A Preliminary Water Quality Study of Owasco Lake, NY, and its Watershed.

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Introduction

The Finger Lakes in western and central New York State are critical to the health, well-being and economy of the region. Created by glacial ice and melt-water erosion approximately 15,000 years ago, all eleven Finger Lakes: Conesus, Hemlock, Canadice, Honeoye, Canandaigua, Keuka, Seneca, Cayuga, Owasco, Skaneateles, and Otisco, contain approximately 8 trillion gallons of water (30.8 km^3), and occupy a 2,630 square mile (4,970 km^2), 14-county region. These lakes are a source of Class AA drinking water to the 1.5 million residents in the surrounding communities and nearly 200 million gallons of water per day is withdrawn from the Finger Lakes. For example, Skaneateles and Otisco provide drinking water for the City of Syracuse; Hemlock and Canadice provide drinking water for the City of Rochester; and, Seneca Lake provides drinking water for nearly 100,000 local residents. Tourism and water-based recreation, sport fisheries, wildlife habitat, and a diverse industrial and agricultural sector, including an internationally known winery industry, comprise the important economic, social, ecological and occasionally environmentally competing attributes within these watersheds.

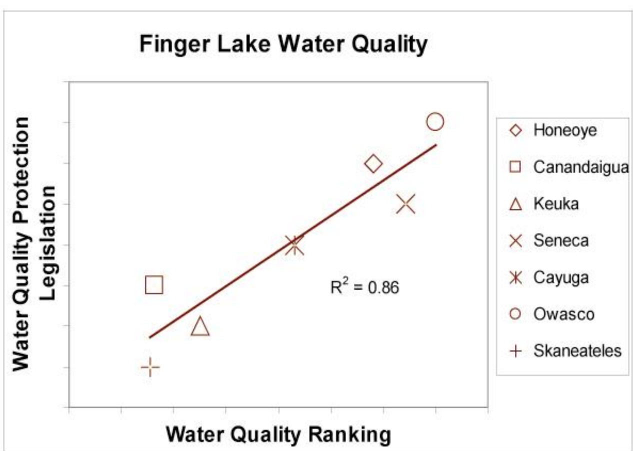


Fig. 1. The 2005 water ranking of seven Finger Lakes.

Unfortunately, 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 Clean Water Act Section 303-D List.

A 2005 water quality survey, under the direction of Dr. John Halfman, Finger Lakes Institute, Hobart and William Smith Colleges, ranked water quality parameters from the seven central Finger Lakes and determined that Owasco, Honeoye and Seneca Lakes had the worst water quality, whereas Skaneateles, Canandaigua and Keuka Lakes had the best water quality and Cayuga was in between these end-members (Fig. 1., Halfman and Bush, 2006). The ranking was based on the analysis of monthly surface and bottom water samples from at least two mid-lake sites in each lake, analyzing water samples for total coliform and *E. coli* bacteria, algae concentrations (chlorophyll-a), nutrient concentrations (dissolved phosphates, nitrates and silica), suspended sediment concentrations, and water transparency measured by secchi disk depths. The preliminary report noted a correlation between the ranking and the degree of water quality protection legislation. However, more study is required to determine the significance of this correlation as it may alternatively reflect, for example, land use activities and/or the impact of recent exotics like zebra and quagga mussels. The continuation of this water quality comparison in 2006 indicated that Owasco remained within the most impaired group of lakes (2006 report pending).

Owasco Lake is one of the smaller Finger Lakes but it is still critical to the local health, well-being and economy of its watershed and surrounding region. It has a volume of 0.78 km^3, surface area of 26.7 km^2, length of 17.9 km, maximum depth of 54 meters, and watershed area of 470 km^2 (Bloomfield, 1978; Mullins et al., 1998). It provides Class AA drinking water for the City of Auburn, Town of Owasco and lakeshore residents with total permitted withdrawals of 16 million gallons of water per day. The lake is also essential for the economic and social structure of the region supporting a tourism and agricultural-based economy, water-based recreation and other attributes. Finally, Owasco has the largest watershed surface area to lake volume ratio (17:1) of the Finger Lakes. The large ratio plays a critical role in the lake's short water residence time of 1 to 3 years (Callinan, 2001). It suggests that the lake is quickly influenced by runoff and associated pollutant threats from the watershed, but also may more quickly respond to remediation efforts to improve water quality in the lake.

An award from the Fred L. Emerson Foundation, Auburn, NY, enabled an expansion of the Finger Lakes water quality survey to include a detailed investigation of Owasco Lake and its watershed. The objectives for this closer look were to:

(1) establish consistent and comprehensive monitoring to document spatial and temporal trends in nutrient concentrations and other water quality parameters in the lake;
(2) bring particular focus to the extent and sources of nutrients from the watershed to the lake and associated watershed-lake interactions; and,
(3) promote the development of effective and comprehensive watershed management policies to initiate the remediation of Owasco Lake.

This mid-project report focuses on a first-order interpretation of the results from the 2006 field season. The goals are to:

(1) summarize the 2006 Owasco Lake and watershed data, and provide a snapshot of the ecological health and water quality within the watershed;
(2) investigate potential linkages between water quality and sources of pollution; and,
(3) suggest remediation strategies to eventually improve water quality in Owasco Lake and better preserve this critical natural resource for future generations.

Water Quality:

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 the outlet from a municipal wastewater treatment plant, a factory drain pipe, or power plant cooling-water outflow. Typically point source pollutants are easier to regulate, monitor, and control. For example, the discharge of municipal wastewater effluent is regulated by New York State Pollutant Discharge Elimination System (SPDES). These permits are designed to minimize the health risks to humans by maintaining water quality standards, and balance economic considerations. Non-point source pollutants are more diffuse; examples include runoff from the application of road salt or fertilizer. Non-point source pollutants are more difficult to regulate, monitor, and control, but are becoming the focus of recent EPA and State 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, soils, 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 in high population density areas and individual onsite wastewater systems in low population density areas (e.g., a rural septic system). All of these systems are designed to remove the solid and dissolved organic materials from the wastewater by settling out the particulates and utilizing bacterial respiration to decompose the dissolved organics, but occasionally these systems fail and discharge raw sewage into a nearby waterway. Aerobic bacterial respiration converts the organics into carbon dioxide (colorless and odorless) and dissolved nutrients. Some systems will then discharge the nutrient-rich effluent to the environment, whereas larger municipal systems and more sophisticated onsite systems will take additional steps to chemically remove the nutrients before discharging the “treated” wastewater to the environment. In a similar light, the disposal of organic wastes from confined animal feeding operations (CAFOs) and other forms of animal husbandry is a concern. Runoff from agricultural land is known for sediment and fertilizer/pesticide-rich water, and current legislation attempts to control these pollutants through various “best management practices” (BMPs). Contour plowing, settling ponds, buffer vegetation strips, minimal tillage farming, manure digesters, and other BMPs can reduce agricultural impact on nearby waterways but always at a cost to the farmer.

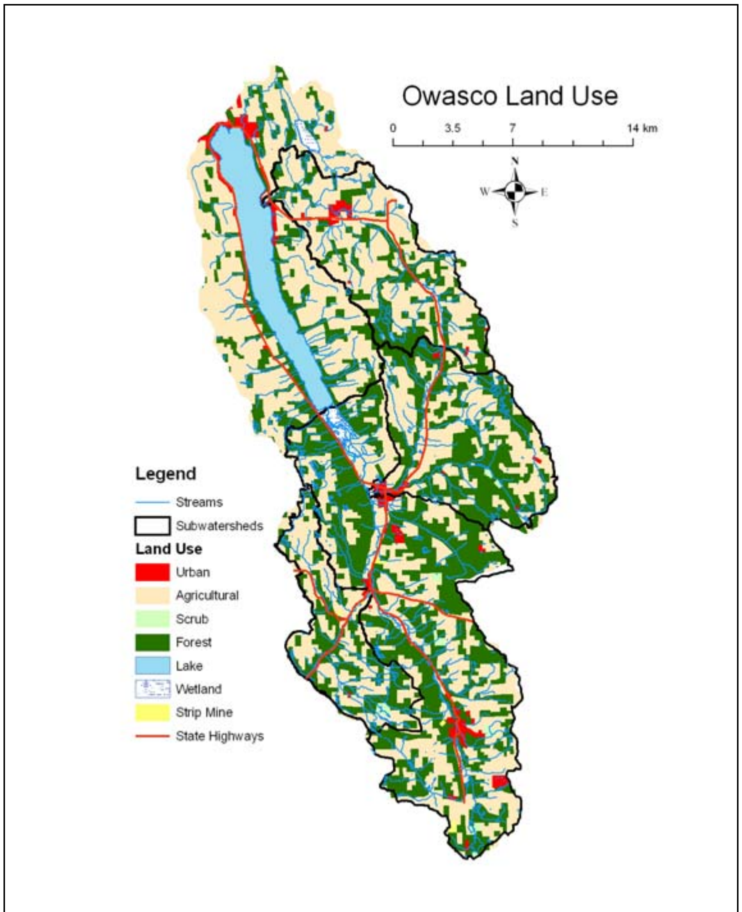


Fig. 2. Lake sites.

Water Quality Indicators

The Owasco watershed is dominated by a rural landscape with a mix of forested (39%) and agricultural (52%) land, and smaller amounts of urban and other areas (Fig. 2). The land use suggests that the primary water quality threats are nutrients generated from organic wastes and agricultural runoff, and its stimulation of excessive algal and near-shore plant growth. These issues are interrelated and are therefore the focus of this report. Indicators of water bodies impaired by nutrient loading are also indicators of eutrophication. They include high concentrations of nutrients, algae, and diminished water clarity.

Nutrients are critical for life. Due to their scarcity in lakes, lake ecosystems are extremely well adapted to recycle the available nutrients. In a basic aquatic nutrient cycle (Fig. 3), nutrients dissolved in the water are assimilated by plants (algae and near-shore plants) through photosynthesis and converted into amino acids, proteins, cell tissue, RNA and DNA, and other critical compounds. When the algae are eaten, these organic compounds are passed up the food chain to other organisms like zooplankton and lake trout. When any of these organisms die, bacteria decompose the organic material and release almost all of the nutrients back into the water column to be assimilated by plankton and other plants once again.

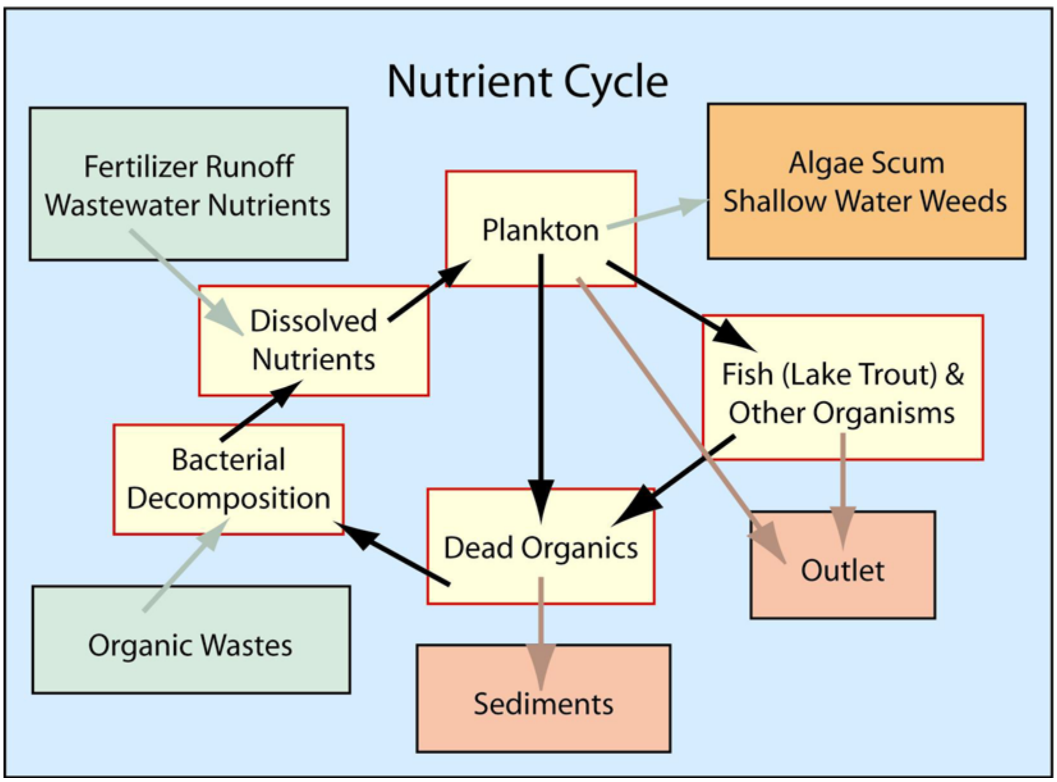


Fig. 3. A typical nutrient cycle for lake ecosystems (yellow boxes). Typical human-induced additions (green boxes) to, their impact (orange box), and natural sinks (red boxes) from the nutrient cycle are also shown.

Dissolved nutrients (nitrate, phosphate and silica) enter nearby waterways from a variety of natural and human-induced sources. Natural sources include the weathering of bedrock, erosion of soils, and even within rainwater. The human-induced sources include municipal wastewater treatment plants, onsite wastewater systems, runoff from agricultural areas, runoff from manicured lawns and other sources, and are water quality concerns because they can over "fertilize" a lake and make it more productive, i.e., more eutrophic.

Thus, nutrient loading can potentially transform an oligotrophic (poorly productive) lake to a eutrophic (highly productive) lake, where the extra nutrients stimulate additional algal (microscopic aquatic plants), macrophyte (near-shore rooted plants) and other plant growth. If the aquatic system becomes eutrophic, then a foul smelling/tasting scum of blue-green algae typically dominates the base of the food chain and covers the surface of the lake. The population increase of algae decreases water clarity (transparency), as the extra algae impede the transmission of light through water. When the algae die (algae live for only a few days), then bacteria naturally decompose the organic material. The decomposition process consumes dissolved oxygen from the bottom waters and recycles the nutrients back into the environment. If the removal of oxygen from the summer-time bottom waters (below the thermocline) is severe enough (somewhere below 6 mg/L, as each species has its own level of tolerance), it will place respiratory stress on all aquatic animals like lake trout, crawfish and worms, because dissolved oxygen is needed to survive. Complete de-oxygenation of the bottom waters in eutrophic lakes induces fish kills, and may release a "rotten egg" odor cause by the bacterial mediation of hydrogen sulfide. Eutrophic systems also increase the need and difficulty to filter algae out of the water for municipal drinking supplies. Unfortunately once perturbed, aquatic ecosystems typically remain perturbed because the nutrients are continually and efficiently recycled in the ecosystem, and continue to "fertilize" plant growth at enhanced levels. Anoxic bottom waters also allow phosphates, previously stored in the sediments as particles in oligotrophic systems, to dissolve and enter the water column.

Excess nitrates also induce health risks to humans, specifically methemoglobinemia or blue-baby syndrome. The EPA has set 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 do contribute to the fertilization and eutrophication of waterways. Phosphate is critical for the eutrophication of most temperate lakes because it is typically the limiting nutrient for algal growth. Dissolved silica is an additional nutrient required by diatoms, a form of algae found in most lakes, to form their frustules (shells).

Algal concentrations, measured directly by the concentration of chlorophyll, and indirectly by total suspended solid concentrations, and secchi disk depths, are indicators of water clarity, lake productivity, and the ecological health of a lake. Chlorophyll content is a direct measure of algal concentrations, as all algae utilize chlorophyll to harness energy from sunlight to perform photosynthesis. The total suspended solids (TSS) analysis filters a known volume of water and measures the mass of the filtered material. Thus TSS data measure everything suspended in the water column, both algae and sediments. 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) secchi disk depths can be 100 feet (30 m) or more in ultra-oligotrophic (low productivity) systems. Whereas in eutrophic (highly productive) systems like ponds on farms, secchi disk depths can be as shallow as a few centimeters. Secchi disk depths however, are also influenced by suspended sediments delivered by streams or resuspended by waves and currents. Careful comparison of these parameters differentiates if the impairment to water clarity is due to algae, suspended sediments, or both.

Typically, a combination of nutrient concentrations, algal concentrations, secchi disk depths, and dissolved oxygen concentrations are utilized to document the degree of eutrophication and water quality degradation in aquatic systems (Table 1).

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

Trophic Status	**Secchi Depth (m)**	**Total Nitrogen (N, mg/L, ppm)**	**Total Phosphate (P, μg/L, ppb)**	**Chlorophyll a (μg/L, ppb)**	**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

Hope exists. Poor water quality can be reversed because nutrients can be removed from a lake. Common removal mechanisms include the loss of nutrients and organisms through an outlet or burial of organic matter into the sediments before bacteria completely recycles the nutrients back to the water column. For Owasco Lake, the natural flushing or residence time of water is short, ~1 to 3 years, and significantly faster than the other Finger Lakes. It suggests that the outlet transfers an important fraction of the dissolved nutrients and organic matter out of the lake.

Therefore, if the sources of nutrients to the lake are reduced so that the sources (inputs) are well below the removal mechanisms (outputs), then the amount of nutrients in the lake will be smaller over time, and as a consequence, water quality in the lake will improve over time. Please note: Nutrient inputs must be consistently and persistently below the outputs on decade time-scales to reduce the amount of nutrients in a lake.

Table 2. Site locations and maximum water depths.

Site Name	**Latitude**	**Longitude**	**Water Depth**
Site A	42° 53.9' N	76° 32.25' W	6 m
Site 1	42° 52.4' N	76° 31.35' W	34 m
Site B	42° 51.6' N	76° 30.7' W	16 m
Site C	42° 50.35' N	76° 30.85' W	50 m
Site 2	42° 49.15' N	76° 30.45' W	52 m
Site D	42° 47.1' N	76° 29.0' W	45 m
Site CC1	42° 45.9' N	76° 28.35' W	29 m
Site CC2	42° 45.7' N	76° 32.2' W	18 m
Site E	42° 45.5' N	76° 28.0' W	3 m
Site CC3	42° 45.5' N	76° 28.2' W	2 m
Site CC4	42° 45.75' N	76° 27.85' W	2 m

2006 Methods

Lake Samples: Site selection in the lake focused on spatial coverage and potential pollutant sources to the lake (Table 2, Fig. 4). The first six sites (1 & 2, A, C – E) were distributed mid-lake, along the elongated, north-south axis of the lake starting just offshore of the outlet (Site A) and extending just offshore of the Owasco Inlet (Site E). One additional site was offshore of Dutch Hollow Creek (Site B), and four additional sites were clustered at the southern end of the lake (Sites CC1 – CC4), just offshore of Owasco Inlet at the recommendation of NYS DEC. Water quality samples were collected from surface and bottom water depths at Sites 1 & 2, sites used for the Finger Lakes Institute's, Finger Lakes comparative water quality survey. Surface water samples were collected from the other sites. All sites were sampled every two to three weeks from May through October, 2006. Sample dates and precipitation totals for Ithaca, NY are shown at the end of this report.

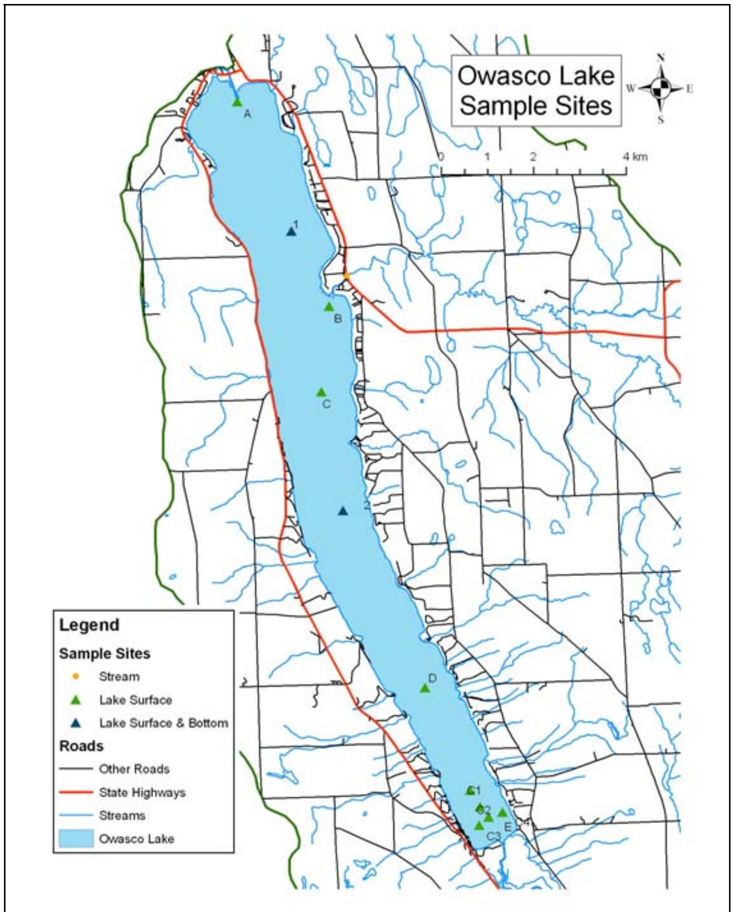


Fig. 4. Lake sites.

A CTD water quality profile, secchi disk depth, plankton tows, and water samples were collected at each site. Water quality profiles of temperature (°C), conductivity (specific conductance, μS/cm), light transmission (log-proportional to water clarity, %, and inversely log-proportional to water turbidity), dissolved oxygen (ml/L) and pH were collected electronically using a SeaBird SBE-19 CTD, which was lowered from the surface to ~1m above the lake floor. Water samples were collected and analyzed onsite for temperature (°C), conductivity (specific conductance, μS/cm), dissolved oxygen (ml/L) and pH using hand-held Oakton probes and analyzed back in the laboratory for total phosphate concentrations, dissolved phosphate, nitrate and silica concentrations, chlorophyll-a concentrations, total suspended solids concentrations, and major ions (Na, Ca, Mg, K, Cl, SO_4, Alkalinity). The laboratory procedures are outlined below. Additional water samples were collected for total organic matter, dissolved organic matter, total Trihalomethane potential, total coliform, *E. coli* and fecal bacteria counts, and were analyzed by a commercial laboratory by the Cayuga County Health Department.

Stream Samples: Stream water quality samples were collected from seven sites within the Owasco watershed on a similar schedule, typically on the same day as, or within one day of, the lake samples (Fig. 5). Selection of individual stream sites emphasize watershed size and land use activities, focusing on larger watersheds because they typically deliver more non-point-source pollutants to a lake, and agriculturally-rich watersheds, because they typically deliver more nutrients, soil particles, herbicides and pesticides to a lake. Thus, stream sites were located on Dutch Hollow Creek and Owasco Inlet. Dutch Hollow Creek is the 2nd largest tributary to the lake and it drains an agriculturally-rich landscape (64%), both crop and animal husbandry. Owasco Inlet drains the largest fraction of the Owasco watershed, contains a mixture of agricultural (46%) and forested land, and two wastewater treatment facilities.

The first site was located near the terminus of Dutch Hollow Creek (at Rt. 38A). The other six sites were distributed within the Owasco Inlet watershed along Rt. 38 starting just downstream of Moravia, Locke and Groton, to just upstream of Groton (on Stevens Rd). Two major tributaries to Owasco Inlet, Mill Creek (flows into Owasco Inlet between the Moravia and Locke sites) and Hemlock Creek (flows into Owasco Inlet between the Locke and downstream Groton sites), were also sampled along Rt. 38 just upstream of the tributary's confluence with Owasco Inlet.

Distributing six sites along the Inlet enabled a stream segment analysis, and potential delineation of the probable sources of pollution to the Inlet. The reasoning is simple. The concentration of any pollutant increases downstream from the source of that pollutant. Thus, if the concentration of a pollutant increases from one site to the next downstream site, it indicates that the source of that pollutant, e.g., discharge from a wastewater treatment plant, is somewhere between those two sites. In this case, the site selection bracketed the two municipal wastewater treatment facilities (Groton and Moravia), and sampled the major tributaries to Owasco Inlet for their respective additions to the Inlet.

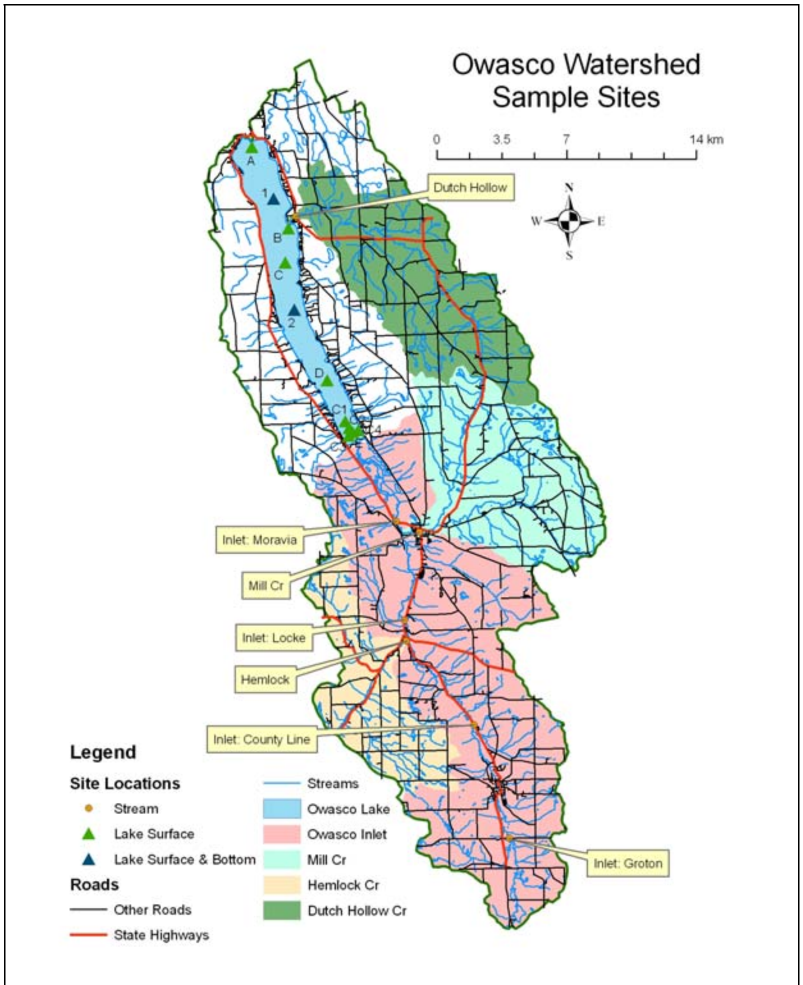


Fig. 5. Stream sites.

Water samples were measured onsite for temperature (°C), conductivity (specific conductance, μS/cm), dissolved oxygen (ml/L) and pH using hand-held Oakton probes. Water samples were also transported to the laboratory and analyzed for nutrients (total phosphate, and dissolved phosphate, nitrate and silica), total suspended solids and major ion concentrations. Most importantly, stream discharge (the volume of water per unit time) was also calculated from stream width, stream velocity (using a Marsh-McBirney flow meter) and stream depth measurements, both velocity and depth were measured at five equally distributed locations across the stream's width at each site.

Laboratory Analyses: Laboratory procedures for nutrient, chlorophyll-a, and total suspended solid concentrations followed standard limnological techniques (Wetzel and Likens, 2000). A known volume of water was immediately filtered through pre-weighed, 0.45 μm glass-fiber filters. The filter and residue were dried at 80°C overnight and the weight gain and filtered volume used to determine the total suspended sediment concentrations (mg/L). Another 1 L of lake water was immediately filtered through a Gelman HA 0.45 μm membrane filter. The filtered residue was kept frozen until chlorophyll analysis, and the filtrate stored at 4°C for soluble reactive (dissolved) phosphate (μg/L), nitrate (mg/L) and silica (μg/L) analyses by spectrophotometer. A third unfiltered, raw water sample was analyzed for total phosphates (μg/L) by spectrophotometer. 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 μg/L, nitrate 0.1 mg/L, and silica 5 μg/L. All water samples were kept at 4°C until analysis.

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

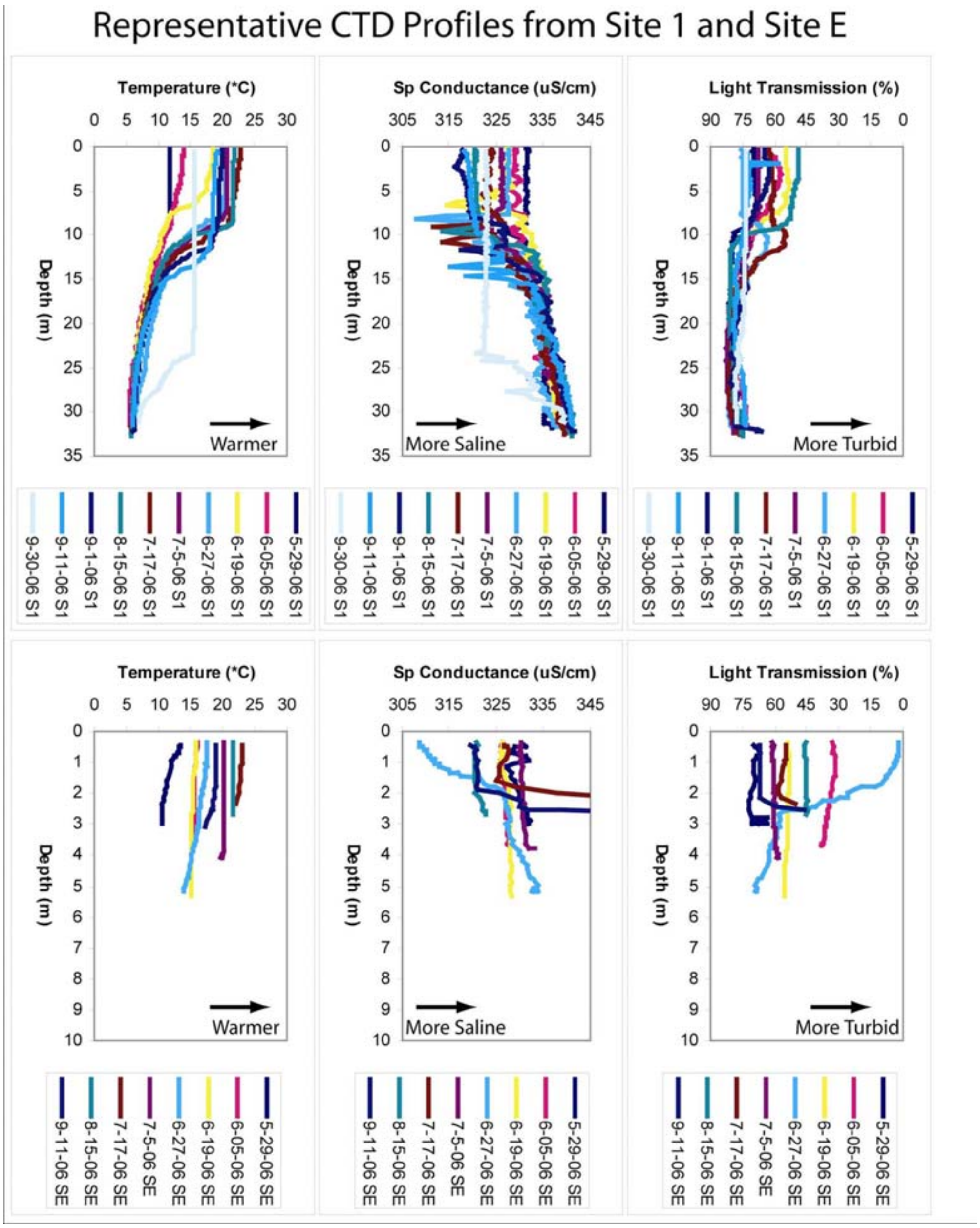


Fig. 6. Representative CTD profiles from Site 1 (open water) and Site E (southern end near Owasco Inlet.

2006 Results

Lake Results

Lake CTD Profiles: The CTD collects water quality profiles of temperature, conductivity (specific conductance), water clarity (light transmission), dissolved oxygen, and pH. Representative temperature, salinity and water clarity profiles are shown in Fig. 6. The plots include all of the profiles collected from two representative sites in 2006. Site 1 is a mid-lake, relatively deep-water (34 m) site, and Site E a southern-end, shallow-water (3 m) site just offshore of the Owasco Inlet.

The water temperature profiles were typical for any summer season. A well defined thermocline, the depth in the water column that separates the warmer, surface water epilimnion from the colder, bottom water hypolimnion, was observed at each deep lake site, typically at a depth of 10 meters, but ranged from 7 to 13 m and occasionally farther due to seiche activity after strong winds blowing parallel to the long axis of the lake, and/or surface water cooling and vertical mixing in the fall season. Surface water temperatures were coldest at the end of May (12°C), warmest at the end of July (24°C), and cooled down again by the end of the survey in early October. Bottom temperatures were a constant 4 to 5°C. The thermocline was much deeper (27 m) on September 30 at Site 1. This greater depth occurred during strong southerly winds blowing towards the northern end of the lake, and probably reflecting the depression of the thermocline by the accumulation of warmer, epilimnetic surface water towards the northern end of the lake. Water temperatures at Site E located at the southern end of the lak,e near the Owasco Inlet, were uniform with water depth on any given day, reflecting the site's shallow depth. The temperature on any day was similar to the open water epilimnion.

Conductivity (specific conductance, proportional to water salinity) data from the epilimnion of the open lake ranged from 317 to 332 μS/cm, and decreased slightly through the summer season. Bottom water conductivities were 335 to 340 μS/cm, and did not change as much as the surface water. In contrast, salinities at the southern end of the lake (Site E) revealed a larger range, from 308 to over 345 μS/cm. The majority of the Site E values were similar to the open water concentrations except for the profile from 6-27, and the lower few cm of a few other profiles.

The 6-27 date was during a major rain storm, and indicates that more dilute stream water (mean stream conductivities of 260 μS/cm on 6-27) diluted the lake at that site on that day. A plot of Ithaca daily precipitation data and sample dates are available at the end of the report. The dilution suggests that more dilute rain and stream water, after significant rain events, probably decreased the conductivity of the epilimnion for the entire lake over the summer season. Subsequent mixing by waves and surface currents made the epilimnetic conductivities uniform across the lake on most other sample dates. The increase in specific conductance at the lower few cm of a few profiles at Site E resulted from lowering the CTD into the mud and measuring significantly larger sediment pore water salinities.

Light transmission data revealed near surface (epilimnetic) and lake floor zones of increased turbidity (decreased water clarity). The near surface turbidity occupied most of the epilimnion and seasonally revealed transmission values as low as 40%. The origin of the epilimnetic turbidity is probably autochthonous, and proportional to plankton biomass. Weakly developed benthic nepheloid layers with light transmission decreasing from 80%, particle-free water, approximately 10 to 15 m above the lake floor, down to 60% at the lake floor, were observed at

Site C, 2 and D, the deepest sites in the survey. These nepheloid layers were less turbid than the surface algal-rich epilimnion, and were too deep thus too dark for accumulations of live algae. The data suggest that the source of the benthic turbidity is the Owasco Inlet and other tributaries. This surface and benthic water interpretations are consistent with the survey's secchi disk, TSS and chlorophyll-a data.

Fig. 7. A turbid plume of water from Taughannock Creek, Cayuga Lake. Photo by Bill Hecht.

The southern sites (E and CC1 – CC4), just offshore of Owasco Inlet, revealed the highest turbidities in the lake. The large values were detected just after significant rain storms. For example, the profiles on 6-27 revealed transmission values as low as a few percent, turbid enough to lose sight of your fingers as you placed your hand in the water. Interestingly, not all of the southern sites revealed increased turbidities after each rain event, suggesting that the turbid plume of water entering the lake from the Inlet mixes slowly and non-uniformly with the lake. Thus, some sites sampled "open lake water" while others sampled the turbid plume. A good example of open-lake *vs*. turbid plume variability in proximity to a major tributary is the distinct sediment-rich, brown, plume of water entering the bluer Cayuga Lake from Taughannock Creek (Fig. 7).

Dissolved oxygen concentrations decreased from 100% saturation at the surface down to as low as 6 mg/L in late July and August at the base of the epilimnion, only to increase slightly below saturation in the upper hypolimnion and finally decrease down to 7 mg/L near the lake floor by the end of the survey. These low values approached concentrations that induce respirative stress in aquatic organisms, and are interpreted to result from the oxygen-consuming respiration of animals and bacteria at the base of the epilimnion, and at the lake floor. The pH slowly increased in the surface waters and averaged around 8.5, and slowly deceased over the summer season down to just over 7 in the bottom waters. These differences and trends are interpreted to reflect the uptake of carbon dioxide thus increasing the pH by epilemnetic algae and release of carbon dioxide thus decreasing pH by bacterial respiration at the lake floor. The temperature, conductivity, turbidity, dissolved oxygen and pH profiles were very similar to the results measured by the Owasco Lake water quality monitoring buoy (http://www.ourlake.org/ and are reproduced at the end of this report).

Lake Nutrient Data:

Open-water, site averaged total phosphate (TP) concentrations ranged from 7.0 to 10 μg/L, and the average of all the open-water TP data was 9.0 with a standard deviation (±) of 4.6 μg/L. The seasonal mean bottom water concentrations were slightly larger (by 0.4 and 2.1 μg/L) than overlying surface water samples at Sites 1 and 2. Dissolved phosphorus concentrations (SRP) revealed similar trends. The range of site averaged phosphorus concentrations was 0.9 to 3.1 μg/L, P, and the average of all open lake concentration was 1.8 ± 2.6 μg/L. Bottom water samples were slightly larger (by ~1.5 μg/L) than overlying surface water samples at Sites 1 and 2. Seasonal site averaged nitrate concentrations ranged from 0.7 to 0.9 mg/L, N, and the average of all the nitrate data was 0.8 mg ± 0.2 mg/L. Seasonal mean bottom water concentrations were slightly larger (by ~0.2 mg/L) than overlying surface water samples at Sites 1 and 2. Finally, mean dissolved silica concentrations ranged from 580 to 1530 μg/L, Si, and averaged 760 ± 450 μg/L in the open lake. Bottom water mean concentrations were larger (by 400 and 900 ug/L) than overlying surface water samples at Sites 1 and 2.

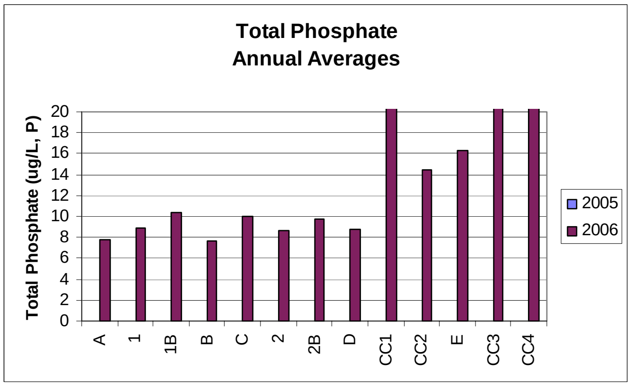


Fig. 8. Site averaged total phosphate. “B” designates the bottom water sample. CC1 = 94, CC3 = 125, CC4 = 607

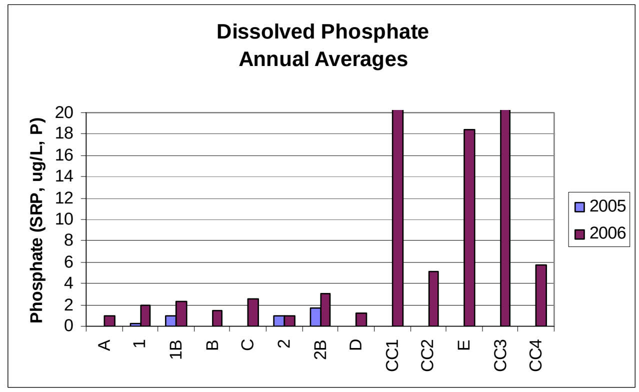


Fig. 9. Site averaged dissolved phosphate. “B” designates the bottom water sample. CC1 = 97, CC3 = 80.

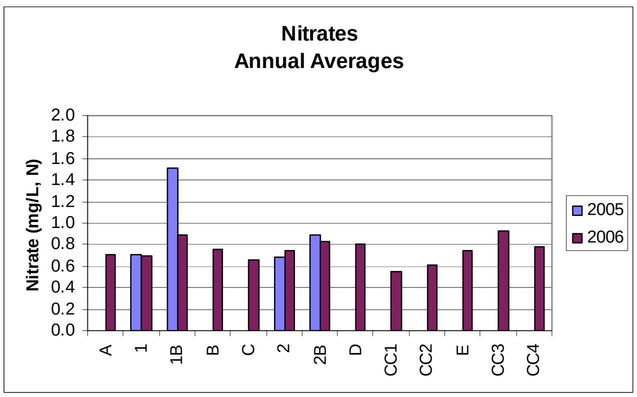


Fig. 10. Site averaged nitrate.
“B” designates the bottom water sample.

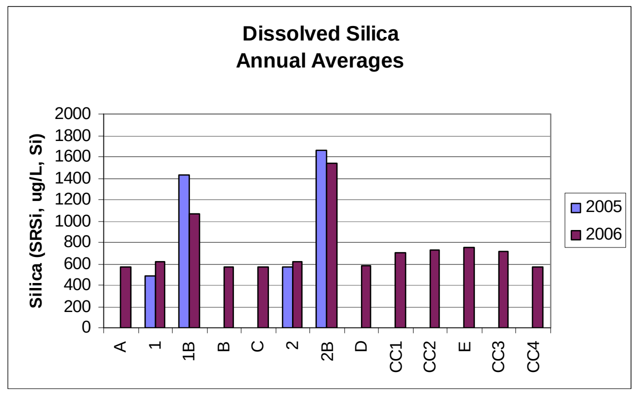


Fig. 11. Site averaged dissolved silica.
“B” designates the bottom water sample.

The epilimnetic, open-lake concentrations are uniform and reflect the well mixed nature of the epilimnion by wind, waves, and surface currents. None of these open-lake concentrations are a health threat. The nutrient concentrations suggest that the lake is borderline oligotrophic – mesotrophic. The epilimnion to hypolimnion increase in nutrient concentrations and decrease in chlorophyll concentrations are interpreted to reflect the algal uptake of nutrients and their growth in the epilimnion, and algal decomposition and nutrient release by bacteria in the hypolimnion, especially near the lake floor.

The average total phosphate concentrations were significantly larger at the southern sites than the open lake, and the range of southern site averaged concentrations was 14 to 490 μg/L, P, and a southern mean concentration of 127 ± 460 μg/L. Phosphate concentrations were not uniformly large at all the sites on every day but instead were detected after significant flood events, and even then they were only detected at sites within the turbid Owasco Inlet plume. Otherwise the southern-end concentrations were similar to the open lake. Mimicking total phosphate trends, dissolved phosphate concentrations were significantly larger at the southern end than the open lake at those sites within the Owasco Inlet plume and during flood events. The range of site averaged concentrations was 5.1 to 73 μg/L, P, and a southern end mean concentration of 30 ± 80 μg/L. Nitrate and silica concentrations did not reveal any major changes between the open lake and the southern end, and is interpreted to reflect the similar lake and Inlet concentrations. Nor were any differences observed in any of the nutrient data at Site B, offshore of Dutch Hollow Creek, compared to open-lake sites. The similarity offshore of Dutch Hollow Creek is interpreted to reflect the smaller impact Dutch Hollow Creek has on the lake than the Inlet. The elevated southern end total phosphate and dissolved phosphate concentrations are a concern, and place this portion of the lake into the eutrophic designation during flood events. This suggests that the Owasco Inlet is a major source of nutrients to the lake.

If phosphate rather than nitrate limits algal growth in the lake, then the large concentration of phosphate at the southern end is a greater concern. Both nitrogen and phosphorus are essential nutrients. Typically, the availability of one nutrient always disappears before depleting the other nutrient thereby limiting growth. Because algae require these elements in a 7:1 (N:P) ratio, the nitrogen to phosphorus ratio is indicative of which nutrient limits growth. Nitrogen typically limits algal growth if the N:P ratio in a lake is below 10 and phosphorus typically limits algal growth if the N:P ratio is over 20. The ratio of nitrogen to phosphorus in Owasco Lake based on the averaged open-lake concentrations was 90:1 (N:P), which indicates that phosphorus is the limiting nutrient. A N:P ratio of 6:1 is revealed by the averaged nutrient concentrations at the southern end.

Phosphorus as the limiting nutrient is typical for most lakes, because the natural sources of phosphates are limited to the weathering of relatively rare rocks. Once weathered, phosphate delivery to a lake is even further hampered, because it easily binds to soil particles and is nearly insoluble in water. In contrast, nitrates are released by certain plants and bacteria, do not bind to soil particles, and are water soluble. Nitrates are also delivered to the lake in rainfall. Thus, the detection of elevated phosphorus concentrations in the southern end is a concern.

Lake Chlorophyll-a, Secchi Disk, & TSS Data:
Site averaged chlorophyll-a concentrations ranged from 1.0 to 3.0 μg/L and all of the analyses averaged 2.1 ± 1.7 μg/L. Bottom water mean chlorophyll-a concentrations were slightly smaller (by 1.0 and 1.5 μg/L) than overlying surface water samples at Sites 1 and 2, as expected because algal growth is limited to the well-lit surface waters. Chlorophyll-a concentrations were slightly elevated at the southern end with southern-end site averaged concentrations of 2.3 ± 1.2 μg/L, but the larger concentrations were not at the same time as the flood events. Like the open-lake nutrient concentrations, all of the chlorophyll-a concentrations place Owasco Lake in the borderline oligotrophic – mesotrophic category.

Site averaged secchi disk depths ranged from 0.9 to 3.9 m, and the average depth at all sites was 3.4 ± 1.2 m. The site averaged depths from the open water sites were 2.9 mg/L and slightly deeper than secchi depths measured at the southern end, with site averaged depths ranging from 2.1 to 2.5. These depths classify the lake as mesotrophic.

Site averaged total suspended solids (TSS) concentrations ranged from 1.0 to 2.3 mg/L, and the average of all the TSS data was 1.6 ± 1.1 mg/L. Bottom mean TSS concentrations were slightly smaller (by 0.2 to 0.6 mg/L) than overlying surface water samples at Sites 1 and 2. TSS concentrations were slightly larger at the southern end compared to the open lake, and revealed a range of mean concentrations from each southern-end site of 1.9 to 4.2 mg/L, and a southern-end average concentration of 3.3 ± 3.7 mg/L. The largest turbidities were coincident with flood events.

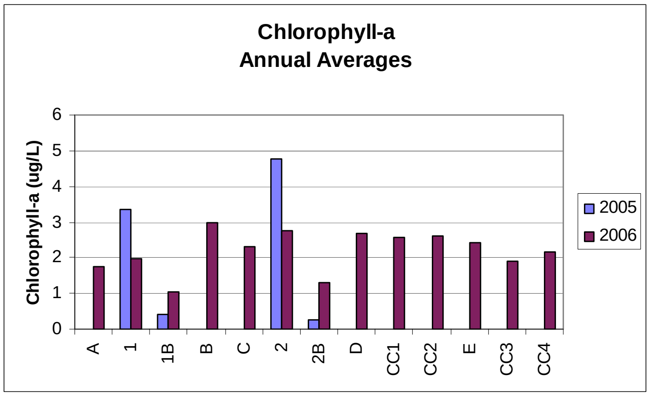


Fig. 12. Site averaged chlorophyll-a.
“B” designates the bottom water sample.

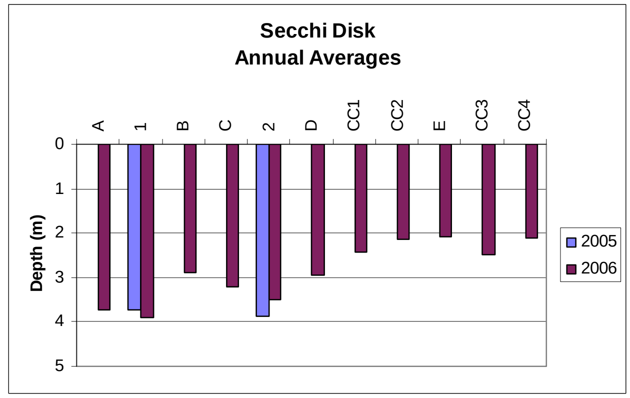


Fig. 13. Site averaged secchi disk depths.

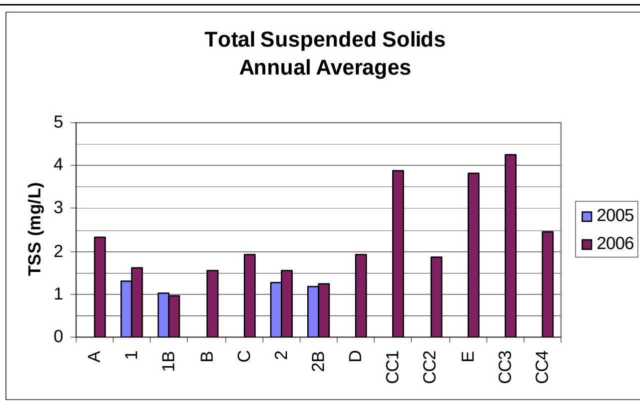


Fig. 14. Site averaged total suspended solids.
“B” designates the bottom water sample.

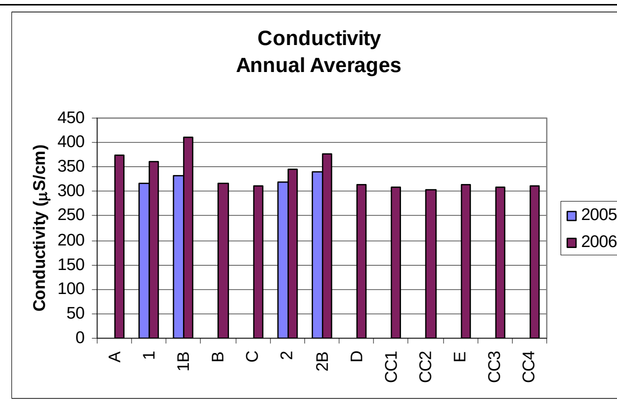


Fig. 15. Site averaged conductivity (specific conductance).
“B” designates the bottom water sample.

The secchi disk depths and TSS data co-vary across the lake, revealing larger turbidities at the southern end of the lake, especially after intense rain events. The covariance suggests that the Owasco Inlet also impairs water clarity at the southern end. This covariance is not observed in the chlorophyll-a data, and suggests that the larger turbidities at the southern end are due to suspended sediment particles and not larger concentrations of algae. The lack of covariance of phosphates and total suspended solids with the algae concentrations is surprising because large phosphate concentrations should promote more algal growth. Perhaps algal growth at the southern end was limited by the lack of light, since less light penetrates the water column full of suspended sediments. However, the addition of nutrients and suspended sediments from runoff events that are not found in the open lake suggests that threats to water quality in Owasco Lake exist, the excess nutrients are being assimilated within the lake somewhere (perhaps zebra mussels and/or near-shore macrophytes), and if water quality is to improve steps must be taken to significantly decrease or remove these threats.

Total & Dissolved Organic Matter, Total Trihalomethane Potential and Bacterial Counts: Water samples were analyzed through the Cayuga County Health Department for total and dissolved organic matter, Trihalomethane potential, and total coliform, fecal and *E. coli* bacterial counts. Site averaged concentrations are presented in the table. None of the concentrations were above EPA maximum contaminant levels (MCLs), although the Trihalomethane potential was large. If these potentials represented actual concentrations, the results would be a concern.

Plankton and Major Ion Data: The phytoplankton are dominated by the diatoms *Flagillaria*, with smaller numbers of *Rhizoselenia*, *Asterionella*, and *Tabellaria*, and the dinoflagellate *Dinobryon*, with some *Ceratium*. The seasonal succession moved from *Asterionella* to *Rhizoselenia* & *Flagillaria* to *Dinobryon*. The zooplankton are dominated by rotifers, with some copepods and cladocerans. The major anions were dominated by bicarbonate (measured as alkalinity), and cations by calcium and magnesium reflecting the weathering of carbonate-rich bedrock and soils.

Stream Results

Stream Discharge: Site averaged discharge data ranged from 0.8 to 4.5 m^3/s, and the average of all the flow data was 2.1 ± 2.1 m^3/s. In general, the mean discharge is larger at those sites with a larger drainage basin upstream from the site. For example, on any given sample date, the discharge increased from upstream to downstream in Owasco Inlet. In fact, the sum of the mean discharge from Mill Creek, a tributary to Owasco Inlet, to the mean discharge measured at

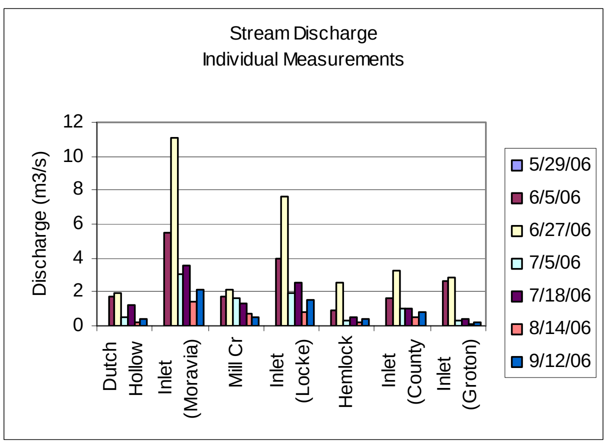


Fig. 16. Stream discharge.

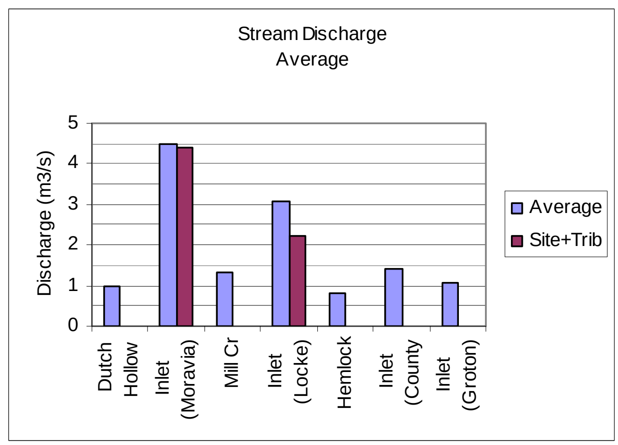


Fig. 17. Site averaged stream discharge.

Locke, the closest upstream site, approximates the discharge at Moravia, the next site downstream of Mill Creek. This indicates the sampling scheme analyzed the major sources of water along this stretch of stream, and the stream is dominated by surface flow rather than losing or gaining water to/from the groundwater system along this stretch. A similar analysis from County Line to Locke reveals unaccounted water by what was provided by Hemlock Creek. It may reflect additional water from the unmeasured tributaries entering Owasco Inlet, and/or the water gained from the groundwater system between these two sites along this stretch.

Individual discharge measurements at any one site varied considerably from one date to the next. For example, discharge ranged from under 2 to 11 m^3/s at the site just downstream of Moravia. The variability is interpreted to reflect the amount of rain just prior to sampling the stream, as the largest flow at all the sites was on 6-27, a rainy day (see the precipitation and sample date plot at the end of the report). Ignoring significant precipitation events, the overall early to late summer decline in discharge is interpreted to reflect the increased interception of water by plants for photosynthesis, and/or greater infiltration/runoff ratios of water into the ground to replenish groundwater supplies through the summer.

Stream discharge (water volume per unit time, e.g., m^3/s) is a critical variable to measure because it is one of two variables required to calculate the flux or loading of any stream delivered substance (e.g., phosphates, nitrates, suspended solids, etc.). Flux is defined as the mass of pollutant delivered to a lake per unit time, or mass/time. Water analyses typically measure the concentration of the pollutant in streams, thus provide the mass of the pollutant per unit volume of water, e.g., mass/volume, and not the flux or mass/time of pollutant. The flux of a substance is calculated from its concentration times the stream discharge, or mass/volume x volume/time, resulting in mass/time. This distinction is important because a stream with a large concentration, but small discharge, will provide a similar flux of a pollutant as another stream with a small concentration and large discharge.

During a heavy rain, two things typically happen. The stream discharge increases because approximately half of the precipitation runs off the landscape to the stream in a short amount of time (days). The other half of the precipitation infiltrates into the ground and enters the groundwater system, or is intercepted and absorbed by vegetation. The concentrations of those materials delivered to the stream by surface runoff rather than point sources or groundwater flow (e.g., nitrates, suspended sediments, herbicides and pesticides) typically also increase during rain events. Flood events therefore increase both the stream discharge and the concentration of these surface runoff pollutants, generating the largest flux (loadings) of surface runoff pollutants, like nitrates. In contrast, a stream also delivers pollutants from point sources and groundwater flow. These sources are typically not directly proportional to the runoff of rainfall. Thus, the most important time for delivery of these materials is not during flood events but instead during base flow. In fact, point source and base flow pollutant concentrations are diluted by rain events. In conclusion, two different mechanisms are critical in a stream to the transport of pollutants: (1) the flood events, the flux resulting from the occasional heavy rain, and (2) the non flood events or base flow flux, resulting from base level flow. For streams typical of central New York, the total annual flux from the flood events typically exceeds the base flow flux in any given year.

Stream Nutrient and Other Data:
Site averaged total phosphate (TP) concentrations ranged from 15 to 39 μg/L, P, and the average of all the analyses was 24 ± 23 μg/L. The County Line site on the Inlet, just downstream from Groton, had the largest and Mill Creek had the smallest mean total phosphate concentrations. Dissolved phosphorus concentrations (SRP) revealed similar trends. The range of mean concentrations at individual sites was 4 to 49 μg/L, P, and the average of all the analyses was 16 ± 19 μg/L. Site averaged mean nitrate concentrations ranged from 0.6 to 1.3 mg/L, N, and the average of all the measurements was 0.8 ± 0.7 mg/L. Dutch Hollow Creek and Hemlock Creek had the largest and the Owasco Inlet at Groton the smallest, mean nitrate concentrations. Finally, mean dissolved silica concentrations ranged from 1800 to 2000 μg/L, Si, and all analyses averaged 1930 ± 519 μg/L. No spatial or temporal trends were observed in the silica data. Site averaged total suspended solid concentrations ranged from 3.6 to 31 mg/L and the average of all the analyses was 14 ± 25 mg/L. The Moravia site had the largest and Mill Creek had the smallest mean concentrations. Specific conductance data ranged from 300 to 420 μS/cm and all the measurements averaged 380 ± 80 μS/cm. The site just upstream of Groton had the largest

and Mill Creek had the smallest, mean TSS concentrations. Dissolved oxygen concentrations were near saturation throughout the survey.

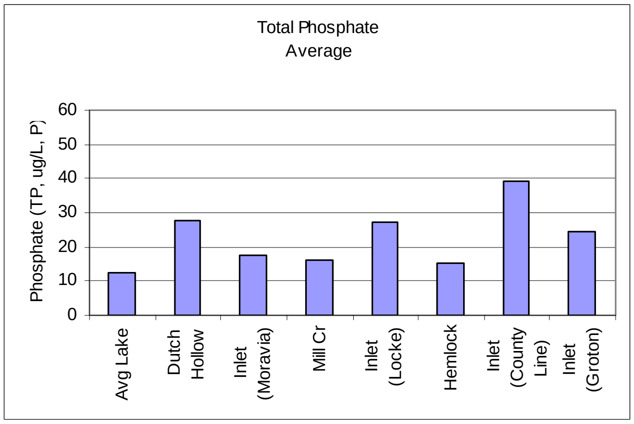


Fig. 18. Site averaged total phosphate.

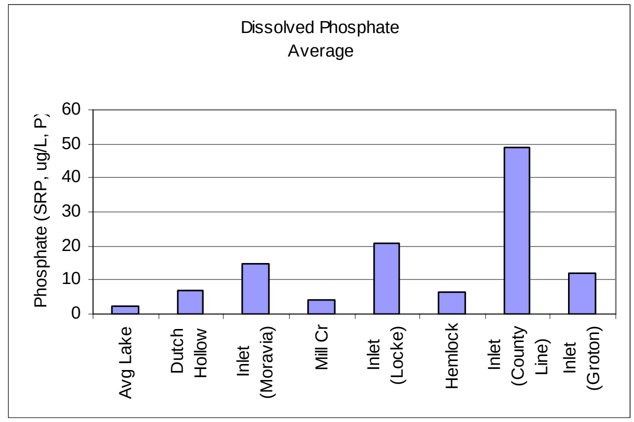


Fig. 19. Site averaged dissolved phosphate.

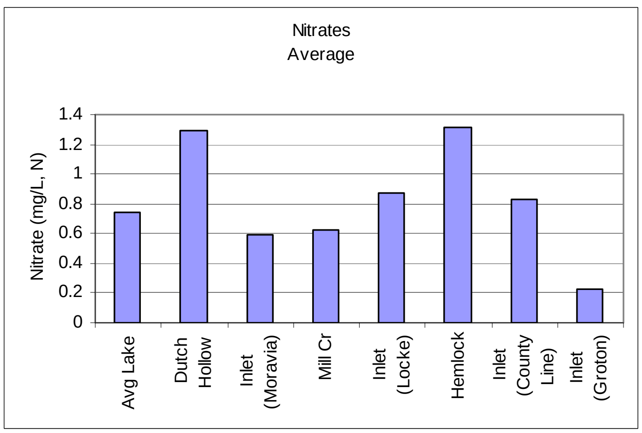


Fig. 20. Site averaged nitrate.

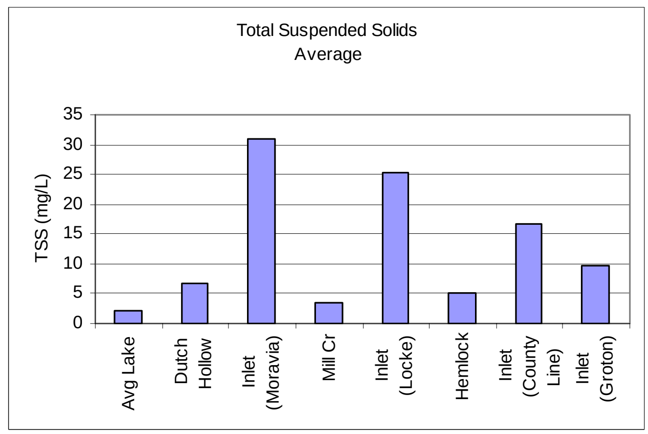


Fig. 21. Site averaged total suspended solids.

All of the stream mean nutrient, TSS, and major ion concentrations were larger than the average open-water lake concentration, indicating that the lake is gaining nutrients, suspended solids and ions from the watershed. None of the parameters changed significantly at any one site from one sample date to the next, except for suspended solids and specific conductance. Total suspended solids on 6-27 was much larger whereas specific conductance was smaller than any other sample date and corresponds to the flood event in the basin.

Stream Fluxes:
The flux of all of the measured parameters typically increased down stream along the Owasco Inlet, and was interpreted to reflect the accumulation of additional water with similar or slightly smaller concentrations moving downstream. For example, the flux of most of the parameters measured between County Line and Locke and between Locke and Moravia increased by the supplied flux of material delivered by the major tributary between these sites, irrespective of the change in concentration. It suggests that surface runoff, rather than groundwater or point sources, are critical for Owasco Inlet, and also suggests that fluxes and watershed size co-vary. Since the Owasco Inlet watershed is the biggest watershed that empties into Owasco Lake,

approximately four times larger than Dutch Hollow Creek, and spans 57% of the Owasco watershed, it is no surprise that Owasco Inlet reveals the largest flux of material to the lake.

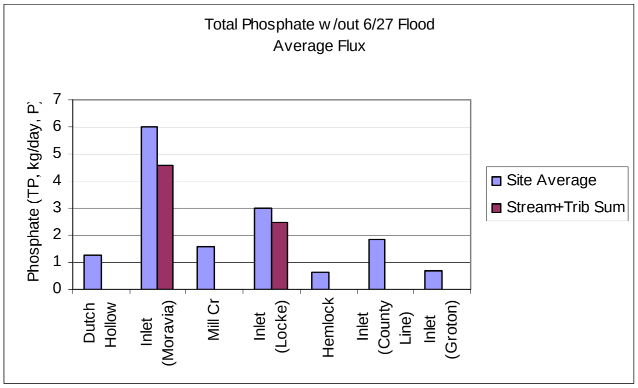


Fig. 22. Site averaged total phosphate flux.

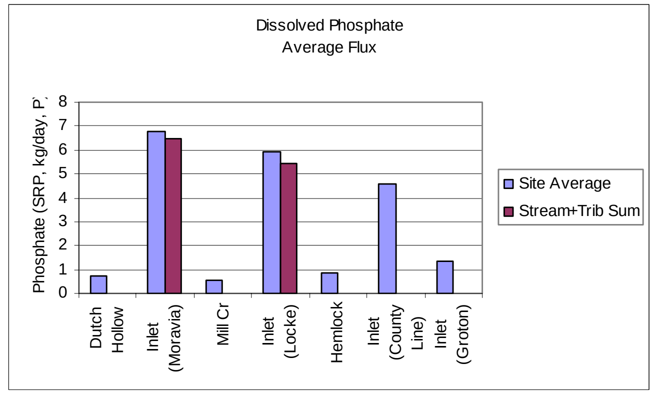


Fig. 23. Site averaged dissolved phosphate flux.

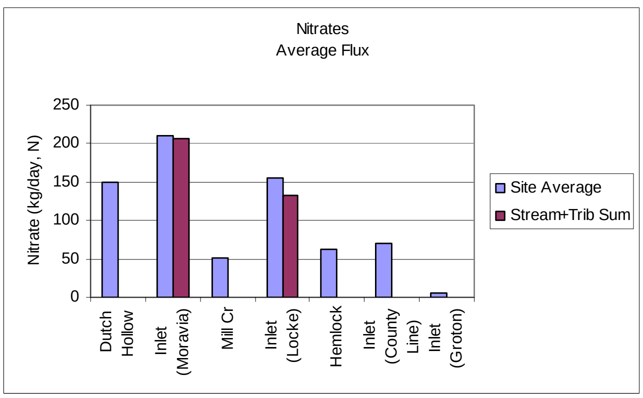


Fig. 24. Site averaged nitrate flux.

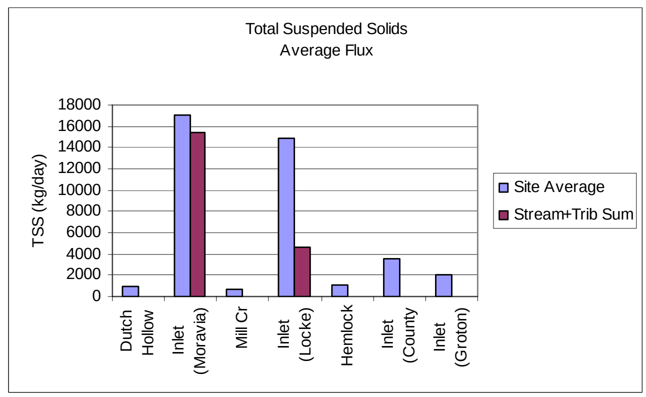


Fig. 25. Site averaged total suspended solids flux.

Specifically, Owasco Inlet contributed more total phosphates (5x), dissolved phosphates (10x), total suspended solids (17x), dissolved silica (4.5x), nitrates (1.5x), and major ions (2.5x) than Dutch Hollow Creek. However, if Owasco Inlet delivers these materials as a simple ratio to watershed size, then Owasco Inlet appears to be delivering more phosphates, especially dissolved phosphates, and more total suspended solids than its size would dictate. Perhaps Dutch Hollow Creek delivers a larger percentage of nitrates and salts than Owasco Inlet because nitrates and salts are more water soluble than phosphates. This watershed has more agricultural land use than Owasco Inlet (64 *vs.* 46%), and agricultural land use is an important non-point source for nitrates and major ions. Sampling additional streams with a varying amount of land use and basin size should be included in future studies to confirm this observation.

The fluxes also suggest that specific segments of Owasco Inlet, compared to other segments, gained more suspended solids and nutrients. The flux of total suspended solids from Hemlock Creek falls short of the measured increase in TSS flux between County Line and Locke. It suggests that the Inlet is actively gaining additional suspended sediments along this stretch of stream. Perhaps the Inlet gains suspended sediments by enhanced stream bank erosion, enhanced delivery of eroded sediments by roadside ditches, or erosion from construction activities and other non-vegetated areas of ground along this stretch of the Inlet.

More importantly, the flux of total phosphate, dissolved phosphate, and nitrates increased faster between the upstream and downstream Groton sites than other segments of the watershed. Specifically, the segment from upstream to downstream of Groton adds approximately 20% of the total phosphates, 50% of the dissolved phosphates, 30% of the nitrates, 15% of the major ions, 8% of the total suspended solids, and 5% of the dissolved silica delivered past Moravia. It suggests a major point source of sediment-free and dissolved silica-free, nutrients (P and N) existed along this stretch. The likely source is the Groton wastewater treatment facility because this treatment plant did not remove nutrients from its "treated" effluent. Natural sources can explain the addition of the silica and suspended solids along this stretch. Interestingly, a similar increase in nutrient loading is not observed from Moravia's municipal wastewater treatment facility. Either the Moravia facility removes nutrients from its effluent or its discharge is small enough to be undetected.

Even though the Groton wastewater plant is a point source of pollutants, it does not supply all of the nutrients and other substances delivered by Owasco Inlet to the lake. This survey indicates that Dutch Hollow Creek, Mill Creek, Hemlock Creek, and the rest of Owasco Inlet deliver a significant share, especially nitrates. Thus, other nutrient and suspended sediment sources are important and must be addressed to reduce the nutrient and suspended loading to the lake. The other major nutrient sources probably include runoff from agricultural land, manicured lawns, and individual onsite septic systems. Major sediment sources probably include agricultural land, construction projects, and roadside ditches.

The flux of materials on any given day was largest during the 6-27 flood event. It suggests that a mechanism to mitigate nutrient and sediment loading to Owasco Lake is to mitigate the impact of flood events in this watershed. However, mitigation of flood events does not remove all of the load in this watershed because base flow contributed its share of nutrients and suspended sediments to Owasco Lake, and the sum of the daily fluxes from all the other sample dates exceeds the flux from the 6-27 event. Clearly, further analysis should investigate the relative importance of flood and base flow in this watershed.

Is water quality getting progressively worse in Owasco Lake? Have zebra and quagga mussels altered the ecology of the lake? Figure 26 reveals historical chlorophyll-a, total phosphate, nitrate and secchi disk depth data from various County and NYS publications, that summarized data from early 1970s by Cornell, 1980s by Upstate Freshwater Institute, and 1990s by NYS DEC. It also includes the 2005 and 2006 data from this report displaying a separate bar for the data from the southern end of the lake in 2006. The plot reveals that most of the open-water concentrations are the same over time. A few exceptions are observed: (1) the southern end has significantly larger phosphate concentrations and shallower secchi disk depths than all of the other data; and, (2) chlorophyll-a concentrations decreased from

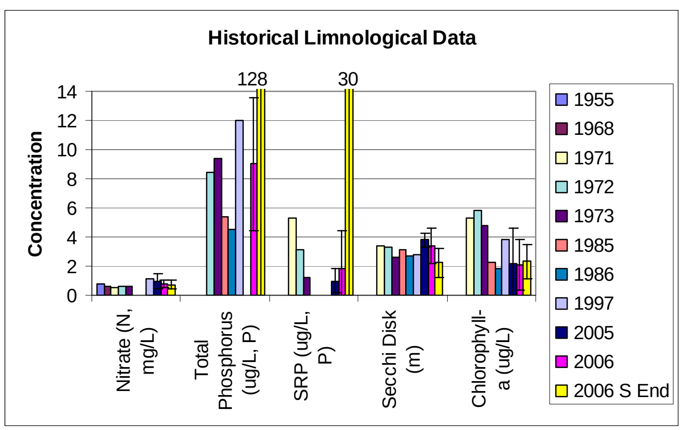


Fig. 26. Historical lake data.

approximately 5 μg/L in the 1970s down to 2 μg/L since the 1970s. Has water quality actually changed? The decrease in chlorophyll-a concentrations since the 1970s probably reflects the ban on phosphate use in soaps and increased emphasis on nutrient removal from wastewater effluent to combat the Great Lakes eutrophication of the 1960s. Have the near-shore macrophytes and/or zebra mussels sequestered enough nutrients over the past few years to mask the delivery of the excess nutrients from Owasco Inlet? Alternatively, is the quick water residence time significant for the nutrient budget? More data like that presented here and data on zebra mussels and the watershed hydrology would be useful but unfortunately not readily available to make a complete assessment. It highlights the need for continued monitoring of aquatic systems to scientifically assess changes in water quality over time.

Conclusions & Recommendations:
Owasco Lake is a borderline oligotrophic – mesotrophic ecosystem. None of the water quality parameters are life threatening at the present time. Water quality is worse at the southern end of the lake. The degraded water quality is interpreted to reflect, and consistent with, measured runoff events from the Owasco Inlet. The delivery of extra nutrients and suspended sediments will further degrade water quality in the lake into the future if not addressed in a meaningful and sustainable manner. The probable sources of nutrients and suspended sediments include a wastewater treatment facility, onsite wastewater systems, agricultural activities, soil erosion, fertilized lawns, roadside ditches, construction activities, and other point and non-point sources.

Due to the variety of the pollutant sources, remediation efforts should be multifaceted to improve water quality in Owasco Lake. A number of remediation efforts are already proposed or recently initiated. All should help improve water quality, and are described below. However, we also offer a word of caution. Additional steps to protect the watershed will probably surface once our expanded analysis of the lake and tributaries in the watershed is complete. Fieldwork is scheduled for summer 2007 and data analysis the following fall and winter. We also plan to scrutinize the existing water quality protection legislation in place within the Skaneateles, Canandaigua, and Keuka watershed, to see what might work best and could easily be adapted to the Owasco watershed.

Groton Wastewater Effluent: The Groton wastewater treatment plant is testing a number of methods to reduce nutrients in its effluent. Various treatments can remove the nutrients, and selection of the best method must balance the effectiveness of the removal process with its costs. Any additional treatment procedure add to the capital and operating costs of running the facility, costs that will be passed on to the users of the Groton facility. If the Groton plant is able to get a new system determined, approved, and online by summer 2007, next year's water quality results should reveal whether or not if these remediation efforts reduce the nutrient loading to the lake. Regardless, Groton should take steps to reduce its nutrient loading to the Inlet.

Owasco Inlet Floodplain: The floodplain/wetland geomorphology of the Inlet from Moravia to the lake suggests that it could remediate the impact of these floodwaters on the lake. Floodplains and wetlands provide excellent natural systems to reduce the peak discharge of flood events and reduce the associated nutrient and suspended sediment loads from the floodwaters, but only if the floodwaters spill over the stream banks and flood the floodplain. At the present time, however man-made levees along the Inlet prevent the natural flooding of the floodplain. These levees enabled homeowners and farmers to utilize the fertile floodplains with a lower risk of loss.

Remediation of the floodplain is probably the most ambitious effort outlined here, because the land within the floodplain must be bought, and artificial levees removed for this plan to work without undue hardships to the local residents. Both tasks are costly, and this plan only addresses the excess nutrients provided by the flood events and not base flow. Thus detailed analysis is required to asses the relative importance of flood vs base flow fluxes, and the cost of the remediation efforts.

Watershed Inspector: Cayuga County has legislation in place to inspect and remediate the impact of onsite wastewater systems. However, the county needs additional funds to hire one or more qualified inspector(s) to insure compliance. This solution should be a high priority issue, and is financially feasible through a $4/inspector/year surcharge to the water bill for all water-users that drawn from Owasco Lake. Hiring a watershed inspector, along with the planned updating of watershed rules and regulations for the Owasco Watershed, will greatly contribute toward reductions in nutrient loading to the lake, thus reducing algal concentrations. The domino effect suggests that this simple surcharge might, in fact, save the water users money by reducing the cost of filtering algae from the water before it is delivered to the consumer.

Agricultural BMPs: Various "best management practices" (BMPs) are available to reduce the contribution from the agricultural sector, both crop farming and animal husbandry. These include contour plowing, settling ponds, buffer vegetation strips, minimal tillage farming, manure digesters, and other BMPs but always at a cost to the farmer. Steps should be taken to investigate which are the best practices for this watershed and which mechanisms must be in place so that the entire economic burden is not placed solely on the farmer. In some cases education is critical to gain acceptance and follow through with adaptation of these practices. Perhaps the ongoing, USDA funded-research on various BMPs in the Conesus watershed by SUNY Brockport, County Soil and Water, and colleagues, will shed light on practical systems to use in the Owasco watershed.

Education: Education is also critical for local residents to understand the need for properly functioning onsite wastewater treatment systems and environmentally friendly (less fertilized) lawns to help reduce the seepage and runoff of nutrients to the lake. The education starts at primary and secondary levels but should also include the average homeowner, government officials, and environmental protection associations.

Finally, additional research should investigate the relative impact of the various point and non-point source pollutants in the region, and develop a preliminary phosphate budget, thus dictating which source(s) require(s) the most legislative effort to improve water quality for the future. Further research should also include the impact of these pollutants on the rest of the ecosystem in the lake, and a comparison of recent events to the historical record. To this end, Senator Michael F. Nozzolio has secured NYS funding to enable an interdisciplinary team of scientists to investigate water quality concerns in the Owasco watershed this coming summer 2007. The team and their tasks include:

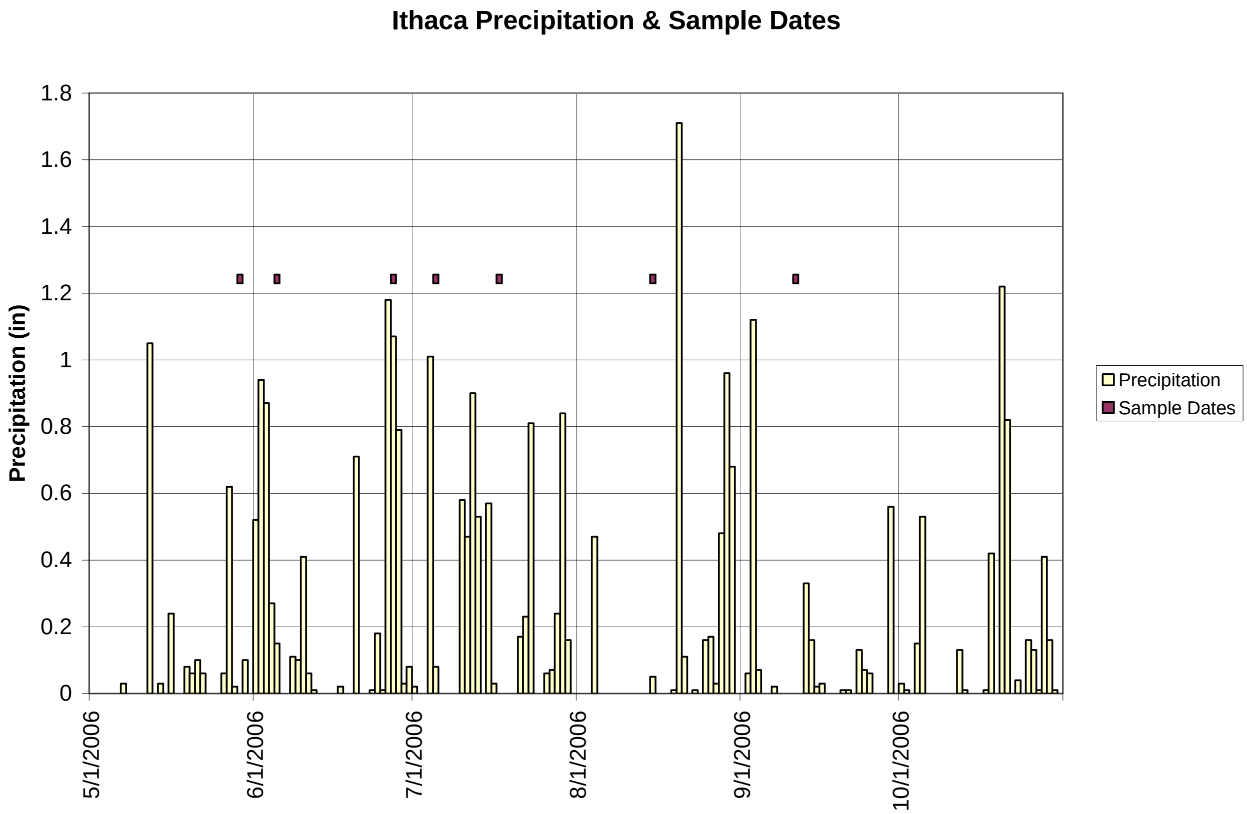
- Dr. John Halfman, Hobart & William Smith Colleges, will expand his lake and stream water quality measurements, and estimate a phosphate budget to the extent possible.
- Dr. Tim Sellers, Keuka College, will investigate limitations to algal productivity including nutrients, light intensity, and suspended sediment concentrations.

- Dr. Meghan Brown, Hobart & William Smith Colleges, will investigate the zooplankton of the lake looking at the zooplankton impact on the ecosystem and its historical record.
- Dr. Bruce Gilman, Finger Lakes Community College, and Dr. Bin Zhu, Finger Lakes Institute Research Scientist, will investigate the variety and density of near-shore plants (Macrophytes) and other forms of shallow-water biota.
- Dr. Dawn Dittman United States Geological Survey, Cortland, and Jim Watkins, Cornell University, will investigate the deep-water biology of the lake focusing on the zebra and quagga mussel impact on deep-water organisms like Diporeia, the major player in the food chain for Lake Trout.
- Dr. Jim Ryan, Hobart & William Smith Colleges, will investigate the concentration, source and fate of personal care products, estrogen and other man-made compounds that are recent water quality concerns across the country.
- Finally, Dr. Tara Curtin, Hobart & William Smith Colleges, will investigate the historical sediment record preserved in the recent sediments to evaluate the impact of sediment loading to the lake.

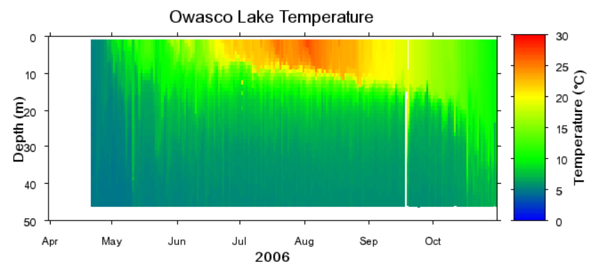
We look forward to next summer.

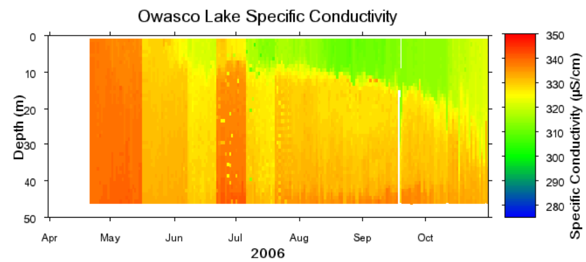
Acknowledgements
The research was supported by grants from the Fred L. Emerson Foundation, John Ben Snow Foundation, Hobart & William Smith Colleges, New York State, and the Andrew Mellon Foundation. We thank members of the Cayuga County Planning Department, Cayuga County Water Quality Management Agency, Cayuga County Health Department, the Owasco Watershed Lake Association, Senator Mike Nozzolio, Barbara Halfman, Sarah Meyer, and Marion Balyszak for their support, data, analyses and encouragement throughout this study. Additional thanks are extended to Clancy Brown, Christina Kinnevey, Rachel Sukeforth, April Abbott, Camille, Marie and Samuel Halfman, the Geo-330 Fall-2006 Limnology class and many other undergraduate students for their assistance in the field and laboratory.

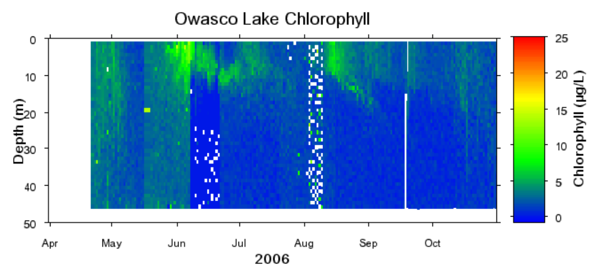
Ithaca May – October, 2006, Precipitation & Owasco Lake & Stream Sample Dates:

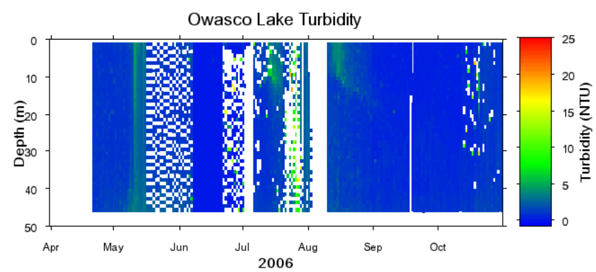


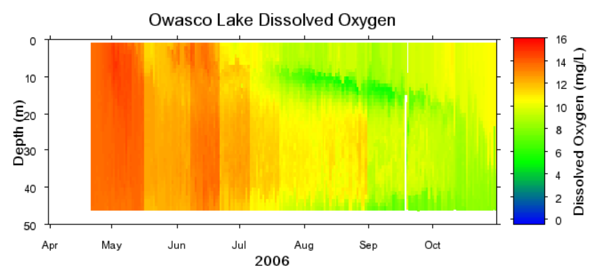
2006 Data from Owasco Lake Water Quality Profiler Buoy (www.ourlake.org)

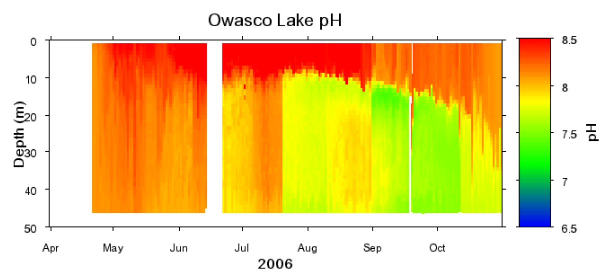












Owasco Lake and Stream, Site Averaged, Limnological & Major Ion Data – 2005 & 2006:

Site Averaged Concentrations (±1σ) Open Lake Sites - 2005	A	1	1Bottom	B	C	2	2Bottom	D	Average Open Lake
Secchi Depth (m)		3.7 ± 0.7				3.9 ± 0.3			3.8 ± 0.5
TSS (mg/L)		1.3 ± 0.3	1.0 ± 0.4			1.3 ± 0.3	1.2 ± 0.3		1.2 ± 0.3
Dissolved Phosphate (μg/L, P)		0.2 ± 0.3	1.0 ± 1.0			1.0 ± 1.0	1.7 ± 0.5		1.0 ± 0.8
Nitrate (mg/L, N)		0.7 ± 0.4	1.5 ± 0.6			0.7 ± 0.2	0.9 ± 0.3		0.9 ± 0.5
Silica (μg/L, Si)		482.9 ± 102.8	1434.2 ± 24.6			574.8 ± 171.0	1659.3 ± 64.9		1037.8 ± 541.4
Chlorophyll-a (μg/L)		3.4 ± 1.4	0.4 ± 0.3			4.8 ± 2.6	0.3 ± 0.3		2.2 ± 2.4
Conductivity (μS/cm)		317.0 ± 14.3	332.3 ± 20.9			318.8 ± 15.4	341.0 ± 13.9		327.3 ± 17.9
Major Ions									
Chloride (mg/L, Cl)		24.3 ± 10.4	18.6 ± 1.1			19.0 ± 0.7	18.9 ± 0.6		17.7 ± 8.9
Sulfate (mg/L, SO_4)		15.9 ± 4.4	13.9 ± 0.9			13.7 ± 0.2	13.9 ± 0.5		12.6 ± 5.3
Alkalinity (mg/L, $CaCO_3$)		110.5 ± 6.0	117.5 ± 8.8			108.0 ± 10.6	117.5 ± 3.8		115.1 ± 3.4
Sodium (mg/L, Na)		11.6 ± 1.2	11.9 ± 1.5			12.8 ± 0.7	12.0 ± 1.6		10.9 ± 4.1
Calcium (mg/L, Ca)		36.8 ± 3.6	44.7 ± 5.3			39.7 ± 4.1	46.2 ± 6.4		36.8 ± 16.1
Magnesium (mg/L, Mg)		8.3 ± 1.4	8.5 ± 1.0			8.7 ± 1.0	8.7 ± 1.4		7.5 ± 2.8

Open Lake Sites - 2006	A	1	1Bottom	B	C	2	2Bottom	D	Average Open Lake
Secchi Depth (m)	3.7 ± 1.3	3.9 ± 1.6		2.9 ± 0.9	3.2 ± 1.1	3.5 ± 1.1		3.0 ± 0.9	3.4 ± 1.2
TSS (mg/L)	2.3 ± 2.4	1.6 ± 0.8	1.0 ± 0.4	1.6 ± 0.7	1.9 ± 1.2	1.5 ± 0.8	1.3 ± 0.4	1.9 ± 0.8	1.6 ± 1.1
Total Posphate (μg/L, P)	7.7 ± 4.3	8.9 ± 3.3	10.4 ± 8.0	7.7 ± 2.8	10.0 ± 4.0	8.7 ± 3.4	9.7 ± 6.7	8.7 ± 2.9	9.0 ± 4.6
Dissolved Phosphate (μg/L, P)	0.9 ± 1.2	1.9 ± 2.2	2.3 ± 2.7	1.5 ± 1.9	2.6 ± 2.8	1.0 ± 1.6	3.1 ± 5.0	1.3 ± 1.5	1.8 ± 2.6
Nitrate (mg/L, N)	0.7 ± 0.1	0.7 ± 0.2	0.9 ± 0.4	0.8 ± 0.2	0.7 ± 0.2	0.7 ± 0.2	0.8 ± 0.3	0.8 ± 0.3	0.8 ± 0.2
Silica (μg/L, Si)	573.0 ± 149.6	614.4 ± 171.7	1066.9 ± 292.0	570.4 ± 145.0	565.9 ± 173.7	616.9 ± 186.8	1533.5 ± 767.6	581.1 ± 131.6	767.7 ± 451.7
Chlorophyll-a (μg/L)	1.8 ± 1.1	2.0 ± 1.3	1.0 ± 1.7	3.0 ± 2.1	2.3 ± 1.5	2.8 ± 1.9	1.3 ± 2.1	2.7 ± 1.2	2.1 ± 1.7
Conductivity (μS/cm)	374.2 ± 177.5	361.2 ± 132.0	410.3 ± 158.8	316.0 ± 12.0	312.4 ± 8.7	346.2 ± 90.2	377.4 ± 110.5	314.8 ± 7.2	351.5 ± 109.1
Total Organic Matter (mg/L)	7.2 ± 9.1	2.7 ± 0.3	2.1 ± 0.2	2.7 ± 0.2	5.3 ± 4.8	2.7 ± 0.2	3.0 ± 0.6	2.0 ± 0.4	3.7 ± 3.9
Dissolved Organic Matter (mg/L)	3.3 ± 0.4	3.2 ± 0.3	2.7 ± 0.4	3.2 ± 0.2	3.6 ± 0.8	3.2 ± 0.4	3.3 ± 0.5	2.7 ± 0.5	3.2 ± 0.5
Total Trihalomethane Potential (μg/L)	260.6 ± 72.4	202.8 ± 107.0	175.1 ± 53.3	314.8 ± 149.4	222.7 ± 113.1	453.2 ± 340.5	195.4 ± 112.6	176.7 ± 52.1	253.6 ± 154.1
Total Coliform Bacteria (CFUs/100mL)									
Fecal Bacteria (CFUs/100mL)	2.0 ± 0.0	2.0 ± 0.0	10.0	3.7 ± 1.5	2.0 ± 0.0	2.0 ± 0.0	4.7 ± 3.1		
E. coli Bacteria (CFUs/100mL)									
Major Ions									
Chloride (mg/L, Cl)	21.2 ± 3.5	21.1 ± 3.0	20.5 ± 1.1	21.3 ± 3.4	22.3 ± 4.5	20.9 ± 3.0	19.2 ± 2.0	20.9 ± 3.7	20.9 ± 3.1
Sulfate (mg/L, SO_4)	15.1 ± 1.8	15.0 ± 1.6	16.0 ± 0.6	15.0 ± 1.8	14.4 ± 2.1	14.9 ± 1.3	14.9 ± 1.6	13.7 ± 3.5	14.847 ± 1.8784
Alkalinity (mg/L, $CaCO_3$)	124.9 ± 10.5	122.0 ± 7.7	124.6 ± 12.4	123.3 ± 12.8	120.5 ± 10.8	121.9 ± 13.0	126.1 ± 9.7	122.0 ± 9.3	123.3 ± 10.3
Sodium (mg/L, Na)	11.8 ± 0.7	11.6 ± 0.5	11.4 ± 1.2	9.3 ± 4.2	11.5 ± 0.7	11.7 ± 0.7	11.4 ± 1.2	10.7 ± 2.4	11.2 ± 1.8
Calcium (mg/L, Ca)	37.9 ± 5.6	39.3 ± 2.4	41.4 ± 3.8	36.3 ± 10.3	40.0 ± 3.0	39.8 ± 2.1	39.9 ± 7.1	36.7 ± 10.0	39.0 ± 5.9
Magnesium (mg/L, Mg)	8.5 ± 0.8	8.5 ± 0.7	8.4 ± 1.0	7.0 ± 3.3	8.7 ± 0.7	8.7 ± 0.7	8.4 ± 0.8	8.0 ± 2.0	8.2 ± 1.4

Southern End Sites - 2006	CC1	CC2	E	CC3	CC4	Average Southern End
Secchi Depth (m)	2.4 ± 0.6	2.2 ± 1.3	2.1 ± 1.0	2.5 ± 0.9	2.1 ± 1.5	2.2 ± 1.0
TSS (mg/L)	3.9 ± 3.5	1.9 ± 0.6	3.8 ± 5.0	4.2 ± 5.5	2.5 ± 0.7	3.3 ± 3.7
Total Posphate (μg/L, P)	73.4 ± 125.6	14.4 ± 8.7	16.3 ± 15.7	102.9 ± 143.4	487.9 ± 1060.9	127.8 ± 458.3
Dissolved Phosphate (μg/L, P)	72.9 ± 139.7	5.1 ± 6.2	18.4 ± 46.8	64.4 ± 136.0	5.7 ± 6.3	30.2 ± 80.5
Nitrate (mg/L, N)	0.5 ± 0.2	0.6 ± 0.2	0.7 ± 0.2	0.9 ± 0.5	0.8 ± 0.3	0.7 ± 0.3
Silica (μg/L, Si)	709.0 ± 305.7	731.3 ± 368.6	750.6 ± 382.2	712.4 ± 474.4	571.9 ± 185.1	700.7 ± 339.3
Chlorophyll-a (μg/L)	2.6 ± 1.7	2.6 ± 0.9	2.4 ± 1.3	1.9 ± 1.5	2.1 ± 0.7	2.3 ± 1.2
Conductivity (μS/cm)	309.4 ± 6.4	304.6 ± 5.9	315.0 ± 10.2	309.0 ± 6.2	312.4 ± 6.8	310.6 ± 8.0
Total Organic Matter (mg/L)	2.8 ± 0.4	3.3 ± 1.0	3.4 ± 0.9	2.9 ± 0.4	2.7 ± 0.4	3.0 ± 0.6
Dissolved Organic Matter (mg/L)	3.3 ± 0.9	3.7 ± 0.7	3.9 ± 0.9	3.2 ± 0.4	3.6 ± 0.4	3.5 ± 0.6
Total Trihalomethane Potential (μg/L)	316.3 ± 236.0	227.9 ± 64.0	512.6 ± 440.3	220.1 ± 60.2	365.4 ± 255.2	318.8 ± 231.7
Total Coliform Bacteria (CFUs/100mL)	8.3 ± 2.9	10.0 ± 10.0		12.3 ± 15.4	7.0 ± 7.5	9.4 ± 8.8
Fecal Bacteria (CFUs/100mL)	5.3 ± 4.2	2.0 ± 2.0	2.0 ± 2.8	7.3 ± 6.1	2.7 ± 2.3	4.0 ± 3.9
E. coli Bacteria (CFUs/100mL)		0.5 ± 0.7	±	0.3 ± 0.6	1.0 ± 0.0	0.4 ± 0.5
Major Ions						
Chloride (mg/L, Cl)	20.1 ± 1.5	18.3 ± 3.1	22.0 ± 4.6	18.1 ± 4.6	16.9 ± 8.4	19.3 ± 5.0
Sulfate (mg/L, SO_4)	16.0 ± 1.8	14.2 ± 4.8	13.8 ± 2.0	14.4 ± 3.4	12.7 ± 6.0	14.1 ± 3.7
Alkalinity (mg/L, $CaCO_3$)	122.2 ± 13.1	121.6 ± 9.2	126.8 ± 13.5	127.0 ± 12.8	124.0 ± 16.3	124.6 ± 12.4
Sodium (mg/L, Na)	11.6 ± 1.0	11.2 ± 1.4	10.1 ± 4.1	10.7 ± 2.1	12.2 ± 1.1	11.0 ± 2.5
Calcium (mg/L, Ca)	39.7 ± 3.2	34.6 ± 9.1	39.3 ± 2.7	36.3 ± 9.3	40.0 ± 3.4	38.0 ± 6.1
Magnesium (mg/L, Mg)	8.3 ± 0.6	8.0 ± 0.6	7.2 ± 3.0	7.8 ± 1.4	8.4 ± 0.7	8.1 ± 0.8

Site Averaged Concentrations (±1σ) Streams - 2006	Dutch Hollow	Inlet (Moravia)	Mill Cr	Inlet (Locke)	Hemlock	Inlet (Cnty Line)	Inlet (Groton)	All Sites
Discharge (m^3/s)	1.0 ± 0.7	4.5 ± 3.5	1.3 ± 0.6	3.1 ± 2.5	0.8 ± 0.9	1.4 ± 1.4	1.1 ± 1.3	2.1 ± 2.1
Nitrate (mg/L, N)	1.3 ± 1.1	0.6 ± 0.4	0.6 ± 0.2	0.9 ± 0.4	1.3 ± 1.3	0.8 ± 0.4	0.2 ± 0.2	0.8 ± 0.7
TSS (mg/L)	6.7 ± 7.1	31.0 ± 45.1	3.6 ± 4.9	25.4 ± 40.3	5.2 ± 5.2	16.8 ± 19.3	9.7 ± 15.3	14.1 ± 25.6
Total Phosphate (μg/L, P)	27.6 ± 35.9	17.3 ± 6.7	16.4 ± 11.9	27.1 ± 16.7	15.0 ± 15.0	39.2 ± 37.6	24.3 ± 24.6	23.8 ± 23.3
Dissolved Phosphate (μg/L, P)	7.0 ± 7.4	14.9 ± 8.1	4.2 ± 3.5	20.9 ± 10.8	6.6 ± 6.6	49.1 ± 30.0	12.1 ± 6.9	16.4 ± 19.1
Dissolved Silica (μg/L, Si)	1823.1 ± 617.2	1906.0 ± 593.9	1978.7 ± 381.3	1930.1 ± 642.4	1994.2 ± 1994.2	2026.9 ± 527.4	1864.3 ± 603.4	1931.9 ± 519.0
Conductivity (μS/cm)	488.4 ± 36.7	368.7 ± 65.6	321.5 ± 35.1	380.8 ± 59.3	372.0 ± 372.0	418.3 ± 76.0	300.2 ± 51.2	381.1 ± 79.3
Major Ions								
Chloride (mg/L, Cl)	30.5 ± 8.4	26.4 ± 2.8	17.5 ± 3.3	23.2 ± 6.4	17.3 ± 3.9	36.5 ± 8.7	24.9 ± 5.8	24.9 ± 8.4
Sulfate (mg/L, SO4)	16.7 ± 2.2	13.5 ± 2.5	11.7 ± 2.0	12.7 ± 5.1	13.9 ± 3.5	14.7 ± 2.6	10.2 ± 2.3	13.3 ± 3.5
Alkalinity (mg/L, $CaCO_3$)	200.0 ± 16.9	154.8 ± 18.0	134.7 ± 13.2	162.3 ± 21.3	169.7 ± 23.2	149.7 ± 15.8	121.8 ± 15.7	154.5 ± 28.1
Sodium (mg/L, Na)	14.9 ± 3.2	15.6 ± 1.4	11.8 ± 3.8	15.2 ± 1.9	13.3 ± 6.4	19.4 ± 5.8	17.2 ± 5.8	15.3 ± 4.7
Calcium (mg/L, Ca)	53.8 ± 23.5	51.5 ± 7.8	46.1 ± 6.4	46.7 ± 10.8	40.7 ± 17.4	53.1 ± 12.6	37.3 ± 11.6	47.0 ± 14.3
Magnesium (mg/L, Mg)	24.4 ± 23.2	22.9 ± 21.7	19.5 ± 19.4	20.6 ± 18.9	19.7 ± 17.0	24.4 ± 23.5	17.1 ± 16.4	21.2 ± 19.7

Owasco Lake, Site Averaged and Date Averaged, Plankton Data – 2005 & 2006.

Site Averaged % Abundance (±1σ) Open Lake Sites - 2005	A	1	1Bottom	B	C	2	2Bottom	D	Average Open Lake
Plankton (% Total)									
Fragillaria		42.9 ± 18.7				38.1 ± 22.2			40.5 ± 20.0
Asterionella		11.6 ± 16.5				10.9 ± 13.0			11.2 ± 14.4
Melosira		0.1 ± 0.4				0.0 ± 0.1			0.1 ± 0.3
Tabellaria		1.0 ± 1.0				1.0 ± 0.9			1.0 ± 0.9
Synedra		7.5 ± 18.7				2.5 ± 6.5			5.0 ± 13.7
Dinobryon		16.8 ± 23.8				14.6 ± 17.8			15.7 ± 20.3
Ceratium		5.3 ± 9.4				5.6 ± 6.8			5.5 ± 8.0
Keratella		1.6 ± 4.4				2.5 ± 3.5			2.0 ± 3.9
Polyarthra		1.2 ± 2.5				4.4 ± 10.6			2.8 ± 7.6
Copepod		0.1 ± 0.3				0.3 ± 0.7			0.2 ± 0.5
Nauplius		0.3 ± 0.4				0.5 ± 0.5			0.4 ± 0.4
Cladoceran		2.3 ± 5.6				3.8 ± 5.3			3.1 ± 5.3

Open Lake Sites - 2006	A	1	1Bottom	B	C	2	2Bottom	D	Average Open Lake
Plankton (% Total)									
Fragillaria	20.9 ± 19.1	24.0 ± 22.7		23.3 ± 22.7	23.5 ± 25.6	24.5 ± 21.0		24.3 ± 25.1	23.5 ± 22.2
Rhizoselenia	12.3 ± 32.5	3.4 ± 10.8		12.4 ± 33.6	12.0 ± 32.6	1.9 ± 5.7		12.3 ± 32.2	8.6 ± 26.0
Asterionella	5.4 ± 5.2	6.4 ± 7.8		4.8 ± 5.1	5.8 ± 5.6	7.7 ± 9.9		6.2 ± 6.5	6.1 ± 7.0
Melosira	1.6 ± 5.5	2.3 ± 10.3		0.7 ± 2.4	0.5 ± 1.9	0.4 ± 1.6		0.9 ± 3.2	1.1 ± 5.3
Tabellaria	0.7 ± 1.2	1.2 ± 1.8		0.9 ± 1.3	0.4 ± 0.8	2.2 ± 3.2		0.4 ± 0.7	1.0 ± 1.9
Synedra	0.6 ± 0.9	0.7 ± 1.1		0.6 ± 0.8	0.6 ± 1.2	0.7 ± 1.3		0.7 ± 1.4	0.6 ± 1.1
Dinobryon	40.6 ± 36.3	42.1 ± 36.1		40.8 ± 40.0	41.7 ± 40.3	40.9 ± 36.7		41.5 ± 40.5	41.3 ± 37.3
Ceratium	1.5 ± 2.9	0.9 ± 1.2		1.1 ± 1.6	0.7 ± 1.5	0.6 ± 0.7		0.7 ± 1.5	0.9 ± 1.6
Keratella	1.9 ± 3.9	2.7 ± 4.9		1.4 ± 3.0	0.9 ± 2.6	2.2 ± 3.5		1.3 ± 4.1	1.8 ± 3.7
Polyarthra	1.6 ± 3.7	0.9 ± 2.0		0.6 ± 1.6	0.8 ± 1.7	0.7 ± 0.9		0.4 ± 1.1	0.8 ± 2.0
Chrysosphaerella	0.1 ± 0.3	0.1 ± 0.5		0.1 ± 0.2	0.0 ± 0.0	0.2 ± 0.6		0.1 ± 0.3	0.1 ± 0.4
Copepod	0.2 ± 0.3	0.1 ± 0.3		0.2 ± 0.7	0.2 ± 0.2	0.3 ± 0.8		0.1 ± 0.3	0.2 ± 0.5
Nauplius	0.3 ± 0.5	0.1 ± 0.2		0.3 ± 0.4	0.1 ± 0.1	0.2 ± 0.3		0.1 ± 0.2	0.2 ± 0.3
Cladoceran	0.9 ± 1.4	0.8 ± 1.9		0.7 ± 1.4	0.4 ± 1.1	0.4 ± 0.5		0.2 ± 0.6	0.6 ± 1.3

Southern End Sites - 2006	CC1	CC2	E	CC3	CC4	Average Southern End
Plankton (% Total)						
Fragillaria	24.4 ± 19.8	23.9 ± 14.5	29.7 ± 24.0	32.7 ± 15.9	27.9 ± 21.8	28.1 ± 19.4
Rhizoselenia	21.2 ± 41.0	16.9 ± 38.2	0.8 ± 2.0	0.5 ± 1.3	0.0 ± 0.0	6.5 ± 22.5
Asterionella	5.3 ± 6.7	8.1 ± 9.0	9.8 ± 7.7	9.4 ± 9.3	7.5 ± 9.8	8.4 ± 8.0
Melosira	0.5 ± 1.2	0.3 ± 0.8	0.8 ± 1.8	0.9 ± 2.3	3.1 ± 4.2	1.0 ± 2.3
Tabellaria	0.0 ± 0.1	0.0 ± 0.1	1.1 ± 2.5	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 1.5
Synedra	0.8 ± 0.7	0.4 ± 0.7	0.9 ± 1.8	0.5 ± 0.6	1.7 ± 2.8	0.8 ± 1.5
Dinobryon	27.6 ± 29.9	27.6 ± 25.8	40.4 ± 37.3	19.3 ± 23.4	21.1 ± 24.8	29.7 ± 30.1
Ceratium	1.1 ± 1.1	1.3 ± 1.9	0.6 ± 0.6	0.6 ± 0.7	0.2 ± 0.3	0.8 ± 1.0
Keratella	0.7 ± 1.3	1.4 ± 3.0	0.4 ± 0.7	1.6 ± 3.3	0.5 ± 0.5	0.9 ± 1.9
Polyarthra	0.7 ± 1.6	0.1 ± 0.2	0.3 ± 0.6	1.3 ± 1.8	1.8 ± 3.8	0.8 ± 1.8
Chrysosphaerella	0.0 ± 0.1	0.1 ± 0.2	1.0 ± 3.5	1.7 ± 4.1	2.4 ± 5.3	1.0 ± 3.3
Copepod	0.1 ± 0.2	0.0 ± 0.0	0.1 ± 0.3	0.1 ± 0.2	0.0 ± 0.0	0.1 ± 0.2
Nauplius	0.1 ± 0.2	0.2 ± 0.3	0.2 ± 0.4	0.0 ± 0.0	0.1 ± 0.3	0.1 ± 0.3
Cladoceran	0.1 ± 0.2	0.0 ± 0.0	0.1 ± 0.2	0.9 ± 0.8	0.0 ± 0.0	0.2 ± 0.5

Date Averaged Data - 2005 Plankton (% Total)	7/8	7/26	9/3	10/1
Fragillaria	32.3 ± 8.8	65.3 ± 7.9	17.8 ± 13.2	46.6 ± 6.1
Asterionella	34.7 ± 5.8	3.1 ± 3.6	4.5 ± 2.4	2.7 ± 1.2
Melosira	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.5	0.0 ± 0.0
Tabellaria	0.7 ± 0.8	0.9 ± 0.4	1.7 ± 1.4	0.9 ± 0.8
Synedra	0.1 ± 0.2	0.0 ± 0.0	19.7 ± 23.6	0.1 ± 0.1
Dinobryon	0.1 ± 0.2	0.5 ± 0.5	17.0 ± 13.5	45.4 ± 8.6
Ceratium	0.5 ± 0.5	13.4 ± 9.3	7.9 ± 8.3	0.2 ± 0.3
Keratella	0.4 ± 0.8	0.5 ± 0.6	7.1 ± 5.2	0.1 ± 0.2
Polyarthra	0.1 ± 0.2	0.7 ± 0.9	10.2 ± 13.9	0.1 ± 0.3
Chrysosphaerella	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Copepod	0.7 ± 0.9	0.3 ± 0.4	0.0 ± 0.0	0.0 ± 0.0
Nauplius	0.5 ± 0.6	0.7 ± 0.6	0.3 ± 0.2	0.1 ± 0.1
Cladoceran	0.9 ± 1.4	0.5 ± 0.4	10.1 ± 7.0	0.6 ± 0.4

Date Averaged Data - 2006 Plankton (% Total)	5/24	5/29	6/5	6/19	6/27	7/5	7/17	8/15	9/1	9/11	9/30
Fragillaria	7.7 ± 4.2	0.8 ± 0.9	3.0 ± 3.0	23.8 ± 10.5	44.9 ± 12.4	23.0 ± 10.6	53.7 ± 11.7	8.5 ± 15.9	65.3 ± 14.9	16.1 ± 9.9	20.1 ± 1.6
Rhizoselenia	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.2	0.0 ± 0.0	0.6 ± 2.0	6.6 ± 12.0	73.7 ± 42.0	0.2 ± 0.4	1.3 ± 1.6	0.1 ± 0.2
Asterionella	26.6 ± 7.3	4.9 ± 4.4	8.2 ± 4.9	9.6 ± 4.7	13.3 ± 7.7	3.4 ± 2.2	10.2 ± 4.5	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
Melosira	0.2 ± 0.4	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.1	0.9 ± 2.3	0.0 ± 0.0	8.0 ± 11.3	0.1 ± 0.2
Tabellaria	6.9 ± 3.1	1.8 ± 1.6	1.0 ± 1.2	1.3 ± 1.0	0.6 ± 1.4	0.1 ± 0.2	0.9 ± 2.1	0.7 ± 2.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Synedra	1.9 ± 1.4	0.1 ± 0.2	0.0 ± 0.1	0.3 ± 0.4	0.3 ± 0.4	0.9 ± 0.9	2.6 ± 1.5	0.6 ± 1.8	0.3 ± 0.5	0.2 ± 0.3	0.1 ± 0.3
Dinobryon	54.5 ± 11.0	91.0 ± 6.8	87.4 ± 8.6	58.3 ± 17.4	23.8 ± 16.2	67.1 ± 14.8	12.0 ± 8.3	0.0 ± 0.0	0.8 ± 0.8	0.4 ± 0.6	5.5 ± 4.1
Ceratium	0.1 ± 0.2	0.0 ± 0.0	0.1 ± 0.2	0.6 ± 1.1	0.4 ± 0.5	0.9 ± 0.5	3.1 ± 2.8	0.1 ± 0.1	0.4 ± 0.4	1.5 ± 1.1	0.7 ± 0.8
Keratella	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 1.0	0.9 ± 1.1	0.6 ± 0.9	0.7 ± 1.1	0.1 ± 0.3	1.9 ± 1.5	6.5 ± 6.1	10.6 ± 2.1
Polyarthra	0.6 ± 0.9	0.0 ± 0.0	0.0 ± 0.1	0.9 ± 1.2	0.5 ± 0.6	0.2 ± 0.5	0.2 ± 0.3	0.7 ± 2.4	0.4 ± 0.4	3.5 ± 3.8	1.9 ± 0.7
Chrysosphaerella	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.9 ± 4.9	0.0 ± 0.0	0.2 ± 0.3	1.5 ± 1.1
Copepod	0.2 ± 0.2	0.0 ± 0.1	0.0 ± 0.1	0.4 ± 0.9	0.4 ± 0.7	0.0 ± 0.1	0.2 ± 0.3	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.1	0.2 ± 0.4
Nauplius	0.1 ± 0.1	0.1 ± 0.2	0.0 ± 0.1	0.2 ± 0.3	0.3 ± 0.5	0.1 ± 0.2	0.2 ± 0.3	0.0 ± 0.0	0.3 ± 0.3	0.2 ± 0.4	0.3 ± 0.4
Cladoceran	0.3 ± 0.3	0.1 ± 0.2	0.0 ± 0.1	0.4 ± 1.0	0.9 ± 1.3	0.2 ± 0.5	0.5 ± 0.9	0.0 ± 0.0	0.4 ± 0.5	1.5 ± 2.2	0.1 ± 0.2