WATER QUALITY OF THE FINGER LAKES, NEW YORK: 2005 – 2008.

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INTRODUCTION

The Finger Lakes of western and central New York are critical to the health, well-being and economy of the region. The eleven Finger Lakes, Conesus, Hemlock, Canadice, Honeoye, Canandaigua, Keuka, Seneca, Cayuga, Owasco, Skaneateles, and Otisco, contain 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 (Fig. 1). These lakes are a source of Class AA drinking water to the 1.5 million residents in the surrounding communities. For example, Skaneateles and Otisco Lakes provide drinking water for the City of Syracuse; and, Hemlock and Canadice Lakes provide drinking water for the City of Rochester. Total withdrawals are approximately 190 million gallons of water per day from all the Finger Lakes, except Honeoye (Callinan, 2001).

The natural beauty of the Finger Lakes region attracts approximately 22 million tourists each year. The tourism generates over $2 billion annually with significant growth projected for the immediate future. Water-based recreation, sport fisheries, wildlife habitat, and a diverse industrial and agricultural sector, that includes a renowned wine and grape industry, comprise the important economic, social, ecological and occasionally competing environmental attributes of the Finger Lakes Region. Thus, these lakes must be protected from numerous threats to water quality.

A preliminary water quality survey, conducted in 2005 and published in 2006 under the direction of Dr. John Halfman, Finger Lakes Institute at Hobart and William Smith Colleges, ranked water quality parameters for Skaneateles, Owasco, Cayuga, Seneca, Keuka, Canandaigua and Honeoye Lakes (Fig. 2, Halfman and Bush, 2006). These lakes were selected because they span the diversity of land use activities and bedrock geologies in the region, they contain 98% of the water in the Finger Lakes, and they are closest to the Colleges in Geneva, NY. The ranking was based on monthly surface water samples, CTD profiles and secchi disk depths from at least two mid-lake, deep-water sites in each lake. Water samples were analyzed for total coliform and *E.*

Owasco, and Honeoye Lakes had the worst water quality, whereas Skaneateles, Canandaigua and Keuka Lakes had the best water quality. Cayuga Lake fell in between the end-members. The 2005 preliminary report also noted a correlation between the water quality ranking and a first-order, qualitative assessment of water quality protection legislation. Water quality was better in lakes with more stringent and more importantly more active water quality protection activities.

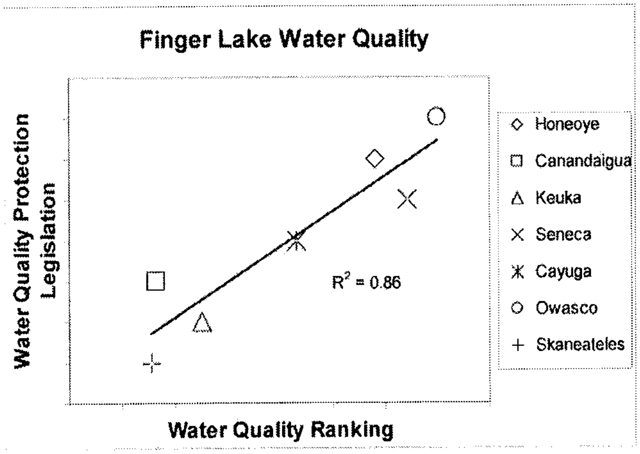


Fig. 2. The 2005 water quality ranking of 7 Finger Lakes.

The 2005 results spearheaded continued research on these seven Finger Lakes. We dovetailed two types of studies: (1) continued comparison between the Finger Lakes to investigate year to year changes in water quality, and (2) more detailed investigations in selected watersheds to more fully understand the source of nutrients and other water quality impairments to these lakes. In this report, we summarize our current understanding of the limnology and water quality of these lakes, investigate year to year changes in water quality in each basin, and summarize detailed investigations in the Seneca, Owasco and Cayuga watersheds. This report also includes an initial water quality evaluation of Otisco Lake, added to our Finger Lakes comparison program in 2008. Our goal is to explain the science so that state, county and local policy makers, residents, farmers, engineers, and all the other stakeholders understand the current situation and probable water quality trends into the future because everyone has to work together to preserve, protect and in some cases improve water quality in the Finger Lakes.

WATER QUALITY INDICATORS

The rural landscape and agricultural land use activities dominate the Finger Lake watersheds with agriculture covering 46.5% of the region, forests 38.3%, lakes 9.4%, and urban areas 4.3%. The land use suggests that the primary water quality threat to these lakes is nutrient loading from the decomposition of organic wastes and agricultural runoff. The reasons are simple. Excess nutrients stimulate algal and nearshore plant productivity, which in turn progressively reduces water quality and water clarity in a lake until the lake becomes eutrophic and impaired.

Nutrients, dissolved phosphates (PO_4^{-3}), nitrates (NO_3^-) and silica ($H_2SiO_4^{-2}$), are essential for life because they are required for critical building blocks of life including amino acids, proteins, cell tissue, RNA and DNA. In a basic aquatic nutrient cycle (Fig. 3), dissolved nutrients enter the food chain by their assimilation and incorporation 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 to the other organisms in the lake like zooplankton and lake trout. When any of these organisms die, bacteria complete the methane instead or carbon dioxide. If sulfur is available, the bacteria release a "rotten egg" odor caused by the bacterial formation of hydrogen sulfide. Unfortunately, once nutrients enter a lake, the ecosystem typically remains enriched in nutrients because nutrients are continually and efficiently recycled within the lake. Thus, the excess nutrients continue to "fertilize" plant growth at enhanced levels. Only a small fraction of the nutrients are permanently lost from the lake out the outlet or buried into the sediments. Burial is only significant in oxygenated systems because anoxic bottom waters allow phosphates, previously buried in the sediments as particles (oxides) in oxygen-rich oligotrophic systems, to subsequently dissolve and re-enter the water column.

Excess nitrates also induce health risks to humans, specifically methemoglobinemia or blue-baby syndrome, and the EPA sets a maximum contaminant level (MCL) for nitrate concentrations at 10 mg/L for safe drinking water. Phosphates and silica at natural concentrations do not pose health risks but contribute to the fertilization and eutrophication of waterways. Phosphate is critical for the eutrophication of lakes because it is typically the limiting nutrient for algal growth. Thus its concentration is typically very close to zero, and almost all of the available phosphorus is incorporated into organic matter. Occasionally nitrate is the limiting nutrient, especially in eutrophic lakes. If this is the case, a few groups of algae circumvent the scarcity of nitrogen by "fixing" nitrogen (N_2) from the atmosphere into a useful organic form. Blue-green algae are nitrogen fixers, they dominate nitrate poor systems, and typically dominate eutrophic aquatic systems. We include dissolved silica in the list of nutrients because silica is required by diatoms, a form of algae found in most lakes, to form their frustules (shells). The presence or absence of silica does not impact the trophic status. Instead its presence allows diatoms to dominate an ecosystem, whereas its scarcity favors other forms of algae.

Algal concentrations are another indicator of lake productivity and the ecological health of a lake. Algal concentrations are measured directly by the concentration of chlorophyll, and indirectly by fluorometer, total suspended solids and secchi disk depths. The secchi disk 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 depth is noted. The secchi disk depth is the average of these two depths. In very ultra-oligotrophic (low productivity) systems thus very transparent waters, secchi disk depths can be 100 feet (30 m) or more. In eutrophic (highly productive) lakes and ponds, secchi disk depths can be as shallow as a few centimeters.

Thus, nutrient, algal and dissolved oxygen concentrations are useful trophic status indicators. Typically, a combination of nutrient, algal, dissolved oxygen concentrations, and secchi disk depths are utilized to document the degree of productivity, or trophic status, in aquatic systems (Table 1).

Table 1. Typical concentrations for oligotrophic (low productivity) and eutrophic (high productivity) lakes (EPA).

Trophic Status	**Secchi Depth**	**Total Nitrogen**	**Total Phosphate**	**Chlorophyll a**	**Oxygen**

conductivity (specific conductance, uS/cm), dissolved oxygen (ml/L), pH, turbidity, algal biomass (WetLabs ECO-FLU fluorometer), and light intensity (Biospherical PAR).

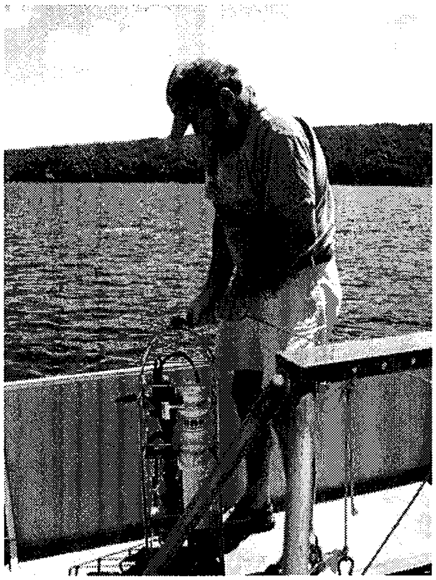
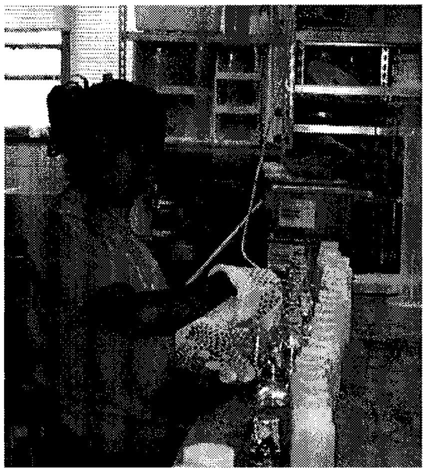


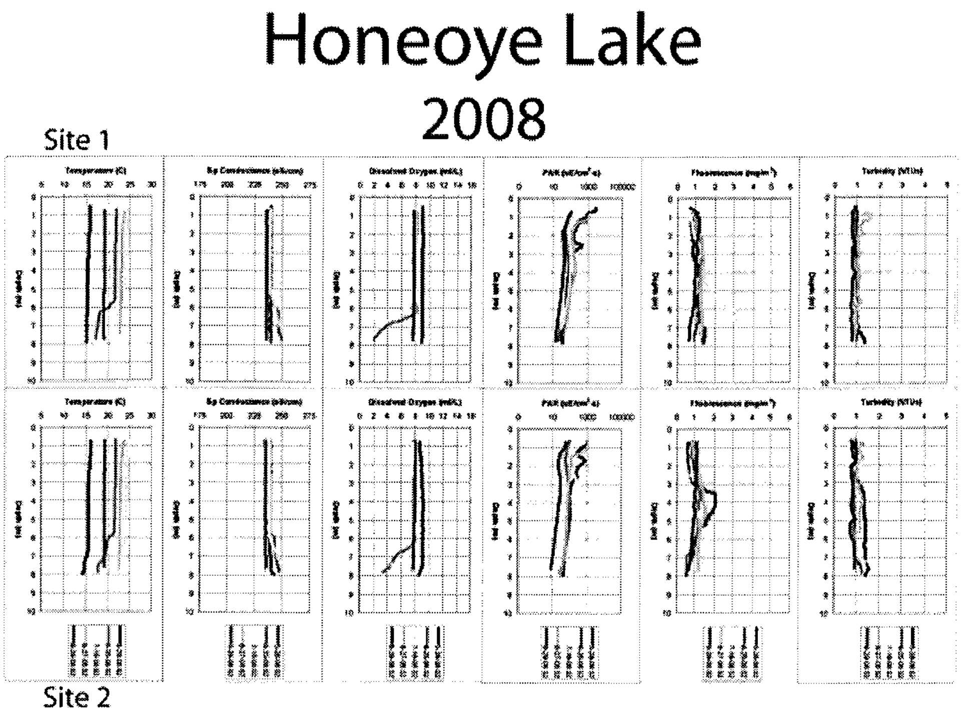
Fig. 5. The SBE-25 CTD.

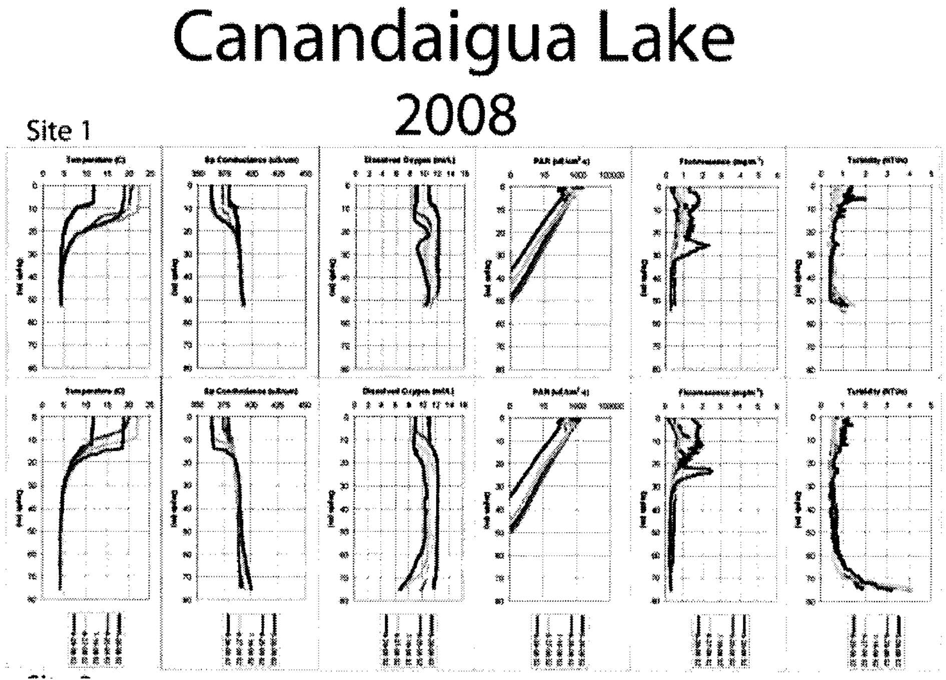
Nutrient, chlorophyll-a, and total suspended solids analyses followed standard limnological techniques (Wetzel and Likens, 2000). Typically four liters of lake water was filtered through a pre-weighed 0.45 μm glass-fiber filter. The filter and residue were dried at 90°C overnight. The weight gain and filtered water volume determined the total suspended sediment concentration. Typically one liter of lake water was filtered through a Gelman HA 0.45 μm membrane filter. The filtered residue was kept frozen until chlorophyll analysis, where the chlorophyll pigments were extracted in acetone and analyzed by the trichromic method using a 1-cm cell in a spectrophotometer. The filtrate was analyzed for subsequent soluble reactive (dissolved) phosphate (SRP), nitrate and silica colorimetric analyses by spectrophotometer. Samples were treated in an acidic molybdate reagent and analyzed by spectrophotometer using a 10-cm cell at 885 for phosphates and in a 1-cm cell at 810 nm for silica. Nitrates were prepared with a Hach Low Range Nitrate Kit (Model NI-14) and concentrations were colorimetrically detected by spectrophotometer using a 1-cm cell at 540 nm in the laboratory.

A third unfiltered water sample was analyzed for total phosphates. This sample was in potassium persulfate at 100°C for 1 hour to release all phosphates into solution and subsequently analyzed by colorimetric analysis by spectrophotometer using the SRP procedure (Fig. 6). Laboratory precision was determined annually by analyzing replicate tests on the same water sample, and typically was 0.2 mg/L for total suspended solids, 0.1 μg/L for phosphate, 0.1 mg/L for nitrate, and 5 μg/L for silica. All water samples were kept at 4°C until analysis and typically analyzed within a week of collection.



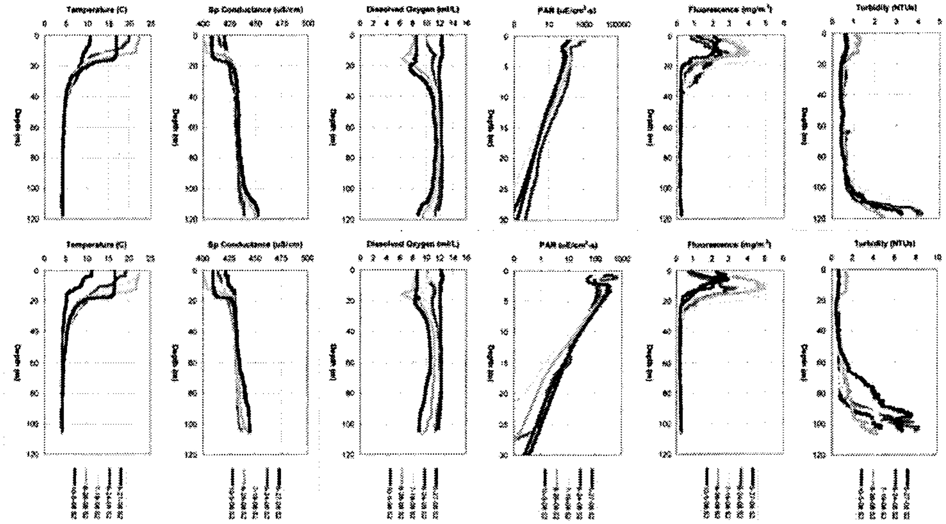
For quality control, over 100 randomly selected sample splits were analyzed by Life Science Laboratories, a commercial laboratory, for total phosphate, dissolved phosphate and nitrates within a few weeks of sample collection in 2007. The comparison indicates that our results are statistically equivalent 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 vertically mixed during overturn, and these parameters become uniform throughout the entire water column.





Cayuga Lake
2008

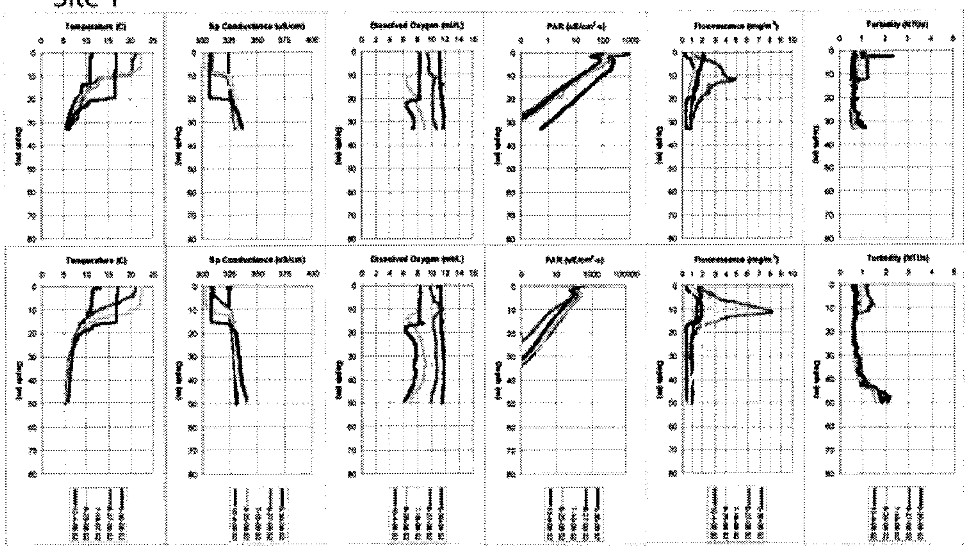
Site 1



Site 2

Owasco Lake
2008

Site 1



Site 2

Specific Conductance Profiles: Specific conductance is proportional to the salinity of the water. In general, the salinity reflects the input of salt from surface runoff, including road salt and weathering reactions, and loss of salt through the outlet and burial in the sediments. Specific ions like calcium are also lost through the formation of water column precipitates (whiting events of calcium carbonate) or incorporation into the shells of organisms (zebra and quagga mussel calcium carbonate shells) and in both cases eventual burial in the sediments.

In the Finger Lakes, specific conductance data ranged from a low of 230 μS/cm in Honeoye Lake to 730 μS/cm in the hypolimnion of Seneca Lake in 2005 (Fig. 7). The change between basins can be attributed to differences in bedrock geology, as limestones weather more easily and thus provide more salts than other bedrock in the region, and hypothesized access to saline groundwater from the rock-salt bearing Salina Formation and/or salt wastes in Seneca and to a lesser degree Cayuga Lakes. Honeoye typically revealed well mixed profiles.

Typically conductivities were 15 to 20 μS/cm smaller in the epilimnion than the hypolimnion in most lakes. This difference becomes larger through the stratified season. The largest difference was up to 50 μS/cm and consistently observed in Seneca Lake. Two hypotheses may account for this difference. It may reflect the input of saline groundwater to the hypolimnion as hypothesized by Wing et al. (1995) or the input of dilute surface runoff to the epilimnion as discussed by Halfman and Franklin (2008). The CTD data from all the lakes support the second hypothesis as the conductivity typically remained constant in the hypolimnion each season, whereas the conductivity decreased through the summer in the epilimnion. Temporally, the largest decrease in epilimnion conductivities occurred just after the heavy rains (3" in Geneva) during the aftermath of Hurricane Katrina in 2005. This decrease was especially pronounced in Owasco Lake, which is expected as it has the largest watershed area to lake surface area ratio of the lakes in the survey. Over longer time scales, the specific conductance of Seneca Lake has steadily decreased over the past four years from a high of 730 μS/cm in 2005 to a low of 655 μS/cm in the fall of 2008. Each year the lower salinity epilimnion would mix with the more saline hypolimnion during overturn, and as a result the entire water column would become slightly fresher.

Dissolved Oxygen: Temperature, photosynthesis and respiration influenced dissolved oxygen concentrations in these lakes. Water temperature is inversely related to the saturation concentration of oxygen, i.e., warmer water holds less dissolved oxygen than colder water at saturation (the maximum concentration). Photosynthesis by algae and macrophytes release oxygen to the water and respiration by all living things in the lake, especially bacteria, consumed oxygen dissolved in the water.

Most of the lakes in the survey revealed saturated dissolved oxygen profiles with summer epilimnion concentrations slowly decreasing as the surface waters warmed through the spring to summer season (Fig. 7). Cayuga, Owasco, and to a lesser degree Canandaigua and Keuka Lakes, revealed below saturation concentrations in the hypolimnion and was probably due to respiration by bacteria. Occasionally oxygen enrichments (Skaneateles & Canandaigua) or deficits interpretations were consistent with TSS and chlorophyll-a data. The new fluorometer data confirmed this hypothesis. Algal peaks were best developed in the epilimnion for Seneca, Cayuga, Owasco and Otisco Lakes. The peak in algal abundance deepened to the metalimnion and upper hypolimnion in Skaneateles, Keuka and Canandaigua Lakes. In all lakes the amount of algae peaked in the middle of the summer. Maximum algal concentrations were near 3 mg/m^3 in Keuka, Canandaigua, and Skaneateles Lakes, between 3 and 10 mg/m^3 in Seneca, Cayuga, and Owasco Lakes, and was typically near 5 mg/m^3 in Otisco Lake. The largest peak was above 25 mg/m^3 on 8/25 just below the thermocline in Otisco Lake. The water column in Honeoye was typically well mixed.

Benthic nepheloid layers were observed in all but Honeoye and Seneca Lakes. The nepheloid layers persisted throughout the field season but their extent varied from lake to lake. Honeoye is probably too well mixed to reveal anything but uniform turbidity profiles. The absence of benthic nepheloid layers in Seneca requires further investigation as it may reflect sample sites that do not occupy the deepest part of the lake where the nepheloid development is typically more pronounced. The nepheloid layers were best developed in Cayuga Lake where light transmission values started to decrease from background values of 60% ~20 m above the lake floor to 30% (maximum turbidities) just above the lake floor. We previously speculated that the bottom water nepheloid layers are accumulations of resuspended fine-grained sediments and/or allochthonous material that are transported to the lake floor by density currents (Halfman and Bush, 2006). The 2007 & 2008 fluorometer and nephelometer profiles confirmed this hypothesis because the material is primarily non-fluorescing materials, and therefore are composed of accumulating dead algae and settling sediments.

Secchi Disk, Chlorophyll-a, TSS Data: Annual average secchi disk depths were deeper in Canandaigua and Skaneateles Lakes (6.5 and 7.5 m, respectively), and shallower in Cayuga, Owasco, Honeoye and Seneca Lakes (~4 m) and Otisco Lakes (~3 m, Fig. 8). The depths inversely correlated to annual average chlorophyll-a concentration (an annual average 10 μg/L (mg/m^3) in Honeoye to < 1 μg/L in Skaneateles Lake) and TSS data (an average of 2.5 mg/L in Honeoye to < 1 mg/L in Skaneateles Lake, Figs. 9 & 10). Annual average chlorophyll-a concentrations were larger in epilimnion than the hypolimnion for all the lakes except for the well-mixed Honeoye. Thus algae are concentrated in the epilimnion. Annual average TSS concentrations were larger in the hypolimnion of Cayuga, by 1.5 mg/L, and to a lesser extent in Canandaigua and Keuka Lakes by 1 mg/L, and is discussed below. Honeoye Lake revealed the largest variability in these parameters, and reflects the presence or absence of an algae bloom on the sample date.

Georgian and Halfman (2008) investigated the correlation of secchi disk, chlorophyll-a, TSS, Fluorometer and nephelometer data. The largest correlations were observed between chlorophyll and fluorescence data and between total suspended solids and nephelometer data with correlation coefficients, r^2, above 0.60. The lowest correlations were between fluorometer and nephelometer data, and between total suspended sediments and fluorometer data with coefficients, r^2, below 0.25. The associations indicate that each parameter measures a subset of water clarity.

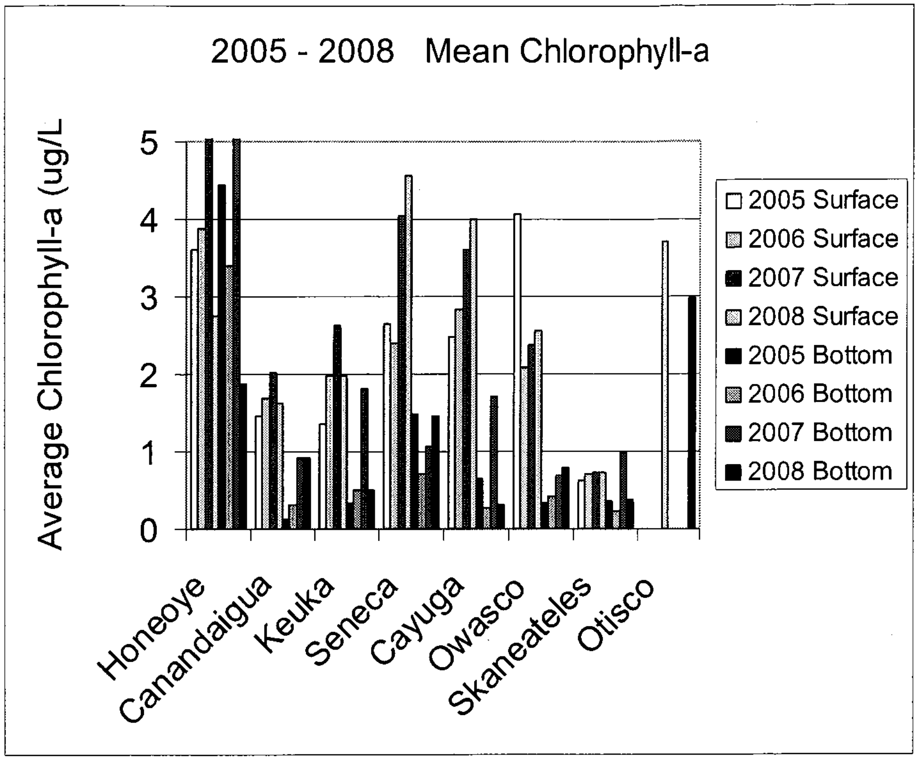
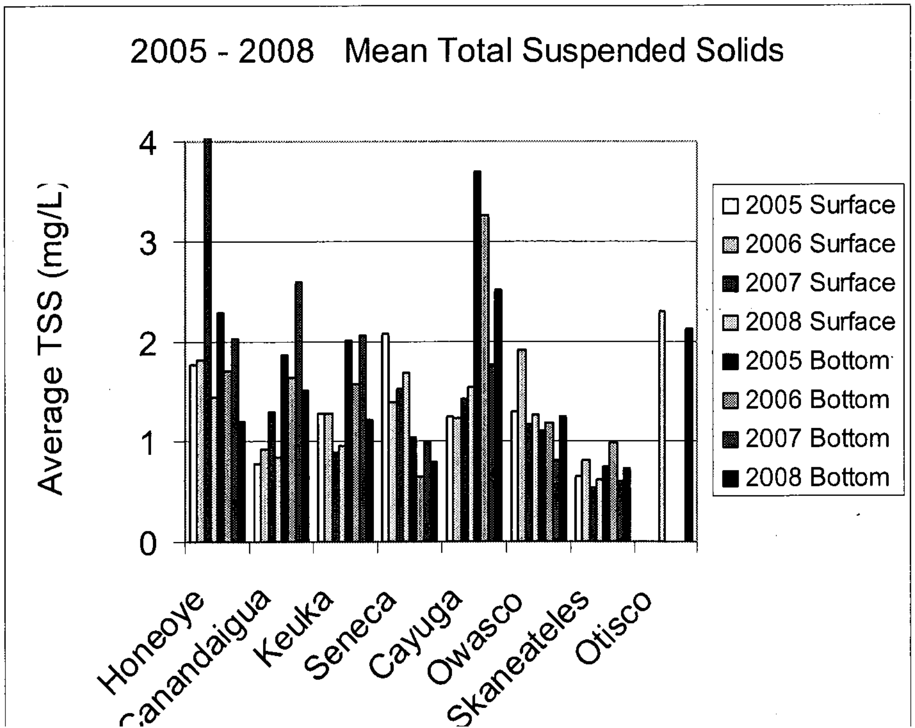


Fig. 9. Annual mean chlorophyll-a concentrations from the Finger Lakes.



the concentration threshold for impaired water bodies. Thus, Honeoye was impaired by this definition, and Otisco Lake is very close to impairment.

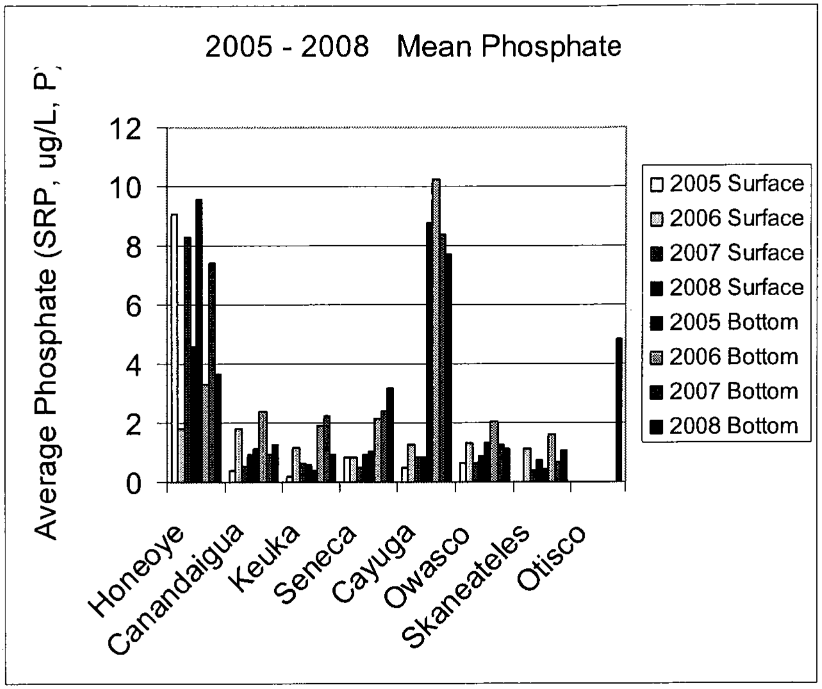
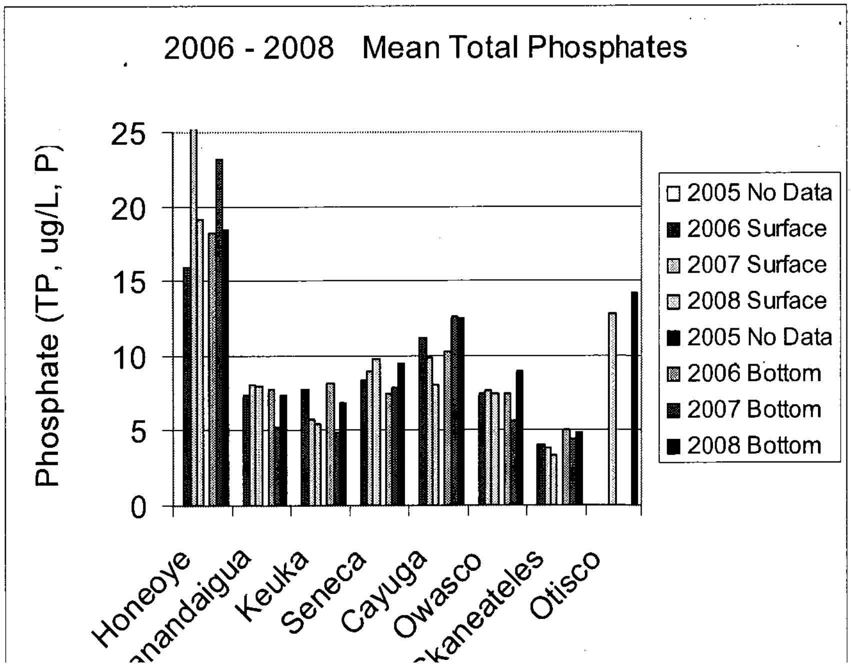


Fig. 12. Annual mean soluble reactive phosphate concentrations from the Finger Lakes.



the observed full range of annual averages for each parameter. A rank of one represents the best water quality observed in any lake over the four years of study, and a rank of 29 the worst water quality. Twenty nine corresponds to seven lakes that were surveyed for four years 2005 – 2008 for 28 annual averages, plus one more for the one year of data from Otisco. Finally, the annual ranks for each parameter at each lake were averaged to establish an annual average rank for each lake. These ranks were normalized to a 1 to 29 scale and are shown in Figure 15.

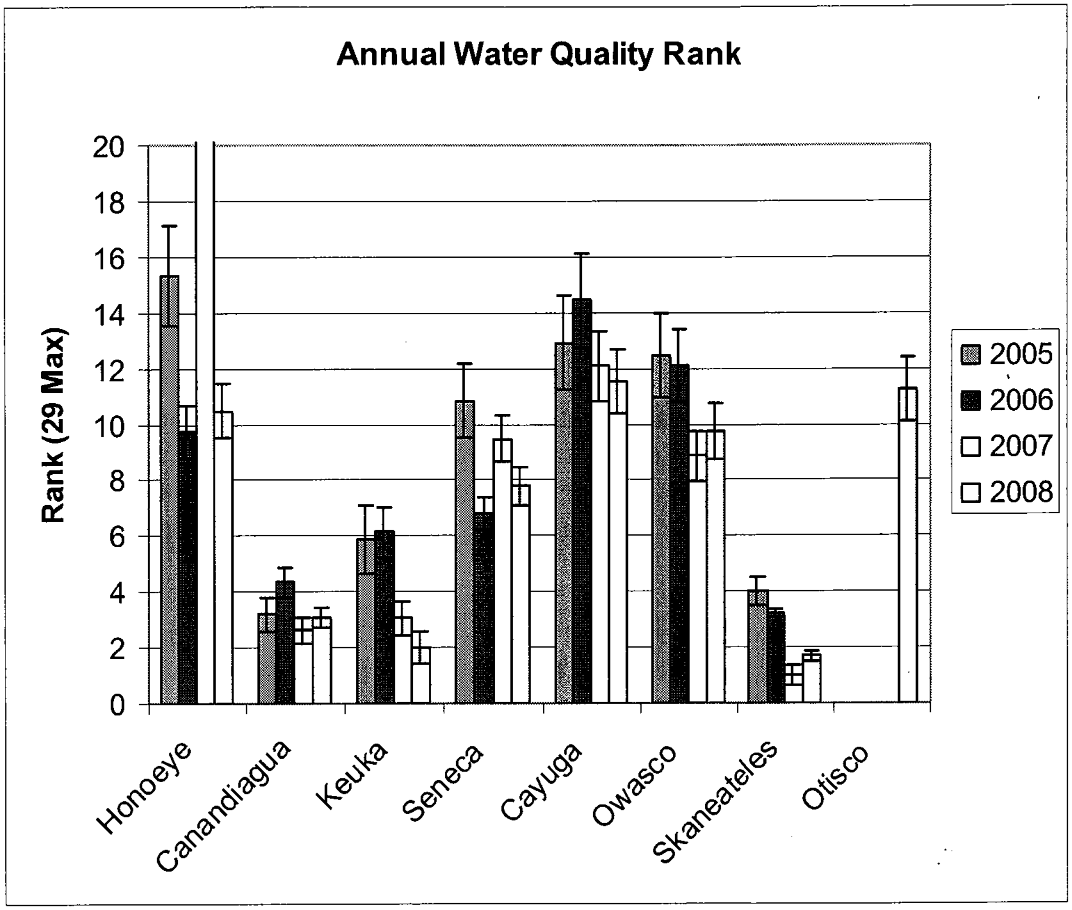
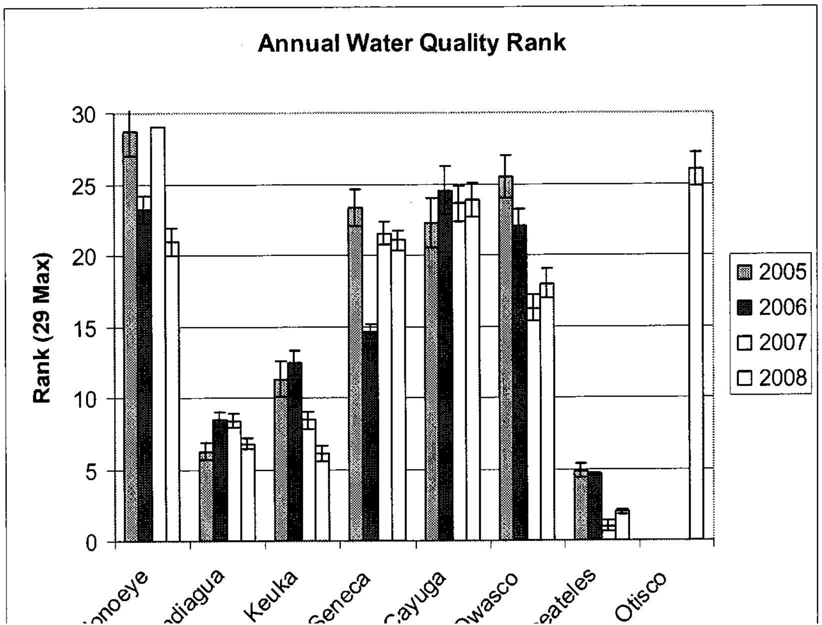


Fig. 15. Annual Water Quality Ranks..

These annual ranks range from 1, the lake with the best water quality over the four years, to 29, the lake with the worst water quality over the four years. The other ranks were proportionally distributed between 1 and 29. Thus, lakes with a water quality similar to the best lake, got a rank close to one, other lakes with a water quality close to the worst lake got a rank close to 29. Simply put, a rank of 1 corresponds to the smallest combination of nutrient (TP, SRP, nitrate), suspended sediment, and chlorophyll-a concentrations, and deepest secchi disk depths; whereas, a rank of 29 corresponds to the largest combination of nutrient (TP, SRP, nitrate), suspended sediment, and chlorophyll-a concentrations, and shallowest secchi disk depths. The other ranks fall proportionally between 1 and 29.

ranging from a low of ~10 in 2006 to the highest rank of 29 (worst water quality lake over the four year study) in 2007. Honeoye's shallow depth and small size sets this lake apart from the other lakes in the survey. The shallow depth allows the entire water column to mix in only this lake during windy days. Mixing breaks down any stratification and bottom water anoxia that established during calm days. Anoxia events are important because they allow the release of phosphates from the sediments, providing a significant internal source of nutrients. 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 in oxygenated lakes typically are lost from the aquatic ecosystem; whereas, phosphates are instead liberated from the sediments and recycled back to the water column in anoxic systems. When recycled, a significant bloom of algae typically occurs stimulated by the sudden release of nutrients.

Honeoye's annual average chlorophyll-a concentrations have varied from a low of 2.7 ± 1.9 in 2008 to 28.2 ± 52.8 µg/L in 2007. The difference between years and large standard deviation in 2007 reflected sampling a bloom of blue-green algae on 7/24/07 and not sampling major blooms during the other sample dates. Ignoring the 7/24/07 chlorophyll-a results reduces the 2007 annual average from 28 ± 52.8 to 3.3 ± 1.5 µg/L, a concentration very similar to the other annual average concentrations at Honeoye Lake. Even though the annual chlorophyll-a concentration decreased significantly after ignoring the bloom event, the 2007 rank still remained at 29. Interestingly, ranks for the other impaired lakes increased proportionally, typically from the low teens to the low 20s (Fig. 16). The relative order of ranks from lake to lake did not change. Honeoye sought and was recently granted permission to spread alum in the deep sediments of the lake. Alum binds phosphates and locks them into the sediment column. It is imperative to follow future water quality changes in Honeoye to see if the treatment improves water quality in the future, once the internal sediment loading of phosphates is significantly reduced.



Ranks for Keuka, Owasco and Skaneateles Lakes decreased from 2006 to 2007, and remained relatively low in 2008 (Fig. 15). Owasco watershed research revealed that the variability in phosphorus loading from the watershed played a critical role in the productivity and water quality of this phosphate limited lake (Halfman et al., 2008). Hydrogeochemical data from the major tributaries flowing into Owasco Lake revealed that water residence time, and population served with drinking water. Rank versus watershed size revealed a correlation if Honeoye, Otisco and Owasco were excluded from the analysis.

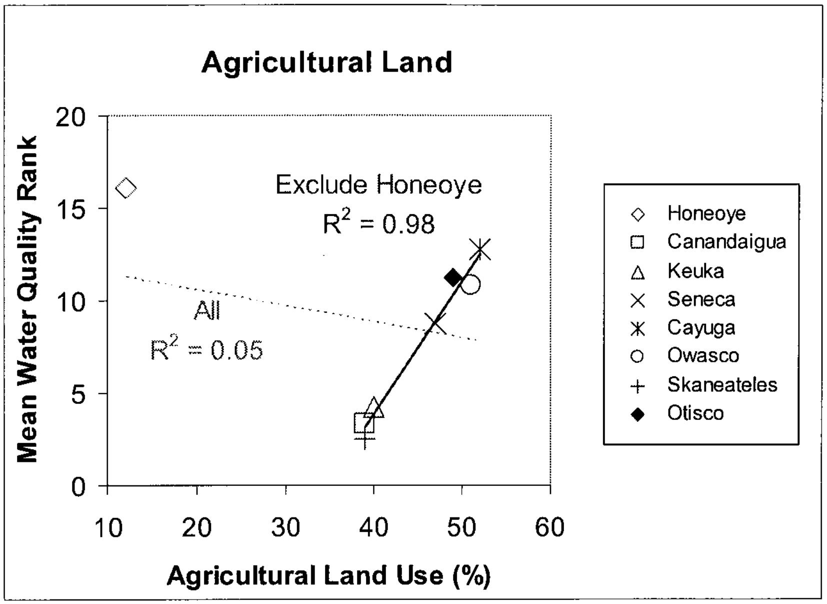


Fig. 17. Mean Rank vs. Agricultural Land Use.

An agricultural correlation does not dictate causation but is supported by nutrient loading studies in the Seneca and Owasco watersheds. Nutrient concentrations are 10 to 100 times larger in tributaries than the respective lake indicating a nutrient loading problem (Halfman et al., 2008; Halfman and Franklin, 2008, Fig. 18). Tributaries draining agricultural land transport more nutrients to the lake than more forested drainages. Field data from Conesus watershed and the watershed surrounding the Catskill reservoirs revealed similar trends (Makarewicz, 2007 Pionke et al., 1999). Computer models utilizing natural average nutrient loading curves confirm our field data (Evans, 2008).

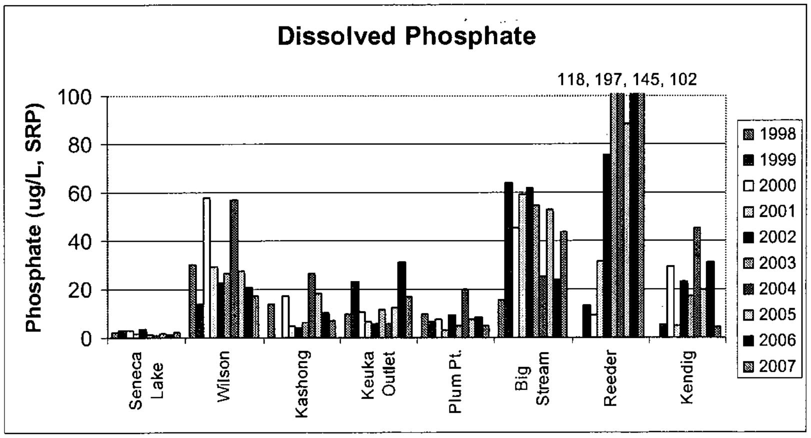


Fig. 18. Nutrient Loading by Seneca Tributaries.

Both nitrates and phosphates are not identical in their delivery. Nitrates are easily and ubiquitously transported in runoff as nitrates are water soluble. Phosphates however, are not easily transported because they attach onto soil particles. Major runoff events that transport eroded soils also transport large quantities of phosphates attached to the particles. Thus their impact is most critical during major runoff events. The correlation is confirmed by preliminary field data in the Owasco and Seneca watersheds, observations from elsewhere, and assumed by the Owasco watershed computer modeling. The relative contribution of phosphorus by base flow and peak flow (major runoff events) requires

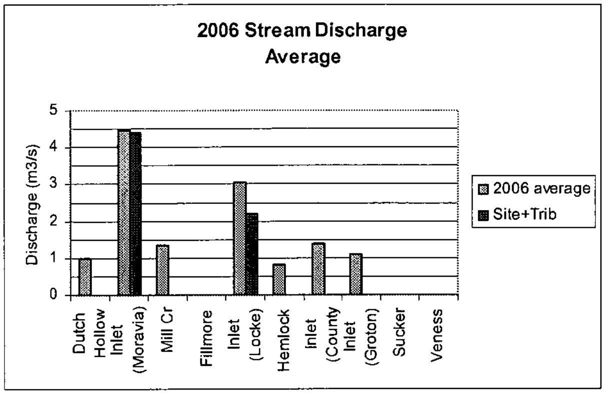


Fig. 20a. Owasco watershed 2006 discharge data.

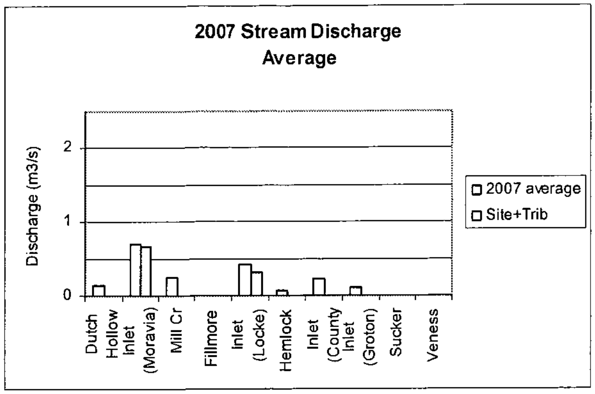


Fig. 20b. Owasco watershed 2007 discharge data.

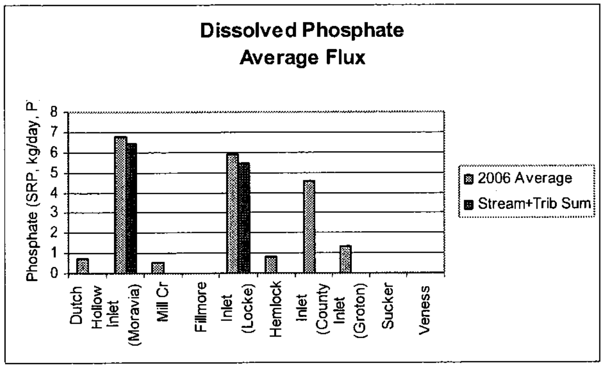


Fig. 21a. Owasco watershed 2006 nutrient flux data.

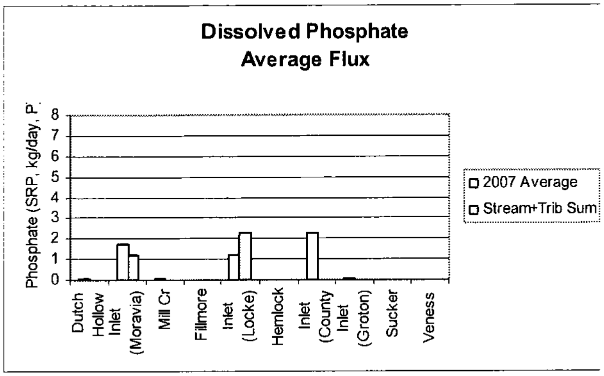


Fig. 21b. Owasco watershed 2007 nutrient flux data.

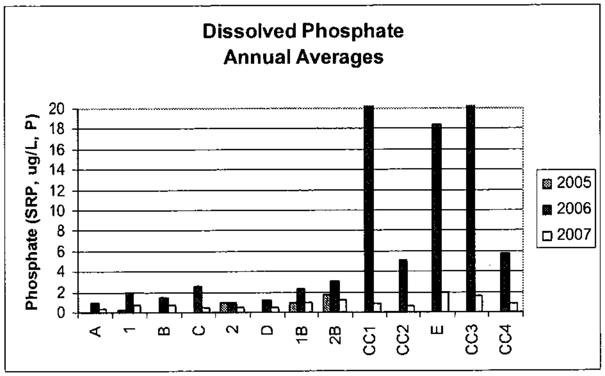


Fig. 22a. Owasco Lake SR phosphate data.

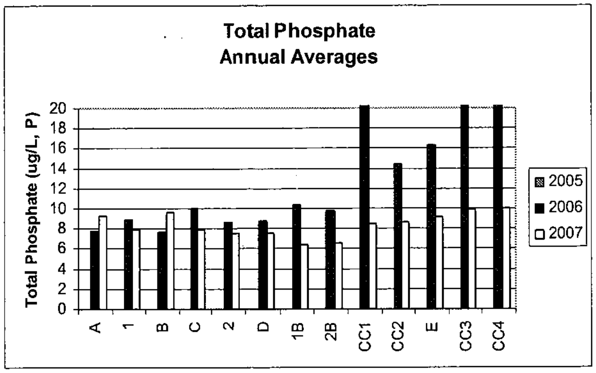


Fig. 22a. Owasco Lake total phosphate data.

Data from the Seneca and Owasco watersheds also confirm the degrading impact of nutrients from the treatment of organic wastes by municipal wastewater treatment plants. Segment analysis of Owasco Inlet in the Owasco watershed and Big Stream in the Seneca watershed revealed that effluent from municipal waste water treatment facilities in Groton and Dundee, respectively, was a major source of nutrients to these streams. The Groton plant delivered 20%

chain in the ecosystem, and thus enhance algal populations. For example, the carnivorous zooplankton *Cercopagus pengoi* feed on herbaceous zooplankton species. If sufficient grazing decimates herbaceous zooplankton populations then zooplankton are incapable of reducing algal blooms. The result is an algae bloom, similar to a bloom in eutrophic lakes, without the nutrient supply to be a eutrophic lake. Preliminary data from Owasco and Seneca Lakes also reveal evidence for a 'top down" impact (Brown and Balk, 2008). Similar results are observed through the introduction of zooplanktivorous fish like alewife. These fish eat the herbaceous zooplankton, and can severely decrease their populations, which in turn are not available to keep the phytoplankton populations in check. Thus evidence exists for "top down" alteration of aquatic ecosystems as well, and perhaps the non uniformity of the year to year ranking is a result of different perturbations impacting different watersheds with different outcomes.

Water Quality Protection Legislation

The United States Environmental Protection Agency (US EPA) sets legislation that regulates and protects the quality of surface water. The Safe Drinking Water Act and subsequent amendments must be upheld or replaced with a more stringent standard by environmental regulatory agencies in the individual states. During the latter part of the 20th century, legislation was passed to control point source pollution. In New York, potential point-source polluters had to apply for permits to discharge wastes into surface waters. More recent legislation has focused on non-point source pollutants including legislation that controls land use options and best management practices, e.g., the reduction of runoff from agricultural land. Additional legislation focused on the repair, maintenance, and upgrades of on-site wastewater treatment. However the application of the more recent regulations is not state-wide.

The Catskill Watershed Cooperative (CWC) is an example where stringent water quality protection legislation protection was adopted for this primary drinking water supply for New York City. The nineteen reservoirs and three controlled lakes in the rural setting located north of the city and just west of the Hudson River supply ~90% of the city's drinking water. The incentive for New York City to establish stringent water quality protection legislation was to avoid the huge construction costs for EPA mandated water filtration plants. City funds supported the rehabilitation and maintenance of on-site wastewater systems. Their funds also support storm-water runoff reduction from agricultural land through best management practices (BMPs), and public education through various outreach efforts. Specifically, their programs focus on rehabilitation and replacement of septic systems, septic system maintenance programs, septic system monitoring programs, community wastewater management systems, stormwater control programs, local technical and economic assistance to encourage growth of environmentally friendly business ventures, and best management practices at agricultural sites.

In the Finger Lakes region, each watershed has a variety of regulations to maintain water quality. The degree of water quality regulation depends on citizen involvement and awareness, and the specificity and degree of implementation of the legislative goals. 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 wine industry along its shores. Once Seneca Lake is degraded, it will stay degraded for generations.

Nutrient sources include both point and non-point sources and include wastewater treatment facilities, stream bank erosion, and runoff over agricultural areas. On-site systems and enhanced lakeside lawn care provide additional concerns. Everyone has a stake in protecting and preserving water quality in the Finger Lakes because they provide critical sources of drinking water and are essential to the regional economy. Lets all work together to reverse disturbing water quality trends and projected outcomes. If we do, then the preliminary evidence from Owasco Lake suggests that water quality in these lakes will improve after "turning off" multiple sources of nutrients from their watershed. Outstanding models exist and are ready to implement across the entire region.

A few future water quality research topics are highlighted here. First, continued monitoring is critical in each basin to assess the impact of nutrient loading on the water quality in these lakes and the relative change between lakes. Second, future studies must investigate the relative contributions of peak versus base flow conditions on nutrient loading from the watershed to the lake. This data are critical to differentiate the relative contribution of point-source pollutants like waste water treatment facilities important during base flow to non-point source pollutants like runoff from agricultural areas, both plant and animal operations, during peak flow. Third, more research is required to assess the impact of on-site systems, enhanced lawn care and other perturbation along the lake shore. Finally, stakeholders within each watershed should constantly re-evaluate their water quality protection legislation and degree of enforcement/compliance within the watershed. Only concerted efforts from every stakeholder in the watershed will maintain and hopefully improve water quality in the Finger Lakes for generations to come.

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Annual Mean Lake Data:

2005 Average Values (± 1σ)	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
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 Average Values (± 1σ)	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 Average Values (± 1σ)	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 Average Values (± 1σ)	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
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
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
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

Average of the 4 Years (± 1σ)	Honeoye	Canandaigua	Keuka	Seneca	Cayuga	Owasco	Skaneateles	Otisco
Secchi Depth (m)	4.2 ± 0.3	6.5 ± 0.5	5.3 ± 1.1	4.7 ± 0.7	4.1 ± 0.3	4.1 ± 0.6	7.6 ± 0.8	3.1 ±
Total Suspended Solids (mg/L), Surface	2.7 ± 2.2	1.0 ± 0.2	1.1 ± 0.2	1.7 ± 0.3	1.4 ± 0.2	1.4 ± 0.3	0.7 ± 0.1	2.3 ±
Total Suspended Solids (mg/L), Bottom	1.8 ± 0.5	1.9 ± 0.5	1.7 ± 0.4	0.9 ± 0.2	2.8 ± 0.8	1.1 ± 0.2	0.8 ± 0.2	2.1 ±
Dissolved Phosphate (μg/L, SRP), Surface	5.9 ± 3.4	0.9 ± 0.6	0.7 ± 0.4	0.8 ± 0.2	0.9 ± 0.3	0.9 ± 0.3	0.8 ± 0.5	0.8 ±
Dissolved Phosphate (μg/L, SRP), Bottom	6.0 ± 3.0	1.4 ± 0.7	1.4 ± 0.8	2.2 ± 0.9	8.8 ± 1.1	1.4 ± 0.4	1.0 ± 0.5	4.8 ±
Total Phosphate (μg/L, TP), Surface	23.5 ± 10.4	7.8 ± 0.4	6.3 ± 1.3	9.0 ± 0.7	9.7 ± 1.6	7.5 ± 0.1	3.7 ± 0.3	12.8 ±
Total Phosphate (μg/L, TP), Bottom	20.0 ± 2.8	6.8 ± 1.4	6.6 ± 1.7	8.2 ± 1.1	11.8 ± 1.3	7.3 ± 1.6	4.8 ± 0.3	14.2 ±
Nitrate as N (mg/L), Surface	0.0 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.4 ± 0.2	0.9 ± 0.2	0.7 ± 0.0	0.5 ± 0.1	0.3 ±
Nitrate as N (mg/L), Bottom	0.0 ± 0.0	0.3 ± 0.0	0.2 ± 0.0	0.4 ± 0.1	1.3 ± 0.2	1.0 ± 0.2	0.6 ± 0.0	0.3 ±
Silica (SR μg/L), Surface	805 ± 99	1035 ± 65	518 ± 53	213 ± 88	394 ± 143	638 ± 97	266 ± 73	334 ±
Silica (SR μg/L), Bottom	815 ± 82	1496 ± 122	1126 ± 59	371 ± 72	1017 ± 19	1487 ± 41	740 ± 58	1298 ±
Chlorphyll a (μg/L), Surface	9.6 ± 12.4	1.7 ± 0.2	2.0 ± 0.5	3.4 ± 1.1	3.2 ± 0.7	2.8 ± 0.9	0.7 ± 0.1	3.7 ±
Chlorphyll a (μg/L), Bottom	3.8 ± 1.5	0.6 ± 0.4	1.8 ± 1.9	1.2 ± 0.4	0.7 ± 0.7	0.6 ± 0.2	0.5 ± 0.3	3.0 ±