March 31, 2006

Cayuga Lake Water Quality Monitoring, Related to the LSC Facility: 2005

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1. Objective/Study Area

The primary objective is to conduct an ambient water quality monitoring program focusing on the southern portion of Cayuga Lake to support long-term records of trophic state indicators, including concentrations of phosphorus and chlorophyll, and Secchi disc transparency, and other measures of water quality.

Cayuga Lake is the second largest of the Finger Lakes. A comprehensive limnological description of the lake has been presented by Oglesby (1979). The lake is monomictic (stratifies in summer), mesotrophic (intermediate level of biological productivity), and is a hardwater alkaline system. Much of the tributary inflow received by the lake enters at the southern end; e.g., ~ 40% is contributed by the combination of Fall Creek and Cayuga Inlet (Figure 1a). Effluent from two domestic wastewater treatment (WWT) facilities also enters this portion of the lake (Figure 1a). The discharge from Cornell's LSC facility enters the southern portion (e.g., south of McKinney's Point) of the lake along the east shore (Figure 1a). The LSC facility started operating in early July of 2000.

2. Design

2.1. Description of Parameters Selected for Monitoring

2.1.1. Phosphorus (P)

Phosphorus (P) plays a critical role in supporting plant growth. Phosphorus has long been recognized as the most critical nutrient controlling phytoplankton (microscopic plants of the open waters) growth in most lakes in the north temperate zone. Degradation in water quality has been widely documented for lakes that have received excessively high inputs of P from man's activities. Increases in P inputs often cause increased growth of phytoplankton in lakes. Occurrences of particularly high concentrations of phytoplankton are described as "blooms". The accelerated "aging" of lakes associated with inputs of P from man's activities has been described as cultural eutrophication.

The three forms of P measured in this monitoring program, total P (TP), total dissolved P (TDP), and soluble reactive P (SRP), are routinely measured in many limnological and water quality programs. TP is widely used as an indicator of trophic state (level of plant production). TDP and SRP are measured on filtered (0.45 µm) samples. Most TDP is assumed to be ultimately available to support phytoplankton growth. SRP is a component of TDP that is usually assumed to be immediately available to support phytoplankton growth. Particulate P (PP; incorporated in, or attached to, particles) is calculated as the difference between paired measurements of TP and TDP. The composition of PP can vary greatly in time for a particular lake, and between different lakes. Contributing components include phytoplankton and other P-bearing particles that may be resuspended from the bottom or received from stream/river inputs.

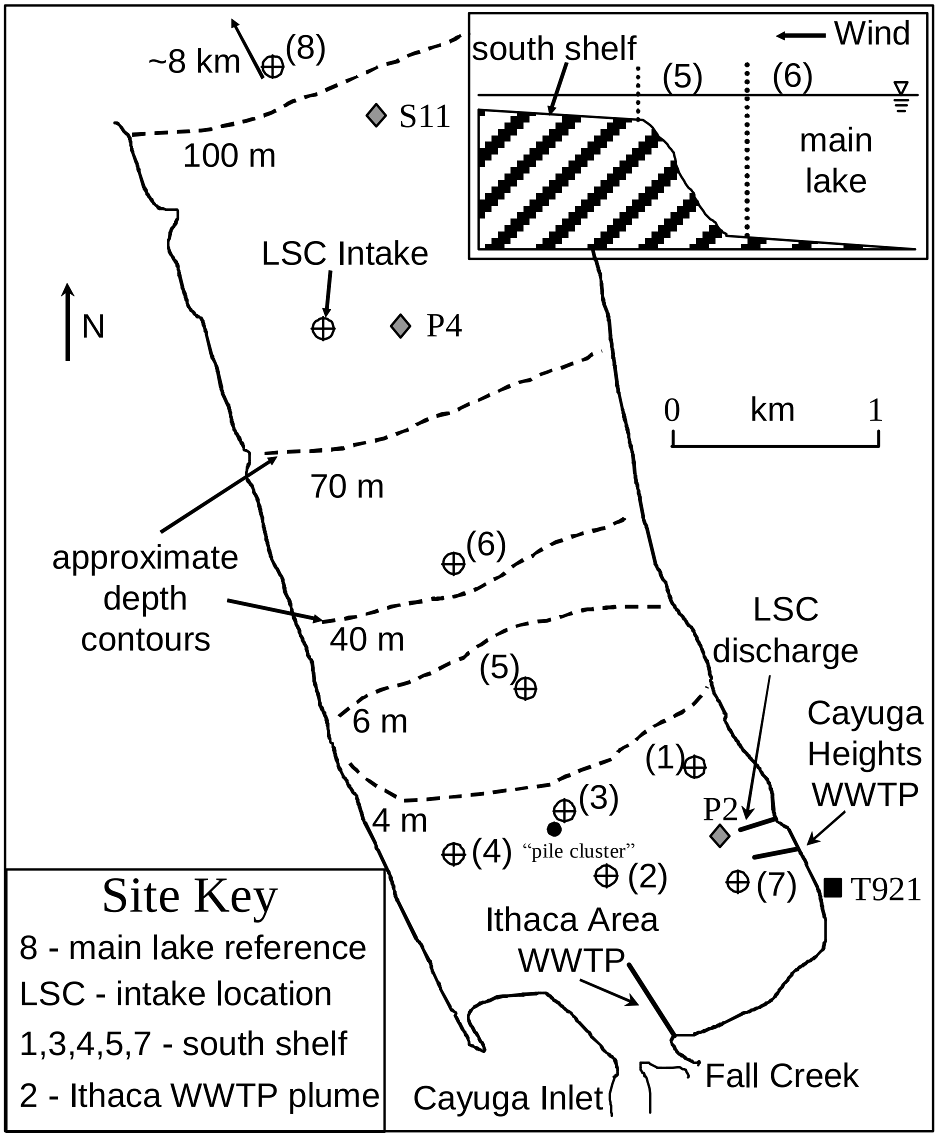

Figure 1a. Sampling sites, setting, approximate bathymetry, for LSC monitoring program, southern end of Cayuga Lake. Sites sampled during 1994 – 1996 study (P2, P4 and S11; Stearns and Wheler 1997) are included for reference. Locations of sampling sites and outfalls are approximate.

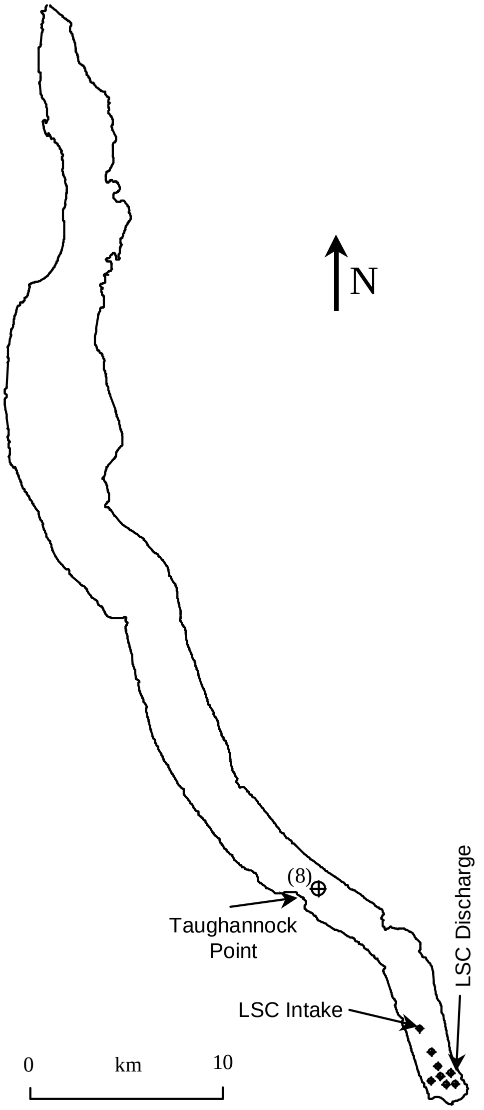

Figure 1b. Sampling sites for LSC monitoring program, within the context of the entire Cayuga Lake basin.

2.1.2. Clarity/Optical Properties

The extent of the penetration of light in water (e.g., ability to see submerged objects), described as clarity, is closely coupled to the public's perception of water quality. Light penetration is particularly sensitive to the concentration, composition and size of particles. In lakes where phytoplankton are the dominant component of the particle population, measures of clarity may be closely correlated to concentrations of TP and phytoplankton biomass (e.g., as measured by chlorophyll). Clarity is relatively insensitive to phytoplankton biomass when and where concentrations of other types of particles are high. In general, light penetration is low when concentrations of phytoplankton, or other particles, are high.

Two measures of light penetration are made routinely in this program, Secchi disc transparency (in the field) and turbidity (laboratory). The Secchi disc measurement has a particularly long history in limnological studies, and has proven to be a rather powerful piece of information, even within the context of modern optical measurements. It remains the most broadly used measure of light penetration. The higher the Secchi disc measurement the greater the extent of light penetration. Turbidity, as measured with a nephelometric turbidimeter, measures the light captured from a standardized source after passage through a water sample. Turbidity and Secchi disc depth are regulated by a heterogeneous population of suspended particles that include not only phytoplankton, but also clay, silt, and other finely divided organic and inorganic matter. The higher the turbidity value the higher the concentration of particles that limit light penetration.

Two other optical measurements are made as part of this program, irradiance and beam attenuation. These parameters are included to augment the information concerning light penetration. Depth profiles of irradiance are collected to determine the attenuation (or extinction) coefficient, another measure of light penetration.

2.1.3. Chlorophyll/Fluorescence

Chlorophyll **a** is the principal photosynthetic pigment that is common to all phytoplankton. Chlorophyll (usually as chlorophyll **a**) is the most widely used surrogate measure of phytoplankton biomass, and is generally considered to be the most direct and reliable measure of trophic state. Increases in chlorophyll concentrations indicate increased phytoplankton production. The major advantages of chlorophyll as a measure of phytoplankton biomass are: (1) the measurement is relatively simple and direct, (2) it integrates different types and ages of phytoplankton, (3) it accounts to some extent for viability of the phytoplankton, and (4) it is quantitatively coupled to optical properties that may influence clarity. However, the chlorophyll measurement does not resolve phytoplankton type, and the chlorophyll content per unit biomass can vary according to species and ambient environmental conditions. Therefore, it is an imperfect measure of phytoplankton biomass. Fluorescence has been widely used as a surrogate measure of chlorophyll. Fluorescence measurements are made in the field in this program.

Rather wide variations in chlorophyll concentrations can occur seasonally, particularly in productive lakes. The details of the timing of these variations, including the occurrence of blooms, often differ year-to-year. Seasonal changes in phytoplankton biomass reflect imbalance between growth and loss processes. Factors influencing growth include nutrient availability (concentrations), temperature and light. Phytoplankton are removed from the lake either by settling, consumption by small animals (e.g., zooplankton), natural death, or exiting the basin. During intervals of increases in phytoplankton, the rate of growth exceeds the summed rates of the various loss processes.

2.1.4. Temperature

Temperature is a primary regulator of important physical, chemical, and biochemical processes in lakes. It is perhaps the most fundamental parameter in lake monitoring programs. Lakes in the northeast go through major temperature transformations linked primarily to changes in air temperature and incident light. Important cycles in aquatic life and biochemical processes are linked to the annual temperature cycle. Deep lakes stratify in summer in this region, with the warmer less dense water in the upper layers (epilimnion) and the colder more dense water in the lower layers (hypolimnion). A rather strong temperature/density gradient in intermediate depths between the epilimnion and hypolimnion (metalimnion) limits cycling of materials from the hypolimnion to the epilimnion during summer. Gradients in temperature are largely absent over the late fall to spring interval, allowing active mixing throughout the watercolumn (e.g., turnover).

2.2. Timing

Lake sampling and field measurements were conducted by boat during the spring to fall interval of 2005, beginning in mid-April and extending through late October. The full suite of laboratory and field measurements was made for 16 bi-weekly monitoring trips. Additionally, recording thermistors were deployed continuously at one location; temperature measurements were made hourly over the mid-April to late October interval. The thermistors were exchanged biweekly with fresh units for data downloading and maintenance. Deployments made on October 24, 2005 will be retrieved in April 2006. Measurements are recorded on a daily basis over this later interval. Laboratory measurements of phosphorus concentration, T_n, dissolved oxygen concentration (DO), and pH were made on samples from the LSC influent and effluent collected weekly during operation of the LSC facility.

2.3. Locations

An array of sampling sites (e.g., grid) has been adopted that provides a robust representation of the southern portion of the lake (Figure 1a and b). This sampling grid may reasonably be expected to resolve persistent water quality gradients that may be imparted by the various inputs/inflows that enter this portion of the lake. Further, inclusion of these sites is expected to contribute to fair representation of average conditions for this portion of the lake.

Seven sites were monitored for the full suite of parameters in the southern end of the lake (sites 1 through 7). The intake location for the LSC facility and site 8, located further north as a reference for the main lake conditions, were also sampled. Positions (latitude, longitude) for the eight sites are specified in Table 1. The configuration of sites includes two transect lines; one with 3 sites along an east-west line extending from an area near the discharge location, the other with 4 sites running approximately along the main axis of the lake (Figure 1a). Additionally, two sites (1 and 7) bound the location of the LSC discharge, paralleling the east shore (Figure 1a). The position for thermistor deployment ("pile cluster") is shown in Figure 1a and specified in Table 1. The "Global Positioning System" (GPS) was used to locate the sampling/monitoring sites. A reference position located at the southern end of the lake (T921; Figure 1a) was used to assess the accuracy of the GPS for each monitoring trip.

Table 1: Specification of site locations (GPS) and depths (sonar) for ambient water quality monitoring (refer to Figure 1a). Sites sampled during 1994 – 1996 study (P2, P4 and S11; Stearns and Wheler 1997) are included for reference.

Site No.	Latitude	Longitude	Depth (m)
1 (discharge boundary)	42°28.3'	76°30.5'	5
2	28.0'	30.8'	3
3	28.2'	30.9'	4
4	28.2'	31.4'	4
5	28.5'	31.1'	6
6	28.8'	31.3'	40
7 (discharge boundary)	28.0'	30.3'	3.5
8 (off Taughannock Pt.)	33.0'	35.0'	110
thermistor "pile cluster"	28.1'	31.0'	4
LSC Intake	29.4'	31.8'	78
P2	28.20'	30.40'	4
P4	29.31'	31.41'	65
S11	29.60'	31.45'	72

2.4. Field Measurements/Seabird Profiling

Instrumentation profiles were collected in the field at 9 locations (sites 1 through 8 and the LSC Intake; Figure 1a) with a SeaBird profiler. Profiles extended from the surface to within 2m of the lake bottom, or to 20 m at deeper sites. Deeper profiles were obtained for the intake site. Parameters measured in the profiles and the potential utility of the information are summarized in Table 2. Additionally, dissolved oxygen was measured at site 3 each monitoring trip with a HydroLab Surveyor 3, calibrated and operated according to the manufacturer's specifications. Secchi disc transparency was measured at all sites with a 20 cm diameter black and white quadrant disc (Wetzel and Likens 1991).

Table 2: SeaBird profiler: parameters and utility.

Parameter	Utility
Temperature	heat budget, density stratification
Conductivity	tracer, mixing patterns
Fluorescence	measure of chlorophyll
Beam attenuation	identification of particle rich layers, including benthic nepheloid layers
Irradiance Scalar Downwelling	determination of attenuation coefficients

2.5. Field Methods

Water samples were collected with a well-rinsed Van Dorn sampler or submersible pump, with depths marked on the line/hose. Care was taken that the sampling device was deployed vertically within the water column at the time of sampling. Samples for laboratory analysis were composite-type, formed from equal volumes of sub-samples collected at depths of 0, 2 and 4 meters for sites 5, 6, LSC, and 8. Composite samples for sites 1, 2, 3, 4, and 7 were formed from equal volumes of sub-samples collected at depths of 0 and 2 meters. The composite-type samples avoid over-representation of the effects of temporary secondary stratification in monitored parameters. In addition, samples were collected at the LSC intake site at 1m and 3m above the bottom (depth of ~ 77m). Sample bottles were stored in ice and transported to the laboratory on the same day of sampling. Chain of custody procedures were observed for all samples collected for laboratory analysis.

2.6. Laboratory Analyses, Protocols

Laboratory analyses for the selected parameters were conducted according to methods specified in Table 3. Detection limits for these analyses are also included. Most of these laboratory analyses are “Standard Methods”. Results below the limit of detection are reported as ½ the limit of detection. Chlorophyll concentrations were determined by fluorometric assay (USEPA 1992). The acidified turbidity method has been applied by this study team for a number of hard water systems such as Cayuga Lake. Specifications adhered to for processing and preservation of samples, containers for samples, and maximum holding times before analyses, are summarized in Table 4.

2.7. Quality Assurance/Control Program

A quality assurance/control (QA/QC) program was conducted to assure that ambient lake data collected met data quality objectives for precision, accuracy, representativeness, comparability, and completeness.

Table 3: Specification of laboratory methods for ambient water quality monitoring.

Analyte	Method No.	Reference	Limit of Detection
total phosphorus	4500-P	APHA (1992)	0.6 $\mu g \cdot L^{-1}$
soluble reactive phosphorus	4500-P	APHA (1992)	0.3 $\mu g \cdot L^{-1}$
total dissolved phosphorus	4500-P	APHA (1992)	0.6 $\mu g \cdot L^{-1}$
turbidity	2130-B	APHA (1992)	-
acidified turbidity		Effler and Johnson (1987)	-
chlorophyll **a**		Parsons et al. (1984)	0.4 $\mu g \cdot L^{-1}$
	445.0	USEPA (1992)	0.4 $\mu g \cdot L^{-1}$

2.7.1. Field Program

Precision of sampling and sample handling was assessed by a program of field replicates. Samples for laboratory analyses were collected in triplicate at site 1 on each sampling day. Triplicate samples were collected at one of the other eight stations each monitoring trip. This station was rotated each sampling trip through the field season. Secchi disc measurements were made in triplicate at all sites through the field season. Precision was high for the triplicate sampling/measurement program, as represented by the average values of the coefficient of variation for the 2005 program (Table 5).

2.7.2. Laboratory Program

The laboratory quality assurance/control program conducted was as specified by the National Environmental Laboratory Accreditation Program (NELAP 2003). NELAP methods were used to assure precision and accuracy, completeness and comparability (NELAP 2003). The program included analyses of reference samples, matrix spikes, blind proficiency samples, and duplicate analyses. Calibration and performance evaluation of analytical methods was as specified in the NELAP program; this includes control charts of reference samples, matrix spikes, and duplicate analyses.

Table 4: Summary of processing, preservation, storage containers and holding times for laboratory measurements; see codes below.

Parameter	Processing	Preservation	Container	Holding Time
total phosphorus	c	a	1	1
soluble reactive phosphorus	a	b	1	2
total dissolved phosphorus	a	a	1	1
chlorophyll **a**	b	c	2	3
turbidity	c	b	2	2
acidified turbidity	d	b	2	2

codes for Table 4:

processing: a - filter with 0.45 µm cellulose acetate filter
b - filter with 0.45 µm cellulose nitrate filter
c - whole water sample
d - acidified to pH = 4.3 for 1 min.

preservation: a - H_2SO_4 to pH < 2
b - none
c - store filter frozen until analysis

container: 1 - 250 ml acid washed borosilicate boston round
2 - 4L polypropylene container

holding time: 1 - 28 days
2 - 24 hours
3 - 200 days

Table 5: Precision for triplicate sampling/measurement program for key parameters for 2005, represented by the average coefficient of variation.

Parameter	**Site 1**	**Rotating Site***
total phosphorus	0.09	0.07
chlorophyll **a**	0.15	0.16
turbidity	0.07	0.10
Secchi disc	< 0.01	< 0.01

* average of Sites 2, 3, 4, 5, 6, 7, 8, LSC

3. Results, 2005

The measurements made in the 2005 monitoring program are presented in two formats here: (1) in tabular form (Table 6) as selected summary statistics for each site, and (2) as time plots (Figure 2) for selected sites and site groupings. Detailed listings of data are presented in Appendix I. LSC Discharge Monitoring Report Data are presented in Appendix 2. The adopted summary statistics include the mean, the range of observations, and the coefficient of variation (CV = standard deviation/mean; Table 6). The plots present three time series; these include (except for Secchi disc) one for site 2, another for site 8, and the third is an "average" of sites intended to represent overall conditions in the southern portion of the lake. This southern portion is designated as the "shelf", as depths are less than 6 m. The "average" for the shelf is the mean of observations for sites 3, 4, 5, and the average of sites 1 and 7 (together to represent conditions in the eastern portion of the study area; see Figure 1a). Observations for site 6 are not included in this averaging because this location, while proximate, is in deeper water (> 40 m; i.e., off the shelf). Measurements at site 8 are presented separately in these plots to reflect lake-wide (or the main lake) conditions. Observations for site 2 are separated from the other sites of the southern end because the results indicate this location is at times within the discharge plume of the Ithaca Area WWTP. Time series for site 2 appear as insets in the time plots (Figure 2) to accommodate the greater magnitudes of some of the observations for this site, and still allow resolution of temporal structure observed for other locations. The Secchi disc plot (Figure 2e) presents observations for sites 6, LSC, and 8; the deeper sites, where observations were always less than the bottom depth. Time series for the LSC influent, the LSC effluent, and the shelf are presented separately (Figure 2j-o). Paired profiles of temperature, the beam attenuation coefficient (BAC), and chlorophyll fluorescence obtained at the LSC intake site on 16 monitoring dates in 2005 are presented (Figure 3).

Previous annual reports (UFI 1999, 2000, 2001, 2002, 2003, 2004, 2005) documented occurrences of extremely high concentrations of forms of phosphorus (TP, TDP, and SRP) and nitrogen (TDN and T-NH_3) at site 2. These occurrences are likely associated with the proximity of site 2 to the Ithaca Area WWTP discharge (Figure 1a) enriched in these components. High concentrations of phosphorus continued to be observed at this site in 2005 (Figure 2a-c). Site 2 is omitted in the formation of the average for the shelf because the effect is localized, temporally irregular, and is representative of only a relatively small volume of water.

Table 6: Summary of results of monitoring program according to site, 2005.

TP ($\mu gP \cdot L^{-1}$)			
SITE	**MEAN**	**CV**	**RANGE**
1	18.7	0.31	10.8 – 30.5
2	28.7	0.35	12.7 – 52.1
3	18.7	0.32	10.0 – 30.3
4	15.0	0.41	5.7 – 31.4
5	15.3	0.32	9.3 – 30.0
6	14.1	0.27	9.3 – 23.7
7	23.4	0.41	8.8 – 41.3
8	12.4	0.21	8.8 – 18.4
LSC	12.9	0.24	7.1 – 21.1

Chl a ($\mu g \cdot L^{-1}$)			
SITE	**MEAN**	**CV**	**RANGE**
1	3.9	0.48	0.7 – 7.2
2	4.3	0.56	0.6 – 7.7
3	4.2	0.50	0.5 – 7.1
4	3.1	0.64	0.3 – 6.8
5	3.8	0.47	0.3 – 6.6
6	4.3	0.49	0.4 – 9.6
7	4.1	0.45	0.7 – 6.9
8	3.8	0.48	0.3 – 6.8
LSC	4.3	0.46	0.3 – 7.7

TDP ($\mu gP \cdot L^{-1}$)			
SITE	**MEAN**	**CV**	**RANGE**
1	5.5	0.76	2.6 – 17.8
2	8.2	0.60	2.5 – 18.9
3	5.6	0.75	2.4 – 15.2
4	4.6	0.66	2.7 – 14.7
5	4.2	0.75	1.5 – 14.7
6	4.1	0.73	2.0 – 14.1
7	6.9	0.55	2.9 – 16.0
8	3.7	0.71	2.2 – 12.7
LSC	3.7	0.74	2.0 – 13.1

$\mathbf{T_n}$ (NTU)			
SITE	**MEAN**	**CV**	**RANGE**
1	2.3	0.94	0.5 – 7.2
2	3.0	0.80	0.7 – 9.5
3	3.0	1.06	0.6 – 14.3
4	1.3	0.83	0.4 – 4.6
5	1.6	0.77	0.6 – 5.0
6	1.3	0.79	0.5 – 4.2
7	2.9	0.87	0.7 – 8.3
8	1.0	0.80	0.4 – 3.6
LSC	1.1	0.90	0.5 – 4.6

SRP ($\mu gP \cdot L^{-1}$)			
SITE	**MEAN**	**CV**	**RANGE**
1	2.3	1.34	0.3 – 10.2
2	3.7	1.05	0.2 – 11.3
3	1.8	1.63	0.2 – 8.7
4	1.6	1.58	0.2 – 8.4
5	1.4	1.84	0.2 – 8.4
6	1.3	1.92	0.2 – 7.9
7	2.9	1.00	0.2 – 8.7
8	1.2	1.89	0.2 – 7.1
LSC	1.3	1.89	0.2 – 7.3

Temperature (°C) @ 2m			
SITE	**MEAN**	**CV**	**RANGE**
1	17.3	0.36	6.8 – 25.5
2	17.2	0.38	5.8 – 26.5
3	17.2	0.37	5.5 – 26.5
4	17.2	0.38	5.0 – 26.7
5	17.4	0.38	4.6 – 26.2
6	17.2	0.39	4.7 – 26.3
7	17.3	0.36	6.9 – 26.5
8	17.1	0.43	3.4 – 25.6
LSC	17.0	0.42	3.9 – 26.1

Table 6 (cont.): Summary of results of monitoring program according to site, 2005.

Beam Attenuation Coeff. (m^{-1}) @ 2m			
SITE	**MEAN**	**CV**	**RANGE**
1	1.9	0.68	0.6 – 4.6
2	2.5	0.87	0.5 – 9.0
3	1.9	0.66	0.5 – 4.6
4	1.2	0.71	0.3 – 3.4
5	1.4	0.70	0.5 – 4.2
6	1.3	0.54	0.6 – 3.2
7	2.1	0.72	0.4 – 5.9
8	1.1	0.47	0.5 – 2.3
LSC	1.2	0.54	0.5 – 3.1

K_s Attenuation Coeff. (m^{-1})			
SITE	**MEAN**	**CV**	**RANGE**
1	-	-	-
2	-	-	-
3	-	-	-
4	-	-	-
5	-	-	-
6	0.39	0.33	0.26 – 0.77
7	-	-	-
8	0.37	0.25	0.25 – 0.62
LSC	0.37	0.35	0.24 – 0.80

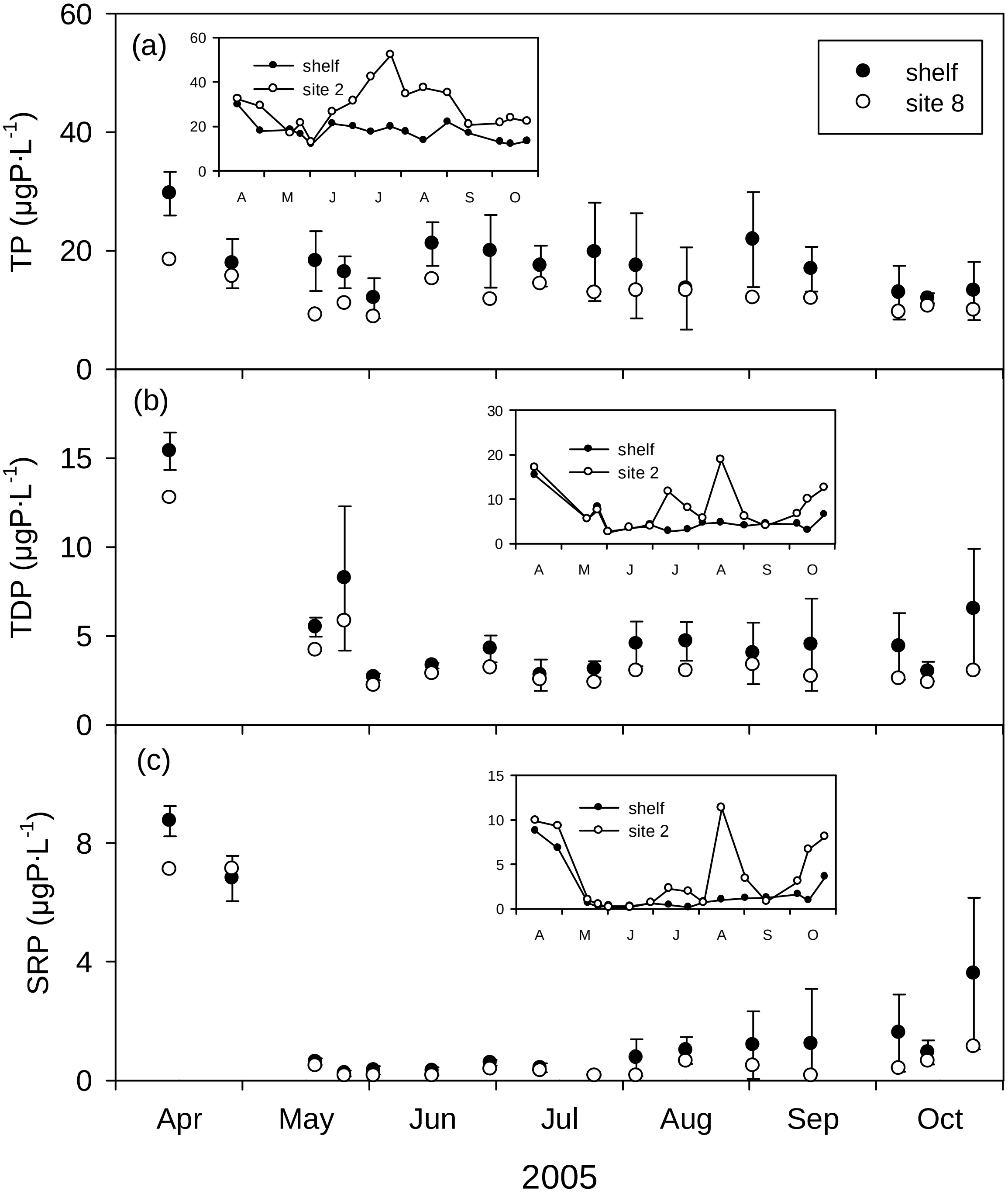

Figure 2a-c. Time series of parameter values for Cayuga Lake for 2005: (a) TP, (b) TDP, and (c) SRP. Insets present results for site 2. Results for the "shelf" are averages; the error bars represent spatial variation with dimensions of ± 1 standard deviation.

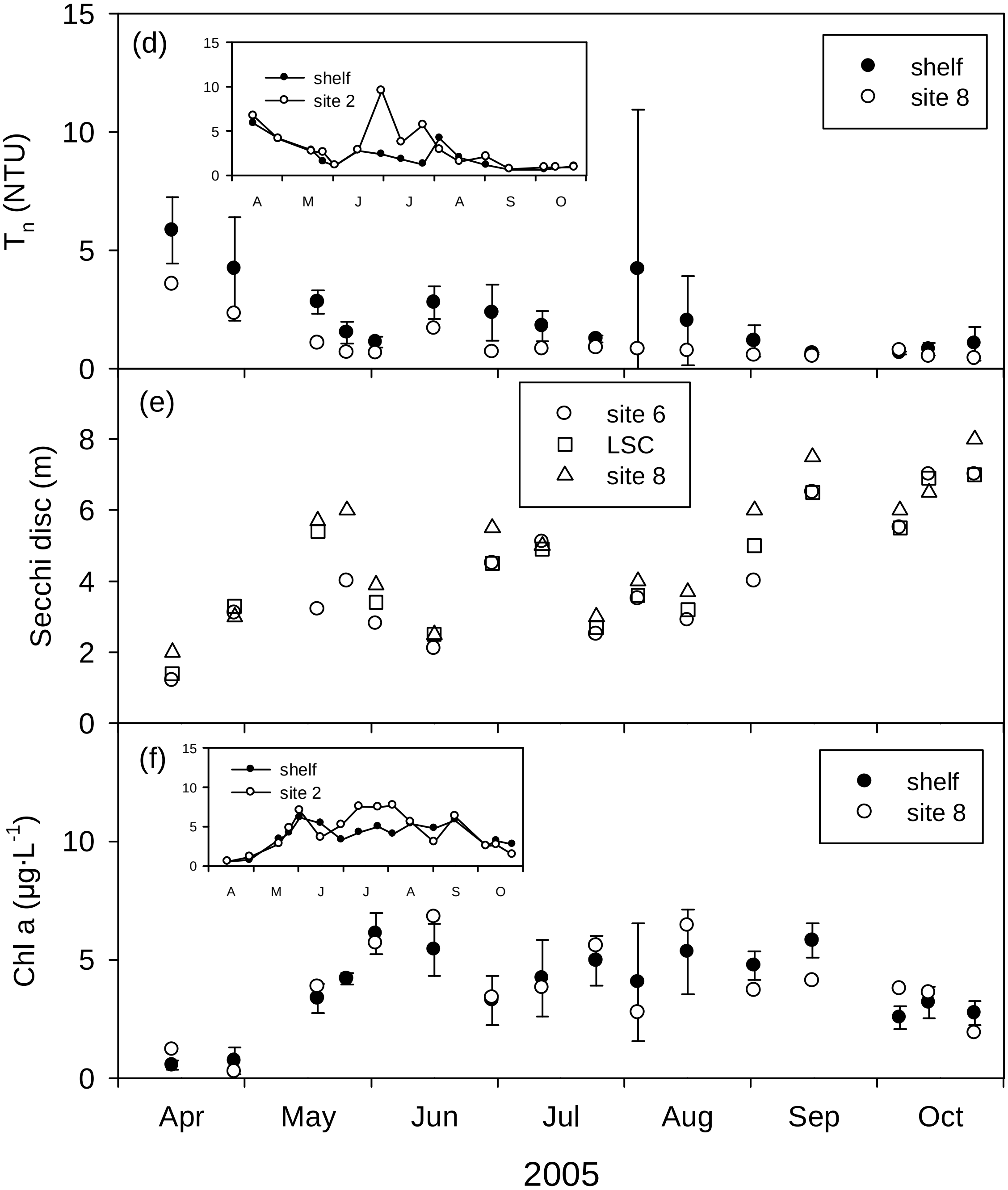

Figure 2d-f. Time series of parameter values for Cayuga Lake for 2005: (d) T_n, (e) Secchi disc, and (f) Chl a. Insets present results for site 2. Results for the "shelf" are averages; the error bars represent spatial variation with dimensions of ± 1 standard deviation.

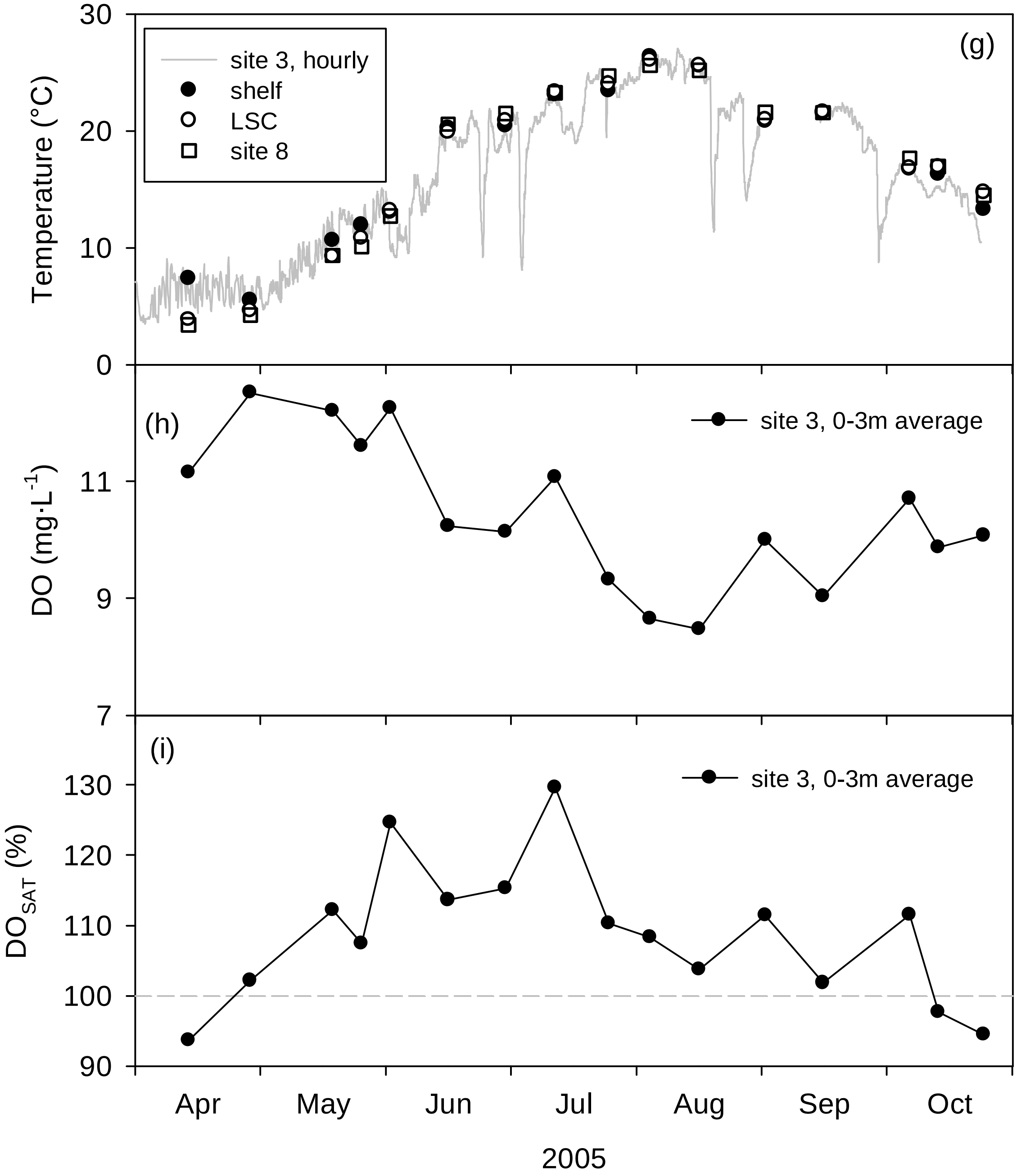

Figure 2g-i. Time series of parameter values for Cayuga Lake for 2005: (g) temperature (hourly data not collected from September 1 to 15), (h) DO, and (i) DO_{SAT}.

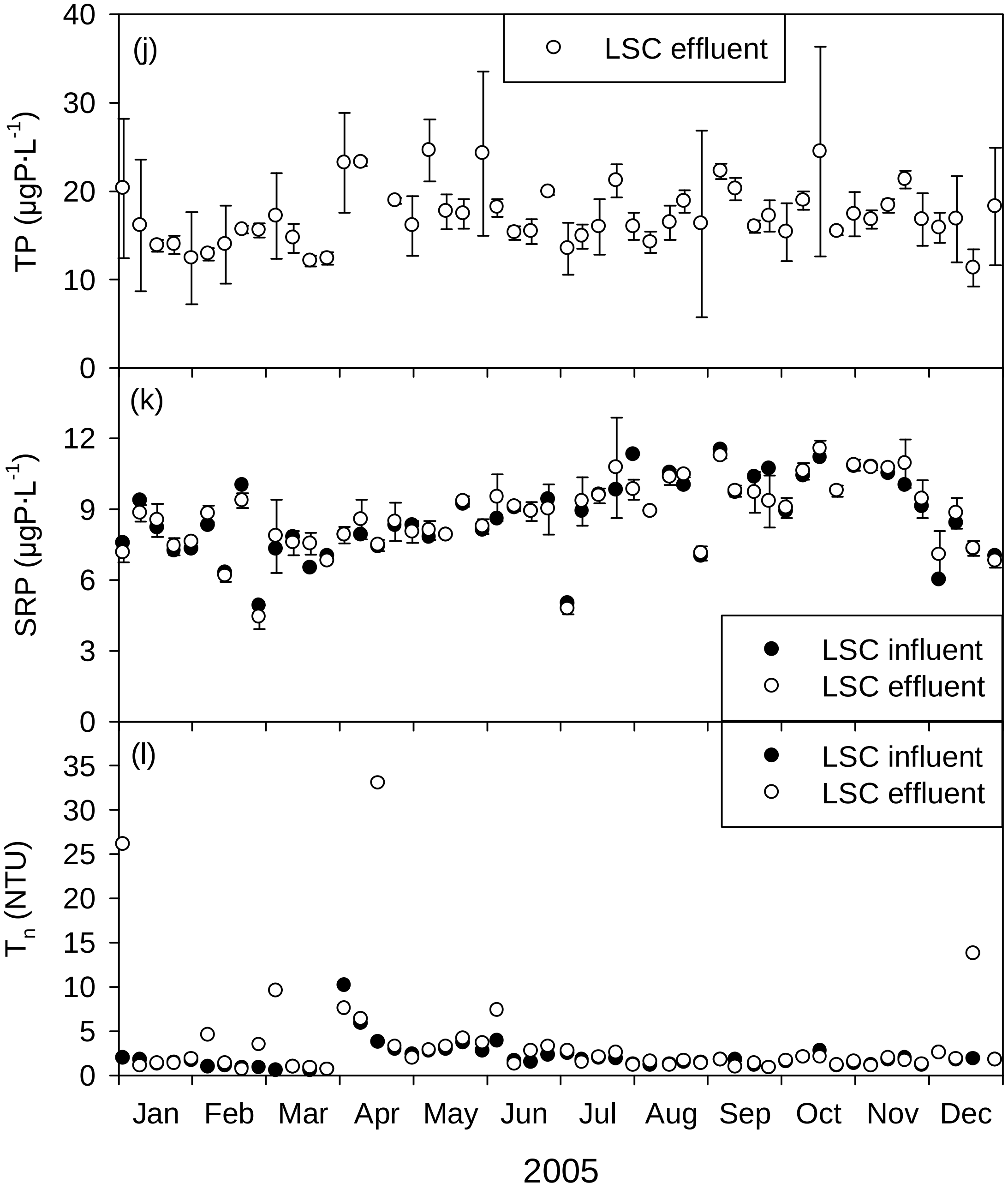

Figure 2j-l. Time series of parameter values for the LSC influent and effluent for 2005: (j) TP (influent not measured), (k) SRP, and (l) T_n. Error bars represent 95% confidence intervals determined from analyses of field triplicates.

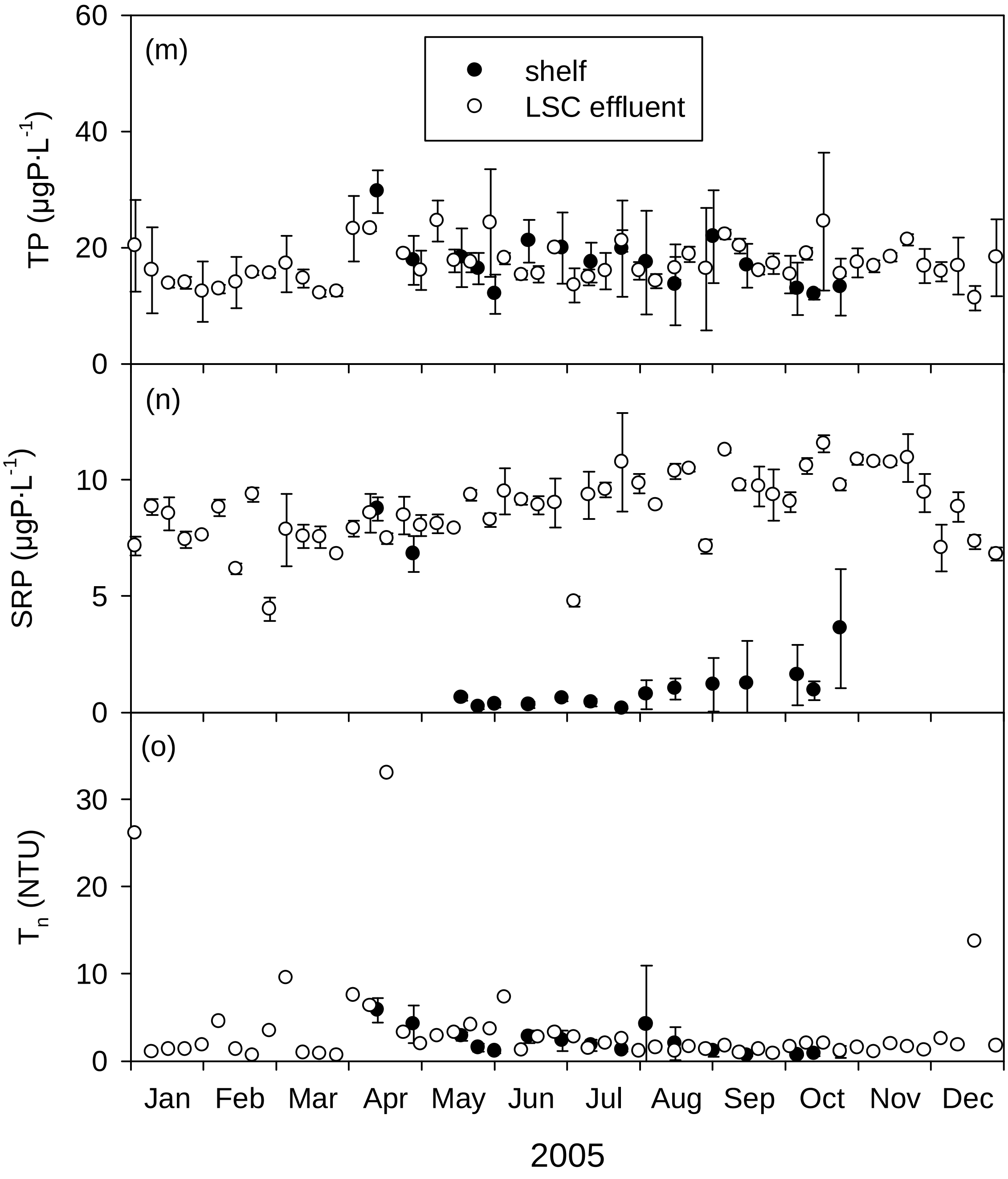

Figure 2m-o. Time series of parameter values for the south shelf and the LSC effluent for 2005: (m) TP, (n) SRP, and (o) T_n. Results for the "shelf" are averages; the error bars represent spatial variation with dimensions of ± 1 standard deviation. Error bars for the LSC effluent represent 95% confidence intervals determined from analyses of field triplicates.

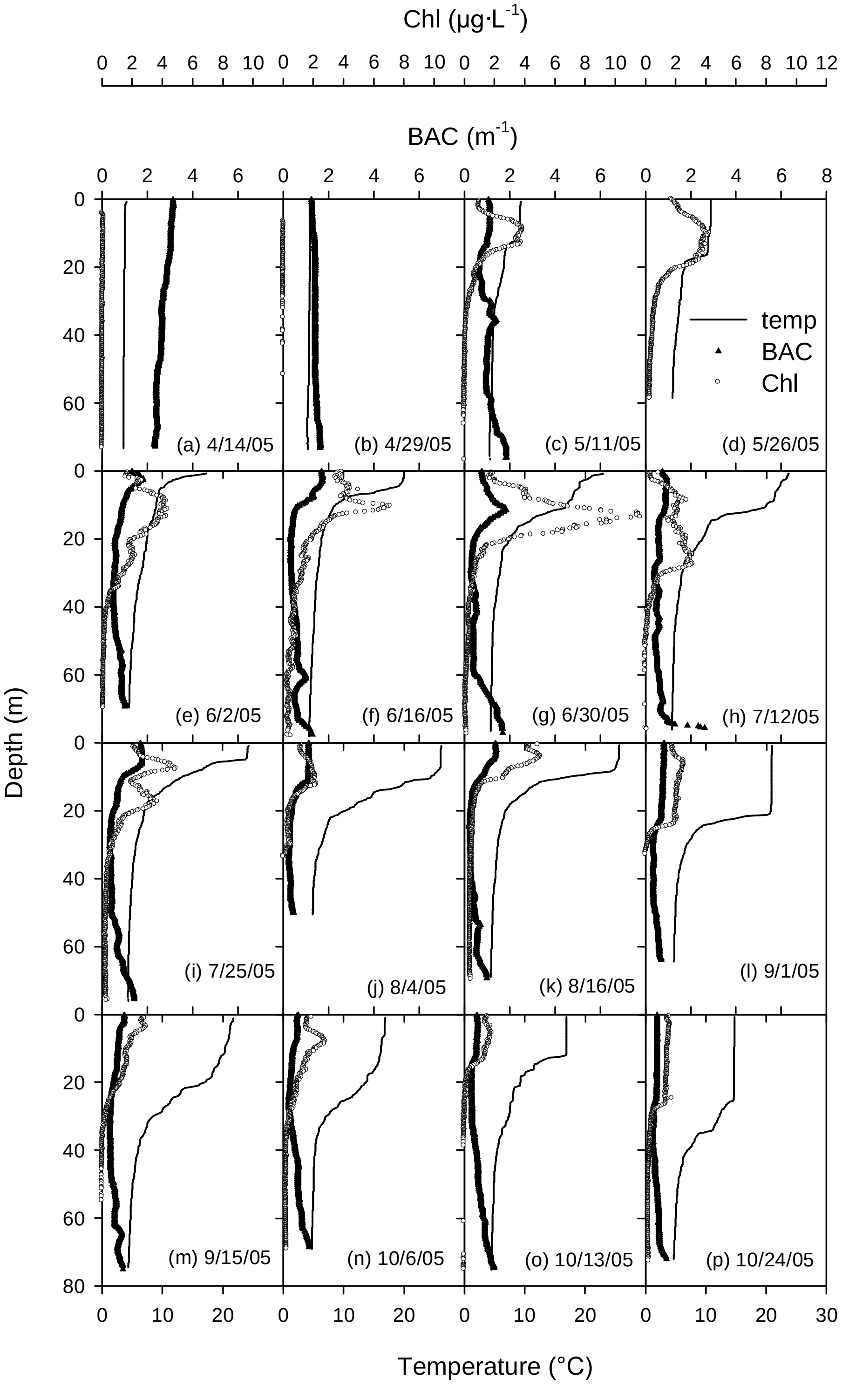

Figure 3. Vertical profiles of temperature, chlorophyll fluorescence, and beam attenuation coefficient (BAC) for LSC site in 2005: (a) April 14, (b) April 29, (c) May 11, (d) May 26, (e) June 2, (f) June 16, (g) June 30, (h) July 12, (i) July 25, (j) August 4, (k) August 16, (l) September 1, (m) September 15, (n) October 6, (o) October 13, and (p) October 24.

4. Selected Topics

4.1. Measures of Clarity

Secchi disc is a systematically flawed measure of clarity for much of the southern portion of Cayuga Lake monitored in this program because of its shallowness. Secchi disc transparency (SD) was observed to extend beyond the lake depth at sites 2, 3, 4, 5 and 7 on several occasions during the 2005 study interval (see Appendix 1). Use of the population of SD measurements available (i.e., observations of SD < lake depth) results in systematic under-representation of clarity for each of these sites by eliminating the inclusion of deeper measurements. In addition, the SD measure is compromised as it approaches the bottom because reflection by the bottom rather than particles in the water can influence the measure. It may be prudent to consider an alternate representation of clarity that does not have these limitations. Turbidity (T_n) represents a reasonable alternative, in systems where particles regulate clarity (Effler 1988).

The relationship between SD and T_n is evaluated in the inverse format (e.g., Effler 1988) in Figure 4. A linear relationship is expected (Effler 1988), and has been observed for the observations made during this study (1998 – 2005; Figure 4). Based on these results (Figure 4), T_n should be considered as an alternate, and apparently more robust, measure of light penetration in shallow portions of the monitored area. The relationship between SD and T_n has remained consistent throughout the seven study years. However, the regression was influenced strongly by observations of high turbidity (> 40 NTU) made during major runoff events. These observations contribute significantly to the imperfect relationship (e.g., low slope) depicted in Figure 4.

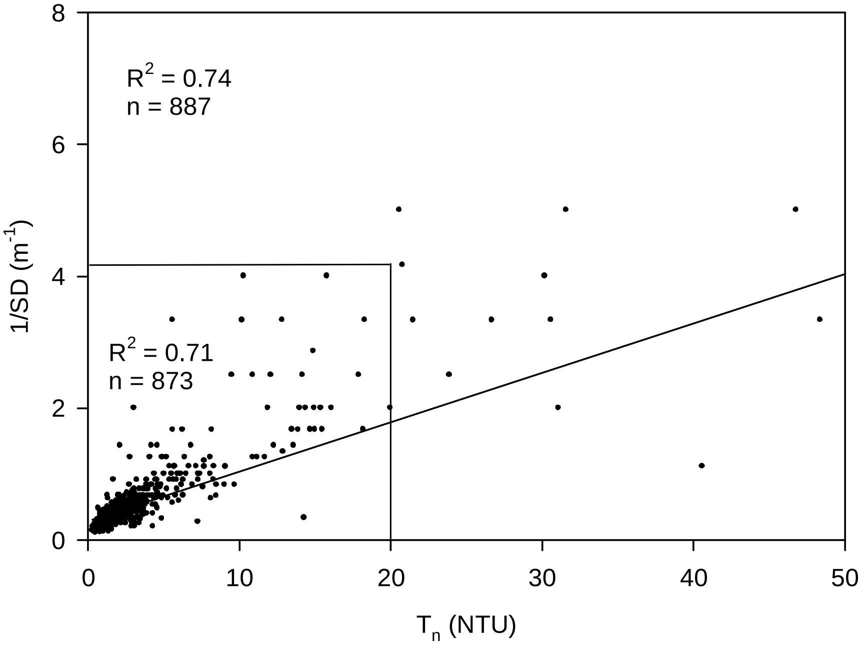

Figure 4. Relationship between Secchi disc transparency (SD) and turbidity in the southern end of Cayuga Lake based on paired measurements made during the 1998 – 2005 study interval.

4.2. Inputs of Phosphorus to Southern End of Cayuga Lake

Phosphorus loading is an important driver of primary production in phosphorus limited lakes. Thus, it is valuable to consider the relative magnitudes of the various sources of phosphorus that enter the southern end of Cayuga Lake. Monthly average loading estimates are presented for the Ithaca Area (IAWWTP) and Cayuga Heights (CHWWTP) wastewater treatment plants (WWTPs) for the 2000–2005 interval (Table 7, Figure 5), based on flow and concentration data made available by these facilities. Discharge flows are measured continuously at these facilities. Concentrations of total phosphorus (TP) in the effluents are measured twice per week at the Ithaca Area WWTP and once per week at the Cayuga Heights WWTP. The estimates of the monthly loads (Table 7, Figure 5) are the product of the monthly average flows and concentrations. Other estimation techniques may result in modest differences in these loads. Rather wide monthly and interannual differences in loading rates have been observed for both WWTPs (Table 7) over the 2000 – 2005 interval. Phosphorus loading from IAWWTP exhibited less month-to-month variability in 2004 and 2005 than in the preceding four years (Table 7). Average phosphorus loading from this facility for the May to October interval decreased about 30% from 2000 and 2001 to 2002–2005. Estimated phosphorus loads for CHWWTP were nearly 50% lower in 2005 than in 2004 (Table 7). The TP permit requirement is 40 pounds per day (18.1 kg per day) for the IAWWTP and 1 $mg \cdot L^{-1}$ for the CHWWTP.

Estimates of monthly tributary phosphorus loading presented in the **Draft Environmental Impact Statement** (DEIS) for the LSC facility, for the combined inputs of Fall Creek and Cayuga Inlet, for the May – October interval are included for reference in Table 7 and Figure 5. These were developed for what was described in that document as an “average hydrologic year”. The estimates were based on historic data for these two tributaries. Tributary loads can vary substantially year-to-year, based on natural variations in runoff. Further, the tributary phosphorus loads of Table 7 and Figure 5 were not for TP, but rather total soluble phosphorus [see Bouldin (1975) for analytical protocols] to better represent the potential for these inputs to support plant growth.

Estimates of monthly TP loading to the shelf from the LSC facility and the percent contribution of this source during 2005 are presented in Table 7 and Figure 5. Concentrations of TP were measured weekly at the LSC discharge. The estimates of the monthly loads (Table 7, Figure 5) are the product of the monthly average flows and concentrations that are reported monthly as part of the Discharge Monitoring Report (DMR; Appendix 2). The average TP loading rate from LSC during the May – October period was 1.8 $kg \cdot d^{-1}$, or 6.8% of the total TP load to the shelf. This is a smaller contribution than the 2.9 $kg \cdot d^{-1}$ projected in the DEIS for the LSC facility (Stearns and Wheler 1997), but higher than reported for the preceding five years of operation (Table 7). The LSC facility contributed a larger fraction of TP to the shelf in 2005 than the 4.8% projected in the DEIS. This is attributable to substantially lower TP loading from the wastewater treatment facilities in 2005 (13.8 $kg \cdot d^{-1}$) than was projected in the DEIS (45.4 $kg \cdot d^{-1}$). The peak monthly loading rate for LSC (2.1 kg d^{-1}) occurred in May 2005, and the maximum monthly contribution to total phosphorus loading to the shelf (9.9%) occurred in August (Table 7). Loading rates were similar during May to September of 2005 and substantially lower in October. From 2000 to 2004 phosphorus loading from the LSC facility to the shelf remained consistent at about 1.1 kg·d^{-1} (May – October average) with a relative contribution of about 3.5% (Table 7).

Paired measurements of SRP and T_n for the LSC influent and effluent were essentially equal for the vast majority of observations, suggesting the absence of substantial inputs within the facility (Figure 2k-l). Three occurrences of high turbidity were observed in the LSC effluent, one in January, one in April and in December (Figure 2l). The cause of these higher T_n values is unknown. The average concentration of SRP in the LSC effluent was higher in 2005 (April – October average of 9.1 μg L^{-1}) than in the five previous years of operation when average SRP concentrations ranged from 4.0 to 6.9 μg L^{-1}. Average levels of TP, SRP and T_n in the LSC effluent and on the shelf are presented in Table 8. Total phosphorus concentrations were essentially equal in the LSC effluent and in the receiving waters of the shelf (Figure 2m, Table 8). Concentrations of SRP averaged about 7 μg·L^{-1} higher in the LSC effluent than on the shelf (Figure 2n, Table 8). Average turbidity levels were 2.4 NTU higher in the LSC effluent than on the shelf. This difference was largely the result of one very high T_n value for the LSC effluent on April 18 (Figure 2o). When this value is omitted from the average, turbidity levels were 0.4 NTU higher in the LSC effluent than on the shelf. Levels of TP, SRP and T_n on the shelf during 2005 were unusually uniform over time and space (Figure 2m-o). This was due to the absence of major runoff events during the May to September interval.

The increased TP loading from LSC in 2005 was related to a 22% increase in flow rate and a 44% increase in effluent TP concentrations over May to October averages from 2000 to 2004. The increased flow rate was caused by greater cooling demands associated with the unusually hot summer of 2005. The increased TP concentrations in the LSC effluent appear to be associated with a change in hypolimnetic water quality that has occurred over the last two to three years. Since 2003 increases in TP, SRP, and T_n have been observed in the LSC effluent (Figure 6) and in the lake adjacent to the LSC intake (Figure 7). Paired measurements of SRP and T_n in the LSC influent and effluent compared closely in 2005 (Figure 2k, l), as they have throughout operation of the facility (UFI 2001, 2002, 2003, 2004, 2005). This supports the position that the increased effluent concentrations were associated with an in-lake phenomena rather than a change within the LSC facility.

Table 7: Estimates of monthly external loads of phosphorus to the southern portion of Cayuga Lake over the 2000 to 2005 interval.

Year	IAWWTP[a] (kg d^{-1})	CHWWTP[a] (kg d^{-1})	Tributaries[b] (kg d^{-1})	LSC[c] (kg d^{-1})	Total (kg d^{-1})	% LSC
2000						
May	24.1	3.5	29.0	-	56.6	-
June	16.6	5.1	15.8	-	37.5	-
July	13.7	3.4	8.8	1.4	27.3	5.1
August	19.1	4.6	6.0	1.0	30.7	3.3
September	18.5	4.0	7.5	0.9	30.9	2.9
October	15.4	4.1	13.1	0.6	33.2	1.8
Mean	*16.5*	*4.1*	*13.3*	*1.0*	*34.9*	*2.9*
2001						
May	15.8	5.5	29.0	0.7	51.0	1.4
June	11.2	4.0	15.8	1.1	32.1	3.4
July	15.2	4.2	8.8	1.0	29.2	3.4
August	15.2	7.1	6.0	1.4	29.7	4.7
September	22.0	6.6	7.5	1.0	37.1	2.7
October	16.4	2.8	13.1	0.7	33.0	2.1
Mean	*16.0*	*5.0*	*13.3*	*1.0*	*35.4*	*3.0*
2002						
May	12.4	4.4	29.0	0.6	46.4	1.3
June	7.9	3.5	15.8	1.0	28.2	3.5
July	10.4	3.8	8.8	1.8	24.8	7.3
August	16.2	2.0	6.0	1.2	25.4	4.7
September	11.4	2.8	7.5	1.0	22.7	4.4
October	13.6	3.1	13.1	0.7	30.5	2.3
Mean	*12.0*	*3.3*	*13.3*	*1.1*	*29.7*	*3.5*
2003						
May	11.0	2.7	29.0	0.6	43.3	1.4
June	6.0	7.8	15.8	1.2	30.8	3.9
July	8.5	3.9	8.8	1.2	22.4	5.4
August	13.8	3.1	6.0	1.2	24.1	5.0
September	11.9	3.4	7.5	1.3	24.1	5.4
October	14.5	5.3	13.1	0.9	33.8	2.7
Mean	*11.0*	*4.4*	*13.3*	*1.1*	*29.8*	*4.0*
2004						
May	11.0	6.6	29.0	1.3	47.9	2.7
June	11.0	7.2	15.8	1.2	35.2	3.5
July	11.7	7.1	8.8	0.9	28.5	3.2
August	11.6	3.4	6.0	1.4	22.4	6.2
September	11.5	7.9	7.5	1.1	28.0	3.9
October	10.9	10.6	13.1	0.6	35.2	1.7
Mean	*11.3*	*7.1*	*13.3*	*1.1*	*32.9*	*3.5*
2005						
May	11.0	3.7	29.0	2.1	45.8	4.6
June	10.3	3.5	15.8	1.9	31.5	6.0
July	9.4	2.8	8.8	2.0	23.0	8.7
August	9.4	2.9	6.0	2.0	20.3	9.9
September	10.5	3.8	7.5	1.8	23.6	7.6
October	10.4	5.1	13.1	1.1	29.7	3.7
Mean	*10.2*	*3.6*	*13.3*	*1.8*	*29.0*	*6.8*

[a] total phosphorus; from USEPA website-http://www.epa.gov/enviro/index_java.html

[b] total soluble phosphorus, for average hydrologic year; summation of Fall Creek and Cayuga Inlet; from Draft Environmental Impact Statement, LSC Cornell University, 1997

[c] total phosphorus; from facility permit reporting

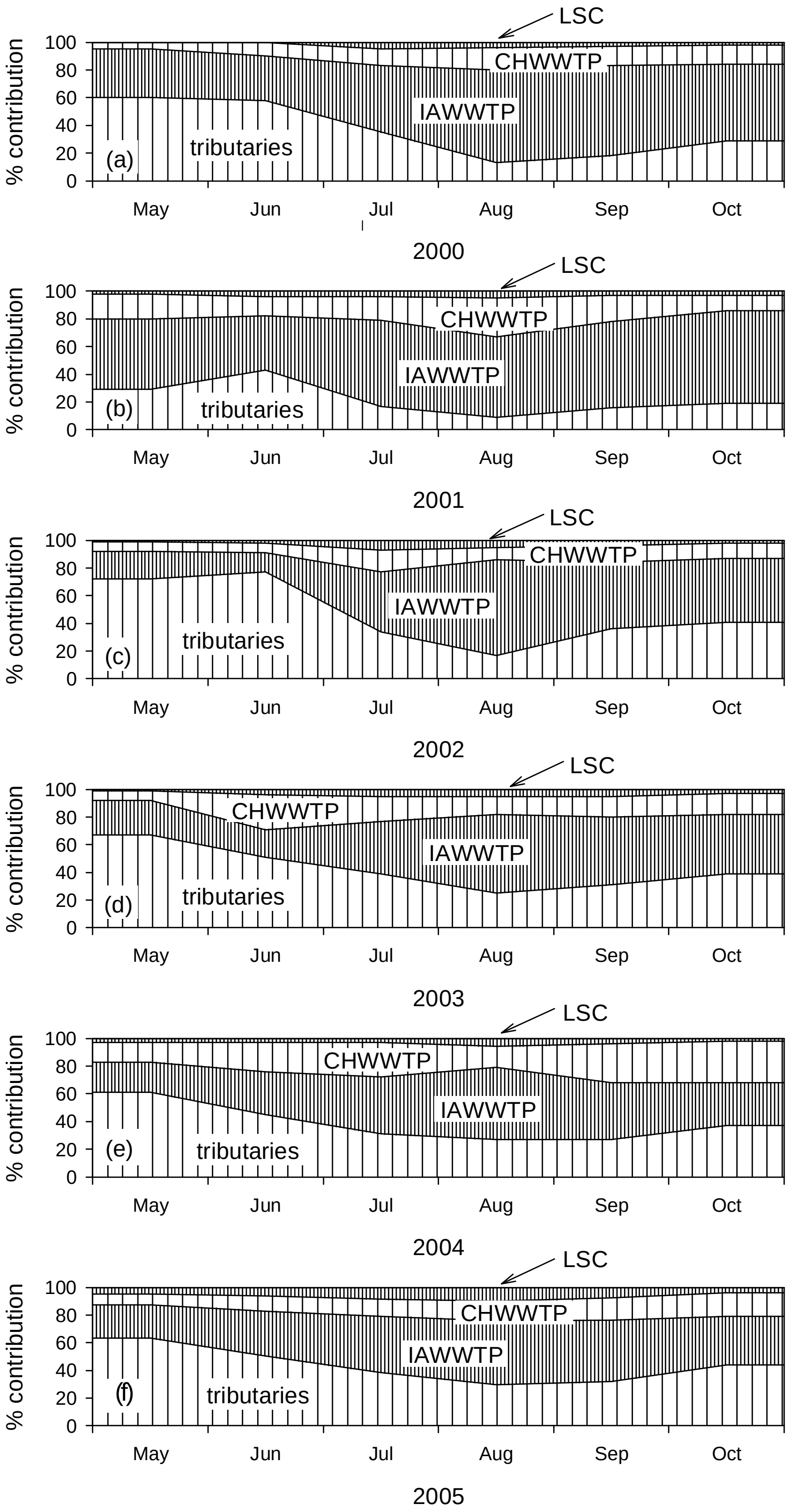

Figure 5. Time series of estimated monthly external loads of phosphorus to the southern portion of Cayuga Lake, partitioned according to source: (a) 2000, (b) 2001, (c) 2002, (d) 2003, (e) 2004, and (f) 2005. Loads are for total phosphorus with the exception of tributary loading, which is for total soluble phosphorus.

Table 8: Average values and standard deviations for TP, SRP, and T_n in the LSC effluent and on the shelf. Averages determined from observations made during the April – October interval of 2005.

Location	TP (µg·L^{-1})	SRP (µg·L^{-1})	T_n (NTU)
LSC effluent (n = 31)	18.3±3.3	9.1±1.4	3.5±5.7
Shelf (n = 16)	17.5±4.5	1.8±2.5	2.1±1.5

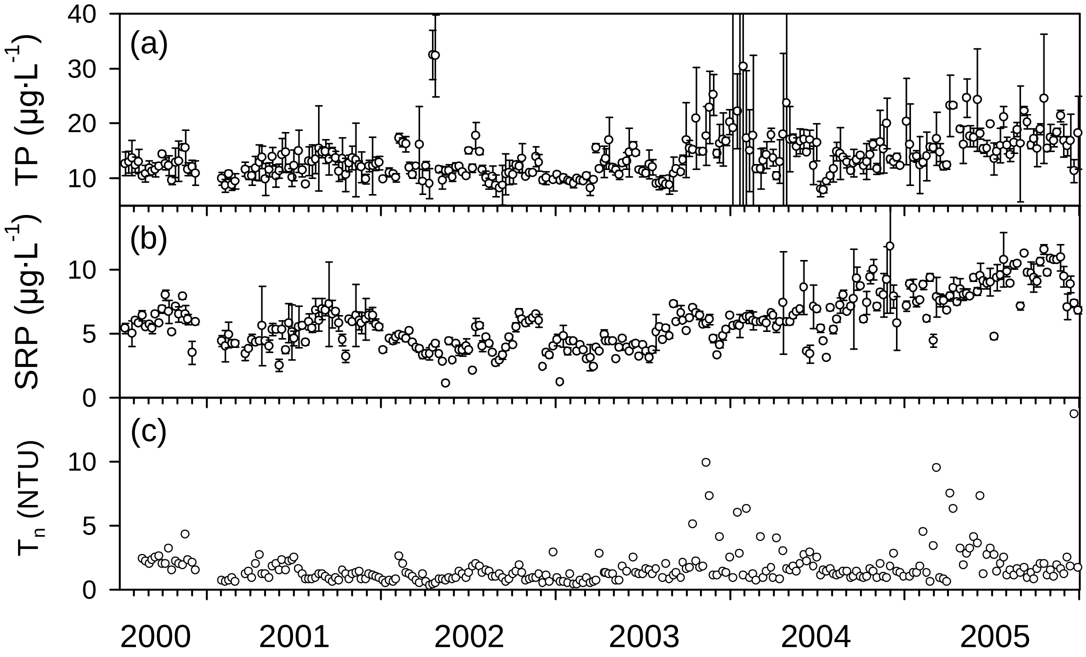

Figure 6. Time series of concentrations measured weekly in the LSC effluent for the 2000 – 2005 interval: (a) total phosphorus, (b) soluble reactive phosphorus, and (c) turbidity. Error bars represent 95% confidence intervals determined from triplicate samples.

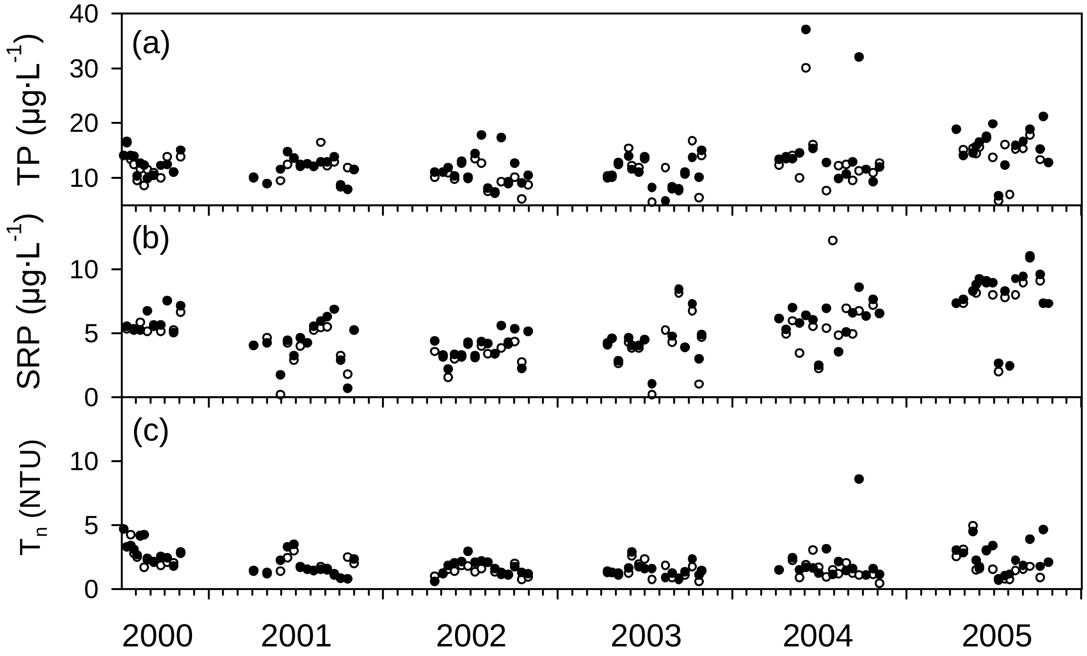

Figure 7. Time series of concentrations measured bi-weekly at the LSC intake site (~77 m deep) for the 2000 – 2005 interval: (a) total phosphorus, (b) soluble reactive phosphorus, and (c) turbidity. Open circles are measurements from 3 m above the lake bottom, the approximate depth of the LSC intake. Filled circles are measurements from 1m above the lake bottom.

An unambiguous explanation for the apparent increases in TP, SRP, and T_n in the lake's hypolimnion has not been identified. In large deep lakes such as Cayuga, changes in hypolimnetic water quality are expected to occur over long time scales, on the order of decades rather than years. Temporary increases in T_n and the particulate fraction of TP in bottom waters can be caused by plunging turbid inflows and internal waves or seiches. However, hypolimnetic SRP levels are generally considered to reflect lake-wide metabolism rather than local effects. Soluble reactive phosphorus is produced during microbial decomposition of organic matter and often accumulates in the hypolimnia of stratifying lakes during summer. Increases in primary production (phytoplankton growth) and subsequent decomposition could cause increases in SRP levels, but noteworthy increases in chlorophyll concentrations (phytoplankton biomass) have not been observed (Table 10). Longer intervals of thermal stratification, increased hypolimnetic temperatures or depletion of dissolved oxygen could also cause higher concentrations of SRP in the bottom waters. Such changes have not been observed. The apparent increase in hypolimnetic SRP concentrations may represent a short-term anomaly rather than a long-term trend. This metric of lake metabolism should be diligently monitored in the future in order to discern the permanence and significance of these changes.

4.3. Variations in Runoff and Wind Speed

Meteorological conditions and coupled features of runoff have important effects on lake ecosystems. These conditions are not subject to management, but in fact demonstrate wide variations in many climates that can strongly modify measures of water quality (e.g., Auer and Effler 1989, Lam et al. 1987). Thus the effects of natural variations in these conditions can be mistaken for impacts of man's activities (e.g., pollution). The setting of the southern end of the lake, including the localized entry of tributary flows and its shallowness, may promote interpretive interferences with the measurements of total phosphorus (TP), Secchi disc transparency (SD), and turbidity (T_n). These interferences are associated with potential influxes of non-phytoplankton particles that would diminish SD and increase T_n and TP concentrations, features that could be misinterpreted as reflecting increases in phytoplankton concentrations. These influxes may be associated with external loads carried by the tributaries, particularly during runoff events, and internal loads associated with sediment resuspension, driven by wind events (e.g., Bloesch 1995). Thus, it is prudent to consider natural variations in tributary flow and wind speed in evaluating seasonal and interannual differences in these parameters for the southern end of Cayuga Lake. Interannual variations in runoff and wind speed are discussed in **Section 4.7 – Interannual Comparisons**, and illustrated in Figures 13, 14 and 15.

Runoff and wind conditions for the study period of 2005 are represented here by daily average flows measured in Fall Creek by USGS, and daily average wind speed, out of the north to northwest, measured by Cornell University (Figure 6). These conditions are placed in a historic perspective by comparison to available records. Fall Creek has been reported to be a good indicator of lake-wide runoff conditions (Effler et al. 1989). The record for Fall Creek is quite long, 81 years; the wind database contains 23 years of measurements. Daily average flow measurements for Fall Creek and wind speed for 2005 are compared to time-series of daily median values for the available records (Figure 6a and c). Additionally, monthly average flows for the study period are compared to quartiles for the period of record (Figure 6b). Due to the orientation of the southern end of Cayuga Lake, winds out of the north to northwest (315° - 360°) are expected to drive the greatest turbulence, and thus resuspension, in this part of the lake. However, if seiche action is a major cause of sediment resuspension a south wind will also be important.

When compared to the historic record, Fall Creek flows during 2005 were elevated during April and October and well below average from May to September (Figure 6a, b). Only three major (>500 cfs) runoff events occurred during the April to October interval of 2005, two in April and one in October (Figure 6a). Monthly average flows were above the 75th percentile in April and October and below the 25th percentile from May to September (Figure 6b). The average flow for the May to September interval of 2005 (51 cfs) was the 13th lowest of the 81 years of record. This is in marked contrast to 2004, when the average flow for May to September (270 cfs) was the highest of the 1925 – 2005 record. In-lake sampling was conducted primarily during low-flow intervals in 2005 and the distinct signatures of high runoff events (e.g., high TP and T_n, and low Secchi disc transparency) that have been manifested in previous years were not observed during this study season.

Winds from the north to northwest were above average for extended periods during early May, late July, August, and early September (Figure 6c). Wind velocities were distinctly above average on the monitoring days of July 25, August 16, and September 1 (Figure 6c). High winds out of the north to northwest on June 22, July 2, August 17, and September 27 may have contributed to apparent seiches that are suggested by sudden drops in temperature measured by the recording thermistors (Figure 2g). Temperature patterns indicative of seiche activity from August 26 to 28 were observed in the absence of high winds from the north to northwest.

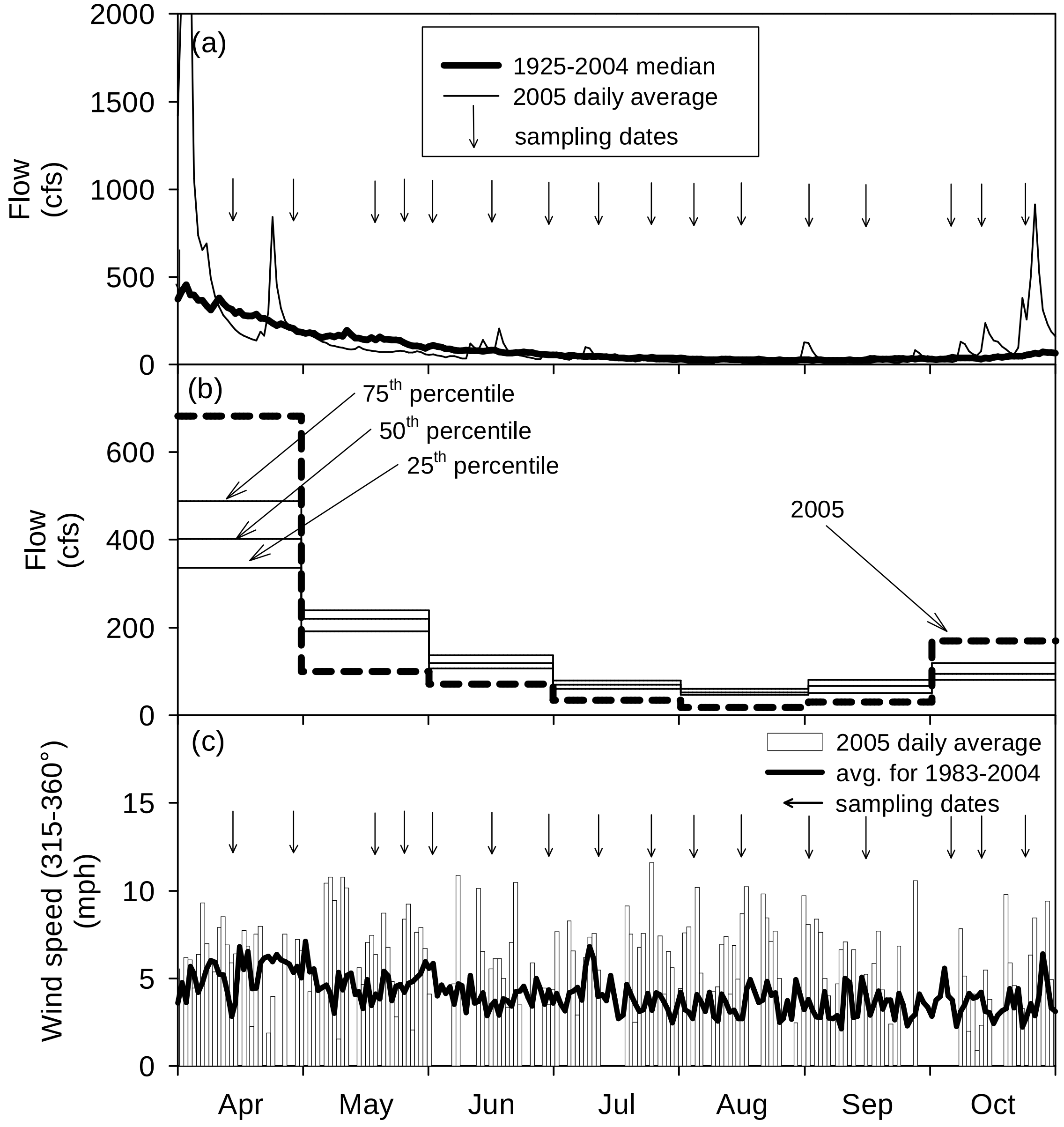

Figure 8. Runoff and wind conditions for the April – October interval of 2005: (a) daily average flows in Fall Creek, compared to median daily values for the 1925 – 2004 record, (b) monthly flows in 2005 compared, to quartile levels of flow for the 1925 – 2004 record, and (c) daily average wind speed out of the north to northwest, compared to average values for the 1983 – 2004 record.

4.4. Limitations in Measures of Trophic State on the Shelf

Recurring scientific evidence, provided by the findings of seven consecutive study years (Upstate Freshwater Institute 1999, 2000, 2001, 2002, 2003, 2004, 2005) has demonstrated that T_n and TP are systematically flawed indicators of the trophic state on the shelf. In particular, substantial variations and increases in both parameters on the south shelf appear to be uncoupled at times from patterns and magnitudes of phytoplankton biomass. These features appear to be associated with greater contributions of non-phytoplankton particles (e.g. clay and silt) to the measures of TP and T_n on the south shelf. Four lines of circumstantial evidence supporting this position have been presented in previous annual reports, based on observations from the 1998 - 2004 study years (Upstate Freshwater Institute 1999, 2000, 2001, 2002, 2003, 2004, 2005). Observations from the 2005 study year provide additional evidence that T_n and TP are compromised as trophic indicators in this system because of the contributions of inanimate non-phytoplankton particles (tripton):

1. high T_n (Figure 2d) values were observed during 2005 for the shelf and site 8 following major runoff events in April (Figure 8a). This suggests greater contributions of non-phytoplankton particles to the measurements of T_n following runoff events.

2. elevated T_n values were reported for the 1999, 2000 and 2002 study years (Upstate Freshwater Institute 2000, 2001, 2003) at the deep water sites during “whiting” events in late July and August. These increases in T_n were driven largely by increases in T_c (calcium carbonate turbidity). Large increases in T_c indicative of a “whiting” event were not observed during the 2005 study interval (Figure 9).

3. the ratio of particulate P (PP) to chlorophyll **a** was often substantially higher on the south shelf than at the deep stations (Figure 10), suggesting greater contributions of non-phytoplankton particles to the PP pool at the southern end of the lake. Further, unlike the deep sites, the ratio was often above the range of values commonly associated with phytoplankton biomass (e.g., Bowie et al. 1985).

4. application of previously reported literature values of light scattering (e.g., T_n) per unit chlorophyll (e.g., Weidemann and Bannister 1986) to the chlorophyll **a** observations indicate that non-phytoplankton particles made greater contributions to T_n on the shelf than in deep waters (Figure 11). Non-phytoplankton particles were responsible for the high T_n levels on the shelf following major runoff events in April and after a series of modest events in June (Figure 11).

The 2005 results demonstrate that substantial temporal variations continue to occur for TP and T_n on the shelf that are uncoupled from the trophic state issue. Additional measurements were made in 1999 and 2000, beyond the scope of the LSC monitoring program, to more comprehensively resolve the constituents/processes regulating the SD and TP measurements (Effler et al. 2002). Effler et al. (2002) demonstrated that inorganic particles (primarily clay minerals, quartz and calcium carbonate), rather than phytoplankton, are the primary regulators of clarity, represent most of the PP, and are responsible for the higher T_n, lower SD, and higher TP on the shelf compared to deeper portions of the lake.

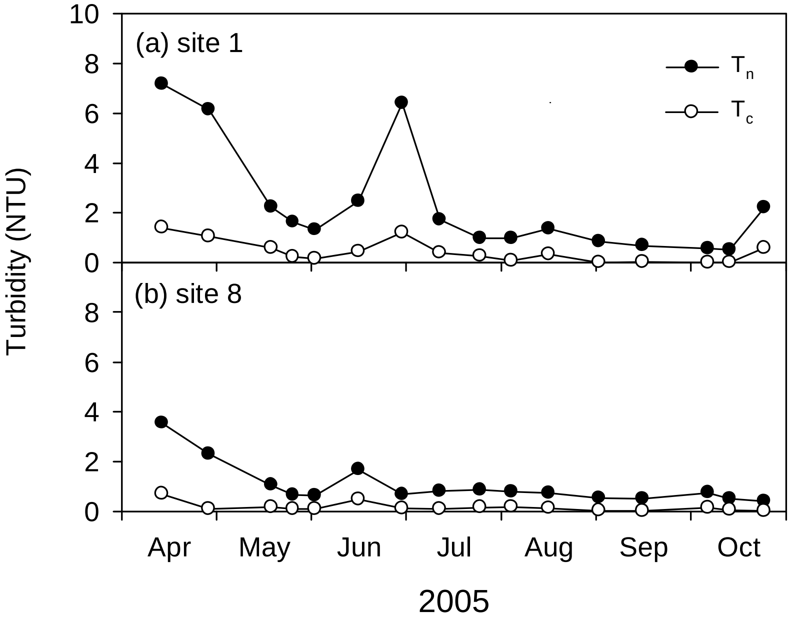

Figure 9. Distributions of total turbidity (T_n) and calcium carbonate turbidity (T_c) in the upper waters of Cayuga Lake in 2005: (a) site 1, (b) site 8.

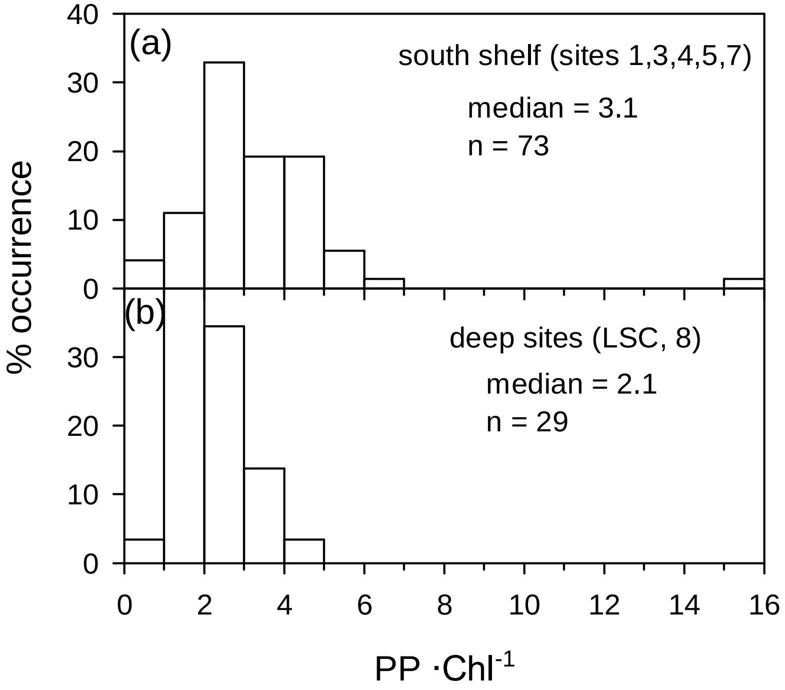

Figure 10. Distributions of the particulate P (PP) to chlorophyll **a** ratio values in Cayuga Lake in 2005: (a) south shelf sites, and (b) deep water sites.

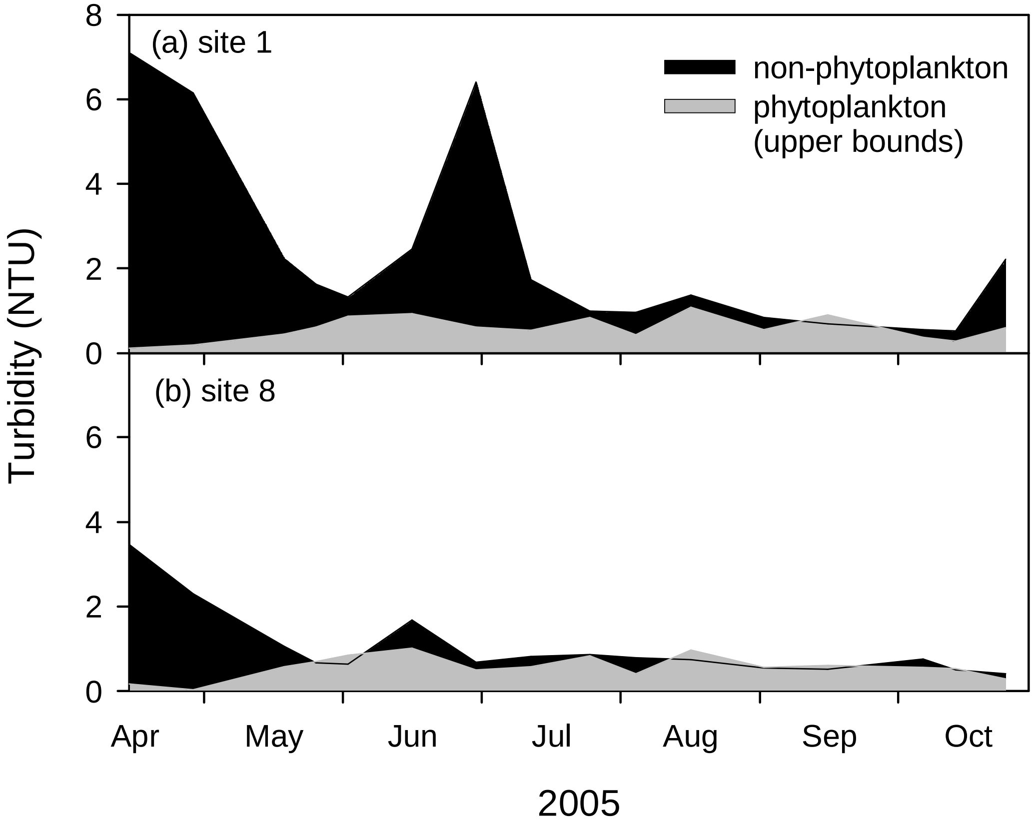

Figure 11. Time-series of T_n and contributions from components (phytoplankton and non-phytoplankton) for the April – October interval of 2005: (a) site 1, and (b) site 8.

4.5. Continuation of the Long-Term Record of Water Quality/Eutrophication Indicators

Systematic changes in water quality can only be quantitatively documented if reliable measurements are available for historic conditions. Concentrations of TP and chlorophyll **a** have been measured irregularly in the open waters of Cayuga Lake over the last three decades. Measurements made over the late 1960s to mid 1970s were made mostly as part of research conducted by Cornell University staff (Tables 9 and 10). These data were collected mostly at deep water locations. No comprehensive data sets were found to represent conditions in the 1980s. Measurements were continued in the 1994 – 1996 interval as part of studies conducted to support preparation of the **Draft Environmental Impact Statement** for the LSC facility (Stearns and Wheler 1997). These included observations for both the shelf and deeper locations (Tables 9 and 10). The record continues to be updated annually, for both a deep water location and the shelf, based on monitoring sponsored by Cornell University related to operation of the LSC facility (1998 – 2005, documented here).

Summer (June – August) average concentrations are presented for the lake's upper waters; sources of data are included (Tables 9 and 10). Higher TP concentrations were observed on the shelf compared to deeper portions of the lake in all years monitored (Table 9). The 2005 summer average TP concentrations fell within the range of values observed since 1998 for both the deep water site and the shelf (Table 9). Chlorophyll **a** concentrations were distinctly higher on the shelf than at deeper water sites from 1994 to 1996, though similar levels were observed over the 1998 – 2005 interval (Table 10). In 2005, chlorophyll **a** concentrations were nearly equal on the shelf and at the deep water location (Table 10). The 1998 average does not include June observations. Summer average concentrations of TP and chlorophyll **a** for deep water sites are consistent with a mesotrophic trophic state classification (i.e., intermediate level of primary productivity; e.g., Chapra and Dobson 1981, Dobson et al. 1974, Vollenweider 1975).

Table 9: Summer (June - August) average total phosphorus (TP) concentrations for the upper waters of Cayuga Lake. June – September averages are included in parentheses for the 1998 – 2005 study years.

Year	**Total Phosphorus ($\mu g \cdot L^{-1}$)**		**Source**
	Deep-Water Location(s)	**Southern Shelf**	
1968$^{\Delta}$	20.2 (n = 19)	-	Peterson 1971
1969$^{\Delta}$	15.3 (n = 22)	-	Peterson 1971
1970$^{\Delta}$	14.0 (n = 32)	-	Peterson 1971
1972^{x}	18.8 (n = 22)	-	USEPA 1974
1973$^{\Delta}$	14.5 (n = 88)	-	Godfrey 1973
1994$^{*,\oplus}$	21.7	30.8	Stearns and Wheler 1997
1995$^{*,\otimes}$	16.5	23.7	Stearns and Wheler 1997
1996$^{*,\otimes}$	12.4	21.7	Stearns and Wheler 1997
1998^{+}	14.7 (14.7)	26.5 (24.7)	UFI 1999
1999^{++}	10.6 (9.8)	15.9 (14.5)	UFI 2000
2000^{++}	11.9 (11.6)	19.4 (18.7)	UFI 2001
2001^{++}	14.0 (14.2)	21.4 (20.4)	UFI 2002
2002^{++}	14.7 (14.1)	22.1 (22.2)	UFI 2003
2003^{++}	10.2 (10.4)	13.6 (14.4)	UFI 2004
2004^{++}	15.8 (15.3)	21.5 (24.9)	UFI 2005
2005^{++}	12.8 (12.6)	17.3 (17.8)	this report

$^{\Delta}$ Myers Point
^{x} one sample, multiple sites and depths
* averages of 0 m observations
$^{+}$ July – August, 0 – 4 m composite samples
$^{++}$ 0 – 4 m composite samples
$^{\oplus}$ site in 62 m of water, south of Myers Point, surface samples
$^{\otimes}$ site in 70 m of water, south of Myers Point, surface samples

Table 10: Summer (June – August) average chlorophyll **a** concentrations for the upper waters of Cayuga Lake. June – September averages are included in parentheses for the 1998 – 2005 study years.

Year	Chlorophyll a ($\mu g \cdot L^{-1}$) Deep-Water Location(s)	Southern Shelf	Source
1966*	2.8	-	Hamilton 1969
1968**	4.3	-	Wright 1969
1968 – 1970	4.8	-	Oglesby 1978
1970	3.7	-	Trautmann et al. 1982
1972	10.3	-	Oglesby 1978
1973	8.2	-	Trautmann et al. 1982
1974	8.1	-	Trautmann et al. 1982
1977	8.6	-	Trautmann et al. 1982
1978	6.5	-	Trautmann et al. 1982
1994	5.5	8.9	Stearns and Wheler 1997
1995	4.8	6.8	Stearns and Wheler 1997
1996	3.4	7.6	Stearns and Wheler 1997
1998^{+}	4.8 (4.8)	5.7 (5.2)	UFI 1999
1999^{++}	4.7 (4.6)	4.4 (4.2)	UFI 2000
2000^{++}	4.8 (4.7)	5.5 (5.4)	UFI 2001
2001^{++}	4.7 (4.5)	4.6 (4.4)	UFI 2002
2002^{++}	5.1 (5.2)	4.8 (5.6)	UFI 2003
2003^{++}	5.6 (5.6)	6.0 (5.9)	UFI 2004
2004^{++}	4.7 (5.3)	6.5 (6.9)	UFI 2005
2005^{++}	4.9 (4.7)	4.8 (4.9)	this report

* Hamilton 1969, 15 dates
** Wright 1969, 4 dates – 7 to 9 longitudinal sites
$^{+}$ July – August, 0 – 4 m composite samples
$^{++}$ 0 – 4 m composite samples

4.6. Comparison to Other Finger Lakes: Chlorophyll a

Synoptic surveys of all eleven Finger Lakes have been conducted in recent years (NYSDEC, with collaboration of the Upstate Freshwater Institute) that support comparison of selected conditions among these lakes. Chlorophyll **a** data (Callinan et al., 2000) collected from those surveys are reviewed here, as this may be the most representative indicator of trophic state of the measurements made. Samples (n=15 to 16) were collected in these surveys over the spring to early fall interval of 1996 through 1999. The sample site for Cayuga Lake for this program coincides approximately with site 8 of the LSC monitoring program (Figure 1b).

There is not universal agreement on the concentrations of chlorophyll **a** that demarcate trophic states. A summer average value of 2.0 $\mu g \cdot L^{-1}$ has been used as the demarcation between oligotrophy and mesotrophy (Dobson et al. 1974, National Academy of Science 1972). There is less agreement for the demarcation between mesotrophy and eutrophy; the boundary summer average value reported from different sources (e.g., Dobson et al. 1974, National Academy of Science 1972, Great Lakes Group 1976) ranges from 8 to 12 µg·L^{-1}.

The average chlorophyll **a** concentration for Cayuga Lake for this synoptic program (3.5 µg·L^{-1}) is compared to the values measured in the other ten Finger Lakes in Figure 12. These data support Cayuga Lake's classification as mesotrophic. Six of the lakes had average concentrations lower than observed for Cayuga Lake (Figure 12). Two of the lakes, Canandaigua and Skaneateles, had concentrations consistent with oligotrophy, while two (Conesus and Honeoye) bordered on eutrophy (Figure 12).

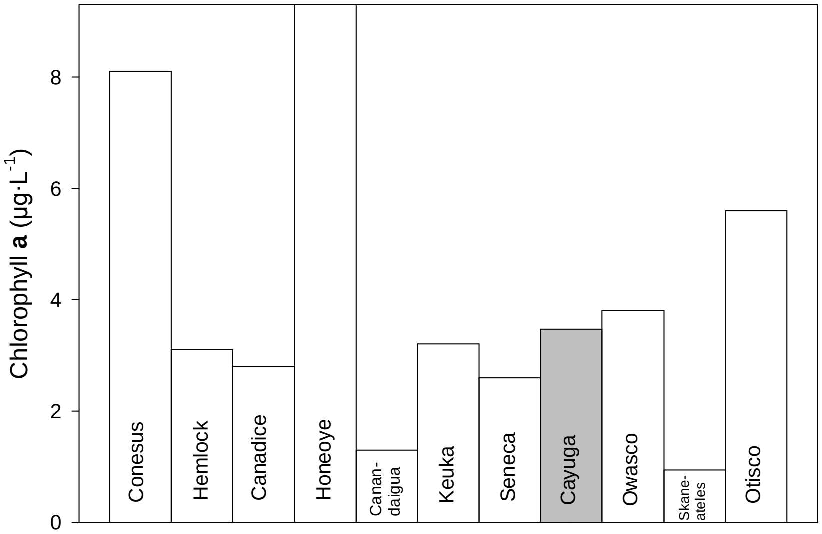

Figure 12. Comparison of average chlorophyll a concentrations for the spring-early fall interval for the eleven Finger Lakes, based on samples (n=15 to 16) collected over the 1996 through 1999 interval (data from Callinan et al. 2000).

4.7. Interannual Comparisons

Interannual differences in water quality can occur as a result of both human interventions and natural variations in climate. Because of its location and shallowness, water quality on the south shelf can vary substantially from year to year as a result of changes in forcing conditions. Conditions for runoff, wind speed and summed TP loading from the Ithaca Area WWTP, Cayuga Heights WWTP and the LSC facility, for 2005 are compared here to the seven previous study years (1998 – 2004; Figure 13). When compared to flow conditions of the preceding seven years, the most striking feature of the Fall Creek hydrograph for 2005 is the absence of major runoff events over the May to September interval (Figure 13a).

Daily average wind speeds, out of the north to northwest, for the 1998 - 2004 interval and the 2005 study period are presented in Figure 13b for comparison. Major year-to year differences have not been observed for this metric (Figure 13b). Estimates of monthly average total phosphorus (TP) loads to the shelf from point sources are compared here for 1998 - 2004 and 2005 (Figure 13c). Monthly estimates of TP loads for 2005 were near the low end of the range of values observed over the previous seven study years (Figure 13c).

Time series of TP, Chl, and T_n are presented for the April – October interval of the eight study years (Figure 14). Data were not collected during the April – June interval of 1998. Plotted values (the mean of observations for sites 3, 4, 5, and the average of sites 1 and 7) are intended to represent conditions on the shelf. Total phosphorus concentrations during 2005 were generally within the range of values observed over the previous seven study years (Figure 14a). The highest TP concentrations of 2005 were observed during April, a period of high runoff (Figure 6a, Figure 14a). High TP concentrations (e.g., $> 30\ \mu g \cdot L^{-1}$) were not observed during the study intervals of 1999, 2003 and 2005.

Chlorophyll **a** concentrations for the shelf in 2005 were generally typical of the previous seven study years, though a distinct late summer peak was not observed in 2005 (Figure 14b). In general, chlorophyll **a** concentrations have been lowest during spring and highest during mid-summer (Figure 14b). High turbidity values were observed on sampling dates that coincided with major runoff events in early July 1998, early April 2000, mid-June 2000, early April 2001, and late June 2001 (Figure 14c). The highest turbidity values measured in 2005 were associated with major runoff events in April (Figure 14c). High turbidity values (e.g., > 5 NTU) were not observed in 1999, an extremely low runoff year.

The temporally detailed data presented in Figures 13 and 14 are summarized in Figure 15 as box plots for the eight study years. The dimensions of the boxes are identified according to the key located to the right of Figure 15a. Fall Creek flows were highest in 2004; runoff was also relatively high in 2000, 2002 and 2003 (Figure 15a). Flows were relatively low for the study intervals of 1999, 2001 and 2005. Average wind speeds were essentially equal for the eight study years (Figure 15b). Total phosphorus loading from point sources was relatively low in 1999, 2002, 2003 and 2005, and higher in 1998, 2000, 2001 and 2004 (Figure 15c). Month-to-month variability in TP loading from point sources has decreased since the 1998 and 1999 study years (Figure 15c). Study period medians for TP, Chl and T_n on the shelf were lowest for 1999, the driest of the study years (Figure 15d-f). Temporal variability for these three metrics was also lower during the 1999 study interval (Figure 15d-f). Chlorophyll concentrations on the shelf have been highest in years with the highest runoff (e.g., 2000, 2003 and 2004). However, no persistent long-term trends are apparent for TP, Chl or T_n on the shelf.

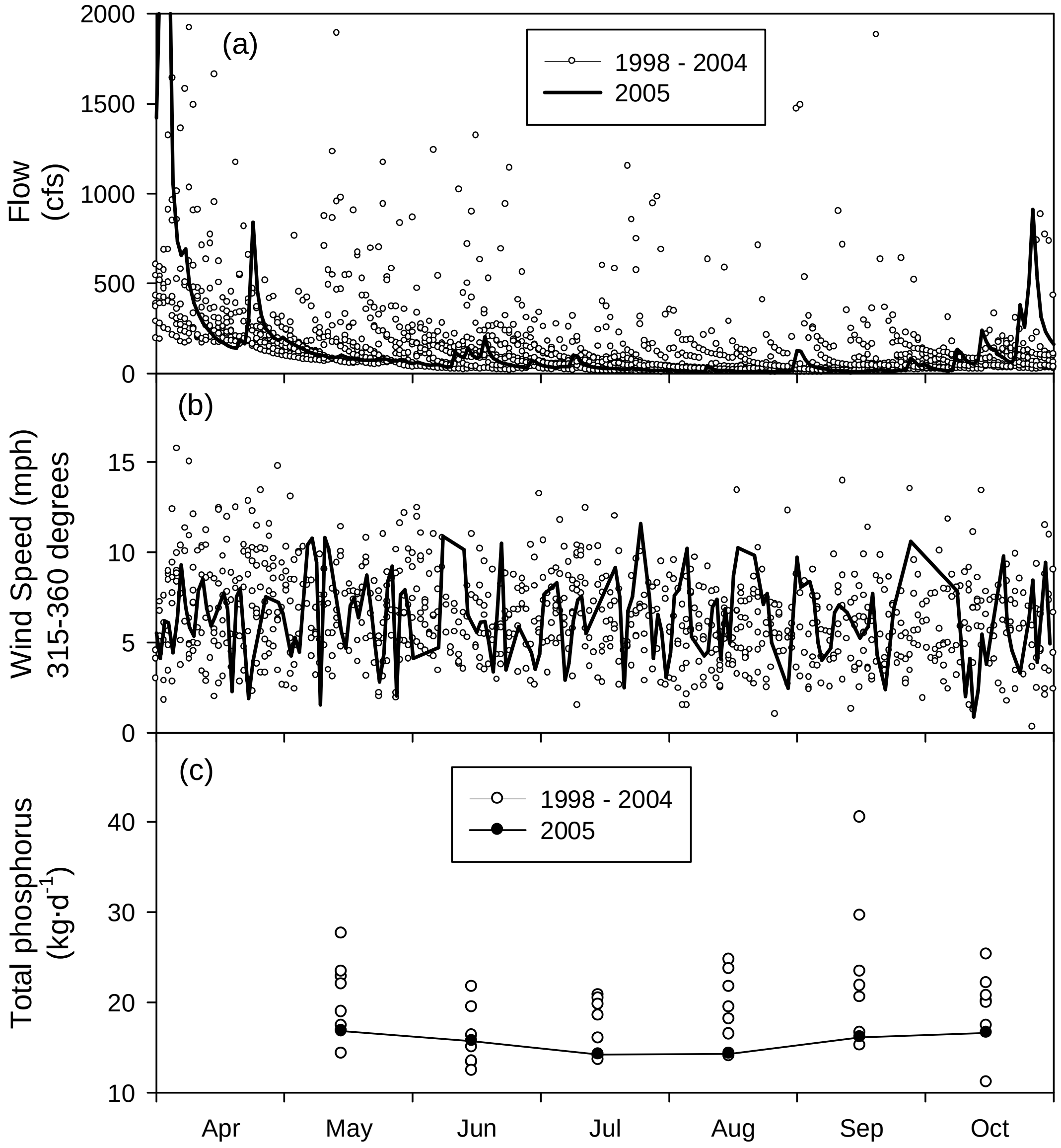

Figure 13. Comparison of 2005 conditions for runoff, wind and total phosphorus loading with conditions from the 1998 – 2004 interval: (a) daily average flows in Fall Creek, (b) daily average wind speed, and (c) summed monthly loads of total phosphorus (TP) to southern Cayuga Lake from the Ithaca Area WWTP, Cayuga Heights WWTP, and the LSC facility.

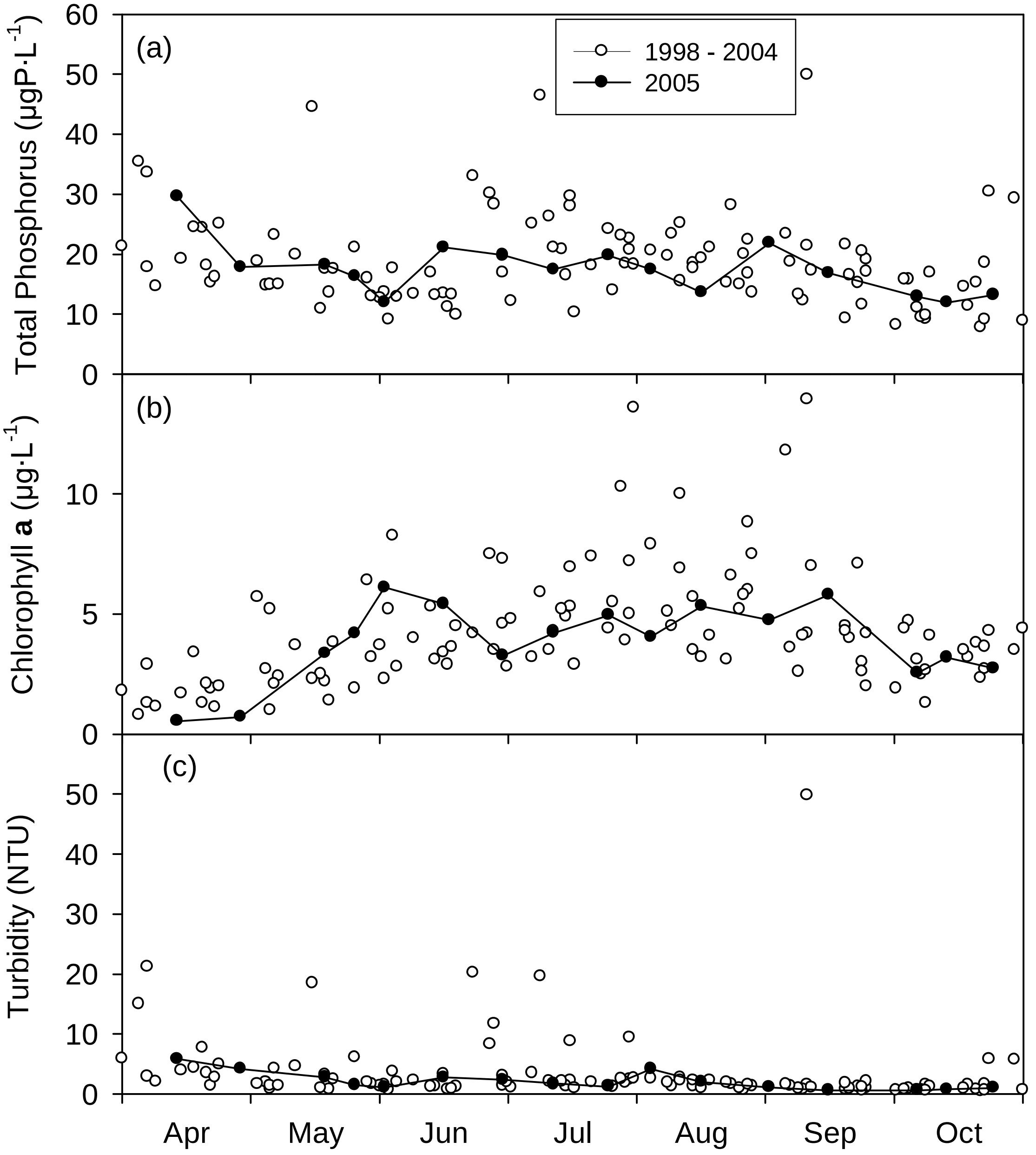

Figure 14. Comparison of 2005 conditions for total phosphorus, chlorophyll **a**, and turbidity on the south shelf of Cayuga Lake with conditions from the 1998 - 2004 interval: (a) total phosphorus (TP), (b) chlorophyll **a**, and (c) turbidity (T_n).

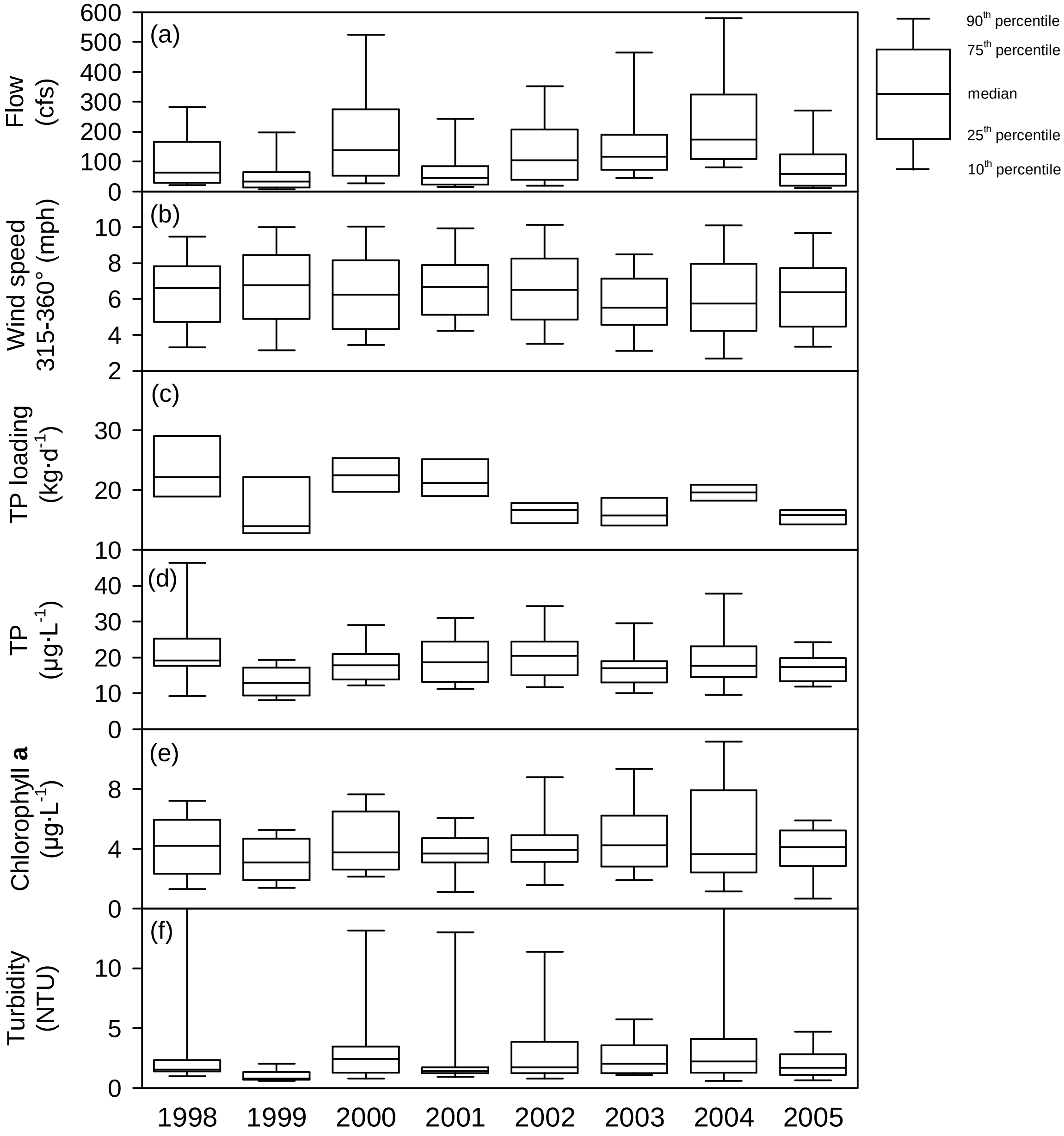

Figure 15. Comparison of study interval averages for runoff, wind, total phosphorus loading, total phosphorus concentration, chlorophyll **a** concentration and turbidity: (a) Fall Creek flow, (b) wind speed, (c) summed loads of total phosphorus (TP) from the Ithaca Area WWTP, Cayuga Heights WWTP and the LSC facility, (d) total phosphorus concentration on the south shelf, (e) chlorophyll **a** concentration on the south shelf, and (f) turbidity on the south shelf. 1998 averages for total phosphorus concentration, chlorophyll **a** concentration and turbidity are for the July – October interval; all other averages are for the April – October interval.

4.8. Noteworthy Observations from the 2005 Data

1. sites 2 and 7, which are located adjacent to wastewater effluents, were enriched in all three forms of phosphorus (TP, TDP, and SRP) and turbidity compared to the other monitored sites (Figure 2, Table 6).

2. chlorophyll **a** (Chl) concentrations were lowest at site 4 and similar at the other monitored sites (Table 6).

3. the deep water sites (6, 8 and LSC) had the lowest concentrations of total phosphorus (TP) and turbidity (T_n), on average, of the monitored sites (Figure 2, Table 6).

4. substantial spatial variations were observed within the southern end of the lake ("shelf"; exclusive of site 2) for most parameters included in the monitoring program (Figure 2, Table 6).

5. variances of measures of trophic state (Chl, TP, and T_n) were generally greater for the south shelf sites than for deep water sites (sites 6, 8 and LSC; Figure 2, Table 6).

6. the highest turbidity values measured in 2005 were associated with high runoff during April (Figure 12c).

7. more than 65% of the phosphorus was in a particulate form [e.g., (TP-TDP)/TP] at all sites, on a monitored period average basis.

8. average concentrations of TP, TDP and SRP were higher for sites located on the eastern side of the shelf (sites 1 and 7) than for sites on the western side (sites 4 and 5; Table 6).

9. chlorophyll concentrations, on a monitoring period average basis, were similar across the spatial bounds of sampling, though substantial spatial variability was observed on individual days (Figure 2f, Table 6).

10. temperatures were relatively uniform over the monitored bounds of the upper waters of the lake during the period of measurements (Figure 2g, Table 6).

11. temperatures, measured hourly at the "pile cluster", dropped precipitously on a number of occasions, suggesting the occurrence of seiche activity (Figure 2g).

12. turbidity (T_n) values and concentrations of soluble reactive phosphorus (SRP) were essentially equal in the LSC influent and effluent, with the exception of higher turbidity levels in the effluent during January, April and December (Figure 2j-l).

13. total phosphorus (TP) concentrations in the LSC effluent were less than 20 $\mu g \cdot L^{-1}$ during most of 2005 (Figure 2j).

14. the concentration of total phosphorus (TP) in the LSC effluent was similar to the concentration on the south shelf on most sampling days (Figure 2m); on average, the TP concentration in the LSC effluent was 0.8 $\mu g \cdot L^{-1}$ higher than the receiving waters of the shelf (Table 8).

15. the concentration of soluble reactive phosphorus (SRP) was higher in the LSC effluent than on the shelf on most sampling days (Figure 2n), consistent with projections made in the **Draft Environmental Impact Statement** (Stearns and Wheler, 1997); on average, the concentration was 7.3 $\mu g \cdot L^{-1}$ higher (Table 8).

16. turbidity (T_n) values for the LSC effluent were similar to values on the shelf on most sampling days (Figure 2o); on average, turbidity was 1.4 NTU higher in the LSC effluent (Table 8). This difference was largely the result of one very high T_n value for the LSC effluent on April 18 (Figure 2o).

17. dissolved oxygen concentrations at site 3 were within 10 % of saturation (equilibrium with the atmosphere) over much of the study interval, though distinctly higher values occurred during June and July (Figure 2i).

18. modest increases in BAC were observed near the bottom at the LSC site on several occasions, indicating the occurrence of small increases in turbidity with the approach to the bottom at this site (Figure 3).

19. chlorophyll fluorescence profiles indicate subsurface peaks in phytoplankton concentrations at the LSC intake site during the stratification period of 2005 (Figure 3). These peaks usually occurred above, or at, the maximum temperature (i.e., density) gradient, at depths $\leq$ 20 meters.

20. Secchi disc transparency (SD) was observed to extend beyond the lake depth at multiple sites on several occasions during the 2005 study interval (Appendix 1).

21. the 2005 results continue to support turbidity (T_n) as an alternate measure of light penetration in shallow portions of the shelf (Figure 4).

22. phosphorus loading from the Ithaca Area WWTP averaged 10.2 kg d^{-1} over the May to October interval of 2005 (Table 7). This was the lowest loading rate from this facility during the 2000 – 2005 interval. Phosphorus loading from the Cayuga Heights WWTP (3.6 kg d^{-1}) was also relatively low compared to previous years (Table 7).

23. LSC contributed an estimated 6.8% of the TP load to the shelf over the May to October interval of 2004, a larger contribution than projected (4.8%) in the **Draft**

Environmental Impact Statement (Stearns and Wheler 1997; Table 7, Figure 5). This is attributable to smaller inputs from wastewater treatment facilities and higher TP concentrations at the LSC intake location.

24. the average TP loading rate to the shelf from LSC for the May to October interval of 2005 was 1.8 $kg \cdot d^{-1}$, 38% lower than the 2.9 $kg \cdot d^{-1}$ projected in the **Draft Environmental Impact Statement**, but higher than reported for the preceding five years of operation. The increased TP loading from LSC in 2005 was related to a 22% increase in flow rate and a 44% increase in effluent TP concentrations over the May to October averages from 2000 to 2004.

25. increases in TP, SRP, and T_n since 2003 have been observed in the LSC effluent (Figure 6) and in the lake adjacent to the LSC intake (Figure 7). The cause of these increases has not been definitively established.

26. the Fall Creek hydrograph for 2005 depicts major storms in April and October and an absence of major runoff events from May to September (Figure 6a). Compared to the long-term record (1925 – 2004), Fall Creek flows were above normal during April and October and below normal from May to September (Figure 6a-b).

27. winds out of the north to northwest were distinctly above long-term median values for extended periods during early May, late July, August, and early September (Figure 6c). Annual median wind speeds have been essentially equal over the 1998-2005 interval (Figure 15b).

28. the 2005 results continue to support the position that TP and T_n are systematically flawed indicators of trophic state on the shelf.

29. the 2005 results continue to support the findings of Effler et al. (2002), that inorganic particles, rather than phytoplankton, are the primary regulator of T_n and SD on the shelf (Figure 11).

30. summer average concentrations of TP and Chl for deep water sites continue to be consistent with mesotrophy, an intermediate level of primary productivity (Tables 9 and 10).

31. study period median values for TP on the shelf were lowest in 1999 and similar in the other study years (Figure 15d).

32. study period median values for Chl on the shelf have exhibited little interannual variability over the 1998 – 2005 interval, though the lowest peak values were observed during the low runoff years of 1999, 2001 and 2005 (Figure 15e).

33. study period median values for T_n on the shelf were lowest for the low runoff years of 1999, 2001 and 2005 (Figure 15f).

34. no conspicuous changes in water quality have been observed on the shelf since start-up of the LSC facility in July 2000 (Upstate Freshwater Institute 1999, 2000, 2001, 2002, 2003, 2004, 2005).

5. Summary

This report presents the design and salient findings of a water quality monitoring study conducted for Cayuga Lake in 2005, sponsored by Cornell University. This is the eighth annual report for a monitoring program that has been conducted annually since 1998. A number of noteworthy findings are reported here for 2005 that have value for lake management. Water quality on the south shelf has been observed to vary substantially from year to year. Potential sources of variation include interannual differences in runoff, loading from WWTPs, and wind. Runoff during the May to September interval of 2005 was substantially lower than the long-term average. The average flow for Fall Creek over the May to September interval of 2005 was the 13th lowest of the 1925 to 2005 record. This is in stark contrast to 2004, which had the highest runoff during summer of the 81 year record. As a consequence of lower flows, summer average levels of total phosphorus and turbidity were lower in 2005 than in 2004, both on the shelf and in the main lake. Summer average chlorophyll concentrations on the shelf decreased in 2005 from the higher levels of 2003 and 2004. The 2005 results continue to support the position (Effler et al. 2002), that inorganic particles, rather than phytoplankton, are the primary regulator of clarity on the shelf. Summer average concentrations of total phosphorus and chlorophyll **a** for deep water sites continue to be consistent with mesotrophy, a classification shared by seven of the eleven Finger Lakes. Total phosphorus concentrations and turbidity values were similar in the LSC effluent and the receiving waters of the shelf. Soluble reactive phosphorus concentrations were distinctly higher in the LSC effluent than on the shelf. LSC contributed an estimated 6.8% of the TP load to the shelf over the May – October interval of 2005, a larger contribution than projected (4.8%) in the **Draft Environmental Impact Statement**. This is attributable to smaller inputs from wastewater treatment facilities and higher total phosphorus concentrations at the LSC intake location. The cause of higher phosphorus concentrations at the LSC intake has not been definitively established. The total phosphorus loading rate to the shelf from LSC was 38% lower than projected in the **Draft Environmental Impact Statement**, but higher than reported for the preceding five years of operation. No conspicuous changes in water quality have been observed on the shelf since start-up of the LSC facility in July 2000.

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Appendix I

Data Listing

Total Phosphorus (µgP·L^{-1})

Date:	4/14/05	4/29/05	5/11/05	5/26/05	6/2/05	6/16/05	6/30/05	7/12/05	7/25/05	8/4/05	8/16/05	9/1/05	9/15/05	10/5/05	10/13/05	10/24/05
Site:																
1	28.6	20.9	17.5	17.1	11.2	25.2	30.5	17.4	12.9	20.2	17.6	20.8	16.2	10.8	11.6	20.8
2	32.3	29.1	16.8	21.4	12.7	26.4	31.3	42.2	52.1	34.4	37.3	34.9	20.8	21.5	23.7	22.1
3	29.4	21.4	24.7	13.8	16.7	22.7	20.8	21.3	14.1	14.0	10.0	30.3	14.6	19.5	13.2	12.6
4	25.0	14.7	13.5	16.1	9.1	17.8	15.2	14.7	31.4	11.5	5.7	14.2	17.2	11.9	11.9	10.0
5	30.0	13.7	19.8	15.3	12.1	18.4	15.5	14.4	13.6	13.6	18.6	16.0	13.6	9.3	11.3	10.0
6	23.7	15.1	12.5	15.4	9.6	17.5	13.4	14.1	16.2	12.3	19.8	13.3	12.9	9.3	9.6	11.3
7	39.5	22.1	12.5	23.1	8.8	25.9	26.0	21.3	27.1	41.3	22.8	33.3	27.9	10.9	11.3	19.8
8	18.4	15.7	9.1	11.1	8.8	15.2	11.8	14.4	12.9	13.3	13.3	12.0	11.9	9.6	10.6	10.0
LSCT	21.1	12.7	10.1	13.4	7.1	13.2	13.8	13.4	14.6	14.2	15.6	12.9	13.6	10.3	10.3	9.6
LSCB	18.8	14.1	14.5		15.7	16.5	17.1	19.8		6.7	12.3		15.9	16.5	18.8	15.2
LSC3B		15.1	15.3		14.4	15.5	17.5	13.7		5.7	16.0	6.9	15.2	15.2	17.8	13.3

Total Dissolved Phosphorus (µgP·L^{-1})

Date:	4/14/05	4/29/05	5/11/05	5/26/05	6/2/05	6/16/05	6/30/05	7/12/05	7/25/05	8/4/05	8/16/05	9/1/05	9/15/05	10/5/05	10/13/05	10/24/05
Site:																
1	17.8		5.5	6.7	2.9	3.4	5.6	3.4	2.6	3.6	3.7	3.1	4.8	3.8	3.7	12.5
2	17.0		5.5	7.5	2.5	3.5	3.9	11.7	8.0	5.7	18.9	6.1	4.0	6.7	10.0	12.6
3	15.2		4.8	14.3	2.5	3.5	4.5	3.5	2.8	5.3	4.7	4.3	3.0	7.0	2.4	5.4
4	14.7		6.1	6.2	2.9	3.2	3.9	2.9	3.7	4.0	4.3	2.7	3.0	3.0	3.4	4.7
5	14.7		5.5	5.7	2.5	3.2	3.5	1.5	2.7	3.0	3.6	2.7	3.7	3.0	2.7	4.3
6	14.1		5.7	5.8	2.5	2.9	2.9	3.2	2.7	2.7	4.3	2.8	3.0	3.0	2.0	3.7
7	16.0		5.5	6.8	2.9	3.4	4.8	3.2	4.0	8.0	8.6	9.6	11.9	5.3	3.4	10.6
8	12.7		4.2	5.8	2.2	2.9	3.2	2.5	2.4	3.0	3.0	3.4	2.7	2.6	2.4	3.0
LSCT	13.1		3.9	5.5	2.2	2.5	2.9	2.5	2.4	2.7	3.7	3.0	3.0	2.4	2.0	4.0
LSCB	12.4		11.4		10.5	11.1	11.1	11.5		5.3	10.9	6.9	11.3	11.3	12.3	10.6
LSC3B	11.8		11.1		9.8	11.1	11.4	10.8		4.3	10.0	4.6	10.6	10.9	11.9	10.6

Soluble Reactive Phosphorus (µgP·L^{-1}) values reported as 0.2 are ½ the limit of detection (0.3*0.5 = 0.15) rounded to one decimal place

Date:	4/14/05	4/29/05	5/11/05	5/26/05	6/2/05	6/16/05	6/30/05	7/12/05	7/25/05	8/4/05	8/16/05	9/1/05	9/15/05	10/5/05	10/13/05	10/24/05
Site:																
1	10.2	6.3	0.8	0.5	0.3	0.5	2.0	0.5		0.5	0.5	0.8	1.2	1.2	1.7	7.5
2	9.9	9.3	1.0	0.5	0.2	0.2	0.6	2.3	1.9	0.6	11.3	3.4	0.8	3.1	6.6	8.1
3	8.7	6.5	0.6	0.2	0.5	0.3	0.6	0.6		0.3	0.8	1.1	0.3	3.4	0.6	2.8
4	8.4	7.4	0.7	0.2	0.3	0.3	0.6	0.3	0.2	1.1	1.5	0.5	0.5	0.6	0.6	2.3
5	8.4	7.4	0.5	0.3	0.2	0.2	0.5	0.3	0.2	0.2	0.5	0.3	0.2	0.6	1.0	1.9
6	7.9	7.6	0.3	0.2	0.3	0.2	0.3	0.3	0.2	0.2	0.6	0.4	0.3	0.3	0.6	1.5
7	8.7	5.5	0.5	0.2	0.5		1.0	0.3	0.2	2.4	2.1	4.9	6.8	2.3	1.3	7.3
8	7.1	7.1	0.5	0.2	0.2	0.2	0.4	0.3	0.2	0.2	0.6	0.5	0.2	0.4	0.6	1.1
LSCT	7.3	7.3	0.3	0.3	0.2	0.2	0.3	0.3	0.2	0.2	0.6	0.6	0.2	0.3	0.5	1.5
LSCB	7.3	7.6	8.3		8.7	9.2	8.9	8.9		2.6	8.3	2.4	9.2	9.4	11.0	9.6
LSC3B	7.3	7.3	8.3		8.1	9.1	9.1	7.9		1.9	7.8	2.4	7.9	8.9	10.8	9.1

Chlorophyll a ($\mu g \cdot L^{-1}$)

Date:	4/14/05	4/29/05	5/11/05	5/26/05	6/2/05	6/16/05	6/30/05	7/12/05	7/25/05	8/4/05	8/16/05	9/1/05	9/15/05	10/5/05	10/13/05	10/24/05
Site:																
1	0.7	1.2	3.0	4.1	5.8	6.2	4.1	3.6	5.6	2.9	7.2	3.7	6.0	2.4	1.8	4.0
2	0.6	1.1	2.8	4.8	7.0	3.6	5.2	7.5	7.4	7.7	5.5	3.0	6.3	2.5	2.7	1.4
3	0.5	0.8	3.5	3.9	6.9	5.6	3.8	6.4	4.9	7.1	5.9	5.4	4.9	3.1	3.9	3.1
4	0.3	0.3	2.7	4.2	6.8	3.9	2.0	2.5		1.4	2.7	5.1	6.6	2.5	2.8	2.0
5	0.7	0.3	4.1	4.5	5.4	6.6	2.9	3.8	3.9	2.8	6.2	4.1	6.1	2.7	3.6	2.8
6	0.6	0.4	4.3	4.4	5.7	3.9	4.7	3.4	6.1	3.6	9.6	4.9	5.6	3.6	3.7	3.8
7	0.7	1.8	3.3	4.2	4.8	4.8	4.7	4.7	6.4	6.9	6.0	5.1	5.3	1.4	3.1	2.2
8	1.2	0.3	3.9		5.7	6.8	3.4	3.8	5.6	2.8	6.4	3.7	4.1	3.8	3.6	1.9
LSCT	0.3	0.5	4.0	4.5	5.8	5.1	4.7	4.0	7.5	3.8	7.7	4.0	4.8	4.4	3.9	3.0
LSCB	0.7	0.2	0.2		0.6	0.5	0.8	1.4		0.4	0.3	0.2	0.3	0.3	0.7	0.2
LSC3B	0.7	0.2	0.2		0.4	0.6	1.0	0.4		0.9	0.2	0.3	0.2	0.3	0.3	0.2

Turbidity (NTU)

Date:	4/14/05	4/29/05	5/11/05	5/26/05	6/2/05	6/16/05	6/30/05	7/12/05	7/25/05	8/4/05	8/16/05	9/1/05	9/15/05	10/5/05	10/13/05	10/24/05
Site:																
1	7.2	6.2	2.2	1.6	1.3	2.5	6.4	1.7	1.0	1.0	1.4	0.8	0.7	0.6	0.5	2.2
2	6.7	4.1	2.7	2.6	1.1	2.8	9.5	3.7	5.7	2.9	1.6	2.1	0.7	0.9	0.9	0.9
3	6.0	5.9	3.3	1.4	1.3	3.4	3.1	2.5	1.3	14.3	1.1	1.3	0.6	0.6	1.1	0.7
4	4.6	1.8	3.2	1.6	0.8	1.8	0.9	1.3	1.1	0.4	0.8	0.7	0.7	0.7	0.5	0.7
5	5.0	3.0	2.4	1.0	1.0	2.9	1.9	1.2	1.2	0.9	1.3	0.6	0.6	0.6	0.9	0.6
6	4.2	2.3	2.1	0.9	0.9	2.1	0.8	0.8	1.3	0.8	1.1	0.6	0.6	0.5	0.6	0.5
7	8.3	6.3	2.4	2.6	1.4	3.7	0.7	2.6	1.8	1.3	8.3	3.2	0.7	0.7	0.9	2.0
8	3.6	2.3	1.1	0.7	0.6	1.7	0.7	0.8	0.9	0.8	0.7	0.5	0.5	0.8	0.5	0.4
LSCT	4.6	2.1	0.9	0.7	0.7	1.6	0.8	0.9	1.0	0.8	1.0	0.8	0.5	0.7	0.6	0.5
LSCB	3.0	2.8	4.5		2.2	1.7	3.0	3.3		0.7	1.0	1.1	2.2	1.8	3.8	1.7
LSC3B	2.5	3.1	4.9		1.5	1.5	3.0	1.5		0.6	0.8	0.7	1.4	1.5	1.7	0.8

$CaCO_3$ Turbidity (NTU)

Date:	4/14/05	4/29/05	5/11/05	5/26/05	6/2/05	6/16/05	6/30/05	7/12/05	7/25/05	8/4/05	8/16/05	9/1/05	9/15/05	10/5/05	10/13/05	10/24/05
Site:																
1	1.4	1.0	0.6	0.2	0.2	0.4	1.2	0.4	0.3	0.1	0.3	0.0	0.0	0.0	0.0	0.6
2	0.8	1.0	0.7	0.2	0.1	0.7	1.8	0.8	2.8	0.2	0.1	0.0	0.1	0.1	0.1	0.0
3	1.0	0.5	1.7	0.2	0.4	1.1	0.6	0.4	0.4	10.9	0.0	0.1	0.0	0.0	0.1	0.1
4	0.8	0.4	0.7	0.1	0.2	0.4	0.1	0.2	0.2	0.1	0.3	0.0	0.0	0.2	0.0	0.2
5	0.3	1.5	0.9	0.1	0.2	0.6	0.1	0.2	0.3	0.2	0.3	0.0	0.0	0.2	0.3	0.2
6	0.7	0.4	0.7	0.0	0.1	0.6	0.1	0.1	0.3	0.1	0.3	0.1	0.0	0.0	0.0	0.1
7	1.1	0.9	0.6	0.1	0.2	1.3	0.1	1.2	0.8	0.2	7.6	0.7	0.0	0.4	0.4	0.2
8	0.7	0.1	0.2	0.1	0.1	0.5	0.1	0.1	0.2	0.2	0.1	0.0	0.0	0.1	0.1	0.0
LSCT	0.6	0.3	0.0	0.0	0.0	0.4	0.0	0.2	0.3	0.1	0.1	0.2	0.0	0.2	0.1	0.0
LSCB	0.4	0.5	2.0	0.0	0.5	0.1	0.5	0.7	0.0	0.1	0.2	0.6	1.4	0.2	2.4	0.6
LSC3B	0.3	0.7	2.4	0.0	0.3	0.7	0.4	0.4	0.0	0.1	0.1	0.3	0.4	0.3	0.4	0.2

Secchi Disc (m)

Date:	4/14/05	4/29/05	5/11/05	5/26/05	6/2/05	6/16/05	6/30/05	7/12/05	7/25/05	8/4/05	8/16/05	9/1/05	9/15/05	10/5/05	10/13/05	10/24/05
Site:																
1	0.9	1.0	2.8	1.8	2.1	1.5	0.8	3.0	2.6	3.5	3.0	3.7	bottom	bottom	bottom	4.0
2	0.9	1.5	2.4	-	2.2	1.5	0.4	1.9	1.1	1.8	2.5	1.9	bottom	bottom	bottom	2.3
3	1.0	1.1	2.2	3.0	2.3	1.5	0.5	2.0	2.8	3.0	3.3	3.1	bottom	bottom	bottom	bottom
4	1.1	4.0	2.2	2.9	2.6	-	bottom	3.0	3.0	bottom	bottom	bottom	bottom	bottom	bottom	bottom
5	1.0	4.0	1.8	4.0	3.0	1.9	4.5	4.0	2.8	4.0	3.3	4.3	6.0	5.2	B	bottom
6	1.2	3.1	3.2	4.0	2.8	2.1	4.5	5.1	2.5	3.5	2.9	4.0	6.5	5.5	7.0	7.0
7	0.9	1.1	2.4	1.9	2.5	1.5	bottom	2.8	2.9	bottom	bottom	1.6	-	bottom	bottom	2.3
8	2.0	3.0	5.7	6.0	3.9	2.5	5.5	5.0	3.0	4.0	3.7	6.0	7.5	6.0	6.5	8.0
LSCT	1.4	3.3	5.4	-	3.4	2.5	4.5	4.9	2.7	3.6	3.2	5.0	6.5	5.5	6.9	7.0

Temperature (°C) @ 2m

Date:	4/14/05	4/29/05	5/11/05	5/26/05	6/2/05	6/16/05	6/30/05	7/12/05	7/25/05	8/4/05	8/16/05	9/1/05	9/15/05	10/5/05	10/13/05	10/24/05
Site:																
1	7.5	6.8	10.8	12.1	12.0	20.3	20.0	22.8	25.0	25.5	25.5	20.8	21.5	16.4	16.6	12.8
2	8.1	5.8	10.5	12.6	12.9	20.4	20.1	23.1	23.2	26.5	25.7	20.7	21.5	17.5	15.4	10.6
3	7.7	5.5	11.0	11.8	13.6	20.5	20.2	23.1	22.3	26.5	25.5	20.7	21.5	16.7	16.3	12.2
4	6.9	5.0	10.2	12.1	12.8	19.5	20.7	23.5	22.0	26.7	25.6	20.9	21.5	16.9	16.0	14.4
5	6.8	4.6	10.3	11.4	13.3	20.4	20.8	22.9	24.9	26.2	25.5	21.0	21.5	16.8	16.8	14.7
6	5.9	4.7	9.8	11.2	12.7	20.2	20.2	22.9	24.4	26.3	25.5	21.0	21.6	16.8	16.9	14.7
7	8.5	6.9	11.1	12.7	12.6	20.5	20.1	23.0	24.2	26.5	25.7	20.7	21.5	16.7	15.7	10.6
8	3.4	4.3	9.3	10.1	12.7	20.6	21.5	23.3	24.7	25.6	25.2	21.6	21.6	17.7	17.0	14.5
LSCT	3.9	4.6	9.2	10.8	13.2	19.9	20.9	23.3	24.0	26.1	25.6	21.0	21.6	16.8	16.9	14.7

Dissolved Oxygen (mg·L^{-1}) Site 3

Date:	4/14/05	4/29/05	5/11/05	5/26/05	6/2/05	6/16/05	6/30/05	7/12/05	7/25/05	8/4/05	8/16/05	9/1/05	9/15/05	10/5/05	10/13/05	10/24/05
Depth:																
0	14.3	12.5	13.2	-	11.8	10.3	9.5	-	9.8	8.8	8.5	10.5	-	12.1	-	10.2
1	13.7	12.1	12.5	-	12.6	10.3	9.9	-	9.7	8.9	8.7	10.1	-	12.0	-	10.2
2	13.5	12.6	13.1	12.2	14.0	10.2	11.6	-	9.7	9.1	8.7	9.8	-	11.9	-	10.4
3	13.4	12.8	13.2	-	13.9	10.3	11.7	-	8.0	8.8	8.6	9.6	-	12.2	-	10.9
4	13.3	-	13.2	-	13.7	10.7	-	-	-	-	-	-	-	14.9	-	10.6

Appendix 2

Lake Source Cooling
Discharge Monitoring Report Data

Lake Source Cooling Discharge Monitoring Report Data

DMR Date	Temperature (Centigrade)		Flow Rate (m^3/second)		Dissolved Oxygen (mg/L)		pH (SU)		Total Phosphorus (mg/L)		Reactive Phosphorus[g] (mg/L)	
	Daily Ave	**Daily Max**	**Daily Ave**	**Daily Max**	**Daily Ave**	**Daily Max**	**Min**	**Max**	**Daily Ave**	**Daily Max**	**Daily Ave**	**Daily Max**
Jul-00[a]	10.33	10.89	1.189	1.306	11.0	11.1	7.96	8.09	0.0133	0.0136	0.005[b]	0.005[b]
Aug-00	10.2	11.6	1.02	1.3	11.0	11.5	8.0	8.1	0.0116	0.013	0.0059	0.0064
Sep-00	9.8	11.8	0.81	1.38	10.6	10.9	7.9	8.12	0.0122	0.0144	0.0061	0.0069
Oct-00	9.1	9.8	0.57	0.93	10.4	10.7	7.8	8.1	0.012	0.014	0.0067	0.0081
Nov-00	8.98	9.75	0.49	0.97	10.9[c]	12.2[c]	7.7	8.14	0.014	0.016	0.006	0.008
Dec-00	8.2	9.5	0.48	0.67	12.49	12.49	7.85	7.85	0.0109	0.0109	0.0059	0.0059
Jan-01	7.3	7.6	0.39	0.52	-	-	-	-	-	-	-	-
Feb-01	8.15	8.6	0.26	0.34	17.59	20.33	7.93	8.06	0.0095	0.011	0.0044	0.0049
Mar-01	6.56	8.67	0.31	0.44	15.76	18.18	8.0	8.1	0.0105	0.0116	0.0038	0.0042
Apr-01	7.9	9.6	0.47	0.70	15.5	17.6	7.97	8.06	0.012	0.014	0.008	0.008
May-01	9.1	10.0	0.66	0.86	15.02	18.39	7.9	8.1	0.0114	0.0139	0.0043	0.0053
Jun-01	10.4	11.4	0.97	1.31	12.01	12.34	7.96	8.08	0.0127	0.0147	0.0049	0.0058
Jul-01	10.3	11.8	0.98	1.45	11.46	11.59	7.9	8.02	0.012	0.015	0.005	0.0056
Aug-01	10.7	11.78	1.19	1.52	11.27	11.39	7.84	8.02	0.0139	0.0154	0.0062	0.0069
Sep-01	9.7	10.8	0.81	1.30	10.84	10.90	7.87	7.95	0.0141	0.0148	0.0068	0.0073
Oct-01	9.22	10.67	0.64	1.05	10.57	10.79	7.84	8.05	0.0120	0.0135	0.0049	0.0061
Nov-01	9.50	10.44	0.56	0.99	10.41	10.55	7.85	7.88	0.0122	0.0137	0.0061	0.0064
Dec-01	9.44	10.56	0.48	0.82	10.27	10.35	7.72	7.92	0.0125	0.0128	0.0060	0.0064
Jan-02	9.22	9.44	0.44	0.45	10.55	11.17	7.92	7.96	0.0104	0.0110	0.0043	0.0047
Feb-02	7.89	8.94	0.43	0.44	11.83	11.97	7.69	7.90	0.0155	0.0173	0.0049	0.0052
Mar-02	8.28	9.33	0.38	0.44	12.21	12.57	7.83	7.90	0.0121	0.0161	0.0038	0.0043
Apr-02[f]	9.11	10.94	0.53	1.06	11.69	11.88	7.92	7.98	0.0178	0.0323	0.0037	0.0042
May-02	9.72	10.78	0.68	1.13	11.53	11.75	7.77	8.02	0.0108	0.0116	0.0029	0.0044
Jun-02	10.67	11.83	1.09	1.33	11.08	11.26	7.89	8.06	0.0108	0.0121	0.0039	0.0042
Jul-02	10.72	12.00	1.47	1.92	11.30	12.79	7.75	7.89	0.0142	0.0178	0.0042	0.0056
Aug-02	10.50	11.50	1.41	1.82	12.84	15.58	7.75	7.93	0.0095	0.0103	0.0038	0.0047
Sep-02	10.00	11.00	1.2	1.8	15.21	20.85	8.0	8.0	0.0096	0.0110	0.0037	0.0047
Oct-02	9.4	10.3	0.7	1.8	12.73	24.68	7.8	8.1	0.0118	0.0136	0.0056	0.0066
Nov-02	9.2	10.3	0.6	1.7	9.96	10.40	7.6	8.0	0.0122	0.0139	0.0062	0.0065
Dec-02	8.6	9.1	0.6	1.2	10.54	10.79	7.5	8.1	0.0083	0.0100	0.0033	0.0040

Next page

	Temperature (Centigrade)		Flow Rate (m^3/second)		Dissolved Oxygen (mg/L)		pH (SU)		Total Phosphorus (mg/L)		Reactive Phosphorus[g] (mg/L)	
DMR Date	**Daily Ave**	**Daily Max**	**Daily Ave**	**Daily Max**	**Daily Ave**	**Daily Max**	**Min**	**Max**	**Daily Ave**	**Daily Max**	**Daily Ave**	**Daily Max**
Jan-03	8.2	9.2	0.4	0.5	10.64	11.59	7.5	7.7	0.0103	0.0115	0.0037	0.0048
Feb-03	7.8	8.2	0.3	0.3	13.40	13.84	7.8	7.9	0.0095	0.0099	0.0039	0.0044
Mar-03	7.6	9.2	0.3	0.4	12.52	13.00	7.5	7.9	0.0111	0.0155	0.0032	0.0039
Apr-03	8.2	9.4	0.4	0.8	12.75	13.30	7.6	7.9	0.0138	0.0169	0.0045	0.0049
May-03	8.7	9.6	0.6	0.9	12.73	14.60	7.5	7.8	0.0120	0.0131	0.0039	0.0046
Jun-03	9.4	10.6	1.0	1.5	12.05	12.20	7.7	7.9	0.0136	0.0159	0.0038	0.0042
Jul-03	10.4	10.8	1.2	1.6	11.77	12.86	7.6	7.8	0.0111	0.0125	0.0039	0.0051
Aug-03	10.5	11.6	1.6	2.0	11.63	12.40	7.1	7.8	0.0090	0.0093	0.0051	0.0055
Sep-03	9.6	10.6	1.2	1.8	11.09	11.31	7.4	7.7	0.0128	0.0170	0.0062	0.0073
Oct-03	9.1	10.1	0.6	0.9	10.27	10.50	7.6	7.7	0.0166	0.0209	0.0065	0.0070
Nov-03	8.9	9.9	0.6	1.2	10.42	10.61	7.7	7.8	0.0201	0.0252	0.0055	0.0061
Dec-03	8.2	8.8	0.6	1.0	10.61	10.64	7.6	7.9	0.0170	0.0202	0.0048	0.0064
Jan-04	7.7	9.0	0.4	0.5	10.82	11.13	7.7	8.1	0.0320	0.0561	0.0057	0.0061
Feb-04	8.5	8.8	0.2	0.2	11.31	11.66	7.9	8.1	0.0154	0.0178	0.0061	0.0063
Mar-04	7.8	8.5	0.3	0.5	11.72	12.10	7.9	8.0	0.0141	0.0179	0.0061	0.0066
Apr-04	8.4	9.7	0.4	0.9	12.25	12.80	7.9	8.1	0.0163	0.0237	0.0062	0.0074
May-04	9.2	10.2	0.9	1.4	11.88	12.40	7.9	8.2	0.0166	0.0172	0.0064	0.0069
Jun-04	9.6	10.8	0.9	1.5	11.76	12.10	7.9	8.3	0.0157	0.0171	0.0065	0.0086
Jul-04	10.1	11.0	1.2	1.5	11.69	12.00	7.9	7.9	0.0089	0.0104	0.0056	0.0070
Aug-04	9.8	10.9	1.2	1.6	11.70	11.48	7.7	8.3	0.0135	0.0148	0.0066	0.0080
Sep-04	9.5	10.3	1.0	1.4	10.35	11.00	7.0	7.9	0.0127	0.0141	0.0082	0.0093
Oct-04	8.9	9.5	0.5	0.8	10.65	10.80	7.6	8.0	0.0139	0.0161	0.0082	0.0100
Nov-04	8.8	9.4	0.5	0.7	10.35	11.00	7.0	7.9	0.0127	0.0141	0.0082	0.0093
Dec-04	8.6	9.6	0.5	0.6	10.55	11.00	7.8	7.9	0.0130	0.0138	0.0068	0.0079
Jan-05	8.5	8.9	0.3	.5	10.80	11.10	7.8	8.1	0.0153	0.0203	0.0079	0.0088
Feb-05	8.3	8.9	0.3	0.4	11.28	11.60	7.7	7.8	0.0145	0.0157	0.0072	0.0094
Mar-05	7.9	8.5	0.3	0.4	12.28	13.40	7.8	7.9	0.0145	0.0172	0.0075	0.0079
Apr-05	8.2	9.3	0.5	0.8	12.10	12.60	7.8	7.9	0.0218	0.0233	0.0081	0.0086
May-05	11.4	11.5	1.2	1.2	11.94	12.60	7.5	7.8	0.0200	0.0246	0.0083	0.0093
Jun-05	10.1	10.9	1.3	1.7	11.73	12.10	7.7	7.8	0.0172	0.0199	0.0091	0.0120
Jul-05	10.2	11.1	1.4	1.8	11.80	12.60	7.6	7.7	0.0162	0.0205	0.0097	0.0150
Aug-05	9.9	10.7	1.4	1.7	11.26	11.60	7.8	8.0	0.0164	0.0188	0.0093	0.0105
Sep-05	9.5	10.2	1.1	1.6	11.00	11.10	7.7	8.0	0.0189	0.0222	0.0100	0.0138
Oct-05	9.0	10.0	0.7	1.4	10.48	10.70	7.7	7.9	0.0183	0.0245	0.0104	0.0115

Lake Source Cooling Discharge Monitoring Report Data

DMR Notes:

1. To comply with changes in the NYS DEC DMR Manual for Completing the Discharge Monitoring Report for the State Pollutant Discharge Elimination System, sample measurements will be reported in the same number of significant digits that are specified in the permit. All calculations will be performed prior to any rounding, and, when rounding, if the digit being dropped is 0-4, the preceding number will be left as is, if the digit being dropped is 5-9, the preceding number will be increased. This change took effect for the reporting of September 2002.
2. Since June 2002, reactive phosphorus results below the limit of detection of 0.3 µg/L have been changed to 0.3 µg/L for all DMR calculations. Prior to this a value of ½ the limit of detection was used for DMR calculations.

[a] During the month of July 2000, the Lake Source Cooling Heat Exchange Facility was commercially operational (following a brief commissioning period) from July 17 through July 31, therefore the data reported in the DMR is reflective of the 15 days of operation out of the 31 total days in the month.

[b] The data reported for soluble reactive phosphorus in July 2000 is from one sampling date, 7/27/2000, during the last calendar week of July. The SPDES permit requires soluble reactive phosphorus samples to be analyzed weekly. Although a sample was collected by Cornell University during the third calendar week of July, the sample was not analyzed due to laboratory error. This error has been corrected.

[c] One of the five samples analyzed for dissolved oxygen had a false high result and was eliminated from reporting on this DMR on the recommendation of our consultant/analytical laboratory, Upstate Freshwater Institute Inc.

[d] The LSC discharge was shut down for emergency repairs on December 8, 2000 and remained off line for the rest of the month of December. The data reported on the DMR is reflective of monitoring conducted between December 1 and December 8 (samples collected weekly, so the data is from one sampling event).

[e] Please note that there are no data presented in the DMR for effluent parameters DO, pH, total phosphorus, and reactive phosphorus. The LSC discharge was shut down for emergency repairs on December 8, 2000 and remained off line until January 29, 2001. Effluent sampling was conducted the week of January 29 as required by the permit; the effluent sample was collected on Thursday February 1. The effluent data for the sample collected during the last week of January will be included with the data presented in the February DMR.

[f] Analytical results from 4/18/02 were not included in these calculations because holding times were exceeded.

[g] Flow and temperature data for 6/11/03 – 6/14/03 were missing and could not be included in the calculation.

[h] Analyses for Total Phosphorus and Soluble Reactive Phosphorus from plant effluent samples on 6/7/04 were invalidated due to laboratory error and were not included in the monthly calculated averages and maximum values.

[i] Plant effluent samples for Soluble Reactive Phosphorus on 7/19/04 failed quality assurance at the analytical laboratory and were not included in the monthly calculated averages and maximum values.

[j] 17 hours of plant temperature and flow data were missing from 10/17/04 and therefore could not be included in the plant effluent temperature and flow averages and maximums

[k] The sample for Soluble Reactive Phosphorus on 12/20 failed quality assurance at the analytical laboratory and was not included in the monthly calculated averages and maximum values. The Phosphorus samples from 12/27 exceeded hold times and were not included in the monthly calculated averages and maximum values.