WATER QUALITY OF THE EIGHT EASTERN FINGER LAKES, NEW YORK: 2005 – 2016.

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EXECUTIVE SUMMARY

- The eleven Finger Lakes of western and central New York are critical to the health, well-being and economy of the region.
- The range in trophic status, size, water residence times, bedrock geology, land use characteristics, and other features revealed by the FLs present an ideal natural laboratory to investigate a wide range of water quality issues, many pertinent to the Great Lakes.
- Professor John Halfman, Hobart and William Smith Colleges has maintained a water quality monitoring program of the eight eastern Finger Lakes for the Finger Lakes Institute since 2005 (Honeoye, Canandaigua, Keuka, Seneca, Cayuga, Owasco, Skaneateles, & Otisco). The program collected and analyzed monthly CTD profiles, plankton tows, Secchi disk depths, most recently, (2016) fluoroprobe profiles, and surface and bottom water samples for nutrient (TP, SRP, NO3, Si), chlorophyll-a, total suspended solids, and major ion analyses back in the laboratory at a minimum of two mid-lake, deep-water sites in each lake.
- Selected stream analyses and two autonomous water quality and meteorological monitoring buoys deployed in the Seneca and Owasco watersheds provide additional data to better understand the limnology and water quality issues in these lakes.
- Relative ranks of the surface water data indicated that Skaneateles, Canandaigua and Keuka Lakes have the best water quality (ultra-oligotrophic to oligotrophic), Honeoye and Otisco Lakes have the worst water quality (eutrophic to borderline mesotrophic-eutrophic), and Seneca, Cayuga and Owasco Lakes were in between these end-members (borderline oligotrophic-mesotrophic to mesotrophic).
- Year to year changes in the water quality ranks and individual parameters revealed a reginal water quality degradation in 2014 and 2015. This deviation coincided with larger spring rainfalls, and their associated nutrient and sediment loads. This timing also coincided with the establishment of blue-green algae blooms and associated toxins in a number of the FLs, surprisingly even in some oligotrophic and mesotrophic systems.
- Phosphorus was the limiting nutrient in these Finger Lakes except for Honeoye Lake and seasonally in Keuka Lake.
- Preliminary phosphorus budgets for Seneca and Owasco Lakes revealed larger inputs to than outputs from each lake, a classic nutrient loading problem. However, it pinpoints potential remediation solutions for these lakes, remediation efforts that must be in place for multiple water residence times (decades+) to be effective. Other ecological and water quality stressors exist but were not detailed in this report.
- Conesus, Honeoye, Canandaigua, Seneca, Owasco and Otisco experienced a recent rise in blue-green algae (BGA) blooms, many blooms with harmful concentrations of toxins. Since

2005 (and earlier), all of the monitored FLs (even Skaneateles Lake) have had BGA in the plankton community that peaked in late August.

- Blue-green algae concentrations significantly exceeded typical open-water algal concentrations. It indicates that the buoyancy regulation and presumed wind-driven nearshore locations for many BGA blooms probably concentrated the surface scum of algae into smaller volumes of water.
- The Owasco Lake monitoring buoy data indicated that the nearshore BGA blooms occurred after (a week or two) summer solstice and the warmest air and water temperatures, and were absent after daily mean solar insolation decreased to 150 $\mu E/cm^2$, and air and surface water temperatures fell below 10°C and 15°C, respectively. Blooms were more likely during calm or nearly calm, sunny days after an episode of rainfall but were not detected on every calm or nearly calm day and/or every rainfall event. The dominant southerly winds coincided with the northerly locations for the majority of the detected nearshore blooms.
- Even though scientists are still learning about the drivers for the recent rise in BGA blooms in these lakes, one thing is clear, point and nonpoint source nutrient reduction strategies in each watershed provide a potential remediation strategy for this most recent threat to water quality in the Finger Lakes.

INTRODUCTION

The Finger Lakes of western and central New York are critical to the health, well-being and economy of the region. The eleven lakes, Conesus, Hemlock, Canadice, Honeoye, Canandaigua, Keuka, Seneca, Cayuga, Owasco, Skaneateles, and Otisco, contain a combined 8.1 trillion gallons of water (30.8 km^3), and their watersheds occupy a 2,630 square mile (4,970 km^2), 14-county region (Table 1, Fig. 1)[1]. These lakes provide Class AA drinking water to 1.5 million residents in the surrounding communities. For example, Skaneateles and Otisco Lakes provide drinking water to the City of Syracuse, and Hemlock and Canadice Lakes provide drinking water to the City of Rochester. Total withdrawals from Finger Lake sources are approximately 190 million gallons of water per day[1].

Table 1. Finger Lake Statistics[1,2]

Lake	Water Volume ($10^6 m^3$)	Surface Area (km^3)	Drainage Area (km^2)	Maximum Water Depth (m)	Permitted Withdrawals (MGD)
Conesus	157	14	168	18	6.9
Hemlock	106	7	96	29	37 for Hemlock
Canadice	43	3	32	27	& Canadice
Honeoye	35	7	95	9	0
Canandaigua	1,640	42	407	84	16
Keuka	1,434	47	405	57	5.36
Seneca	15,540	175	1,181	186	9
Cayuga	9,379	172	1,870	132	11.2
Owasco	781	27	470	52	16.0
Skaneateles	1,563	36	154	84	58.0
Otisco	78	8	94	20	20.0

[1] Callinan, C., 2001. Water Quality Study of the Finger Lakes. New York State Department of Environmental Conservation. 151 pgs.

[2] Bloomfield, J., 1978. Lakes of New York State. Vol. 1. Ecology of the Finger Lakes. New York, Academy Press, 499pg.

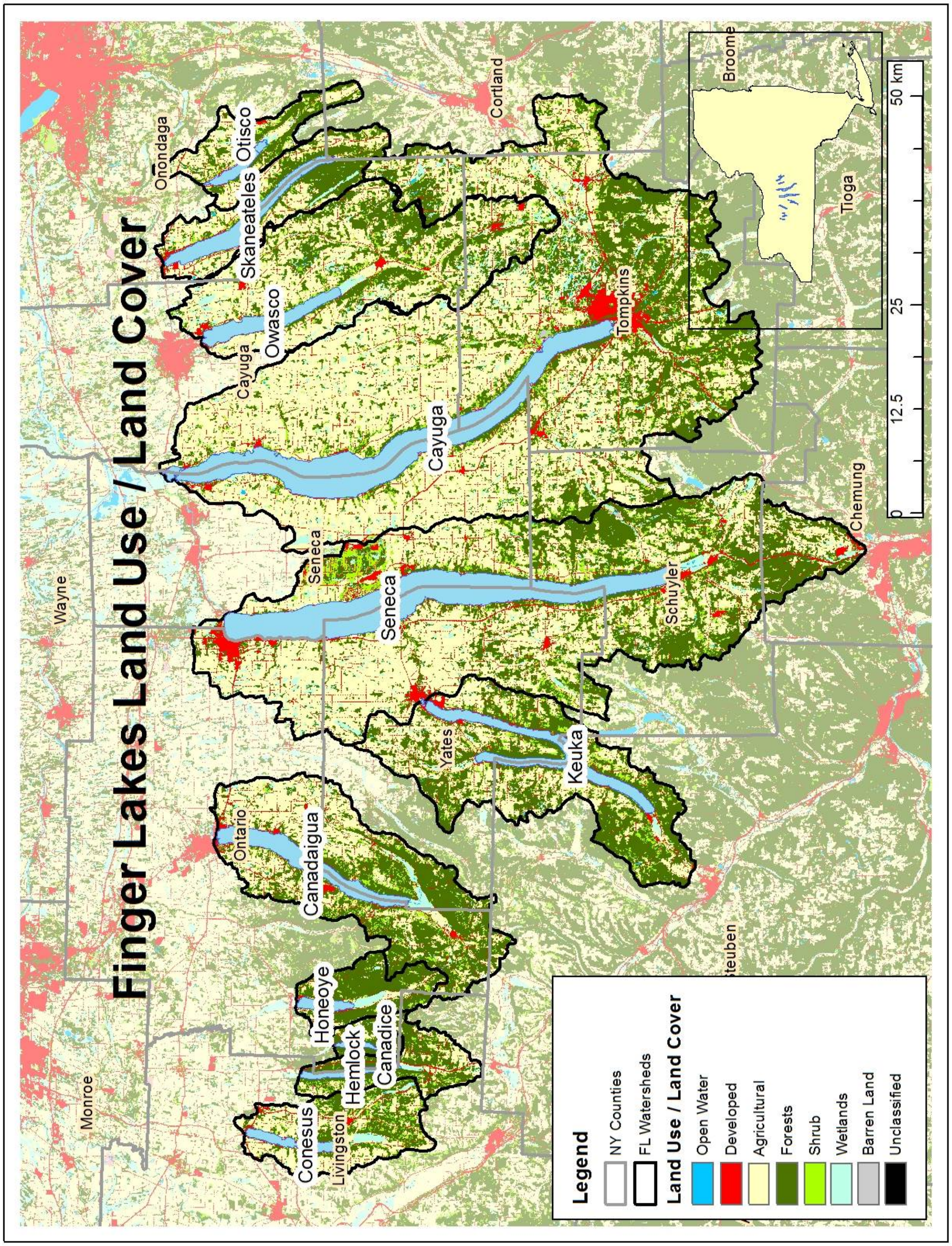

Fig. 1. The Finger Lakes, their watersheds, and land use / land cover (30x30m NDLC 2011 data). The insert shows the location of the lakes within New York State. Geneva, NY, occupies the northwest shores of Seneca Lake.

The initial 2006 Finger Lake Institute's water quality report and its 2009 update under the direction of Dr. John Halfman, Finger Lakes Institute at Hobart and William Smith Colleges ranked water quality parameters for Honeoye, Canandaigua, Keuka, Seneca, Cayuga, Owasco, Skaneateles and Otisco Lakes[3]. These eight lakes were selected because they span the diversity of land use activities and bedrock geologies in the region, contain 98% of the water in the Finger Lakes, and are closest to the HWS campus in Geneva, NY. The ranks were based on monthly limnological monitoring of mid-lake, deep-water sites in each lake during the May through September field season, and indicated that Otisco and Honeoye Lakes had the worst water quality, Skaneateles, Canandaigua and Keuka Lakes had the best water quality, and Cayuga, Seneca and Owasco Lakes fell in between the end-members. Year-to-year changes in rank indicated that water quality had changed over time in most of these lakes.

Maintaining or improving water quality will impact the local region in numerous ways. First, the Finger Lakes supply drinking water to Rochester, Syracuse and other neighboring communities. Numerous lakeside homeowners also draw drinking water directly from their lake. Thus, good water quality is critical for our health and pocketbooks. Second, good water quality supports a variety of tourism industries in the region, including an internationally celebrated winery industry. Third, good water quality positively impacts local tax revenues. Property assessments[4] in the Owasco and Seneca watersheds reveal a significantly larger number of parcels, and larger property assessments per acre for parcels adjacent to the lakeshore than those properties away from the lake (Fig. 2). Other lakes probably have similar or more skewed trends. The dichotomy places a shaky reliance on the revenue from the lakeshore acreage, as it would decline in the wake of deteriorating water quality. Thus, municipal officials should do everything in their power to maintain water quality in their lakes. Most importantly, we owe it to future generations to leave the Finger Lakes in better shape than when we got them.

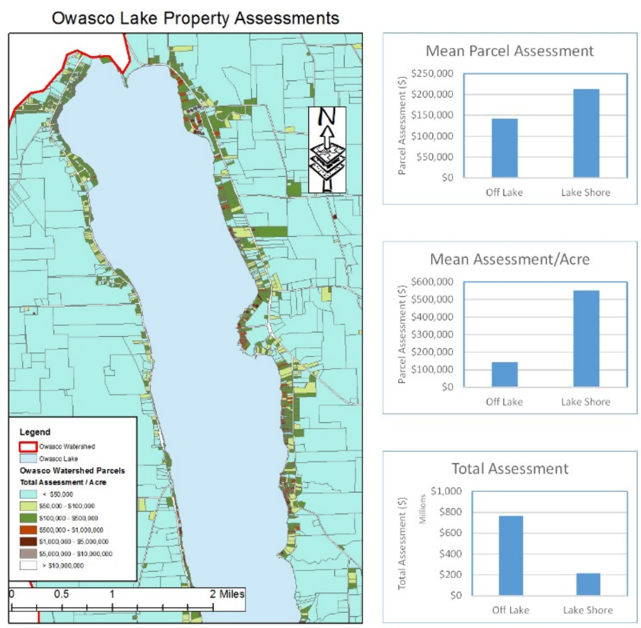

Fig. 2. Owasco Lake property assessments per acre of land.

Since the initial FLI survey, continued water quality investigations dovetailed: (1) monitoring of the eight eastern Finger Lakes to investigate year-to-year changes in water quality, (2) more detailed investigations of selected watersheds to more fully understand the source and inputs of nutrients, and (3) acquisition of water quality and meteorological monitoring buoys that were

[3] Halfman, J.D., and K. F. Bush, 2006. A preliminary water quality study of selected Finger Lakes, New York. Finger Lakes Institute, Hobart and William Smith Colleges. 15 pg.
Halfman, J.D., and K. O'Neill, 2009. Water quality of the Finger Lakes, New York: 2005 – 2008. Finger Lakes Institute, Hobart and William Smith Colleges. 33 pg.

[4] Assessment data and parcel's map acquired from the respective counties in the summer of 2016.

deployed through the April to October ice-free, field season in Seneca (since 2006) and Owasco Lakes (since 2014).

This report is an update on our current understanding of water quality parameters of the Finger Lakes. It also provides insights into the recent rise in blue-green algae blooms based on the collected data and its interpretations. The ultimate goal is to present the water quality data and explain its scientific interpretations and implications, so that the general public, policy makers, and other stakeholders understand the recent trends in water quality.

WATER QUALITY INDICATORS

The rural landscape of the Finger Lakes region is dominated by agricultural (43%) and forested (31%) land use activities with lesser amounts of urban (6%) land (Fig. 1). Open water spans 10% and wetlands another 6% of the watersheds. The regional land use implies that the common water quality threat to these lakes is nutrient loading from agricultural and urban sources. The reason is simple. Excess nutrients stimulate algal and nearshore plant growth, which reduces water quality and water clarity in lakes, and speeds up the eutrophication and associated impairment process.

Dissolved phosphate (PO_4^{-3}) and nitrate (NO_3^-) are essential nutrients for all life as they are crucial for building, for example, amino acids, proteins, cell tissue, RNA and DNA. Nutrients enter the food chain through the assimilation of these dissolved compounds by plants, phytoplankton (algae, microscopic aquatic plants) and macrophytes (nearshore rooted vegetation). When the algae and other plants are eaten, these nutrients are passed up the food chain in their organic forms to the other aquatic organisms like, e.g., zooplankton, small fish, lake trout and birds. When an organism dies, bacteria decompose the organic matter and release the nutrients, in their dissolved form, back into the water column to be assimilated by algae and other plants once again. The result is a nutrient cycle (Fig. 3). Due to the scarcity of nutrients in lakes, lake ecosystems are very proficient at recycling the available pool of nutrients.

Nutrient loading from a variety of point and nonpoint sources potentially transforms an oligotrophic (poorly productive) lake to an eutrophic (highly productive) lake, because the extra nutrients stimulate additional algal and macrophyte growth, that in turn, increase the amount of material in each box of the nutrient cycle. Other, typically undesirable but related impacts occur. The increase in algae decreases water clarity (e.g., transparency), as the extra algae increasing block the transmission of light through water. The increased algal concentrations increase the cost of water filtration costs for municipal water supplies. Finally, the algal community in eutrophic systems is typically dominated by a foul smelling/tasting (aka yucky), occasionally highly toxic, surface scum of blue-green algae (BGA). Not a pleasant scenario for the local municipal water purveyors and the tourism - winery economies.

Unfortunately, once nutrients enter a lake, the ecosystem typically remains enriched, because nutrients are continually and efficiently recycled within the lake. Thus, the excess nutrients continue to “fertilize” plant growth at enhanced levels. Currently, only a small fraction of the nutrients are permanently lost from the lake out the outlet or buried into the sediments.

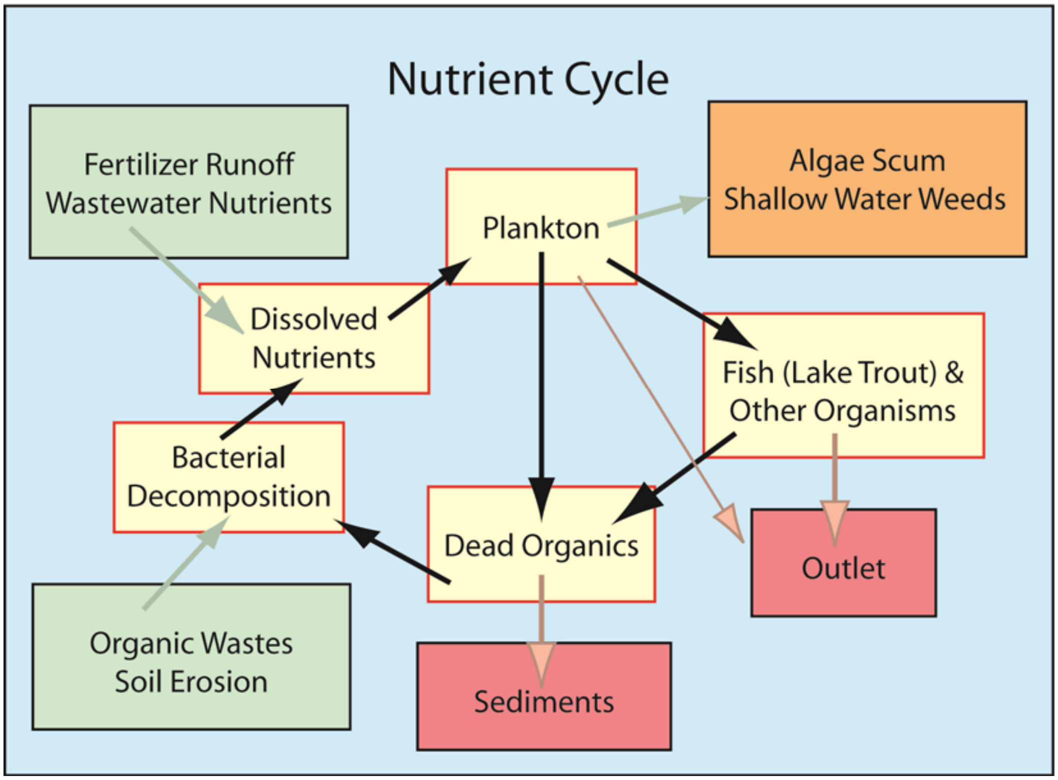

Fig. 3. A typical nutrient cycle for a lake (yellow boxes). Typical natural and human-induced additions (green boxes), their impact (orange box), and natural sinks (red boxes) from the nutrient cycle are also shown.

The increase in BGA blooms in many Finger Lakes raises a larger concern. The excess biomass increases the filtration costs to supply drinking water. Some species of BGA produce toxins that pose a health threat to humans and other warm bodied animals. BGA taxa that can produce toxins do not synthesize toxins all the time, but when toxins are produced the blooms are called harmful algal blooms (HABs). Different toxins are synthesized by different BGA taxa that impact different parts of the body, most notably, the liver, the nervous system, and/or gastrointestinal system. Liver cyanotoxins like mycrocystins are most commonly found in HAB blooms, and at high doses can cause organ damage, heart failure and death in lab animals. Mycrocystins can be synthesized by various species of *Mycrocystis* and *Anabaena* genera, which have been detected in all the surveyed Finger Lakes, even Skaneateles Lake. Anatoxins impact the nervous system and can be synthesized by *Anabaena* and other BGA genera. Their impact on humans at low concentrations still remains elusive.

The World Health Organization (WHO) has issued a provisional finished drinking water guideline of 1 μg/L for chronic (extended) exposure to mycrocystin, and recreational, e.g., swimming, exposure limit of 20 μg/L. The EPA's maximum contaminant level (MCL) in drinking water for mycrocystin is 0.3 μg/L for infants and 1.6 μg/L for school-age children and adults. Their recreational contact limit is 4 μg/L. EPA thresholds for anatoxins are not yet available, although 4 μg/L might be used. The short half-life of anatoxins make it difficult to monitor. No one wants BGA toxins in their municipal water supplies like what happened at Toledo, OH in 2014. Unfortunately, BGA toxins up to 0.22 μg/L have been detected in a municipal water supply drawing water from Owasco Lake, but the incident was short lived and measured concentrations never exceeded the DEC's MCL for infants. Nearshore residents, as a simple rule, should play it safe. If the water looks green, then stay out of and do not drink the water. More details are available at the NYS-DEC HABs website[5].

Indicators of Trophic Status & Water Quality: Phosphates (PO_4^{-3}), the dissolved form of phosphorus, at natural concentrations do not pose a health risk but contribute to the fertilization and eutrophication of waterways. Phosphate is critical for eutrophication, because it is typically the limiting nutrient for algal growth in freshwater systems. "Limiting" means, the supply of the limiting nutrient is exhausted before the other nutrients, and its scarcity limits additional photosynthesis until new sources are found. Phosphate concentrations are typically very close to zero (~ < 1 μg/L, P), as almost all of the available phosphorus is effectively incorporated into organic matter in phosphorus limited lakes. Total phosphorus (TP), a measure of the dissolved and particulate phosphorus in a lake, is a better measure of the amount of phosphorus available to the ecosystem. The NYS DEC uses a total phosphorus threshold of 20 μg/L for impaired water bodies. This concentration also defines the boundary between mesotrophic and eutrophic lakes (Table 2).

Excess nitrates are health risks to humans, specifically methemoglobinemia or blue-baby syndrome. Thus, the EPA sets a maximum contaminant level (MCL) for nitrate concentrations at 10 mg/L for safe drinking water. Occasionally nitrogen is the limiting nutrient in freshwater systems, especially in eutrophic lakes, like Honeoye Lake. Some BGA species like those in the *Anabaena* genus can "fix" atmospheric nitrogen (N_2) for their source of nitrogen if dissolved forms run dry, whereas most other forms of algae including some forms of BGA like *Mycrocystis* cannot "fix" N_2 and are instead dependent on the dissolved forms of nitrogen, nitrate (NO_3^-) or ammonium (NH_4^+), for photosynthesis.

Algal concentrations are another indicator of lake productivity and its trophic status. Algal concentrations are measured directly by the concentration of chlorophyll, and indirectly by fluorometer, total suspended solids and Secchi disk depths. The DEC is currently establishing a new criterion for portable water bodies based on chlorophyll concentrations. Any water body with a chlorophyll concentration below a 4 to 6 μg/L threshold is considered potable[6]. The boundary between oligotrophic, mesotrophic and eutrophic systems are 4 and 10 μg/L, respectively.

The Secchi disk measures water clarity. It is a weighted disk, 20 cm in diameter, and painted with two black and two white quadrants. It is slowly lowered into the water until it disappears, and this water depth is noted. The disk is lowered some more, and then slowly pulled up until it reappears, and this second water depth is noted. The Secchi disk depth is the average of these two depths. In ultra-oligotrophic (low productivity) systems, i.e., very transparent waters, Secchi disk depths can be 30 m (~100 feet) or more. In eutrophic (high productivity) lakes and ponds, Secchi disk depths can be as shallow as a few centimeters. Secchi disk depths defining the boundaries for mesotrophic lakes are 4 and 2 meters.

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[5] New York State, Department of Environmental Conservation, Harmful Algal Blooms website.

[6] Callinan, C.W., J.P Hassett, J.B. Hyde, R.A. Entringer & R.K. Klake. 2013. Proposed nutrient criteria for water supply lakes and reservoirs. American Water Works Association Journal, E157-E172.

Dissolved oxygen concentrations are another indicator of the trophic status in lakes. When the algae die (algae live for only a few days), bacteria decompose, i.e., respire, the organic material. Bacterial decomposition consumes dissolved oxygen and releases carbon dioxide, as it recycles nutrients, in their dissolved state, back into the environment. If the removal of oxygen from the summer-time hypolimnion (water depths below the thermocline) is severe enough, respiratory stress is placed on all cold water and lake-floor loving aquatic animals, e.g., lake trout, because dissolved oxygen is required for survival by all respiring organisms. The concentration threshold for induced stress is somewhere below 6 mg/L, each species has its own level of tolerance. Complete de-oxygenation of the bottom waters typically happens in eutrophic lakes by the middle or end of the summer season. Once anoxic, other strains of bacteria continue the recycling process, using other oxidants to decompose the organic matter. Anoxic decomposition processes release methane (odorless) and/or hydrogen sulfide (rotten egg smell) instead of carbon dioxide.

Thus, nutrient, algal and dissolved oxygen concentrations, and Secchi disk depths are useful trophic status indicators (Table 2). Typically, every parameter in a lake does not fall within the same trophic state boundaries, because all lakes are not uniform in volume, area, shape, watershed character and other factors. A lake can be designated by majority rule, or listed as borderline, e.g., borderline oligotrophic-mesotrophic, if its parameters are split between states.

Table 2. Trophic Status Guidelines for Oligotrophic (low productivity), Mesotrophic (mid-range productivity), and Eutrophic (high productivity) lakes.

Trophic Status	Secchi Depth (m)	Total Nitrogen (N, mg/L, ppm)	Total Phosphate (P, μg/L, ppb)	Chlorophyll a (μg/L, ppb)	Bottom Water Oxygen (% saturation)
Oligotrophic	> 4	< 2	< 10	< 4	> 80
Mesotrophic	2 to 4	2 to 5	10 to 20	4 to 10	10 to 80
Eutrophic	< 2	> 5	> 20 (> 30)	> 10	< 10

WATER QUALITY MONITORING METHODS

Field Methods: Water quality was routinely monitored at Honeoye, Canandaigua, Keuka, Seneca, Cayuga, Owasco, Skaneateles and Otisco Lakes at a minimum of two, deep water, mid-lake sites on at least a monthly basis during the May to September field season (Fig. 4). Otisco Lake was added to the Finger Lakes monitoring program in 2008. Sampling was more frequent and/or at more sites during portions of the past decade at Seneca, Cayuga, and Owasco Lakes. In addition, major tributaries to Seneca and Owasco Lakes were sampled utilizing stream segment analysis to pinpoint nutrient sources. Daily or more frequent stream samples were collected to quantify total nutrient fluxes (loads) to the lake, and the relative loads between precipitation induced events and intervening base flow stream states.

A CTD water quality profile, Secchi disk depth, vertical plankton tow, and surface and bottom water samples were collected at each site. The CTD electronically gathers water column profiles of temperature (°C), conductivity (reported as specific conductance, μS/cm, a measurement proportional to salinity), dissolved oxygen (mg/L), pH, turbidity (NTUs), photosynthetic active radiation intensities (PAR, $\mu E/cm^2$-s), and fluorescence (a measure of chlorophyll-a, μg/L) using a SeaBird SBE-25 CTD (Fig. 5). The CTD was lowered from the surface to ~1m above the lake floor, collecting data every 0.5 seconds (~0.2 meters) along the downcast. The plankton net (with a 20 cm diameter opening and an 80-μm mesh) was towed from a depth of 20 m to the surface (or from just above the lake floor, if shallower than 20 m). The captured plankton were preserved in an alcohol-formalin solution for identification back in the laboratory. Water samples were analyzed onsite for temperature (°C), conductivity (specific conductance, μS/cm), pH, dissolved oxygen (mg/L), and alkalinity (mg/L, $CaCO_3$) using hand-held probes and field titration kits, and analyzed back in the laboratory for total phosphate (μg/L, P), dissolved phosphate (SRP, μg/L, P), nitrate (mg/L, N), chlorophyll-a, and total suspended solid (mg/L) concentrations. Finally, a recently acquired fluoroprobe collected algal profiles at each site during one or two surveys in 2016. The BBE Fluoroprobe collects profiles of water temperature and differentiates between four different algal groups based on their accessory pigments. It distinguishes between: 'green' algae (Chlorophyta and Euglenophyta), 'brown' algae (diatoms: Baccillariophyta, Chyrsophyta, and Dinophyta), 'blue-green' algae (Cyanophyta), 'red' algae (Cryptophyta) and 'yellow' substances.

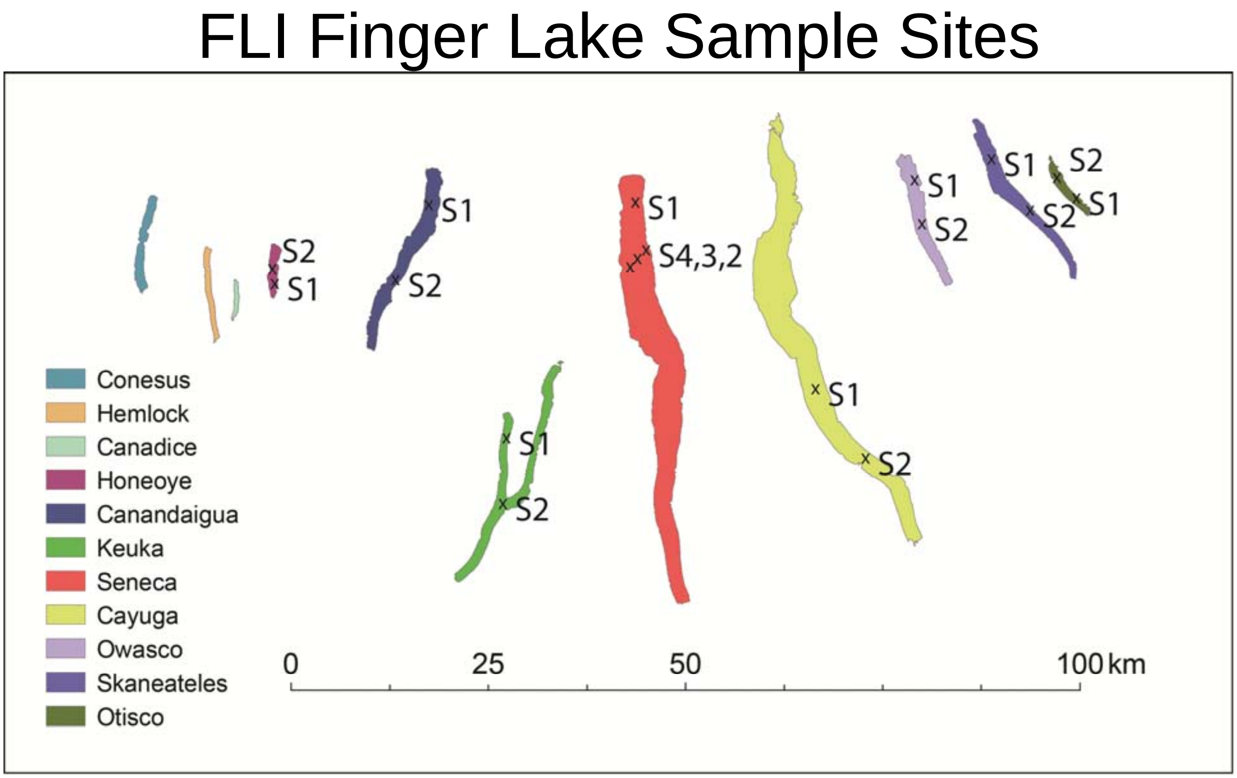

Fig. 4. Sample site locations.

Stream Methods: Although stream sampling was not part of the FLI Finger Lake Survey, stream sampling methods are outlined here because selected streams were analyzed to pinpoint the source of nutrients and sediments. Stream segment analysis, where multiple sites are sampled along selected streams, was used to pinpoint nutrient and sediment source(s) along each stream course. At each stream site, stream discharge was measured and water samples were collected for nutrient and suspended sediment analyses back in the laboratory. Stream discharge (the volume of water per unit time flowing past a site) was calculated from measured stream width, depth and velocity data, the last two variables at 5 or 10 equally spaced locations perpendicular to stream flow at the site (using a 30 m tape, wading rod and HACH FH950 portable velocity flow meter with electromagnetic sensor). Stream discharge (water volume per unit time, e.g.,

m^3/s) is required to calculate nutrient and suspended sediment loads, because a load (mass/time, e.g., kg/day) equals stream discharge (volume water/time, e.g., m^3/s) times its concentration (mass/volume water, e.g., mg/L).


Fig. 5. The CTD.

A Teledyne ISCO automated water sampler and data loggers were deployed at the terminus of Dutch Hollow Brook from April through October starting in 2011 to determine daily nutrient and suspended sediment loads and investigate the impact of event *vs.* base flow variability on the delivery of nutrients and sediments to Owasco Lake. The sampler was programmed to collect 1-L of water every 8 (or 24) hours which were subsequently analyzed for total phosphorus, dissolved phosphate, nitrates, dissolved silica, and total suspended solids. The data loggers recorded hourly stream stage (height), temperature and specific conductance data. The stage data and periodic (weekly to bi-monthly) stream discharge measurements established a rating curve, a relationship between stream height and stream discharge to estimate a stream discharge for every ISCO water sample and, in turn, its daily load to the lake.

Monitoring Buoys: The FLI meteorological and water quality monitoring buoys manufactured by YSI/Xylem were deployed at mid-lake sites in northern Seneca and central Owasco Lakes from April through October. The Seneca buoy was purchased and initially deployed in 2006 and upgraded in 2014 with common set of sensors as the Owasco buoy. The Owasco buoy was purchased and initially deployed in 2014. Both buoys were programmed to collect water column profiles every 12 hours (noon and midnight) of temperature (°C), conductivity (μS/cm, reported as specific conductance), dissolved oxygen (mg/L & % saturation, by optical sensor), turbidity (NTUs by backscattering), and fluorescence measuring both total chlorophyll and blue-green algae phycocyanin (μg/L, after specific pigment excitation by different wavelengths of light). Data was collected every 1.5 meters down the entire water column starting at 1 m using an YSI/Xylem EXO2 water quality sonde. The buoys also contained a standard suite of meteorological sensors that recorded five-minute average air temperature, barometric pressure, relative humidity, light intensity and wind speed and direction data every 30 minutes. All of the buoy data were periodically transferred to HWS by cellular technologies ~1 or 2 hours after collection and uncorrected data were made available on the internet[7].

Laboratory Methods: Nutrient, chlorophyll-a, and total suspended sediment concentrations were analyzed in the laboratory following standard limnological techniques[8]. Briefly, an aliquot of each sample was colorimetrically analyzed for total phosphate by spectrophotometer after digestion of organic-rich particles in hot (100ºC) persulfate for 1 hour. Additional sample water was filtered through pre-weighed, 0.45 μm glass-fiber filters. The filter and residue were dried at 80°C for at least 24 hours. The weight gain and filtered volume determined the total suspended sediment concentration. Lake water was also filtered through a Gelman HA 0.45 μm membrane filter, and the filtered residue was kept frozen until chlorophyll-a analysis by spectrophotometer

[7] Buoy Data & Information for Seneca Lake & Owasco Lake.
[8] Wetzel, R. and G. Likens, 2000. Limnological Analyses. 3rd Edition. Springer, New York.

at a suite of wavelengths after acetone extraction. The filtrate was stored at 4°C until colorimetric analysis of dissolved phosphate (SRP), nitrate and dissolved silica by spectrophotometer. At least 100 plankton (colonies were counted as one individual) from each tow were enumerated typically to species level under a microscope and reported as relative percentages. Laboratory precision was determined by periodic replicate analyses resulting in the following mean standard deviations: total suspended sediments ±0.2 mg/L, phosphate ±0.1 μg/L (both TP and SRP), silica ±5 μg/L, and nitrate ±0.1 mg/L.

For additional quality control, over 100 randomly selected sample splits were analyzed by Life Science Laboratories, a commercial laboratory, for total phosphate, dissolved phosphate and nitrates within a few weeks of sample collection in 2007. The comparison indicates that our results were statistically equivalent to the Life Science data ($r^2 = 0.84$ for nitrate, $r^2 = 0.93$ for dissolved phosphate (SRP) and $r^2 = 0.76$ for total phosphate (TP)). The correlations were hampered by the time delay between sample date and lab analysis, a few TP outliers, and most importantly, the analytical detection limits at each lab. Life Science Laboratory has a much higher detection limit of 0.2 mg/L compared to the 0.1 mg/L at HWS for nitrate, and 3 μg/L for TP and SRP compared to 1 μg/L at HWS. Thus, Life Sciences could not provide data for 15% of the nitrate, 70% of the SRP, and 40% of the TP sample splits in 2007. For these reasons, analysis of sample splits was discontinued.

RESULTS

2015 CTD Temperature Profiles: The 2015 CTD profiles are shown here as profiles from other years were similar and electronically available[9], and not shown here to save paper. Surface waters warmed from ~ 4ºC (39ºF) in the early spring survey to nearly 25ºC (~75ºF) by mid-summer (Fig. 6). Water temperatures warmed quicker in the smaller lakes. Surface waters were cooler by the last survey date (late September). Bottom waters in the deeper lakes remained at or slightly above 4ºC throughout the survey, because the maximum density of freshwater is 4ºC, and dense things sink (baring any water density modifications by salinity and suspended sediments).

The depth of the largest temperature change between the uniformly warm epilimnion (surface waters) to the uniformly cold hypolimnion (bottom waters) defines the thermocline. The thermocline was typically at a depth of 10 to 20 m in the surveyed lakes. However, its depth oscillated up and down by a few meters in response to internal seiche activity, and deepened over the stratified season by large surface waves generated by storms mixing the epilimnion to deeper depths, and during the seasonal warming and subsequent cooling of the epilimnion. The depth interval where the temperature declines from the uniformly warm epilimnion to the uniformly cold hypolimnion temperatures defines the metalimnion.

A few lakes revealed different responses. A thermocline was typically not observed in Honeoye Lake. Mixing by wind-driven waves was apparently sufficient to maintain mixed conditions in this shallow lake (7 m survey site depths). The same wind events would mix the epilimnion, i.e., to depths of 10 to 20 m in the deeper lakes. In fact, water column mixing by wind driven waves defines the base of the epilimnion. In Otisco Lake, the hypolimnion was typically warmer than

[9] Click here for yearly Finger Lakes Data.

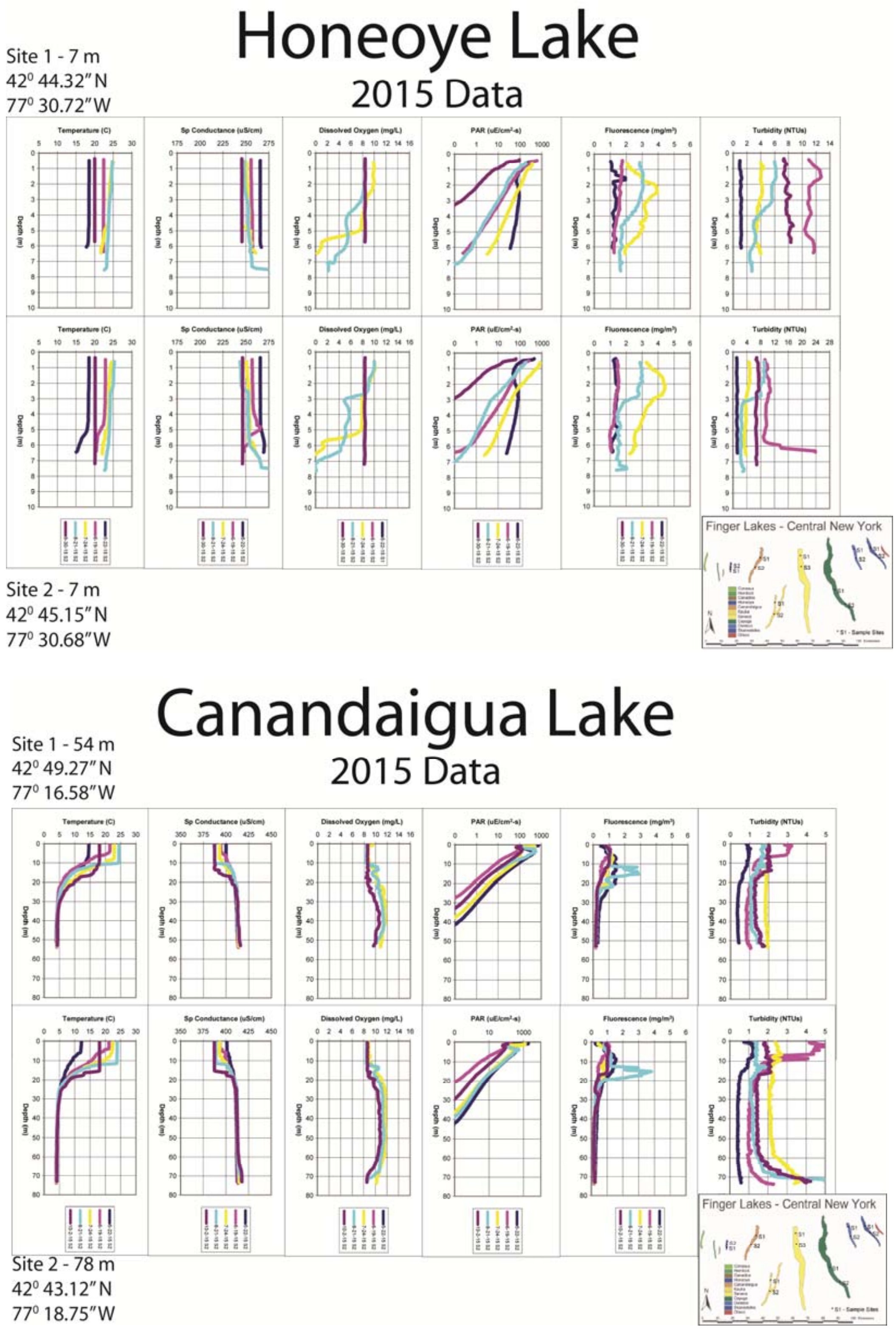

Fig. 6. CTD Profiles from Honeoye and Canandaigua Lakes.

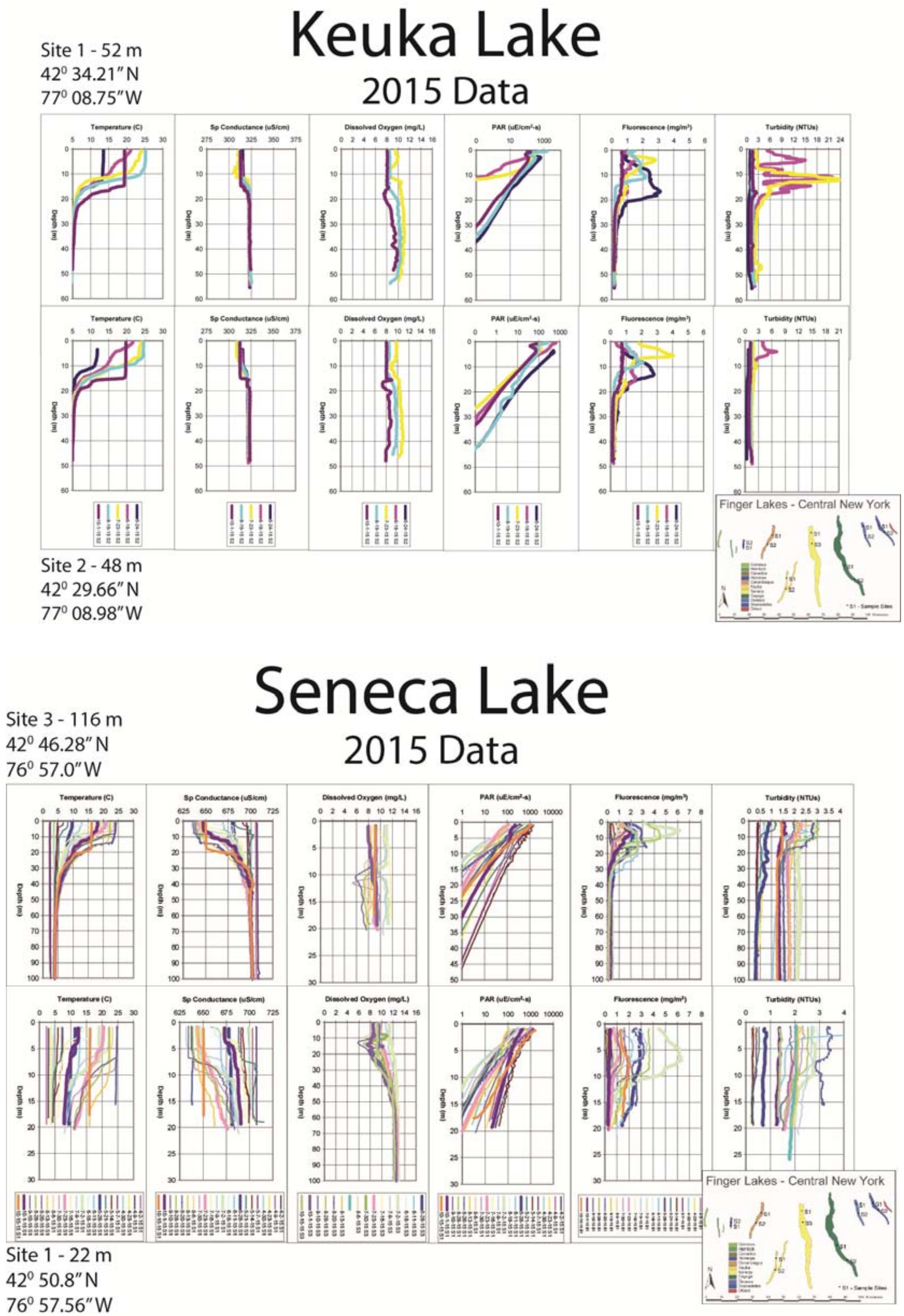

Fig. 6. CTD Profiles from Keuka and Seneca Lakes.

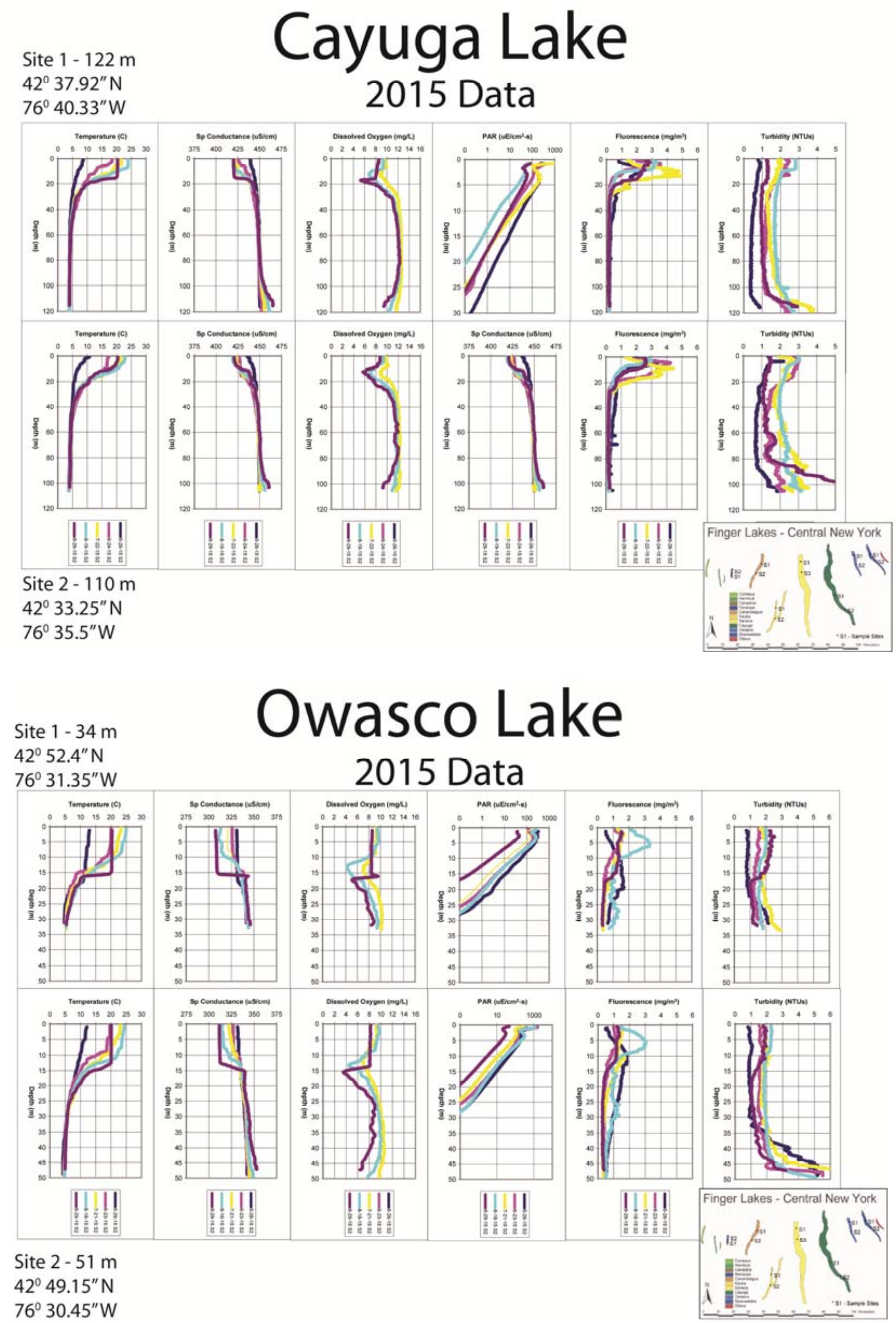

Fig. 6. CTD Profiles from Cayuga and Owasco Lakes.

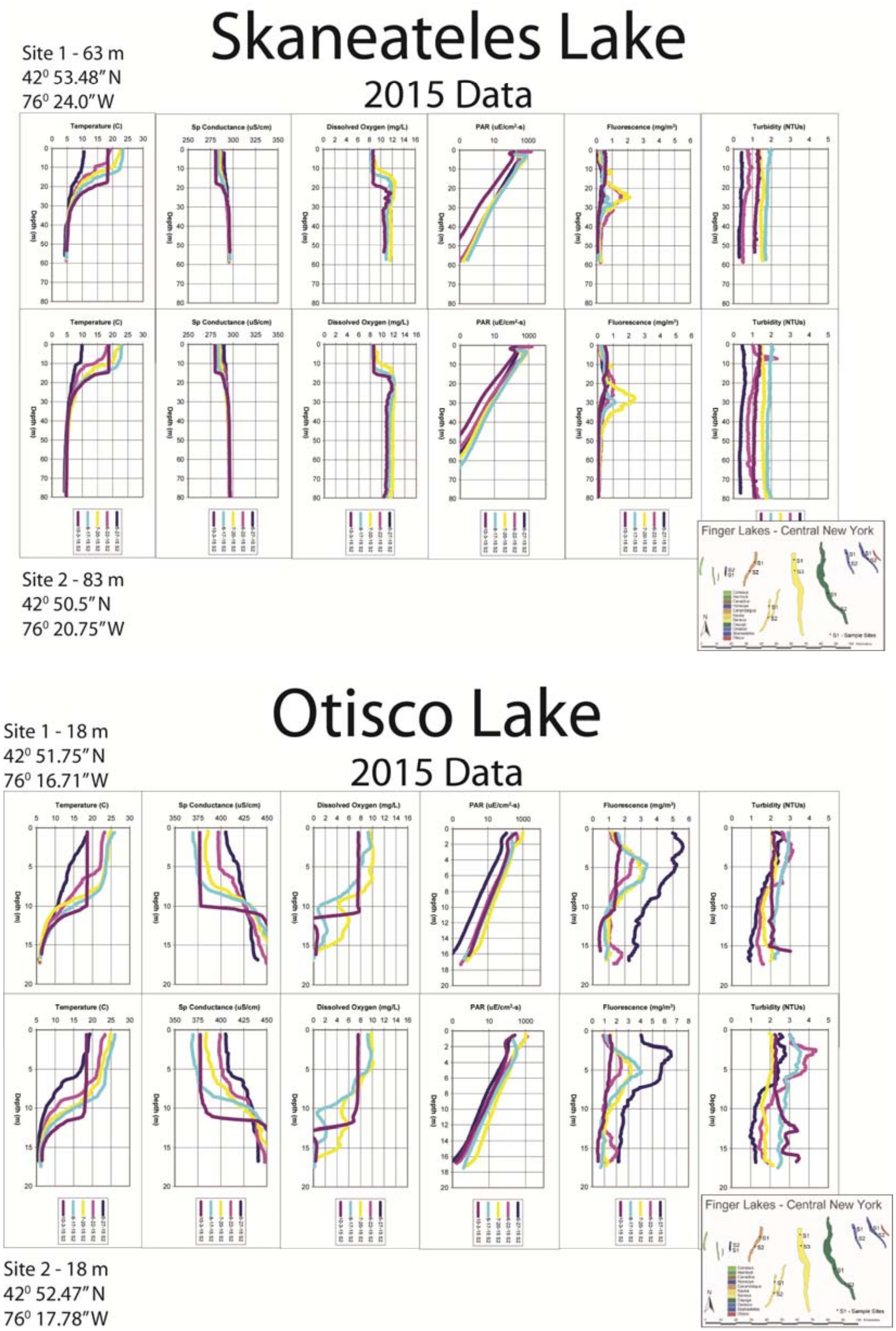

Fig. 6. CTD Profiles from Skaneateles and Otisco Lakes.

4ºC in the summer, some years up to ~ 9ºC. Presumably, wind stress in this relatively shallow lake maintained isothermal conditions as the entire water column warmed up to in some cases 9°C in the early spring until stratification commenced sometime later in the spring, as the profiles do not reveal bottom water warming through the summer. The exception is 2015 when its hypolimnion remained at 4°C.

The separation of the epilimnion from the hypolimnion is fundamental to lake processes because the stratification typically isolates the hypolimnion from sunlight and atmospheric oxygen. Thus, stratification typically separates the nutrient depleted, slightly less saline and algal-enriched epilimnion from the oxygen depleted, nutrient enriched and slightly more saline hypolimnion. The extent of these differences intensifies through the summer season, especially in productive lakes. During fall and spring overturn, these differences are erased as the entire water column mixes during overturn. In winter, the majority of the Finger Lakes stratify again, when progressively less dense, colder (0 to 4°C) water and ice (<= 0°C), float above the denser 4°C bottom water. Lakes with two overturns each year (spring and fall) are classified as dimitic lakes. The exception is Seneca Lake. A year-long deployment of a thermistor string from the summer of 2015 through the summer of 2016 indicated that overturn continued through the entire winter season in Seneca Lake[10]. Apparently Seneca's small lake surface area to volume ratio compared to the other Finer Lakes and a persistent winter wind, retarded sufficient heat transfer to develop winter stratification. A lake with only one overturn each year is classified as a monomictic lake, in Seneca's case, a warm monomictic lake (stratification in summer and mixing all winter).

Average surface (upper 10 m) and bottom (a 10 m interval within the hypolimnion) water temperatures were calculated from the available Seneca and Owasco Lake CTD profiles (Fig. 7). Both lakes revealed the progressive warming a subsequent cooling of the epilimnion, and the relatively constant and cold, 4°C, temperatures in the hypolimnion. In Seneca Lake, water below 4°C was detected in the isothermal springs of 2014 and 2015. Both occurrences followed the coldest winters through this time span, and the continuous cooling and mixing of the entire water column. Owasco Lake is dimictic like the other deep Finger Lakes, and the bottom waters rarely cooled below 4°C during overturn.

A hint of gradual warming perhaps due to global warming is observed in the best-fit, 2nd order, polynomial trend line through the averaged surface water temperatures in Seneca Lake. Unfortunately, a rise in surface water temperatures due to global warming is challenging to detect and isolate from other forcing functions with these temporally limited data sets. A recent compilation of water temperature data from 226 lakes throughout northeastern US (Pennsylvania, New York and New England), each lake with weekly to daily surface temperature data since 1985, and 85 lakes with data extending back to 1975 indicates that surface water temperatures have increased, on average, by ~0.05°C/year[11]. A few lakes in the survey have actually cooled over time. Other forcing functions besides global warming include the intensity of the preceding winter, the strength of the winds, the extent of cloud cover, and human perturbations, and any of these complications may mask any global warming signal.

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[10] Dr Nathan Hawley, Great Lakes Environmental Research Lab, Ann Arbor, MI, unpublished data.

[11] Richardson, D.C., et al., in preparation. Accelerated lake surface warming and increasing thermal stratification in 226 lakes in northeastern North America.

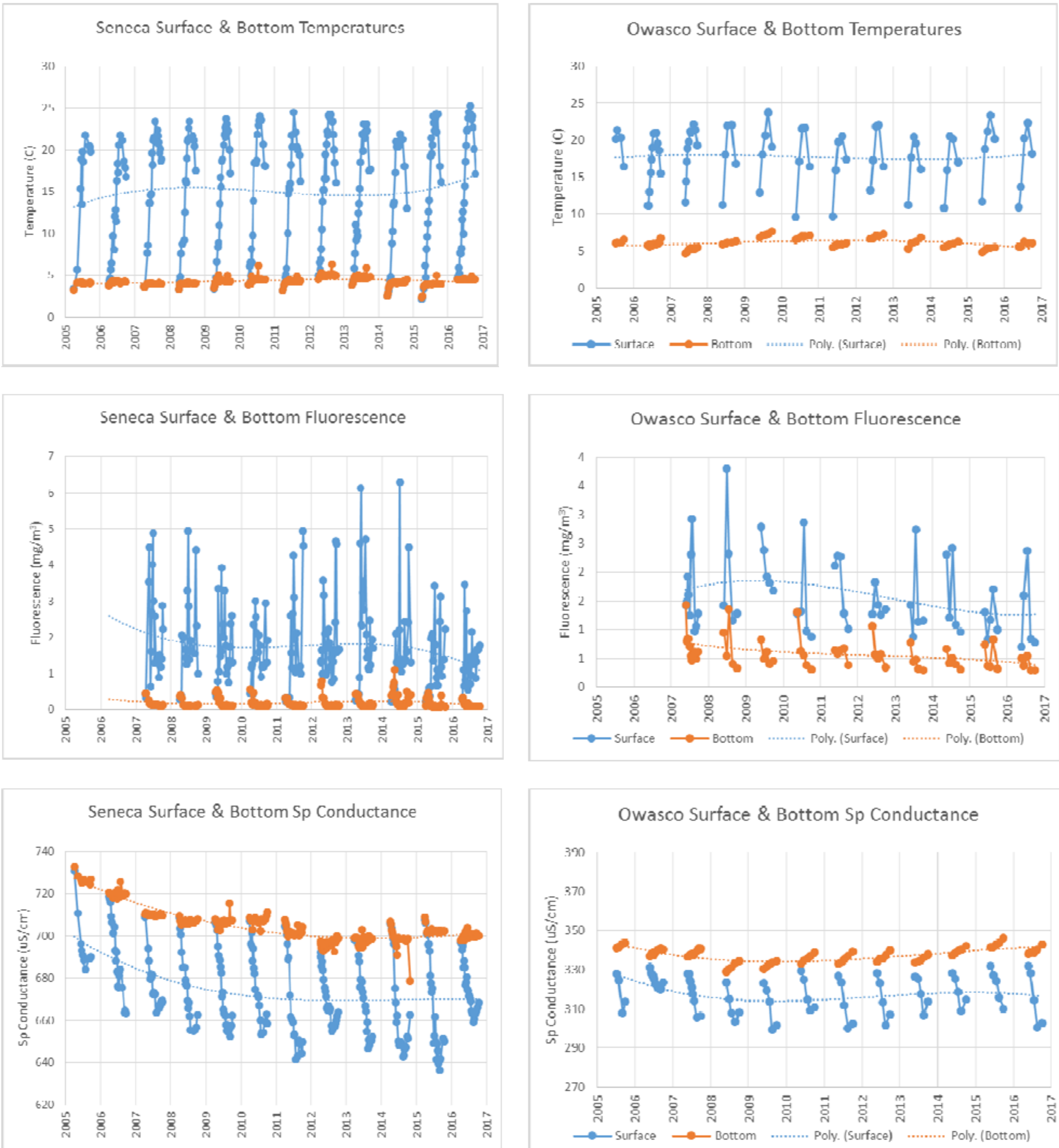


Fig. 7. Surface and bottom water average CTD data from Seneca (left) and Owasco (right) Lakes.

CTD Specific Conductance Profiles: In the Finger Lakes, specific conductance (aka salinity) data ranged from 230 μS/cm in Honeoye Lake to 730 μS/cm in the hypolimnion of Seneca Lake (Fig. 6 &7). None of these concentrations are life threatening. A specific conductance of 700 μS/cm is approximately 0.35 ppt (or 350 mg/L), and within the EPA's 0 to 500 mg/L salinity range for freshwater. The change between basins can be attributed to differences in bedrock geology, as limestones weather more easily and thus watersheds overlying limestones contribute more dissolved ions (calcium and bicarbonate) to lakes than other bedrock in the region. For example, Honeoye and Keuka Lakes revealed a smaller specific conductance and have much less limestone underlying their watersheds than the other lakes. The extent of de-icing salt use in the watershed, and hypothesized access to saline groundwater from the rock-salt bearing Salina Formation and/or salt mine wastes in Seneca Lake, and to a lesser degree Cayuga Lake, are other major sources of dissolved ions.

Average epilimnetic specific conductance gradually decreased by 10 to 50 μS/cm (~5 to 25 mg/L) in the epilimnion of these lakes through the stratified season (Fig. 7). The evidence indicates that the epilimnion was increasingly diluted during the stratified season with less saline precipitation directly onto the lake and precipitation induced runoff to the lake[10]. For example, a large decrease in epilimnion conductivities was detected between two surveys that straddled heavy rains (3" in Geneva) from the tail end of Hurricane Katrina in 2005. Katrina's impact was especially pronounced in Owasco Lake, because this watershed has the largest watershed area to lake surface area ratio of the lakes in the survey, and thus received a relatively larger volume of fresh water to its epilimnion from the same amount of rainfall. Over longer time scales, the largest summer season decreases in Seneca and/or Owasco Lakes were in 2011, 2014 and 2015, years with the most spring through fall rainfall[12].

Seneca Lake has the largest specific conductance and largest summer season decrease in specific conductance (~50 μS/cm) because its salinity is still decreasing from a 1960s to 1970s high due to the discharge of (unregulated) salt mine wastes at this time[13]. Since then and more specifically since 2005 as shown in Fig. 7, the specific conductance of Seneca Lake has steadily decreased from a high of 730 μS/cm in 2005 to a low of 635 μS/cm in the fall of 2015. Each year the lower salinity epilimnion mixed with the more saline hypolimnion during overturn, and resulted in a slightly less saline water column. The epilimnetic specific conductance increases a bit in the fall, reflecting the decay of the thermal stratification, and mixing of progressively larger amounts of more saline hypolimnion into the epilimnion. Finally, the specific conductance of the hypolimnetic did not vary significantly during each stratified season. Its uniformity indicates that Seneca Lake lacks a unique lake floor or groundwater source of sodium and chloride ions (salt) as previously hypothesized[12].

CTD Dissolved Oxygen Profiles: Water temperature, photosynthesis and respiration influence dissolved oxygen (DO) concentrations in lakes. The saturation concentration of oxygen in water is inversely related to the water's temperature, i.e., warmer water holds less dissolved oxygen than colder water at saturation, water at equilibrium (in contact) with the atmosphere. Biological processes, photosynthesis and respiration, modify these concentrations. Photosynthesis by algae and macrophytes releases/adds oxygen to the water. Respiration by all living things, especially bacteria, consumes/removes dissolved oxygen from the water. Biological influences are minimal in the epilimnion, because any bio-induced change re-equilibrates with atmospheric oxygen over time as the epilimnion is in contact with the atmospheric. In contrast, the hypolimnion is isolated from the atmosphere, and any bio-induced change in DO is permanent until the next overturn. The hypolimnion is too dark for significant photosynthesis to add DO, but respiration is

[12] Halfman, J.D., H.A, Simbliaris, B.N. Swete, S. Bradt, M.C. Kowalski, P Spacher & I. Dumitriu. 2016. The 2016 Water Quality Report for Owasco Lake, NY. Finger Lakes Institute, Hobart and William Smith Colleges. xx pg.

[13] Halfman, J.D., 2014. A 2014 update to the chloride hydrogeochemistry in Seneca Lake, New York. Finger Lakes Institute, Hobart and William Smith Colleges. 27 pg.

significant and continually decreases DO concentrations in the hypolimnetic during the stratified season from its initial spring overturn saturated concentrations. The extent of the depletion reflects the amount of algal to decompose, i.e., the lake's trophic status. If enough respiration ensues, aka in an eutrophic lake, the hypolimnion turns anoxic.

Most of the lakes in the survey revealed saturated dissolved oxygen (DO) profiles in the epilimnion. DO concentrations slowly decreased through the summer but remained at or close to saturation as the surface waters warmed through the spring to summer season (Fig. 6). In the hypolimnion of Seneca, Cayuga, Owasco, Otisco, and to a lesser degree Canandaigua and Keuka Lakes, below saturation concentrations were revealed just below the thermocline and/or just above the lake floor, due to respiration by bacteria and other organisms. Honeoye typically revealed well mixed profiles, but oxygen depletion was observed during surveys after a series of calm days. Occasionally oxygen enrichments were observed in Skaneateles & Canandaigua just below the thermocline. The increase can be attributed to the juxtaposition of photosynthesis just below the thermocline in these very clear lakes.

Otisco Lake was the only lake in the survey that consistently revealed anoxic conditions in the hypolimnion during the latter half of the summer season. Interestingly, this lake had a similar supply of organic matter to decompose as Seneca, Owasco and Cayuga Lakes, lakes that lacked bottom water anoxia. The same amount of material to respire should induce the same DO response in the hypolimnion. The difference in the oxygen depletions between these lakes is related to their relative sizes. The hypolimnion is over 10 to 20 times larger in Seneca and Cayuga Lakes than Owasco Lake, which in turn is 10 times larger than Otisco Lake. Thus, Seneca and Cayuga Lakes, and to a lesser extent Owasco Lake, have a larger capacity, i.e., more DO available to respire the similar supply of algal organic matter. The result is a smaller change in hypolimnetic DO concentrations in the larger lakes. Owasco, the in between sized lake, revealed significant dissolved oxygen depletion (to 30% saturation) in the hypolimnion.

CTD PAR – Photosynthetic Active Radiation Profiles: Light is critical for photosynthesis, and the PAR sensor measures the intensity of light at the wavelengths utilized by algae. The quantity of light typically decays exponentially with water depth in a lake, and are typically displayed on an exponential scale, so that exponential decay appears as a straight line. The available light decays to darkness as longer wavelengths of light (infrared, red, orange, yellow) are absorbed and converted to heat, and the shorter wavelengths of light (ultraviolet, violet, blue) are scattered back to the atmosphere (thus deep lakes look blue from above). The attenuation of light is intensified and its penetration depth is limited to shallower depths as the concentration of suspended matter (both organic and inorganic) increases in the water column. The loss of light with water depth is critical to aquatic life. When it falls below 1% of surface light intensities, algae and other plants can no longer photosynthesize enough organic matter to survive. This boundary is typically at the thermocline. Thus in deep lakes, the hypolimnion is pitch black and lack photosynthesizing algae. The amount of light at the surface depends on the cloud cover, time of day and time of year.

Light exponentially decreased with water depth in all the Finger Lakes and typically reached the 1% threshold at a shallower depth than the thermocline (Fig. 6). The 1% threshold extends into the upper hypolimnion in the very clear Skaneateles Lake. The lakes with more algae had shallower light penetration depths. Only Honeoye and on a few occasions Otisco have measurable light at the lake floor in these relatively shallow lakes. The frequent decline in light beyond the exponential decay at the upper few meters of the water column was due to the passage of the sensor through the shadow of the field vessel.

CTD Turbidity & Fluorescence Data: Suspended sediments are composed of inorganic (fluvial muds) and organic (algae) fractions. The sources to the lake include tributary inputs, erosion by waves re-suspending nearshore, lake-floor sediments, and the production of algae. Suspended sediments are lost from a lake by transport out the outlet, and settling to the lake floor (suspended sediments are denser than water). The inorganic fraction is denser thus settles faster than the organic fraction. The nephelometer detects the concentration of all suspended particles using light backscattering technologies. The fluorometer detects the concentration of algae suspended in the water using the light induced fluorescent properties of algae.

Surface and bottom water zones of increased turbidity were observed in many of the Finger Lakes (Fig. 6). The fluorometer indicated that the epilimnetic turbidity was primarily due to algae blooms. Algal peaks of 3 to 10 μg/L were detected in the epilimnion of Seneca, Cayuga, Owasco and Otisco Lakes. Smaller peak concentrations were detected in the metalimnion of Keuka and Canandaigua and down into the upper hypolimnion of Skaneateles. The water column in Honeoye was typically mixed and lacked distinct algal peaks. A comparison of survey dates to monitoring buoy fluorescence data indicate that peak concentration more often reflected the juxtaposition of the survey date with the infrequent, week-long blooms.

Average surface and bottom water fluorescence profiles starting in 2008 (the purchase of the CTD's fluorometer) through 2016 of revealed a spikey epilimnetic concentration of algae and much less algae in the hypolimnion (Fig. 7). The surface water record reflected the coincidence (or lack of) of the survey dates with algal blooms. Larger fluorescence values were detected during 2008, 2013 and 2014. These years, especially 2014, experienced more precipitation, suggesting a link between runoff of nutrients and algae concentrations in the lake. The linkage is not perfect, implying the imperfect juxtaposition between the survey dates and actual algal blooms, top-down ecological pressures, and other sources of nutrients.

Benthic (lake floor) nepheloid layers were observed in all the surveyed Finger Lakes, but Honeoye and Seneca. Benthic nepheloid layers result from settling algae and accumulation of fine-grained sediments that settle from above or are transported to the lake floor by density currents. Years with larger nepheloid turbidities typically corresponded to years with more precipitation, thus more sediment laden runoff. The nepheloid layers persisted throughout the field season but their extent varied from lake to lake. The benthic nepheloid layers were best developed in Cayuga Lake where turbidities increased to 10 or more NTUs. Larger lake floor turbidities were usually detected at the southern site in Cayuga Lake where the largest subwatersheds empty into the lake (Site 2). Honeoye mixed too frequently for persistent nepheloid layers. The absence of benthic nepheloid layers in Seneca, even in the occasional profile from the deepest and southern locations in Seneca Lake, may reflect smaller streams, and thus smaller sediment supplies in proportion to the lake's watershed flowing into the large lake.

Two years, 2014 and 2015, compared to the other years in the survey revealed larger turbidities throughout the entire water column (Fig. 8). Turbidities were typically larger than 2 NTUs in a few profiles in 2014 and 2015 and a few NTUs smaller in the same lakes in the other years.

These larger turbidities were coincident with the larger than normal precipitation totals especially in the early spring. Spring rains supply more sediments because conditions are ripe for the largest turbidity loads. For example, farm fields are bare, just tilled for planting, and at the best state to maximize soil erosion by runoff. Additional springtime factors increase the runoff to infiltration and evapotranspiration ratios. Plant life is unavailable to slow down runoff and retard soil erosion, and maximize evapotranspiration, thus increasing the percentage of rainfall diverted to runoff. The ground is also more saturated blocking or slowing down infiltration and increasing the percentage of rainfall diverted to runoff[14]. More runoff means more soil erosion.

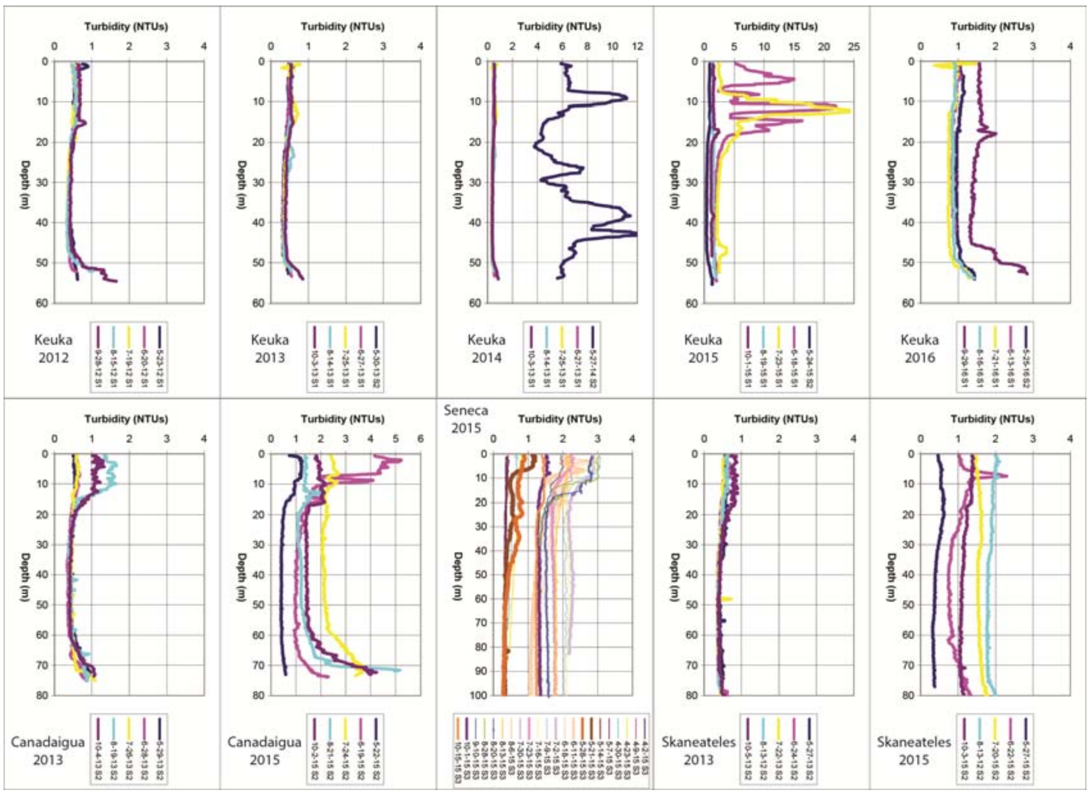


Fig. 8. Turbidity Profiles from 2012 through 2016 at Site 1 in Keuka Lake, 2013 & 2015 at Site 2 in Canandaigua Lake, 2015 at Site 3 in Seneca Lake, and 2013 & 2015 at Site 2 in Skaneateles Lake.

Fluoroprobe Data: The September/August 2016 fluoroprobe data revealed significant variations in the dominant plankton group(s) between the Finger Lakes, and a new plankton group, cryptophytes that was not recovered by the plankton tows (Fig. 9). In Canandaigua Lake, green algae and cryptophytes dominate. In Keuka, diatoms and cryptophytes dominate. In Seneca, diatoms dominate. In Cayuga & Skaneateles, diatoms, greens and cryptophytes share dominance. In Owasco, cryptophytes dominate. In Otisco, greens dominate. Blue-green algae dominated the upper portions of the water column in Honeoye Lake, were detected in the epilimnion of Canandaigua and Skaneateles Lakes, and absent in the epilimnion of the other Finger Lakes. The cryptophyte group was detected at larger concentrations deeper in the water column than the other algal groups, at times below the thermocline. Finally, the apparent rise in

[14] Halfman, J.D., 2014. Finger Lakes impacted by heavy mid-May rain/runoff. 12 pg.

blue-green concentrations below the thermocline was an artifact, a temperature dependence response of the blue-green algae sensor.

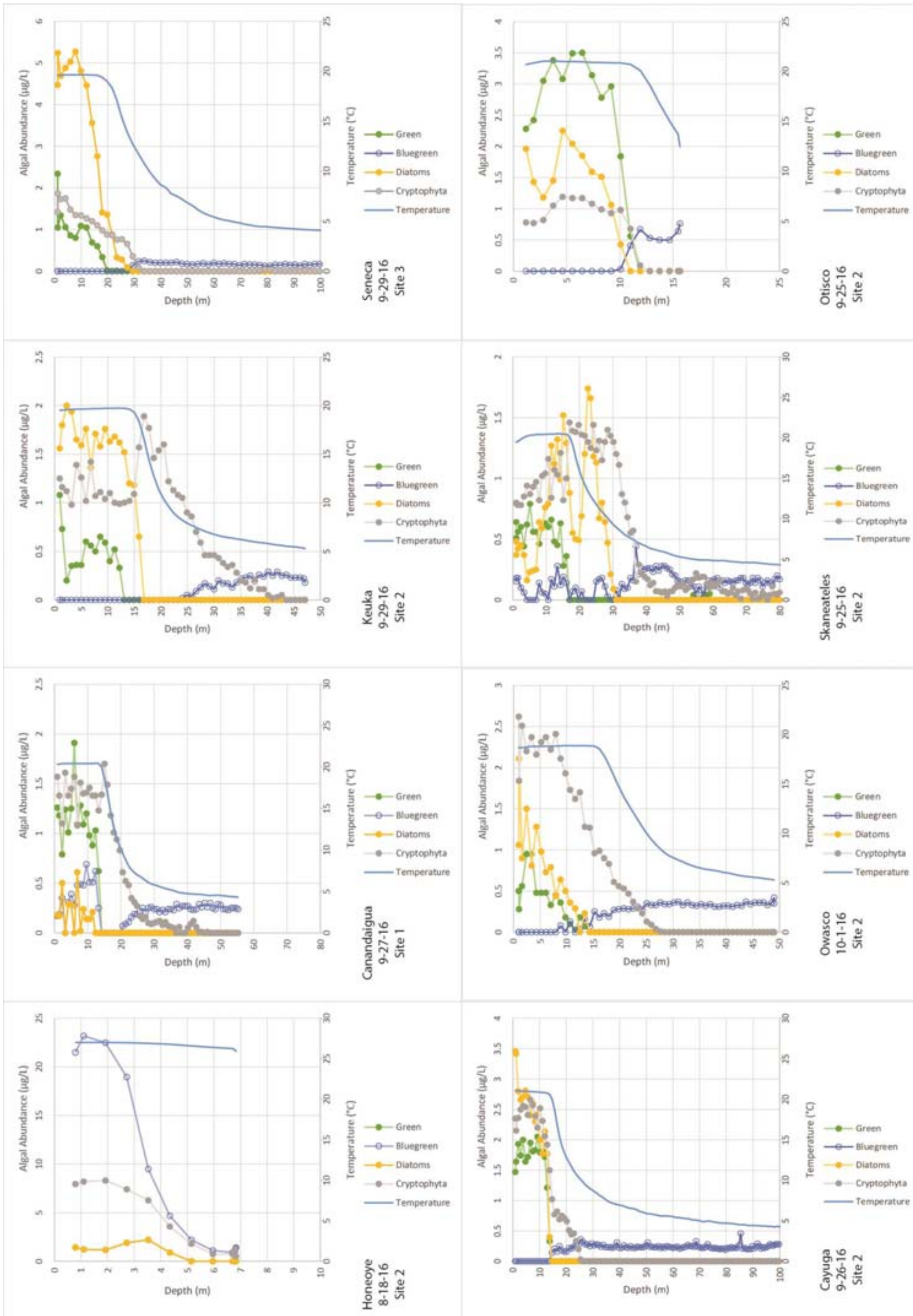


Fig. 9. Fluoroprobe profiles of major algal groups and water temperature from the September or August surveys. Note the scale changes between plots to highlight the taxa within each lake and not the relative concentrations between lakes. The other site(s) in each lake was (were) similar to the profile shown here.

Secchi Disk, Chlorophyll-a, TSS Data: Annual mean Secchi disk depths ranged from 1.6 to 9.7 m, and were deepest (least turbid) in Skaneateles Lake, and shallowest (most turbid) in Honeoye, Cayuga, Owasco and Otisco Lakes (Table 3, Appendix1, Fig. 11). Annual mean Secchi disk depths in Seneca Lake revealed the largest multi-year change, by 4.5 m, compared to the other lakes. The transition to deeper depths from 1993 up to 1998 was due to the invasion and establishment of the zebra mussel starting in 1992, and its filter feeding of algal and other particulates from the water column[15]. Once established, zebra mussel densities were large enough to effectively filter the entire lake in 3 or 4 days. 1998 marked the initial crash of zebra mussels in Seneca Lake, and the release of nutrients previously sequestered by the mussels back to the water column. Since then, Secchi disk depths have slowly declined back to pre-1992 depths reflecting increasing concentrations of algae despite quagga mussels joining zebra populations in the lake. The other lakes were not sampled until 2005, thus not early enough to detect the impact of their 1990's zebra mussel invasion on water clarity. Seneca Lake Secchi disk depths have also become very deep (over 20 m) during the isothermal spring starting in the early 2010's. It suggests that grazing by the existing zebra and quagga mussel population and light-limited algal growth were intense enough to keep algal biomass very low and the water column very clear during the isothermal spring. The other lakes were not sampled early enough in the year, i.e., during the isothermal spring, to detect the presence or absence of the isothermal spring clear zone. Honeoye Lake has also had a significant shift from deeper to shallower Secchi disk depths starting in 2009 for unknown reasons. Finally, Honeoye, Canandaigua, Keuka, Seneca, Cayuga and Otisco Lake revealed shallower Secchi depths, thus more turbid water, in 2014 and/or 2015 than other years in the survey. These two years had more early spring precipitation.

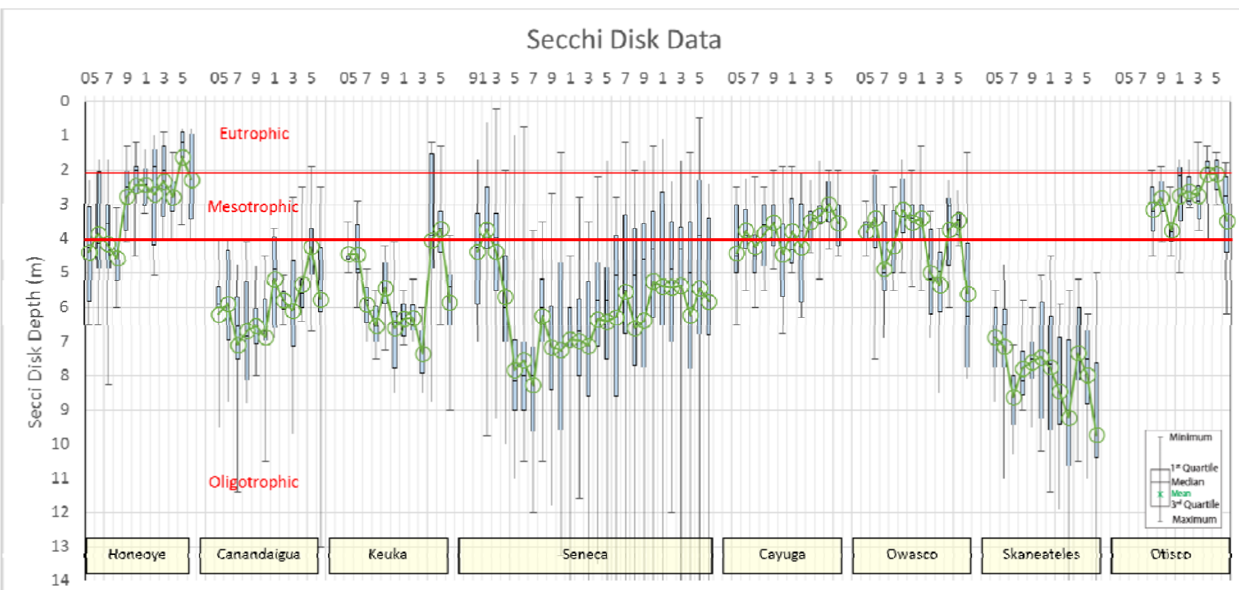


Fig. 11. Surface box and whisker plots of Secchi disk depths and chlorophyll concentrations. The numbers on the x-axis identify the year, e.g., 05 is 2005 and 91 is 1991.

[15] Halfman, J.D., D. Zorn, C. Roberson, L Cleckner and S. Meyer, 2012. Seneca Lake Watershed Management Plan: Characterization and Evaluation. 139 pg.

Surface chlorophyll-a concentrations ranged from annual means less than 1 µg/L in Skaneateles Lake to ~10 µg/L (mg/m^3) in Honeoye Lake (Table 3, Appendix 1, Fig. 12). Some of the variability between the surface concentrations may reflect the variable depth of the algal peaks in these lakes and/or coincidence between the survey dates and algal blooms. Cayuga, Owasco and Otisco revealed the next largest chlorophyll concentrations, and Canandaigua and Keuka the next smallest chlorophyll concentrations. Annual average chlorophyll-a concentrations were larger in epilimnion than the hypolimnion for all the lakes except for the well-mixed Honeoye, as algae primarily live in the sunlit epilimnion. Surface chlorophyll concentrations in Seneca Lake were smaller from 1993 through 1998. This 1990's decline paralleled and was consistent with the deeper Secchi disk depths due to grazing pressures by zebra mussels. Surface chlorophyll concentrations were larger in Honeoye, Canandaigua, Keuka, Seneca, Cayuga, Owasco, and Skaneateles in 2014 and/or 2015 than other years, consistent with the spike in turbidity data and rainfall totals.

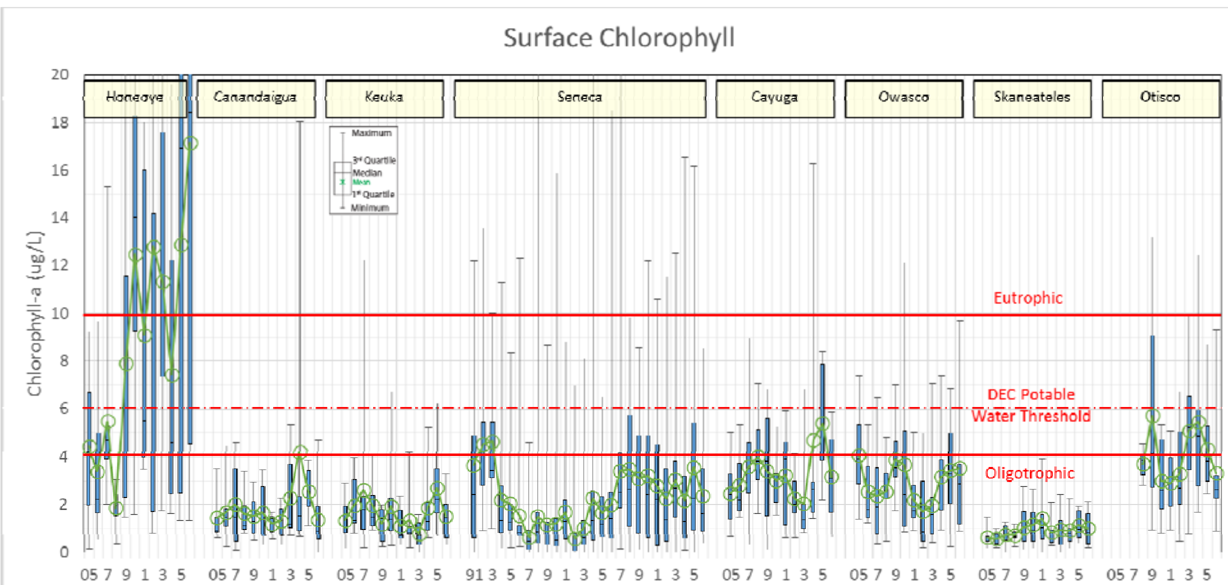


Fig. 12. Surface box and whisker plots of chlorophyll concentrations.

Surface total suspended solids (TSS) annual mean concentrations were proportional to the chlorophyll and inversely proportional to the Secchi disk data (Table 3, Appendix 1, Fig. 13). The largest concentrations were detected in Honeoye Lake and the smallest in Skaneateles Lake. Honeoye Lake revealed the largest date-to-date and year-to-year variability in TSS, most likely reflecting the intensity of the algal bloom on the sample dates. Surface TSS concentrations were relatively larger in 2014, and to a lesser extent in 2015, than other years in Honeoye, Canandaigua, Keuka, Seneca, Cayuga, Owasco, and Skaneateles, another rainfall impact.

Bottom water TSS concentrations were largest in Cayuga Lake reflecting the presence of its previously described benthic nepheloid layer compared to the other Finger Lakes (Fig. 14). It may relate to the proportionally larger drainages flowing into the southern portion of Cayuga lake.

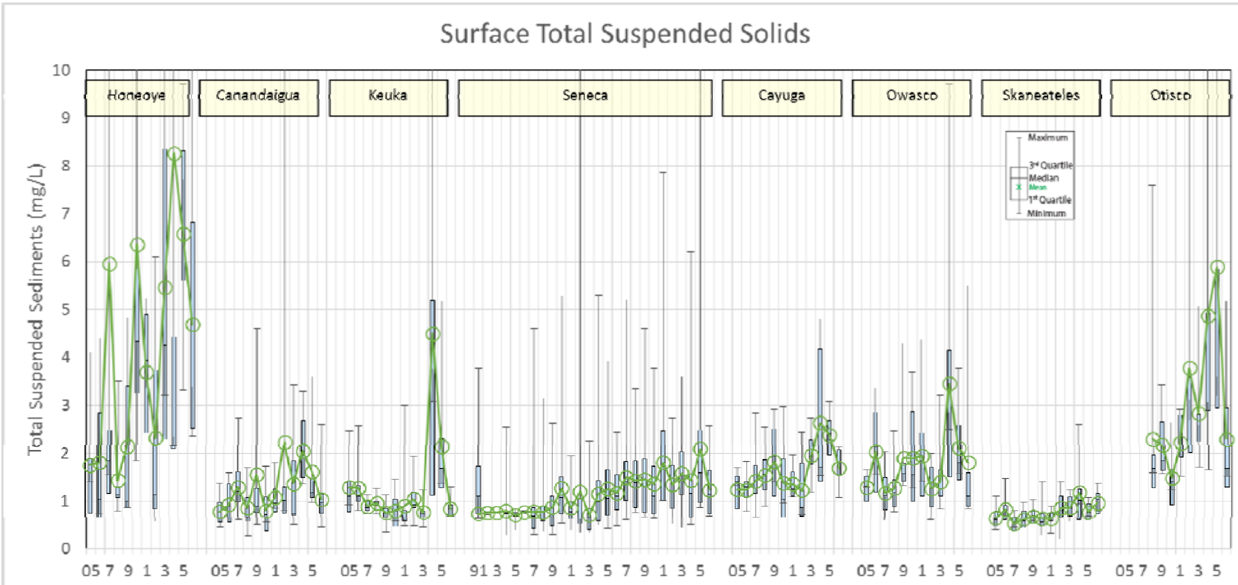


Fig. 13. Surface box and whisker plot of total suspended solids concentrations.

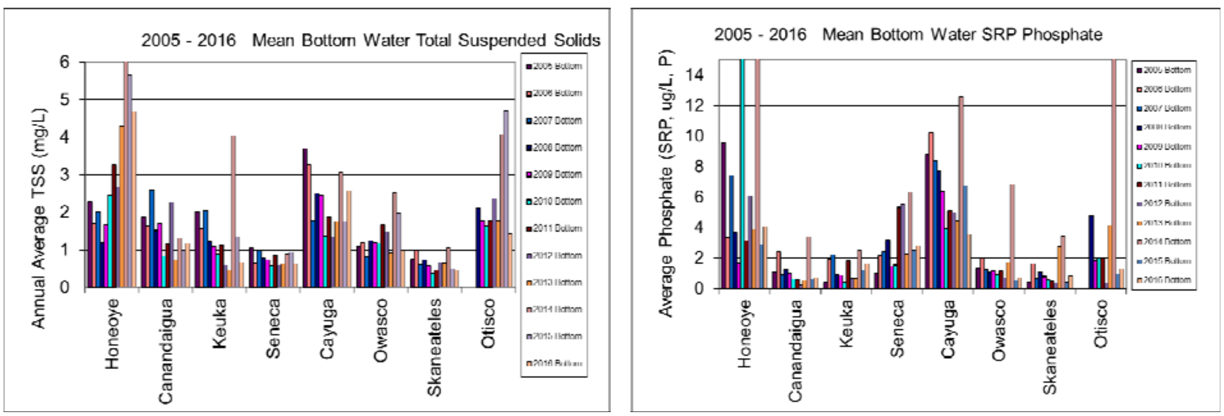


Fig. 14. Hypolimnetic total suspended solids annual average concentrations (left) and hypolimnetic soluble reactive phosphate annual average concentrations (right).

Nutrient Data: Surface total phosphate (TP) concentrations were largest in Honeoye Lake with annual means up to 52 μg/L, P (ppb, Table 3, Appendix 1, Fig. 15). Honeoye is impaired based on DEC's 20 μg/L definition. Otisco Lake revealed the next largest TP concentrations with annual means between 10 and 35 μg/L that were occasionally above 20 μg/L. Thus, Otisco was occasionally an impaired water body. TP concentrations were smallest in Skaneateles, Canandaigua and Keuka Lakes with annual means from 5 to 15 μg/L. Between these end-members, Seneca and Cayuga Lakes had slightly more TP than Canandaigua, Keuka and Owasco Lakes. Minimal change was observed between the epilimnion and hypolimnion in each lake. The largest TP concentrations in each lake were detected in 2014. The mean concentration in 2014 was typically twice the mean from the preceding year in each lake.

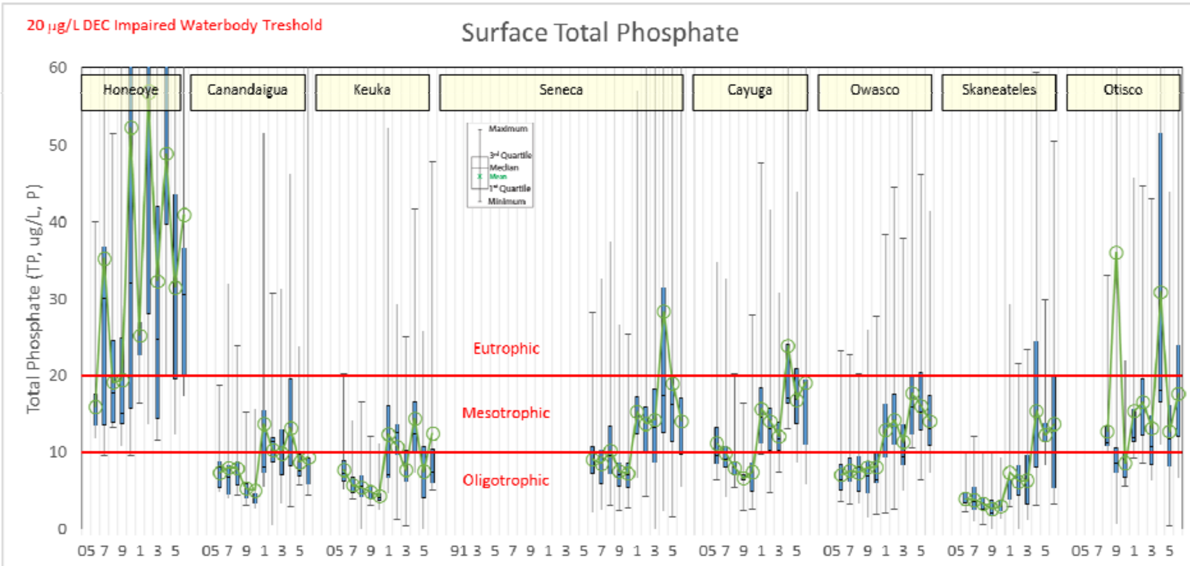


Fig. 15. Surface box and whisker plot of total phosphate concentrations.

Surface soluble reactive phosphate (SRP) annual mean concentrations were largest in Honeoye Lake from 0.5 to 17 μg/L, P (ppb, Table 3, Appendix 1, Fig. 16). They were typically well below 1 μg/L in the epilimnion of the other lakes implying that phosphorus limits algal growth in these other Finger Lakes. The exception was Seneca Lake, where annual means were up to 3 μg/L in the early 1990's and the past few years of the record. The large concentrations of SRP and small nitrate concentrations in Honeoye Lake suggested that phosphate was not the limiting nutrient in Honeoye Lake (see nitrate section below). Temporally, all of the lakes revealed significantly larger SRP concentrations in 2014, and for some lakes also in 2015, than other years in the record. For example, the mean SRP increased 15 times, from < 1 to > 15 μg/L, from 2013 to 2014 in Otisco Lake.

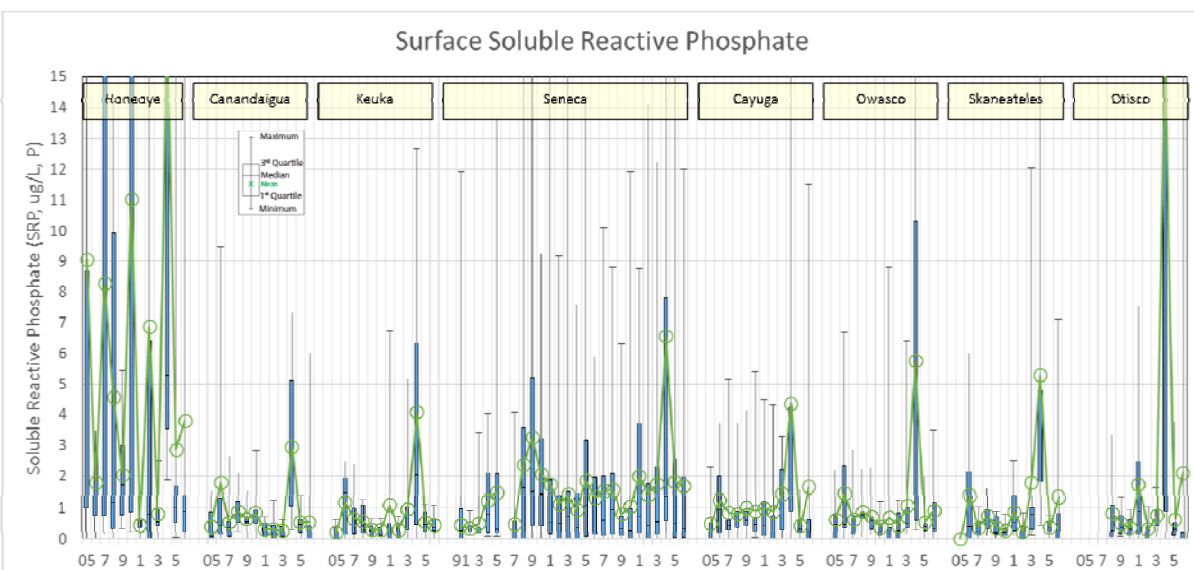


Fig. 16. Surface box and whisker plot of soluble reactive phosphate concentrations.

The hypolimnetic SRP concentrations were larger than the respective epilimnetic concentrations in these lakes, except for the shallow Honeoye Lake (Table 3, Appendix 1, Fig. 14). The largest hypolimnetic SRP concentrations were detected in Cayuga Lake. These large SRPs are a concern because internal waves, surface current induced upwelling events, fall and spring overturn, and Cornell's Lake Source Cooling project provide mechanisms to bring the nutrient rich hypolimnion to the surface, fertilizing algal growth, and degrading water quality. The hypolimnetic SRP concentrations in Cayuga started to decline in 2006, and the timing paralleled a reduction in SRP in the wastewater treatment effluent at the southern end of the lake due to plant upgrades in 2006. SRP peaks for Honeoye, Keuka, Seneca, Cayuga, Owasco, Skaneateles and Otisco in 2014 may reflect the input of nutrients to the bottom of the lakes, another rainfall influence. In contrast, the hypolimnetic SRP concentrations in Seneca Lake increased in 2011, 2012, and 2014. The reasons for these additional changes are unclear at this time.

Nitrate annual mean concentrations were largest in Cayuga, Owasco, and Skaneateles Lakes from 0.4 to 0.6 mg/L, N, and smallest in Canandaigua, Keuka and Honeoye Lakes from 0 to 0.04 mg/L (Table 3, Appendix 1, Fig. 17). Bottom water annual mean results typically revealed more, up to 0.5 mg/L more, nitrates than surface water, especially in Keuka and Cayuga. None of these nitrate concentrations were health threats.

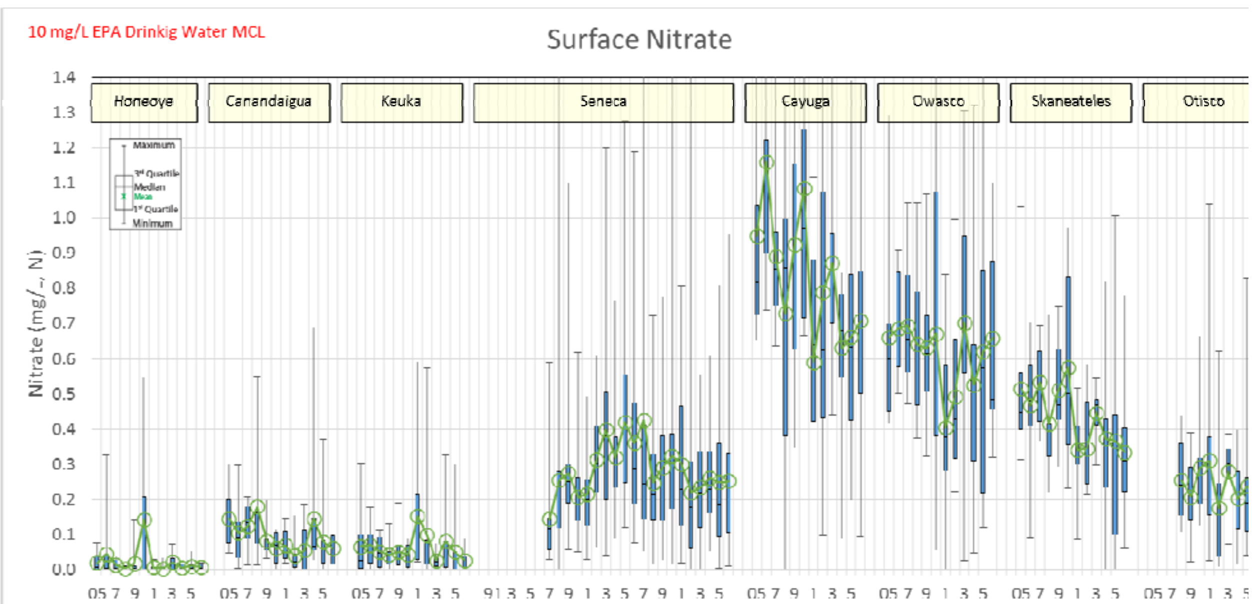


Fig. 17. Surface box and whisker plots of nitrate concentrations. The numbers on the x-axis identify the year, e.g., 05 is 2005 and 91 is 1991.

Redfield measured the ratio of P:N in algae across the globe and always got the same answer 1:7. The implication is simple, algal photosynthesis requires phosphorus and nitrogen in a fixed ratio, 1:7. If the supply of these two nutrients in the water column is skewed above or below this ratio, then the skew direction highlights which nutrient limits algal growth, because the lake runs out of the under supplied nutrient and photosynthesis stops. The mean annual nitrate (total nitrogen was not available) and total phosphate data always revealed P:N ratios near or below the Redfield 1:7 (P:N) ratio in Honeoye Lake and seasonally in Keuka Lake. The lack of total nitrogen data means the ratios (the XX number in the 1:XX ratio) were actually larger than what was presented here. The ratios in Cayuga, Owasco and Skaneateles Lakes were significantly above Redfield ratios, from 1:80 to 1:100. Ratios in Canandaigua, Seneca, and Otisco were slightly above the Redfield ratio, and range from 1:10 to 1:40. Thus phosphorus limits growth in these six lakes, nitrogen in Honeoye, and both, seasonally, in Keuka Lake.

Table 3. Maximums, Minimums & Means of the 2005-2016 Annual Mean Data

	Honeoye	Canandaigua	Keuka	Seneca	Cayuga	Owasco	Skaneateles	Otisco
Secchi Max	4.6	7.1	7.3	8.3	4.5	5.6	9.7	3.8
Mean	3.0	6.0	5.6	6.2	3.8	4.1	8.0	2.8
Min	1.6	4.2	3.7	3.7	3.0	3.2	6.9	2.1
Chlorophyll Max	8.3	2.2	4.5	2.1	2.6	3.5	1.2	5.9
Mean	4.2	1.3	1.3	1.1	1.7	1.8	0.8	3.1
Min	1.4	0.8	0.7	0.7	1.2	1.2	0.5	1.5
TSS Max	56.9	13.7	14.4	28.4	23.9	17.7	15.5	36.1
Mean	34.4	9.0	8.5	13.4	13.2	11.4	7.1	18.2
Min	16.0	5.1	4.3	7.3	6.7	7.1	2.7	8.6
TP Max	16.9	3.0	4.1	6.6	4.4	5.8	5.3	15.7
Mean	5.7	0.8	0.9	1.6	1.3	1.2	1.1	2.6
Min	0.5	0.3	0.2	0.3	0.4	0.4	0.0	0.3
SRP Max	0.1	0.2	0.2	0.4	1.2	0.7	0.6	0.3
Mean	0.0	0.1	0.1	0.3	0.8	0.6	0.4	0.2
Min	0.0	0.0	0.0	0.1	0.6	0.4	0.3	0.2
Nitrate Max	1780	1091	1080	1426	595	1022	730	1013
Mean	1029	934	612	352	381	725	406	473
Min	595	741	424	100	257	529	157	315
Silica Max	17.2	4.2	2.7	4.6	5.4	4.1	1.4	5.7
Mean	8.9	1.9	1.7	2.4	3.3	2.9	0.9	4.1
Min	1.9	1.2	0.8	0.6	2.0	1.7	0.6	2.9

Seneca used 1991 through 2016 annual means, Otisco used 2008 through 2016 annual means.

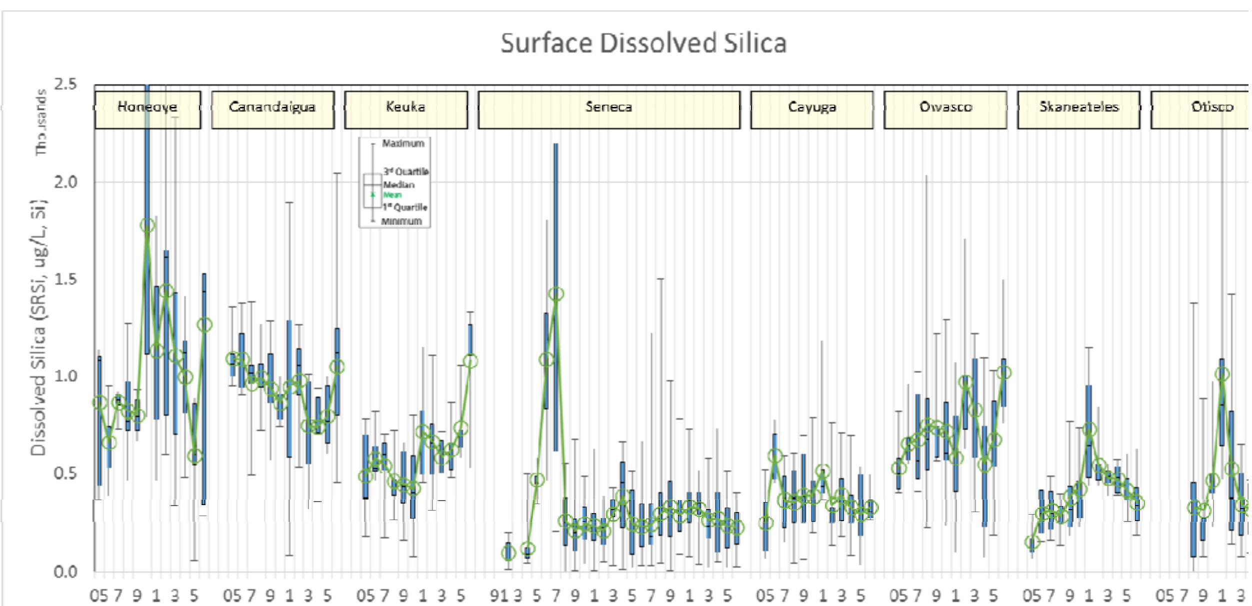


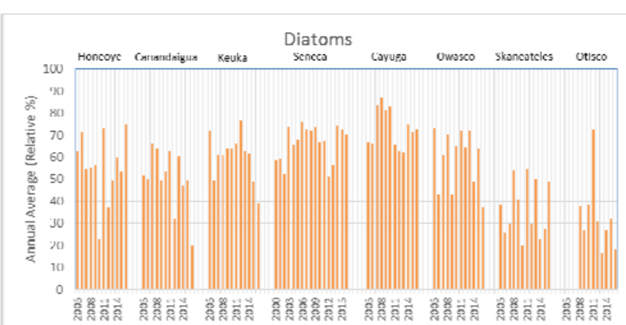
Fig. 18. Surface box and whisker plots of dissolved silica concentrations.

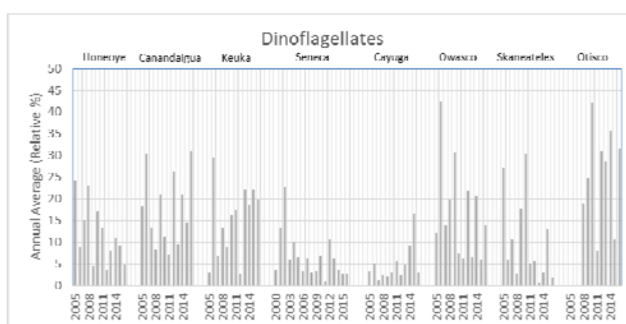
Surface soluble reactive silica (SRSi) annual mean concentrations were largest in Canandaigua (900 μg/L, Si, ppb), Honeoye (1,000 μg/L) and Keuka Lakes (600 μg/L), and smallest in Seneca (240 μg/L), Cayuga (390 μg/L) and Skaneateles (400 μg/L) Lakes (Table 3, Appendix 1, Fig. 18). Dissolved silica concentrations were typically larger in the hypolimnion than the epilimnion, and Owasco, Cayuga and Otisco Lakes revealed the largest increase (~700 to 1,400 μg/L, 380 to 950 μg/L and 400 to 725 μg/L, respectively). Silica annual mean concentrations exceeded 1,000 μg/L in Seneca Lake from 1995 through 1997, significantly larger than those in other years (< 500 μg/L). This timing paralleled increased water clarity, presumably by zebra mussel filtration. It suggests that the smaller numbers of algae could not assimilate as much silica as in other years.

Plankton: The plankton assemblages were dominated by diatoms in all of the Finger Lakes (Appendix 2, Fig. 19). Seneca, Cayuga and Keuka consistently had the largest percentages of diatoms (50 to 80% of the taxa) whereas Otisco, Skaneateles had the least (20 – 30%). Dinoflagellates and blue-green algae were the next common plankton group with many annual percentages from 5 to 20%. Canandaigua, Keuka, Owasco and Otisco had the largest percentages (> 10%) of dinoflagellates, Cayuga and Seneca the least (< 5%), and Skaneateles in between. More green algae were detected in Honeoye, Cayuga, Skaneateles and Otisco Lakes, up to 5% of the plankton community; and Canandaigua, Keuka, Seneca and Owasco had the least at only a few percent of the plankton community. Honeoye, Canandaigua, Keuka and Skaneateles had the largest percentages of blue-green taxa (> 20%), and Seneca and Cayuga the least (< 5%). The implications will be discussed a later section. Please note, relative percentages used here do not dictate large concentrations of algae, just dominance of the populations. Cryptophytes were not detected in the plankton tows even though they dominated the fluoroprobe data in many lakes, because they are small, typically 10 to 50 μm, smaller than the 80 μm mesh size of the plankton net.

The year-to-year change in plankton at each lake was noisy but lacked long term trends. Seasonal trends were observed but not shown here. Diatoms typically dominated in the early spring and early summer. Dinoflagellates or green algae dominated in the summer. Blue-green algae typically increased in numbers in the late summer and fall.

Fragellaria, *Tabelleria*, *Diatoma*, *Asterionella*, *Synedra*, *Melosira*, *Rhizoselenia* and *Cymbella* dominated the diatom taxa. *Dinobryon* and *Ceratium* dominated the dinoflagellate taxa. *Closteriopsis* and *Closterium* dominated the green taxa. *Anabeana*, *Stichosiphon*, *Gomphospaeria* and *Mycrocysitis* dominated the blue-green taxa.





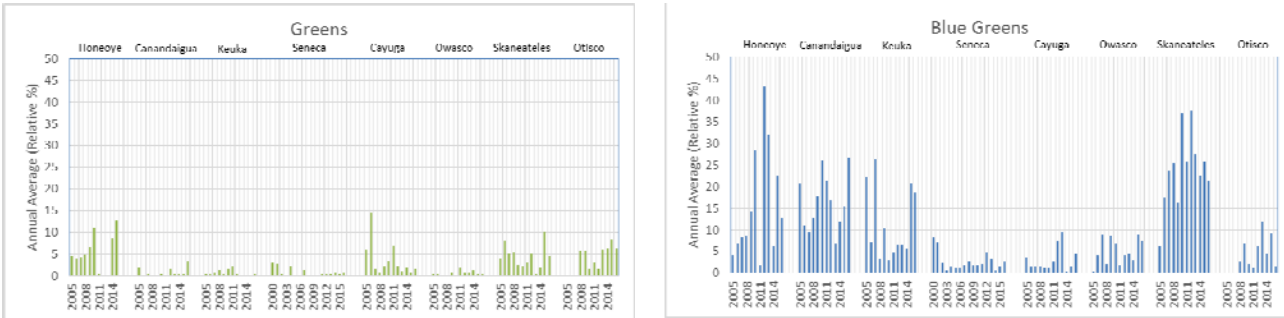


Fig. 19. Annual average plankton tow data from the 8 easternmost Finger Lakes.

Seneca and Owasco Lake Buoy Data: Only the 2015 buoy data from Owasco Lake are shown and discussed here for consistency with the CTD data, i.e., to save paper. Buoy data from other years and from Seneca Lake are available elsewhere[16]. The 2015 data revealed higher resolution but otherwise consistent changes in the water column as the CTD results (Fig. 20). In Owasco Lake, epilimnetic (surface water) temperatures increased from mid-May through early August to 25ºC (77ºF), then fluctuated between 22.5 and 25ºC to 9/9 until cooling down to 13ºC (55ºF) by the end of the deployment. These changes were related to the daily, weekly and seasonal changes in climate/weather patterns. Hypolimnetic temperatures slowly increased from 4 to 5.6ºC (39ºF) during the deployment. Perhaps warmer groundwater seeped into the hypolimnion.

The depth of the thermocline, the boundary between the epilimnion and hypolimnion, gradually increased through the deployment from under 10 m to over 20 m. The increase in depth was faster during September and October reflecting the vertical mixing of surface water with deeper water with similar temperatures as the surface water cools into the fall, i.e., the gradual decay of summer stratification. It also revealed daily oscillations in response to internal seiche activity.

The epilimnetic specific conductance decreased from just over 330 µS/cm in early June by 20 µS/cm by early October and increased by ~10 µS/cm until recovery (10/26, Fig. 20). The decrease reflects the dilution of the epilimnion by stream inputs and rainfall. The subsequent increase reflects the mixing of slightly more saline hypolimnetic water into the epilimnion as the surface waters cool and vertically mix to deeper depths in the fall. The hypolimnion salinity increased from ~340 µS/cm by 10 µS/cm from deployment to early October, then decreased by a few µS/cm until recovery.

The turbidity in the epilimnion decreased through the early spring by 2 NTUs to ~1 NTU, then increased in late August and early September to values between 2 & 3 NTUs (Fig. 20). The early spring turbidities most likely reflected the runoff from spring rains and subsequent resuspension events, whereas the late summer turbidities probably reflected the increase in algal populations, as storm and wind events were more prevalent in the early spring and declined in late August and early September. Lake-floor turbidities increased through the spring and early summer to 6 NTUs and declined to 2 NTUs afterwards, again the change is interpreted to reflect the early spring rains and wind/wave resuspension events supplying suspended sediment to the nepheloid layer in the early part of the field season.

[16] Buoy Data & Information for Seneca Lake & Owasco Lake.

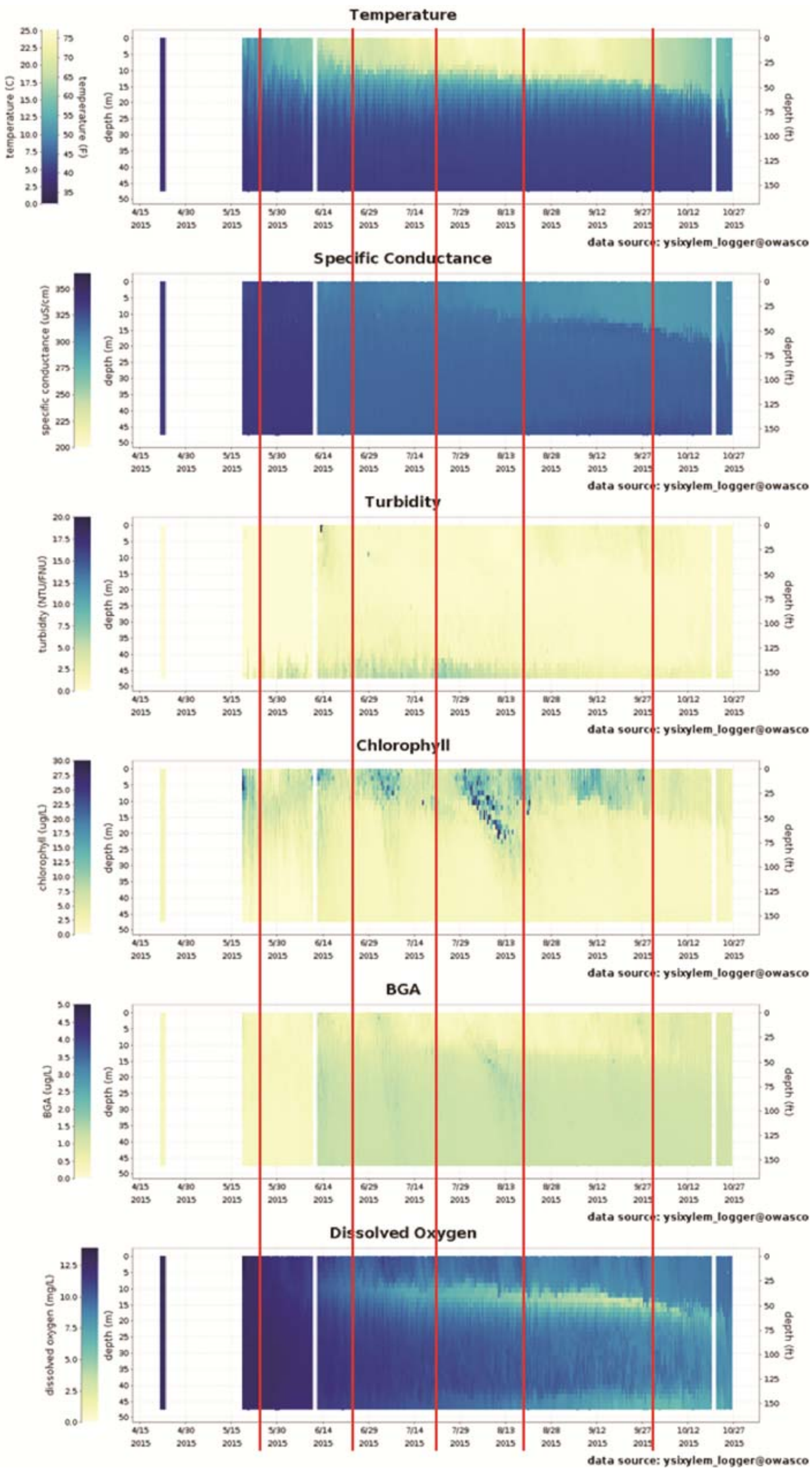


Fig. 20. Owasco's 2015 buoy data. The red lines depict the monthly monitoring cruise dates.

The chlorophyll-a concentrations changed significantly from ~1 to over 5 μg/L on different temporal scales (Fig. 20). One to two week long blooms with concentrations exceeding 5 μg/L were detected in mid-June, late July/early August and early September. The algae were typically concentrated within the upper 20 m of water, i.e., through the epilimnion and upper hypolimnion, however the late July bloom extended into the hypolimnion to depths of 25 to 30 meters. The June/July blooms most likely responded to the large rains and associated nutrient runoff. The September and October algae probably gained extra nutrients from the thermal decay of the season stratification, and mixing of nutrient-rich hypolimnetic waters into the epilimnion. In contrast, the CTD fluorescence and surface chlorophyll data from the monthly surveys missed the majority of the June & July blooms.

Epilimnetic dissolved oxygen (DO) concentrations were at or near saturation throughout the deployment (Fig. 20). DO concentrations in the upper hypolimnion and along the lake floor were slowly depleted during the 2015 summer stratified season until September, and then slowly increased until the end of the deployment. Specifically, DO concentrations decreased from nearly saturated concentrations in early June to 30% below saturation just below the thermocline and decreased to 45% saturation along the lake floor by the end of September just after the major algal blooms, and rose to 60% saturation by the end of the deployment. Throughout the intermediate depths of the hypolimnion, DO was only depleted to 50 to 60% saturation. The depletion reflects the relative amounts of respiration by bacteria, zooplankton and other animals at these depths. The subsequent increase may be due to the mixing of saturated epilimnetic waters with the hypolimnion during the seasonal decay of the epilimnion in the fall.

The BGA results will be discussed in a later section. Please note: The apparent rise in blue-green concentration below the thermocline was an artifact, a temperature dependence artifact, of the blue-green algae sensor.

FINGER LAKES WATER QUALITY

Water quality in the eight surveyed Finger Lakes ranged from oligotrophic to eutrophic systems (Table 4, Appendix, Fig. 21). Water quality in some of these lakes has also changed over time. Since Callinan's water quality survey in the late 1990's, Keuka and Otisco Lakes improved their classifications, Keuka from mesotrophic down to oligotrophic and Otisco from eutrophic down to mesotrophic, Cayuga and Seneca declined in trophic status from boarder-line oligotrophic up to mesotrophic, and Skaneateles and Honeoye remained oligotrophic and eutrophic, respectively. Thus, water quality varied from year to year, even with the crude "3-bin" trophic classification.

Table 4. The 2015 and 2016 Trophic Status* of the Finger Lakes.

2015	**Secchi Depth**	**Total Phosphorus**	**Chlorophyll**	**Dissolved Oxygen**	**Over All**	**Callinan's Designation**
Honeoye	1.6	31.6	19.0	10 - 80	Eutrophic	Eutrophic
Canandaigua	4.2	8.7	2.6	> 80	Oligotrophic	Oligotrophic
Keuka	3.7	7.6	2.7	> 80	Oligotrophic	Mesotrophic
Seneca	3.6	13.8	3.7	> 80	Mesotrophic	Oligotrophic
Cayuga	3.0	16.9	5.4	> 80	Mesotrophic	Oligotrophic
Owasco	3.3	15.5	3.8	10 - 80	Mesotrophic	Oligotrophic
Skaneateles	8.0	12.3	1.1	> 80	Oligotrophic	Oligotrophic
Otisco	2.1	12.7	4.3	> 10	Mesotrophic	Eutrophic
2016	**Secchi Depth**	**Total Phosphorus**	**Chlorophyll**	**Dissolved Oxygen**	**Over All**	**Callinan's Designation**
Honeoye	2.3	41	22.7	10 - 80	Eutrophic	Eutrophic
Canandaigua	7.7	18	1.8	> 80	Oligotrophic	Oligotrophic
Keuka	5.9	12.5	1.5	> 80	Oligotrophic	Mesotrophic
Seneca	4.3	15.1	2.7	> 80	Oligotrophic	Oligotrophic
Cayuga	3.5	16.5	3.0	> 80	Mesotrophic	Oligotrophic
Owasco	5.6	14.1	3.5	10 - 80	Mesotrophic	Oligotrophic
Skaneateles	9.7	13.7	1.0	> 80	Oligotrophic	Oligotrophic
Otisco	3.2	16.1	3.0	> 10	Mesotrophic	Eutrophic

*Oligotrophic in blue, Mesotrophic in orange and Eutrophic in red.

To increase the sensitivity of the water quality analysis, an annual water quality rank for each lake was calculated from surface water concentrations of total phosphorus, dissolved phosphates (SRP), nitrates, chlorophyll-a, total suspended solids, and Secchi disk depths, parameters fundamental to water quality and water clarity. First, the annual average of each water quality parameter was calculated for each lake from the available monthly surface water data (Appendix 1). Then, every annual mean for each parameter was ranked by proportionally interpolating each annual mean to the entire range (maximum – minimum) of annual means. In this way, each parameter was proportionally adjusted to a similar scale, the best annual mean got a rank of 1, the worst annual mean got the maximum rank, and the other annual means were proportionally adjusted between these endmembers (Fig. 21). "Best" means the clearest, and smallest nutrient, algae and suspended sediment concentrations. The Secchi disk ranks were adjusted so that the best water quality (deepest depths, clearest waters) received the smallest ranks, and worse water quality the largest ranks. Finally, the ranks for every parameter in any given year in any given lake were averaged and ranked once again, to get a mean annual rank for that lake in that year.

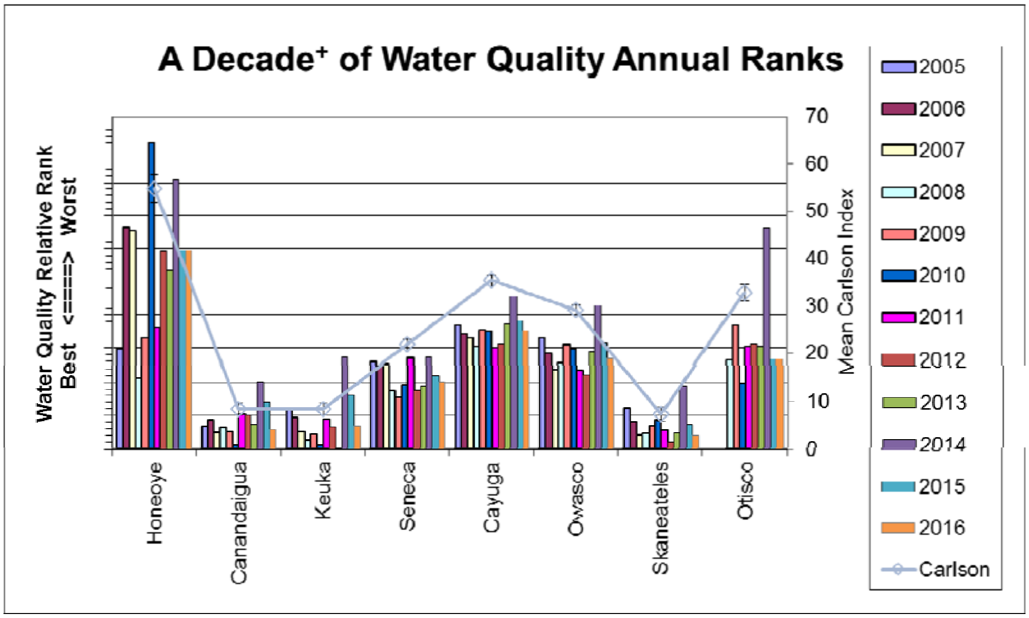


Fig. 21. Annual Water Quality Ranks. The scales are offset slightly for clarity.

Carlson's Trophic Status Index, an independent measure of water quality, was calculated for every lake to test the validity of these ranks. Carlson's Index mathematically manipulates the surface concentrations of chlorophyll, total phosphate, and Secchi disk depths to determine a trophic state index[17]. A smaller index reflects better water quality, whereas a larger index reflects poorer water quality. The equation for each parameter was designed so that the boundary between oligotrophic and mesotrophic lakes yielded an Index of ~40, and the boundary between mesotrophic and eutrophic lakes yielded an Index of ~50. Each lake's mean Index, the mean of each year's annual average Index of the three parameters, is plotted above (Fig. 21). The results revealed a similar lake to lake variability as the annual ranks presented here.

The water quality ranks revealed that the water quality during any year was consistently better in Skaneateles, Canandaigua and Keuka Lakes, than Owasco, Cayuga, and Otisco Lakes. Seneca Lake fell in between. At the other end of the spectrum, Honeoye had the worst rank. Year-to-year changes in water quality were observed. For example, water quality decreased in 2014 and/or 2015 for Canandaigua, Keuka, Cayuga, Owasco, Skaneateles and Otisco compared to other years in the record. These two years correspond to the larger concentrations of suspended sediments, total phosphorus, dissolved phosphates and chlorophyll, the two rainiest years in the recent past (Fig. 22).

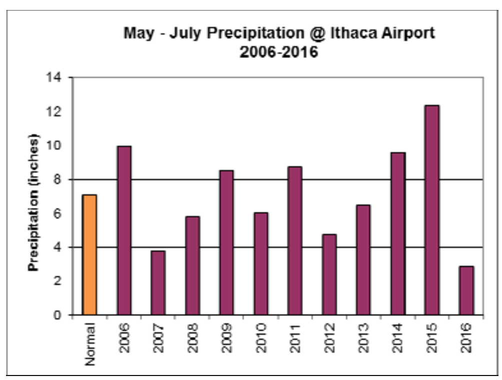


Fig. 22. Annual precipitation totals during the 8-month, March – October, field season and May – June spring months at the Ithaca Airport.

[17] Carlson, R.E., 1977. A Trophic State Index for Lakes. Limnology and Oceanography, 22: 361-369.

The mean rank for each lake was compared to common stressors of water quality to determine the cause(s) for the changes in water quality. They included the percentage of agricultural land, watershed area, lake volume, lake volume to surface area ratio, watershed area, water residence time, total population and population served with drinking water. Rank versus watershed area revealed a correlation when the smallest lakes, Honeoye, Otisco and Owasco were excluded from the analysis. When all of the lakes were taken into account, no correlation ($r^2 = 0.1$) was observed. Only one parameter, the percentage of agricultural land within each watershed, revealed a strong correlation to the water quality ranks ($r^2 = 0.92$) but only after Honeoye was excluded from the comparison (Fig. 23). It suggests that runoff from agricultural landscapes and its associated nutrient sources fertilize thus degrade the receiving lake.

Excluding Honeoye Lake from this analysis is reasonable because its watershed history, shallow depth and small size sets it apart from the other Finger Lakes. In the 1800's, the timber industry completely deforested Honeoye's watershed. It has since reforested. However, severe soil erosion and the associated nutrient loading during deforestation have haunted Honeoye Lake ever since because these nutrients are effectively recycled from the sediments due to its small size.

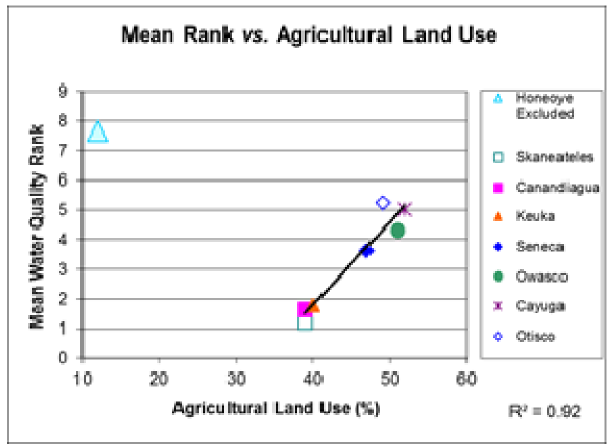


Fig. 23. Mean Rank vs. Agricultural Land Use.

During relatively calm days in the summer Honeoye stratifies and the bottom waters can become anoxic. Anoxia releases phosphate and reduced (favored nitrogen by algae) nitrogen (ammonium) from the sediments, providing a significant internal source of nutrients not available to the other Finger Lakes. In contrast, the deeper Finger Lakes are typically oxygenated to the lake floor. Oxygenated bottom waters precipitate and lock phosphates as particles in the sediments. Thus, any phosphates buried in the mud as organic matter or attached to sediment particles stay in the mud in oxygenated lakes and typically are lost from the aquatic ecosystem. Otisco's hypolimnion turns anoxic during the stratified season. However, Otisco is still deep enough so that the liberated phosphates and ammonium from the sediments typically remain in the hypolimnion and do not persistantly fertilize the algae in the epilimnion during the summer season. Occasionally, CTD fluorescence peaks were detected at or just below the thermocline in this lake. This algal growth was presumably utilizing the hypolimnetic nutrient supply.

Finally, Honeoye is unique in that it is nitrogen limited and not phosphorus limited as in the other Finger Lakes.

Causes of Water Quality Degradation

Nutrient Sources: Is the 2014 – 2015 degradation in water quality related to precipitation events? Evidence from streams within the Seneca and Owasco watersheds supports this nutrient loading hypothesis. At Seneca, phosphorus concentrations are 10 to 100 times larger in tributaries draining the watershed than in the lake, indicative of a nutrient loading problem (Fig. 24)[18]. These annual mean concentrations presented here are underestimates because a vast majority of them were collected during base flow and not during events. The source of the phosphorus was multifaceted and included runoff from agricultural land (both crop and animal farms), municipal wastewater treatment facilities, soil, road ditch and stream bank erosion, construction activities, lakeshore residences (on-site septic systems and lawn care fertilizers), and specifically to Reeder Cr., wastewater effluents and exploded munitions related to the former Seneca Army Depot. The nutrient loads paint a consistent scenario with the decline in water clarity and water quality in Seneca Lake since the late 1990's (see Fig. 11, and the Secchi disk section).

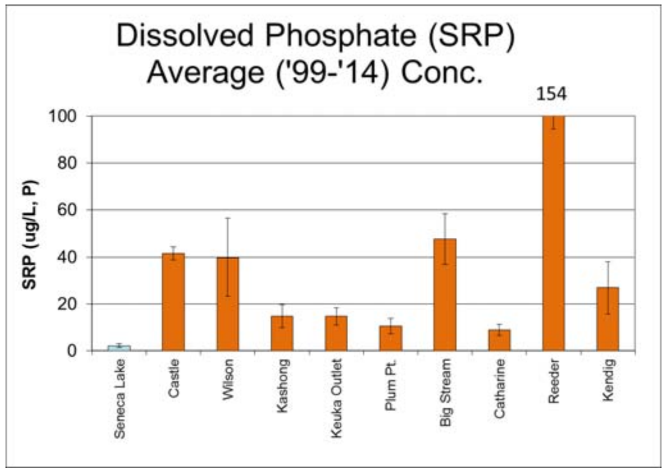


Fig. 24. Average dissolved phosphate (SRP) concentrations in the major Seneca Lake subwatersheds (orange) compared to SRP concentrations in the lake (green-left side).

Research in the Owasco watershed highlighted the importance of precipitation events on nutrient loads[19]. Event *vs.* base flow analyses at Dutch Hollow Brook, an agriculturally intense subwatershed in the Owasco watershed, revealed that over 90% of the nutrient and sediment loads were delivered during precipitation induced runoff events compared to base flow inputs, especially in the spring season (Fig. 25). For example, in 2015 over 81,000 kg/day of suspended sediment and 7.7 kg/day of phosphorus were delivered to Owasco Lake by events, whereas only 185 kg/day of sediments and 0.5 kg/day of phosphorus were delivered by base flow. This difference was less staggering in 2016, a relatively "dry" year. Annual nutrient and sediment loads positively correlated to precipitation totals, especially precipitation totals during the spring (r^2 =

[18] Halfman, J.D., D. Zorn, C. Roberson, L Cleckner and S. Meyer, 2012. Seneca Lake Watershed Management Plan: Characterization and Evaluation. 139 pg.
Halfman, J.D., H.A, Simbliaris, B.N. Swete, S. Bradt, M.C. Kowalski, P Spacher & I. Dumitriu. 2016. The 2016 Water Quality Report for Owasco Lake, NY. Finger Lakes Institute, Hobart and William Smith Colleges. 49 pg.

[19] Halfman, J.D., E.S. Brown, T.F. Ware, K.A. O'Neill, C.K. Franklin and R.E. Dye, 2008. Owasco Lake, New York: Water Quality and Nutrient Sources. In: Halfman, J.D., M.E. Balyszak and S.A. Meyer (eds.), A 2007 Water Quality Study of Owasco Lake, New York. Finger Lakes Institute, Hobart and William Smith Colleges. 37 pg. and subsequent annual reports to …
Halfman, J.D., H.A, Simbliaris, B.N. Swete, S. Bradt, M.C. Kowalski, P Spacher & I. Dumitriu. 2016. The 2016 Water Quality Report for Owasco Lake, NY. Finger Lakes Institute, Hobart and William Smith Colleges. 49 pg

0.81, Fig. 26). Thus, rainfall events and runoff from agricultural areas are significant for the delivery of nutrient and sediments to the lake.

An extreme example follows: The application of cow manure on farm fields, expecting the manure to “naturally” fertilize the fields, can lead to significant and unwelcomed consequences. In one case, manure application on snow just before a major snow melt and rain storm washed approximately one metric ton of phosphorus into Owasco Lake, an amount close to the total annual input of phosphorus to the lake (see budget section later).

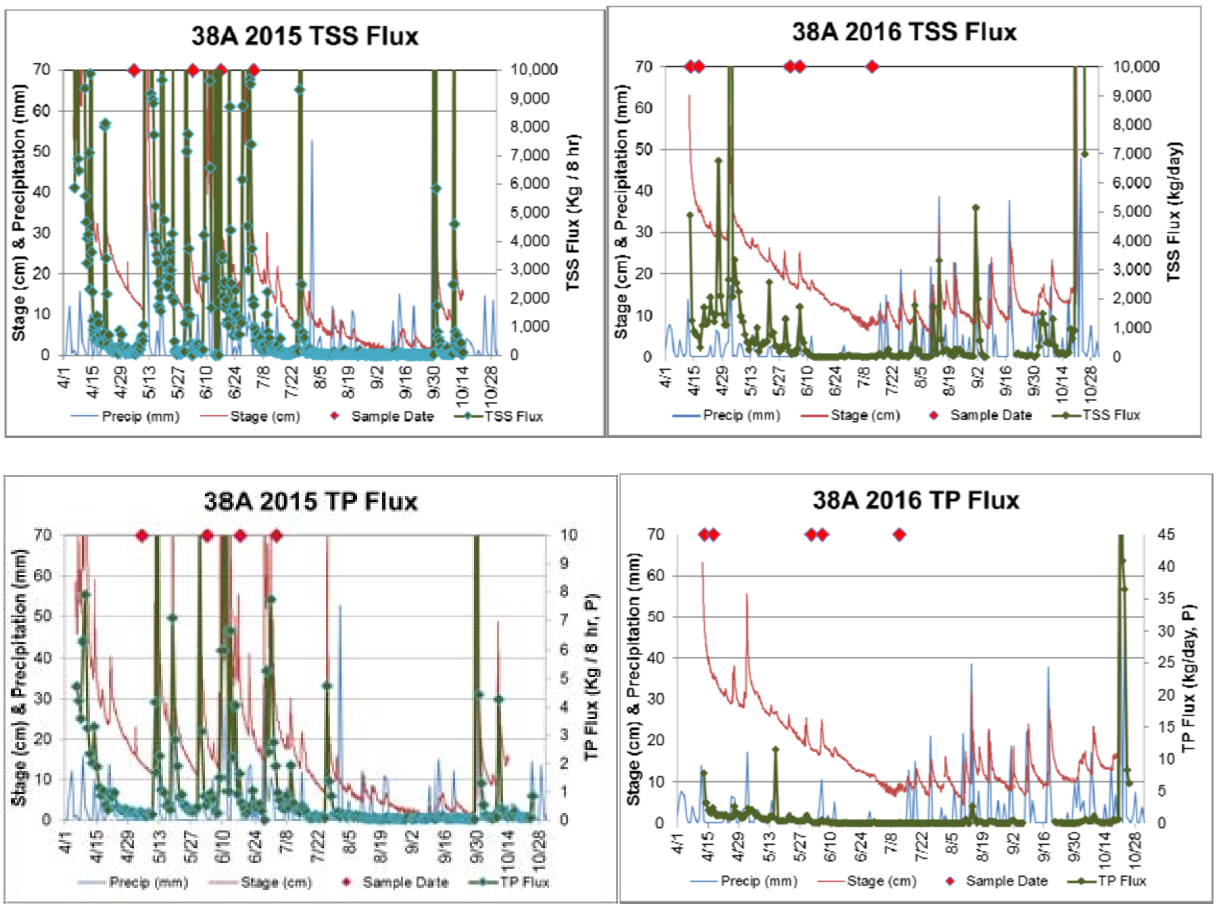


Fig. 25. Nutrient and sediment loads from Dutch Hollow Brook to Owasco Lake. Also plotted are the stream stage (discharge) and daily rainfall (CoCoRaHS: NY-CY-8).

Besides runoff from agricultural areas, other sources of phosphorus exist. Stream segment analysis along the Owasco Inlet in the Owasco watershed and along Big Stream in the Seneca watershed revealed that effluent from municipal wastewater treatment facilities in Groton[20] and

[20] Halfman, J.D., E.S. Brown, T.F. Ware, K.A. O’Neill, C.K. Franklin and R.E. Dye, 2008. Owasco Lake, New York: Water Quality and Nutrient Sources. In: Halfman, J.D., M.E. Balyszak and S.A. Meyer (eds.), A 2007 Water Quality Study of Owasco Lake, New York. Finger Lakes Institute, Hobart and William Smith Colleges. 37 pg.

Dundee[21] were a major source of nutrients to these streams. For example, the Groton facility delivered over 80% of the total phosphorus, nearly 100% in of the dissolved phosphates, and 45% of the total nitrates flowing down Owasco Inlet in 2007. Their contributions were especially noticeable and least diluted during base flow and "dry" years. Since then, the Groton facility installed tertiary treatment and lost nutrient rich wastes from a nearby fish farm that went bankrupt. Both consequences combined to reduce the facility's nutrient loads to the lake (Fig. 27). The Penn Yan and Moravia facilities were less significant point sources of phosphorus to nearby streams.

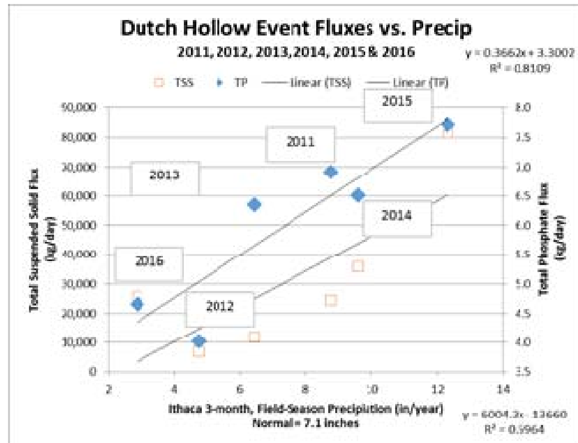


Fig. 26. Total phosphorus and sediment loads from Dutch Hollow Brook to Owasco Lake versus spring season rainfall from the Ithaca Airport.

In summary, nutrient loading from soil erosion, especially from agricultural areas, improper disposal of animal wastes, stream bank erosion, roadside ditch erosion, construction site erosion, wastewater treatment facilities lacking tertiary treatment, poorly functioning or improper on-site wastewater systems (septic systems), use of excessive and phosphorus bearing lawn fertilizers, and other sources have impacted the Finger Lakes, some sources more than others. Every effort should be made to continue reducing every source, if the nutrient loading issue is expected to be curtailed. These reductions must be long lived because each lake will require multiple water retention times to natural flush out the excess phosphorus once the inputs have been sharply curtailed.

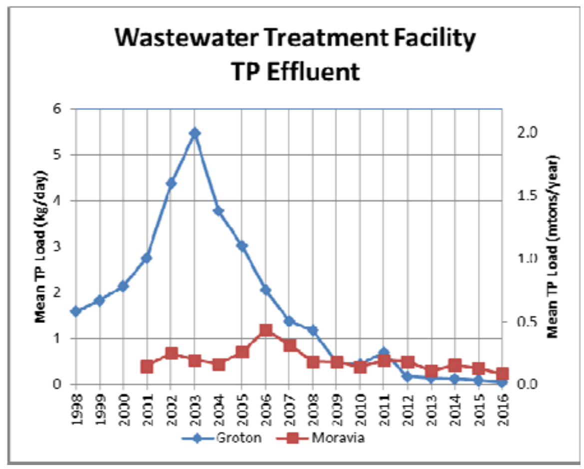


Fig. 27. Phosphorus loads from two municipal wastewater facilities in the Owasco watershed.

Whole Lake Phosphorus Budgets: How much loading is too much for a given lake? A phosphorus budget answers the question by compiling all the inputs of phosphorus to the lake and all the outputs of phosphorus from the lake (Fig. 28). The difference, i.e., inputs – outputs, determines the net impact on the lake, because the amount of phosphorus increases in the lake, when inputs are larger than outputs. Phosphorus decreases in the lake, when inputs are less than outputs. Alternatively, phosphorus remains the same, i.e., at equilibrium, when inputs equal outputs. To improve water quality, inputs of phosphorus must be smaller than outputs for a number of years (multiple water retention times). A sustained reduction allows existing phosphorus to leave by the outlet or be buried in the sediments, and eventually the declining supply of phosphorus limits algal growth and improves water quality and clarity.

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[21] Bowser, L.P., 2002. [Nitrate loading in the Seneca Lake Watershed. Is Hog Farming having an effect?] Honors Thesis, Hobart & William Smith Colleges. 45 pg.

The Seneca Lake Watershed Plan calculated a preliminary phosphorus budget for Seneca Lake[22]. The inputs were estimated from bi-monthly stream discharge and nutrient concentrations measured in the major subwatersheds draining into Seneca Lake over the preceding two year period. The inputs also included the published loads from municipal wastewater treatment facilities. Atmospheric deposition of phosphorus to the lake was estimated from measurements at Cornell University. Finally, contributions from lakeshore septic systems were lacking but it was estimated from studies elsewhere[23]. Data were also not available to assess the impact of other activities by lakeside residents like highly manicured and well fertilized lawns surrounding a year-round, lake-side home compared to the previous rustic, lawn-free, summer cabin. These last two issues require additional study to more accurately assess their relative impact. However the initial estimates suggest that they are only minor players compared to the loads from the streams and wastewater treatment facilities.

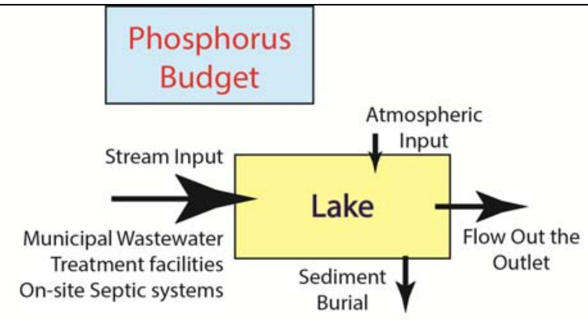


Fig. 28. A generalized phosphorus budget for a lake.

The output was controlled by two primary routes, flow out the outlet and burial of organic matter in the sediments. Flow of phosphorus out the outlet was calculated by multiplying the mean concentration of TP in the lake by the USGS measured mean daily flow of water out the outlet. The sediment burial was less constrained due to the limited number of sediment cores with organic matter concentrations and sedimentation rates. This too is probably not significant because the loss by burial was much smaller than the loss by flow out the outlet.

The total input was estimated at 55 metric tons of phosphorus per year (mtons/yr), with streams supplying ~40 mtons/yr. The outputs were estimated at 10 mtons/yr, with the outlet providing the majority of this loss. Thus, the net annual addition of phosphorus to Seneca Lake was 45 mtons. This net accumulation of phosphorus is significant because it is approximately 1/3rd of the total amount of phosphorus within the lake (~155 mtons), estimated from the mean TP concentration in the lake and its volume. Thus, Seneca Lake received a significant increase in phosphorus each year, continually fertilizing additional algal growth. Finally, this net accumulation is most likely an underestimate because the majority of the stream samples were measured during base flow, and event *vs.* base flow research indicates that precipitation induced events contribute significantly more phosphorus than base flow each year.

Annual phosphorus budgets for Owasco Lake from 2011 through 2016 revealed a persistent positive flow of phosphorus to the lake as well (Fig. 29). A positive balance was probably also true for 2009 and 2010, because stream data in these two years were based on base flow samples and lacked event contributions. Only one year, 2012, revealed a negative balance. This year was also very dry, curtailing the nonpoint source, runoff related, inputs from streams.

[22] Halfman, J.D., D. Zorn, C. Roberson, L Cleckner and S. Meyer, 2012. Seneca Lake Watershed Management Plan: Characterization and Evaluation. 139 pg.
[23] Hargen, K.E., A.M. Paterson & P.J. Dillon, 2011. A total phosphorus budget for the Lake of the Woods and the Rainy River Catchment. J Great Lakes Res., 37: 753-763.

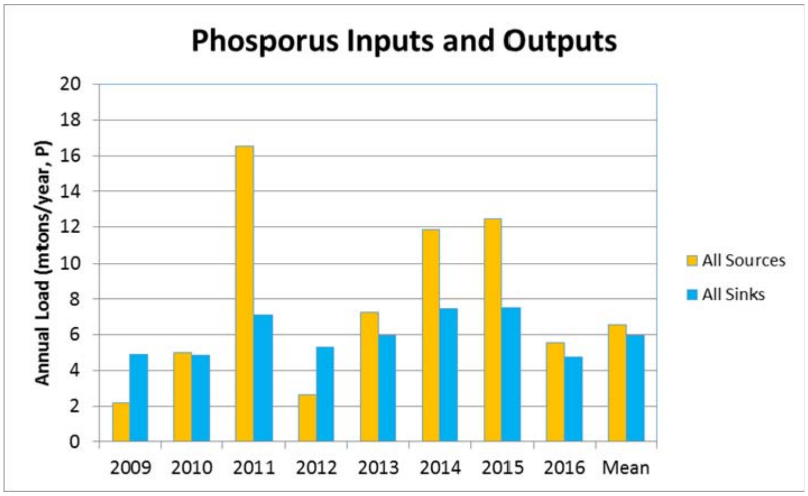


Fig. 29. Estimated annual total phosphorus inputs and outputs for Owasco Lake

The negative balance highlights a silver lining. If the sources of nutrients are curtailed, e.g., reduced through better management practices, then then Owasco Lake might stay in a negative balance over many years, losing phosphorus from the lake, and eventually improving water quality.

Nutrient loading is a "bottom up" stressor to aquatic ecosystems by stimulating algal blooms and ultimately degrading water quality in the lake. But it is not the only factor controlling water quality in these lakes. "Top down" perturbations can remove algal predators, and thus enhance algal populations and decrease water quality. For example, the carnivorous zooplankton *Cercopagus pengoi* feed on herbaceous zooplankton species. If their grazing decimates herbaceous zooplankton populations enough, then zooplankton are not available to reduce algal populations. The result is a bloom similar to those induced by nutrient stimulated eutrophic lakes, but without the addition of nutrients. Preliminary data from Owasco and Seneca Lakes revealed evidence for a 'top down" impact[24]. Similar results were observed in e.g., Otsego Lake, through the introduction of zooplanktivorous fish like alewife. These fish severely decrease herbaceous zooplankton populations. The associated reduction in the algal predation induces an algal bloom. In contrast, the filter feeding zebra and quagga mussels increase water clarity. Thus "top down" alterations most likely influenced some of the year-to-year variability in ranks, as well.

[24] Brown, M, and M. Baulk, 2008. The potential link between lake productivity and the invasive zooplankter *Ceropagis pengoi* in Owasco Lake (New York, USA). In: Halfman, J.D., M.E. Balyszak and S.A. Meyer (eds.), A 2007 Water Quality Study of Owasco Lake, New York. Finger Lakes Institute, Hobart and William Smith Colleges. 12 pg.

BLUE-GREEN ALGAE

The recent rise in blue-green algae (BGA) blooms and their associated toxins with concentrations above MCLs in many Finger Lakes is disturbing (Table 5). The Finger Lakes were not unique, in that 95 lakes in New York State had confirmed BGA blooms, 38 of those also had confirmed high toxin concentrations (> MCL) in 2016[25]. The numbers of impacted lakes has grown since 2012 from 58 lakes to 172 lakes in 2016 however the trend over time may reflect the increasing number of people looking for blooms in more recent years. The most disturbing aspect, BGA blooms were detected in oligotrophic (Canandaigua) and mesotrophic (Cayuga, Owasco and Seneca) lakes as well as the expected eutrophic (Honeoye) systems. Luckily they were not detected in all of the Finger Lakes (no reports from Hemlock, Canadice, Keuka and Skaneateles). Those lakes lacking BGA blooms have less agricultural land and more forested land in their watersheds, and have stricter watershed protection legislation, thus less runoff of nutrients during events. These same lakes revealed a more subdued response to the 2014 and 2015 rainy springs.

Table 5. Blue-Green Algae in the Finger Lakes[26]

Lake	2012	2013	2014	2015	2016
Conesus			C (7 wks)	C (3 wks)	C (4 wks)
Hemlock	-	-	-	-	-
Canadice	-	-	-	-	-
Honeoye	S (12 wks)	HT (18 wks)	C (8 wks)	HT (7 wks)	C (9 wks)
Canandaigua				HT (4 wks)	C (3 wks)
Keuka	-	-	-	-	-
Seneca				C (6 wks)	HT (2 wks)
Cayuga			S (3 wks)		C (7 wks)
Owasco	HT (1 wk)	C (7 wks)	HT (12 wks)	HT (9 wks)	HT (9 wks)
Skaneateles	-	-	-	-	-
Otisco				S (? Wks)	

Bloom status key: S = suspicious, C = confirmed, HT = confirmed with high toxins; and # weeks detected in lake.

The plankton tow data revealed that Honeoye, Canandaigua, Keuka and Skaneateles had the largest percentage of blue-green taxa (> 20%), and Seneca and Cayuga the least (< 5%, Fig 18). *Mycrocystis* was the most common form of BGA. It is surprising that the three cleanest Finger Lakes had the largest percentages of blue-green taxa as BGA were thought to only impact eutrophic systems. More importantly, blue-green algae have been detected at the same relative percentages in these lakes since the start of the FLI survey in 2005. In fact, blue-green species were detected in the Finger Lakes as long ago as 1914[27]. Yet some of these lakes with BGA taxa in the plankton tows have yet to experience a significant nearshore bloom of BGA. Something (or somethings) must have triggered the recent and large nearshore BGA blooms in many but not all of the Finger Lakes.

The fluoroprobe data indicated that blue-green algae dominated the upper portions of the water column in Honeoye Lake and were detected in the epilimnion of Canandaigua and Skaneateles

[25] Rebeca Gorney, NYS-DEC, personal communication, 2016.
[26] Harmful Algal Blooms (HABs) Archive Page, NYS DEC Website.
[27] Bloomfield, J.A. (ed.), 1978. Lakes of New York State. Vol.1: The Ecology of the Finger Lakes. Academic Press.

Lakes (Fig. 9). Blue-greens were absent in the epilimnion of the other Finger Lakes on the survey dates. The absence may reflect the late September timing of the survey, a time when many BGA blooms were beginning to wane from lakes throughout New York. This distribution of BGA is at first glance surprising, because nearshore BGA blooms were detected in Seneca, Cayuga and Owasco Lakes, where the fluoroprobe indicated no presence offshore on the isolated survey dates. It emphasizes that the huge BGA blooms in the Finger Lakes are primarily nearshore phenomena. Huge offshore BGA blooms were only detected in Honeoye Lake. In addition, nearshore BGA blooms were not detected in Skaneateles Lake, but the fluoroprobe detected them offshore, albeit in low concentrations. The dichotomy raises an important questions. For example, have BGAs blooms not yet been detected in Skaneateles Lake because no one has actively looked for them, or have BGA blooms not thrived in Skaneateles due to the lack of nutrients?

The blue-green algae sensor on the Owasco Lake monitoring buoy detected an increase in BGA concentrations within the epilimnion during the June and July blooms and again during September (Fig. 19). However, BGA concentrations at the buoy never exceeded 1 μg/L, compared to the occasional nearshore concentrations of over 4,000 μg/L[28]. The low open-water BGA concentrations near the buoy site were confirmed by 1 μg/L and lower concentrations in a number of mid-July and early August water samples collected by the Watershed Inspector and local residents. The discrepancy reflects the surface and nearshore hugging distribution of intense BGA blooms, as the buoy BGA sensor is never shallower than 1 meter and is deployed in a central, open-lake location.

The concentration of the largest nearshore BGA blooms are, at first glance, staggering (Fig. 30). In the open water, algal and TP concentrations rarely exceed 10 to 20 μg/L. However, some of the measured BGA concentrations exceeded these "typical" concentrations by nearly 1,000 times. It is a limnological and ecological challenge to increase a localized algal population with nutrients or other growth stimulants by 1,000 times. Existing BGA can be concentrated into smaller volumes of water, however.

Two mechanisms can concentrate algae into a smaller volume of water. First, BGA are unique among algal forms in that BGA buoyantly rise from deeper depths to the surface of the lake, and concentrate into smaller volumes of water. BGA cells contain gas vacuoles by which the organism regulates its depth through the addition or removal of gas. Second, light winds may push and accumulate the algae against the shoreline, and BGA again concentrate in smaller volumes of water. Once against the shoreline, the lake floor would also restrict the bloom's depth and thus restrict/reduce the bloom's water volume some more.

BGA blooms are believed to prefer the following conditions:

- warm water temperatures, between 15 to 30°C (60 and 80°F);
- elevated (eutrophic) concentrations of nutrients, especially waters rich in phosphorus, the limiting nutrient for many BGAs;
- lake stratification, as BGA buoyancy regulation provides a competitive edge in a warm, stratified water column;

[28] NYS-DEC and Owasco Lake Watershed Inspector's Office unpublished data, by permission.

- calm or near-calm conditions, as wind-induced turbulence disrupts their buoyancy and subjects algae to deeper depths and lower light levels, limiting their growth;
- rainfall events, as events deliver nutrients to the lake; and,
- other potential factors may include pH.

The last three years of buoy data in Owasco Lake shed some light on the water column and atmospheric conditions that were favorable for BGA blooms in Owasco Lake[29]. A summary of the findings are outlined below.

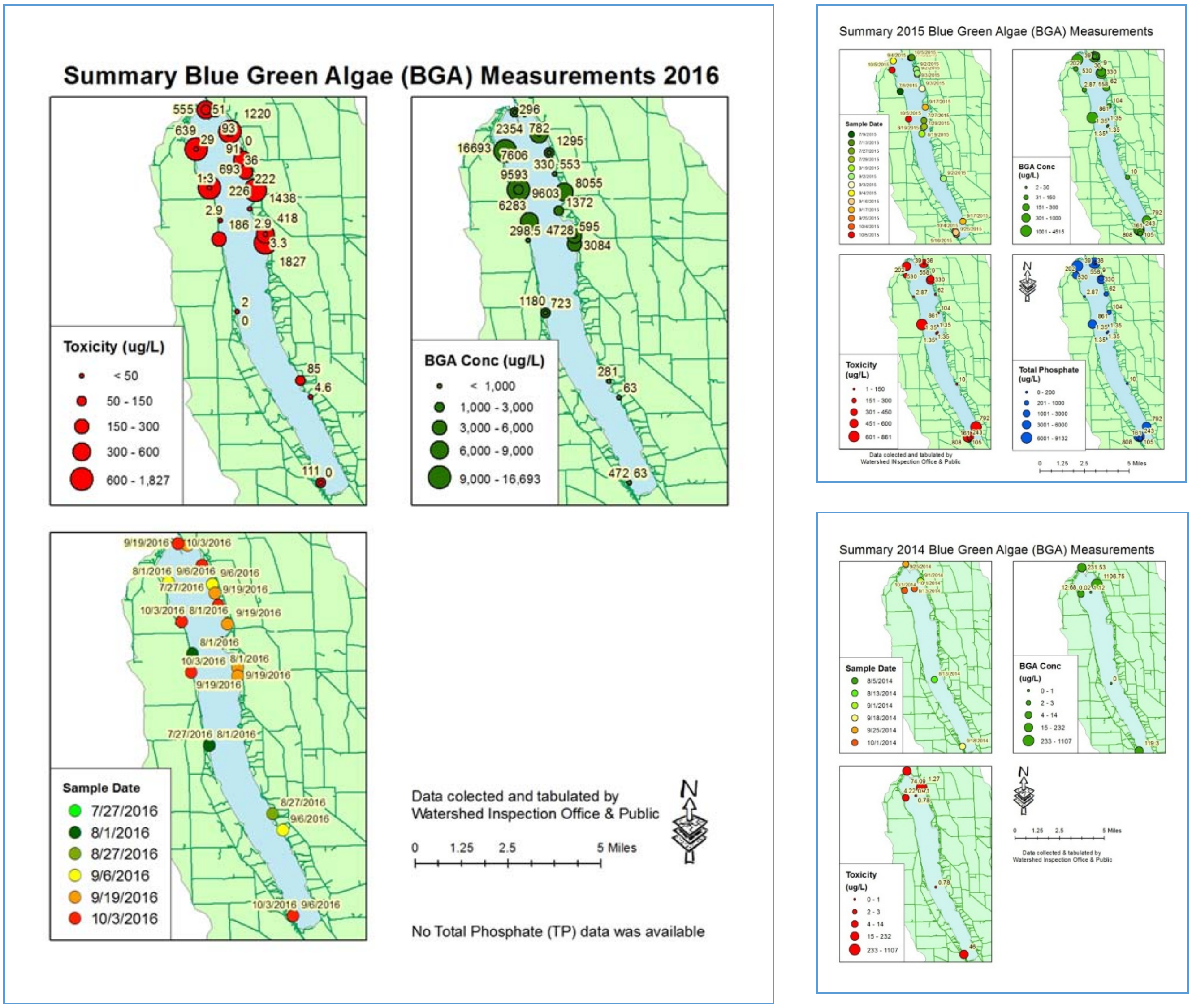


Fig. 30. Maps of the 2016, 2015 & 2014 BGA bloom dates, BGA concentrations and BGA toxin concentrations for Owasco Lake (data from the Owasco Lake Watershed Inspector & DEC).

[29] Halfman, J.D., H.A, Simbliaris, B.N. Swete, S. Bradt, M.C. Kowalski, P Spacher & I. Dumitriu. 2016. The 2016 Water Quality Report for Owasco Lake, NY. Finger Lakes Institute, Hobart and William Smith Colleges. 49 pg.

Buoy Total Algae and BGA Fluorescence: Minimal correlations were observed between the mid-lake buoy fluorescence data and the nearshore BGA occurrence and concentration data. The lack of a correlation was because the buoy measured the open lake, whereas the BGA blooms were located at nearshore locations.

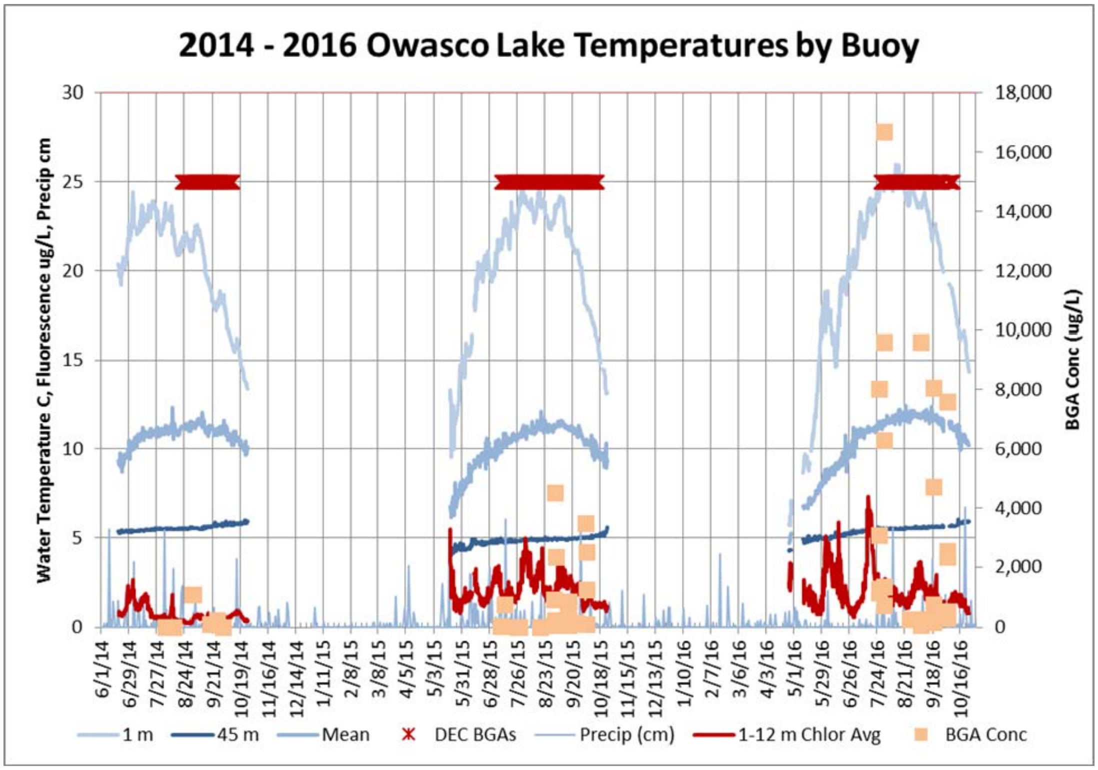
Buoy Lake Temperature: In all three years, BGA blooms started at or a few weeks after the warmest water temperatures (22 or 23°C, 70 – 75°F, Fig. 31). Blooms did not reappear after the surface water cooled below 15°C (60°F). A mean water column temperature, revealing the strength of thermal stratification, appeared to peak during the majority of BGA blooms as well. It indicates that blooms required warm, stratified water. Cold water, below 15°C, appears to terminate BGA blooms.

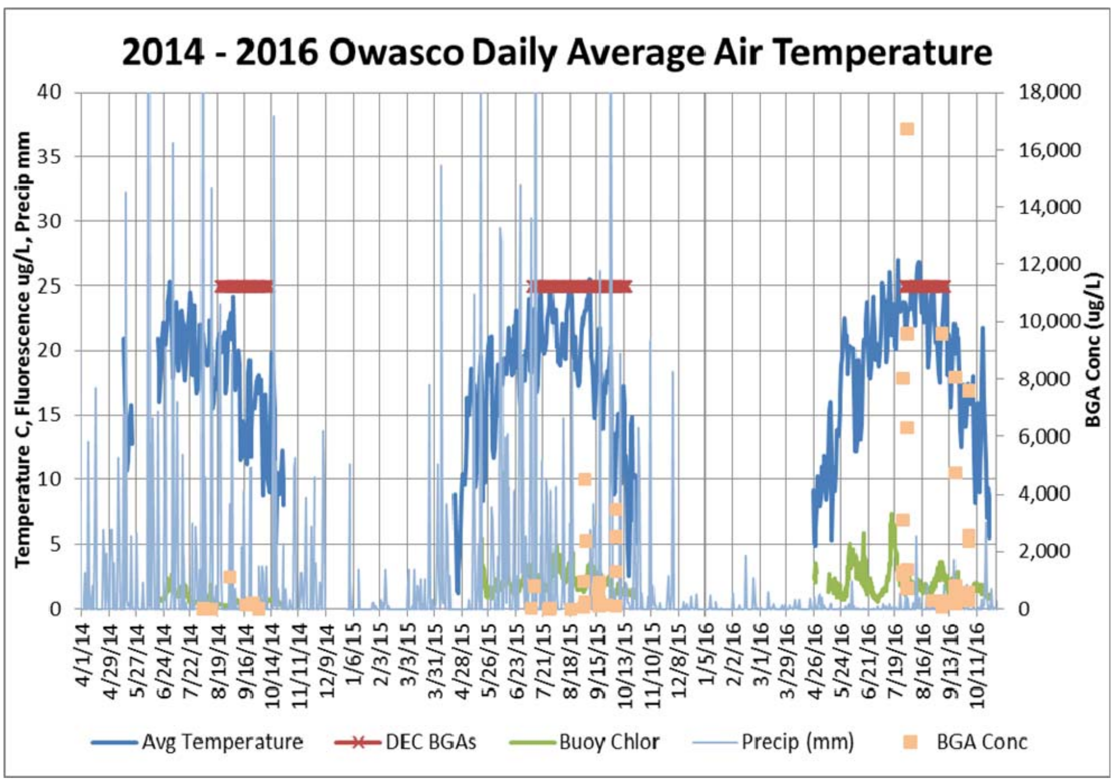
Buoy Air Temperature: Like water temperatures, the BGA blooms start at or a few weeks after peak air temperatures (23 to 24°C, 70-75°F, Fig. 31). Blooms end when the air temperature cooled below 10°C (50°F). Thus, blooms preferred warm air temperatures as well, and cold air temperatures appear to terminate BGA blooms.

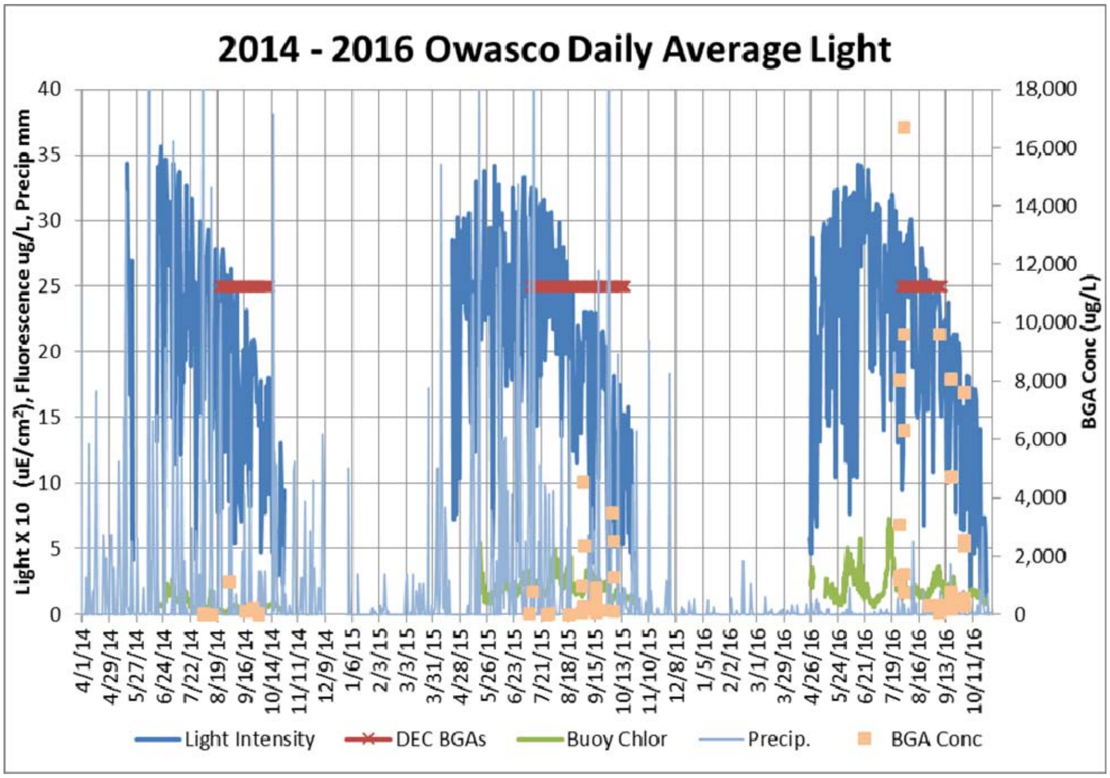
Buoy Sunlight Intensity: The first BGA blooms happened after the summer solstice, and BGA blooms were no longer detected when daily average insolation (sunlight) decreased below 150 $\mu E/cm^2$ (Fig. 31). Perhaps BGA outcompeted other algae in these periods of lower light, i.e., post peak light intensities, because BGA can float closer to the lake's surface, water depths with more light. However, blooms were not pervasive throughout the late summer and early fall. Thus, solar intensity, air temperatures and water temperatures, three interrelated variables, were associated with but were not the sole trigger for blooms.

Rainfall: In all three years, BGA blooms appeared after a day of rainfall (Fig. 31). It suggests that rain and associated runoff delivered sufficient nutrients to stimulate a bloom. Interestingly, the algae appeared to "wait" for the subsequent calm, sunny day just after the rain to bloom. In support, the bloom activity in 2016 was absent until mid-August, and only detected after the first rain events of the summer, late in the summer season. Unfortunately (or fortunately), blooms were not detected after every rainfall event. The decreased spring and summer rainfall of 2016 compared to 2014 and 2015 suggests that high annual rainfall totals, i.e., the "wet" years, were not important for individual bloom genesis. However, the significant spring rains of 2014 and 2015 and their associated nutrient/sediment loads may have delivered enough nutrients to the Finger Lakes to trigger the significant nearshore BGA blooms in the impacted Finger Lakes. Larger rainfalls in 2011 may have triggered the first blooms in Owasco Lake, but apparently the 2011 rains were not sufficient to trigger blooms in the other large Finger Lakes.

Buoy Wind Speed & Direction: BGA blooms favor light wind speeds (Fig. 31). Daily mean wind speeds in 2015 and 2016 were at or below 10 mph (small waves) with only a few days with wind speeds above 15 mph (large waves with white caps). 2014 had fewer calm to light-breeze days and multiple days with wind speeds above 15 mph. It suggests that BGA bloom development was more likely during calm or light-breeze days. However, BGA blooms were not detected on every available calm or nearly calm day in August and September, so calm days are not the sole trigger as well, but windy days prevent nearshore blooms. Wind speeds above 20 mph (very large waves with white caps) coincided with the end of the bloom activity in 2015 and 2016 but not 2014. Thus larger wind speeds probably retarded BGA blooms by mixing BGA throughout the epilimnion and towards open water, thus mixing the blue-green algae into a larger volume of water and decreasing its concentration.







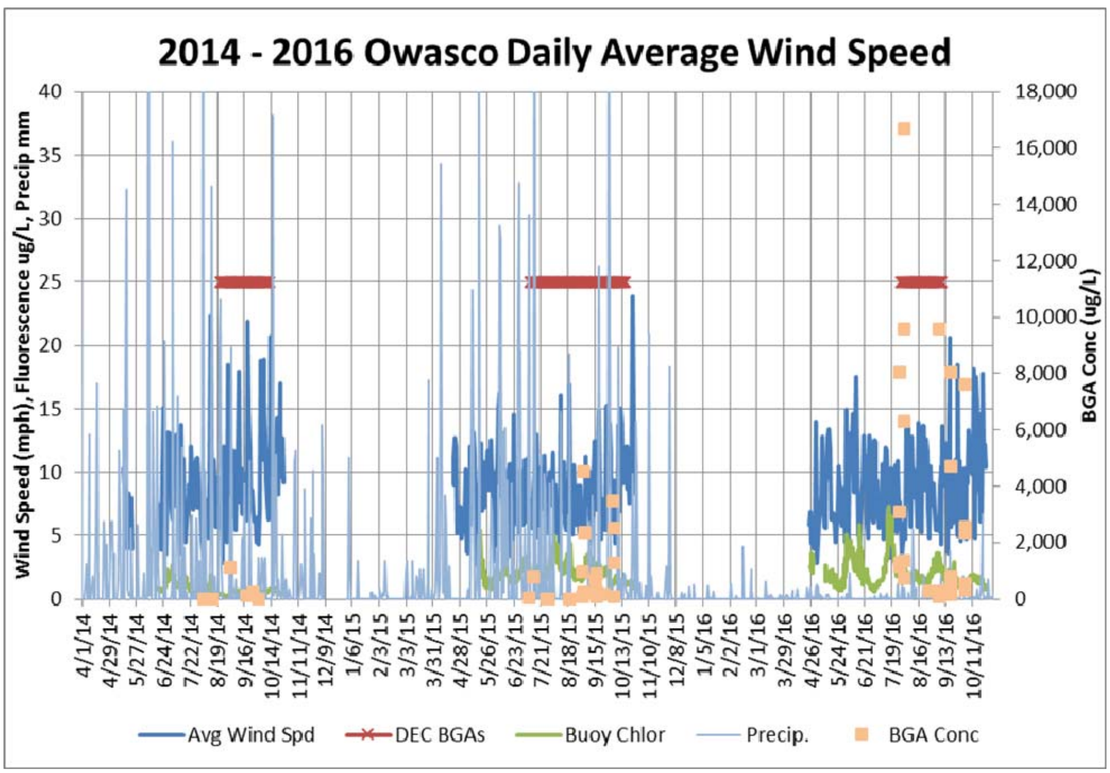


Fig. 31. Average daily total fluorescence, blue-green algae fluorescence, water temperature, air temperature, light intensity (sunlight) and wind speed data from the Owasco Lake monitoring buoy. Also plotted are nearshore BGA bloom concentrations and precipitation data.

The majority of the wind blew from the south in all three years (Fig. 32). The direction was consistent with the majority of the BGA concentrations along the northern margins of Owasco Lake (Fig. 30). A similar BGA lakeshore bloom distribution and wind direction connection was observed in Seneca Lake.

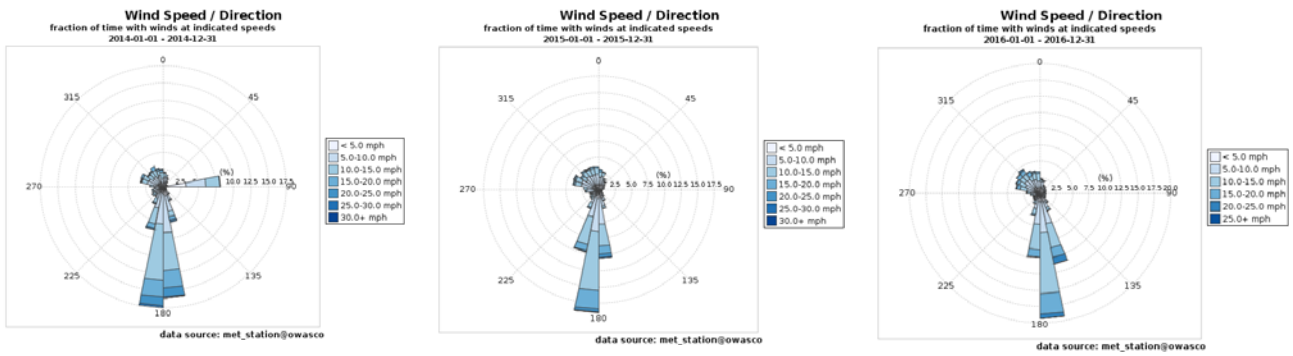


Fig. 32. Wind rose diagrams showing frequency of wind direction and speed for 2014 (left), 2015 (center) and 2016 (right) from the Owasco Lake buoy.

Summary: The buoy water quality and meteorological data indicated that BGA blooms occurred between the summer solstice and a few weeks after the fall equinox, coincident with the warmest and subsequent decline in air and water temperatures. Blooms were more likely during periods of calm or nearly calm weather, but were not detected during every calm day. Sunny calm days after a recent runoff event typically coincided with a bloom but did not consistently initiate a bloom. The southerly wind direction was consistent with the northerly location of the majority of the nearshore blooms. The decay of the epilimnetic thermal stratification in the fall season, due to cooler temperatures and wind events, mixed more nutrients into the epilimnion and perhaps stimulated additional bloom development. Strong winds were also coincident with the last bloom in any given year. The spring rains in 2014 and 2015 that have influenced many water quality parameters may have also initiated the large nearshore blooms found in many Finger Lakes.

Finally, these results focused on the conditions controlling the appearance of BGA blooms. Do not lose the larger focus. The 2014 and 2015 data suggest that nutrient loading induced the increase in BGA bloom activity. Therefore, reductions in nutrient loads are required to remove the BGA threat in the Finger Lakes. Unfortunately, nutrient reductions are not the panacea to stop BGA blooms because nutrient poor Finer Lakes have already experienced blooms with high toxins. More research is required to isolate the other underlying causes for BGA bloom genesis.

WATER QUALITY PROTECTION LEGISLATION

The United States Environmental Protection Agency (US EPA) through the Safe Drinking Water Act is tasked with the regulation and protection of surface water quality. During the latter part of the 20th century, legislation was passed to control point source pollution. In New York, potential point-source polluters like wastewater treatment facilities must be awarded and comply with permits to discharge wastes into surface waters. Occasionally, the permits are updated to reduce the flow of a pollutant into natural waters, just like the Groton Wastewater Treatment Facility had to reduce the amount of phosphorus in its effluent. More recent legislation has begun to focus on nonpoint source pollutants like runoff from agricultural land.

The Catskill Watershed Cooperative (CWC) is an excellent example where stringent water quality protection legislation was adopted to protect this drinking water supply for New York City. The nineteen reservoirs and three controlled lakes in this rural setting located north of the city and just west of the Hudson River supply ~90% of the city's drinking water. New York City's incentive to establish stringent water quality protection legislation is to avoid huge construction and maintenance costs for water filtration plants. New York currently has a filtration exclusion, one of a handful issued across the nation, because these water bodies are very clean. Their water protection programs focus on rehabilitation and replacement of septic systems, septic system maintenance programs, septic system monitoring programs, community wastewater facility management systems, storm-water control programs, local technical and economic assistance to encourage growth of environmentally friendly business ventures, and establishing and maintaining best management practices at agricultural sites. Unfortunately, these practices are not state-wide.

The extent of watershed protection legislation depends on the degree of watershed protection legislation in the local area. Every town, village and city is required to follow basic minimum standards set by the Department of Environmental Conservation in New York State (NYS-DEC). However, each community can establish more stringent legislation like the Catskill Watershed Cooperative, because New York is a home-rule state. For example, all new septic systems must follow basic building codes. However, local communities may increase the local regulations to also include periodic septic system inspections and pump outs. If enhanced watershed protection is to work, every community within the watershed must utilize the same stringent standards. This is relatively easy when the entire watershed is in one county and only spans a few towns, or a single entity owns, regulates and controls lakeshore development and lake use like at the Hemlock-Canadice State Forest. Seneca and Cayuga Lakes face larger hurdles because their larger watershed span many counties, and 40+ towns, villages and cities. Change requires every stakeholder to feel empowered to improve water quality.

In the Finger Lakes region, each watershed has a variety of regulations to maintain water quality. For example, the land protection, agricultural environmental management, and public outreach programs provide stringent water quality protection controls in the Skaneateles Watershed. The Canandaigua Lake Watershed Council utilizes, for example, best management practices to control runoff issues, and initiated a stringent on-site (septic) inspection system. The Owasco Watershed Management Council recently updated the Watershed Plan and is currently investigating a Nine Element Plan to determine venues to improve water quality in the lake. Cayuga County Soil and Water and Owasco Lake Watershed Association also secured state funds to construct pilot nutrient reduction strategies. On the other side of the spectrum, some watersheds could be more proactive.

Many of the regulations/methodologies require money for implementation, another significant hurdle to overcome. Funds are required to support, for example, a "watershed stewards" office, and to provide economic incentives to assist in establishing best management practices for improved water quality protection. Skaneateles has financial resources for watershed protection, because the City of Syracuse, like New York City, draws and supplies unfiltered drinking water from Skaneateles Lake, and thus saves money from avoiding filtration costs. Syracuse then uses some of this savings to support water quality protection measures in the Skaneateles watershed. Other watersheds established a tax on drinking water drawn from their lake.[30] More could be, no, more must be done.

CONCLUSIONS, RECOMMENDATIONS & FUTURE RESEARCH

Water quality across the eight easternmost Finger Lakes range from oligotrophic to eutrophic systems. Skaneateles, Canandaigua and Keuka Lakes are the oligotrophic endmembers and exhibit the best water quality. Honeoye is the eutrophic endmember. Whereas Seneca, Owasco, Cayuga, and Otisco Lakes are in between, i.e., mesotrophic. Nutrient loading explains a large part of this range and year-to-year variability, especially the 2014 and 2015 event although other stressors exist. This timing coincides with the BGA blooms in many Finger Lakes. Nutrient sources include a variety of point sources like wastewater treatment facilities and on-site septic systems, and nonpoint sources like runoff from agricultural areas, roadside ditches and construction sites. Everyone has a stake in protecting and preserving water quality in the Finger Lakes, because these lakes are critical drinking water supplies and are essential to the regional tourism-based economy. Therefore, everyone must work together to reduce nutrient sources and eventually improve water quality in our lakes.

ACKNOWLEDGEMENTS

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[30] Balyszak, M. and K. Rootes-Murdy, 2008. Watershed quality and protection legislation in the Owasco Lake watershed. In: Halfman, J.D., M.E. Balyszak and S.A. Meyer (eds.), A 2007 Water Quality Study of Owasco Lake, New York. Finger Lakes Institute, Hobart and William Smith Colleges. 26 pg.

APPENDIX 1: MEAN ANNUAL LAKE DATA:

2005	Honeoye	Canandaigua	Keuka	Seneca	Cayuga	Owasco	Skaneateles
Secchi Depth (m)	4.4 ± 1.5	6.2 ± 1.9	4.4 ± 0.5	3.8 ± 1.3	4.4 ± 1.4	3.8 ± 0.5	6.9 ± 1.2
Total Suspended Solids (mg/L), Surface	1.8 ± 1.3	0.8 ± 0.4	1.3 ± 0.7	2.1 ± 1.0	1.2 ± 0.4	1.3 ± 0.3	0.6 ± 0.3
Total Suspended Solids (mg/L), Bottom	2.3 ± 1.3	1.9 ± 1.0	2.0 ± 1.0	1.0 ± 0.6	3.7 ± 2.4	1.1 ± 0.3	0.7 ± 0.4
Phosphate (µg/L, SRP), Surface	9.1 ± 12.7	0.4 ± 0.6	0.2 ± 0.2	0.8 ± 1.5	0.5 ± 0.8	0.6 ± 0.8	0.0 ± 0.0
Phosphate (µg/L, SRP), Bottom	9.6 ± 14.0	1.1 ± 1.3	0.4 ± 0.5	1.0 ± 1.3	8.8 ± 5.2	1.3 ± 0.8	0.5 ± 0.6
No Total Phosphate data this year							
Nitrate as N (mg/L), Surface	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.3 ± 0.1	1.0 ± 0.3	0.7 ± 0.3	0.5 ± 0.2
Nitrate as N (mg/L), Bottom	0.0 ± 0.1	0.3 ± 0.1	0.2 ± 0.1	0.5 ± 0.3	1.4 ± 0.8	1.2 ± 0.6	0.6 ± 0.2
Silica (SR µg/L), Surface	868 ± 346	1091 ± 135	489 ± 223	120 ± 56	257 ± 163	529 ± 140	157 ± 80
Silica (SR µg/L), Bottom	834 ± 381	1569 ± 156	1077 ± 94	319 ± 193	1018 ± 110	1547 ± 129	708 ± 78
Chlorphyll a (µg/L), Surface	3.6 ± 2.4	1.5 ± 1.0	1.4 ± 0.9	2.6 ± 1.6	2.5 ± 1.4	4.1 ± 2.1	0.6 ± 0.4
Chlorphyll a (µg/L), Bottom	4.4 ± 3.0	0.1 ± 0.1	4.4 ± 4.4	1.5 ± 1.3	0.7 ± 1.5	0.3 ± 0.3	0.4 ± 0.6
Total Coliform (colonies/100mL), Surface	67.2 ± 104.7	22.5 ± 20.1	44.3 ± 32.8	115.3 ± 185.6	19.1 ± 33.6	170.8 ± 221.4	12.2 ± 12.5
Total Coliform (colonies/100mL), Bottom	140.3 ± 140.0	46.3 ± 95.2	62.7 ± 53.5	28.0 ± 38.8	27.3 ± 22.9	139.2 ± 106.7	96.7 ± 204.7
E. coli (colonies/100mL), Surface	6.8 ± 15.0	0.7 ± 1.0	6.4 ± 12.0	31.3 ± 87.7	0.1 ± 0.2	7.9 ± 14.1	0.1 ± 0.2
E. coli (colonies/100mL), Bottom	1.3 ± 1.9	0.9 ± 1.8	0.4 ± 0.9	0.5 ± 0.6	0.8 ± 1.3	8.7 ± 15.3	1.8 ± 2.1

2006	Honeoye	Canandaigua	Keuka	Seneca	Cayuga	Owasco	Skaneateles
Secchi Depth (m)	3.9 ± 1.8	5.9 ± 1.6	4.5 ± 1.0	5.3 ± 2.4	3.8 ± 1.0	3.4 ± 1.5	7.3 ± 2.0
Total Suspended Solids (mg/L), Surface	1.8 ± 1.5	0.9 ± 0.5	1.3 ± 0.6	1.4 ± 0.4	1.2 ± 0.4	1.9 ± 0.8	0.8 ± 0.3
Total Suspended Solids (mg/L), Bottom	1.7 ± 1.6	1.6 ± 1.0	1.6 ± 0.6	0.7 ± 0.3	3.3 ± 1.5	1.2 ± 0.3	1.0 ± 0.4
Dissolved Phosphate (µg/L, SRP), Surface	1.8 ± 1.3	1.8 ± 3.1	1.2 ± 1.0	0.8 ± 1.0	1.3 ± 1.3	1.3 ± 1.6	1.1 ± 1.9
Dissolved Phosphate (µg/L, SRP), Bottom	3.3 ± 1.8	2.4 ± 2.2	1.9 ± 2.5	2.2 ± 2.0	10.2 ± 2.6	2.0 ± 1.5	1.6 ± 2.2
Total Phosphate (µg/L, TP), Surface	16.0 ± 3.7	7.4 ± 1.9	7.8 ± 2.1	8.4 ± 2.7	11.2 ± 4.6	7.5 ± 2.5	4.0 ± 1.0
Total Phosphate (µg/L, TP), Bottom	18.3 ± 3.8	7.8 ± 2.2	8.1 ± 2.8	7.4 ± 1.9	10.3 ± 3.8	7.4 ± 2.4	5.1 ± 2.4
Nitrate as N (mg/L), Surface	0.0 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.3 ± 0.2	1.2 ± 0.4	0.7 ± 0.2	0.5 ± 0.2
Nitrate as N (mg/L), Bottom	0.0 ± 0.0	0.2 ± 0.1	0.2 ± 0.1	0.4 ± 0.2	1.5 ± 0.3	0.7 ± 0.3	0.6 ± 0.2
Silica (SR µg/L), Surface	660 ± 178	1090 ± 172	579 ± 118	158 ± 76	595 ± 126	595 ± 145	298 ± 113
Silica (SR µg/L), Bottom	694 ± 136	1506 ± 329	1077 ± 284	314 ± 169	991 ± 212	1473 ± 779	701 ± 182
Chlorphyll a (µg/L), Surface	3.9 ± 3.9	1.7 ± 1.2	2.0 ± 1.2	2.4 ± 1.8	2.8 ± 1.5	2.1 ± 1.3	0.7 ± 0.4
Chlorphyll a (µg/L), Bottom	3.4 ± 2.8	0.3 ± 0.2	0.5 ± 0.3	0.7 ± 0.9	0.3 ± 0.2	0.4 ± 0.3	0.2 ± 0.1

2007	Honeoye	Canandaigua	Keuka	Seneca	Cayuga	Owasco	Skaneateles
Secchi Depth (m)	4.2 ± 2.0	7.1 ± 2.0	5.9 ± 0.7	5.0 ± 1.6	4.2 ± 1.1	4.9 ± 1.2	8.6 ± 1.0
Total Suspended Solids (mg/L), Surface	6.0 ± 9.4	1.3 ± 0.7	0.9 ± 0.2	1.5 ± 0.5	1.4 ± 0.5	1.2 ± 0.5	0.5 ± 0.2
Total Suspended Solids (mg/L), Bottom	2.0 ± 0.7	2.6 ± 2.0	2.1 ± 1.1	1.0 ± 0.5	1.8 ± 0.8	0.8 ± 0.1	0.6 ± 0.2
Dissolved Phosphate (µg/L, SRP), Surface	8.3 ± 8.6	0.5 ± 0.8	0.7 ± 0.7	0.5 ± 0.7	0.8 ± 1.3	0.6 ± 0.7	0.4 ± 0.4
Dissolved Phosphate (µg/L, SRP), Bottom	7.4 ± 8.2	0.9 ± 0.6	2.2 ± 2.7	2.4 ± 2.8	8.4 ± 3.6	1.3 ± 0.8	0.7 ± 0.7
Total Phosphate (µg/L, TP), Surface	35.3 ± 28.7	8.0 ± 5.9	5.7 ± 1.2	8.9 ± 3.0	9.9 ± 3.6	7.7 ± 2.3	3.8 ± 1.9
Total Phosphate (µg/L, TP), Bottom	23.2 ± 10.2	5.2 ± 3.1	4.8 ± 2.5	7.8 ± 3.7	12.6 ± 4.5	5.7 ± 2.4	4.5 ± 2.4
Nitrate as N (mg/L), Surface	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.0	0.7 ± 0.9	0.9 ± 0.2	0.7 ± 0.2	0.5 ± 0.1
Nitrate as N (mg/L), Bottom	0.0 ± 0.0	0.3 ± 0.1	0.2 ± 0.1	0.5 ± 0.3	1.3 ± 0.3	1.0 ± 0.2	0.6 ± 0.2
Silica (SR µg/L), Surface	868 ± 58	966 ± 275	542 ± 179	263 ± 184	366 ± 144	676 ± 227	319 ± 117
Silica (SR µg/L), Bottom	866 ± 56	1322 ± 289	1194 ± 349	381 ± 195	1025 ± 211	1454 ± 283	727 ± 201
Chlorphyll a (µg/L), Surface	28.2 ± 52.8	2.0 ± 1.7	2.6 ± 3.5	4.0 ± 2.2	3.6 ± 1.9	2.4 ± 1.8	0.7 ± 0.4
Chlorphyll a (µg/L), Bottom	5.5 ± 3.6	0.9 ± 0.6	1.8 ± 3.1	1.1 ± 1.2	1.7 ± 5.9	0.7 ± 0.5	1.0 ± 0.9

2008	Honeoye	Canandaigua	Keuka	Seneca	Cayuga	Owasco	Skaneateles	Otisco
Secchi Depth (m)	4.6 ± 0.9	6.7 ± 1.6	6.5 ± 0.7	4.7 ± 2.8	3.8 ± 1.0	4.2 ± 1.2	7.8 ± 1.2	3.1 ± 0.9
Total Suspended Solids (mg/L), Surface	1.4 ± 0.8	0.9 ± 0.5	1.0 ± 0.2	1.7 ± 0.8	1.5 ± 0.5	1.3 ± 0.7	0.6 ± 0.2	2.3 ± 1.9
Total Suspended Solids (mg/L), Bottom	1.2 ± 0.2	1.5 ± 1.0	1.2 ± 0.5	0.8 ± 0.4	2.5 ± 1.5	1.2 ± 0.6	0.7 ± 0.4	2.1 ± 0.7
Total Phosphate (µg/L, TP), Surface	19.2 ± 5.6	7.9 ± 3.3	5.4 ± 2.7	9.8 ± 2.9	8.0 ± 1.4	7.4 ± 2.7	3.4 ± 1.7	12.8 ± 3.1
Total Phosphate (µg/L, TP), Bottom	18.4 ± 3.8	7.4 ± 4.5	6.8 ± 4.3	9.4 ± 3.0	12.5 ± 3.7	8.9 ± 2.0	4.8 ± 2.1	14.2 ± 9.6
Dissolved Phosphate (µg/L, SRP), Surface	4.6 ± 6.1	0.9 ± 0.6	0.6 ± 0.5	0.9 ± 1.3	0.8 ± 0.8	0.9 ± 0.7	0.7 ± 0.5	0.8 ± 1.2
Dissolved Phosphate (µg/L, SRP), Bottom	3.7 ± 5.2	1.3 ± 0.9	0.9 ± 0.6	3.2 ± 3.1	7.7 ± 4.2	1.1 ± 1.1	1.1 ± 1.1	4.8 ± 9.7
Nitrate as N (mg/L), Surface	0.0 ± 0.0	0.2 ± 0.2	0.0 ± 0.0	0.2 ± 0.1	0.7 ± 0.4	0.6 ± 0.2	0.4 ± 0.2	0.3 ± 0.1
Nitrate as N (mg/L), Bottom	0.0 ± 0.0	0.3 ± 0.2	0.2 ± 0.1	0.3 ± 0.1	1.1 ± 0.5	0.9 ± 0.4	0.6 ± 0.2	0.3 ± 0.2
Silica (SR µg/L), Surface	823 ± 266	994 ± 163	462 ± 148	309 ± 291	358 ± 188	751 ± 514	290 ± 89	334 ± 413
Silica (SR µg/L), Bottom	865 ± 252	1589 ± 513	1157 ± 419	470 ± 117	1033 ± 225	1474 ± 531	825 ± 231	1298 ± 890
Chlorphyll a (µg/L), Surface	2.7 ± 1.9	1.6 ± 1.0	2.0 ± 1.1	4.6 ± 2.7	4.0 ± 1.4	2.6 ± 1.3	0.7 ± 0.3	3.7 ± 0.6
Chlorphyll a (µg/L), Bottom	1.9 ± 0.9	0.9 ± 1.1	0.5 ± 0.2	1.5 ± 1.4	0.3 ± 0.2	0.8 ± 0.6	0.4 ± 0.2	3.0 ± 1.7

2009	Honeoye	Canandaigua	Keuka	Seneca	Cayuga	Owasco	Skaneateles	Otisco
Secchi Depth (m)	2.8 ± 1.0	6.5 ± 1.0	5.4 ± 0.9	5.1 ± 2.1	3.5 ± 1.0	3.2 ± 1.1	7.6 ± 1.1	2.8 ± 0.8
Total Suspended Solids (mg/L), Surface	2.1 ± 1.7	1.6 ± 1.5	0.7 ± 0.2	1.5 ± 0.7	1.8 ± 0.8	1.9 ± 1.0	0.7 ± 0.2	2.2 ± 0.7
Total Suspended Solids (mg/L), Bottom	1.7 ± 0.7	1.7 ± 0.6	1.1 ± 0.3	0.7 ± 0.4	2.5 ± 1.1	1.2 ± 0.6	0.6 ± 0.3	1.8 ± 0.6
Total Phosphate (µg/L, TP), Surface	19.5 ± 8.9	5.3 ± 1.9	4.9 ± 1.1	8.1 ± 1.9	6.8 ± 1.9	8.1 ± 5.2	2.7 ± 1.8	36.1 ± 60.3
Total Phosphate (µg/L, TP), Bottom	16.1 ± 5.2	3.7 ± 1.9	5.2 ± 2.1	9.7 ± 5.0	9.4 ± 3.0	6.8 ± 5.1	4.9 ± 2.5	10.6 ± 11.1
Dissolved Phosphate (µg/L, SRP), Surface	2.0 ± 1.6	0.7 ± 0.4	0.3 ± 0.2	0.4 ± 0.4	0.9 ± 1.2	0.7 ± 0.6	0.4 ± 0.3	0.5 ± 0.4
Dissolved Phosphate (µg/L, SRP), Bottom	1.7 ± 2.1	1.0 ± 0.9	0.8 ± 0.5	1.5 ± 2.0	6.4 ± 3.1	1.2 ± 0.9	0.8 ± 0.6	1.9 ± 2.1
Nitrate as N (mg/L), Surface	0.0 ± 0.0	0.1 ± 0.0	0.1 ± 0.1	0.3 ± 0.2	0.9 ± 0.5	0.6 ± 0.2	0.5 ± 0.2	0.2 ± 0.1
Nitrate as N (mg/L), Bottom	0.0 ± 0.1	0.3 ± 0.1	0.2 ± 0.2	0.5 ± 0.2	1.1 ± 0.6	0.8 ± 0.3	0.5 ± 0.2	0.3 ± 0.1
Silica (SR µg/L), Surface	801 ± 93	939 ± 239	444 ± 184	279 ± 266	403 ± 205	737 ± 232	384 ± 210	321 ± 297
Silica (SR µg/L), Bottom	821 ± 131	1243 ± 253	1052 ± 265	400 ± 179	976 ± 240	1189 ± 323	661 ± 255	854 ± 444
Chlorphyll a (µg/L), Surface	14.1 ± 14.6	1.5 ± 0.9	1.2 ± 0.7	2.6 ± 2.1	3.5 ± 2.3	3.9 ± 1.7	1.1 ± 0.9	5.7 ± 4.1
Chlorphyll a (µg/L), Bottom	7.9 ± 7.7	0.4 ± 0.1	0.4 ± 0.1	0.9 ± 1.2	0.5 ± 0.2	0.9 ± 0.6	0.3 ± 0.2	2.8 ± 2.1

2010	Honeoye	Canandaigua	Keuka	Seneca	Cayuga	Owasco	Skaneateles	Otisco
Secchi Depth (m)	2.5 ± 1.2	7.1 ± 1.8	6.6 ± 1.4	3.9 ± 1.4	4.5 ± 1.7	3.7 ± 1.1	7.5 ± 1.9	3.8 ± 0.6
Total Suspended Solids (mg/L), Surface	6.4 ± 7.1	0.8 ± 0.5	0.8 ± 0.4	1.7 ± 1.0	1.4 ± 0.9	1.9 ± 1.0	0.6 ± 0.3	1.5 ± 0.7
Total Suspended Solids (mg/L), Bottom	2.5 ± 1.2	0.8 ± 0.4	0.9 ± 0.5	0.6 ± 0.3	1.4 ± 0.7	1.2 ± 0.3	0.4 ± 0.2	1.6 ± 0.9
Total Phosphate (µg/L, TP), Surface	52.4 ± 54.4	5.2 ± 2.8	4.3 ± 1.3	6.5 ± 2.1	7.4 ± 4.7	8.1 ± 4.1	3.0 ± 1.4	8.6 ± 2.2
Total Phosphate (µg/L, TP), Bottom	37.1 ± 24.3	2.9 ± 1.0	3.7 ± 1.2	5.8 ± 2.1	9.7 ± 3.0	5.4 ± 2.2	2.3 ± 1.9	11.4 ± 10.3
Dissolved Phosphate (µg/L, SRP), Surface	11.0 ± 12.4	0.9 ± 0.8	0.3 ± 0.2	0.7 ± 1.4	0.9 ± 1.6	0.4 ± 0.4	0.3 ± 0.2	0.4 ± 0.3
Dissolved Phosphate (µg/L, SRP), Bottom	15.1 ± 15.8	0.6 ± 0.5	0.4 ± 0.4	1.5 ± 2.0	3.9 ± 2.5	0.9 ± 1.2	0.5 ± 0.9	2.0 ± 3.9
Nitrate as N (mg/L), Surface	0.1 ± 0.2	0.1 ± 0.0	0.0 ± 0.0	0.2 ± 0.2	1.1 ± 0.5	0.7 ± 0.5	0.6 ± 0.3	0.3 ± 0.2
Nitrate as N (mg/L), Bottom	0.2 ± 0.2	0.2 ± 0.2	0.2 ± 0.2	0.5 ± 0.3	1.3 ± 0.8	0.9 ± 0.7	0.8 ± 0.4	0.3 ± 0.1
Silica (SR µg/L), Surface	1780 ± 848	845 ± 95	424 ± 256	246 ± 106	385 ± 177	719 ± 337	421 ± 171	467 ± 206
Silica (SR µg/L), Bottom	1854 ± 867	1110 ± 172	878 ± 212	371 ± 173	839 ± 192	1255 ± 395	584 ± 162	935 ± 241
Chlorphyll a (µg/L), Surface	37.9 ± 43.0	2.0 ± 1.2	1.9 ± 1.8	4.7 ± 3.2	3.0 ± 1.3	3.7 ± 3.3	1.2 ± 0.9	3.0 ± 1.7
Chlorphyll a (µg/L), Bottom	12.5 ± 7.3	0.3 ± 0.2	0.5 ± 0.4	0.6 ± 0.6	0.2 ± 0.1	0.5 ± 0.4	0.6 ± 0.6	2.2 ± 0.7

2011	Honeoye	Canandaigua	Keuka	Seneca	Cayuga	Owasco	Skaneateles	Otisco
Secchi Depth (m)	2.4 ± 0.7	5.2 ± 1.4	6.3 ± 0.6	3.1 ± 1.0	3.8 ± 1.2	3.9 ± 1.2	7.8 ± 2.3	2.9 ± 1.1
Total Suspended Solids (mg/L), Surface	3.7 ± 1.5	1.1 ± 0.4	0.9 ± 0.8	2.3 ± 0.5	1.4 ± 0.4	1.6 ± 1.1	0.6 ± 0.2	2.3 ± 0.7
Total Suspended Solids (mg/L), Bottom	3.3 ± 1.1	1.2 ± 0.6	1.1 ± 0.4	0.9 ± 0.3	1.9 ± 0.8	1.7 ± 0.6	0.5 ± 0.2	1.8 ± 0.6
Total Phosphate (µg/L, TP), Surface	25.3 ± 6.1	13.7 ± 11.0	12.4 ± 10.0	18.2 ± 6.7	15.7 ± 6.1	13.0 ± 5.5	7.4 ± 6.3	16.6 ± 7.6
Total Phosphate (µg/L, TP), Bottom	26.9 ± 5.8	7.7 ± 5.8	8.1 ± 5.7	15.7 ± 7.1	18.6 ± 9.5	10.3 ± 7.2	7.5 ± 6.3	16.9 ± 7.4
Dissolved Phosphate (µg/L, SRP), Surface	0.5 ± 0.2	0.3 ± 0.3	1.1 ± 2.2	0.7 ± 1.1	1.0 ± 1.4	0.7 ± 2.2	0.9 ± 0.8	1.2 ± 2.3
Dissolved Phosphate (µg/L, SRP), Bottom	3.1 ± 3.8	0.6 ± 0.7	1.8 ± 2.5	5.3 ± 3.0	5.1 ± 5.5	1.2 ± 2.1	0.5 ± 0.4	2.0 ± 1.7
Nitrate as N (mg/L), Surface	0.0 ± 0.0	0.1 ± 0.1	0.2 ± 0.2	0.2 ± 0.2	0.6 ± 0.4	0.4 ± 0.3	0.3 ± 0.1	0.3 ± 0.3
Nitrate as N (mg/L), Bottom	0.0 ± 0.0	0.1 ± 0.1	0.3 ± 0.4	0.4 ± 0.1	0.9 ± 0.5	0.6 ± 0.4	0.4 ± 0.2	0.4 ± 0.2
Silica (SR µg/L), Surface	1134 ± 534	948 ± 649	719 ± 261	299 ± 120	516 ± 244	645 ± 294	730 ± 287	1106 ± 598
Silica (SR µg/L), Bottom	875 ± 427	1181 ± 447	1148 ± 296	600 ± 170	922 ± 298	1449 ± 425	882 ± 356	1124 ± 534
Chlorphyll a (µg/L), Surface	9.8 ± 6.2	1.2 ± 0.4	1.1 ± 0.8	4.3 ± 2.6	3.3 ± 2.1	1.9 ± 1.2	1.4 ± 1.4	2.8 ± 1.3
Chlorphyll a (µg/L), Bottom	9.1 ± 6.5	0.5 ± 0.4	0.3 ± 0.1	0.8 ± 1.6	0.3 ± 0.2	0.6 ± 0.4	0.4 ± 0.3	1.8 ± 1.7

2012	Honeoye	Canandaigua	Keuka	Seneca	Cayuga	Owasco	Skaneateles	Otisco
Secchi Depth (m)	2.7 ± 1.6	5.8 ± 0.4	6.3 ± 0.5	5.2 ± 2.0	4.2 ± 1.6	4.7 ± 1.5	8.5 ± 1.9	2.6 ± 0.5
Total Suspended Solids (mg/L), Surface	3.0 ± 2.3	2.2 ± 3.1	1.0 ± 0.4	1.4 ± 0.7	1.2 ± 0.7	1.2 ± 0.5	0.8 ± 0.4	3.8 ± 2.8
Total Suspended Solids (mg/L), Bottom	2.7 ± 2.3	2.3 ± 2.9	0.6 ± 0.3	0.6 ± 0.3	1.3 ± 0.6	1.5 ± 0.9	0.7 ± 0.2	2.4 ± 1.6
Total Phosphate (µg/L, TP), Surface	50.4 ± 33.3	10.4 ± 4.9	10.8 ± 4.9	14.9 ± 3.7	14.1 ± 6.7	12.6 ± 6.3	6.0 ± 4.4	16.6 ± 5.3
Total Phosphate (µg/L, TP), Bottom	49.7 ± 38.3	9.9 ± 5.3	7.1 ± 4.2	13.0 ± 6.7	15.7 ± 9.1	9.3 ± 6.4	6.1 ± 5.6	9.7 ± 6.2
Dissolved Phosphate (µg/L, SRP), Surface	7.9 ± 13.9	0.3 ± 0.5	0.3 ± 0.3	1.2 ± 3.3	0.9 ± 1.5	0.4 ± 0.4	0.1 ± 0.2	0.3 ± 0.3
Dissolved Phosphate (µg/L, SRP), Bottom	6.1 ± 11.8	0.3 ± 0.4	0.7 ± 0.7	5.5 ± 10.0	5.0 ± 4.6	0.7 ± 0.8	0.3 ± 0.5	0.4 ± 0.6
Nitrate as N (mg/L), Surface	0.0 ± 0.0	0.0 ± 0.1	0.1 ± 0.2	0.2 ± 0.2	0.8 ± 0.5	0.5 ± 0.2	0.3 ± 0.1	0.2 ± 0.2
Nitrate as N (mg/L), Bottom	0.0 ± 0.0	0.2 ± 0.1	0.1 ± 0.1	0.3 ± 0.1	0.8 ± 0.5	0.6 ± 0.2	0.4 ± 0.2	0.3 ± 0.2
Silica (SR µg/L), Surface	1358 ± 906	979 ± 240	665 ± 276	325 ± 118	346 ± 192	992 ± 393	566 ± 149	527 ± 436
Silica (SR µg/L), Bottom	1393 ± 916	1329 ± 104	1110 ± 151	468 ± 89	1096 ± 146	1592 ± 223	769 ± 118	1048 ± 240
Chlorphyll a (µg/L), Surface	17.0 ± 19.2	1.3 ± 0.7	1.3 ± 1.3	3.3 ± 3.6	2.3 ± 1.1	2.3 ± 1.8	0.9 ± 0.6	3.3 ± 2.2
Chlorphyll a (µg/L), Bottom	12.8 ± 14.9	0.2 ± 0.2	0.3 ± 0.1	0.3 ± 0.3	0.3 ± 0.2	0.6 ± 0.4	0.1 ± 0.1	1.9 ± 1.2

2013	Honeoye	Canandaigua	Keuka	Seneca	Cayuga	Owasco	Skaneateles	Otisco
Secchi Depth (m)	2.3 ± 1.2	6.1 ± 2.2	7.3 ± 0.9	4.2 ± 1.1	3.5 ± 0.7	4.5 ± 0.5	9.2 ± 3.1	2.7 ± 0.9
Total Suspended Solids (mg/L), Surface	5.5 ± 4.0	1.4 ± 1.1	0.8 ± 0.3	1.8 ± 0.5	2.0 ± 0.5	1.5 ± 0.6	0.9 ± 0.3	2.8 ± 1.2
Total Suspended Solids (mg/L), Bottom	4.3 ± 2.3	0.7 ± 0.5	0.5 ± 0.4	0.6 ± 0.4	1.7 ± 1.7	0.9 ± 0.3	0.7 ± 0.4	1.8 ± 0.7
Total Phosphate (µg/L, TP), Surface	32.4 ± 23.8	9.9 ± 4.4	7.7 ± 4.4	12.8 ± 4.2	12.1 ± 3.1	9.3 ± 2.8	6.4 ± 4.5	13.2 ± 7.0
Total Phosphate (µg/L, TP), Bottom	33.3 ± 17.8	7.9 ± 5.8	6.4 ± 4.1	10.5 ± 5.9	11.1 ± 4.4	7.3 ± 3.2	7.1 ± 4.1	13.5 ± 9.8
Dissolved Phosphate (µg/L, SRP), Surface	0.8 ± 0.8	0.3 ± 0.2	1.0 ± 1.6	0.5 ± 0.9	1.4 ± 1.3	0.9 ± 0.7	1.8 ± 3.6	0.8 ± 0.5
Dissolved Phosphate (µg/L, SRP), Bottom	3.9 ± 4.2	0.5 ± 0.3	0.7 ± 0.9	2.3 ± 2.2	4.4 ± 5.1	1.7 ± 1.4	2.8 ± 4.2	4.1 ± 5.8
Nitrate as N (mg/L), Surface	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.2 ± 0.1	0.9 ± 0.3	0.8 ± 0.4	0.4 ± 0.1	0.3 ± 0.1
Nitrate as N (mg/L), Bottom	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.3 ± 0.1	1.3 ± 0.2	1.0 ± 0.2	0.5 ± 0.1	0.4 ± 0.2
Silica (SR µg/L), Surface	1106 ± 707	747 ± 256	583 ± 124	232 ± 87	390 ± 179	733 ± 308	478 ± 57	345 ± 208
Silica (SR µg/L), Bottom	1200 ± 791	1242 ± 191	1017 ± 191	394 ± 135	879 ± 150	1363 ± 294	725 ± 90	919 ± 487
Chlorphyll a (µg/L), Surface	21.7 ± 24.0	2.3 ± 1.8	0.8 ± 0.6	3.7 ± 3.1	2.0 ± 1.8	2.3 ± 2.0	0.9 ± 0.9	5.1 ± 2.6
Chlorphyll a (µg/L), Bottom	11.3 ± 7.6	0.6 ± 0.4	0.7 ± 0.6	1.5 ± 1.4	0.4 ± 0.1	0.5 ± 0.3	0.3 ± 0.1	1.3 ± 1.0

2014	Honeoye	Canandaigua	Keuka	Seneca	Cayuga	Owasco	Skaneateles	Otisco
Secchi Depth (m)	2.8 ± 0.8	5.3 ± 1.1	4.0 ± 2.8	3.8 ± 0.8	3.3 ± 1.0	3.7 ± 1.3	7.3 ± 1.8	2.1 ± 0.8
Total Suspended Solids (mg/L), Surface	8.3 ± 11.8	2.1 ± 0.9	4.5 ± 5.3	1.9 ± 1.2	2.6 ± 1.5	3.5 ± 2.6	1.2 ± 0.7	4.9 ± 3.8
Total Suspended Solids (mg/L), Bottom	10.9 ± 14.7	1.3 ± 0.7	4.0 ± 6.2	0.9 ± 0.6	3.0 ± 1.8	2.5 ± 2.4	1.0 ± 0.8	4.1 ± 3.4
Total Phosphate (µg/L, TP), Surface	49.0 ± 18.2	13.2 ± 7.8	14.4 ± 6.2	19.6 ± 8.1	23.9 ± 13.7	17.7 ± 7.3	15.5 ± 12.1	30.9 ± 23.3
Total Phosphate (µg/L, TP), Bottom	60.1 ± 37.2	8.8 ± 4.4	13.7 ± 7.5	22.3 ± 13.1	26.1 ± 10.4	13.8 ± 9.1	12.2 ± 12.5	30.4 ± 17.5
Dissolved Phosphate (µg/L, SRP), Surface	16.9 ± 20.6	3.0 ± 2.5	4.1 ± 4.7	3.1 ± 3.8	4.4 ± 6.3	5.8 ± 6.5	5.3 ± 7.0	15.7 ± 24.2
Dissolved Phosphate (µg/L, SRP), Bottom	29.7 ± 41.7	3.4 ± 4.1	2.5 ± 3.5	6.3 ± 5.2	12.6 ± 6.2	6.8 ± 8.5	3.4 ± 2.9	16.1 ± 11.5
Nitrate as N (mg/L), Surface	0.0 ± 0.0	0.1 ± 0.2	0.1 ± 0.1	0.2 ± 0.1	0.6 ± 0.2	0.5 ± 0.3	0.4 ± 0.2	0.2 ± 0.1
Nitrate as N (mg/L), Bottom	0.0 ± 0.0	0.2 ± 0.0	0.2 ± 0.1	0.3 ± 0.2	0.9 ± 0.5	0.9 ± 0.6	0.5 ± 0.2	0.4 ± 0.2
Silica (SR µg/L), Surface	1000 ± 335	741 ± 213	622 ± 138	216 ± 113	334 ± 185	550 ± 376	472 ± 71	324 ± 149
Silica (SR µg/L), Bottom	982 ± 267	1033 ± 134	875 ± 74	375 ± 93	747 ± 118	1255 ± 146	608 ± 69	960 ± 237
Chlorphyll a (µg/L), Surface	6.6 ± 6.6	4.2 ± 6.1	1.9 ± 1.5	2.4 ± 1.6	4.7 ± 5.4	3.2 ± 1.9	0.9 ± 0.7	5.5 ± 3.7
Chlorphyll a (µg/L), Bottom	7.4 ± 6.6	0.4 ± 0.2	0.4 ± 0.2	0.7 ± 0.9	0.4 ± 0.3	0.6 ± 0.2	0.4 ± 0.2	2.6 ± 0.8

2015	Honeoye	Canandaigua	Keuka	Seneca	Cayuga	Owasco	Skaneateles	Otisco
Secchi Depth (m)	1.6 ± 1.1	4.2 ± 1.5	3.7 ± 1.5	3.6 ± 1.8	3.0 ± 0.8	3.3 ± 0.5	8.0 ± 1.6	2.1 ± 0.5
Total Suspended Solids (mg/L), Surface	6.6 ± 3.0	1.6 ± 1.0	2.1 ± 1.3	2.2 ± 0.9	2.4 ± 0.4	2.2 ± 0.9	0.8 ± 0.2	5.9 ± 4.9
Total Suspended Solids (mg/L), Bottom	5.7 ± 3.4	1.0 ± 0.4	1.3 ± 1.1	0.9 ± 1.1	1.8 ± 1.2	2.0 ± 1.0	0.5 ± 0.3	4.7 ± 5.3
Total Phosphate (µg/L, TP), Surface	31.6 ± 13.9	8.7 ± 2.8	7.6 ± 5.2	13.8 ± 4.8	16.9 ± 4.9	15.5 ± 6.7	12.3 ± 2.2	12.7 ± 7.6
Total Phosphate (µg/L, TP), Bottom	32.7 ± 13.3	5.7 ± 2.1	6.9 ± 3.7	13.5 ± 5.7	16.7 ± 8.8	9.8 ± 2.8	9.2 ± 3.5	13.1 ± 6.7
Dissolved Phosphate (µg/L, SRP), Surface	2.9 ± 5.6	0.5 ± 0.5	0.5 ± 0.4	0.6 ± 0.8	0.4 ± 0.4	0.4 ± 0.3	0.4 ± 0.2	0.6 ± 1.1
Dissolved Phosphate (µg/L, SRP), Bottom	2.8 ± 4.3	0.6 ± 0.6	1.2 ± 2.0	2.4 ± 2.0	6.2 ± 3.8	0.5 ± 0.5	0.4 ± 0.2	0.9 ± 0.8
Nitrate as N (mg/L), Surface	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.2	0.7 ± 0.3	0.5 ± 0.4	0.4 ± 0.4	0.2 ± 0.2
Nitrate as N (mg/L), Bottom	0.0 ± 0.0	0.2 ± 0.2	0.1 ± 0.1	0.4 ± 0.4	0.8 ± 0.7	0.7 ± 0.7	0.4 ± 0.2	0.3 ± 0.2
Silica (SR µg/L), Surface	595 ± 296	797 ± 155	734 ± 172	195 ± 105	300 ± 185	697 ± 295	417 ± 111	315 ± 170
Silica (SR µg/L), Bottom	614 ± 327	1026 ± 330	932 ± 299	386 ± 163	796 ± 231	1394 ± 495	714 ± 198	1328 ± 524
Chlorphyll a (µg/L), Surface	19.0 ± 15.3	2.6 ± 1.0	2.7 ± 1.6	3.7 ± 2.5	5.4 ± 2.4	3.8 ± 1.8	1.1 ± 0.6	4.3 ± 1.9
Chlorphyll a (µg/L), Bottom	12.9 ± 9.6	0.5 ± 0.1	0.5 ± 0.2	1.6 ± 2.3	0.5 ± 0.1	0.7 ± 0.3	0.7 ± 0.3	2.6 ± 1.3

2016	Honeoye	Canandaigua	Keuka	Seneca	Cayuga	Owasco	Skaneateles	Otisco
Secchi Depth (m)	2.3 ± 1.3	7.7 ± 3.1	5.9 ± 1.4	4.3 ± 1.1	3.5 ± 0.9	5.6 ± 2.5	9.7 ± 4.1	3.2 ± 1.9
Total Suspended Solids (mg/L), Surface	4.7 ± 3.2	1.0 ± 0.8	0.8 ± 0.2	1.3 ± 0.5	1.6 ± 0.5	1.8 ± 1.7	1.0 ± 0.3	2.1 ± 1.5
Total Suspended Solids (mg/L), Bottom	4.7 ± 2.7	1.2 ± 0.7	0.7 ± 0.4	0.6 ± 0.3	2.6 ± 1.6	1.0 ± 0.4	0.5 ± 0.2	1.4 ± 0.5
Total Phosphate (µg/L, TP), Surface	41.0 ± 32.3	18.0 ± 18.6	12.5 ± 11.3	15.1 ± 10.2	16.5 ± 12.7	14.1 ± 5.0	13.7 ± 9.5	16.1 ± 10.0
Total Phosphate (µg/L, TP), Bottom	41.0 ± 31.1	16.4 ± 20.7	17.7 ± 12.8	14.8 ± 9.5	21.4 ± 20.5	10.1 ± 3.1	11.4 ± 7.0	14.2 ± 12.6
Dissolved Phosphate (µg/L, SRP), Surface	3.8 ± 7.1	0.4 ± 0.2	0.4 ± 0.4	1.0 ± 1.6	1.8 ± 3.8	0.9 ± 1.2	1.3 ± 2.4	1.9 ± 6.0
Dissolved Phosphate (µg/L, SRP), Bottom	4.0 ± 6.7	0.7 ± 0.5	1.6 ± 1.6	2.8 ± 2.9	3.5 ± 3.2	0.7 ± 0.6	0.8 ± 1.4	1.3 ± 1.8
Nitrate as N (mg/L), Surface	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.2 ± 0.2	0.7 ± 0.4	0.7 ± 0.3	0.3 ± 0.2	0.2 ± 0.2
Nitrate as N (mg/L), Bottom	0.0 ± 0.0	0.2 ± 0.1	0.2 ± 0.1	0.3 ± 0.2	0.8 ± 0.4	0.9 ± 0.4	0.5 ± 0.3	0.4 ± 0.3
Silica (SR µg/L), Surface	1269 ± 948	917 ± 271	1080 ± 279	205 ± 77	337 ± 79	1022 ± 265	359 ± 140	553 ± 285
Silica (SR µg/L), Bottom	1345 ± 951	1418 ± 378	1342 ± 359	452 ± 252	968 ± 296	1688 ± 452	808 ± 197	1119 ± 576
Chlorphyll a (µg/L), Surface	22.7 ± 17.4	1.8 ± 1.3	1.5 ± 1.1	2.7 ± 1.9	3.0 ± 2.0	3.5 ± 3.2	1.0 ± 0.7	3.0 ± 2.5
Chlorphyll a (µg/L), Bottom	17.2 ± 12.9	0.6 ± 0.5	0.7 ± 0.5	0.8 ± 0.5	1.2 ± 2.0	1.0 ± 0.6	0.6 ± 0.5	1.7 ± 1.1

APPENDIX 2: MEAN ANNUAL PLANKTON TWO DATA (only taxa with a > 10 annual percentage)

Year	Lake	Diatoms: Fragillaria %	Tabellaria %	Diatoma %	Asterionella %	Synedra %	Melosira %	Rhizoselenia	Cymbella %	Dinoflagellates: Dinobryon %	Ceratium %	Greens: Unk. Fil. Green %	Closterium %	Blue Greens: Anabaena %	Stichosiphon	Gomphospaeria %	Mycrocystis %	Zooplanktom: Copepod %	Nauplius %	Cladoceran %	'hook-tail'	Rotifers: Keratella %	Polyarthra %	Vorticella %
2000	Seneca	14	5		36	1			1	0	0			3	1			2	3	6		3	3	
2001	Seneca	17	2		31	3			2	3	9			1	1			0	1	2		6	1	
2002	Seneca	13	4		16	8			0	7	12			1	1			1	4	4		1	1	
2003	Seneca	23	16		27	3			0	3	3			0	0			1	1	2		7	1	
2004	Seneca	12	8		29	2			0	6	2			1	0			3	3	3		3	1	
2005	Canandaigua	4	1		11	7	0		2	16	2	2		4			16	1	0	1		2	0	
2005	Cayuga	11	22		5	3	0		3	0	0	1	0	0			3	1	5	1		2	1	2
2005	Honeoye	25	1		8	1	16		0	22	3	0	3	1			2	0	0	1		0	0	0
2005	Keuka	25	1		26	1	3		2	2	0	0	0	0			22	0	0	1		0	0	0
2005	Owasco	22	3		23	3	1		2	9	3			0		0	0	1	1	2		2	2	4
2005	Seneca	27	10		23	1			0	1	1			0	1			3	3	2		4	4	
2005	Skaneateles	2	2		1	10	0		1	18	3	2	2			0	5	5	6	2		0	0	0
2006	Canandaigua	19	0		7	4	0	14		28	2		0	0			11	0	0	1		1	0	0
2006	Cayuga	16	5		8	14	14		0	4	0	9	0	1			1	0	1	0	0	1	1	1
2006	Honeoye	27	0		17	0	26	0	0	7	2		3	3			2	0	0	1		0	1	2
2006	Keuka	21	0		14	2	0	7	0	28	1	0	0	1			6	0	2	2	0	2	2	1
2006	Owasco	24	2		7	1	1	3	0	42	1	0		0			4	0	0	1	0	2	1	0
2006	Seneca	11		31	25	3	2		0	2	0			0	0		0	0	1	2	0	7	2	
2006	Skaneateles	7	2		3	4	1	0	0	4	2	6	0	0			14	10	9	1		2	0	
2007	Canandaigua	17	0	1	25	18	0	1	0	13	0			0			9	0	0	3	0	1	0	1
2007	Cayuga	32	0	29	18	3	0	0		1	0	1		1			1	0	0	0		1	1	4
2007	Honeoye	17	0	0	24	0	12	0		9	5		3	4			3	0	0	1		0	1	4
2007	Keuka	28	0	0	11	14		6	0	1	4			0		0	24	1	3	1		0	0	0
2007	Owasco	30	1	0	23	2	0	4	0	13	1		0	0		0	8	0	0	3	0	1	0	4
2007	Seneca	6	0	33	23	2	0		0	1	0			1	1		0	1	0	6	0	2	1	
2007	Skaneateles	9	0	0	4	8	0		1	8	3	1	4			10	12	8	5	0		0	0	0
2008	Canandaigua	24	0	4	20	10	0	1	0	5	2			1			9	1	1	2	0	3	1	0
2008	Cayuga	43	0	29	11	1	0	0	0	0	0	0	0	0	0		1	0	1	1	0	1	1	1
2008	Honeoye	11		1	4	0	35	0		10	13	0	4	5	0	0	1	0	0	1		0	2	3
2008	Keuka	28	0	6	8	6	0	0	7	8		0		0	2		0	0	13	1	7	1	1	0
2008	Otisco	23		0	11	1	0	0	0	9	10		0	0	0		0	2	1	3		2	11	5
2008	Owasco	52	0	0	15	0	0	1		19	1			0			1	0	0	1		0	1	4
2008	Seneca	31	0	5	19	7	1	0	0	1	1			0	2		1	3	3	2	1	1	3	1
2008	Skaneateles	13		0	1	28	0		0	2	1	0	4	0	0		19	5	4	0		0	0	
2009	Canandaigua	18	0	5	15	4	0	1	0	17	3	0		0	0		16	2	1	2		0	1	0
2009	Cayuga	22	0	39	19	1	0		0	0	0	2	0	1	0		0	0	0	1	1	1	0	2
2009	Honeoye	18	0	1	11	0	25	0	0	2	2	0	6	12	0	0	1	0	0	1	0	0	1	5
2009	Keuka	32	0	9	14	6		0		7	1	0		0	1	0	8	1	1	4	0	3	0	0
2009	Otisco	24	0	0	2	0	0			23	1		0	5	0	0	0	3	1	2		2	4	17
2009	Owasco	10	7	0	12	1	0	8	0	27	1	0	0	3	0		5	1	1	2	1	4	1	4
2009	Seneca	25	0	18	22	1	0		0	1	0			1	0		0	3	2	2	0	4	1	4
2009	Skaneateles	10	1	2	3	18	0			13	4	1	0	1	0		14	6	5	3		1	2	1
2010	Canandiagua	21	0	3	22	6	1	0	0	3	7		0		25			1	0	0	0	1	0	0
2010	Cayuga	28	1	28	19	1	4	0	0	0	0		0	0	1		0	0	1	2	0	1	0	3
2010	Honeoye	2		1	3	0	15	0		2	14		11	0	28			0	0	1		1	0	1
2010	Keuka	41	0	0	20	1	0			8	7			0	1			0	0	2	1	2	0	3
2010	Otisco	29	0	0	4	0	3	0		36	4			2	0		0	1	1	2	0	0	1	8
2010	Owasco	37	0	2	19	1	0	1	0	5	0		0	0	6		0	1	1	6	0	3	1	0
2010	Seneca	10	0	29	20	1	0		0	2	0			1	0		1	1	1	4	1	5	1	2
2010	Skaneateles	10	0	1	5	1	1	0		28	2	0	2	0	0		37	3	3	1	0	0	0	0
2011	Canandaigua	2	0	22	19	8	0	0	0	6	0		0	0	0		21	1	0	2	0	1	1	0
2011	Cayuga	9	0	26	20	4	1		0	3	0	3	0	0	0		2	0	0	4	0	2	2	4
2011	Honeoye	34	0	0	19	0	18			7	7		0	1			1	0	0	0		0	0	2
2011	Keuka	21	0	10	23	2	0	0	0	14	0	1		0	4		0	0	1	1	0	1	0	2
2011	Otisco	51	0	1	15	4	1		0	4	1			0	0		0	0	0	1		1	3	6
2011	Owasaco	26	14	1	11	0	7	6		4	0	0		0	0		2	1	1	2	1	3	1	3
2011	Seneca	20	4	14	17	4	1		0	0	0			0	0		0	3	1	6	1	6	1	2
2011	Skaneateles	29	1	0	9	11	0		0	3	1		2	0	0		24	3	3	0		1	1	0
2012	Canndaigua	9	0	2	8	3	0	0	1	21	4		0	0	0		15	1	1	2	0	6	2	0
2012	Cayuga	25	0	21	14	1			0	1	0	1		6	0		2	0	0	1		4	0	4
2012	Honeoye	7			0	0			29	1	2		0	31			10	0	0	1		0	1	5
2012	Keuka	43	0	6	21	1	0		0	1	1	0		3	0		1	0	1	1	0	3	0	3
2012	Otisco	23		0	5	0		0	0	28	1		0	4	0		1	1	1	4		3	4	7
2012	Owasco	25	4	0	12	1	7		13	20		0		3	0		1	0	1	1	0	1	0	2
2012	Seneca	12	1	22	8	1	1		0	7	0			4	0		0	0	3	3	0	4	1	5
2012	Skaneateles	10	1	0	1	9	0		1	5	0	3	1		1		34	4	6	1		2	0	
2013	Canandaigua	27	0	4	18	6	1	0	0	9	0		0	0	0		6	1	0	0	0	2	1	0
2013	Cayuga	3	0	36	14	5	0		0	1	1	0	0	9			0	1	1	1	0	3	2	5
2013	Honeoye	12		0	10	0	27		0	2	6			10	0		21	0	0	0		0	0	1
2013	Keuka	20	0	10	31	0	0		0	20	2	0		1			6	0	0	0	0	1	0	0
2013	Otisco	5	0	4	3	1	1			24	0		0	9	0		3	1	1	5		2	5	12
2013	Owasco	28	0	6	27	4	4	0	0	6	0	0		4	0		0	1	1	1		2	1	2
2013	Seneca	10	0	16	23	1	1		1	1	0			2	0		1	3	1	0	0	5	0	2
2013	Skaneateles	2	0	8	5	17	7	0	0	0	0	0	0	0	1		25	7	5	0		0	0	0
2014	Canandaigua	12		5	14	13	1	1		20	1			0	0		12	1	0	1	0	1	1	
2014	Cayuga	4	2	43	20	0	0			3	5	2	0	0	0		0		0	0	0	2	1	0
2014	Honeoye	13		0	7	0	39			4	6		7	3	0		2	1	1	2		0	1	0
2014	Keuka	31	0	6	21	2	0		0	9	2	0		0	0		5	2	2	1		1	3	2
2014	Otisco	15	0	0	6	3	0			34	0	0	0	2	0		1	1	1	1		2	7	4
2014	Owasco	22	0	6	15	0	1	3		20	0	0		0	0		3	3	3	1	0	1	6	2
2014	Seneca	14	0	24	34	0	0		0	2	0			0			0	1	0	1		1	0	1
2014	Skaneateles	3	1		4	9	0	0		2	1	1	0	0	0		22	20	9	3	0	1	1	0
2015	Canandaigua	12	0	3	18	13	0			12	2				0		15	0	1	0		1	2	
2015	Cayuga	20	6	31	11	1	0			16	0	0		1	0		1	0	0	0		0	2	0
2015	Honeoye	2	0	0	3	0	48			5	3		12	17	0		5	0	0	0		0	0	1
2015	Keuka	10	0	2	17	8	5			8	11			3	0	0	18	2	5	0		2	0	2
2015	Otisco	12	0		4	13	1			6	3			2	0	0	6	1	2	5		8	10	7
2015	Owasco	29	7	1	20	0	1	4		4	0			0	0		7	1	1	3		2	3	1
2015	Seneca	7	0	31	34	0	0		0	0	0			1	0		1	1	1	1	0	5	1	1
2015	Skaneateles	3	1	0	3	12	6	0		11	1	0	8	0	0		24	8	6	1		1	1	
2016	Canandaigua	6	0	1	1	5	0	2	0	27	2			0	0		24	0	1	1		2	2	0
2016	Cayuga	11	5	32	17	0	7	0	0	0	1			1	0		3	0	1	1		4	2	0
2016	Honeoye	9		0	28		37	1		1	3			7	0		5		0	0		1	0	0
2016	Keuka	3	0	1	10	21	1	0		14	4			0	0	0	18	1	2	1		7	2	0
2016	Otisco	10			6	1	0	1		30	0		0	0	0	0	1	1	1	4		6	12	0
2016	Owasco	11	3	7	14	0	1	0	0	12	0		0	2	0		5	1	1	2		4	5	2
2016	Seneca	12	0	21	29	1	0		0	0	0			2	0		0	0	0	1	0	5	1	1
2016	Skaneateles	2	2	1	20	6	0		0	0	0	1	3	0	0		13	6	2	1		1	1	