OWASCO LAKE: A 2010 UPDATE.

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INTRODUCTION

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 seven eastern 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 fell in between these end-members (Fig. 1., Halfman and Bush, 2006). The preliminary report noted a correlation between the ranking and a qualitative assessment of water quality protection legislation. Subsequent analysis determined that this ranking more likely reflects other factors, for example, the degree of water quality implementation, land use activities, and/or the impact of recent exotics like the *Dreissena* species, the filter-feeding zebra and quagga mussels, or *cercopagis*, the carnivorous spiny water flea.

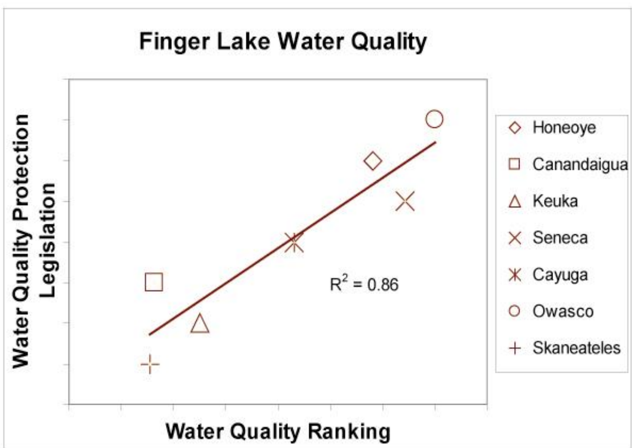

Fig. 1. The 2005 water ranking of seven Finger Lakes (Halfman and Bush, 2006).

Owasco Lake is one of the smaller Finger Lakes but it is still critical to the local health, well-being and economy of the surrounding region. It provides drinking water to ~44,000 people in Cayuga County supplying Class AA water to City of Auburn, Towns of Owasco, Sennett, Fleming, Aurelius, Springport, Brutus, Throop, Montezuma, Mentz, Port Byron, and other 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 an agricultural and tourism based economy. 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 and its ability to respond quickly to internal and external stresses (Callinan, 2001). It suggests that the lake is quickly influenced by runoff and associated pollutant threats from the watershed, but also will more quickly respond to remediation efforts to improve water quality in the lake.

Funding from the Fred L. Emerson Foundation, Auburn, NY, and New York State secured by New York Senator Michael Nozzolio enabled a detailed investigation of Owasco Lake and its watershed in the summers of 2006 and 2007. It enabled an expansion of the Finger Lakes sampling scheme to include 11 lake and 7 stream sites within the Owasco Watershed during these two field seasons. The objectives 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 source 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.

The conclusions of the 2006 and 2007 research are outlined below (Halfman et al., 2007):

(1) Owasco Lake is a borderline oligotrophic – mesotrophic ecosystem. None of the water quality parameters are life threatening at the present time.
(2) Water quality of the lake is impaired at the southern end of the lake, especially during and just after precipitation events and during years with more precipitation. The degraded water quality is interpreted to reflect, and is consistent with, the delivery of point and non-point sources of nutrients and suspended sediments from the Owasco Inlet.
(3) The nutrients and suspended sediments originated from a wastewater treatment facility point source, and non-point sources including onsite wastewater (septic) systems, agricultural activities (both animal and crop agriculture), soil erosion, stream bank erosion, fertilized lawns, roadside ditches and construction activities.
(4) The lake, and especially the southern end of the lake, was less impaired in 2007 than in 2006. The improvement was due to a combination of a DEC mandated reduction in phosphorus loading by the Groton Wastewater Treatment facility, adoption of additional best management practices in the watershed, establishment and follow through on recommendations by the newly established Watershed Inspector, and most importantly, significantly lower rainfall in 2007, and thus lower associated runoff of nutrients and suspended sediments to the lake.
(5) The study indicated that Owasco Lake becomes less impaired when nutrient loading from the watershed to the lake is significantly reduced. Thus, future efforts to reduce nutrient and sediment loadings to the lake should improve water quality in the lake.

A 2010 watershed update discussed water quality data from 2008 and 2009, and stream data from the fall of 2009 through the spring of 2010 (Halfman and O'Neill, 2010). The focus was on the 2009 and 2010 stream water quality data collected and analyzed through support from the Owasco Watershed Lake Association (OWLA) and the Town of Fleming. Once again, Dr. Joe Wasileski, President, OWLA, made this opportunity possible. The major conclusions are outlined below:

(1) Owasco Lake is still a borderline oligotrophic – mesotrophic ecosystem. None of the water quality parameters are life threatening at the present time.
(2) Unfortunately, no data were available due to budgetary constraints to comment on the water quality at the southern end of the lake.
(3) The sources of nutrients and suspended sediments include point sources like wastewater treatment facilities, and non-point sources like on-site wastewater (septic) facilities, agricultural activities (both animal and crop agriculture), soil erosion, stream bank erosion, fertilized lawns, roadside ditches and construction activities.

(4) The measured concentration data and calculated nutrient and sediment fluxes revealed that major precipitation/runoff events and the two largest watersheds, Dutch Hollow Creek and the Owasco Inlet, are significant in the nutrient loading budget for the lake.
(5) Year-to year changes in precipitation impact water quality in the lake. Years with more precipitation revealed degraded water quality compared to dryer years.
(6) Additional steps should be taken and/or intensified to reduce the nutrient loading to the lake and improve water quality in the lake. Without it, water quality will continue to decline, especially in years of high rainfall.
(7) Finally, evidence from Owasco and neighboring lakes indicates that exotic species also influence water quality. For example, zebra and quagga mussels filter feed and thus "improve" water quality by removing suspended matter, mostly algae, from the lake, whereas, the carnivorous spiny water flea (*cercopagis*) graze on and effectively remove herbaceous zooplankton which in turn "degrades" water quality through the associated mid-summer algal blooms.

METHODS

Lake Research: The 2010 lake survey sampled Sites 1 and 2 on a monthly basis in association with the May – October water quality survey by the Finger Lakes Institute (5/19, 6/22, 7/20, 8/17 & 10/2). Additional funding in late summer enabled more frequent and more detailed surveys in late July and August. The extra survey dates included 7/29, 8/6 & 8/28, and surveyed Sites 1, 2, C, D, E, CC3 and CC4. These additional sites were also surveyed on 10/2 as well. The methods and sample sites were identical to earlier investigations and mentioned below (Table 1, Fig. 2).

A CTD water quality profile, secchi disk depth, horizontal and vertical plankton tows (80-μm mesh), and surface and bottom water samples were collected at each site. The CTD electronically gathers water column profiles of temperature (°C), conductivity (as specific conductance, μS/cm), dissolved oxygen (mg/L), pH, turbidity (NTUs), photosynthetically active radiation, (PAR, $\mu E/cm^2$-s), and fluorescence (chlorophyll-a, μg/L) using a SeaBird SBE-25 CTD. The CTD was lowered from the surface to ~1m above the lake floor, collecting data every 0.5 seconds along the downcast. The plankton were preserved in an alcohol-formalin solution until identification and enumeration back in the laboratory. Water samples were analyzed onsite for temperature (°C), conductivity (specific conductance, μS/cm), pH and alkalinity using hand-held probes and field titration kits, and analyzed back in the laboratory for total phosphate, dissolved phosphate, nitrate, chlorophyll-a, and total suspended solid concentrations. Samples were stored at 4°C until analysis.

Table 1. Lake site locations and maximum water depths.

Site Name	Latitude	Longitude	Water Depth
Site 1	42° 52.4' N	76° 31.35' W	34 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 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

Laboratory Analyses: Laboratory procedures for nutrient, chlorophyll-a, and total suspended solid concentrations followed standard limnological techniques (Wetzel and Likens, 2000). Once back in the lab, water was filtered through pre-weighed, 0.45 μm glass-fiber filters. The filter and residue were dried at 80°C overnight. The weight gain and filtered volume determined the total suspended sediment concentration (mg/L). Lake water was also filtered through a Gelman HA 0.45 μm membrane filter. The filtered residue was kept frozen until chlorophyll analysis after acetone extraction by spectrophotometer. The filtrate was stored at 4°C until soluble reactive (dissolved) phosphate (μg/L) and nitrate (mg/L) colorimetric analyses by spectrophotometer. A third, unfiltered, water sample was analyzed for total phosphates (μg/L) colorimetrically by spectrophotometer after the phosphate-rich particulates were digested in hot (100ºC) persulfate. For the plankton enumerations, over 100 individuals were identified to genus level and reported as date averaged relative percentages. 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, and nitrate 0.1 mg/L. All water samples were kept at 4°C until analysis and typically analyzed within a week of collection.

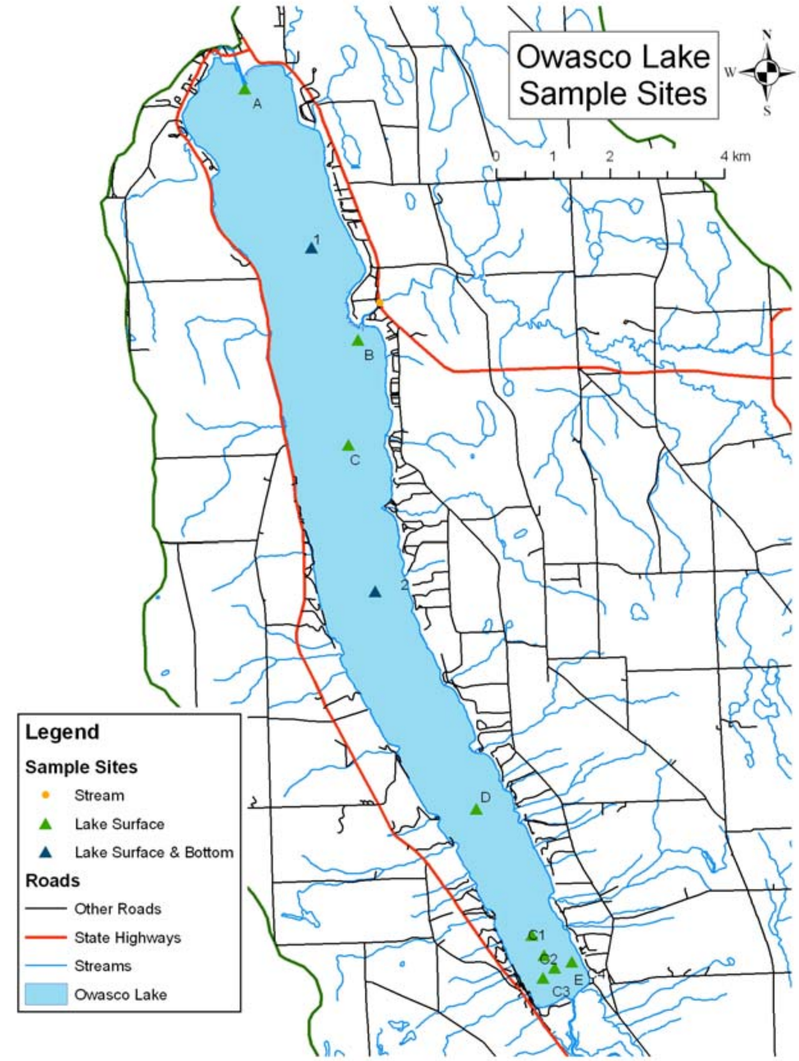

Fig. 2. Lake site locations. Dutch Hollow Creek, the second largest Subwatershed (76 km^2), enters the lake near Site B. The Owasco Inlet, the largest Subwatershed (298 km^2), enters the lake at the southern end of the lake.

LAKE RESULTS & DISCUSSION

Lake CTD Profiles: The water temperature profiles were, for the most part, typical for any summer season (Fig. 3). Surface water (epilimnetic) temperatures in Owasco Lake ranged from just over 10ºC to 25ºC. Bottom water (hypolimnetic) temperatures were uniform, approximately 7ºC. A thermocline, the depth in the water column that separates the warmer, surface-water, epilimnion from the colder, bottom-water, hypolimnion and defined by the depth with the largest decrease in water temperature with water depth, was typically observed at 10 to 17 meters at every site on every survey date. The summer changes in its depth from site to site or data to date can be attributed to internal seiche activity, the periodic, see-saw like, oscillation of the thermocline set up by strong axial wind events. The thermocline was deeper in the early October profile due to the seasonal cooling and decay of the epilimnion. The epilimnion and hypolimnion were slightly warmer (by 1 to 2ºC) in 2010 than previous years but additional data are required to delineate firm reasons for the change.

Epilimnetic conductivity data (reported as specific conductance, a parameter proportional to water salinity) ranged from 300 to 325 μS/cm, and decreased through the summer season whereas the hypolimnetic specific conductance data were ~330 μS/cm and remained uniform over time (Fig. 3). The decline in epilimnetic salinity through the summer season probably reflected the dilution of the epilimnion with less saline runoff over time.

The specific conductance profile on 10/2/10 stands out from the other profiles. It reveals a spike to unusually smaller salinities just above the hypolimnion at Sites D and E (down to 275 μS/cm at Site E), the southernmost sites. This date surveyed the lake just after a major rainstorm. Thus, it is interpreted to reflect the input of relatively fresh runoff to the lake from the Owasco Inlet. This interpretation is consistent with changes observed on this survey date in the turbidity and other profiles described below.

Photosynthetic available radiation (sunlight) decreased exponentially with water depth from a maximum intensity of 200 to 2,000 μE/cm^2-s at the surface to 1% surface light intensities at water depths of 15 to 27 m (Fig. 4). The 1% depth is highlighted because this light intensity is critical for algal to photosynthesize enough biomass to survive. This decrease is normal. Sunlight is progressively and exponentially absorbed and converted to heat or scattered back to the atmosphere after it enters lakes, until the lake becomes dark deeper in the water column. Many of the profiles reveal a sharp decrease at 2 or 3 meters. It corresponds to the sensor passing through the shadow of the boat. The range in surface intensities reflected the season, the extent of cloud cover, and turbidity of the water on the survey date. The 2010 data are consistent with data from earlier years.

Fluorescence profiles, a measure of algal concentrations, revealed the largest concentrations of algae within the epilimnion (Fig. 3). Algal peaks typically extended downward into the metalimnion of the lake. Peak chlorophyll-a concentrations were up to 4 μg/L, but more typically between 1 and 3 μg/L in 2010, with slightly smaller peak concentrations in 2010 than earlier years. Hypolimnetic concentrations were consistently below 1 μg/L. The 10/2/10 profile revealed small algal concentrations in the epilimnion and is consistent with the input of algae-poor, runoff plume of Owasco Inlet water.

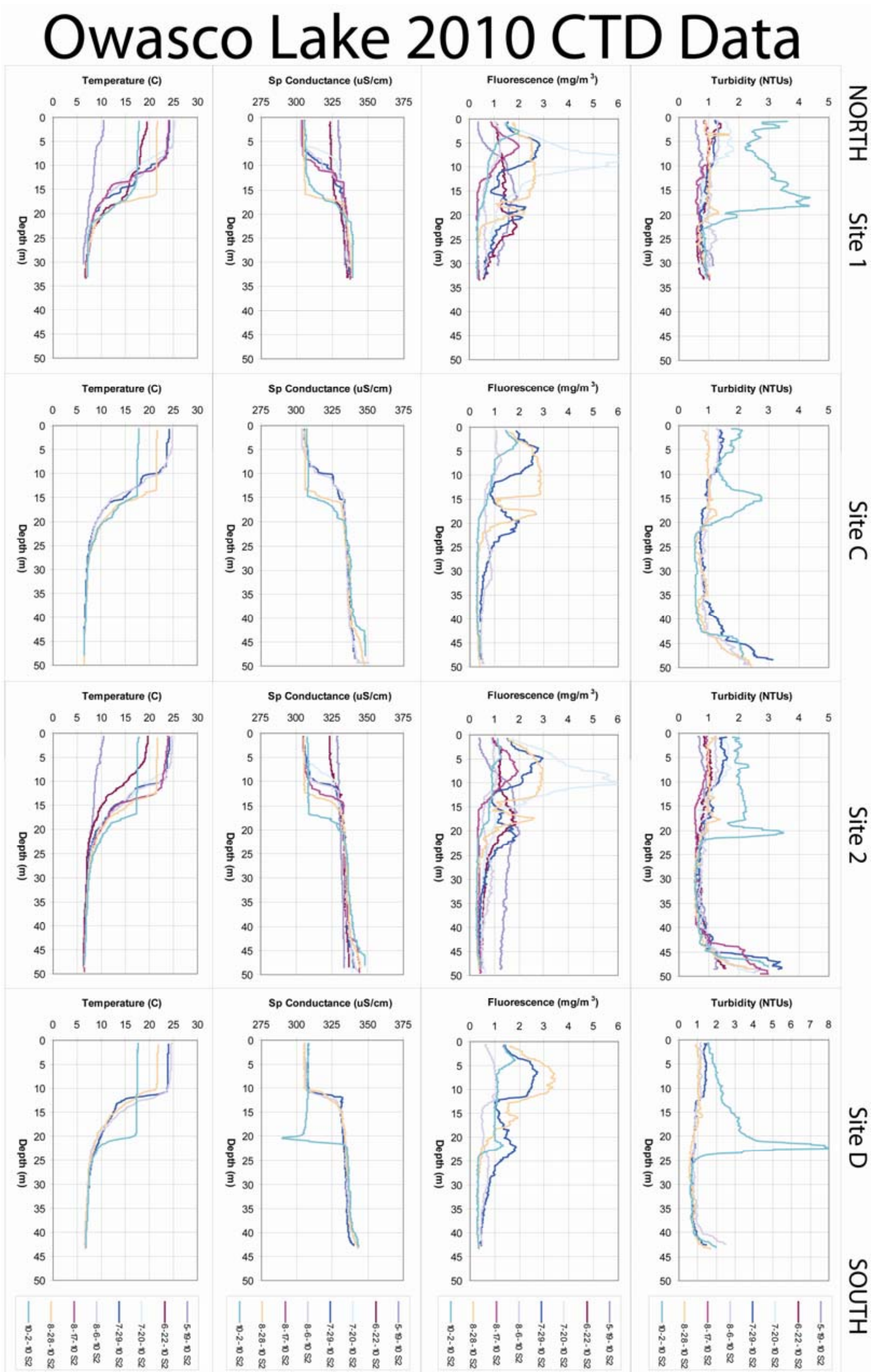

Fig. 3. Owasco 2010 CTD profiles from Sites 1, C, 2 and D, aligned along the north to south transect. Profiles were collected from Sites 1 & 2 on every survey date, and from C & D after funding enabled the survey expansion on 7/29.

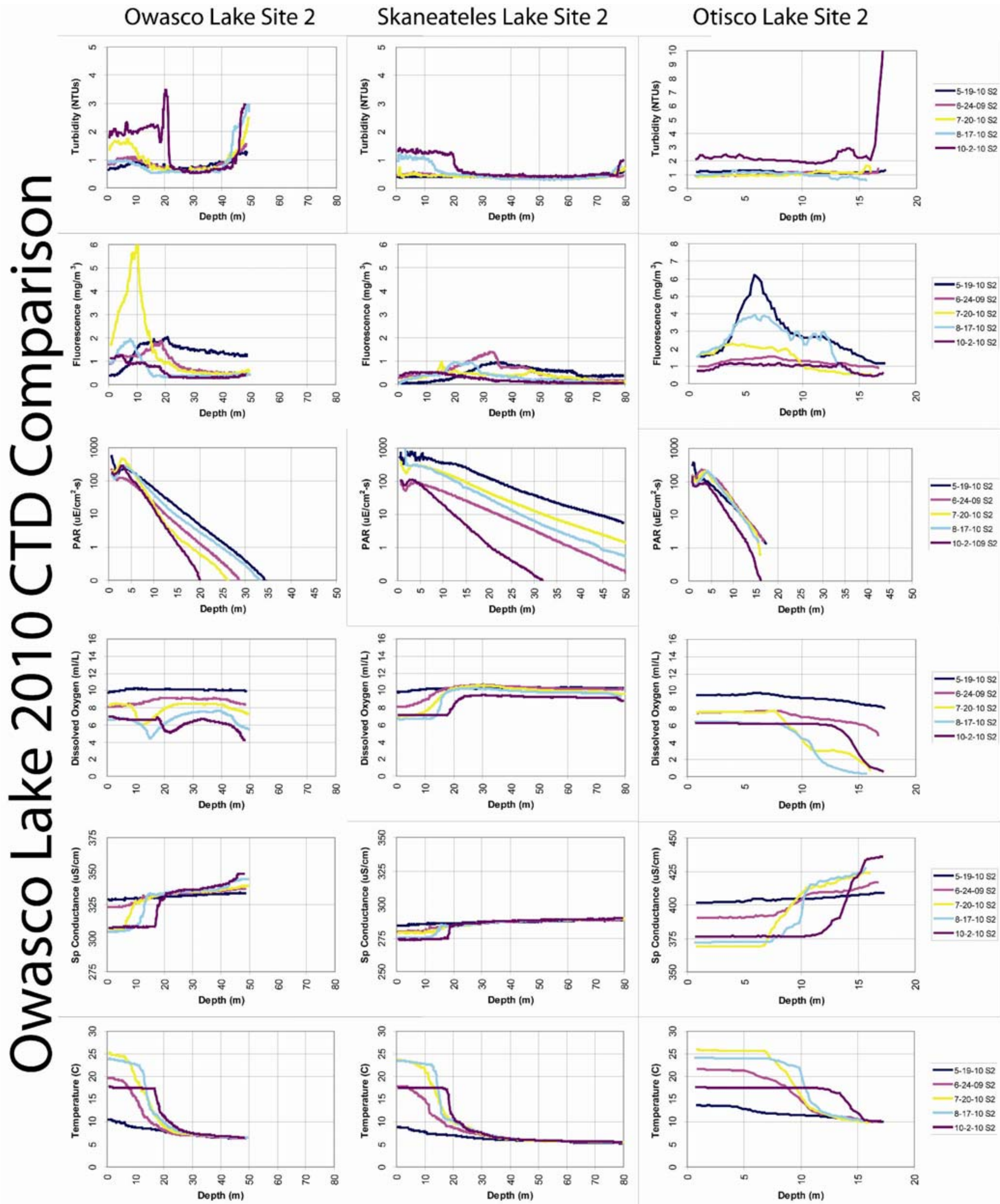

Fig. 4. 2010 CTD Profiles from Owasco, Skaneateles and Otisco Lakes. Please note, the light data are plotted on an exponential scale, so exponential changes with water depth appear as straight lines.

The 2010 turbidity profiles revealed near surface (epilimnetic) and, at Sites C & 2 only, benthic (lake-floor) intervals of increased turbidity (decreased water clarity). The near surface turbidity was detected throughout the epilimnion, occasionally extended down into the metalimnion, and revealed turbidities up to 1.5 NTUs. The shape and extent of the profiles are proportional to fluorescence data. It suggests that the epilimnetic turbidity was primarily algal in origin. The epilimnetic turbidity concentrations are similar to previous years.

The epilimnetic turbidity on 10/2/10 revealed significantly larger turbidities, from turbidities below 1.5 NTUs on any other survey date to a maximum of 2 up to 8 NTUs at any one site on this day. The largest turbidities are located just above the thermocline. The extent and sharpness of the plume decays northward along Sites E, CC1, D, 2 and C until larger turbidities are observed at Site 1 in the north. The plume geometry and coexistence of less saline and algae poor water is consistent with a plume of suspended sediment that entered the lake from the Owasco Inlet, and flowed and dispersed northward to the outlet. The plume was apparently rejuvenated at Site 1, just north of Dutch Hollow Creek, and suggests turbid water from the creek was added to the existing plume, and both flowed towards the outlet. Collectively, the specific conductance, fluorescence and turbidity profiles suggest that Owasco Inlet and other tributary runoff displaced the lower portion of the epilimnion within days of the storm. It highlights the quick response of Owasco Lake to runoff events.

Water density (a function of water temperature, salinity and turbidity) controls the depth of the plume, and a plume found just above the thermocline indicates the plume was slightly more dense than the epilimnion but slightly less dense than the hypolimnion. Any denser, and the plume would have hugged the lake floor as a density current.

Benthic nepheloid layers (bottom water turbid zones just above the lake floor) were prevalent at Sites C & 2, the two deepest sites in 2010. A fluorescence peak was not observed at this depth, indicating that the source of the benthic turbidity was inorganic particles, probably brought to the lake from tributaries and/or nearshore sediments eroded by waves and currents during high winds. Once suspended, the sediments were eventually brought to the deepest basin of the lake by density flows. These nepheloid layers were less prevalent in 2007 & 2008 than 2009 and most prevalent in 2010, and probably reflected a change in sediment inputs from streams and shallow water erosion by waves.

Dissolved oxygen (DO) concentrations were typically between 6 and 10 mg/L in the epilimnion, down to as low as 4 mg/L in late July and August at the base of the epilimnion, only to increase by ~1 mg/L in the upper hypolimnion, and finally decrease down to as low as 4 mg/L in the lower hypolimnion by the end of the survey (Fig. 4). DO concentrations respond to three forcing functions, water temperature, colder water dissolves more gas than warmer water, the amount of photosynthesis and respiration, photosynthesis by algae adds oxygen and respiration by bacteria consumes oxygen, and the diffusion of oxygen between the atmosphere and the lake across the lake's surface. The decrease in the epilimnetic DO concentrations reflected warming of the epilimnion through the summer, as warmer water is saturated at progressively lower concentrations. Any excess DO typically diffuses back to the atmosphere. DO concentrations are maintained at or near saturated conditions in the epilimnion throughout the summer because at these depths photosynthesis by algae is more prevalent than bacterial respiration, and any changes from saturation are slowly equilibrated to saturated conditions over time due to diffusion with oxygen in the atmosphere.

DO concentrations declined to below saturated conditions in the hypolimnion. The decrease reflected the utilization of oxygen by bacterial respiration. Other factors were not important in the hypolimnion because water temperature did not change, the water is too dark for DO additions by photosynthesis, and too isolated from the atmosphere for diffusion across the lake's surface. The hypolimnetic dissolved oxygen was smaller in 2010 than previous years (minima of 4 rather then 6 mg/L), probably reflecting the respiration of more algae. These low concentrations were near the threshold that initiates respiratory stress in sensitive aquatic organisms living in the hypolimnion or on/in the lake floor sediments.

Skaneateles, Otisco and Owasco Lake CTD Comparison: The seasonal progression (cold to warm to cool epilimnion) in the temperature profiles was also observed in Skaneateles and Otisco Lakes (Fig. 4). The small variability between lakes is attributed to the difference in maximum depths and volumes of each lake. The deeper and larger Skaneateles was colder, and the shallower Otisco was warmer than Owasco Lake. The hypolimnetic differences probably reflected the depth and duration of surface mixing by winds and surface currents before the onset of stratification in relation to the maximum water depth of the lake, i.e., the shallower Otisco was kept mixed further into the summer season, thus the entire water column got warmer before the onset of stratification and the isolation of the epilimnion from the hypolimnion. The larger volume of cold water in Skaneateles kept its epilimnion cooler in the summer; the same solar inputs experiences at every lake can not warm up more water. In simple terms, similar seasonal solar inputs impacted the smaller Otisco Lake faster than the other lakes.

The specific conductance profiles from Skaneateles and Otisco Lakes also revealed a decrease in salinity in the epilimnion through the summer season (Fig. 4). However, the decline was smaller in Skaneateles and larger in Otisco than Owasco Lake. These differences probably reflected the relative size of the lakes to their watersheds. For example, similar inputs of less saline rainwater would have a greater influence on the smaller Otisco than the larger Skaneateles. This difference is increased because the watershed to lake surface are ratio is smaller for Skaneateles than any other lake, thus it is subjected to smaller runoff given the same size precipitation event. Both Owasco and Otisco lake-floor salinities increased through the field season, but data are lacking to determine a likely cause at this time.

Otisco was slightly more saline, and Skaneateles slightly less saline, than Owasco (Fig. 4), but the differences between Skaneateles and Otisco was small, only 0.05 ppt (estimated at ~0.13 ppt in Skaneateles to ~0.18 ppt in Otisco Lake). The small variability probably reflected the difference in the underlying bedrock, glacial till and soils and their susceptibility to weathering in the three watersheds, the application of road salt in the watershed, and/or groundwater connections to rock salt bedrock underlying these lakes.

The fluorescence profiles (Fig. 4) revealed more algae in Otisco Lake (from 1 to 4 mg/m^3 with a peak at 6 mg/m^3) than Owasco Lake (0.5 to 2 mg/m^3 with a peak of 6 mg/m^3) and both these lakes had considerably more algae than Skaneateles Lake (consistently below 1 mg/m^3). The depth of the peak in algal concentrations was different as well, 5 m and well above the thermocline in Otisco Lake, 10 to 20 m and closer to the thermocline in Owasco lake, and to 20 to 35 m and below the thermocline in Skaneateles Lake. The concentrations and depth ranges indicate that these three lakes span a range of trophic (algal productivity) states from the less productive Skaneateles Lake to an intermediate Owasco Lake, to a highly productive Otisco Lake.

The turbidity profiles also revealed small differences between the three lakes (Fig. 4). Turbidities were smaller in Skaneateles, and progressively larger in Owasco and Otisco, from below 1 to above 1 NTUs, respectively. The difference parallels the change in fluorescence results, suggesting that the bulk of the turbidity in the epilimnion is due to the algae. The largest turbidity profiles were detected on 10/2/10 in each lake, with turbidities above 1 NTUs in Skaneateles, above 3 NTUs in Owasco, and above 10 NTUs in Otisco Lake. It suggests that the runoff event just before 10/2/10 impacted all three lakes, and had the greatest impact on the smallest / shallowest lake.

Skaneateles dissolved oxygen (DO) concentrations were saturated or close to saturation throughout the water column throughout the 2010 field season. In contract, Otisco hypolimnetic DO concentrations were depleted to anoxic conditions by mid-June, and Owasco hypolimnetic DO depletions were between these extremes (Fig. 4). The difference reflected the degree of algal productivity in the lakes and subsequent bacterial decomposition and respiration of the dead algae in the hypolimnion between these three lakes and their relative size. The least productive lake, Skaneateles, has the smallest demands on hypolimnetic DO by bacteria and largest amount of DO available in the hypolimnion (largest DO concentration and hypolimnion size) to be utilized by the bacteria. Otisco, the most productive lake, had the largest demands and smallest amount of hypolimnetic DO to meet those demands.

Two outcomes are apparent. First, the temperature and specific conductance profiles in Skaneateles Lake were modified to a smaller extent through the summer season than the smaller and shallower Owasco and Otisco Lakes. Second, the biologically related parameters, fluorescence, dissolved oxygen, turbidity (except for the 10/2/10 runoff event), and light penetration, revealed the intermediate trophic nature of Owasco Lake between the Skaneateles and Otisco end members. It parallels observations elsewhere; smaller lakes become eutrophic more easily than larger lakes, assuming similar nutrient inputs. It also reflects the significant effort to reduce nutrient loading to Skaneateles Lake from its watershed. The result, Skaneateles remains oligotrophic, and as a consequence, preserves its ability to deliver drinking water directly from the lake without filtration.

2010 Chlorophyll, Nutrient, TSS and Secchi Data: The 2010 lake data indicate that the lake is not a health threat, as the nitrate concentrations are below the 10 mg/L MCL established by the EPA, nor impaired, as the total phosphate concentrations are always below the 20 mg/L threshold for impaired water bodies established by the DEC (Table 2, Figs. 5 & 6). A few additional observations are noteworthy. First, the dissolved phosphate to nitrate ratio in the lake, the nutrients available for algal uptake, was above 1:1,000. The measured P:N ratio in algae (Redfield Ratio) is 1:7. The difference indicates that phosphate was the limiting nutrient throughout the year, as the supply of phosphorus becomes scarce and thus limited additional growth until more phosphorus entered the lake and all this happened before algae “ran out” of the available of nitrogen. Second, some variability is observed from site to site in the site averaged plots, but most of the variability is small and expected (Fig. 5). Chlorophyll and total phosphate are the exceptions. Slightly larger chlorophyll concentrations were detected at the most northerly site (Site 1) and indicate that the densest algal blooms in 2010 were in the northern portion of the lake. More phosphorus was also detected at the southernmost sites, perhaps reflecting the addition by the Owasco Inlet or small pieces of rooted plants (macrophytes). Third, some variability is observed from one survey date to the next in the date averaged plots (Fig. 6). Secchi disk depths were shallowest and total phosphates, nitrates, chlorophyll and total suspended solids were largest during July and October. It suggests a significant bloom in the mid-summer months, perhaps stimulated by the growth of *cercopagis* (carnivorous spiny water flea) or a nutrient rich runoff event in July, and a major runoff event in October that was observed in the CTD profiles. Fourth, dissolved nutrient concentrations (phosphate, nitrate and silica) reveal a small increase from the epilimnion to the hypolimnion, e.g., annual mean soluble reactive phosphate changed from 0.4 to 0.9 μg/L, nitrate 0.7 to 0.9 mg/L, silica 720 to 1260 μg/L, and chlorophyll-a 3.0 to 2.2 μg/L, and is interpreted to reflect the normal seasonal progression resulting from algal uptake of nutrients and their growth in the epilimnion, and algal decomposition and nutrient release by bacteria in the hypolimnion.

Annual mean nutrient concentrations revealed small changes from 2008 to 2009 that for the most part persisted through 2010. Total phosphate concentrations increased slightly from 2008 to 2009 and 2010 (7.4 to 8.1 and 8.1 μg/L), dissolved phosphate concentrations decreased slightly from 2008 to 2009 and decrease some more in 2010 (0.9 to 0.7 and 0.4 μg/L), chlorophyll-a and TSS concentrations increased (2.6 to 3.9 to 3.7 μg/L; 1.3 to 1.9 to 1.9 mg/L), and secchi disk depths became shallower (4.2 to 3.2 to 3.7 m) from 2008 to 2009 through 2010 as well (Table 4 and Fig. 7). The trends are consistent with increased algal productivity from 2008 to 2009 through 2010 but the change is small. These interpretations are consistent with the CTD data. However, the changes were precipitately close to the range of the annual data (1σ), and were almost too small to be significant. In contrast, nitrate concentrations remained uniform. Uniform nitrate concentrations are expected, because nitrates are not the limiting nutrient in Owasco Lake.

Owasco Trophic Status: Annual mean secchi disk, nutrient and chlorophyll data from 2010 indicate that the open-lake concentrations were either a borderline oligotrophic-mesotrophic or mesotrophic system (Tables 2 & 3, Figs. 5 & 6). Annual mean secchi disk depths and oxygen saturation values are within the mesotrophic range however, total phosphate and chlorophyll concentrations are borderline oligotrophic/mesotrophic. The trophic status was similar in 2009 but 2010 and 2009 were slightly more mesotrophic than the status in 2007 and 2008. The secchi disk depths were deeper, and total phosphate and chlorophyll concentrations were smaller, in 2007 and 2008 than 2009 and 2010.

Table 2. Typical concentrations for oligotrophic (low productivity), mesotrophic (mid-range 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

Table 3. 2010 Lake Data.

2010 Owasco Lake Site Averaged and Date Averaged Data

Site Averaged Surface Water Data

Site	Secchi Depth	Suspended Solids	Total Phosphate	Dissolved Posphate	Nitrate	Silica	Chlorophyll
	(m)	(TSS, mg/L)	(TP, ug/L)	(SRP, ug/L)	(N, mg/L)	(Si, ug/L)	(ug/L)
1	3.8	1.7	7.9	0.4	0.6	597.5	3.9
C	3.9	1.7	9.2	0.3	0.7	627.4	3.4
2	3.8	1.4	6.6	0.7	0.6	604.1	2.8
D	3.9	1.4	7.6	0.7	0.8	534.2	2.0
E	3.3	1.8	8.3	0.2	0.8	458.1	2.3
CC3		0.8	11.3	0.2	0.6	459.7	1.7
CC4		1.0	12.9	0.9	0.4	403.0	1.5
Average	3.7	1.4	9.1	0.5	0.6	526.3	2.5

Site Averaged Bottom Water Data

Site	Secchi Depth	Suspended Solids	Total Phosphate	Dissolved Posphate	Nitrate	Silica	Chlorophyll
	(m)	(TSS, mg/L)	(TP, ug/L)	(SRP, ug/L)	(N, mg/L)	(Si, ug/L)	(ug/L)
1	---	0.9	5.5	1.0	0.9	1197.5	1.3
C	---	1.6	4.2	2.0	0.7	1552.2	0.7
2	---	1.5	5.6	1.5	0.8	1412.9	0.6
D	---	0.9	5.3	1.3	1.0	1377.3	0.5
E	---	---	---	---	---	---	---
CC3	---	---	---	---	---	---	---
CC4	---	---	---	---	---	---	---
Average	---	1.2	5.2	1.5	0.9	1385.0	0.8

Date Averaged Surface Water Data

Date	Secchi Depth	Suspended Solids	Total Phosphate	Dissolved Posphate	Nitrate	Silica	Chlorophyll
	(m)	(TSS, mg/L)	(TP, ug/L)	(SRP, ug/L)	(N, mg/L)	(Si, ug/L)	(ug/L)
5/19/10	5.4	0.8	6.5	1.2	0.4	800.7	0.9
6/22/10	4.0	1.1	7.2	0.5	0.3	608.3	1.1
7/20/10	2.1	2.9	4.2	0.0	0.3	259.0	4.9
7/29/10	3.1	1.2	7.0	1.0	0.7	419.0	2.1
8/6/10	4.0	0.7	10.0	0.1	0.5	512.2	1.5
8/17/10	4.1	1.0	5.7	0.3	0.4	581.9	2.4
8/28/10	5.0	1.5	8.1	0.6	0.5	428.7	3.2
10/2/10	3.3	2.8	11.9	0.2	1.3	868.3	6.4
Average	3.7	1.6	7.7	0.4	0.6	525.3	3.1

Date Averaged Bottom Water Data

Date	Secchi Depth	Suspended Solids	Total Phosphate	Dissolved Posphate	Nitrate	Silica	Chlorophyll
	(m)	(TSS, mg/L)	(TP, ug/L)	(SRP, ug/L)	(N, mg/L)	(Si, ug/L)	(ug/L)
5/19/10	---	1.0	4.7	3.1	0.5	934.2	0.7
6/22/10	---	1.2	8.1	0.4	0.5	995.7	0.2
7/20/10	---	1.2	4.4	0.1	0.5	974.9	1.0
7/29/10	---	1.4	4.2	0.7	1.0	1409.2	2.2
8/6/10	---	0.8	6.3	0.7	0.6	1362.8	0.7
8/17/10	---	1.1	4.3	0.6	0.8	1665.3	0.3
8/28/10	---	1.3	5.6	3.7	0.8	1509.1	0.4
10/2/10	---	1.3	5.5	0.2	2.0	1703.6	0.4
Average	---	1.2	5.5	0.9	0.9	1374.4	0.7

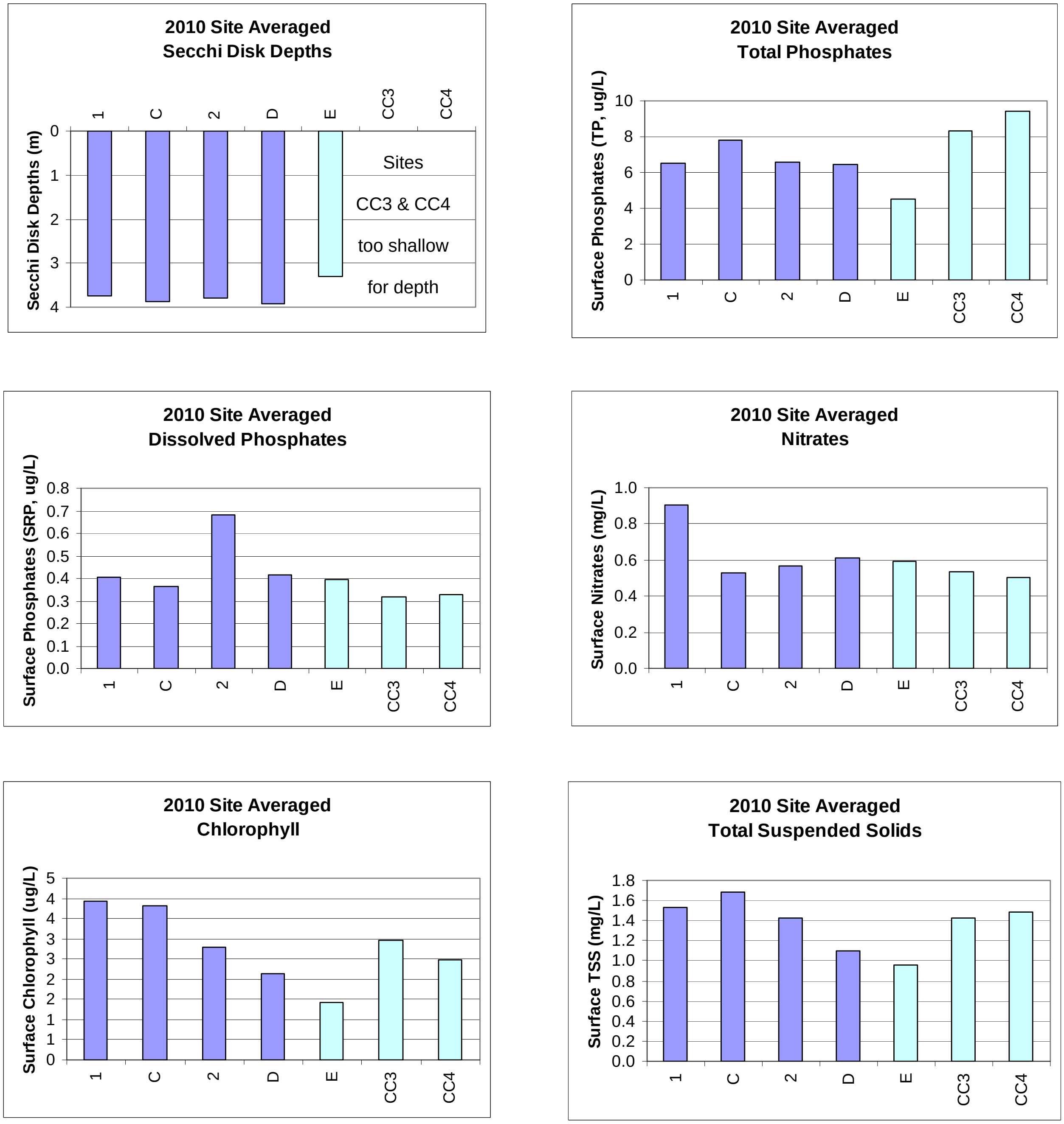

Fig. 5. 2010 site averaged surface water data. The dark blue bars are open water sites, light blue bars southern end sites. Sites CC3 & CC4 were to shallow for a secchi disk reading.

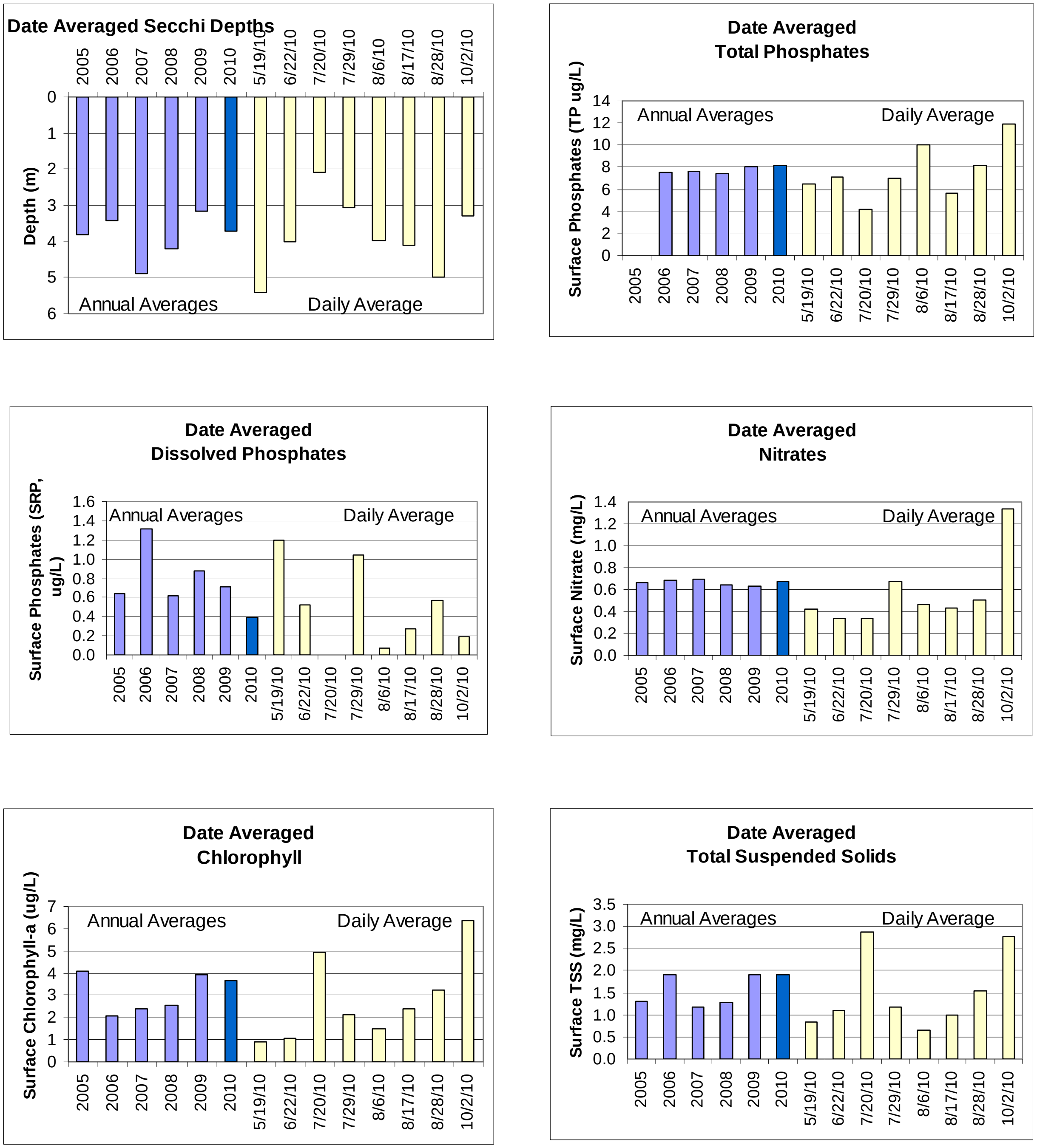

Fig. 6. Annual averaged and 2010 date averaged surface water data.
The dark blue bars are annual averages, yellow bars are 2010 daily averages.

Plankton Data: The phytoplankton species in Owasco Lake are dominated by diatoms, primarily *Flagillaria*, with smaller numbers of *Tabellaria*, *Rhizoselenia*, *Synedra* and *Asterionella* (Table 5, Fig. 8). Other phytoplankton species include the dinoflagellate *Dinobryon*, with some *Ceratium* and *Coalcium*. The seasonal succession typically moved from *Asterionella* to *Flagillaria* to *Dinobryon*. In the past few years, Blue green species have increased in abundance, with *Mycrocystis* representing up to 40% of the plankton this past year. They were most abundance in the later part of the summer season. The onset of *Mycrocystis* is distubring, because it dominates eutrophic systems that are nutrient rich, productive and turbid. Blue greens contain gas vacuoles that enable them to float at or near the surface of the lake and thus it outcompetes other algae for the available light. Although not important here, they can also fix nitrogen from the atmosphere, if nitrogen is the limiting nutrient in the system. The resulting surface-water scum of algae is unpleasant, as it is unsightly, occasionally smells, and some species of blue greens are toxic to humans. Unfortunately, the detection methods used in this research does not differentiate the *Mycrocystis* species in Owasco Lake. Zooplankton species were dominated by rotifers, with some cladocerans. Zebra and quagga mussel larvae are detected in the samples, as well as *cercopagis*, the spiny water flee.

Major Ions: The major ions were still dominated by bicarbonate (HCO_3^-) measured as alkalinity), and calcium (Ca^{2+}) with lesser amounts of magnesium (Mg^{2+}) and sodium (Na^+) reflecting the weathering of carbonate-rich bedrock and soils. It suggests that whiting events, the precipitation of carbonate during algal blooms on hot, calm, summer days, occurred in Owasco Lake, further degrading water clarity and quality. When it happens, the lake turns a milky green color. Carbonates are detected in the sediment and confirm the precipitation of calcite in the water column.

Table 4: Annual Mean Lake Data from the Finger Lake Survey.

2008 Average Values (± 1σ)	Honeoye	Canandaigua	Keuka	Seneca	Cayuga	Owasco	Skaneateles	Otisco
Secchi Depth (m)	4.6 ± 0.9	6.7 ± 1.6	6.5 ± 0.7	4.7 ± 2.8	3.8 ± 1.0	4.2 ± 1.2	7.8 ± 1.2	3.1 ± 0.9
Total Suspended Solids (mg/L), Surface	1.4 ± 0.8	0.9 ± 0.5	1.0 ± 0.2	1.7 ± 0.8	1.5 ± 0.5	1.3 ± 0.7	0.6 ± 0.2	2.3 ± 1.9
Total Suspended Solids (mg/L), Bottom	1.2 ± 0.2	1.5 ± 1.0	1.2 ± 0.5	0.8 ± 0.4	2.5 ± 1.5	1.2 ± 0.6	0.7 ± 0.4	2.1 ± 0.7
Dissolved Phosphate (µg/L, SRP), Surface	4.6 ± 6.1	0.9 ± 0.6	0.6 ± 0.5	0.9 ± 1.3	0.8 ± 0.8	0.9 ± 0.7	0.7 ± 0.5	0.8 ± 1.2
Dissolved Phosphate (µg/L, SRP), Bottom	3.7 ± 5.2	1.3 ± 0.9	0.9 ± 0.6	3.2 ± 3.1	7.7 ± 4.2	1.1 ± 1.1	1.1 ± 1.1	4.8 ± 9.7
Total Phosphate (µg/L, TP), Surface	19.2 ± 5.6	7.9 ± 3.3	5.4 ± 2.7	9.8 ± 2.9	8.0 ± 1.4	7.4 ± 2.7	3.4 ± 1.7	12.8 ± 3.1
Total Phosphate (µg/L, TP), Bottom	18.4 ± 3.8	7.4 ± 4.5	6.8 ± 4.3	9.4 ± 3.0	12.5 ± 3.7	8.9 ± 2.0	4.8 ± 2.1	14.2 ± 9.6
Nitrate as N (mg/L), Surface	0.0 ± 0.0	0.2 ± 0.2	0.0 ± 0.0	0.2 ± 0.1	0.7 ± 0.4	0.6 ± 0.2	0.4 ± 0.2	0.3 ± 0.1
Nitrate as N (mg/L), Bottom	0.0 ± 0.0	0.3 ± 0.2	0.2 ± 0.1	0.3 ± 0.1	1.1 ± 0.5	0.9 ± 0.4	0.6 ± 0.2	0.3 ± 0.2
Silica (SR µg/L), Surface	823 ± 266	994 ± 163	462 ± 148	309 ± 291	358 ± 188	751 ± 514	290 ± 89	334 ± 413
Silica (SR µg/L), Bottom	865 ± 252	1589 ± 513	1157 ± 419	470 ± 117	1033 ± 225	1474 ± 531	825 ± 231	1298 ± 890
Chlorphyll a (µg/L), Surface	2.7 ± 1.9	1.6 ± 1.0	2.0 ± 1.1	4.6 ± 2.7	4.0 ± 1.4	2.6 ± 1.3	0.7 ± 0.3	3.7 ± 0.6
Chlorphyll a (µg/L), Bottom	1.9 ± 0.9	0.9 ± 1.1	0.5 ± 0.2	1.5 ± 1.4	0.3 ± 0.2	0.8 ± 0.6	0.4 ± 0.2	3.0 ± 1.7

2009 Average Values (± 1σ)	Honeoye	Canandaigua	Keuka	Seneca	Cayuga	Owasco	Skaneateles	Otisco
Secchi Depth (m)	2.8 ± 1.0	6.5 ± 1.0	5.4 ± 0.9	5.1 ± 2.1	3.5 ± 1.0	3.2 ± 1.1	7.6 ± 1.1	2.8 ± 0.8
Total Suspended Solids (mg/L), Surface	2.1 ± 1.7	1.6 ± 1.5	0.7 ± 0.2	1.5 ± 0.7	1.8 ± 0.8	1.9 ± 1.0	0.7 ± 0.2	2.2 ± 0.7
Total Suspended Solids (mg/L), Bottom	1.7 ± 0.7	1.7 ± 0.6	1.1 ± 0.3	0.7 ± 0.4	2.5 ± 1.1	1.2 ± 0.6	0.6 ± 0.3	1.8 ± 0.6
Dissolved Phosphate (µg/L, SRP), Surface	2.0 ± 1.6	0.7 ± 0.4	0.3 ± 0.2	0.4 ± 0.4	0.9 ± 1.2	0.7 ± 0.6	0.4 ± 0.3	0.5 ± 0.4
Dissolved Phosphate (µg/L, SRP), Bottom	1.7 ± 2.1	1.0 ± 0.9	0.8 ± 0.5	1.5 ± 2.0	6.4 ± 3.1	1.2 ± 0.9	0.8 ± 0.6	1.9 ± 2.1
Total Phosphate (µg/L, TP), Surface	19.5 ± 8.9	5.3 ± 1.9	4.9 ± 1.1	8.1 ± 1.9	6.8 ± 1.9	8.1 ± 5.2	2.7 ± 1.8	36.1 ± 60.3
Total Phosphate (µg/L, TP), Bottom	16.1 ± 5.2	3.7 ± 1.9	5.2 ± 2.1	9.7 ± 5.0	9.4 ± 3.0	6.8 ± 5.1	4.9 ± 2.5	10.6 ± 11.1
Nitrate as N (mg/L), Surface	0.0 ± 0.0	0.1 ± 0.0	0.1 ± 0.1	0.3 ± 0.2	0.9 ± 0.5	0.6 ± 0.2	0.5 ± 0.2	0.2 ± 0.1
Nitrate as N (mg/L), Bottom	0.0 ± 0.1	0.3 ± 0.1	0.2 ± 0.2	0.5 ± 0.2	1.1 ± 0.6	0.8 ± 0.3	0.5 ± 0.2	0.3 ± 0.1
Silica (SR µg/L), Surface	801 ± 93	939 ± 239	444 ± 184	279 ± 266	403 ± 205	737 ± 232	384 ± 210	321 ± 297
Silica (SR µg/L), Bottom	821 ± 131	1243 ± 253	1052 ± 265	400 ± 179	976 ± 240	1189 ± 323	661 ± 255	854 ± 444
Chlorphyll a (µg/L), Surface	14.1 ± 14.6	1.5 ± 0.9	1.2 ± 0.7	2.6 ± 2.1	3.5 ± 2.3	3.9 ± 1.7	1.1 ± 0.9	5.7 ± 4.1
Chlorphyll a (µg/L), Bottom	7.9 ± 7.7	0.4 ± 0.1	0.4 ± 0.1	0.9 ± 1.2	0.5 ± 0.2	0.9 ± 0.6	0.3 ± 0.2	2.8 ± 2.1

2010 Average Values (± 1σ)	Honeoye	Canandaigua	Keuka	Seneca	Cayuga	Owasco	Skaneateles	Otisco
Secchi Depth (m)	2.5 ± 1.2	7.1 ± 1.8	6.6 ± 1.4	3.9 ± 1.4	4.5 ± 1.7	3.7 ± 1.1	7.5 ± 1.9	3.8 ± 0.6
Total Suspended Solids (mg/L), Surface	6.4 ± 7.1	0.8 ± 0.5	0.8 ± 0.4	1.7 ± 1.0	1.4 ± 0.9	1.9 ± 1.0	0.6 ± 0.3	1.5 ± 0.7
Total Suspended Solids (mg/L), Bottom	2.5 ± 1.2	0.8 ± 0.4	0.9 ± 0.5	0.6 ± 0.3	1.4 ± 0.7	1.2 ± 0.3	0.4 ± 0.2	1.6 ± 0.9
Dissolved Phosphate (µg/L, SRP), Surface	11.0 ± 12.4	0.9 ± 0.8	0.3 ± 0.2	0.7 ± 1.4	0.9 ± 1.6	0.4 ± 0.4	0.3 ± 0.2	0.4 ± 0.3
Dissolved Phosphate (µg/L, SRP), Bottom	15.1 ± 15.8	0.6 ± 0.5	0.4 ± 0.4	1.5 ± 2.0	3.9 ± 2.5	0.9 ± 1.2	0.5 ± 0.9	2.0 ± 3.9
Total Phosphate (µg/L, TP), Surface	52.4 ± 54.4	5.2 ± 2.8	4.3 ± 1.3	6.5 ± 2.1	7.4 ± 4.7	8.1 ± 4.1	3.0 ± 1.4	8.6 ± 2.2
Total Phosphate (µg/L, TP), Bottom	37.1 ± 24.3	2.9 ± 1.0	3.7 ± 1.2	5.8 ± 2.1	9.7 ± 3.0	5.4 ± 2.2	2.3 ± 1.9	11.4 ± 10.3
Nitrate as N (mg/L), Surface	0.1 ± 0.2	0.1 ± 0.0	0.0 ± 0.0	0.2 ± 0.2	1.1 ± 0.5	0.7 ± 0.5	0.6 ± 0.3	0.3 ± 0.2
Nitrate as N (mg/L), Bottom	0.2 ± 0.2	0.2 ± 0.2	0.2 ± 0.2	0.5 ± 0.3	1.3 ± 0.8	0.9 ± 0.7	0.8 ± 0.4	0.3 ± 0.1
Silica (SR µg/L), Surface	1780 ± 848	845 ± 95	424 ± 256	246 ± 106	385 ± 177	719 ± 337	421 ± 171	467 ± 206
Silica (SR µg/L), Bottom	1854 ± 867	1110 ± 172	878 ± 212	371 ± 173	839 ± 192	1255 ± 395	584 ± 162	935 ± 241
Chlorphyll a (µg/L), Surface	37.9 ± 43.0	2.0 ± 1.2	1.9 ± 1.8	4.7 ± 3.2	3.0 ± 1.3	3.7 ± 3.3	1.2 ± 0.9	3.0 ± 1.7
Chlorphyll a (µg/L), Bottom	12.5 ± 7.3	0.3 ± 0.2	0.5 ± 0.4	0.6 ± 0.6	0.2 ± 0.1	0.5 ± 0.4	0.6 ± 0.6	2.2 ± 0.7

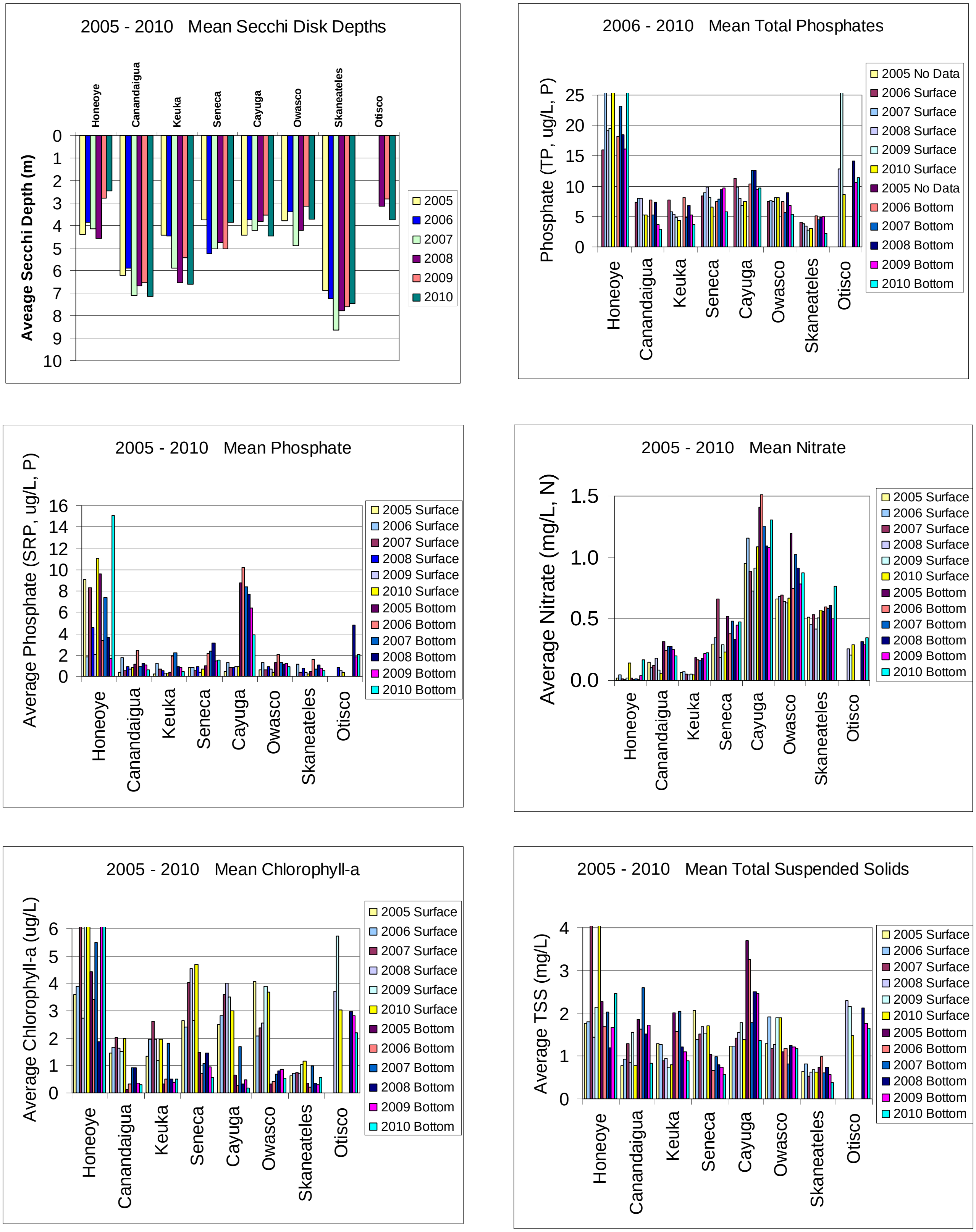

Fig. 7. Annual mean surface and bottom water data from the Finger Lake survey. The plots utilize all available water analyses from the monthly surveys.

Table 5. Date Averaged Plankton Data, 2005 through 2010.

Plankton Group	Diatoms					Dinoflagellates			Rotifers			Zooplankton	Blue Greens	
Plankton Name	Fragillaria %	Tabellaria %	Asterionella %	Synedra %	Rhizoselenia %	Dinobryon %	Ceratium %	Coalcium %	Keratella %	Polyarthra %	Monostyla %	Cladoceran %	Anabaena %	Mycrocystis %
2005														
6/22/05	12.6	3.0	4.8	2.4		10.2	0.6		4.2	4.8	0.0	1.8		
7/8/05	32.3	0.7	34.7	0.1		0.1	0.5		0.4	0.1	20.8	0.9		0.1
7/26/05	65.3	0.9	3.1			0.5	13.4		0.5	0.7	10.1	0.5	0.2	
9/3/05	17.8	1.7	4.5	19.7		17.0	7.9		7.1	10.2		10.1		0.7
10/1/05	46.6	0.9	2.7	0.1		45.4	0.2		0.1	0.1		0.6		0.1
Annual average	34.9	1.4	9.9	5.6		14.6	4.5		2.5	3.2	10.3	2.8		0.3
2006														
5/24/06	7.7	6.9	26.6	1.9	0.0	54.5	0.1		0.0	0.6		0.3		
6/19/06	25.3	0.8	7.9	0.2	0.1	58.7	1.2		0.6	1.0		1.2		
6/27/06	44.3	1.8	13.3	0.3		28.8	0.5		2.2	0.3	0.5	0.7		
7/17/06	44.9	4.1	6.4	3.2	25.2	10.0	2.0		1.0	0.4	0.0	0.6		
9/1/06	65.3		0.1	0.3	0.2	0.8	0.4		1.9	0.4	0.0	0.4		1.5
9/30/06	20.1			0.1	0.1	5.5	0.7		10.6	1.9	2.4	0.1		22.8
annual average	24.3	1.7	7.1	0.7	2.6	41.5	0.7		2.4	0.8	0.3	0.6	0.1	3.8
2007														
5/25/07	1.3	1.0	84.5	6.8	1.3				0.4			1.1		
7/23/07	94.1		2.1	1.0	0.1	0.1			0.1	0.1	1.0			
8/20/07	4.8		0.2			2.1	3.2		1.8	0.3	20.7	0.4	2.3	35.6
9/3/07	10.3		1.0			74.8	0.4		0.1	0.5	0.5	0.5		4.5
9/24/07	60.7	1.4		0.2	4.0	0.7	0.5		1.0	1.0		13.9		5.7
annual average	30.0	0.5	23.3	2.1	3.8	12.9	0.7		0.6	0.4	3.8	2.8	0.4	7.7
2008														
5/30/08	36.8	0.2	52.8	0.5	0.6	0.1			0.0	1.6		0.4		
6/27/08	54.4	0.0	16.1		0.0	26.1	1.6		0.3	0.7		0.2		
7/18/08	89.2	0.0	3.2	0.1		4.6	0.4		0.8	0.1	0.1	0.2		
8/25/08	73.1	0.0	0.1		1.2	1.7		0.4	0.3	0.3	11.2	1.1	1.7	0.6
10/4/08	8.0	0.3	0.8		4.1	61.1	0.8	0.7	0.2	1.7	10.1	1.2	0.2	6.8
Annual Average	52.3	0.1	14.6	0.1	1.2	18.7	0.6	0.2	0.3	0.9	4.3	0.6	0.4	1.5
2009														
5/29/09	4.6	29.3	25.6	1.2	0.3	15.4			8.0	1.9		0.8		
6/24/09	11.3	1.9	34.4	0.2		50.5			0.6	0.3		0.1		
7/22/09	29.7	4.1	1.8	2.1		5.6	3.7		2.3	0.4	12.1	0.7	14.9	0.2
8/18/09	1.1	0.2		0.5	0.2	61.6	0.1	10.1	4.9	0.2	3.1	0.2	0.2	
9/26/09	1.7			1.2	38.6				2.4	0.6	6.1	8.6	1.6	23.8
Annual Average	9.7	7.1	12.3	1.0	7.8	26.6	0.7	2.0	3.6	0.7	4.3	2.1	3.4	4.8
2010														
5/19/10	7.0	0.3	58.3	0.9	0.1	1.3			0.1	1.0		0.2		
6/22/10	1.9	0.5		9.5	0.5	15.3			1.6	2.3	0.9	19.5		
7/20/10	81.3	0.1	5.1	0.5		0.2								0.9
7/30/10	51.4		14.2	0.3	0.1	0.2		11.5	1.5	0.1	9.9	6.4	0.0	0.1
8/6/10	31.5	0.2	24.2		4.6	1.0		5.5	7.7	0.8	4.8	5.7	0.2	1.3
8/17/10	28.3		49.3			3.0		2.9	0.8	0.1	2.3	6.4		3.9
8/28/10	79.6		1.5	0.1	0.1	9.0		0.0	0.2	0.2	0.1	0.1	0.1	1.7
10/2/10	13.1	2.7				6.5	0.1	1.1	14.2	1.1	7.3	6.7	0.3	40.9
Annual Average	36.8	0.5	19.1	1.4	0.7	4.6	0.0	2.6	3.3	0.7	3.2	5.6	0.1	6.1

Note: Only included plankton > 2% of daily average in any year.

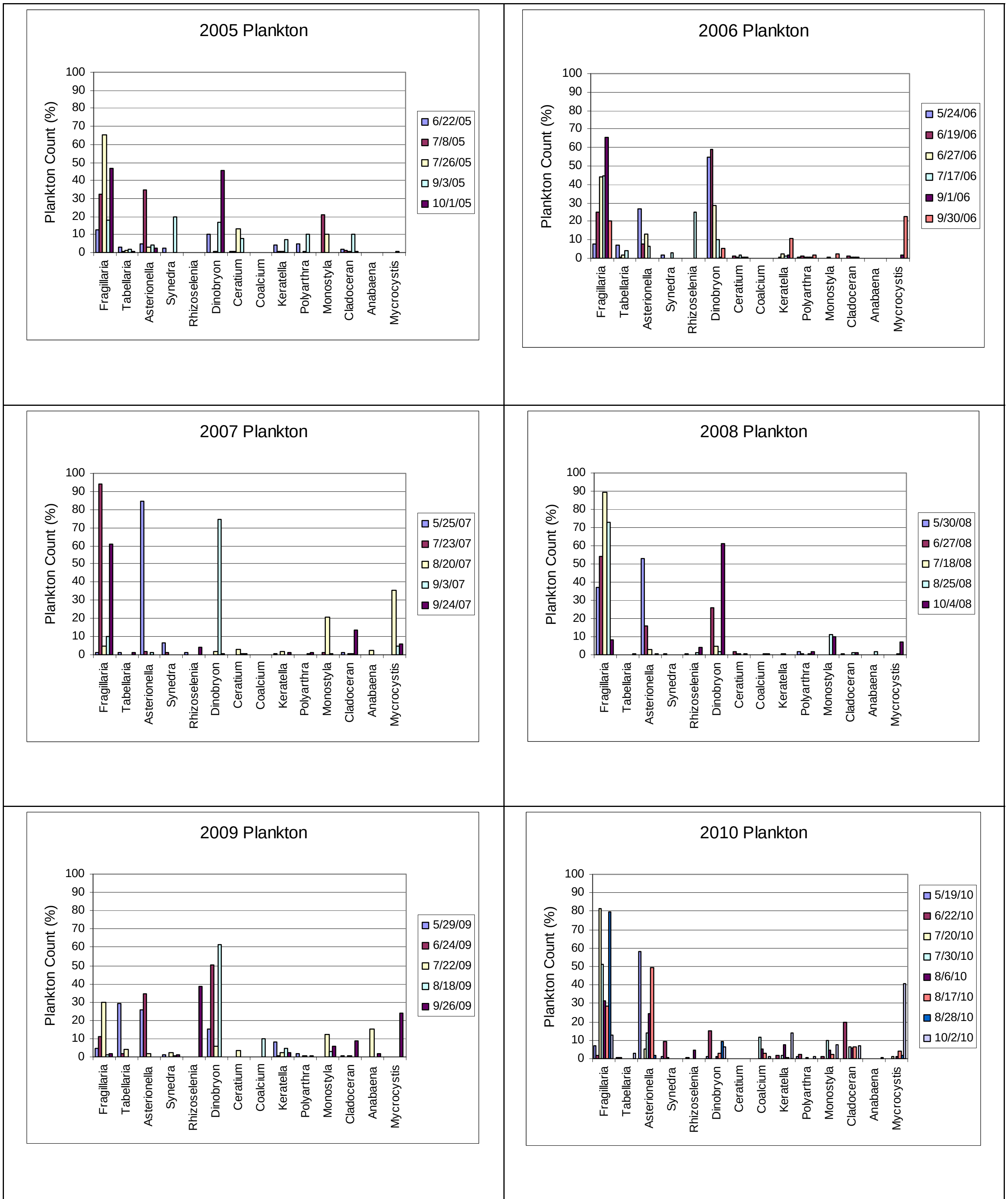

Fig. 8. Date averaged plankton data for the past 6 years.

Owasco Water Quality Rank: Is water quality in Owasco Lake getting progressively better or worse, and how does it compare to the other Finger Lakes? Annual water quality ranks for the eight easternmost Finger Lakes from 2005 to 2010 are shown in Fig. 9. These ranks were based on annual average data, comparing secchi disk depths, and surface water concentrations of chlorophyll-a, total and dissolved phosphate, nitrate and total suspended sediment from the Finger Lake survey. Bacteria counts were included in the initial 2005 ranking but not measured since, and excluded from this tabulation. Canandaigua, Keuka and Skaneateles Lakes stand out as the lakes with the best water quality (ranks consistently below 7). Honeoye and Otisco are the worst lakes in the survey (ranks at or above 12). For example, annual average secchi disk depths are over 7 meters and chlorophyll-a concentrations are 1 to 2 μg/L in the best lakes, but are shallower than 4 meters and above 3 μg/L in the worst. Owasco Lake is still close to the worst end of the spectrum (ranks between 11 and 16).

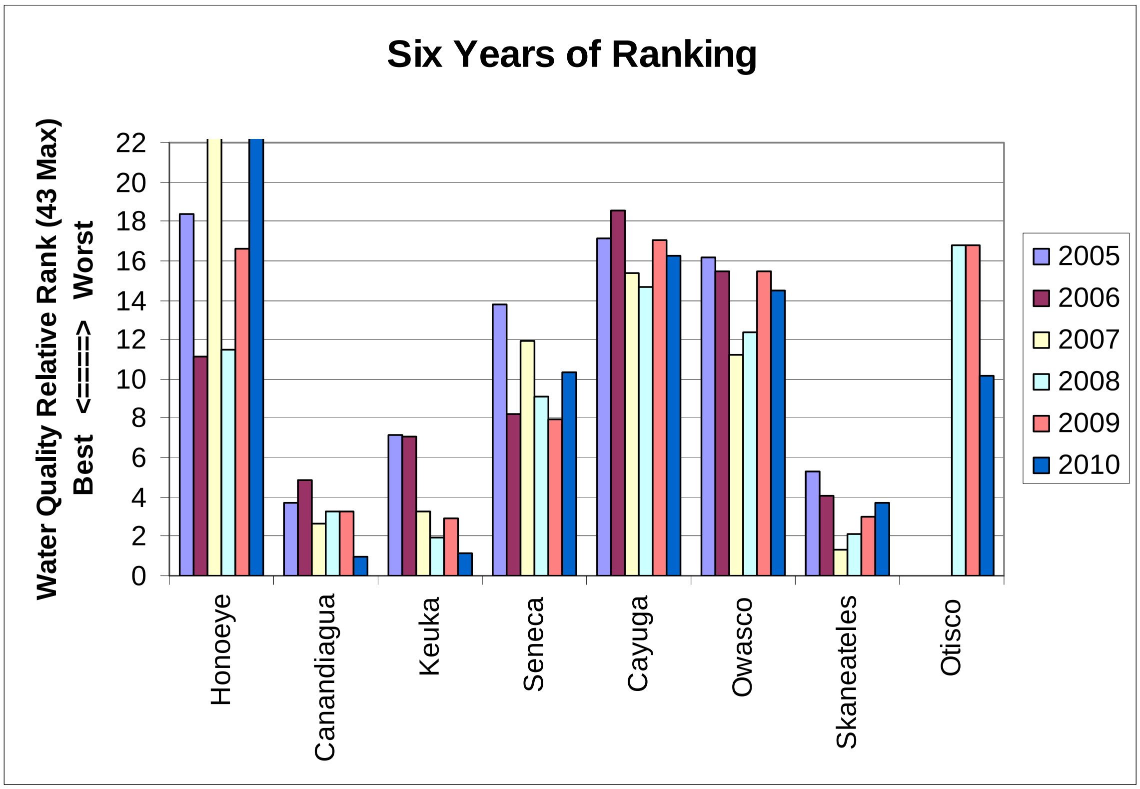

Fig. 9. Annual Water Quality Ranks for the eight easternmost Finger Lakes.

The change in water quality between lakes is due to a number of factors. As discussed earlier, the degree of water quality protection legislation and its implementation are important. For example, the Skaneateles, Canandaigua and Keuka watersheds are excellent examples that have adopted a number of stringent regulations that protect and maintain the pristine nature of their lakes. The effort appeared to work in Canandaigua and Keuka Lakes, as water quality improved over the past 5 years in these lakes. In contrast, water quality in Skaneateles appeared to decline but these changes are small.

In an effort to determine some of the other critical variables influencing water quality, the mean water quality rank for each watershed was compared to water residence time, watershed population, watershed size, lake volume and percentage of agricultural land in each watershed. The only significant result was that the annual rank correlates to the percentage of agricultural land in the watershed (r^2 = 0.81, Fig. 10). Other correlations were weak or very weak with correlations (r^2) of 0.4 and typically much lower. The land use correlation indicates that runoff and nutrient loading of non-point sources is a critical factor that influences water quality in the surveyed Finger Lakes.

Honeoye was excluded from this land use comparison due to its shallow nature (maximum depth < 10 meters) and legacy phosphate stored within the lake that provides significant internal phosphate loading from the sediments. The internal phosphate loading is sufficiently intense to enable nitrates to be the limiting nutrient in this watershed.

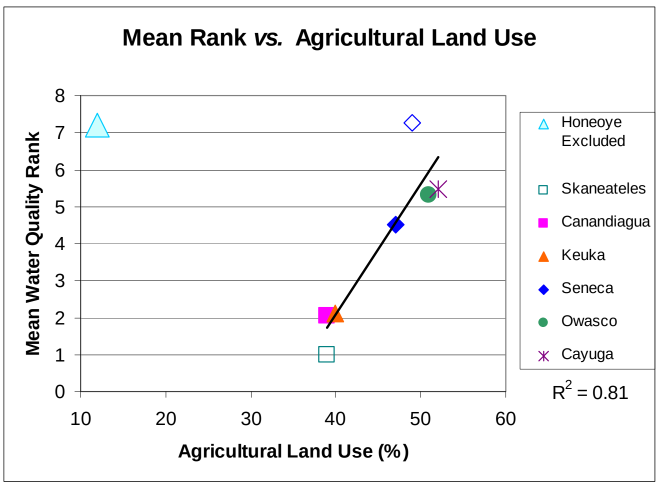

Fig. 10. Correlation of mean water quality ranks to percentage of agricultural land in each watershed. Honeoye was excluded from the analysis.

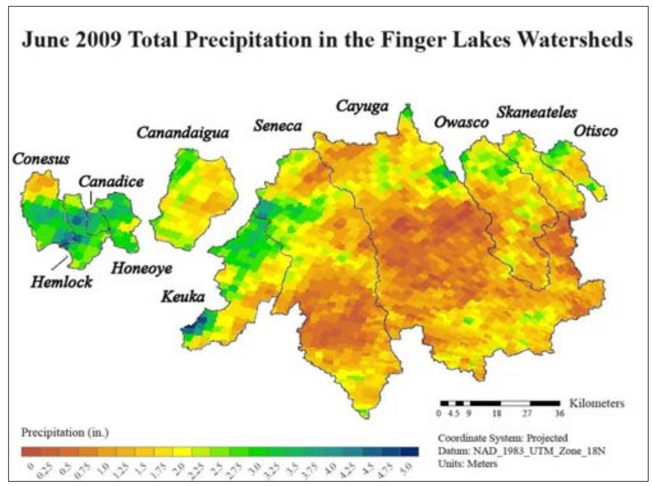

Fig. 11. Rainfall totals for June, 2009, from GIS raster-based 420x420m weather radar data. Notice the huge variability from watershed to watershed.

Year-to-Year Changes in Rank: Water quality in Owasco Lake also changes from one year to the next (Fig. 9). In Owasco Lake, water quality was worst in 2005 and 2006, improved during 2007 and 2008 but declined back to 2006 levels in 2009 and in 2010. The trend was also observed in Cayuga and Skaneateles Lakes, and suggests a regional explanation like precipitation patterns. The annual variability at Owasco is consistent with precipitation totals (r^2 = 0.74) and the implied delivery of non-point source nutrients. Two years, 2007 and 2008, experienced less precipitation in the Owasco Watershed (2008 < 800 mm/yr, 2007 < 400 mm/yr) than the other years, 2005, 2006 and 2009 (> 950 mm/yr) as determined by GIS analysis of NASA's Tropical Rainfall Measuring Mission data, a 27 x 27 km raster dataset of global, monthly precipitation totals. Interestingly, the change in annual precipitation from one year to the next was not consistent between all watersheds in the Finger Lakes. The impact of water residence time and exotic species probably play a part as well. Clearly, more work must be done using more detailed rainfall summaries to substantiate this claim (Fig. 11). The relationship indicates that the year-to-year variability may, in part, be dictated by variations in precipitation, and more specifically, the delivery of non-point source nutrients from the watershed to the lake, e.g., runoff of nutrients from agricultural land.

This analysis identifies an important silver lining. If nutrient loading decreases in any year, then water quality improves! Evidence for year-to-year improvement in water quality is observed in the ongoing nutrient reduction campaigns in Keuka and Canandaigua Lakes. Thus, hope exists to improve water quality in the other Finger Lakes and achieve the ultimate goal to preserve, protect and promote these lakes for future generations. Unfortunately, the opposite is also true. If nutrient loading continues then water quality in the lake will continue to degrade. For example, Seneca Lake has undergone a steady decline in water quality over the past decade, despite a thriving crop of zebra and quagga mussels.

Exotic species like zebra and quagga mussels, and/or *cercopagis*, the spiny water flea, may play a role as well. Zebra and quagga mussels filter feed plankton. Thus, they effectively remove algae and other plankton from the lake, and thus "improve" water quality. In contrast, the spiny water flea feeds on other herbaceous (plant eating) zooplankton. Once eaten, the herbaceous zooplankton are no longer available to eat algae (plants). The typical result is a mid-summer bloom of algae due to decreased algal predation, and thus increases water quality impairment. Dr. Brown's (HWS) preliminary data from the 2007 survey indicated that this carnivore has already influenced water quality in Owasco Lake. She and co-workers from SUNY-ESF and Cornell U. are currently following up on this research. Another recent study investigated the impact of BMPs on the delivery of nutrients and suspended sediments to Conesus Lake from the agriculturally-rich watershed. The parallels to Owasco Lake are intriguing so the outcome of the study is highlighted below.

BMPs in the Conesus Watershed: Do BMPs work to reduce nutrient and sediment loading to a lake from agriculturally rich and other non-point sources? Dr. Joseph Makarewicz, SUNY Brockport, and his research team working in conjunction with Cornell Cooperative Extension offices, County Soil and Water offices, Watershed Inspector office, and most importantly the farming community, have been evaluating the linkages between watershed improvements and downstream outcomes through the use of different Best Management Practices that retain soils, nitrates, organic nitrogen and phosphorus on the landscape in the Conesus watershed. They utilized the Conesus watershed to investigate these linkages by establishing a variety of BMPs in several agriculturally dominated (> 70% agricultural land use) watersheds while also monitoring a predominately forested watersheds. The implemented BMPs included manure management (e.g., no winter spreading, injection instead of spreading, lagoons), fertilizer reductions, crop rotating to increase soybean and alfalfa planting, barnyard drainage, grass and other vegetative buffer strips, winter cover or minimum tillage, subsurface drainage tiles, terracing, sedimentation basins (gully plugs), and fencing animals from streams. All of the watersheds were continually and extensively monitored for stream discharge, suspended sediment and nutrient (nitrate, total and soluble reactive phosphate) concentrations for five years on a weekly basis. The sampling was increased to hourly samples during runoff events. Their findings were published within a special volume of the Journal of Great Lakes Research (Volume 35 Supplement 1), and supported through grants from the US Department of Agriculture with local matching funds.

Makarewicz and his colleagues highlight the following results:

- Before the implementation of the BMPs, the streams and delivery of nutrients and suspended sediments were event responsive. Over 80% of the nutrient and sediment loss from the watershed occurred within the six largest major precipitation events each year.

- Clearly, the BMPs implemented in the Conesus Lake watersheds induced significant reductions in the delivery of nutrients and sediments to the lake.

- The Great Gully watershed, where BMPs impacted the largest percentage of the watershed revealed the greatest reduction in the delivery of nutrients and suspended sediments to the lake (approximately 50% less sediments, 30% less nitrates, 50% less total phosphates and 60% less dissolved phosphates, Fig. 12).

- These reductions yielded a parallel reduction in metaphyton (plankton, 72% reduction), macrophytes (rooted nearshore plants, 30 to 50% reduction) and microbial (25% reduction) communities in nearshore regions of Conesus Lake adjacent to the tributaries with BMPs.

- The nutrient and sediment reductions at Great Gully however, did not attain the much smaller loadings / hectare from the forested watershed, North McMillian Creek. Even after five years, this agriculturally-rich watershed still delivered more nutrients and sediments to the lake than the non-agricultural (forested) watershed.

- Agriculturally intense watersheds with minimal BMPs implementation did not reveal significant reductions in nutrient and suspended sediment loads.

In conclusion, BMPs effectively and significantly reduce nutrient and suspended sediments loads to and improve water quality in the nearby lake.

CONCLUSIONS & RECOMMENDATIONS:

This report confirms and expands on earlier findings. As previously observed, Owasco Lake is a borderline oligotrophic – mesotrophic lake with more parameters leaning towards a mesotrophic system in 2010 than before. CTD and water chemistry data indicate that the lake is well mixed but responds rapidly to runoff events. The most notable event was detected on 10/2/10, when a runoff-derived turbid plume was detected in the epilimnion.

As discussed in earlier reports, the variety of the pollutant sources in the Owasco watershed suggests a multifaceted approach to remediate water quality in Owasco Lake. The approaches include but are not limited to the utilization of a watershed inspector, increase use of agricultural BMPs, reduce nutrient loading by nutrient point sources like municipal wastewater treatment facilities, the conversion of the Owasco Inlet floodplain to a wetland, and education and outreach at all levels. All of these remediation efforts were recently initiated and/or already proposed for the watershed. This is good, and this important work should be continued into the future. All of them should help improve water quality in the lake. Without it, water quality would decline over time. For example, the reduction of nutrients in the Groton wastewater facility effluent decreased nutrient loading to the lake, and in part, was and still is responsible for improved water quality at the southern end of the lake. The Conesus Lake BMP study provides hope that non-point source nutrient and suspended sediment loading can be reduced in the Owasso watershed as well.

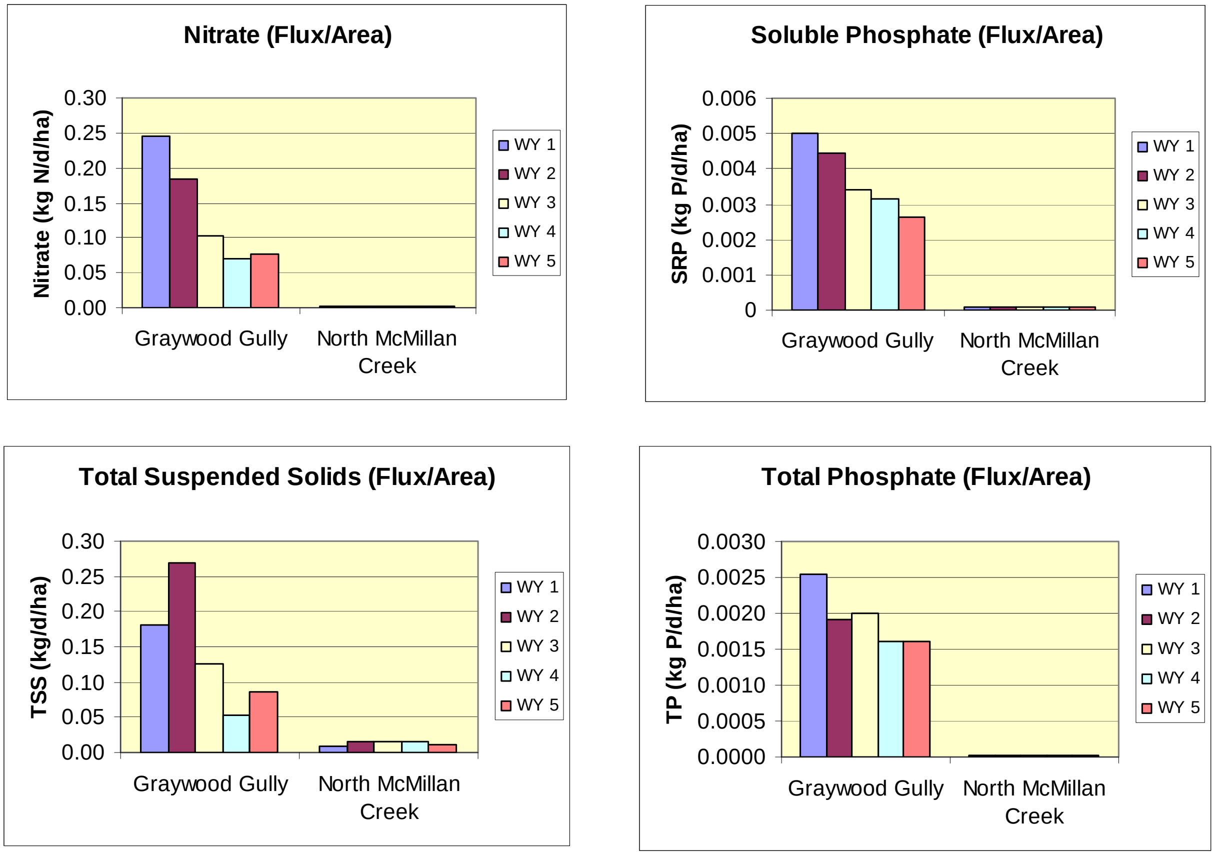

Fig. 12. Mean daily flux of suspended sediments and nutrients per unit area from two Conesus Lake watersheds. Graywood Gully watershed, an agriculturally-rich watershed (>70%) was subjected to a series of BMPs during year 1 that precipitated the observed reductions in nutrient and sediment loadings. North McMillan Creek was a forested watershed, and used as the control.

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