A PRELIMINARY WATER QUALITY STUDY OF SELECTED FINGER LAKES, NEW YORK.

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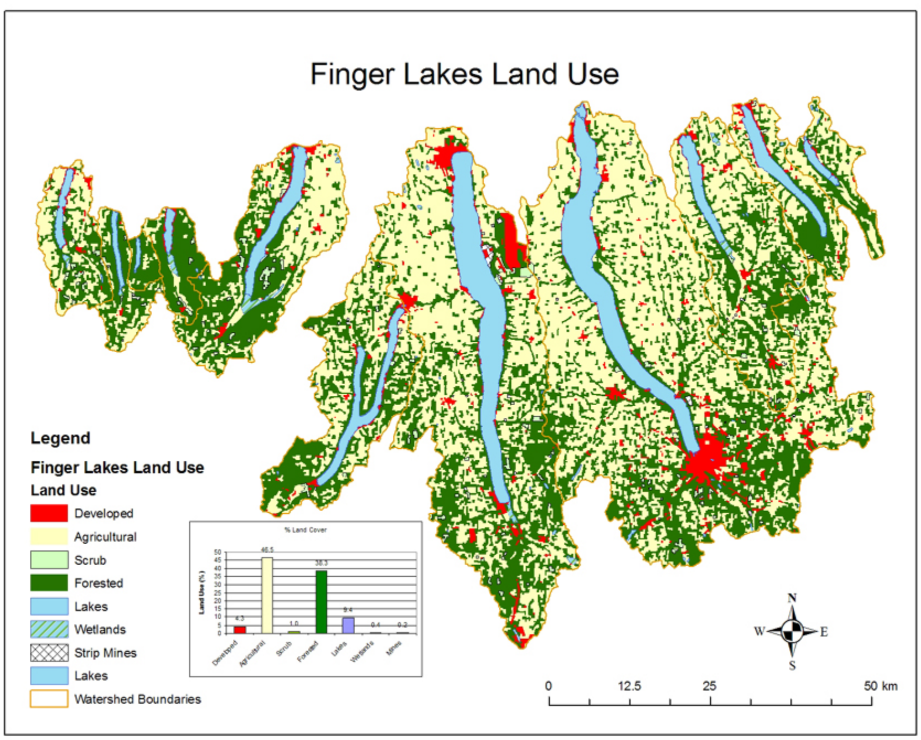
6/1/2006

Introduction

The Finger Lakes of western and central New York are critical to the health, well-being and economy of the region. Created by glacial ice and meltwater erosion approximately 15,000 years ago, 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 occupy a 2,630 square mile (4,970 km^2), 14-county region. The basins eventually drain into Lake Ontario to the north via the Genesee and Oswego Rivers. 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; Hemlock and Canadice Lakes provide drinking water for the City of Rochester; and, Seneca Lake provides drinking water for nearly 100,000 local residents with total withdrawals of nearly 200 million gallons of water per day from the Finger Lakes. The natural beauty of the Finger Lakes region attracts approximately 22 million tourists annually. 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 environmentally attributes of the Finger Lakes Region. Thus, these lakes must be protected from numerous threats to water quality.

All of the Finger Lakes are subjected to a variety of environmental threats including non-point source agricultural pollutants, shoreline development, increasing recreational use, and the introduction of exotic species like the spiny waterflea, zebra mussel and Eurasian watermilfoil. As a consequence, all of the Finger Lakes are listed as threatened, stressed, or impaired in the most recent New York State Department of Environmental Conservation Priority Waterbodies List (PWL) with some also listed on the federal 303D List. Finger Lakes residents and policy makers are just beginning to realize these threats to their water supplies and the complex nature of the problems to be addressed.

The diversity in physiography, water quality, ecology, land use, bedrock and soil characteristics, and other factors among the eleven watersheds fosters an ideal situation for scientific study and modeling. Their size is large enough to mimic processes that occur in the Laurentian Great Lakes, yet small enough to easily undertake watershed-scale investigations. For example, Hobart and William Smith Colleges have taken advantage of the diversity in land use and bedrock characteristics between the numerous subwatersheds that drain into Seneca Lake to study the impact of land use on non-point source pollution, and the distribution of limestone bedrock on acid rain neutralization as well as the success of zebra/quagga mussel colonization in the lake. The future of these lakes clearly depend on our scientific understanding, but will also be determined by the collective involvement of individuals from many disciplines and viewpoints including scientists, policy makers, economists, engineers, as well as those concerned with the quality of life issues, human values and human behaviors.

In this report, we summarize our preliminary investigation on water quality indicators from the seven central Finger Lakes, Honeoye, Canandaigua, Keuka, Seneca, Cayuga, Owasco, and Skaneateles Lakes. These lakes were selected because they span the diversity of watershed character, they contain 98% of the water in the Finger Lakes, and for their relative ease of access from the Colleges in Geneva, NY. Our primary goal is to summarize the 2005 data, which provide a snapshot of the ecological health and water quality in these lakes. We will also assess if some lakes have relatively better or worse water quality. Our secondary goal is to investigate potential linkages between water quality and water quality protection legislation. Details of this research are available in Kathleen Bush’s honors thesis (Bush, 2006).

Water Quality

Water quality is a concern because water is a critical resource that is easily abused and polluted. Pollutants are subdivided into point and non-point sources. Point source pollutants are discharged from an identifiable spot, like a sewer outlet, a factory drain pipe, or power plant cooling-water outflow. Non-point source pollutants are more diffuse; examples include runoff from road salt or fertilizer after their application. Typically point source pollutants are easier to regulate, monitor, and control. For example, the municipal wastewater treatment plants must permit their discharge of wastes into neighboring bodies of water. The permit process is designed to minimize the health risks by maintaining water quality standards, and balance economic considerations that allow corporations to function. Non-point source pollutants are more difficult to regulate, monitor, and control, but are becoming the focus of recent legislation.

Pollutants are also subdivided by source. Sources are typically split into organic waste (e.g., onsite and municipal wastewater systems), agricultural waste (e.g., runoff of fertilizers, organics, sediment, herbicides and pesticides), and industrial waste (e.g., heavy metals, organic compounds and their byproducts, thermal wastes). Each source has its own degree of legislation and control. For example, treatment of human organic wastes is accomplished through municipal wastewater treatment facilities or individual onsite wastewater systems (e.g., a household septic system). The degree of treatment varies. All systems are designed to remove the organic materials by settling out the particulate organics and utilizing bacterial respiration of the dissolved organics. Some systems will then discharge the nutrient-rich effluent to the environment, whereas others will also chemically remove the nutrients before discharging the "cleansed" wastewater to the environment. Runoff from areas cleared for agricultural use is notorious for having sediment laden and fertilizer/pesticide rich, water, and current legislation attempts to control these sources through various "best management practices" (BMPs). Contour plowing, settling ponds, buffer vegetation strips, minimal tillage farming and other BMPs can reduce agricultural impact on nearby waterways but always at a cost to the farmer.

Water Quality Indicators

The rural landscape and agricultural land use activities dominate the Finger Lake watersheds with agriculture covering 46.5% of the watersheds, forests 38.3%, lakes 9.4%, and urban areas 4.3%. The land use suggests that the primary water quality threats are organic wastes and agricultural runoff, and are therefore the focus of this study.

Total coliform and *E. coli* bacteria are used as potential indicators for excess human fecal contamination in waterways. The bacteria are created by humans, are relatively easy to measure, and if present above the Environmental Protection Agency's (EPA's) maximum contamination level (MCL), flag the potential for other water quality vectors associated with improper treatment of human wastes that cause dysentery and other gastrointestinal water-borne diseases. An MCL is the highest concentration of a pollutant permissible in a public water supply. The presence of these bacteria however, does not dictate human fecal contamination because humans are not the only source. Any warm blooded animal is a source of these bacteria, including wild geese, ducks, deer and domesticated pigs and cows. Therefore, the presence of high concentrations of bacteria on any sample date may reflect the temporary occupation of the site by wild geese, as excessive numbers of water fowl, rather than human wastes, are the source of bacteria at a number of sites in the Finger Lakes region.

Dissolved nutrients (nitrate, phosphate and silica) enter nearby waterways from municipal wastewater treatment plants, onsite wastewater systems, agricultural runoff and related sources. They are water quality concerns because they can "fertilize" the waterway with additional nutrients and make the aquatic system more productive. Thus, nutrient loading can potentially transform an oligotrophic (poorly productive) lake to an eutrophic (highly productive) lake, where the extra nutrients stimulate algal (microscopic aquatic plants), macrophyte (rooted plants) and other plant growth. If the aquatic system becomes eutrophic, then a slimy and occasionally foul smelling/tasting scum of blue-green algae typically dominates the base of the food chain and accumulates on the surface of the water. The algae eventually die and bacteria decompose the organic material naturally. The decomposition process consumes dissolved oxygen from the bottom waters and recycles the nutrients back into the environment. The removal of oxygen from the bottom waters (below the thermocline) in eutrophic systems is severe enough to kill animals that need dissolved oxygen to survive (respiration), like lake trout, crawfish and worms. De-oxygenation can also release "rotten egg" odors. Once perturbed, the cycle unfortunately continues because the recycled nutrients from the decomposition process "fertilize" continued plant growth at enhanced levels.

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 in temperate lakes due to its scarcity. 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).

Algal concentrations, measured by the concentration of chlorophyll and/or by secchi disk depths, are another indicator of lake productivity and the ecological health of a lake. 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 transparent waters (plankton poor waters) secchi disk depths can be 100 feet (30 m) or more in ultra-oligotrophic (low productivity) systems. In an eutrophic (highly productive) pond on a farm, secchi disk depths can be as shallow as a few centimeters.

Typically, a combination of these indicators, larger nutrient concentrations, larger algal concentrations, and more shallow secchi disk depths are utilized to document the degree of eutrophication and degree of water quality degradation in aquatic systems (see table below).

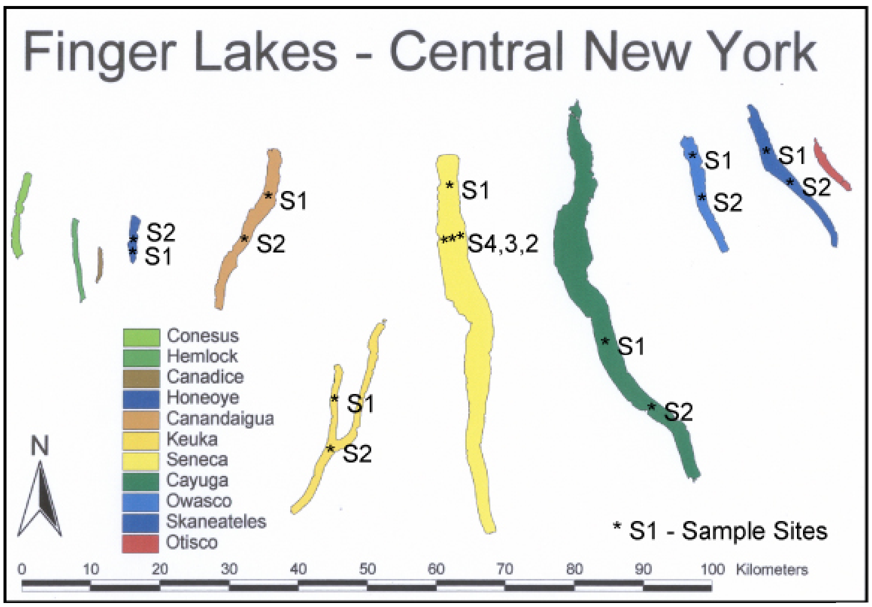
Trophic Status	Secchi Depth (m)	Total Nitrogen, N (N, mg/L, ppm)	Total Phosphate (P, ug/L, ppb)	Chlorophyll a (ug/L, ppb)
Oligotrophic	> 4	< 2	< 10	< 4
Eutrophic	< 2	> 5	> 20 (> 30)	> 10

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

2005 Methods

Water quality samples were routinely collected from surface and deep water at two deep water sites on a monthly basis during the 2005 field season in Honeoye, Canandaigua, Keuka, Seneca (4 sites), Cayuga, Owasco, and Skaneateles Lakes. At each site, surface and bottom water samples were collected for bacteria, nutrient and chlorophyll assays. In addition, secchi disk depth and water column CTD profile were collected from each site. The profile utilized a SeaBird SBE-19 CTD, which was lowered from the surface to ~1m above the lake floor to collect continuous water column profiles of temperature (°C), conductivity (specific conductance, uS/cm), light transmission (proportional to water clarity, %), dissolved oxygen (ml/L) and pH. Water samples were analyzed for dissolved nutrient (phosphate, nitrate and silica), chlorophyll-a, and total suspended solids analyses back in the laboratory.

Bacteria samples were collected in sterile, 100 mL, whirl-pak bags and stored at 4° C until analysis in the lab. Duplicate analyses were performed on each sample, and the average reported for that sample site and date. The lab procedure followed the EPA approved method (HACH #10029) that incubated filtered samples in m-ColiBlue24 broth at 35° C for 24 hours. The coliform and *E. coli* colonies where then counted under low power microscope and reported as colony forming units / 100 mL of sample water (CFUs/100mL). Sterile technique is critical, as the samples are easily contaminated. Sterile technique occasionally yields false positives as well. The average deviation from the mean of duplicate analyses was 30 CFUs/mL for total coliform, and 1 CFUs/mL for *E. coli* bacteria.



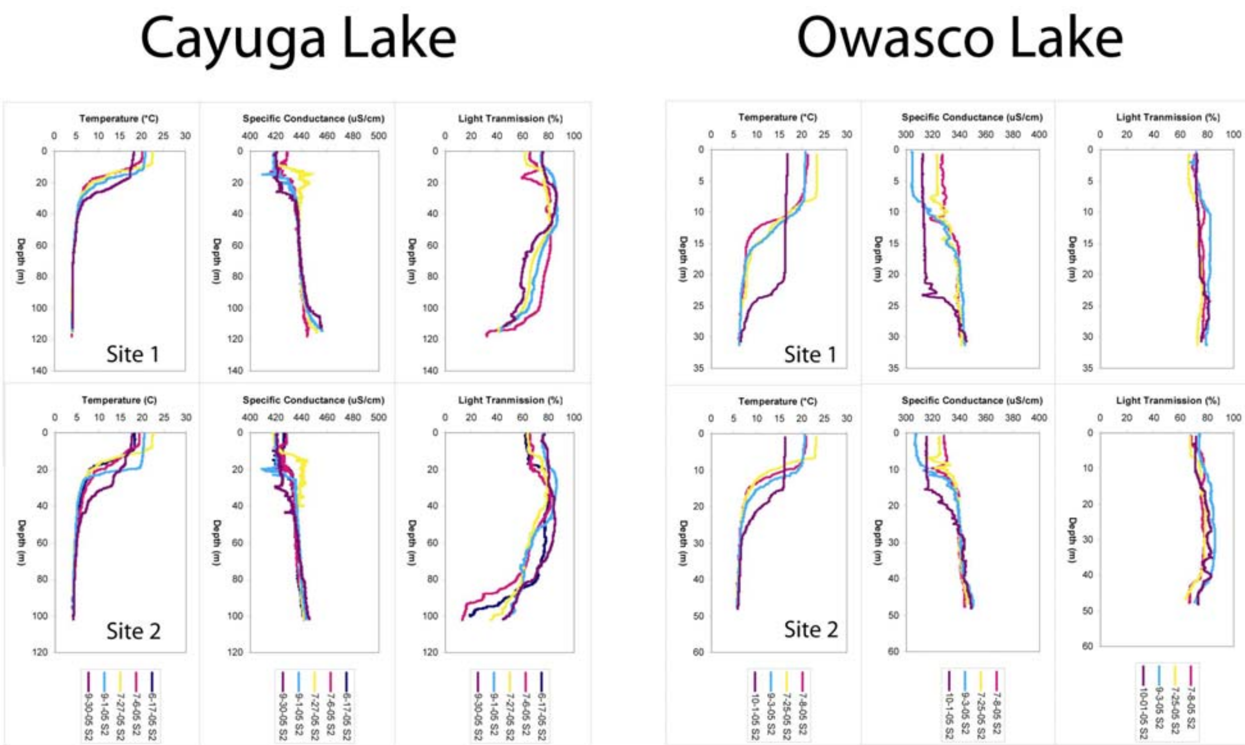
Nutrient, chlorophyll-a, and total suspended solids analyses followed standard limnological techniques (Wetzel and Likens, 2000). Water was collected, brought to the lab, and exactly four liters were filtered through a 0.45 um glass-fiber filters. The filter and residue were dried at 80° C overnight and the weight gain used to calculate the total suspended sediment concentrations (mg/L). Another 1 L of lake water was filtered through a Gelman HA 0.45 um membrane filter. The filter and residue were digested in acetone to release the chlorophyll for chlorophyll-a analysis by spectrophotometer. The filtrate was analyzed for soluble reactive (dissolved) nutrient concentrations. Soluble reactive phosphates (ug/L), nitrates (mg/L) and silica (ug/L) were measured using standard spectrophotometric techniques. Laboratory precision was determined by analyzing replicate tests on the same water

sample on a number of occasions: total suspended solids 0.2 mg/L, phosphate 0.1 ug/L, nitrate 0.1 mg/L, and silica 5 ug/L.

Plankton samples to enumerate relative species (%) and water samples for major ion analyses were collected but the data are not elaborated on in this report. Surface and depth integrative (20 m) plankton tows were collected in 85 um mesh nets, preserved in a formalin/alcohol solution, and ~100 individuals identified to species level. Major ions (chloride, sulfate, sodium, potassium, calcium and magnesium) concentrations (mg/L) were also measured on filtered (0.45 um) water samples by Dionex DX-120 ion chromatograph.

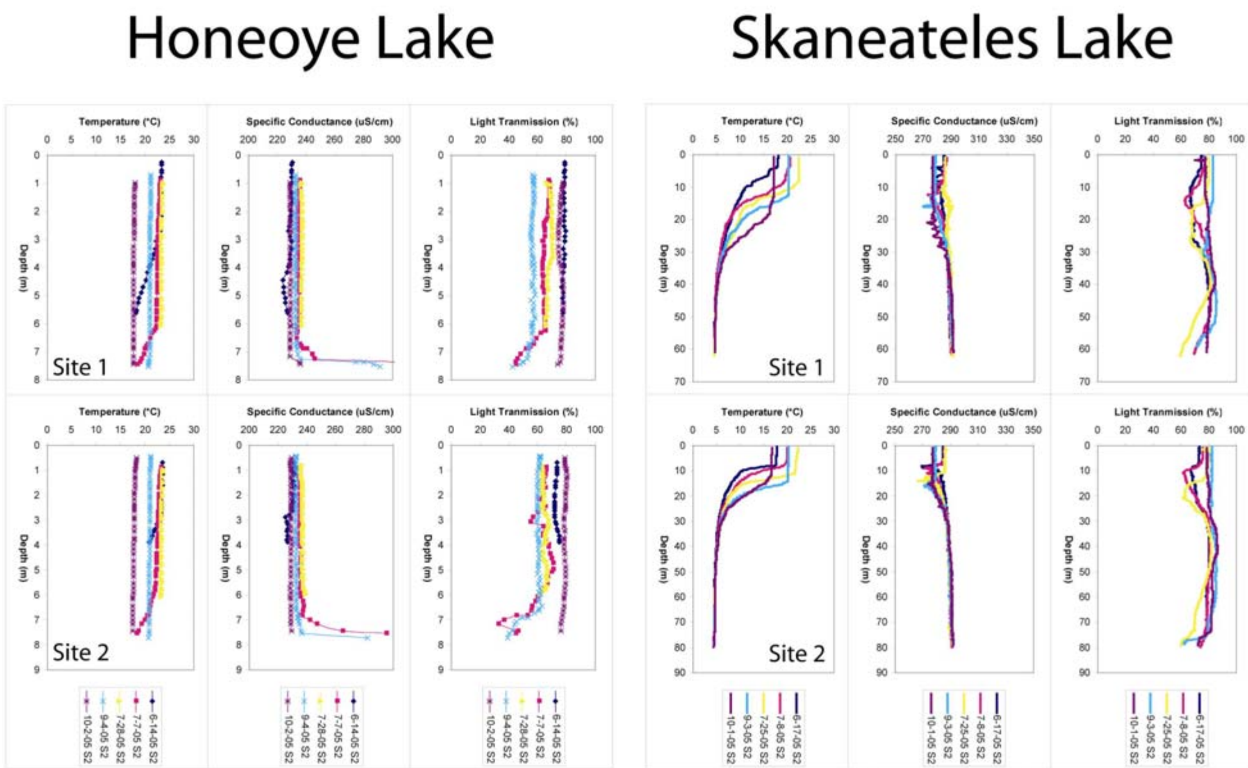
2005 Results

CTD Profiles: The temperature profiles were typical for any summer season. A well defined thermocline was observed in each deep lake at water depths ranging from 10 to 20 m. The deepest thermocline was found in the largest lakes (Cayuga & Seneca Lakes). The exception is Honeoye Lake, where wind stress over its shallow depth (7 m deep) presumably maintains a well-mixed water column. Surface temperatures were coldest in mid-June (17-20°C), and warmest in the end of July (22-24°C). Bottom temperatures were near 4°C in the deep lakes.



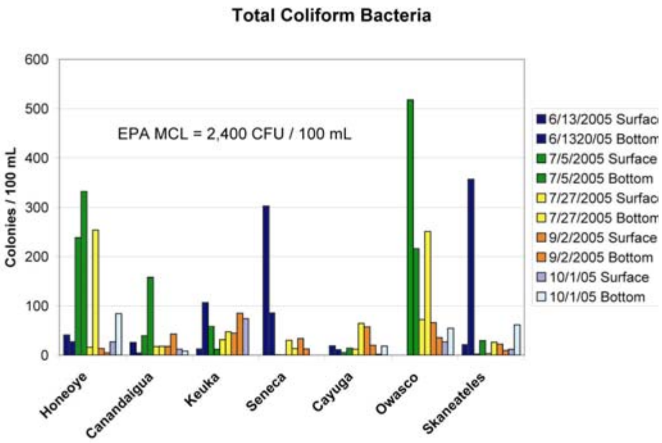
Specific conductance data ranged from 230 uS/cm in Honeoye Lake to 730 uS/cm in the hypolimnion of Seneca Lake. In Canandaigua (380 uS/cm), Keuka (300 uS/cm) and Skaneateles (280 uS/cm) Lakes, the specific conductance profiles were uniform with water depth and between sites. Surface conductivities in Cayuga (430 uS/cm), Owasco (320 uS/cm), and Seneca Lakes increased by 15 to 20 uS/cm from the epilimnion to the hypolimnion. The largest increase was consistently observed in Seneca Lake, perhaps reflecting 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. This year's data supports the second hypothesis as the conductivity remained constant in the hypolimnion, whereas the conductivity decreased through the summer in the epilimnion. Temporally, the early September profiles in all but Honeoye and Keuka Lakes revealed the smallest epilimnion conductivities, which may reflect the input of dilute runoff from the heavy rainfall (3" in Geneva) during the aftermath of Hurricane Katrina. This decrease was especially pronounced in Owasco Lake.

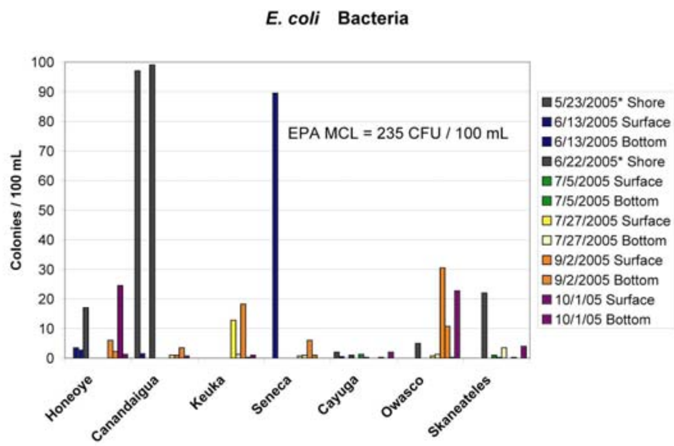
Light transmission data revealed surface, near surface and bottom water zones of increased turbidity. Typically turbid layers were observed throughout the entire epilimnion in Cayuga, Canandaigua, Keuka, Owasco, and Seneca Lakes. These layers were best developed in Cayuga and Seneca Lakes, and least developed and only occasionally observed in the epilimnion of

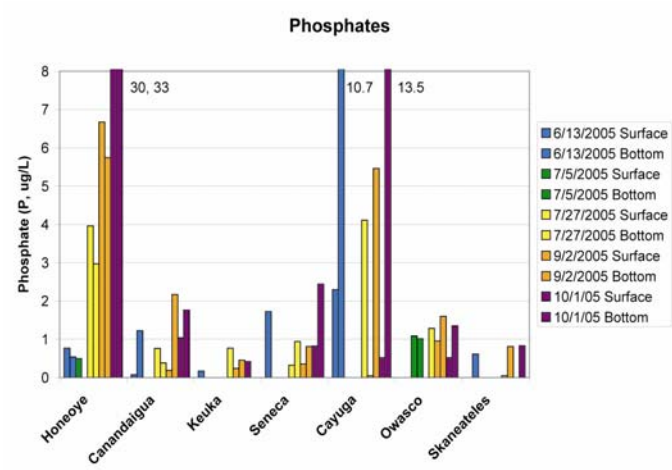


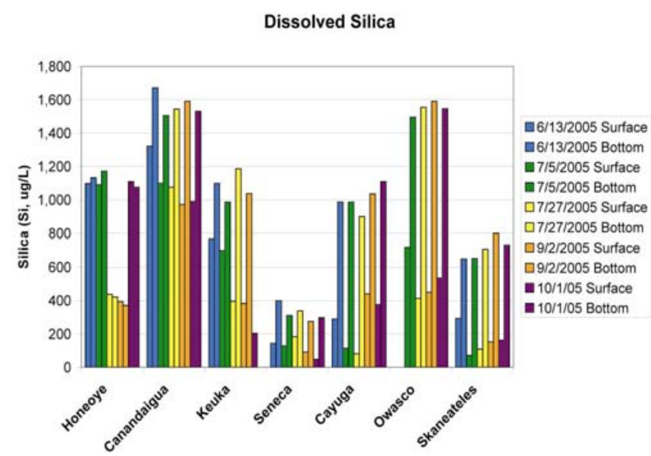
Canandaigua Lake. Turbid zones were observed in the lower metalimnion through upper hypolimnion of Skaneateles Lake. We speculate that the source and magnitude of the surface and near surface turbid zones are autochthonous and the extent of the turbidity is proportional to plankton biomass. These interpretations are consistent with TSS and chlorophyll-a data. 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. The nepheloid layers were best developed in Cayuga Lake with light transmission values starting to decrease from background values of 60% ~20 m above the lake floor, decreasing to 30% (maximum turbidities) just above the lake floor. We speculate 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. We also speculate that the benthic nepheloid layers are not present in Seneca Lake because the larger salinities in Seneca Lake prevent density current emplacement of the suspended sediments. Alternatively, the relatively shallow depth of the deepest site (110 m) compared to the maximum depth of the lake (200 m) may have missed its nepheloid layer.

Bacteria Data: Both total coliform and *E. coli* bacterial concentrations were well below the EPA maximum contaminant levels (MCLs) for Class AA drinking water. The majority of the total coliform counts were below 50 CFUs/100mL, *E. coli* counts were below 5 CFUs/mL, and the results did not reveal any significant trends within each lake. Between lakes, Owasco and Honeoye Lakes revealed the largest counts while Keuka, Cayuga and Skaneateles Lakes revealed the smallest counts.

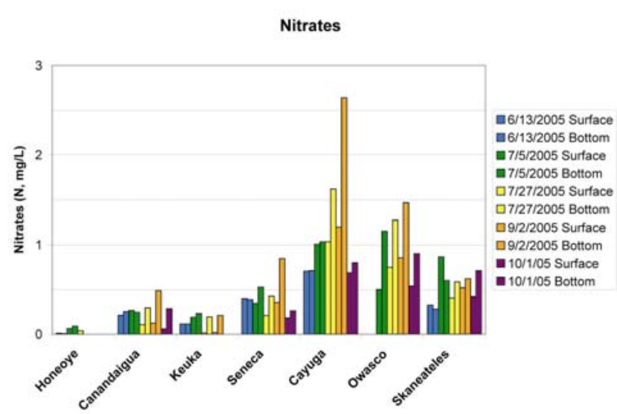








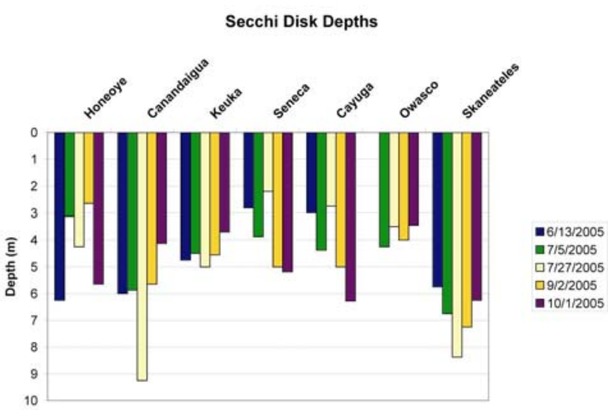
Nutrient Data: Nitrate concentrations were largest in Cayuga, Owasco, Seneca and Skaneateles Lakes (0.5 to 2.5 mg/L), and smallest in Canandaigua, Keuka and Honeoye Lakes (0.2 to 0 mg/L). Bottom water samples had more (up to 1 mg/L) nitrates than surface water, especially in the September samples. The abundant nitrate suggests that it is not the limiting nutrient in all of the surveyed lakes except for Honeoye Lake. Input of nitrate from agricultural activities, municipal wastewater treatment facilities, septic systems, and atmospheric fallout (acid rain) are probably sources of excess nitrate in the Finger Lakes.

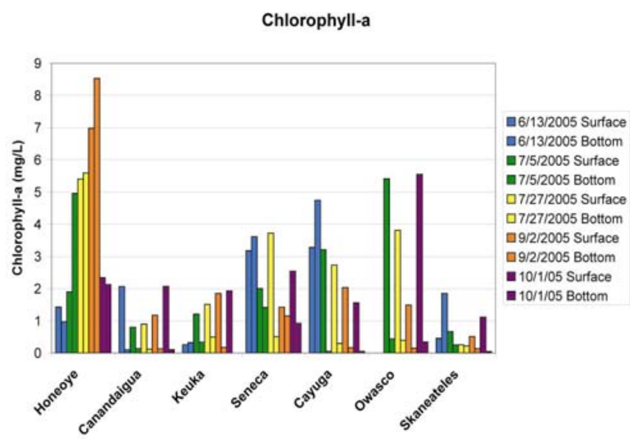


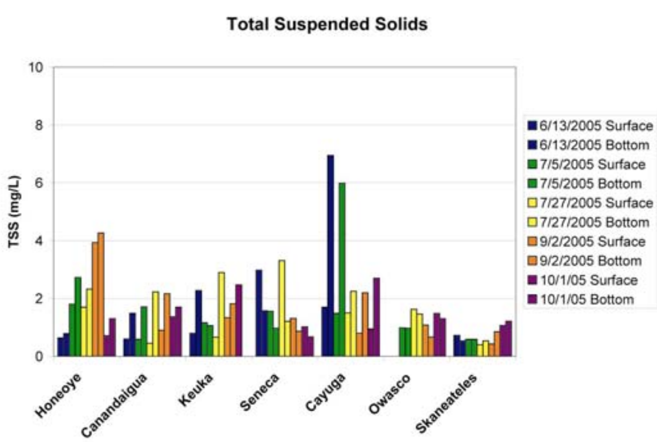
Soluble reactive phosphate (SRP) concentrations were largest in Honeoye Lake. Except for a few isolated larger values, the measured phosphate concentrations were below 1.0 ug/L in the other lakes. The largest concentrations were typically detected in the hypolimnion. Concentrations were always very low, i.e., near or below detection, in Skaneateles Lake. The limited phosphate availability in Honeoye Lake suggests that phosphate rather than nitrate is the limiting nutrient in all but Honeoye Lake.

Surface water soluble reactive silica (SRSi) concentrations were largest in Canandaigua (1100 ug/L), Honeoye (800 ug/L) and Keuka Lakes (550 ug/L), and smallest in Seneca (150 ug/L) and Skaneateles (150 ug/L) Lakes. Bottom water silica concentrations were typically larger than the surface waters and Owasco Lake revealed the largest increase (525 to 1550 ug/L). Interestingly, dissolved silica concentrations in Honeoye Lake were larger in June (~1000 ug/L) and smallest in July and September (400 ug/L), whereas phosphate concentrations were smallest in June (< 1.0 ug/L) and largest in July and September (4 ug/L).

Secchi Disk, Chlorophyll-a, TSS Data: Date averaged secchi disk depths were deeper in Canandaigua and Skaneateles Lakes (~7 m), and shallower in Cayuga, Owasco, Honeoye and Seneca Lakes (~4 m). This data mimicked variability in chlorophyll-a concentration between







lakes (an average 5 mg/L in Honeoye to < 1 µg/L in Skaneateles Lake) and variability in TSS data (an average of 2.5 mg/L in Honeoye to < 1 mg/L in Skaneateles Lake). Average chlorophyll-a concentrations were larger in surface water than in bottom water samples for all the lakes except for Honeoye. Average TSS concentrations were larger in the surface water for Honeoye, Owasco, and Seneca Lakes, perhaps reflecting the larger surface water algae concentrations in these lakes, and larger bottom water turbidities in the other lakes as suggested by the light transmission profiles.

Discussion

These lakes exhibit a range of water quality results. In general, Skaneateles, Canandaigua and Keuka Lakes revealed the best water quality, as defined by the lowest bacteria counts, nutrient concentrations, and chlorophyll-a concentrations, and deepest secchi disk depths. Honeoye, Owasco and Seneca Lakes revealed the worst water quality, and Cayuga Lake falls between the two end-member populations. None of the Finger Lakes surveyed are significant health threats. , water quality should be improved in the worst cases before they become significantly degraded.

A qualitative water quality ranking (1 – 7, best to worst water quality) was estimated from the total coliform, *E. coli*, phosphate, nitrate, chlorophyll-a and secchi disk data to assess the significance of the variability between lakes. To estimate the ranking, the average for each water quality parameter from each lake's surface water sample was calculated, and then normalized on a scale of 1 to 7. For example, the normalized ranking for chlorophyll in Honeoye Lake was 6.2 and was calculated by dividing its 2005 average surface chlorophyll-a concentration (3.6 ug/L) by the largest 2005 average surface chlorophyll-a concentration (4.1 ug/L). Then, each lake's rank was estimated from the average of the individual water quality rankings. These rankings were then normalized on a scale of 1 to 7. The exercise yields the following water quality ranking from best to worst:

Best Water Quality (least bacteria, nutrients, chlorophyll, and deepest secchi depths)

1. Skaneateles (1.5)
2. Canandaigua (1.6)
3. Keuka (2.5)
4. Cayuga (4.3)
5. Honeoye (5.8)
6. Seneca (6.4)
7. Owasco (7.0)

Worst Water Quality (most bacteria, nutrients, chlorophyll, and shallowest secchi depths)

This order does not change when any one of these water quality parameters is excluded from the average ranking, in that, Skaneateles, Canandaigua and Keuka always have the best water quality; Honeoye, Seneca and Owasco always have the worst water quality; and, Cayuga Lake is in between, although the position within the "best" and "worst" end-member populations changes slightly. The bottom waters in Honeoye Lake become anoxic during calm periods in the late summer months, positioning this lake as the most eutrophic of the three worst lakes. The data presented here places Owasco and Seneca as mesotrophic lakes (in between oligotropic and eutrophic systems).

The relatively poor water quality in Honeoye, Seneca and Owasco Lakes is a concern, even though Seneca and Owasco are not eutrophic at the present time. Water quality degradation in both Honeoye and Owasco Lakes have stimulated local and state agency interest and concern due to changing plankton communities and the impact on drinking water, weed growth, fish populations and other concerns, and debate is currently under way on how best to improve the water quality. Water quality degradation has been noticed by concerned citizens in the Seneca Lake watershed, but it has not stimulated as much concern at the regulatory level. This lack of concern is disturbing because Seneca Lake contains 50% of the water in the Finger Lakes, and has the longest water residence time of the Finger Lakes (20 years vs. a few years). If nothing is done to improve water quality in Seneca Lake, then it will become eutrophic for generations.

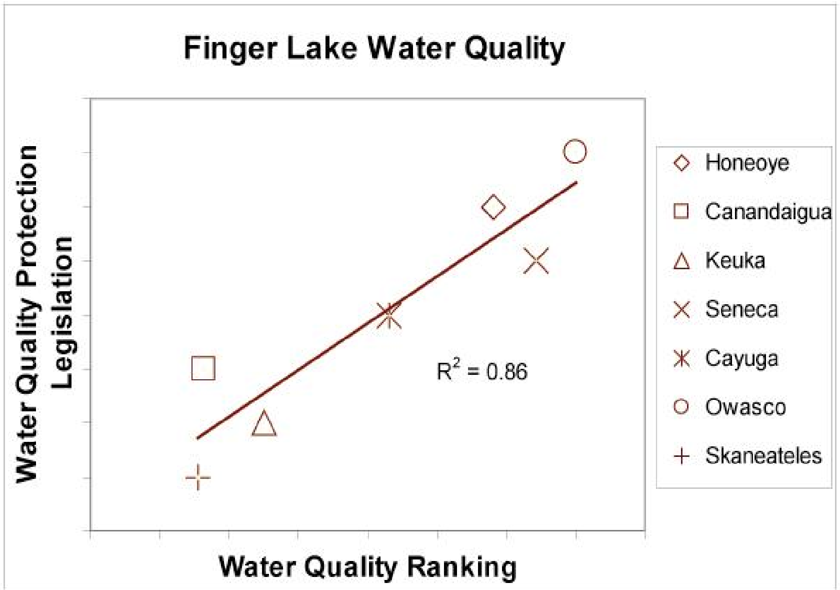
Water Quality Protection Legislation

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 onsite wastewater treatment (e.g., septic systems). However the application of the more recent regulations is not state-wide.

The Catskill Watershed Cooperation (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.

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 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 Watershed Council utilizes BMPs and other agricultural programs to control runoff issues. Seneca Lake Pure Waters Association and the Genesee/Finger Lakes Regional Planning Council use public education and other rather vague county programs to protect the Seneca Lake Watershed. For the purpose of this report, we estimated a first-order approximation of the degree of legislative "protection" between each watershed from best (most protective) to worst (least protective):

1. Skaneateles (least productive & most protective)
2. Keuka
3. Canandaigua
4. Cayuga
5. Seneca
6. Honeoye
7. Owasco (most productive & least protective)



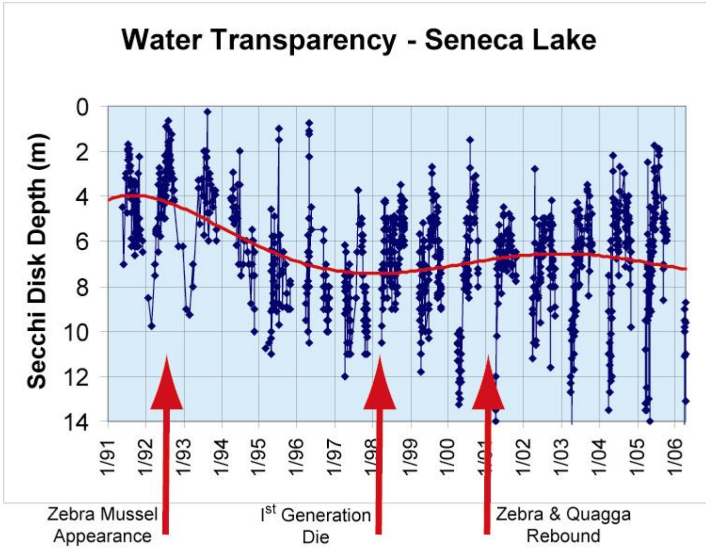
Please note, this ranking is our preliminary attempt, and we believe it will change as we learn more about the effectiveness of specific legislation in each watershed and as various watersheds adopt more stringent legislation. We also believe that our list of legislation is not exhaustive. However, our list provides a starting point to open the dialogue between watersheds, for each to find ways to improve water quality, and preserve this precious resource for years to come.

Does legislation improve water quality? Our preliminary water quality ranking correlates (r^2 = 0.86) to our best estimate of the degree of legislative protection, and suggests that water quality can be improved in some of the worst lakes through a more uniform adaptation of existing water quality protection legislation.

This water quality-to-legislative protection correlation is consistent with research at Conesus Lake. The implementation of BMPs in selected subwatersheds has reduced the flux of bacteria and nutrients to the lake (Makarewicz, 2002). This study implemented BMP control measures in selected subwatershed and compared the flux of bacteria and nutrients between these “improved” subwatersheds to historical data, and unaltered subwatershed and forested subwatersheds. Water quality improved in subwatersheds with BMP measures, although the degree of improvement was dependent on the actual BMP utilized in the subwatershed. Therefore, the correlation between the water quality data and degree of protection presented in this study suggests that the entire region should adapt uniform and stringent legislation to protect and preserve these natural resources for future generations.

Historically, water quality has improved in the Finger Lakes since the 1970s. Historical chlorophyll and secchi dick data (historical nutrient and bacterial data are not available) reveal smaller chlorophyll and deeper secchi disk depths from 1970s to the 1990s but typically minimal change since 1990s to 2005 (1970 and 1990 data from Callinan, 2001). The improvement in water quality since the 1970s probably reflects better wastewater treatment and the ban on phosphates in soaps implemented in the 1970s.

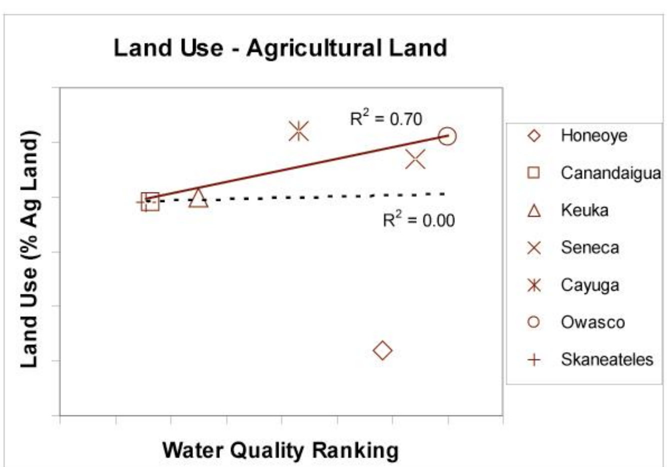
Other factors could influence the water quality parameters, however. For example, the introduction of the zebra mussel has increased water clarity, decreased algal concentrations and modified nutrient concentrations in Seneca Lake. Specifically, secchi disk depths increased since the introduction of zebra mussels in 1992 by 6 to 8 meters to maximum depths in 1998, only to rebound by a few meters afterwards. These water clarity trends are inversely



proportional to the observed changes in chlorophyll concentrations. Thus, it is possible that the introduction of zebra mussels and more recently quagga mussels has had a greater influence on water quality since the early 1990s than changes in legislation. Extrapolating to other Finger Lakes is difficult at this time because the degree of change in water quality trends reflects the timing of the zebra mussel introduction, which has varied between lakes and the extent of the increase in water clarity by their filter feeding.

Potential Causes of Water Quality Degradation

Nutrient runoff from agricultural land, improper disposal of organic wastes, and other land use practices can degrade water quality. To test a potential nutrient runoff to water quality relationship, the percentage of agricultural land within each watershed was plotted against the watershed's average water quality ranking. When all of the lakes are taken into account, no correlation ($r^2 = 0.00$) is observed. However, when Honeoye Lake is removed from the analysis, a correlation ($r^2 = 0.70$) is observed. Removing Honeoye Lake is plausible because Honeoye is nitrogen limited and not phosphorus limited as in the other lakes, Honeoye is significantly shallower than the other lakes, and historically its watershed was heavily agricultural until the fields were abandoned and overgrown with forests. Nutrient loading by the earlier agricultural activities has perhaps remained in Honeoye Lake as nutrients are effectively recycled and not lost in aquatic ecosystems. Perhaps stricter BMPs are required for the remaining 6 Finger Lakes to reduce nutrient loading from agricultural regions. Please note: a correlation does not dictate causation.



We lack suitable field data to assess the impact of organic wastes on the water quality ranking. However, a number of older wastewater treatment plants release significant quantities of nutrients to nearby watersheds. We suspect a correlation does exist between the disposal/treatment of human wastes and the water quality rankings estimated above, especially from those watersheds with a higher concentration and/or higher percentage of on-site systems and municipal systems with only primary and secondary treatment. The relative contribution of human wastes to water quality degradation requires further study.

Data are also insufficient to assess the impact of land use activities by lakeside residents. For example, a highly manicured lawn surrounding a year-round, lake-side home will probably release more nutrients to the lake than a rustic, lawn-free, summer cabin. This too requires additional study to assess its impact.

Conclusions, Recommendations & Future Research

Water quality varies across the seven Finger Lakes and range from oliogotrophic to eutrophic systems. Skaneateles, Canandaigua and Keuka Lakes are the oligotrophic end members and exhibit the best water quality, whereas Seneca, Owasco and Honeoye are the mesotrophic/eutrophic end members and exhibit the worst water quality. Cayuga Lake lies between these two groups.

The "worst" status of Honeoye, Seneca and Owasco Lakes is a concern, and steps should be taken to improve water quality in these lakes. Of special concern is Seneca Lake because it contains 50% of the water in the Finger Lakes; and, once Seneca Lake is degraded, it will stay degraded for generations due to the multi-decade water residence time.

Our preliminary water quality ranking correlates ($r^2 = 0.86$) to our first-order ranking of the degree of legislative protection, and suggests that water quality can be improved in some of the worst lakes through a uniform adaptation of the most stringent water quality protection legislation. All of the Finger Lakes could probably benefit if they adapted the legislation utilized in the Catskill region.

Current water quality protection legislation and the degree of enforcement within each watershed require more thorough scrutiny.

Future research should include total nutrient assays, especially total phosphate concentrations, in order to assess recent trends from the historical phosphate data, and to better assess the nutrient dynamics in each lake. More data are required to assess changes in water quality over time, and assess the impact of other time-sensitive influences on water quality, like zebra mussels.

Finally, more research should investigate the relative impact of the various non-point source pollutants in the region, thus dictating which source(s) require(s) the most legislative effort to improve water quality for the future.

Acknowledgements

The research was supported by grants from Hobart & William Smith Colleges, the Kloman Foundation, The Environmental Research Fund, the JB Snow Foundation, and the Mellon Foundation. We thank Captain John Nichols and John Abbott for professional service on the William Scandling. We thank Ian West, Rachel Sukeforth, and many other undergraduate students for assistance in the field and laboratory.

Data:

Summary: Finger Lakes Data

2005 Average Values (1s)	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	0.3 ± 0.3	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
pH, Surface	8.4 ± 0.3	8.6 ± 0.2	8.4 ± 0.3	8.6 ± 0.4	8.5 ± 0.4	8.4 ± 0.3	8.5 ± 0.3
pH, Bottom	8.3 ± 0.2	8.2 ± 0.2	8.1 ± 0.2	8.3 ± 0.3	8.1 ± 0.2	8.0 ± 0.2	8.3 ± 0.3
Alkalinity (ppm, CaCO3), Surface	73.9 ± 5.3	116.6 ± 14.1	89.0 ± 8.2	95.9 ± 16.9	107.6 ± 17.8	109.9 ± 7.8	100.0 ± 6.9
Alkalinity (ppm, CaCO3), Bottom	76.1 ± 4.2	125.6 ± 24.6	88.9 ± 11.3	101.6 ± 14.3	110.6 ± 10.3	117.5 ± 6.3	104.5 ± 9.3
IC - Sodium (Na, mg/L) Surface	12.1 ± 2.1	16.5 ± 2.1	14.3 ± 4.6	81.1 ± 5.9	25.8 ± 2.4	12.2 ± 1.1	8.9 ± 1.0
IC - Sodium (Na, mg/L) Bottom	11.5 ± 1.3	17.2 ± 1.6	13.4 ± 0.8	82.5 ± 4.8	25.5 ± 2.4	12.0 ± 1.4	9.0 ± 1.2
IC - Potassium (K, mg/L) Surface	1.1 ± 0.2	1.8 ± 0.2	2.0 ± 0.2	2.5 ± 0.3	2.1 ± 0.2	1.4 ± 0.2	1.4 ± 0.6
IC - Potassium (K, mg/L) Bottom	1.1 ± 0.1	1.9 ± 0.2	2.1 ± 0.2	2.6 ± 0.2	2.1 ± 0.2	1.5 ± 0.2	1.3 ± 0.2
IC - Magnesium (Mg, mg/L) Surface	7.0 ± 1.0	10.7 ± 1.2	9.0 ± 0.8	9.9 ± 1.1	10.3 ± 1.0	8.5 ± 1.2	7.9 ± 0.5
IC - Magnesium (Mg, mg/L) Bottom	6.6 ± 0.6	11.0 ± 0.8	9.0 ± 0.8	10.2 ± 0.7	10.3 ± 1.1	8.6 ± 1.2	7.9 ± 0.5
IC - Calcium (Ca, mg/L) Surface	25.0 ± 4.5	38.6 ± 4.9	31.7 ± 3.1	37.3 ± 3.6	40.6 ± 4.1	38.3 ± 3.9	38.9 ± 3.7
IC - Calcium (Ca, mg/L) Bottom	23.5 ± 3.0	42.2 ± 3.9	31.7 ± 3.4	41.4 ± 2.9	44.6 ± 3.5	45.4 ± 5.5	40.6 ± 4.0
IC - Chloride (Cl, mg/L) Surface	17.8 ± 5.6	28.6 ± 2.1	24.6 ± 6.0	129.2 ± 8.6	42.6 ± 0.6	21.6 ± 7.4	13.8 ± 0.7
IC - Chloride (Cl, mg/L) Bottom	18.2 ± 0.8	29.0 ± 1.2	20.2 ± 5.7	129.6 ± 2.0	43.3 ± 0.6	18.7 ± 0.8	13.8 ± 0.4
IC - Sulfate (SO4, mg/L) Surface	11.0 ± 4.8	22.8 ± 0.7	22.8 ± 2.8	36.6 ± 3.8	31.0 ± 0.8	14.8 ± 3.1	15.8 ± 0.2
IC - Sulfate (SO4, mg/L) Bottom	11.0 ± 0.7	23.2 ± 0.4	19.9 ± 5.2	36.8 ± 0.4	30.8 ± 0.6	13.9 ± 0.7	16.0 ± 0.2

2005 Average Values (1s)	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
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
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	0.3 ± 0.3	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

2005 Ranking	Honeoye	Canandaigua	Keuka	Seneca	Cayuga	Owasco	Skaneateles
Secchi Depth (m)	2.5	0.7	2.5	3.2	2.5	3.1	0.0
Phosphate (µg/L, SRP), Surface	7.0	0.3	0.2	0.6	0.4	0.5	0.0
Nitrate as N (mg/L), Surface	0.2	1.1	0.5	2.2	7.0	4.9	3.8
Chlorphyll a (µg/L), Surface	6.2	2.5	2.3	4.5	4.3	7.0	1.1
Total Coliform (colonies/100mL), Surface	2.8	0.9	1.8	4.7	0.8	7.0	0.5
E. coli (colonies/100mL), Surface	1.5	0.1	1.4	7.0	0.0	1.8	0.0

	Honeoye	Canandaigua	Keuka	Seneca	Cayuga	Owasco	Skaneateles
Mean Ranking	3.4	0.9	1.4	3.7	2.5	4	0.9
Normalized to 7	5.8	1.6	2.5	6.4	4.3	7	1.6