THE 2007 PROGRESS REPORT: PHOSPHATE AND SUSPENDED SEDIMENT DISTRIBUTIONS AND POTENTIAL SOURCES TO SOUTHERN CAYUGA LAKE.

John D Halfman, Tara F. Ware (WS'08) and Kerry A. O'Neill (WS'09)
Department of Geoscience & Environmental Studies Program
Finger Lakes Institute
Hobart and William Smith Colleges
Geneva, NY 14456
halfman@hws.edu

2/22/08

INTRODUCTION

Water quality is critical to the health, well being and economy of the region. The Finger Lakes Institute water quality survey of the seven central Finger Lakes, Skaneateles, Owasco, Cayuga, Seneca, Keuka, Canandaigua and Honeoye Lakes, indicated that Cayuga Lake moved from a middle ranking in 2005 to 2nd worst in 2006 and remained 2nd worst in 2007. The ranking is based on monthly secchi disk depths and surface water analyses for total coliform and *E. coli* bacteria (only in 2005), chlorophyll-a (algae concentrations), nutrient concentrations (total phosphates since 2006, soluble reactive phosphates, nitrates and dissolved silica), and suspended sediment concentrations from at least 2 deepwater sites in each lake. The water quality degradation in Cayuga Lake is disturbing and consistent with impairment of the lake's southern end.

The water quality ranking was based on surface water data, and ignored bottom water data. This is unfortunate because hypolimnetic (bottom-water) data in Cayuga Lake reveal more total phosphates (~10 μg/L, P), nitrates (~1.5 mg/L, N), and especially more soluble reactive phosphates (~10 μg/L, P) and total suspended sediments (~3 mg/L), than bottom water results from the other lakes (Fig. 1). The nutrient concentrations are a concern because bottom waters are exposed to the sunlit surface waters and could then promote algal and macrophyte growth. For example, fall and spring overturn mix the water column when the lake is isothermal. The hypolimnion is brought to the lake's surface at the far ends of the lake by strong internal seiche activity. Cornell's Lake Source Cooling Project also draws cold, nutrient-rich, bottom water and returns warm, nutrient-rich, water back to the epilimnion the lake. Thus, a two year study was initiated in 2007 to understand the sources of phosphates and suspended sediments to the hypolimnion (bottom waters) of southern Cayuga Lake. This report summarizes our 2007 findings.

METHODS:

The 2007 field season utilized nine sites, the two used in the Finger Lake Survey, two sites directly offshore of Taughannock and Salmon Creeks, and five more sites following a mid-lake transect southward to the shelf offshore of the southern end of the lake (Fig. 2, Table 1). Site F, located at the shelf edge, was used on the first few survey dates and subsequently replaced with a slightly deeper site, Site G. At each site, a CTD electronically collected water profiles of conductivity, temperature, pH, dissolved oxygen, turbidity, photosynthetic active radiation (PAR) and fluorescence (algal concentrations). At each mid-lake site, surface, mid-depth (40 m above the lake floor), and bottom water (within 2 m of the lake floor) samples were collected and

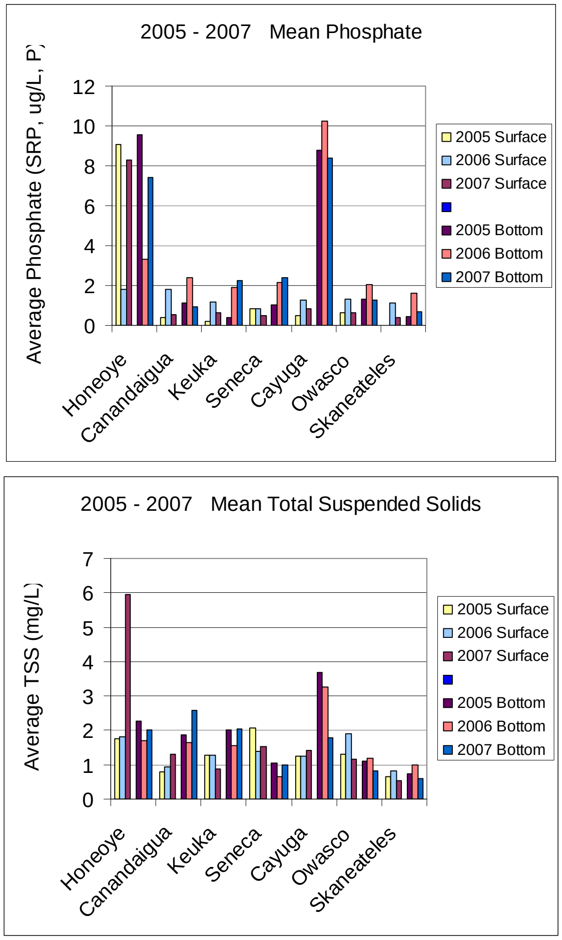

Fig. 1. *Finger Lake Comparative Data.*

Table 1. Site Locations

Site #	Latitude (ºN)	Longitude (ºW)	Water Depth (m)	Sample Depths
1	42.63195	76.67222	122	S, M & B
2	42.55417	76.59167	110	S, M & B
A	42.55000	76.59833	55	
B	42.53333	76.55500	88	S, M & B
C	42.53683	76.55383	50	
D	42.51667	76.53667	90	S, M & B
E	42.49167	76.52500	73	S, M & B
F	42.47500	76.51667	5	S
G	42.48333	76.55383	54	S, M & B

analyzed in the laboratory for total phosphate, soluble reactive phosphate, nitrate, dissolved silica, chlorophyll-a, total suspended sediment (TSS) and major ion (sodium, calcium, magnesium, potassium, chloride and sulfate) concentrations. The analyses followed standard limnological techniques, TSS by filtration (0.45 μm filtration), major ions by ion chromatograph, and chlorophyll-a and nutrients by spectrophotometer (0.45 μm filtration). Finally, horizontal and depth integrative plankton tows, secchi disk depths, pH, conductivity, temperature, dissolved oxygen and alkalinity titrations were performed at each mid-lake site.

During the course of the 2007 field season, over 100, randomly selected sample splits were analyzed by a commercial laboratory for total phosphate (TP), soluble reactive phosphate (SRP) and nitrates within a few weeks of sample collection for quality control. The results from both labs were statistically the same (r^2 = 0.84 for nitrate, 0.93 for SRP, and 0.76 for TP), and hampered by the time delay between sample collection and analysis, a few TP outliers, and more importantly the detection limits for each lab. Replicate analyses at HWS revealed a precision of 0.2 mg/L for total suspended solids, 0.1 μm/L for SRP and TP, 0.1 mg/L for nitrate, and 5 μm/L for dissolved silica. The detection limits for Life Science Laboratory are 0.2 mg/L for nitrate and 3 μm/L for phosphate, and thus unfortunately, Life Science Laboratory could not detect over 70% of the SRP, 40% of the TP, and 15% of the nitrate sample split analyses.

RESULTS AND PRELIMINARY INTERPRETATIONS:

CTD Profiles (Fig. 3): The water temperature profiles were typical for any relatively deep, temperate lake and were consistent between sites on any specific day. The thermocline, where the decrease in temperature with depth is the largest, typically developed at 15 to 20 meters. The depth is important because it defined the boundary between the warmer, less-dense, epilimnion

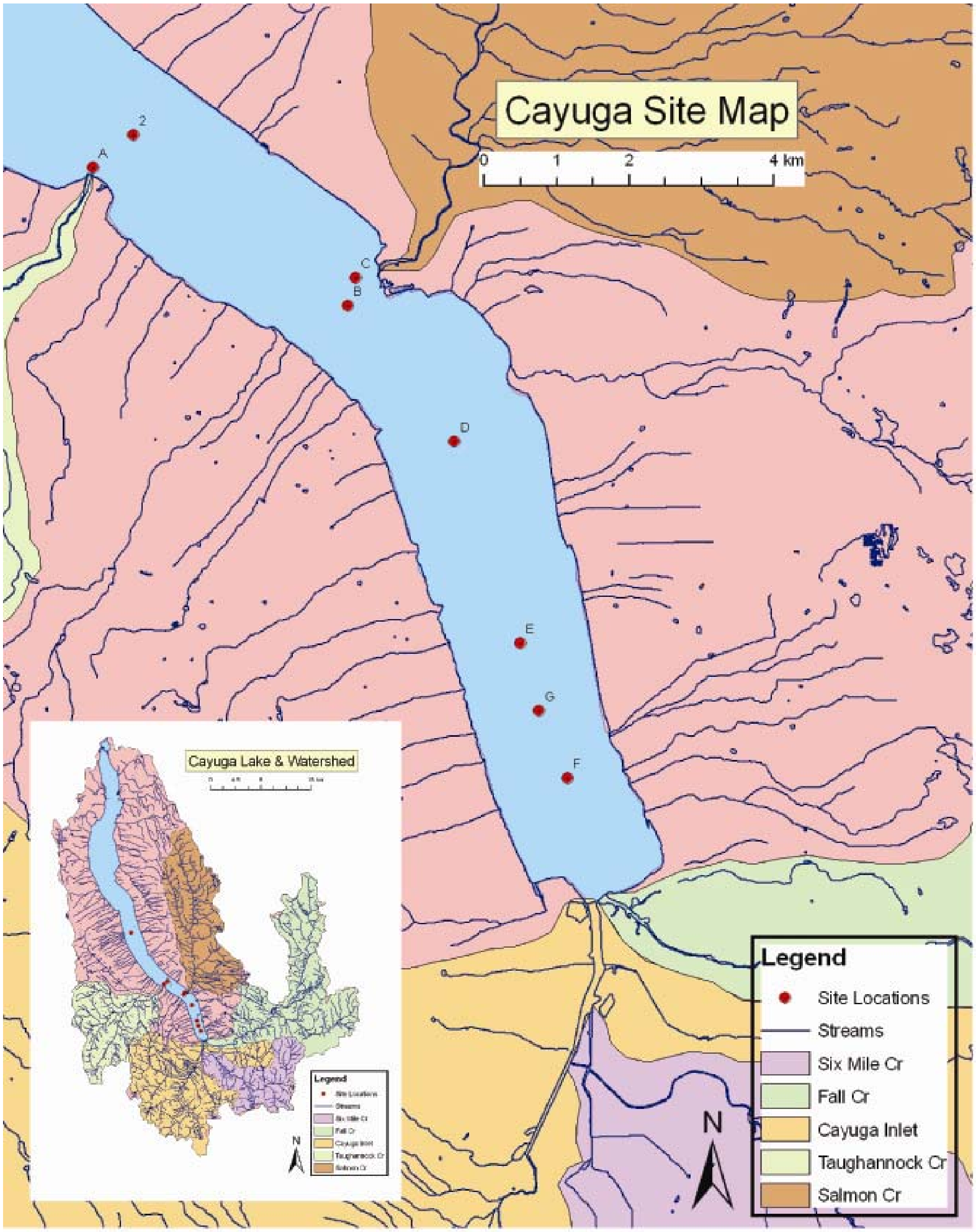

Fig. 2. *Sample sites for the 2007 survey.*

surface waters) from the colder, more-dense, hypolimnion (bottom waters). The thermocline depth varied from day to day, and was related to the onset or decay of thermal stratification and/or internal seiche activity. The thermocline depth placed the mid-depth water sample for Site G in the lower epilimnion and not the middle hypolimnion as at the other sites.

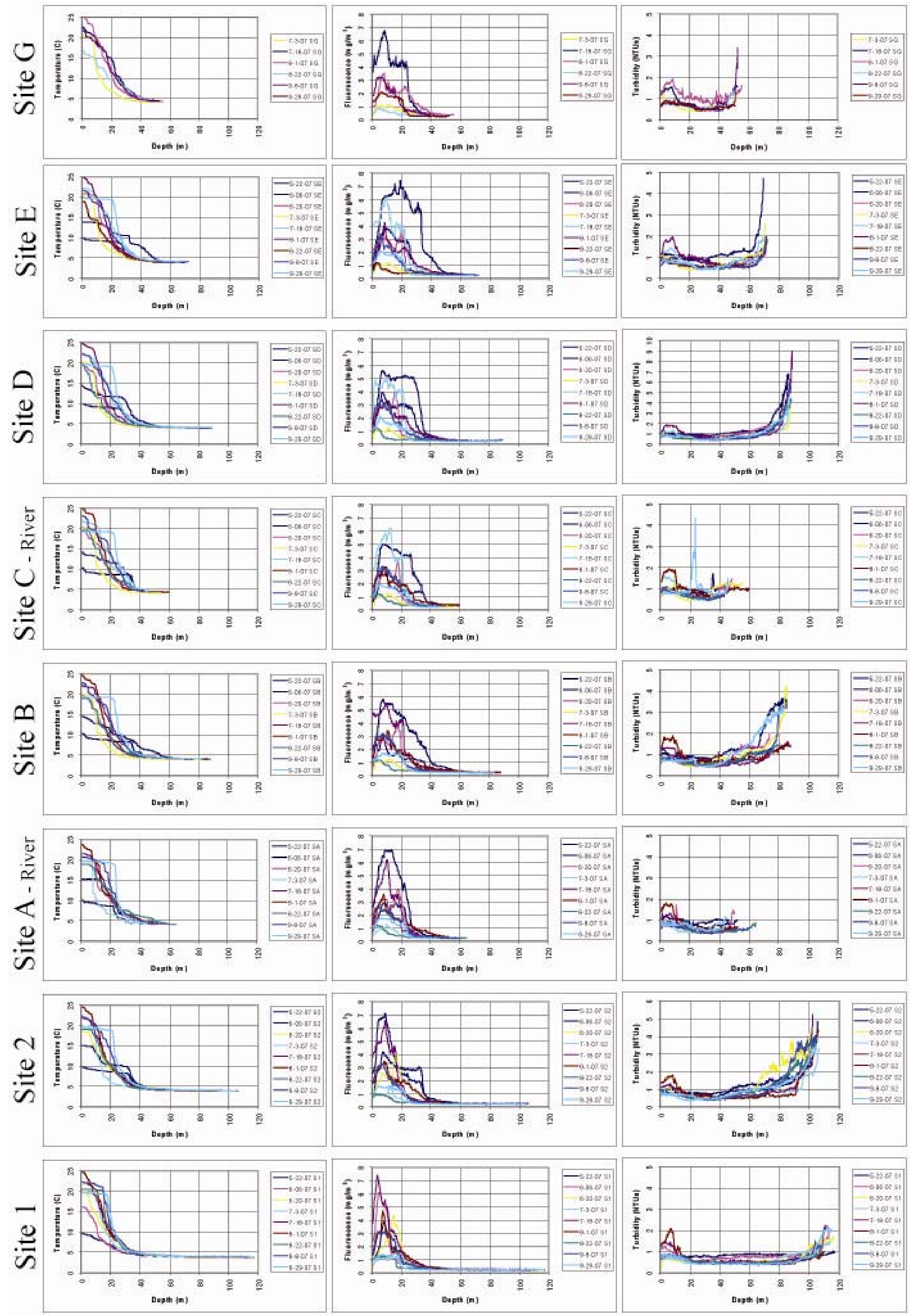

Fig. 3. *CTD Profiles from each survey date for each site.*

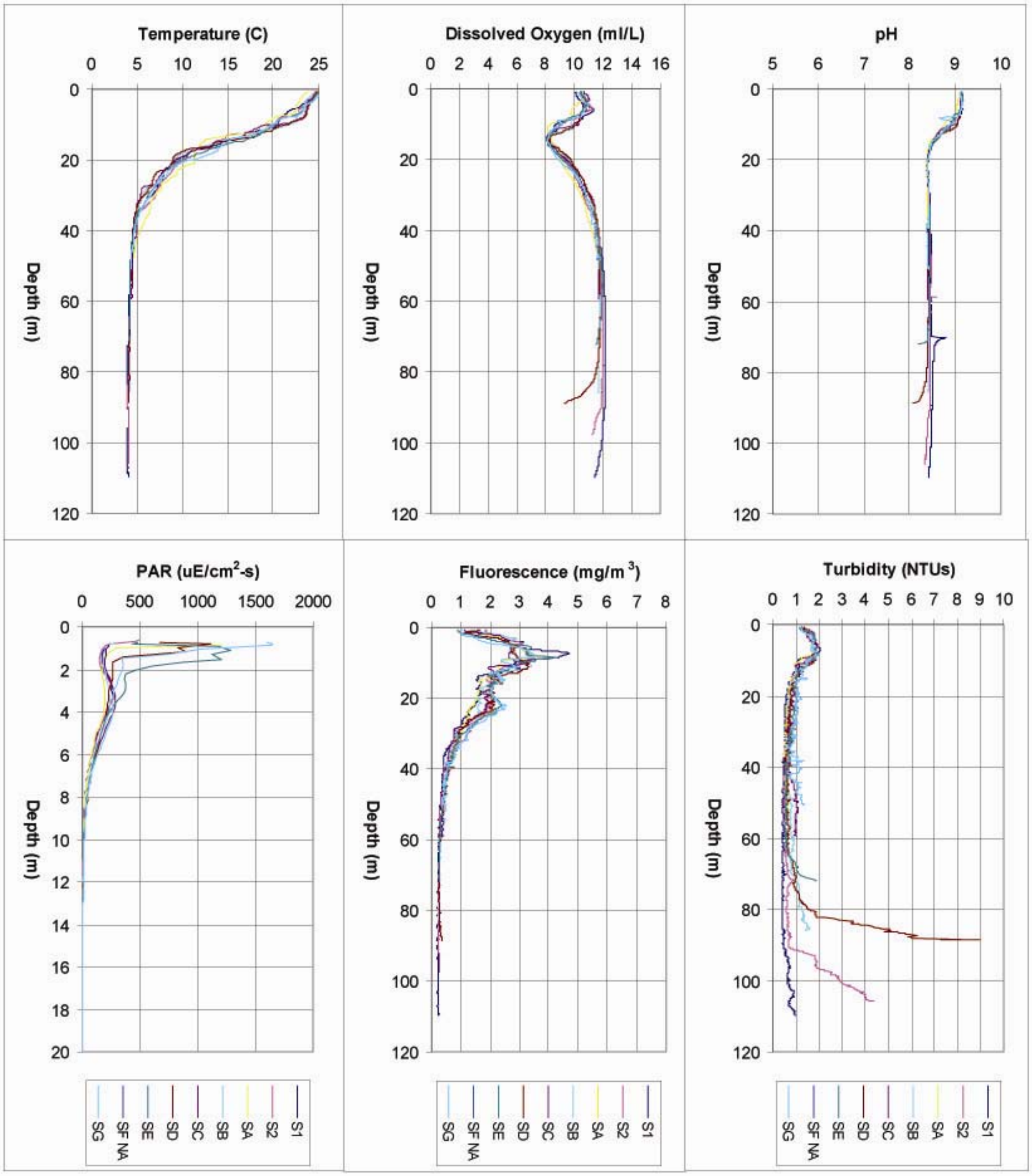

Fig. 3. *CTD Profiles from each site on 8-1-07.*

Specific conductance in the epilimnion ranged from just under 400 to just over 425 μS/cm, and conductivities decreased through the summer season. Hypolimnion specific conductivities ranged from 430 to 440 μS/cm, and conductivities increased at the lake floor through the stratified season. The small surface water decrease in salinity is interpreted to reflect the input of slightly less saline river water into more saline lake water through the summer. The even smaller deepwater increase in salinity is interpreted to reflect the seepage of ions through the sediments from the underlying bedrock and/or decomposition of organics by bacteria.

Algae, by fluorescence, were observed through out the epilimnion and into the upper hypolimnion. Algal concentrations ranged from near 0 to almost 8 μm/L (mg/m^3). The largest concentrations occurred during spring (5/22, 6/6), and mid-summer (7-18) blooms. The peak in algal density was typically 10 to 15 m below the lake surface. Algal concentrations typically declined to < 1 μm/L by 40 m. This depth distribution is concurrent with sufficient light for photosynthesis. Specifically, PAR profiles revealed 1% surface light intensities (the lower limit for net algal production) at water depths of 15 to 25 meters, the specific depth on any given day reflecting the density of algae, suspended sediments, cloud cover, and lake surface roughness.

Dissolved oxygen (DO) and pH profiles were typical for the oligotrophic-mesotropic lake. Hypolimnetic DO concentrations remained near saturation, 12 ml/L (> 16 mg/L), and declined slightly, by 3 ml/L (4 mg/L), within 20 to 30 m of the lake floor. Epilemnetic DO concentrations remained near saturation, and were supersaturated during algal blooms. Profiles of pH revealed more basic water in the epilimnion (pH ~ 9) than the hypolimnion (pH ~8.2).

Total suspended sediment concentrations ranged from near 0 to 9 NTUs. Concentrations up to 2 NTUs were detected in the epilimnion and up to 9 NTUs just above the lake floor. The surface water turbidity probably corresponds to the population of algae. The bottom water turbidity, when developed, depicts classic nepheloid layers, where suspended sediments increase from background concentrations of just below 1 NTU about 20 m above the lake floor to the largest turbidities in the profile just above the lake floor. Sites 2, B and especially Site D revealed the best nepheloid layers. Decaying leaf matter and other sediments were collected in a bottom water sample at Site B when the CTD unfortunately hit the lake floor.

Secchi Disk, Chlorophyll-a, Total Suspended Solids and Nutrient Concentrations (Fig. 4): Annual mean secchi disk depths were near 4 m, and were slightly deeper (4.3 m) at the northernmost site, Site 1, and shallower (3.9 m) at the southernmost site, Site G. Variability between sample dates at any site corresponds to changes in the algal density mentioned above.

Chlorophyll-a data were larger in the epilimnion than the hypolimnion with annual mean concentrations ranging from 2.6 to 4.0 μg/L in the surface vs. always below 1.1 and typically below 0.5 μg/L, in the hypolimnion. The observed changes from day to day and between sites are consistent with the fluorescence results.

Annual mean total suspended solids concentrations ranged from 1.1 to 2.6 mg/L. The surface mean TSS concentrations were similar across the lake from 1.6 to 1.7 mg/L, except for smaller concentrations at Site G. The largest TSS concentrations were detected at Sites 2, B and D in the bottom water. One exceptionally large result of 15.9 mg/L from Site B on 7/3 was excluded from the site average due to the possible collection of CTD disturbed sediments in the sample. In contrast, the bottom water TSS concentrations at other sites (1, A, C, E, F & G) were less turbid than the surface water. On 9-29 just after a rain storm, Site C located just offshore of Salmon Creek, detected a mid-depth turbidity plume just above the thermocline. The geometry and timing are consistent with warm, turbid, creek water extending out into the lake at the base of the less dense, warm but relatively sediment free epilimnion and on top of the denser, colder hypolimnion.

Mean nutrient concentrations were typically smaller in the epilimnion than the hypolimnion, except that these differences were less pronounced or not observed at Site G. Mean nitrate concentrations ranged from 0.8 to 1.0 mg/L in the epilimnion to 1.1 to 1.3 mg/L in the hypolimnion. Mean dissolved silica concentrations ranged from 289 to 410 μg/L in the epilimnion to 936 to 1011 μg/L in the hypolimnion. Mean total phosphate concentrations ranged from 5.3 to 13.6 μg/L. Largest concentrations were in the bottom water samples, and decreased to approximately 8 to 10 μg/L in the surface and mid-depth samples. Mean soluble reactive phosphate concentrations ranged from 0.3 to 11.5 μg/L. Largest concentrations were in the bottom water samples, and decreased by approximately 50% at the mid-depth sample and decreased again to less than 1.2 μg/L at the surface.

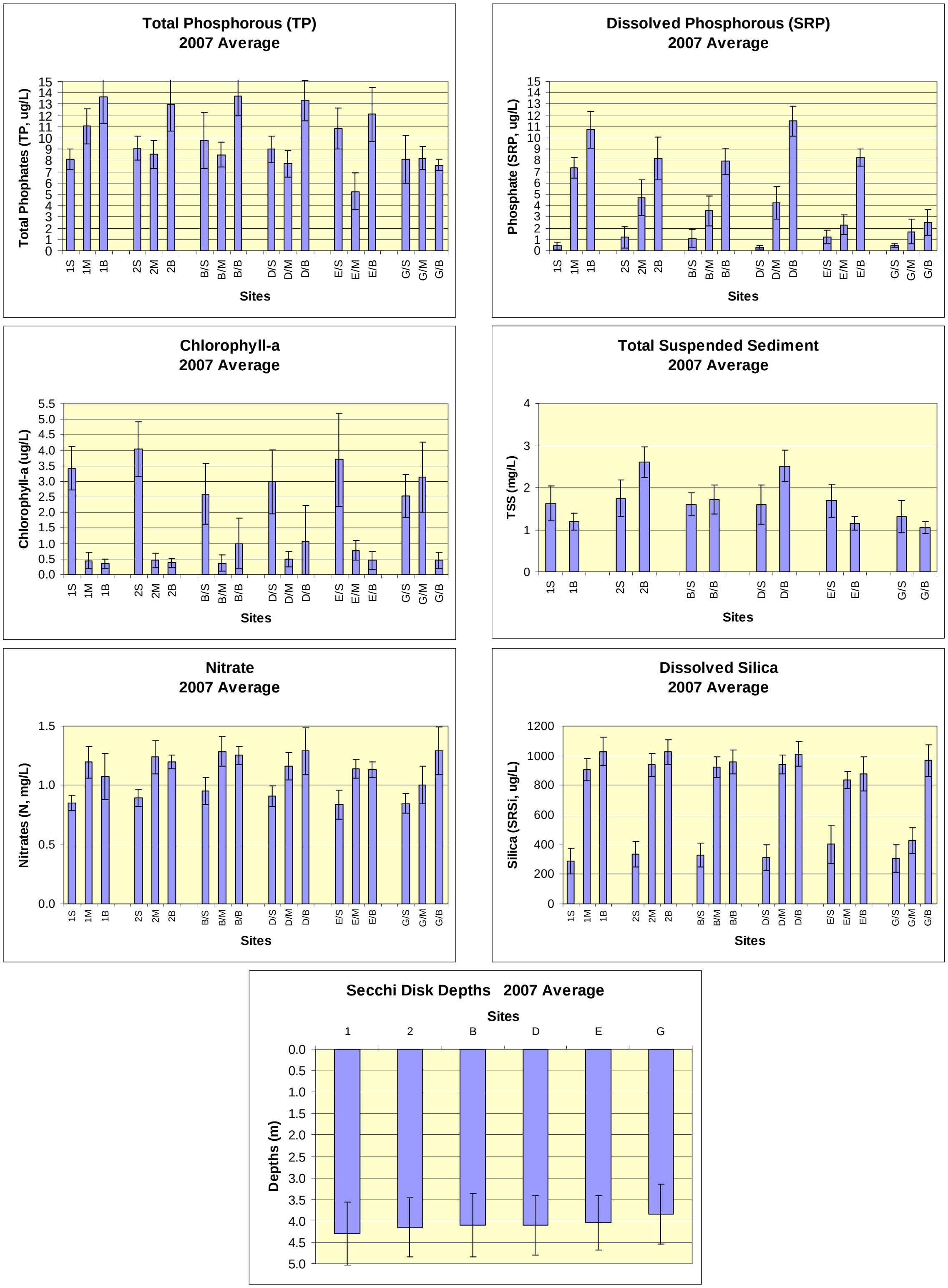

Fig. 4. Site averaged water quality data (1σ standard deviation).

Bottom Water Suspended Sediments and Nutrients: The observed secchi disk depths, nutrient and chlorophyll-a concentrations indicate that Cayuga Lake is borderline oligotrophic-mesotrophic. The differences in nutrient and chlorophyll-a concentrations with water depth are typical for a temperate lake, and are interpreted to reflect the net algal growth and uptake of soluble nutrients during photosynthesis in the epilimnion and net bacterial release of soluble nutrients during decomposition of algae in the hypolimnion. However, these concentration differences are still more pronounced in Cayuga Lake then the neighboring lakes. In addition, CTD profiles from Cayuga Lake reveal the best developed nepheloid layers among the sampled Finger Lakes. Keuka and Canandaigua Lakes revealed less pronounced nepheloid layers, and minimal, if any, nepheloid accumulations are detected in Skaneateles, Owasco, Seneca and Honeoye Lakes. The unique associations at Cayuga Lake suggests a common source for bottom water suspended sediments and nutrients.

Nepheloid layers can originate from three sources: fluvial events, resuspension events, and/or settling of algal remains. The available evidence to support each source will be briefly discussed below.

A fluvial source is supported by the following observations. When it rained the day before a sample date, a thermocline-depth turbid plume was detected offshore of Salmon Creek. Subsequent particle settling of the coarsest particles and slower settling of the fine (glacial) clays to the lake floor would promote the development of the observed nepheloid layers. The nepheloid layer was best developed at Sites 2, B and D located in the southernmost bathymetric basin of the lake, where Salmon, Taughannock, Fall, Virgil Creeks, and Cayuga Inlet empty into the lake. We believe additional plumes were not detected in 2007 because 2007 was a dry year, with 2007 rainfall totals 65% lower than totals in 2006 during the 5-month field season at the Ithaca Airport. Research at Owasco Lake during the past two years indicated that the Owasco Inlet was a critical source of suspended sediments and phosphates to the lake in 2006, a wet year, but not in 2007, a dry year. In 2006, flood events routinely impaired lake water quality at the southern end of the lake with mean annual total suspended sediment concentrations of 1.9 to 4.2 mg/L compared to a mean lake concentration of 1.8 mg/L, and mean annual phosphate concentrations of 75 to 500 μg/L compared to a mean lake concentration of 10 μg/L. Terrestrial organics were detected in a bottom water sample at Site B. Finally, Cayuga lakeshore residents have remarked that spring melt and other significant runoff events always generate offshore turbid plumes (Fig. 5). We speculate that the nepheloid layer reflects this initial spring input, and subsequently waxes and wanes through the remainder of the year as resuspension and algal sources add to and particle settling removes sediments over time.

Resuspension events due to wave action from strong northwesterly winds are supported by the temporal association of the largest nepheloid turbidities with wind events just before sample dates during 2007. The lack of a nepheloid layer in the northern basin, Site 1, suggests that algae are less critical than fluvial and resuspension events to the development of the nepheloid layers in Cayuga Lake. Clearly, the 2008 field season has the potential to provide additional data.

The high phosphates probably originate from the same sources as the suspended sediments. However the phosphate distribution is not limited to the southern basin but instead was detected through out the hypolimnion. We suggest that once phosphates are brought to the southern basin, bacterial respiration releases the phosphates to the hypolimnion. Subsequent lake-wide mixing during fall and spring overturn, distributes the phosphates uniformly through out the lake, only to decline in the epilimnion and increase in the lower hypolimnion after stratification by algal uptake and bacterial decomposition. Other researchers have reported the primary sources of phosphates and supplemented by suspended sediments originate from the southern drainages, with Fall Creek and Cayuga Inlet providing 50% of the phosphates, Ithaca's wastewater facility 45% and Cornell's Lake Source Cooling Project less than 3%. We suggest that Taughannock and Salmon Creeks are important contributors as well. Our phosphate concentration data combined with Cornell's Lake Source Project pump rates indicates that this source inputs a similar quantity of phosphates as estimated above.

Fig.4. *A turbid plume offshore of Taughannock Creek, left, and another offshore the south end, right. Photos by Bill Hecht.*

CONCLUSIONS:

The results of the 2007 field season indicate that Cayuga is borderline oligotrophic-mesotrophic lake. Suspended sediments and phosphates are more concentrated in the hypolimnion of Cayuga Lake compared to neighboring Finger Lakes, especially soluble reactive phosphate. The source is probably fluvial and resuspension events and smaller amounts of algal sources. However, the interpretation was hampered by low rainfalls. Hopefully, the 2008 field season will be wet and windy enough to observe the relative importance of fluvial and resuspension events on the nepheloid development and maintenance in the southern bathymetric basin of the lake.

ACKNOWLEDGEMENTS:

We acknowledge the support of many folks to carry out this study. It includes financial support from the Fred Emerson Foundation, the John Ben Snow Foundation, the Andrew Mellon Foundation, the Triad Foundation, Hobart and William Smith Colleges, New York State, and specifically for this research, the Park Foundation. Casey Franklin, Rachael Dye, and Evan Brown assisted with the 2007 field and laboratory analyses, and were built on numerous undergraduate projects over the past decade.