2001, 2013). Extreme storm events in June and July of 2017 likely contributed to these increases as seen by increases in lake TP and Chl-a and decreases in clarity immediately following these storms (Figures 17 and 18 and Chapter 9). Figure 48 shows that the average weighted (average of both City of Syracuse’s rain gauge data from Glen Haven and the Village of Skaneateles) precipitation was above average throughout the early months of 2017 and was much higher than the 30-year average after the storms previously mentioned. The 2017 average cumulative rainfall was 57.4 in compared to the 30-year average of 43.0 in. and the monthly averages for May, June and July were also above the 30-year average: 5.9 in compared to 3.7 in, 6.7 in compared to 4.0 in, and 7.0 in compared to 4.0 in, respectively.

The City of Syracuse’s Glen Haven (Sempronius) rain gauge captured rain events of 2.9 in, 4.9 in and 4.32 in on June 4 to 6, June 30 to July 1 and July 11 to July 14, respectively. These events caused severe flooding and increased runoff in the watershed. The July 1 event was also captured in the United States Geological Service (USGS) stream gauge data from the Owasco Inlet (closest location to Skaneateles Lake) located in Moravia, NY (USGS 04235299). These stream gauge data indicated that this storm increased flow rates to a record high (records kept since 2009) of 4,220 cubic feet per second (cfs) on July 1. These flow rates are nearly double the typical high spring flow rates which range between 2,000 and 3,000 cfs. Runoff events increase suspended sediment in the water column, decreasing water clarity and can lead to an increase of nutrients in a waterbody. This is evident in an increase of TP and decrease in water clarity as observed in Skaneateles last year in July (see Skaneateles Lake chapter).

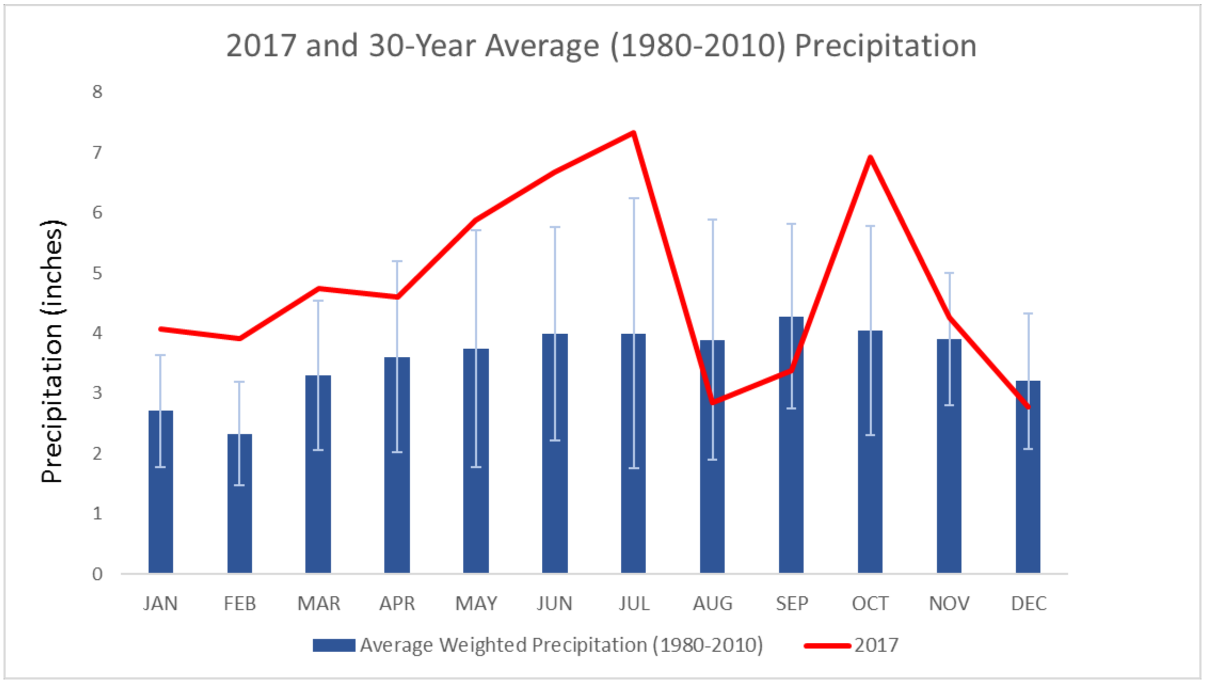


Figure 48. Precipitation (in) patterns in Skaneateles watershed

Maximum air temperatures from the Auburn airport (http://www.nws.noaa.gov/climate/xmacis.php?wfo=bgm) were historically high, with six days that exceeded 80°F (each day greater than the 95th percentile over the last 50 years) between early September and early October (HABs Action Plan). Figure 49 shows daily maximum air temperature readings from the Auburn NOAA Weather station from 1980-2010 (some years lack data) with the 2017 September maximum temperature readings overlaid. Beginning on September 17th, daily maximum temperatures were at or above the 75th percentile of data over the 30-year average and remained elevated until September 28.

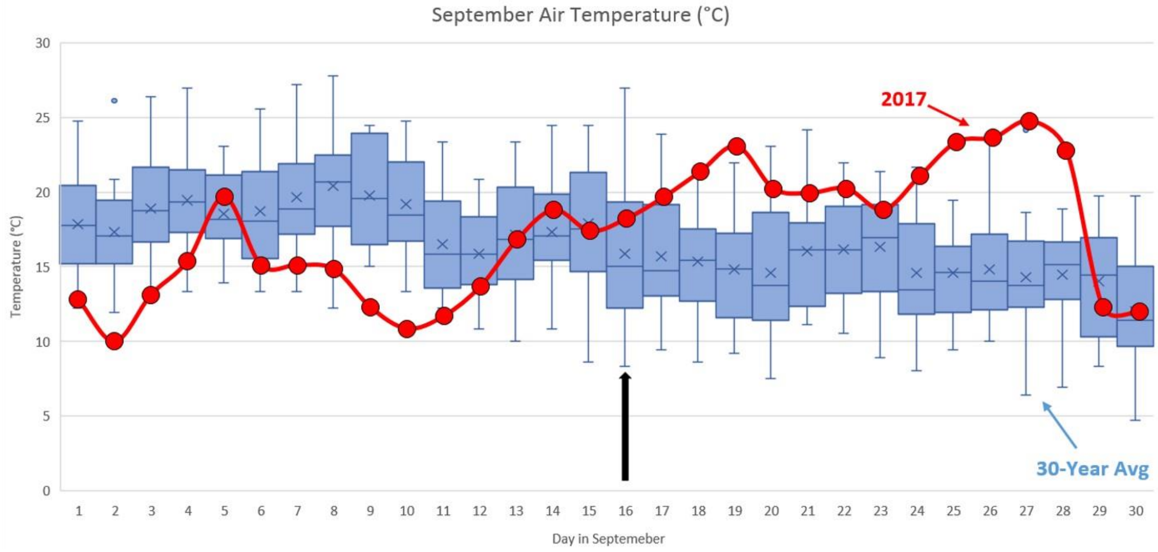


Figure 49. Box-whisker plot of daily September air temperatures (C°) from Auburn NOAA weather station with the daily 2017 temperature data overlaid as the red line. The black arrow indicates the date the HAB was reported and confirmed on Skaneateles Lake. Mid-September through the end of the month was consistently warmer than the 30-year average.

Warm water temperatures favor the growth of HABs (Pearl and Otten 2013). Figure 50a shows 2017 surface water temperature in Skaneateles Lake (with standard deviation) compared to the 10-year average (2004-2013) and Figure 50b shows the 2017 difference from the same 10-year average (2004 also shown). Beginning in mid-September, coinciding with increasing air temperature, surface water temperature began to warm rapidly just prior to the reported HAB. (City of Syracuse, personal communication). Early September surface water temperatures were below average but due to the extremely warm air temperature (Figure 49), the surface temperature rapidly rose above the historic average.

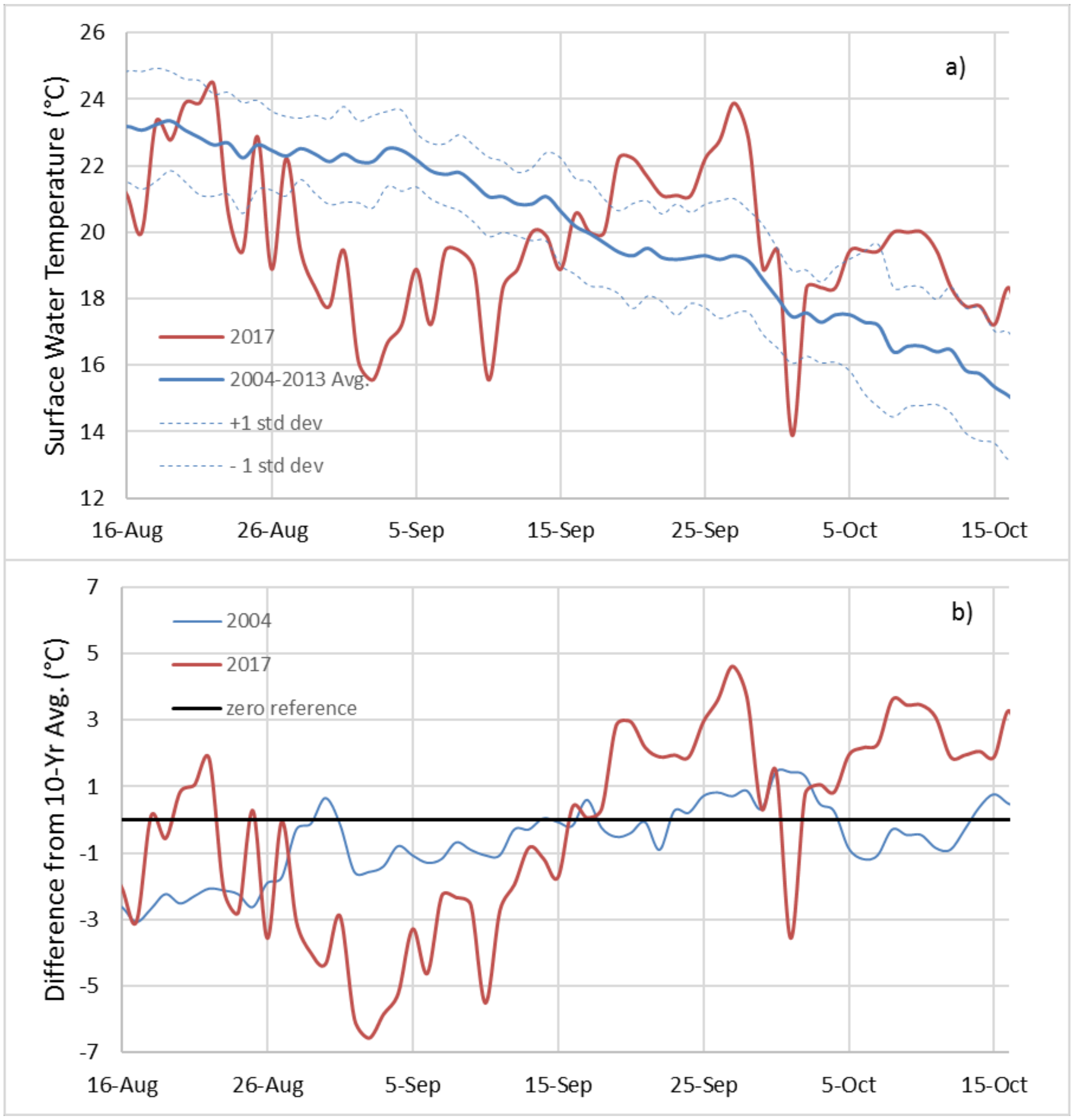


Figure 50. a) 2017 surface water temperature (C°) (with standard deviation) compared to the 10-year average (2004-2013) as well as b) 2017 (and sample year 2004) difference from the same 10-year average

Case Study: Owasco Lake

Owasco Lake is a mesotrophic Finger Lake that has experienced HABs since at least 2012. Between 2013 and 2017, there were a total of 84 HAB reports generated based on water quality sampling and/or visual reporting by the Cayuga County DOH, Owasco Watershed Lake Association (OWLA), and the Owasco Lake Watershed

Inspection Program (OLWIP). Confirmed or Confirmed with High Toxins HABs were reported during 34 days of sampling, occurring primarily between late July and early September, although bloom frequency and duration clearly extended beyond these discrete sampled events.

Cyanobacteria HABs have been most commonly associated with the northern and northeastern shorelines of Owasco Lake (along Emerson Park and the Owasco Yacht Club), and although all were identified as shoreline blooms, these blooms extended into the open waters of the lake. Because sampling is often limited to the shoreline, particularly as part of the volunteer monitoring program, the sampling effort does not necessarily reflect the true extent of the blooms. And as noted above, blooms were frequently present between discrete sampling events, so the duration of these blooms cannot be easily evaluated. Northern shoreline blooms have resulted in beach closures at multiple locations since 2012 (NYSDEC 2018).

An Owasco Lake HABs surveillance program was established in 2014 to monitor and report occurrences of HABs in Owasco Lake. The program consists of 24 zones, which volunteers monitor weekly for nearshore HABs (Figure 51a). The Owasco Lake HABs surveillance network provides data on the presence and absence of blooms every week from mid-summer through September.

In 2017, Owasco Lake experienced a short-lived HAB in late July and a HAB in mid-September which covered a large portion of the lake's northern end (Figure 51b). Shoreline concentrations of BG Chl-a were extremely high in September, ranging from 300 to greater than 20,000 µg/L. These bloom samples were also determined to be Confirmed with High Toxins Blooms, with microcystin concentrations ranging from 55 to 1,700 µg/L. Despite these nearshore conditions, the CSLAP results from the open-water showed low concentrations for both BG Chl-a (0 - 2.4 µg/L) and the microcystin toxin (all less than 0.3 µg/L). The reasons for this discrepancy are likely a combination of the spatial and vertical distribution of cyanobacteria. Blooms tend to accumulate in the upper few centimeters of the water column and tend to be more concentrated on the lee shore (downwind) of lake where CSLAP samples are collected at 1.5m and in mid-lake locations.

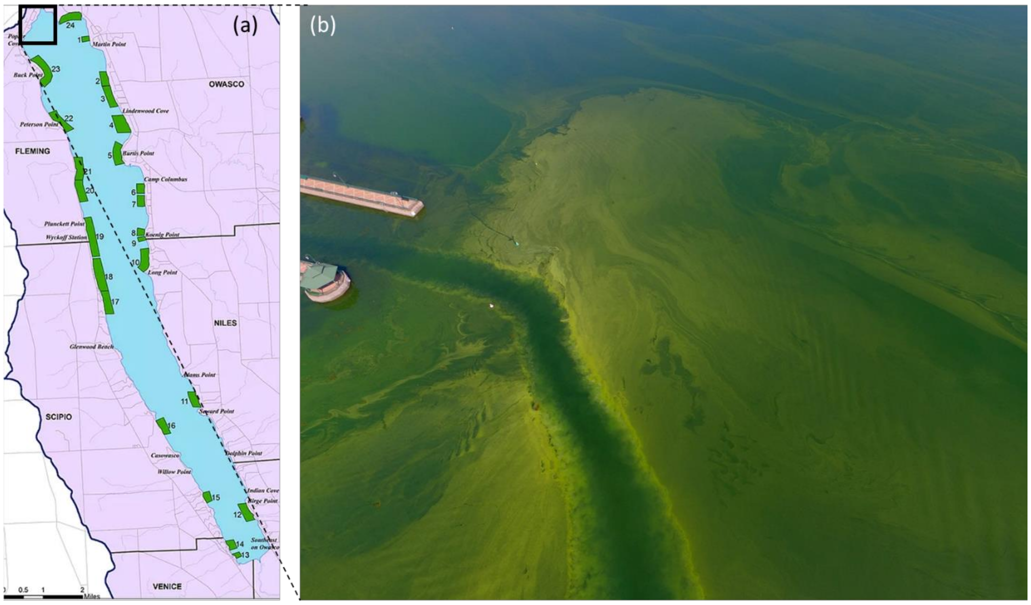


Figure 51. (a) map of Owasco Lake HABs surveillance zones and (b) a large HAB near the lake outlet at the northern end (September 18, 2017. Photo and map courtesy of T. Schneider – OWLIP)

Figure 52 shows the geophysical distribution of bloom reports on four dates in 2017. The majority of bloom reports were reported in the northern/eastern part of the lake, consistent with previous results from the NYSDEC and other researchers. However, there are often reports of HABs in the south-eastern part of Owasco Lake as well (Zone 12).

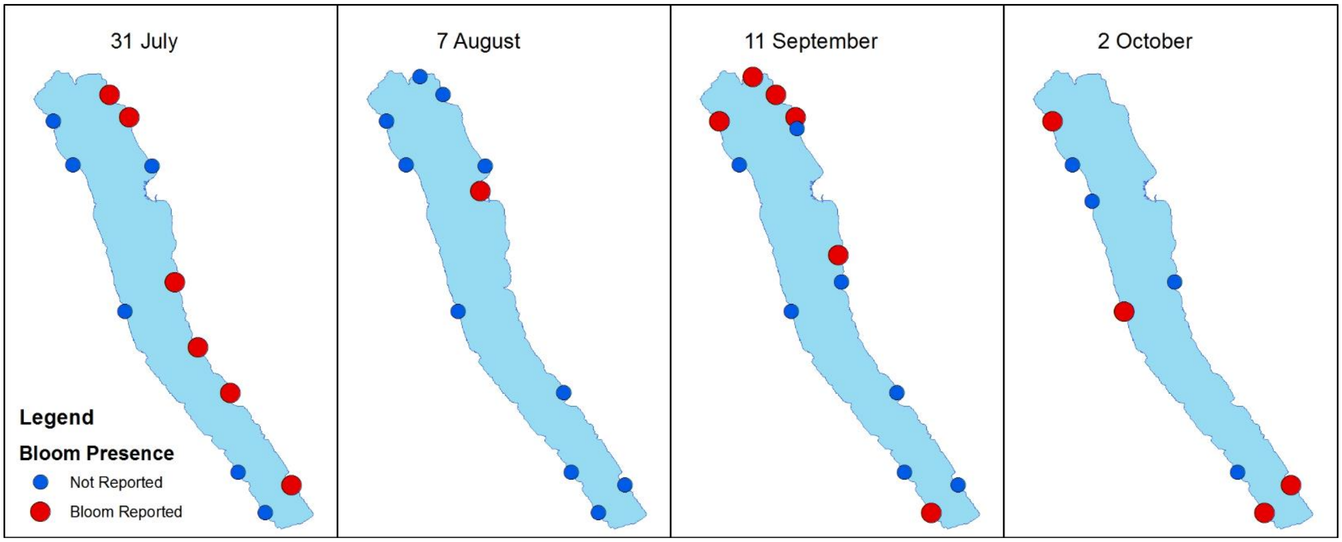


Figure 52. Maps of Owasco Lake HABs surveillance reports (Bloom/No Bloom) for July 31, August 7, September 11, and October 2.

Since 2014, Dr. John Halfman (FLI and Hobart and William Smith Colleges) has deployed and maintained an automated water quality and meteorological station on Owasco Lake, near CSLAP Site 1 (Halfman et al. 2017). Because of this valuable dataset, the meteorological conditions of late summer 2017 were evaluated to provide context for the September blooms. Late summer of 2017 represented a very warm, high sunlight, and relatively calm period in the Finger Lakes region.

The HABs surveillance network identified 27 Bloom reports in September, starting on September 4th. Air temperatures rose steadily from 13.6°C on September 2nd until a cold front moved through the region in late September where the air temperature dropped from 23.7 °C on the 27th to 15.8°C on the 28th. Owasco Lake water temperatures at 1m depth were relatively cool in August and early September (Halfman et al. 2017) but warmed rapidly in mid-September from 19.1°C on Sept. 11 to 21.8 °C on Sept. 25 consistent with the increase air temperature.

In early September, wind speeds and directions were highly variable (Figure 54). Winds were mostly out of the South and ranged from 8-16 mph. Conversely, from Sept. 8-15, wind speeds were relatively low, averaging 6.8 mph (ranging from 3.6-10.2 mph). Wind directions were also variable, but mostly from the South (Figure 53). As an example, on Sept.,15, wind speeds were extremely low, averaging 3.6 mph with all observations less than 10 mph. From Sept. 15-22 winds remained low with daily average observations ranging from 3.4-7.9 mph and remained mostly out of the South. This pattern of relatively low winds, mainly from the South continued through September. On September 28, consistent with the cold front, wind speeds increased and the direction changed to the North. In early October, winds substantially increased, ranging from 5-15 mph from October 1-15. The blooms dissipated with the change in weather conditions as the last bloom report for Owasco Lake was on October 2.

These meteorological pattern likely exacerbated HAB conditions on Owasco Lake in 2017 (Halfman et al. 2017).

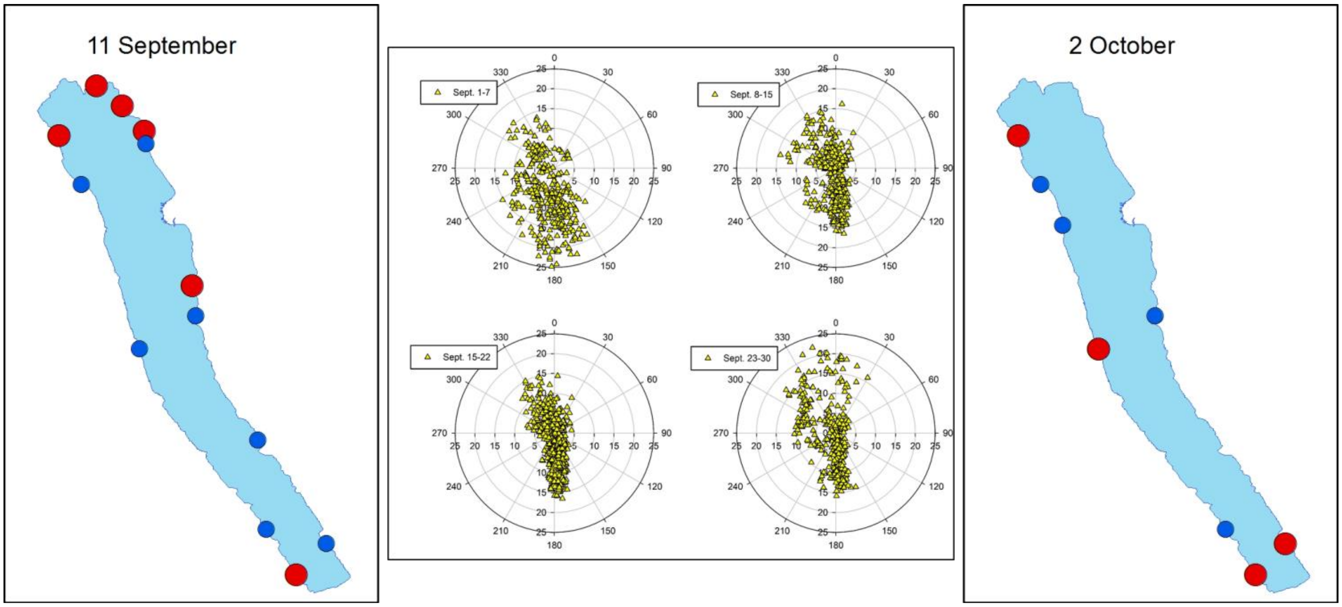


Figure 53. Owasco Lake HABs surveillance reports (Bloom/No Bloom) September 11, and October 2 with wind rose data (Meteorological data courtesy of Halfman 2017).

Owasco Lake has two municipal drinking water intakes (City of Auburn and Town of Owasco) in the northern end that routinely monitor for microcystin in the raw and finished drinking water. In 2017 microcystin concentrations were below detection since the start of monitoring in July through September, consistent with the low open water toxin concentrations (Figures 54 and 55; Cayuga County Health Department). In early October, both facilities detected low concentrations (< 0.5 µg/L) in the plants' raw water. The exact mechanism of algal material and toxin transport from accumulated areas to the drinking water intakes remains unclear. Most nearshore blooms were in subsidence by late September and it is likely that as blooms die, suspended algal material in the water column settle through the water column to the intake depths. It should again be noted that toxin levels in the treated drinking water never exceeded the 0.3 µg/L USEPA guidance value for microcystin.

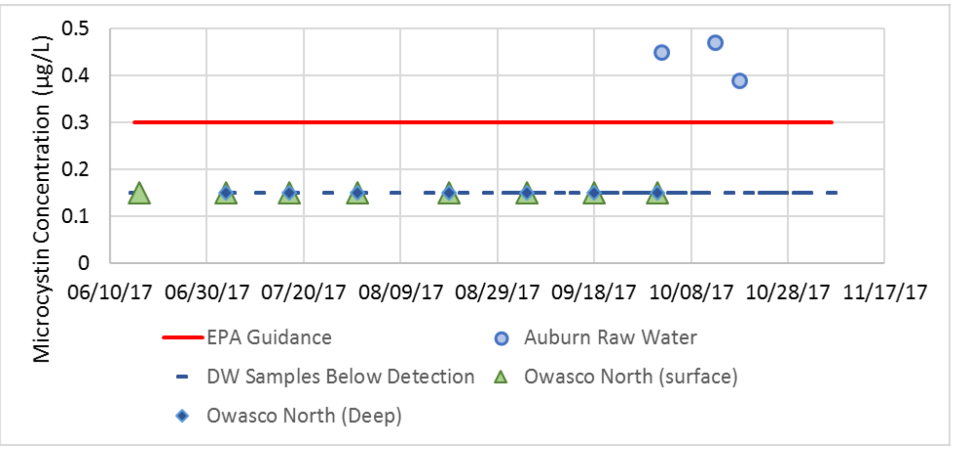


Figure 54. Time series of microcystin concentration (µg/L) for: The City of Auburn raw drinking water and CSLAP Site 1 (North) at the surface (1.5 m) and deep (9 m) with the EPA 10-d guidance value as reference.

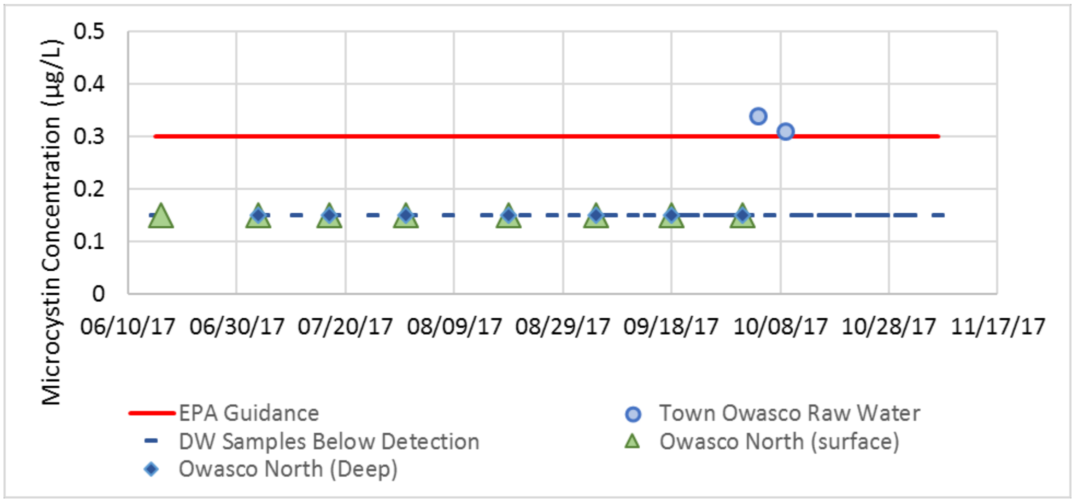


Figure 55. Time series of microcystin concentration (µg/L) for: The City of Auburn raw drinking water and CSLAP Site 1 (North) at the surface (1.5 m) and deep (9 m) with the EPA 10-d guidance value as reference.

Case Study: Seneca Lake

Seneca Lake has the second longest shoreline of the Finger Lakes, and in 2017 had a well-organized HABs surveillance effort. Sporadic, localized HABs were noted around the lake in August and early September, with most observers reporting "no bloom present", but on the 15th of September the east shore had multiple reports of small and large localized blooms. Starting around September 19th, the reports of localized blooms spread to the western shore (Figure 56). On the 26th of September, the surveillance network again reported mostly "no blooms." An unusually large number of samples (52) were taken during the bloom period, and the resulting analytical data is discussed here. Samples were analyzed for toxin concentrations, species composition and cyanobacterial chlorophyll-a concentration by fluoroprobe ("BG Chl-a").

The number of samples taken during the bloom varied each day, from a maximum of nine on 21st September to just one taken on the 18th September. The small sample size *per day* makes statistical analysis problematic. Furthermore, these data come with several important caveats. Anatoxin is relatively unstable and short-lived and so may not represent actual production; this microscopy was qualitative, not quantitative, and may not accurately reflect diversity; and sampling and sample treatment influences the results in unpredictable ways.

These cautions notwithstanding, the time series graphs are suggestive of time-dependent trends, but are not definitive and should not be over interpreted. Two peaks in maximum Chlorophyll and toxin concentrations are discernable during the bloom (Figures 57a and b). The maximum anatoxin concentration found in the samples peaked three days before maximum microcystin concentration in the samples. The number of samples with Dinoflagellates identified as present decreased as the bloom proceeded, so that in the latter stages no dinoflagellates were noted as present in any of the samples (Figure 58). However, this correlation is not significant, even when excluding 18th September (only one sample), resulting in R^2=0.424.

Looking at the dataset it appears that concentrations of anatoxin and microcystin in samples were not correlated (R^2=0.0058); nor were total Chl-a or BG Chl-a correlated with microcystin concentrations (R^2=0.0782, 0.0749 respectively; n=51). It has been hypothesized that cyanobacteria produce toxins to affect other species in a process called allelopathy (Chia *et al* 2018; Suikkanen *et al*, 2004). The hypothesis leads to a supposition that the presence of multiple genera of cyanobacteria would lead to the generation of toxins to impede competing species. However, the number of genera identified in each sample was plotted against the concentration of microcystin (Figure 59), with no obvious relationship or correlation (R^2=0.003). Further research would be needed to explore this postulated trigger for toxin production.

Of note are the meteorological conditions experienced over the whole of the Finger Lakes in September 2017 and in Seneca Lake. In addition to the elevated temperatures, a period of low wind speed occurred. On Seneca Lake, this was recorded by the Hobart and William Smith Colleges' buoy, which is moored off Clark Point. Figure 60 shows that maximum, average and minimum wind speeds all dropped in the days before widespread blooms were reported on the 15th September. Low wind speeds continued throughout the bloom, and wind speeds increased coincidentally with bloom dissipation. Wind direction was variable before the bloom, but was generally southerly, trending westerly over the first week of the bloom (Figure 61).

In summary, the well-organized surveillance effort and the large number of samples taken during the Seneca Lake HAB in September 2017 has yielded data which suggest that the bloom spread over several days from the eastern shore to the western shore. Meteorological data suggest that low wind speeds were associated with the generation of the bloom, and higher wind speeds coincided with its eventual disappearance. Further data would be needed to conclude that genus diversity is correlated with bloom toxicity, and that concentrations of anatoxin and microcystin in samples are not correlated

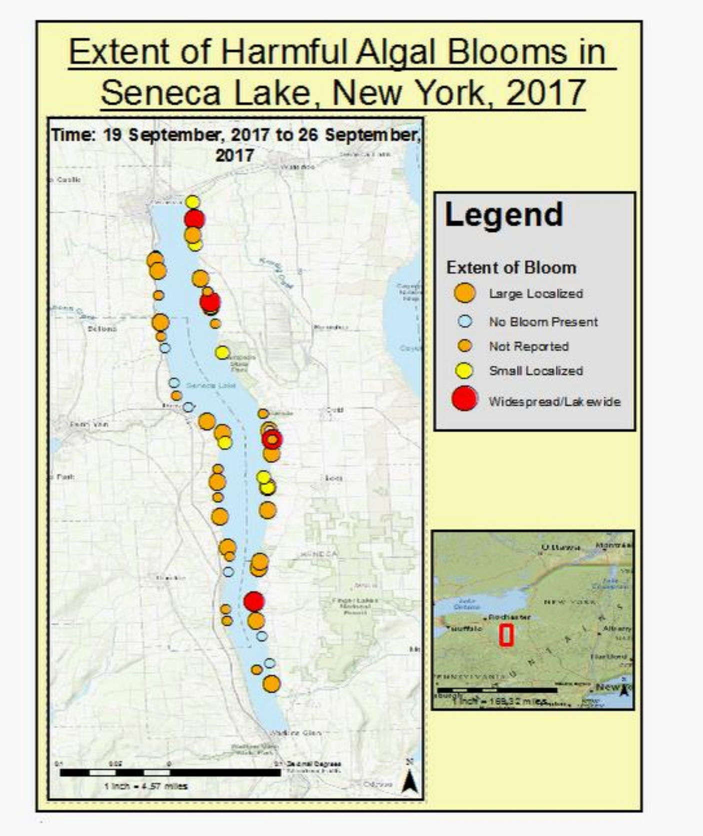


Figure 56. Bloom reports on Seneca Lake in week beginning 19th September.

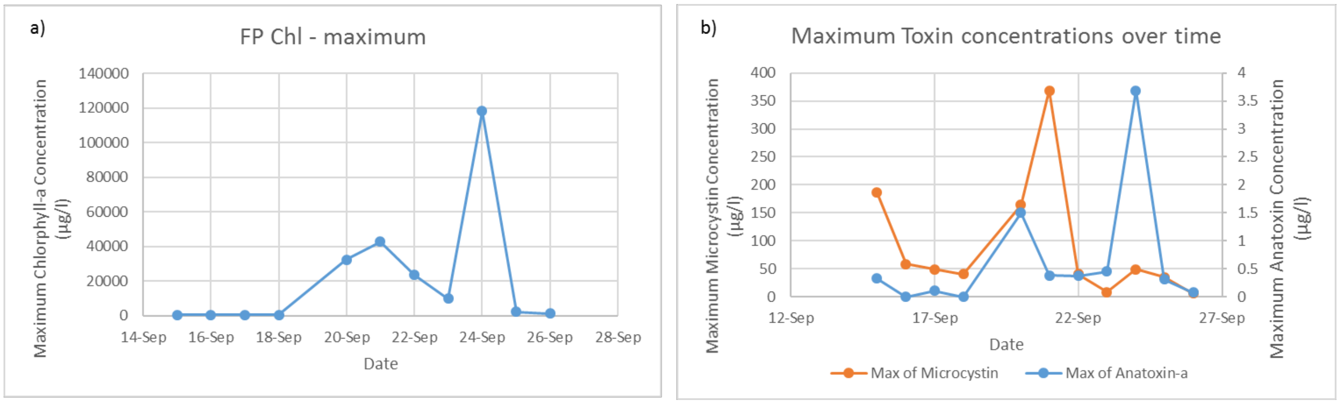


Figure 57. Panel (a) maximum fluoroprobe chlorophyll concentrations (μg/L) per day plotted over the duration of the bloom and (b) maximum toxin concentration. Note the magnified scale of the anatoxin concentration axis.

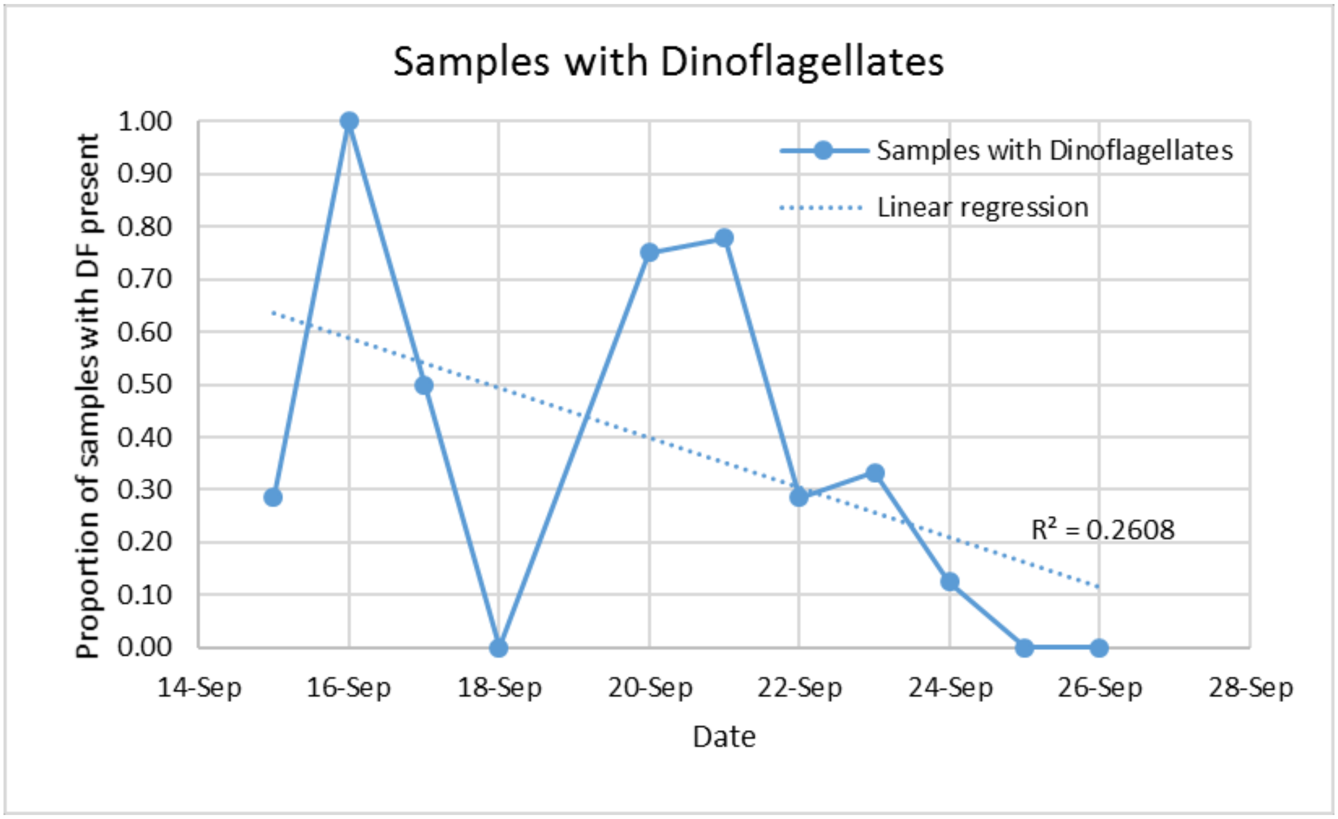


Figure 58. The proportion of samples taken each day with Dinoflagellates noted as present.

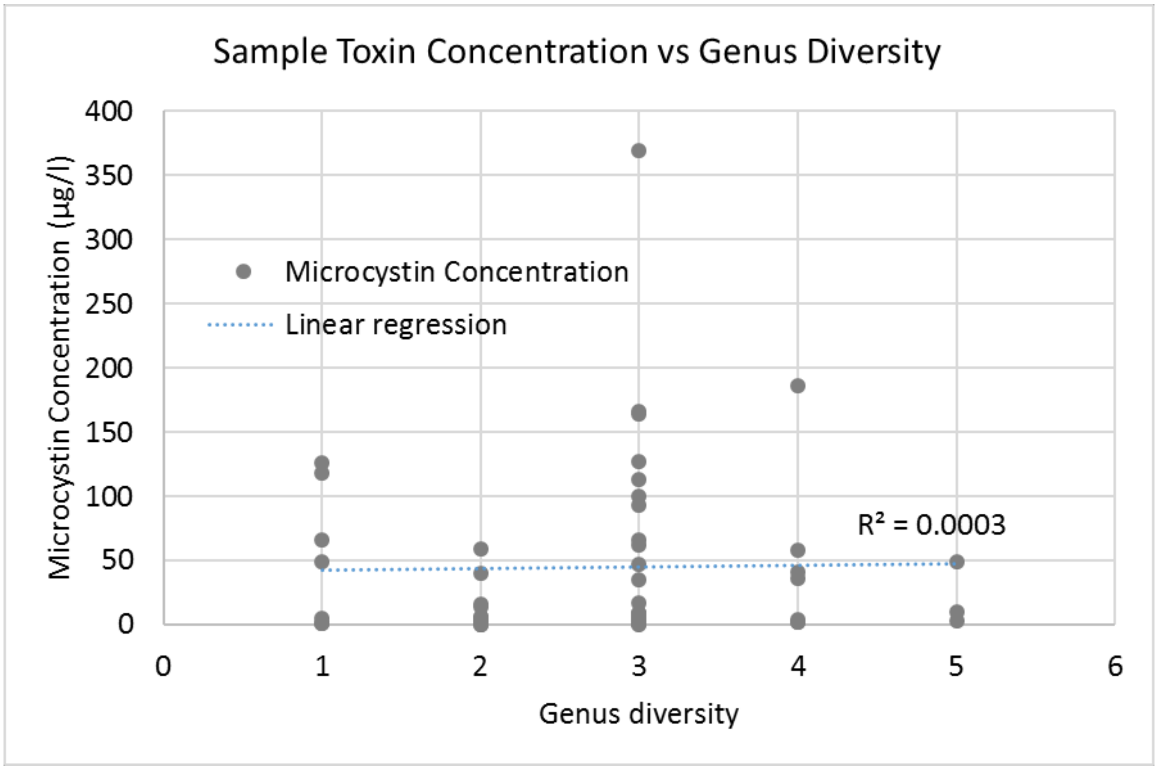


Figure 59. Genus diversity (the number of different genera in each sample) plotted against microcystin (µg/L) concentrations. Most samples had 3 genera noted.

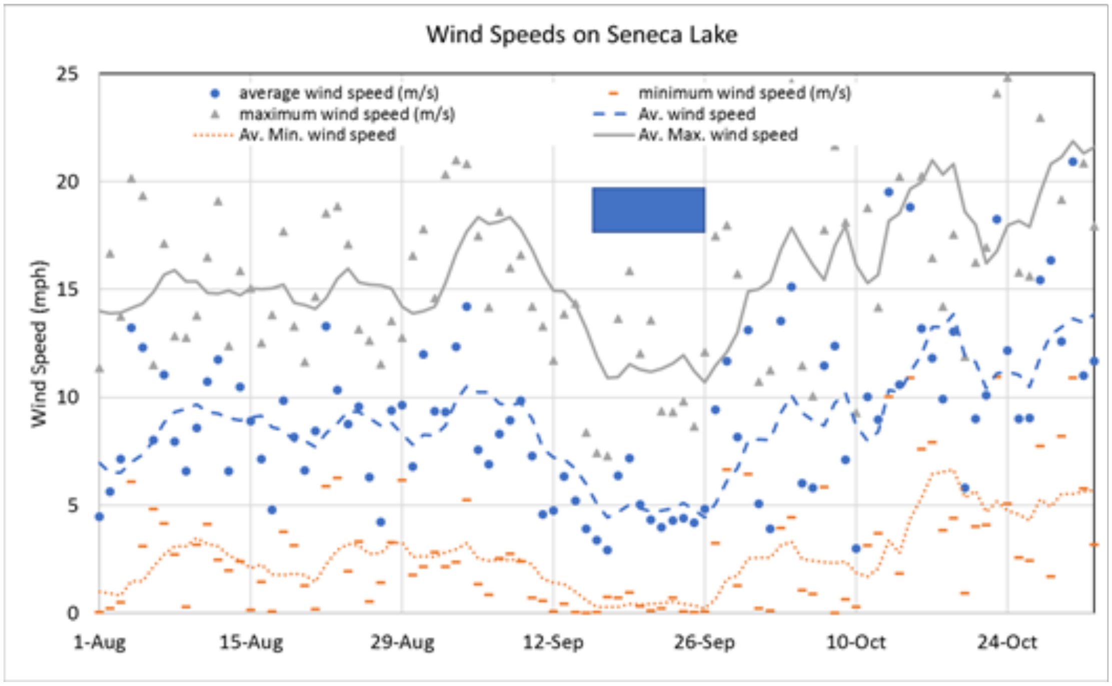


Figure 60. Bloom occurrence (denoted by the blue box) coincided with a decrease in minimum, average and maximum wind speeds (mph). Data from Hobart and William Smith Colleges FLI Buoy.

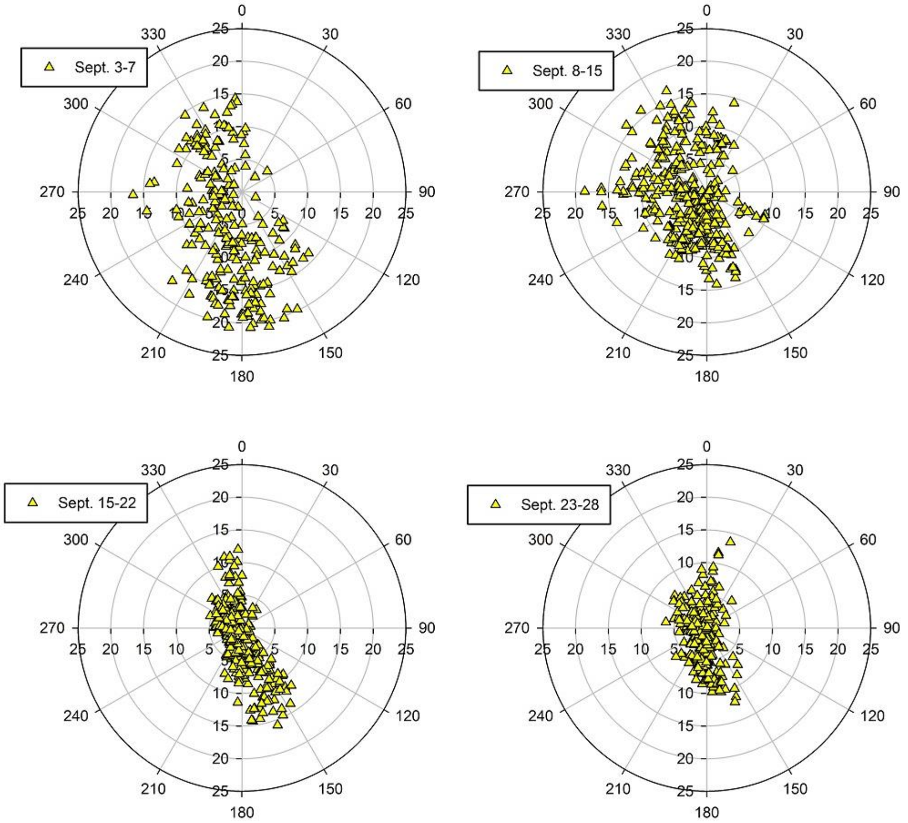


Figure 61. Wind directions in the week before the Seneca Lake bloom (Sept 8-15) had a noticeable westerly component, compared to preceding and subsequent weeks, likely blowing open water blooms to the eastern shoreline. Western shoreline appearances of HABs were not driven by easterly winds (Sept 15-22). Data from Hobart and William Smith Colleges FLI Buoy.

Summary

In summary, the Finger Lakes have good water quality but represent environments adequate for the development of HABs (Table 19). All 11 lakes have: (1) favorable climate, (2) N-S orientation, (3) long fetch lengths, (4) long retention times, and (5) the presence of invasive dreissenid mussels. With the documented blooms on Skaneateles, Keuka, and other low nutrient lakes in NYS and across the country (Sarnelle et al. 2012) it is now apparent that even these oligotrophic systems provide enough resources to allow the development of HABs.

Complex physical, environmental, and biological factors interact to influence the proliferation, extent, and duration of HABs both within lakes and between systems. Local scale meteorology, nutrient ratios, concentrations of dissolved organic matter, micro-nutrient availability, mussel prevalence, and zooplankton grazing pressure are some of the many factors that influence a bloom's development and longevity. These and other factors will continue to be researched in the Finger Lakes to identify proximate bloom triggers, determine the factors driving bloom growth and collapse, and develop additional management plans for mitigating HABs.

Table 19. Factors that influence the occurrence of harmful algal blooms (HABs)

	Factor						
Lake	**Climate**	**Productivity (Chl-a)**	**Nutrients (TP)**	**Orientation**	**Fetch Length**	**Water Residence**	**Dreissenid mussels**
Conesus	X	✓✓	✓✓✓	X	✓✓	✓	X
Hemlock	X	✓✓	✓✓	X	✓✓	✓✓	X
Canadice	X	✓	✓	X	✓	✓✓	X
Honeoye	X	✓✓✓	✓✓✓	X	✓	✓	X
Canandaigua	X	✓✓	✓	X	✓✓	✓✓	X
Keuka	X	✓✓	✓	X	✓✓	✓✓	X
Seneca	X	✓✓	✓✓	X	✓✓✓	✓✓✓	X
Cayuga	X	✓✓	✓✓	X	✓✓✓	✓✓	X
Owasco	X	✓✓	✓✓	X	✓✓	✓✓	X
Skaneateles	X	✓	✓	X	✓✓	✓✓✓	X
Otisco	X	✓✓	✓✓✓	X	✓	✓	X
Description	temperature, light, precipitation and runoff, wind	✓oligo ✓✓meso ✓✓✓eu	✓< 0.01mg/L ✓✓0.01 - 0.02 mg/L ✓✓✓> 0.02 mg/L	all ~ N-S orientation	✓< 10 km ✓✓10 – 25 km ✓✓✓> 25 km	✓< 2 y ✓✓2-10y ✓✓✓> 10y	present in waterbody

✓ indicates a factor's positive influence on HABs

X presently a factor common to all eleven Finger Lakes

Section 7: Future Work

This report provides information regarding current limnological conditions within the Finger Lakes and documents observed changes over the past four decades relative to 2017. Important questions remain unanswered and additional research is necessary to better understand and define potential trends identified in this report.

Through the expanded CSLAP initiative, made possible through funding from the Environmental Protection Fund, volunteer scientists monitored twenty-two locations on all eleven Finger Lakes during the summer (June – September) of 2017. The continued sampling of these sites will support a robust dataset and more comprehensive assessment of the Finger Lakes upon which to make critical management decisions.

Continued and expanded CSLAP sampling in 2018, HABs monitoring networks, the continuing statewide HABs analyses overseen by NYSDEC as part of the Governor's HABs Initiative, and the continuing partnerships among agencies, lake associations, and lakefront residents will enhance our understanding of Finger Lakes water quality. Six additional sites have been added to CSLAP in 2018 (an extra site on Keuka, two on Seneca Lake and three on Cayuga Lake) and more parameters have been added to aid in the evaluation of these waters for eutrophication and HABs.

In future reports, analysis will include more lake-specific information and possibly utilize additional, external data. Third party data will be evaluated to insure compliance with NYSDEC's quality assurance protocols. NYSDEC's winter sampling program in the Finger Lakes will also be incorporated into future reports to give a year-round view of nutrient concentrations and ecological processes in these lakes.

The CSLAP volunteers put forth a significant effort to provide this data. Quality control results provide assurance that the data collected through CSLAP is of sufficient quality to aid NYSDEC in making accurate assessments and important management decisions to protect the water quality of these important natural resources.

Section 8: References

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Websites and Online Resources

iMapInvasives; http://www.nyimapinvasives.org

NYSDEC and NYFOLA instructional videos; (http://www.dec.ny.gov/chemical/81849.html)

NYSDEC and NYFOLA sampling protocol quizzes; (http://www.dec.ny.gov/ docs/water_pdf/cslapquiz2.pdf

NYSDEC and NYFOLA written sampling protocols; (http://www.nysfola.org/cslap)

NYSDEC Consolidated Assessment and Listing Methodology (CALM); https://www.dec.ny.gov/chemical/36730.htm)

NYSDEC CALM; http://www.dec.ny.gov/docs/water_pdf/asmtmeth09.pdf

NYSDEC Citizen Statewide Lake Assessment Program; https://www.dec.ny.gov/chemical/81576.html

NYSDEC CSLAP on-line data entry; https://www.cslapdata.org/index.php

NYSDEC CSLAP Quality Assurance documents; http://www.dec.ny.gov /chemical/81849.html

NYSDEC HABs Action Plans for 12 priority lakes; https://on.ny.gov/HABsAction

NYSDEC HABs Program Guide; http://www.dec.ny.gov/docs/water_pdf/habsprogramguide.pdf

NYSDEC HABs Program; https://www.dec.ny.gov/chemical/77118.html

NYSDEC HABs FAQs; https://www.dec.ny.gov/chemical/91570.html

NYSDEC HABs Notifications Page; https://www.dec.ny.gov/chemical/83310.html

NYSDEC LCI Program; https://www.dec.ny.gov/chemical/31411.html

NYSDEC Lake Monitoring Standard Operating Procedures; http://www.dec.ny.gov /docs/water_pdf/sop20314.pdf

NYSDEC VISION APPROACH to implement the Clean Water Act 303(d) Program and Clean Water Planning http://www.dec.ny.gov/docs/water_pdf/dowvision.pdf
NYSDEC Waterbody Inventory Priority Water Lists (WI/PWLs) Lower Genesee River; http://www.dec.ny.gov/chemical/36744.html.

NYSDEC WI/PWLs Oswego River/Finger Lakes Basin (West); http://www.dec.ny.gov/chemical/36737.html

NYSDOH HABs information; www.health.ny.gov/harmfulalgae

Section 9: Individual Lake Chapters

Conesus Lake
Hemlock Lake
Canadice Lake
Honeoye Lake
Canandaigua Lake
Keuka Lake
Seneca Lake
Cayuga Lake
Owasco Lake
Skaneateles Lake
Otisco Lake