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Cayuga Lake Water Quality Monitoring, Related to the LSC Facility: 2002

Prepared by:
Upstate Freshwater Institute
Box 506
Syracuse, NY 13214

Sponsored by:
Cornell University
Department of Utilities and Energy Management

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 1). 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.

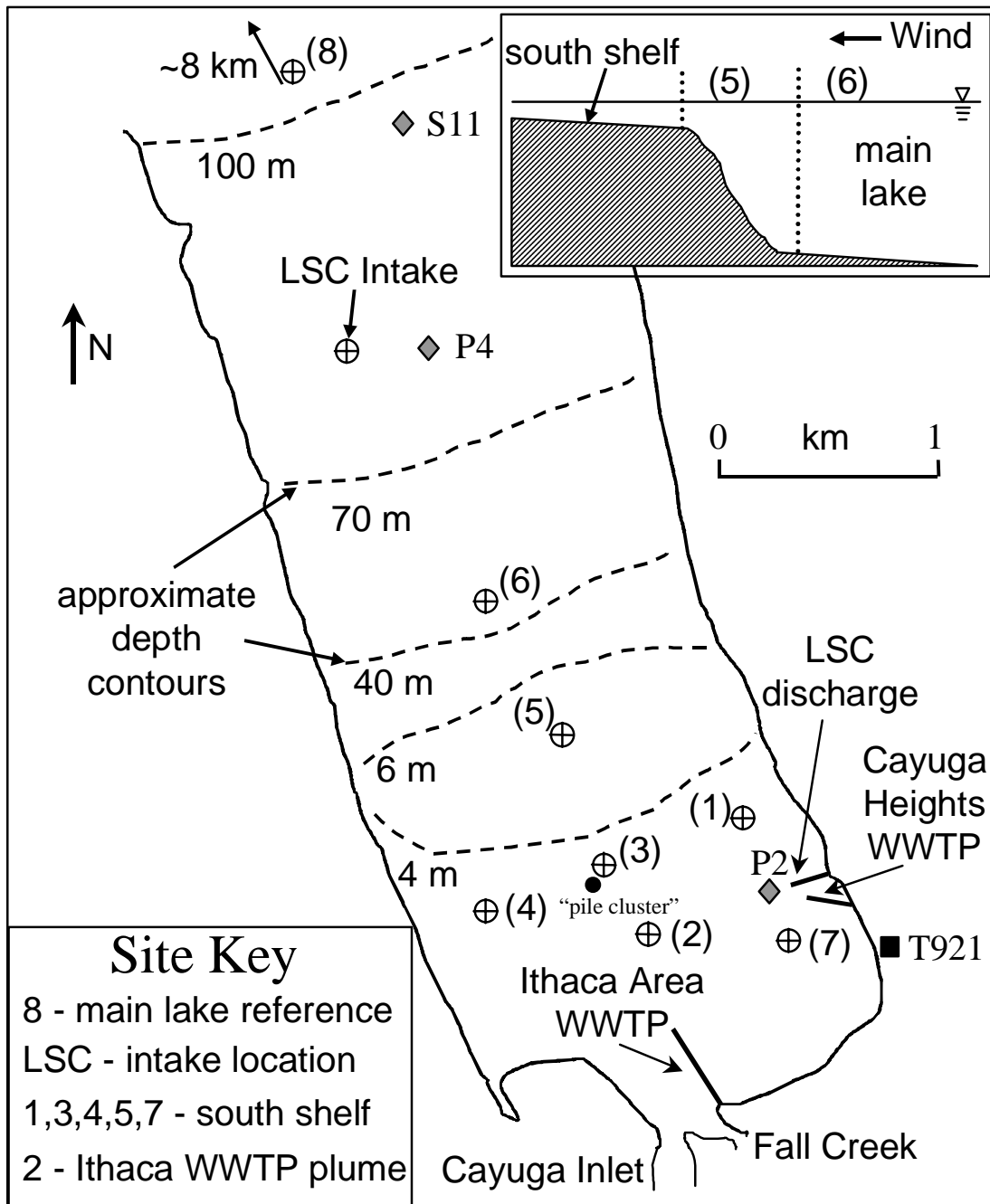


Figure 1a. Sampling sites, setting, approximate bathymetry, for LSC monitoring program, southern end of Cayuga Lake. Sites sampled during 1994 – 1996 study (P2, P4 and S11; Stearns and Wheler 1997) are included for reference.

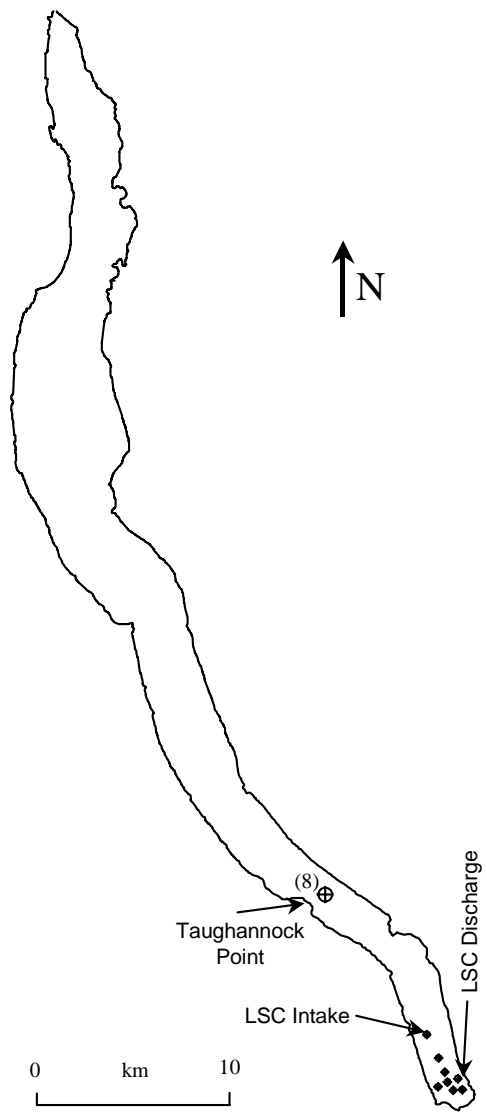


Figure 1b. Sampling sites for LSC monitoring program, within the context of the entire Cayuga Lake basin.

2.1.2. Nitrogen (N)

Nitrogen exists in a number of different forms in lakes. Two forms of N are important to plant nutrition, ammonium ion (NH_4^+) and nitrate (NO_3^-). Ammonium is preferred over nitrate because it is more easily assimilated. For that reason ammonium is frequently depleted to levels below detection limits of common analytical procedures. Nitrogen is probably the second most critical nutrient controlling phytoplankton growth. Nitrogen becomes the limiting nutrient seasonally in a number of lakes. The development of N-limiting conditions is usually considered undesirable, as it can promote proliferation of a group of phytoplankton that is capable of obtaining (“fixing”) N from the atmosphere to augment or meet their N requirements. This group of phytoplankton (N-fixing filamentous blue-green algae/cyanobacteria) is generally considered undesirable because they may cause nuisance conditions, such as floating scums.

The three forms of N measured in this program, total dissolved N (TDN), total ammonia (T- NH_3), and total oxidized N (NO_x), are routinely measured in many limnological and water quality programs. These forms are monitored here to stay apprised of the availability of N to phytoplankton, and the major components of dissolved N in the system. Total ammonia includes ammonium (NH_4^+) and free (or un-ionized; NH_3) ammonia. Ammonium is the dominant component at the pH values common to Cayuga Lake. Two components contribute to NO_x , NO_3^- , and nitrite (NO_2^-). The dominant component, by a wide margin, is NO_3^- , as NO_2^- is almost always present in low concentrations due to its highly reactive character. The difference between TDN and the sum of T- NH_3 and NO_x is an estimate of the concentration of dissolved organic N (DON). Biochemical processes can cause the conversion of DON to T- NH_3 , and T- NH_3 to NO_x .

2.1.3. Chloride (Cl^-)/Specific Conductance

Chloride (Cl^-) behaves in a conservative manner in freshwaters. In other words, it is not taken up or produced as part of chemical and biochemical processes that occur in lakes. For that reason, it is commonly incorporated in monitoring programs as a **tracer**. In lakes, where there are distinct differences in Cl^- concentrations in inflows or discharges, routine measurements may serve to identify the contribution(s) of various inputs, and even the movement of these inputs within the lake. Measurements of Cl^- are included in this program for these reasons.

Specific conductance is an aggregate measure of the summed ionic content of water. This parameter is also used as a tracer, though it does not meet the conservative assumption as well as Cl^- . This parameter is measured in the field.

2.1.4. 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.

2.1.5. 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.

2.1.6. 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 2002, beginning in April and extending through 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 April – October interval. The thermistors were exchanged biweekly with fresh units for data downloading and maintenance. Deployments made on October 31, 2002 will be retrieved in April 2003. 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 1 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 20m 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	determination of attenuation
Scalar	coefficients
Downwelling	

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. The chlorophyll method is one of the most commonly used in lake studies. 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 $\mu\text{g}\cdot\text{L}^{-1}$
soluble reactive phosphorus	4500-P	APHA (1992)	0.3 $\mu\text{g}\cdot\text{L}^{-1}$
total dissolved phosphorus	4500-P	APHA (1992)	0.6 $\mu\text{g}\cdot\text{L}^{-1}$
turbidity	2130-B	APHA (1992)	-
acidified turbidity		Effler and Johnson (1987)	-
total dissolved nitrogen		Ebina et al. 1983	0.01 $\text{mg}\cdot\text{L}^{-1}$
ammonia nitrogen	350.1	USEPA (1983)	0.01 $\text{mg}\cdot\text{L}^{-1}$
nitrate and nitrite nitrogen	353.2	USEPA (1983)	0.01 $\text{mg}\cdot\text{L}^{-1}$
chlorophyll a		Parsons et al. (1984)	0.4 $\mu\text{g}\cdot\text{L}^{-1}$
chloride	4500-CL ⁻	APHA (1992)	0.05 $\text{mg}\cdot\text{L}^{-1}$

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 2002 program (Table 5). The greatest variability was associated with the turbidity measurement (Table 5).

2.7.2. Laboratory Program

The laboratory quality assurance/control program conducted was as specified by the Environmental Laboratory Approval Program (ELAP 1999) of the New York State Health Department. ELAP methods were used to assure precision and accuracy, completeness and comparability (ELAP 1999). 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 ELAP 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
chloride	c	d	2	1
total dissolved nitrogen	a	b	2	4
ammonia nitrogen	a	b or a	2	4
nitrate and nitrite nitrogen	a	b or a	2	4

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 - H₂SO₄ to pH < 2
 b - none
 c - store filter frozen until analysis
 d - none sample kept at < 4° C, and in the dark

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

holding time: 1 - 28 days
 2 - 24 hours
 3. - 200 days
 4 - unpreserved 48 hours, preserved 28 days

Table 5: Precision for triplicate sampling/measurement program for key parameters for 2002, represented by the average coefficient of variation.

Parameter	Site 1	Rotating Site*
total phosphorus	0.11	0.05
chlorophyll a	0.09	0.08
turbidity	0.14	0.07
Secchi disc	< 0.01	< 0.01

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

3. Results, 2002

The measurements made in the 2002 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 much 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 2h) 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 2m-r). Paired profiles of temperature, the beam attenuation coefficient (BAC), and chlorophyll fluorescence obtained at the LSC intake site on 15 monitoring dates in 2002 are also presented (Figure 3).

Previous annual reports (UFI 1999, 2000, 2001, 2002) documented occurrences of extremely high concentrations of forms of phosphorus (TP, TDP, and SRP) and nitrogen (TDN and T-NH₃) 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 and nitrogen continued to be observed at this site in 2002 (Figure 2a-f). 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, 2002.

TP ($\mu\text{gP}\cdot\text{L}^{-1}$)			
SITE	MEAN	CV	RANGE
1	25.2	0.41	11.3 – 46.4
2	33.3	0.44	13.5 – 57.3
3	20.3	0.52	9.3 – 45.3
4	18.4	0.49	7.9 – 41.9
5	17.9	0.45	7.2 – 37.4
6	16.4	0.35	7.2 – 27.8
7	29.0	0.50	10.8 – 62.8
8	12.5	0.23	7.2 – 18.7
LSC	13.3	0.30	6.5 – 21.6

TDN ($\text{mgN}\cdot\text{L}^{-1}$)			
SITE	MEAN	CV	RANGE
1	1.512	0.11	1.263 – 1.891
2	1.668	0.19	1.274 – 2.421
3	1.408	0.10	1.024 – 1.610
4	1.403	0.09	1.224 – 1.608
5	1.526	0.18	1.173 – 2.318
6	1.402	0.11	1.055 – 1.653
7	1.499	0.11	1.180 – 1.800
8	1.446	0.09	1.259 – 1.680
LSC	1.408	0.08	1.229 – 1.636

TDP ($\mu\text{gP}\cdot\text{L}^{-1}$)			
SITE	MEAN	CV	RANGE
1	7.8	0.72	3.1 – 25.5
2	13.6	0.77	2.8 – 43.5
3	5.4	0.53	1.6 – 12.7
4	5.6	0.77	1.0 – 18.6
5	4.7	0.60	1.1 – 10.8
6	3.6	0.45	1.0 – 6.3
7	9.2	0.39	2.2 – 16.2
8	3.9	0.67	1.6 – 13.0
LSC	3.6	0.50	1.5 – 8.1

NO_x ($\text{mgN}\cdot\text{L}^{-1}$)			
SITE	MEAN	CV	RANGE
1	1.073	0.12	0.874 – 1.315
2	1.165	0.16	0.937 – 1.546
3	1.052	0.11	0.849 – 1.343
4	1.030	0.15	0.731 – 1.312
5	1.082	0.13	0.862 – 1.411
6	1.004	0.17	0.688 – 1.340
7	1.026	0.16	0.738 – 1.334
8	1.098	0.17	0.767 – 1.464
LSC	1.081	0.16	0.787 – 1.430

SRP ($\mu\text{gP}\cdot\text{L}^{-1}$)			
SITE	MEAN	CV	RANGE
1	3.1	1.46	0.2 – 18.9
2	8.0	1.06	0.3 – 30.0
3	1.8	0.53	0.2 – 7.5
4	1.8	1.46	0.2 – 10.3
5	1.2	1.27	0.2 – 5.5
6	0.8	1.25	0.2 – 3.8
7	4.1	0.87	0.2 – 12.3
8	0.7	0.98	0.2 – 2.8
LSC	0.6	1.32	0.2 – 3.6

T-NH₃ ($\text{mgN}\cdot\text{L}^{-1}$)			
SITE	MEAN	CV	RANGE
1	0.092	1.10	0.024 – 0.430
2	0.149	0.95	0.012 – 0.461
3	0.047	0.51	0.005 – 0.109
4	0.033	0.37	0.010 – 0.053
5	0.033	0.64	0.005 – 0.089
6	0.027	0.55	0.005 – 0.062
7	0.096	0.80	0.012 – 0.260
8	0.018	0.62	0.005 – 0.048
LSC	0.023	0.72	0.005 – 0.055

Table 6 (cont.): Summary of results of monitoring program according to site, 2002.

CHL a ($\mu\text{g}\cdot\text{L}^{-1}$)			
SITE	MEAN	CV	RANGE
1	4.4	0.56	0.8 – 9.2
2	4.7	0.83	0.8 – 16.7
3	3.5	0.59	1.0 – 8.2
4	3.9	0.80	0.6 – 14.0
5	4.5	0.45	1.0 – 8.5
6	5.1	0.39	1.2 – 9.1
7	6.2	1.22	1.2 – 32.9
8	4.4	0.41	1.2 – 6.8
LSC	4.9	0.42	1.2 – 8.0

Temperature ($^{\circ}\text{C}$) @ 2m			
SITE	MEAN	CV	RANGE
1	16.2	0.35	7.9 – 23.9
2	16.3	0.37	8.1 – 24.1
3	15.9	0.38	6.4 – 23.8
4	16.0	0.39	5.8 – 24.0
5	15.8	0.40	5.6 – 24.2
6	16.1	0.39	5.0 – 24.2
7	16.5	0.35	9.2 – 23.8
8	16.7	0.36	7.2 – 23.8
LSC	16.1	0.39	4.9 – 24.2

Cl ($\text{mg}\cdot\text{L}^{-1}$)			
SITE	MEAN	CV	RANGE
1	43.0	0.08	34.4 – 47.2
2	42.5	0.09	34.8 – 46.7
3	41.8	0.09	30.0 – 44.8
4	41.7	0.13	24.8 – 47.2
5	42.6	0.08	31.9 – 46.5
6	43.3	0.07	35.6 – 46.2
7	42.2	0.13	28.8 – 46.6
8	43.7	0.07	34.6 – 49.3
LSC	42.1	0.12	29.0 – 46.7

Beam Attenuation Coeff. (m^{-1}) @ 2m			
SITE	MEAN	CV	RANGE
1	2.78	1.27	0.75 – 14.04
2	2.34	0.73	0.79 – 7.15
3	2.21	1.12	0.75 – 10.74
4	2.02	1.36	0.68 – 11.43
5	1.93	0.87	0.61 – 7.26
6	1.94	0.78	0.64 – 6.21
7	3.03	1.61	0.60 – 18.97
8	1.36	0.36	0.70 – 2.34
LSC	1.57	0.65	0.52 – 4.50

T_n (NTU)			
SITE	MEAN	CV	RANGE
1	3.9	1.26	0.7 – 21.5
2	3.9	0.93	0.7 – 14.2
3	3.6	1.35	0.7 – 15.8
4	2.6	1.63	0.5 – 17.9
5	3.1	1.31	0.7 – 15.4
6	2.1	0.93	0.5 – 8.1
7	4.8	1.67	0.7 – 30.2
8	1.4	0.62	0.4 – 3.4
LSC	1.7	0.64	0.5 – 4.3

K_s Attenuation Coeff. (m^{-1})			
SITE	MEAN	CV	RANGE
1	-	-	-
2	-	-	-
3	-	-	-
4	-	-	-
5	-	-	-
6	0.51	0.61	0.25 – 1.32
7	-	-	-
8	0.38	0.22	0.24 – 0.49
LSC	0.46	0.65	0.23 – 1.46

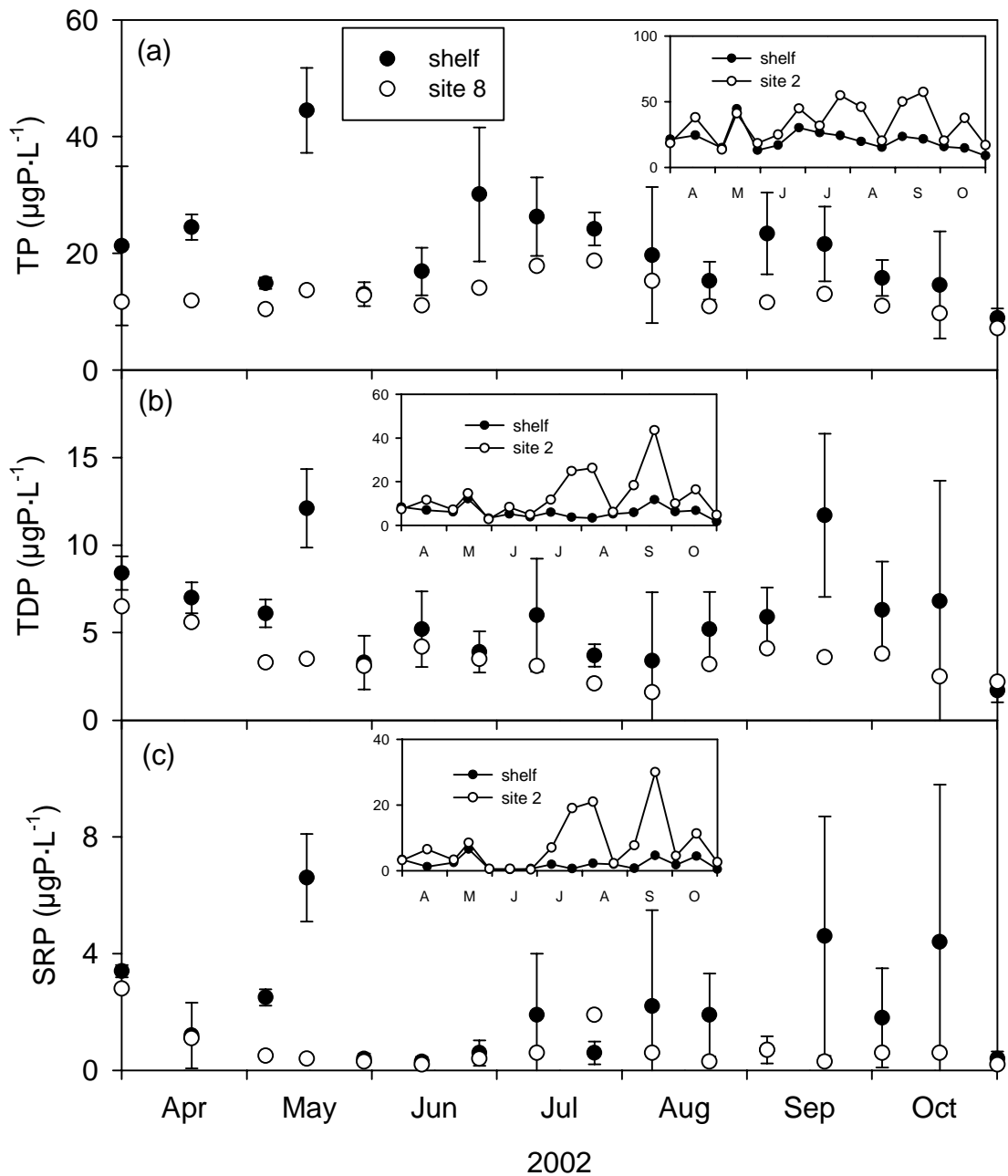


Figure 2a-c. Time-series of parameter values for Cayuga Lake for 2002: (a) TP, (b) TDP, and (c) SRP. Insets present results for site 2. Results for the “shelf” are averages; the error bars represent spatial variation with dimensions of ± 1 standard deviation.

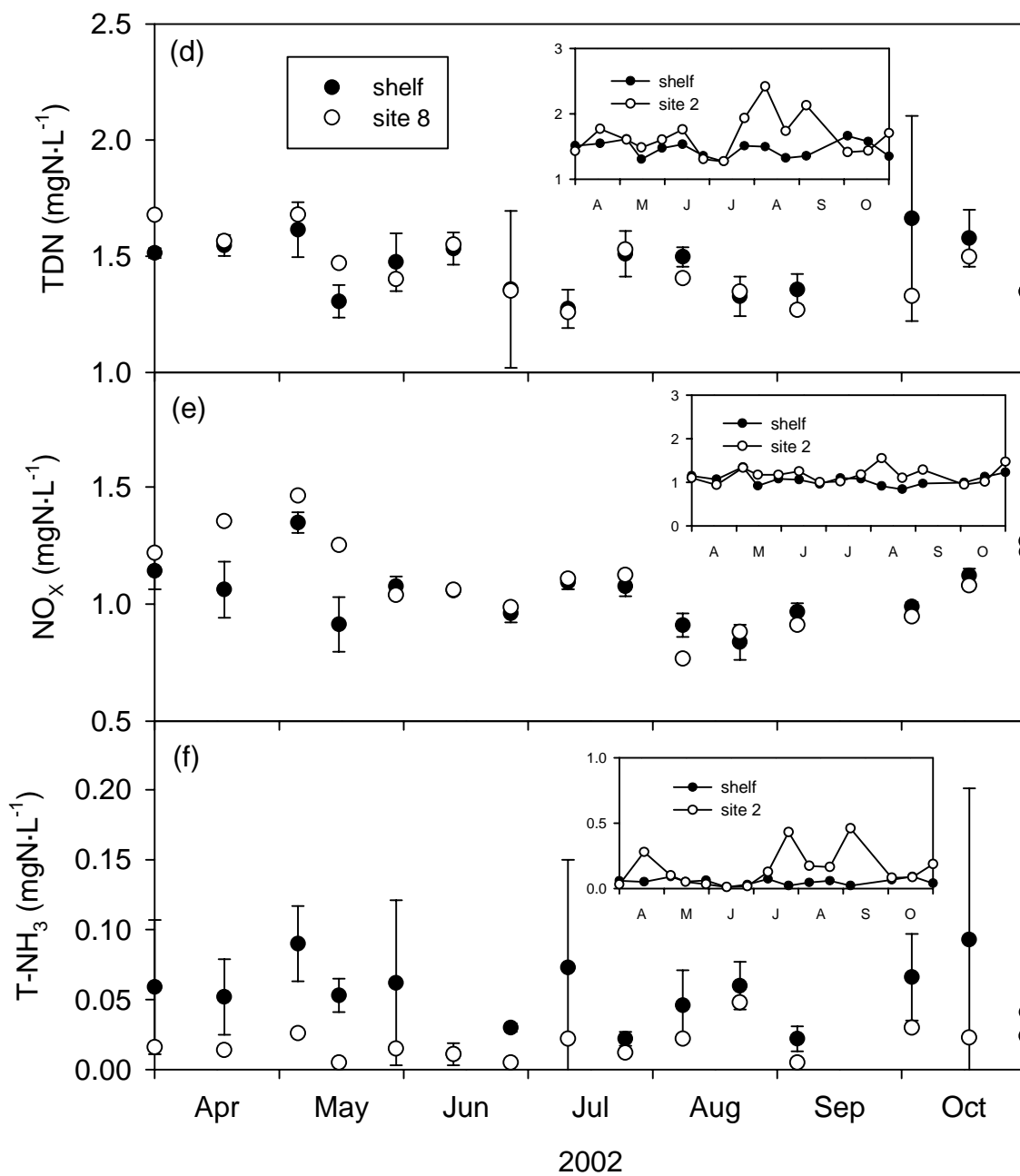


Figure 2d-f. Time-series of parameter values for Cayuga Lake for 2002: (d) TDN, (e) NO_x, and (f) T-NH₃. Insets present results for site 2. Results for the “shelf” are averages; the error bars represent spatial variation with dimensions of ± 1 standard deviation.

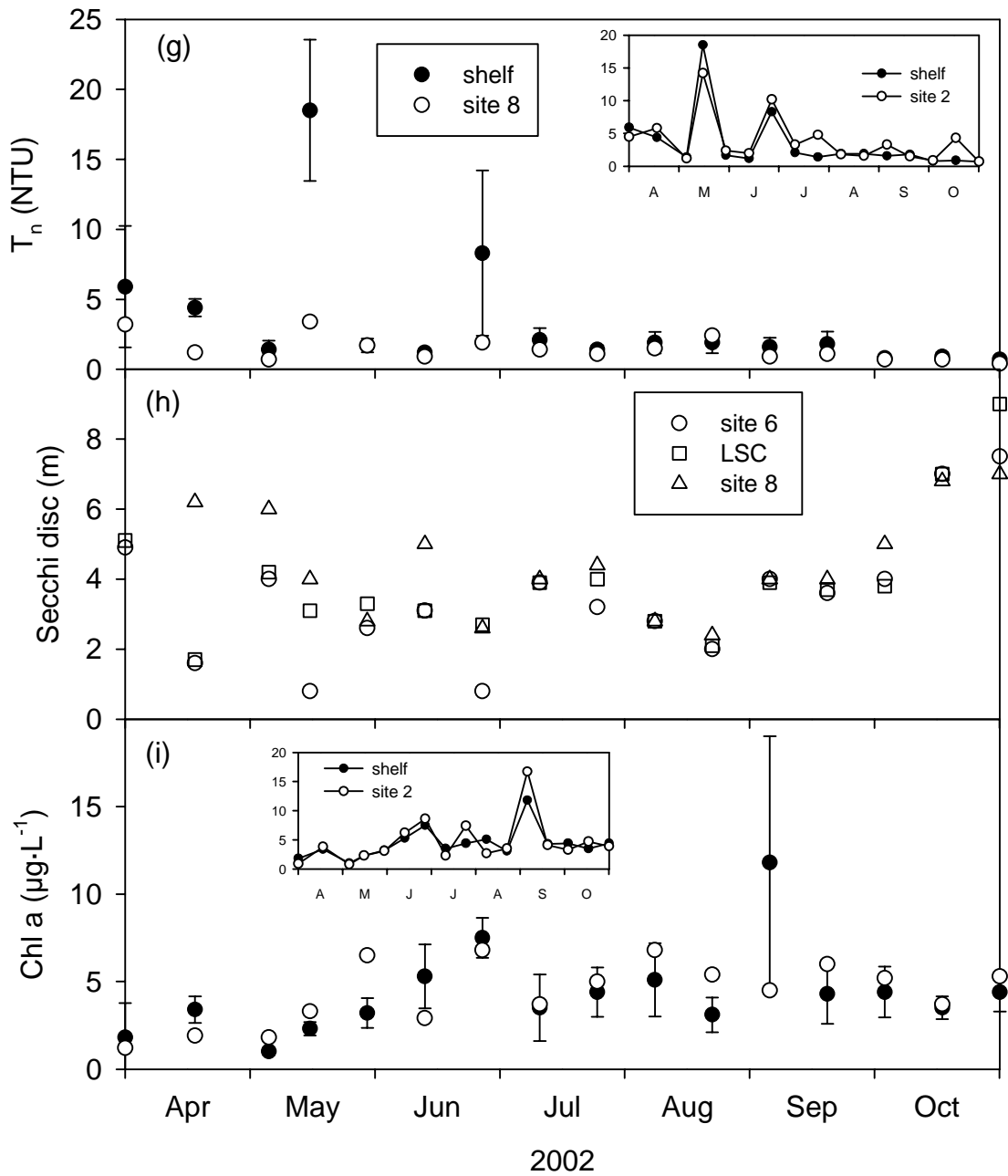


Figure 2g-i. Time-series of parameter values for Cayuga Lake for 2002: (g) T_n , (h) Secchi disc, and (i) $Chl\ a$. Insets present results for site 2. Results for the “shelf” are averages; the error bars represent spatial variation with dimensions of ± 1 standard deviation.

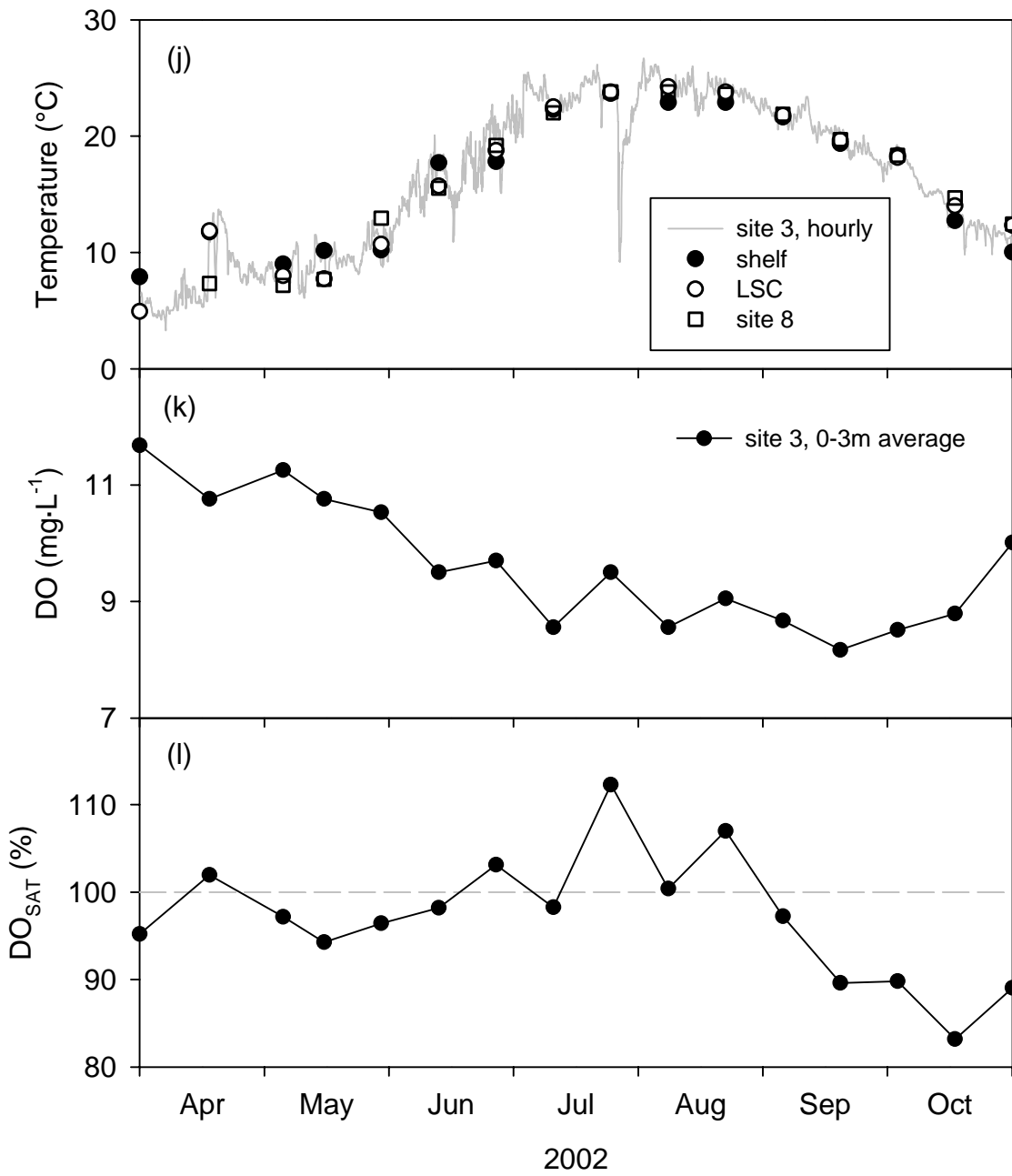


Figure 2j-1. Time-series of parameter values for Cayuga Lake for 2002: (j) temperature, (k) DO, and (l) DO_{SAT}.

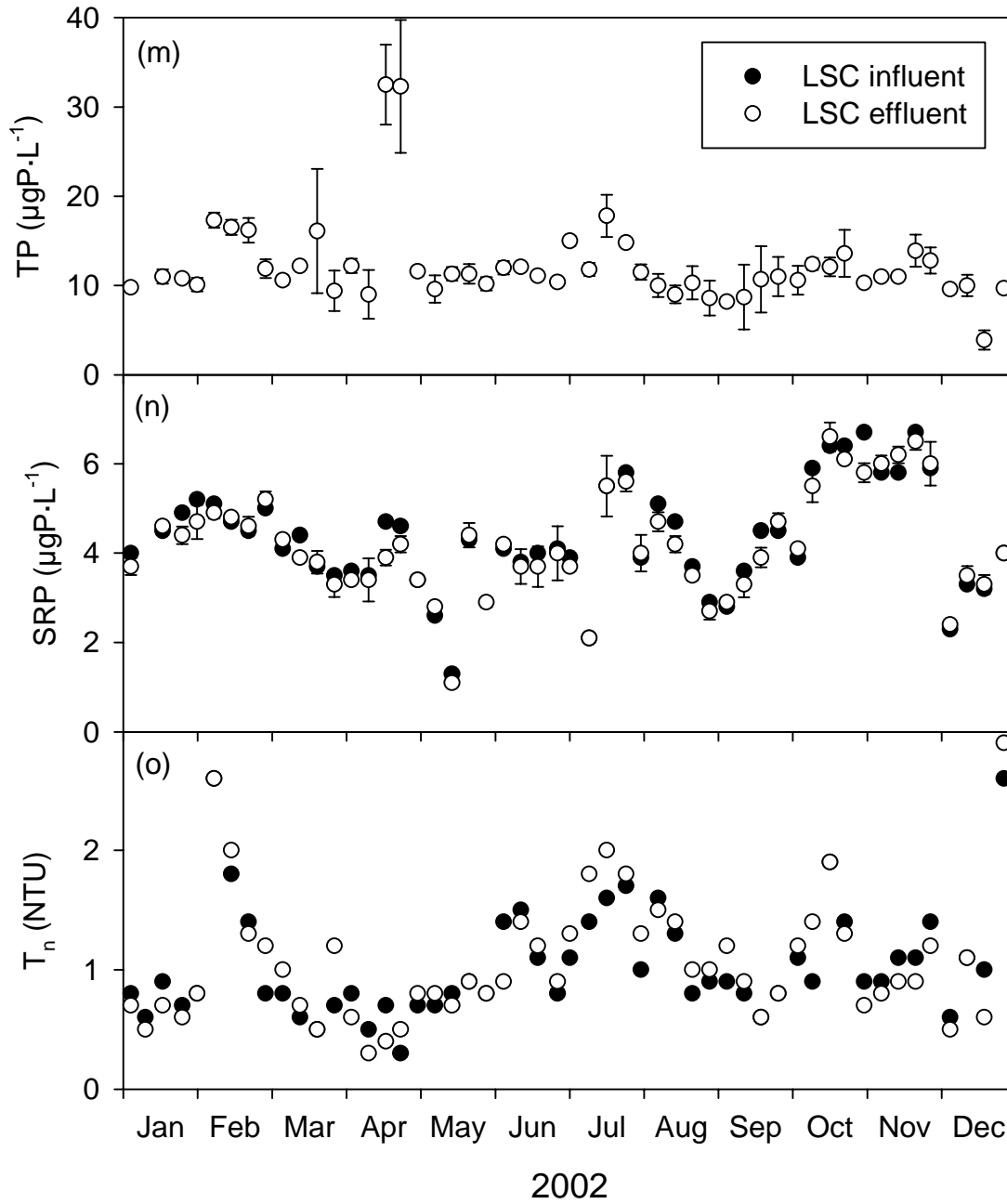


Figure 2m-o. Time series of parameter values for the LSC influent and effluent for 2002: (m) TP, (n) SRP, and (o) T_n . Error bars represent 95% confidence intervals determined from analyses of field triplicates.

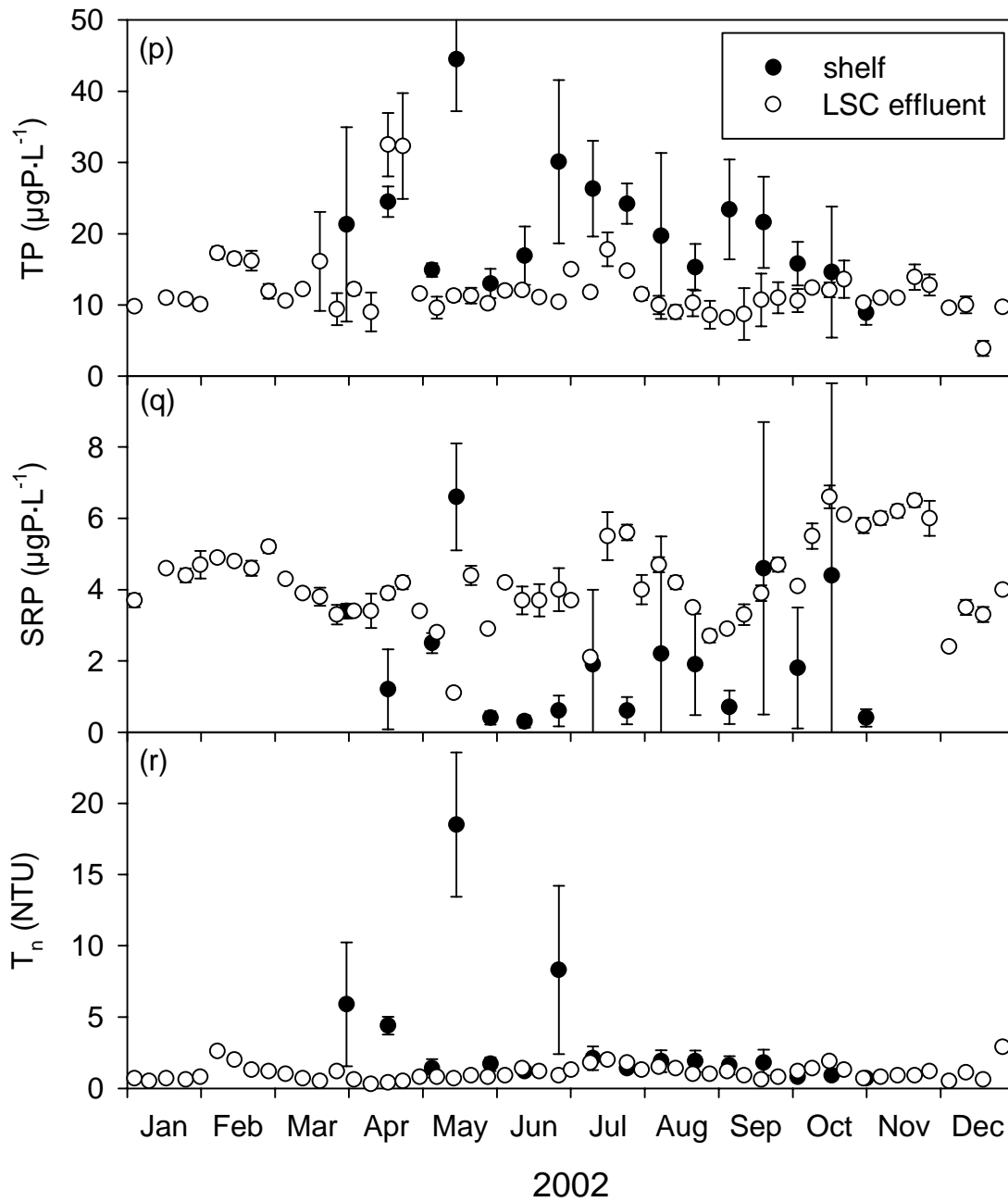


Figure 2p-r. Time series of parameter values for the south shelf and the LSC effluent for 2002: (p) TP, (q) SRP, and (r) T_n . Results for the “shelf” are averages; the error bars represent spatial variation with dimensions of ± 1 standard deviation. Error bars for the LSC effluent represent 95% confidence intervals determined from analyses of field triplicates.

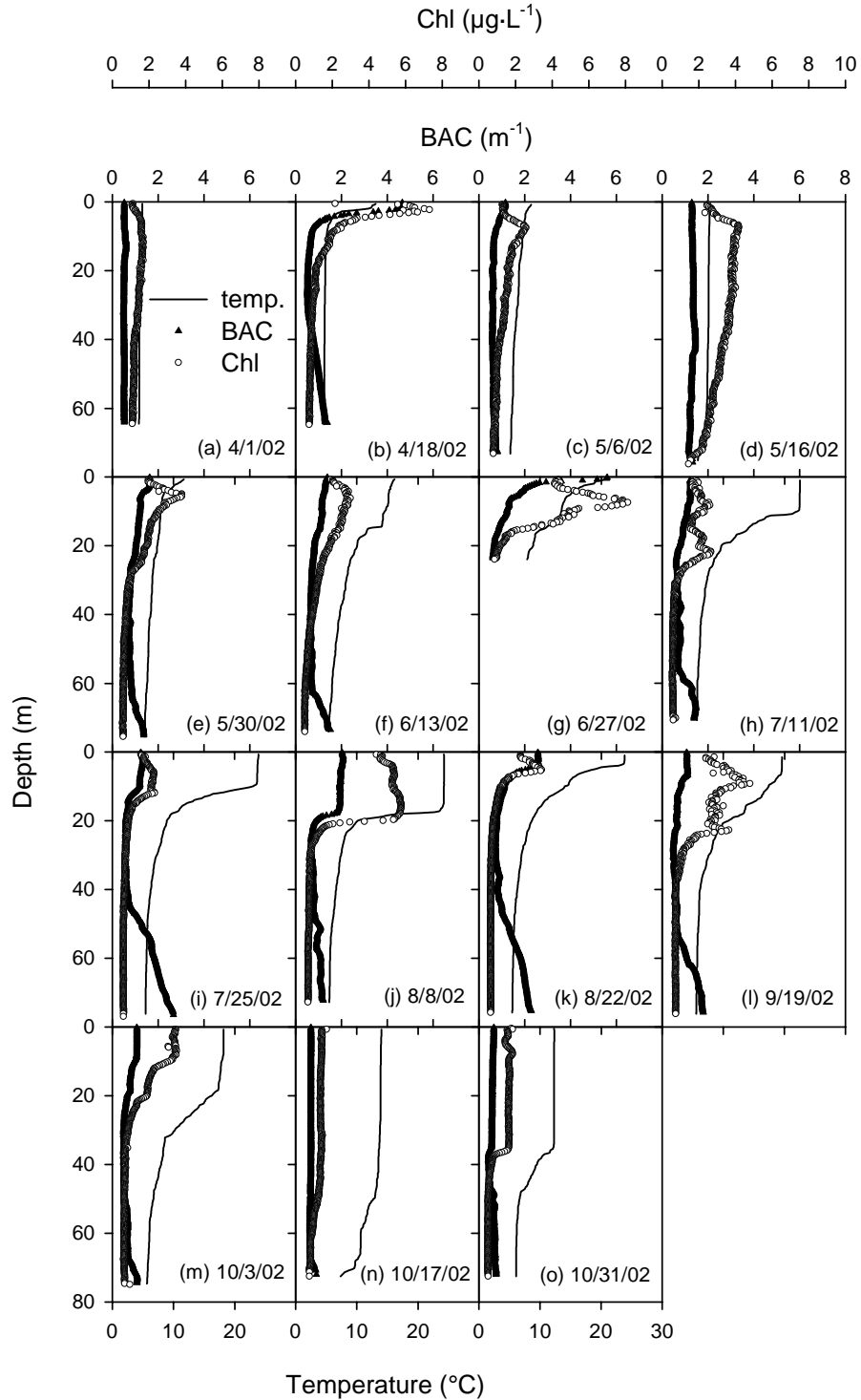


Figure 3. Vertical profiles of temperature, chlorophyll fluorescence, and beam attenuation coefficient (BAC) for LSC site in 2002: (a) April 1, (b) April 18, (c) May 6, (d) May 16, (e) May 30, (f) June 13, (g) June 27, (h) July 11, (i) July 25, (j) August 8, (k) August 22, (l) September 19, (m) October 3, (n) October 17, (o) October 31.

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 1, 2, 3, 4, 5 and 7 on several occasions during the 2002 study interval (see Appendix 1). Use of the population of SD measurements available (i.e., observations of $SD < \text{lake depth}$) 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 – 2002; 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 five study years.

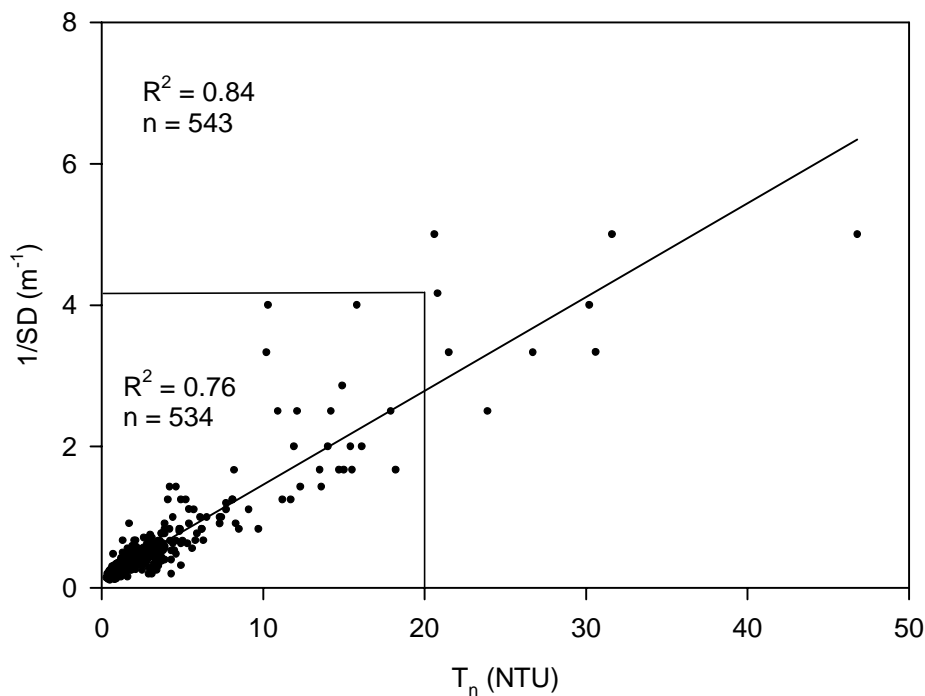


Figure 4. Relationship between Secchi disc transparency (SD) and turbidity in the southern end of Cayuga Lake based on paired observations from the 1998 – 2002 study interval.

4.2. Inputs of Phosphorus to Southern End of Cayuga Lake

Phosphorus loading is an important driver of primary production in phosphorus limited lakes. It is therefore 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 and Cayuga Heights wastewater treatment plants (WWTPs) for the 1998 - 2002 interval (Table 7), 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) 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 has been observed for both WWTPs (Table 7) over the 1998 – 2002 interval. Phosphorus loading from the Ithaca Area WWTP was lower in 2002 than in the previous four years (Table 7). Phosphorus loads during 2002 were also relatively low for the Cayuga Heights WWTP, but slightly higher than 1999 loading estimates (Table 7). The TP permit requirement is 40 pounds per day (18.1 kg per day) for the Ithaca Area WWTP and 1 mg·L⁻¹ for the Cayuga Heights WWTP.

Estimates of monthly tributary phosphorus loading presented in the **Draft Environmental Impact Statement** 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. 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 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 2002 are presented in Table 7. Concentrations of TP are measured weekly at the LSC discharge. The estimates of the monthly loads (Table 7) 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 1.1 kg·d⁻¹, or 3.5% of the total TP load to the shelf. This is a smaller contribution than the 2.9 kg·d⁻¹, or 4.8% of the total TP load to the shelf, projected in the **Draft Environmental Impact Statement** for the LSC facility (Stearns and Wheler 1997).

Average levels of TP, SRP and T_n in the LSC effluent and on the shelf are presented in Table 8. Compared to the receiving waters of the shelf, TP concentrations in the LSC effluent were on average about 8 µg·L⁻¹ lower and SRP concentrations were about 2 µg·L⁻¹ higher (Table 8). Average turbidity levels were 2.3 NTU higher on the shelf than in the LSC effluent. Levels of TP, SRP and T_n varied widely over time and space on the shelf during 2002 (Figure 2p-r). In contrast, the LSC effluent phosphorus concentrations and turbidity levels remained relatively uniform

Table 7: Estimates of monthly external loads of phosphorus to the southern portion of Cayuga Lake, 1998 - 2002.

Month	Ithaca Area WWTP ^a (kg·d ⁻¹)					Cayuga Heights WWTP ^b (kg·d ⁻¹)				
	1998	1999	2000	2001	2002	1998	1999	2000	2001	2002
May	14.1	19.7	24.1	15.8	12.4	8.7	3.7	3.5	5.5	4.4
June	5.8	9.1	16.6	11.2	7.9	7.5	4.3	5.1	4.0	3.5
July	16.4	11.4	13.7	15.2	10.4	4.4	2.6	3.4	4.2	3.8
August	17.0	12.5	19.1	15.2	16.2	4.7	1.5	4.6	7.1	2.0
September	32.8	20.0	18.5	22.0	11.4	7.7	1.8	4.0	6.6	2.8
October	16.2	9.4	15.4	16.4	13.6	9.1	1.7	4.1	2.8	3.1
<i>Mean</i>	<i>17.1</i>	<i>13.7</i>	<i>16.5</i>	<i>16.0</i>	<i>12.0</i>	<i>7.0</i>	<i>2.6</i>	<i>4.1</i>	<i>5.0</i>	<i>3.3</i>

Month	Tributary ^c (kg·d ⁻¹)	LSC ^d (kg·d ⁻¹)			Total (kg·d ⁻¹)			% LSC		
		average year	2000	2001	2002	2000	2001	2002	2000	2001
May	29.0	-	0.7	0.6	56.6	51.0	46.4	-	1.4	1.3
June	15.8	-	1.1	1.0	37.5	32.1	28.2	-	3.4	3.5
July	8.8	1.4	1.0	1.8	27.3	29.2	24.8	5.1	3.4	7.3
August	6.0	1.0	1.4	1.2	30.7	29.7	25.4	3.3	4.7	4.7
September	7.5	0.9	1.0	1.0	30.9	37.1	22.7	2.9	2.7	4.4
October	13.1	0.6	0.7	0.7	33.2	33.0	30.5	1.8	2.1	2.3
<i>Mean</i>	<i>13.3</i>	<i>1.0</i>	<i>1.0</i>	<i>1.1</i>	<i>34.9</i>	<i>35.4</i>	<i>29.7</i>	<i>2.9</i>	<i>3.0</i>	<i>3.5</i>

^a total phosphorus; personal communication with Jose Lozano, Director

^b total phosphorus; personal communication with Brent Cross, Village Engineer

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

^d total phosphorus; from facility permit reporting

Table 8: Average values of TP, SRP, and T_n in the LSC effluent and on the shelf. Averages determined from observations made during the April – October interval of 2002.

Location	TP (µg·L ⁻¹)	SRP (µg·L ⁻¹)	T _n (NTU)
LSC effluent (n = 31)	12.6	4.0	1.1
Shelf (n = 16)	20.9	2.1	3.4

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 10 and 12.

Runoff and wind conditions for the study period of 2002 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 5). 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, about 77 years; the wind database reflects 19 years of measurements. Daily average measurements of Fall Creek flow and wind speed for 2002 are compared to time-series of daily median values for the available records (Figure 5a and c). Additionally, monthly average flows for the study period are compared to quartiles for the period of record (Figure 5b). 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.

Major runoff events occurred during mid-April, mid-May, early June, and mid-June of 2002 (Figure 5a). A smaller storm occurred during late June, and a series of five relatively modest runoff events occurred during September and October (Figure 5a). In-lake sampling was conducted during or immediately following several of these runoff events (Figure 5a). For example, substantial storms immediately preceded the samplings of April 18 and May 16, and the samplings of June 27 and October 17 occurred during runoff events (Figure 5a). The May 16 and late June 27 samplings showed elevated TP concentrations (Figure 2a) and decreased clarity (Figure 2g-h). Monthly average flows were well above the 75-percentile level in May and below the 25-percentile level in April and August (Figure 5b). Monthly average flows were elevated during June and September, and near the long-term average during July and October (Figure 5b).

Major wind events (e.g., protracted intervals of high winds) from the north to northwest did not occur over the study interval of 2002 (Figure 5c). However, winds were above average for extended periods during late April, mid-May and in early August (Figure 5c). Three substantial wind events occurred during September 2002. On September 5 the average wind speed was about twice the long-term average and blew from the north to northwest for 19 hours. On September 11 winds out of the north to northwest had an average speed of 13.9 mph and blew from this direction for 16 hours. Again on September 27 and 28 strong winds from the north to northwest predominated. Wind velocities were distinctly above average on, or before, the monitoring days of April 30, May 16, July 11, August 8 and September 5 (Figure 5c).

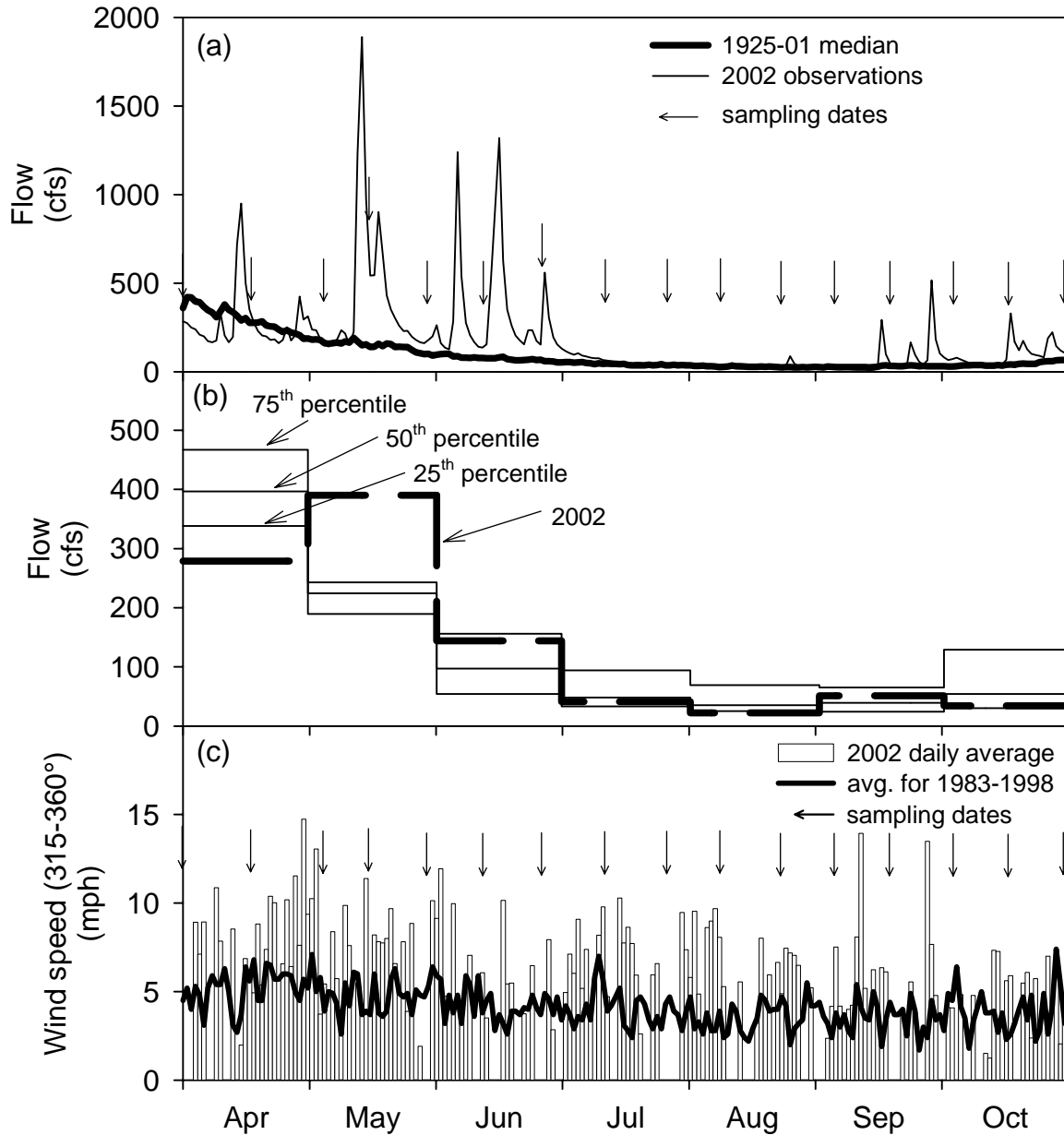


Figure 5. Runoff and wind conditions for the April – October interval of 2001: (a) daily average flows in Fall Creek compared to median daily values for the 1925 – 2001 record, (b) monthly flows in 2002 compared to quartile levels of flow for the 1925 – 2001 record, and (c) daily average wind speed out of the north to northwest.

4.4. Limitations in Measures of Trophic State on the Shelf

Recurring circumstantial scientific evidence, provided by the findings of four consecutive study years (Upstate Freshwater Institute 1999, 2000, 2001, 2002) 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, based on observations from the 1998 - 2001 study years (Upstate Freshwater Institute 1999, 2000, 2001, 2002). Observations from the 2002 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. the highest T_n (Figure 2g) values observed during 2002 for the shelf were observed after the major runoff events of mid-May and late June (Figure 5a). The highest T_n (Figure 2g) value observed for site 8 was observed following the mid-May storm. This suggests greater contributions of non-phytoplankton particles to the measurements of T_n following runoff events.
2. high T_n values were reported for the 1999 and 2000 study years (Upstate Freshwater Institute 2000, 2001) at the deep water sites during “whiting” events in late July and early August. These increases in T_n were driven largely by increases in T_c (calcium carbonate turbidity; Figure 6). The increase in T_c observed during August 2002 is suggestive of a “whiting” event (Figure 6).
3. the ratio of particulate P (PP) to chlorophyll **a** was often substantially higher on the south shelf than at the deep stations (Figure 7), 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 reasonable 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 8). Non-phytoplankton particles were responsible for high T_n on the shelf and in the main lake following the major runoff event of mid-May (Figure 8).

The 2002 results demonstrate substantial seasonal 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.

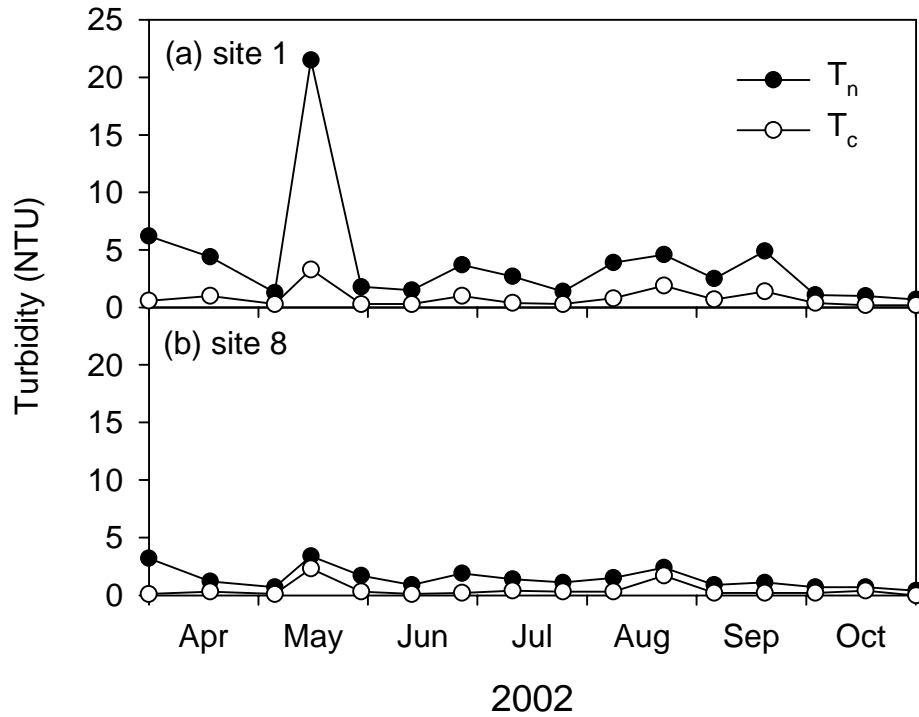


Figure 6. Distributions of total turbidity (T_n) and calcium carbonate turbidity (T_c) in the upper waters of Cayuga Lake in 2002: (a) site 1, (b) site 8.

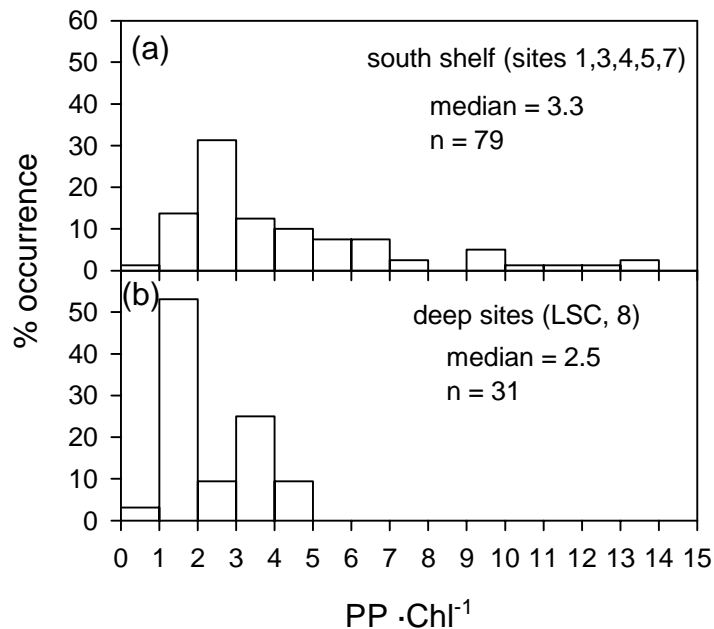


Figure 7. Distributions of the particulate P (PP) to chlorophyll a ratio values in Cayuga Lake in 2002: (a) south shelf sites, and (b) deep water sites.

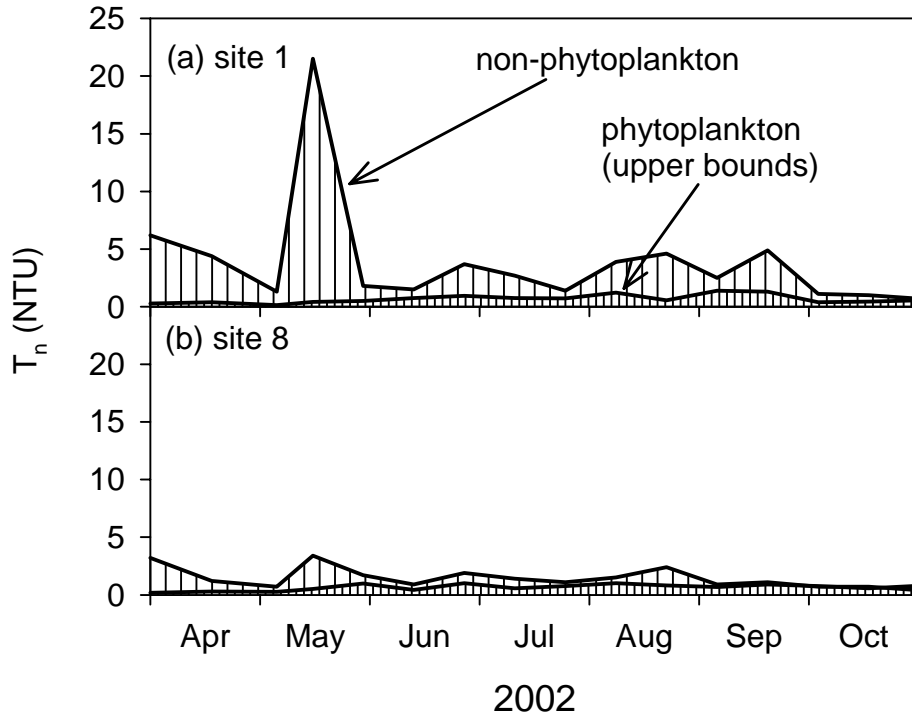


Figure 8. Time-series of T_n and contributions from components (phytoplankton and non-phytoplankton) for the April – October interval of 2002: (a) site 1, and (b) site 8.

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 – 2002, 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 since 1994 (Table 9). Distinctly higher chlorophyll **a** concentrations were observed on the shelf in the summers of 1994 – 1996 compared to deeper water sites, however, the averages were similar over the 1998 – 2002

interval (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 – 2002 study years.

Year	Total Phosphorus ($\mu\text{g}\cdot\text{L}^{-1}$)		Source
	Deep-Water Location(s)	Southern Shelf	
1968 ^Δ	20.2 (n = 19)	-	Peterson 1971
1969 ^Δ	15.3 (n = 22)	-	Peterson 1971
1970 ^Δ	14.0 (n = 32)	-	Peterson 1971
1972 ^x	18.8 (n = 22)	-	USEPA 1974
1973 ^Δ	14.5 (n = 88)	-	Godfrey 1973
1994 ^{*,⊕}	21.7	30.8	Stearns and Wheler 1997
1995 ^{*,⊗}	16.5	23.7	Stearns and Wheler 1997
1996 ^{*,⊗}	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)	this report

^Δ 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

[⊕] site in 62 m of water, south of Myers Point, surface samples

[⊗] 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 – 2002 study years.

Year	Chlorophyll a ($\mu\text{g}\cdot\text{L}^{-1}$)		Source
	Deep-Water Location(s)	Southern Shelf	
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)	this report

* Hamilton 1969, 15 dates

** Wright 1969, 4 dates – 7 to 9 longitudinal sites

⁺ July – August

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 $2.0 \mu\text{g}\cdot\text{L}^{-1}$ 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 $12 \mu\text{g}\cdot\text{L}^{-1}$.

The average chlorophyll **a** concentration for Cayuga Lake for this synoptic program ($3.5 \mu\text{g}\cdot\text{L}^{-1}$) is compared to the values measured in the other ten Finger Lakes in Figure 9. These data support Cayuga Lake's classification as mesotrophic. Six of the lakes had average concentrations lower than observed for Cayuga Lake (Figure 9). Two of the lakes, Canandaigua and Skaneateles, had concentrations consistent with oligotrophy, while two (Conesus and Honeoye) bordered on eutrophy (Figure 9).

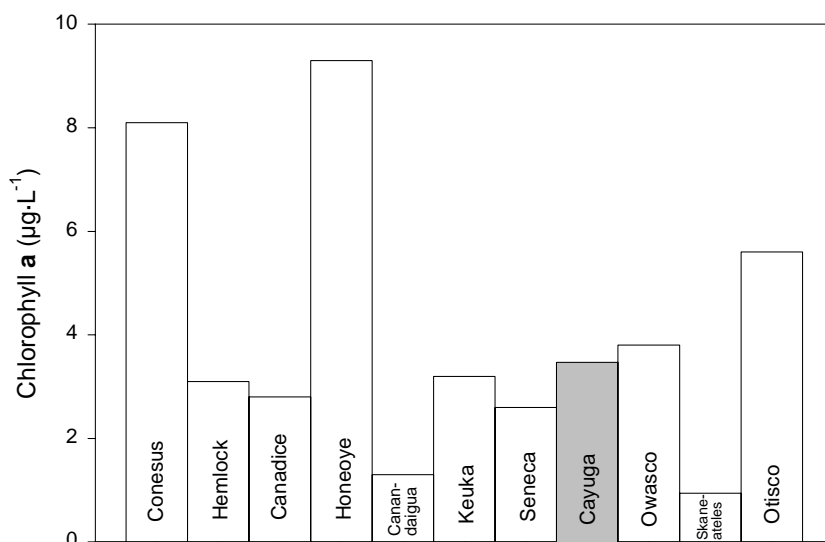


Figure 9. Comparison of average chlorophyll **a** concentrations for the spring-early fall interval for the eleven Finger Lakes, based on samples ($n=15$ to 16) collected over the 1996 through 1999 interval (data from Callinan et al. 2000).

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 2002 are compared here to the four previous study years (1998 – 2001; Figure 10). Daily average flows in Fall Creek were unusually low during April (Figure 10a). The mid-May storm produced the second highest flow rate measured during the five study years (Figure 10a). Fall Creek flows were relatively high in June 2002 because of three substantial runoff events that occurred during the month (Figure 10a). Flows remained low during the August – mid-September interval of 2002; just one minor runoff event occurred from late June through mid-September. Fall runoff events, like those that occurred from mid-September through October of 2002, are typical for this stream (Figure 10a).

Daily average wind speeds, out of the north to northwest, for the 1998 - 2001 interval and the 2002 study period are presented in Figure 10b for comparison. Major year-to-year differences have not been observed for this metric (Figure 10b). However, the elevated wind speeds measured during late April, mid-May, and on two occasions during September of 2002 represent relatively extreme conditions for this area (Figure 10b). Estimates of monthly average total phosphorus (TP) loads from point sources are compared here for 1998 - 2001 and 2002 (Figure 10c). Monthly estimates of TP loading for 2002 were the lowest of the five study years for May, June and September and second lowest for the months of July, August and October (Figure 10c).

Time series of TP, Chl, and T_n are presented for the April – October interval of the five study years (Figure 11). 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. Concentrations of TP were slightly higher during 2002 than in the previous four years (Figure 11a). The high TP concentrations (e.g., $> 30 \mu\text{g}\cdot\text{L}^{-1}$; Figure 11a) observed on the shelf during the 1998, 2000, 2001 and 2002 study intervals were all associated with major runoff events (Figure 11a). High TP concentrations (e.g., $> 30 \mu\text{g}\cdot\text{L}^{-1}$) were not observed during the 1999 study interval.

Chlorophyll **a** concentrations were similar during the five study years with the exception of the higher values observed during the late July – early August interval of 2000 and the spike observed on September 5, 2002 (Figure 11b). The September 2002 spike was influenced heavily by an unusually high Chl concentration at site 7 ($32.9 \mu\text{g}\cdot\text{L}^{-1}$). If site 7 is not included in the shelf averaging, the plotted concentration decreases from $11.8 \mu\text{g}\cdot\text{L}^{-1}$ to $8.8 \mu\text{g}\cdot\text{L}^{-1}$ (Figure 11b). In general, chlorophyll **a** concentrations have been highest during mid-summer; however, Chl concentrations remained low during mid-summer of 2002 (Figure 11b).

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 11c). The high turbidity values measured in mid-May and late June of 2002 were also associated with substantial storm events (Figure 11c). High turbidity values (e.g., $> 5 \text{ NTU}$) were not observed during the 1999 study interval.

The temporally detailed data presented in Figures 10 and 11 are summarized in Figure 12 as box plots for the four study years. The dimensions of the boxes are identified according to the key located to the right of Figure 12a. Fall Creek flows were highest in 2000, second highest in 2002, and lowest in 1999 (Figure 12a). Average wind speeds were essentially equal for the five study years (Figure 12b). Total phosphorus loading from point sources was relatively low in 1999 and 2002, and higher in 1998, 2000 and 2001 (Figure 12c). Greater month-to-month variability in TP loading was observed in 1998 than in the other study years (Figure 12c). Study period medians of TP, Chl and T_n on the shelf were similar for 1998, 2000, 2001, and 2002, and lower for 1999 (Figure 12d-f). Temporal variability for these three metrics was also much lower during the 1999 study interval (Figure 12d-f).

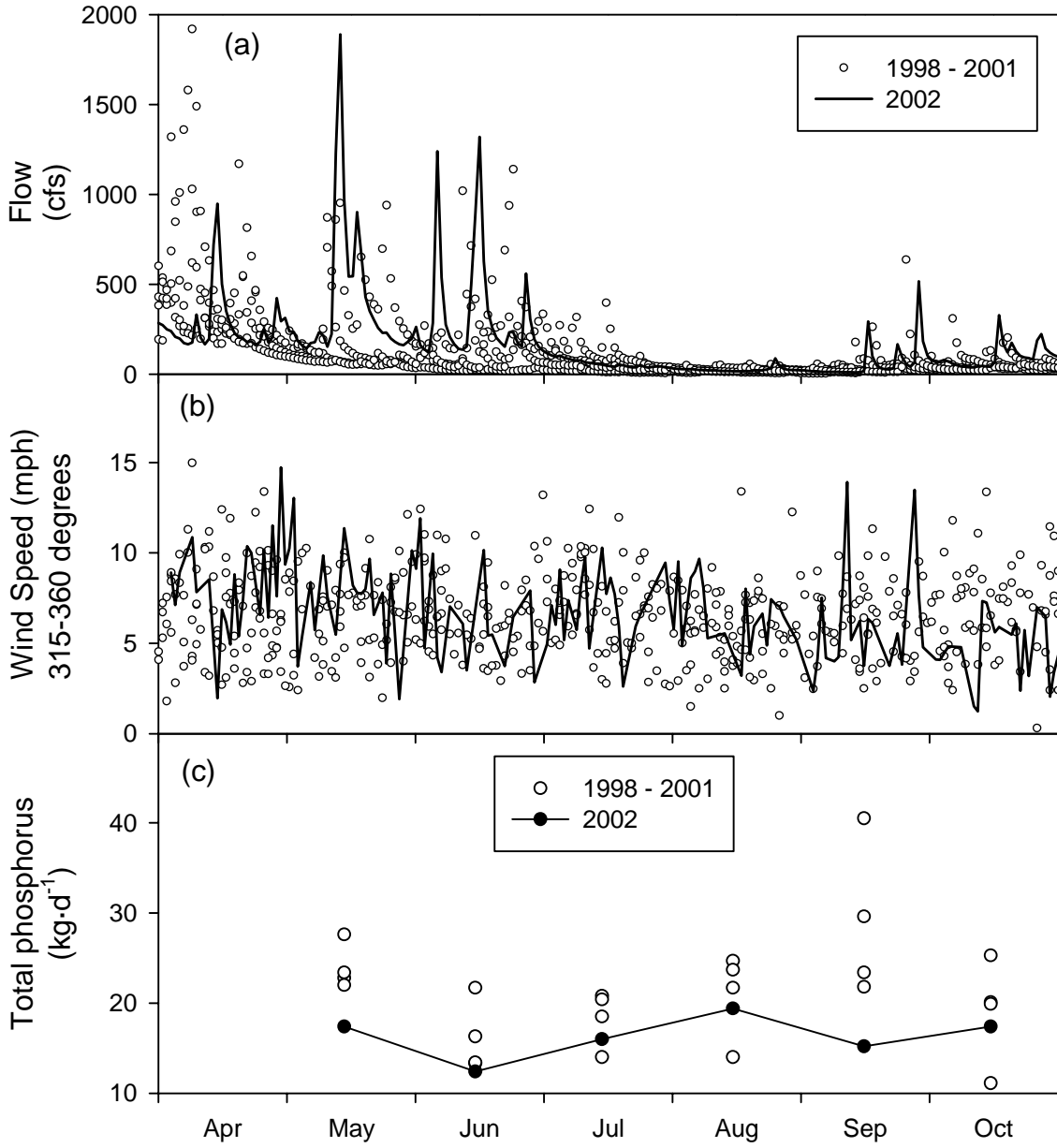


Figure 10. Comparison of 1998, 1999, 2000, 2001 and 2002 conditions for runoff, wind and total phosphorus loading for the April – October interval: (a) daily average flows in Fall Creek, (b) daily average wind speed, and (c) summed monthly loads of total phosphorus (TP) to southern Cayuga Lake from the Ithaca Area WWTP, Cayuga Heights WWTP, and the LSC facility.

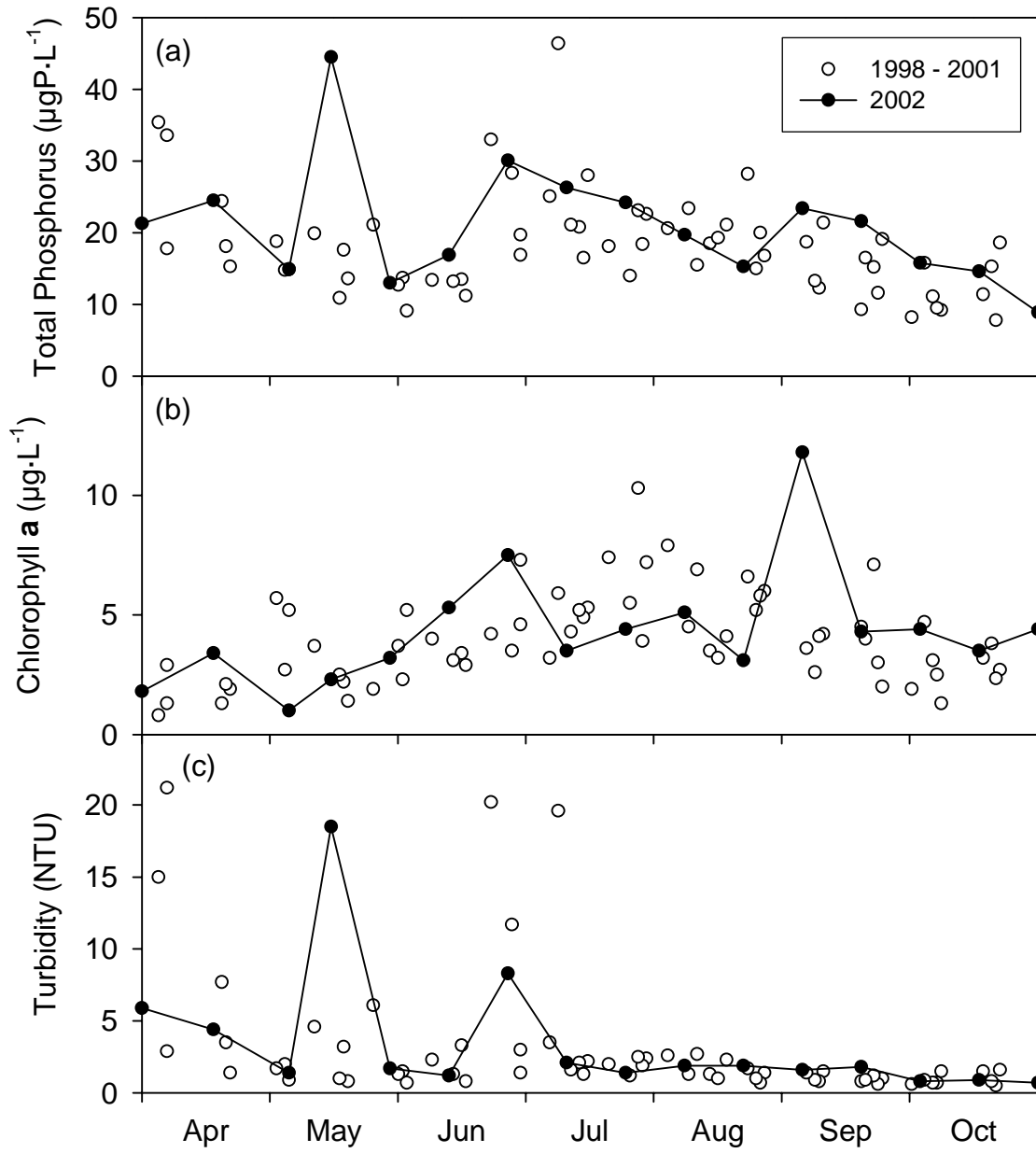


Figure 11. Comparison of 1998, 1999, 2000, 2001 and 2002 conditions for total phosphorus, chlorophyll a, and turbidity on the south shelf of Cayuga Lake for the April – October interval: (a) total phosphorus (TP), (b) chlorophyll a, and (c) turbidity (T_n).

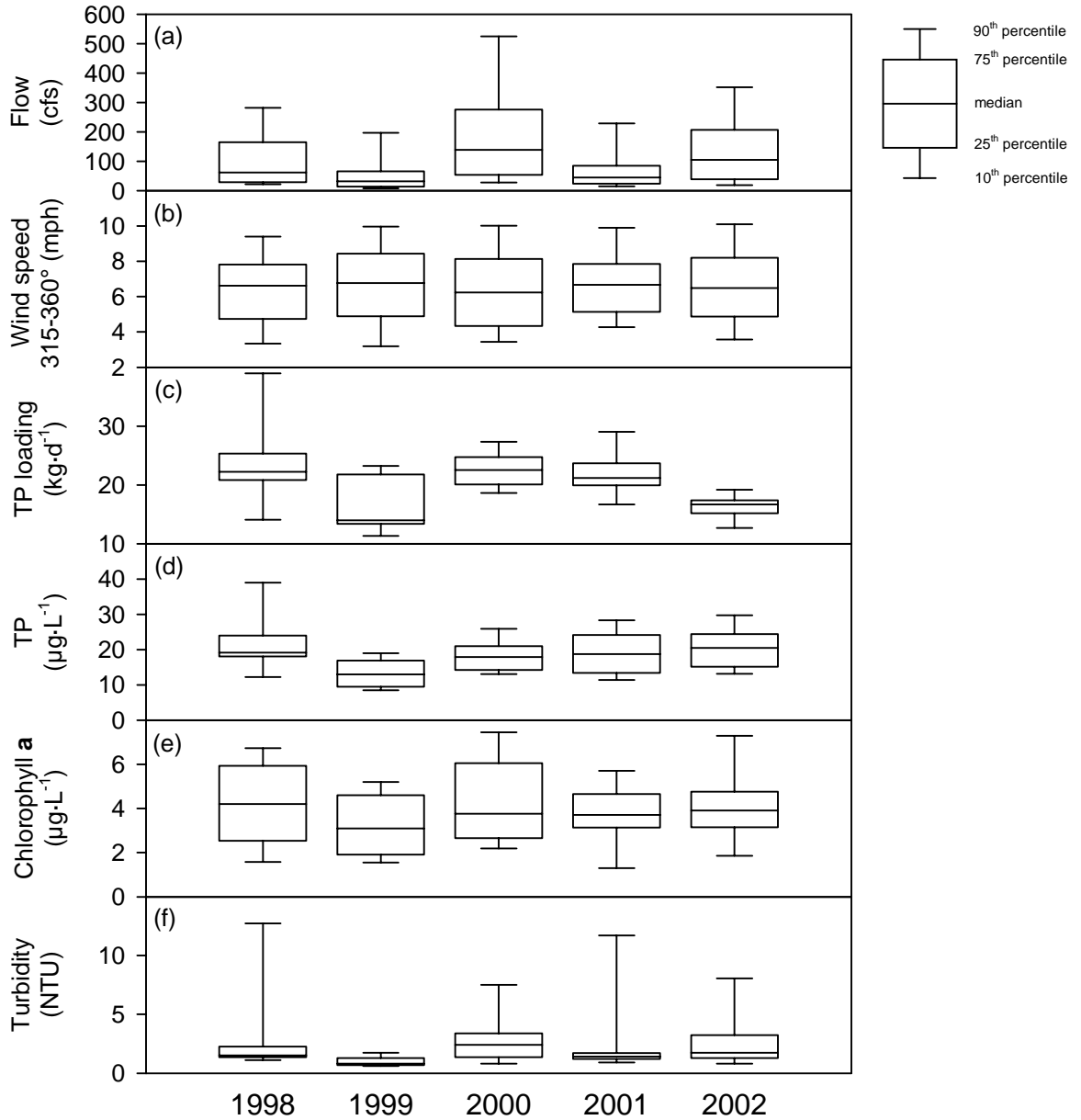


Figure 12. Comparison of study interval averages for runoff, wind, total phosphorus loading, total phosphorus concentration, chlorophyll **a** concentration and turbidity: (a) Fall Creek flow, (b) wind speed, (c) summed loads of total phosphorus (TP) from the Ithaca Area WWTP, Cayuga Heights WWTP and 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 2002 Data

1. site 2 was enriched in all three forms of phosphorus (TP, TDP, and SRP) and all three forms of nitrogen (TDN, NO_x, and T-NH₃) compared to the other monitored sites (Figure 2, Table 6).
2. site 7 had the highest average levels of chlorophyll **a** (Chl) and turbidity (T_n) and was enriched in all three forms of phosphorus (TP, TDP, and SRP) relative to other shelf sites (exclusive of site 2; Figure 2, 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 greater for the south shelf sites than for deep water sites (sites 6, 8 and LSC; Figure 2, Table 6).
6. clarity, as measured by Secchi disc transparency (SD) and turbidity (T_n), was low on the south shelf on May 16 and June 27, following major runoff events (Figure 2g-h).
7. chloride concentrations were spatially and temporally uniform compared to other parameters measured in the monitoring program (Table 6).
8. more than 60% of the phosphorus was in a particulate form [e.g., (TP-TDP)/TP] at all sites, on a monitored period average basis.
9. average concentrations of TP, TDP, SRP, and T-NH₃ were higher in the eastern portion (sites 1 and 7), compared to other sites (4 and 5) on the shelf (Table 6).
10. chlorophyll concentrations, on a monitoring period average basis, were relatively similar across the spatial bounds of sampling, though substantial spatial variability was observed on individual days (Figure 2i, Table 6).
11. temperatures were relatively uniform over the monitored bounds of the upper waters of the lake during the period of measurements (Figure 2j).
12. temperatures, measured hourly at the “pile cluster”, dropped precipitously on July 26 and 27, suggesting the occurrence of a seiche (Figure 2j).
13. turbidity (T_n) values and concentrations of soluble reactive phosphorus (SRP) were essentially equal in the LSC influent and effluent (Figure 2n-o).

14. total phosphorus (TP) concentrations in the LSC effluent were uniformly low except for the higher values on April 18 and April 24 (Figure 2m).
15. the concentration of total phosphorus (TP) in the LSC effluent was less than the concentration on the south shelf on most sampling days (Figure 2p); on average, the concentration was $8.3 \mu\text{g}\cdot\text{L}^{-1}$ lower (Table 8).
16. the concentration of soluble reactive phosphorus (SRP) was higher in the LSC effluent than on the shelf on most sampling days (Figure 2q), consistent with projections made in the **Draft Environmental Impact Statement** (Stearns and Wheler, 1997); on average, the concentration was $1.9 \mu\text{g}\cdot\text{L}^{-1}$ higher (Table 8).
17. turbidity (T_n) values were lower in the LSC effluent than on the shelf on most sampling days (Figure 2r); on average, turbidity was lower by 2.3 NTU (Table 8).
18. dissolved oxygen concentrations at site 3 were within 10 % of saturation (equilibrium with the atmosphere) over most of the study interval (Figure 2k). Notable exceptions were the slight super-saturation ($\sim 110\%$) in late July and under-saturation ($< 90\%$) in September and October.
19. beam attenuation coefficient (BAC) was high in the upper waters at the LSC site on April 18 and June 27 (Figure 3b,g). Substantial runoff events occurred immediately prior to the April 18 sampling and during the June 27 sampling (Figure 5a). Peaks in chlorophyll fluorescence were also observed in the upper waters of the LSC site on these dates (Figure 3b and g).
20. modest increases in beam attenuation coefficient (BAC) were observed near the bottom of the LSC site on several monitored dates, indicating the occurrence of small increases in turbidity with the approach to the bottom at this site (Figure 3).
21. chlorophyll fluorescence profiles indicate subsurface peaks in phytoplankton concentrations occurred at the LSC intake site during the stratification period of 2002 (Figure 3). These peaks usually occurred above, or at, the maximum temperature (i.e., density) gradient, at depths ≤ 20 meters.
22. Secchi disc transparency (SD) was observed to extend beyond the lake depth at multiple sites on several occasions during the 2002 study interval (Appendix 1).
23. the 2002 results continue to support turbidity (T_n) as an alternate measure of light penetration in shallow portions of the shelf (Figure 4).
24. phosphorus loading from the Ithaca Area WWTP was lower in 2002 than in the preceding four years (Table 7). Phosphorus loading from the Cayuga Heights WWTP was much lower in 2002 than in 1998 or 2001 (Table 7).

25. LSC contributed ~ 3.5% of the TP load to the shelf over the May – October interval of 2002, a smaller contribution than projected (4.8%) in the **Draft Environmental Impact Statement** (Stearns and Wheler 1997; Table 7).
26. the Fall Creek hydrograph for 2002 was characterized by a series of storms during May and June and a number of smaller storms during September and October (Figure 5a). Compared to long-term median values, Fall Creek flows were low during April and August and high during May, June and September (Figure 5a-b).
27. major wind events out of the north to northwest were not apparent during the study interval of 2002 (Figure 5c) and annual median wind speeds have been essentially equal over the 1998-2002 interval (Figure 12b).
28. the 2002 results continue to support the position that TP and T_n are systematically flawed indicators of trophic state on the shelf.
29. the 2002 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.
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, Chl and T_n on the shelf were similar for 1998, 2000, 2001 and 2002, and distinctly lower for 1999 (Figure 12d-f).
32. no conspicuous changes in water quality have been observed on the shelf since start-up of the LSC facility in July 2000 (Figure 2; Upstate Freshwater Institute 1999, 2000, 2001, 2002).

5. Summary

This report presents the design and salient findings of a water quality monitoring study conducted for Cayuga Lake in 2002, sponsored by Cornell University. This is the fifth annual report for a monitoring program that has been conducted annually since 1998. A number of noteworthy findings are reported here for 2002 that have value for lake management. Water quality on the south shelf can vary substantially from year to year. Potential sources of variation include interannual differences in runoff, loading from WWTPs, and wind. For example, in 1999, a very dry year, low flows in Fall Creek and low phosphorus loads from WWTPs were associated with the lowest levels of phosphorus, chlorophyll and clarity (high turbidity) measured on the south shelf during the 1998 – 2002 interval. The 2002 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. In fact, the most striking water quality signature of 2002 was the

May runoff event that caused high phosphorus concentrations and extremely low 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 generally lower, and SRP (soluble reactive phosphorus) concentrations were generally higher, in the LSC effluent than on the shelf. LSC contributed ~ 3.5% of the TP load to the shelf over the May – October interval of 2002, a smaller contribution than projected in the **Draft Environmental Impact Statement**. 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 ($\mu\text{gP}\cdot\text{L}^{-1}$)

Date:	4/1/02	4/18/02	5/6/02	5/16/02	5/30/02	6/13/02	6/27/02	7/11/02	7/25/02	8/8/02	8/22/02	9/5/02	9/19/02	10/3/02	10/17/02	10/31/02
Site:																
1	26.0	25.3	11.8	46.4	12.3	19.0	21.2	31.1	23.4	43.3	23.9	24.1	28.5	18.9	36.7	11.3
2	18.3	37.9	13.5	41.2	18.4	24.9	44.7	31.7	54.7	45.9	20.2	50.0	57.3	20.4	37.6	16.9
3	20.2	25.0	15.8	44.1	13.7	14.6	45.3	23.4	23.2	13.2	13.2	21.0	16.8	15.5	10.8	9.3
4	11.3	24.0	14.1	41.9	10.0	15.9	22.7	21.3	22.4	11.5	14.5	24.7	29.3	13.3	9.7	7.9
5	12.7	21.9	14.0	37.4	13.7	14.3	32.4	24.3	22.9	17.3	13.5	15.6	15.8	14.2	9.7	7.2
6	12.0	24.7	14.5	27.8	12.1	16.2	23.8	19.1	23.2	14.6	13.0	13.6	14.1	13.9	12.2	7.2
7	55.7	28.8	19.6	62.8	16.9	26.9	18.7	41.2	33.4	30.3	16.4	40.5	20.3	21.4	20.1	10.8
8	11.7	11.9	10.4	13.7	12.8	11.1	14.1	17.8	18.7	15.3	10.9	11.6	13.0	11.0	9.7	7.2
L SCT	12.0	21.6	12.3	12.4	12.1	12.6	13.1	18.1	19.4	16.6	13.2	11.2	12.3	12.6	6.8	6.5
L SCB	-	11.0	11.0	11.8	10.3	12.9	9.8	14.4	17.8	8.1	7.4	17.3	9.2	12.6	9.0	10.4
L SC3B	-	10.0	-	10.8	9.6	12.6	10.1	13.4	12.7	7.4	7.1	9.2	8.9	10.0	6.1	8.6

Total Dissolved Phosphorus ($\mu\text{gP}\cdot\text{L}^{-1}$)

Date:	4/1/02	4/18/02	5/6/02	5/16/02	5/30/02	6/13/02	6/27/02	7/11/02	7/25/02	8/8/02	8/22/02	9/5/02	9/19/02	10/3/02	10/17/02	10/31/02
Site:																
1	9.8	8.0	6.4	13.7	3.1	9.3	3.7	5.9	3.2	5.5	4.4	5.4	8.6	8.5	25.5	3.1
2	7.3	11.6	7.2	14.6	2.8	8.3	4.9	11.7	24.8	26.2	6.1	18.3	43.5	10.0	16.4	4.7
3	8.2	6.3	5.9	12.7	2.8	4.9	5.2	5.2	3.1	1.6	2.9	6.9	8.2	6.4	4.3	1.7
4	9.7	7.3	5.9	9.9	2.2	4.3	2.5	5.0	3.8	1.0	6.8	5.5	18.6	3.5	2.9	1.5
5	7.3	6.3	5.4	10.8	2.8	3.3	3.5	3.1	3.4	1.6	3.9	3.8	10.3	5.4	2.9	1.1
6	6.3	5.3	4.3	6.3	2.8	3.9	2.5	3.4	3.1	1.0	2.7	3.5	4.7	4.8	2.2	1.1
7	7.0	8.1	8.1	16.2	8.1	7.3	5.5	15.2	5.9	12.9	10.0	9.9	11.0	11.6	8.6	2.2
8	6.5	5.6	3.3	3.5	3.1	4.2	3.5	3.1	2.1	1.6	3.2	4.1	3.6	3.8	2.5	2.2
L SCT	7.0	8.1	3.9	3.2	2.8	4.6	3.2	3.1	2.4	1.6	2.6	3.5	3.7	3.8	2.2	1.5
L SCB	-	7.8	6.5	8.6	5.9	7.3	9.8	4.7	6.3	4.7	5.5	7.5	6.5	7.4	4.0	5.8
L SC3B	-	8.5	8.1	4.5	6.2	7.3	7.0	5.6	6.3	3.7	6.1	5.5	5.8	10.6	3.2	5.0

Soluble Reactive Phosphorus ($\mu\text{gP}\cdot\text{L}^{-1}$) values reported as 0.2 are $\frac{1}{2}$ the limit of detection ($0.3 \times 0.5 = 0.15$) rounded to one decimal place

Date:	4/1/02	4/18/02	5/6/02	5/16/02	5/30/02	6/13/02	6/27/02	7/11/02	7/25/02	8/8/02	8/22/02	9/5/02	9/19/02	10/3/02	10/17/02	10/31/02
Site:																
1	4.0	2.6	2.2	7.3	0.5	0.9	0.2	0.9	0.3	2.1	1.9	0.7	3.3	3.7	18.9	0.9
2	3.2	6.5	3.3	8.5	0.5	0.5	0.3	7.0	19.0	21.0	2.2	7.7	30.0	4.5	11.3	2.6
3	3.7	1.4	2.5	7.5	0.2	0.2	1.2	1.9	0.6	0.6	0.6	0.9	3.5	1.5	2.1	0.2
4	3.3	0.4	2.1	5.1	0.3	0.2	0.4	0.7	0.6	0.5	2.9	0.4	10.3	0.6	1.1	0.2
5	3.3	0.3	2.5	5.5	0.3	0.2	0.7	0.2	0.2	0.7	0.6	0.2	0.5	0.7	2.1	0.6
6	3.8	0.3	1.5	2.1	0.2	0.2	0.2	0.4	0.4	0.5	0.6	0.4	0.4	0.4	0.8	0.2
7	2.7	2.9	3.4	9.1	0.7	0.2	0.2	8.9	2.0	12.3	4.6	1.8	4.9	4.8	6.1	0.4
8	2.8	1.1	0.5	0.4	0.3	0.2	0.4	0.6	1.9	0.6	0.3	0.7	0.3	0.6	0.6	0.2
L SCT	3.6	0.3	1.0	0.4	0.5	0.2	0.2	0.2	0.2	0.8	0.5	0.7	0.4	0.4	0.6	0.2
L SCB	-	4.4	3.3	2.1	3.3	3.1	4.1	3.2	4.3	4.2	3.4	5.6	4.1	5.3	2.2	5.1

LSC3B	-	3.5	3.1	1.5	3.0	3.3	4.3	3.0	4.0	3.4	3.4	3.8	4.3	4.3	2.7	5.1
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Total Dissolved Nitrogen (mgN·L⁻¹)

Date:	4/1/02	4/18/02	5/6/02	5/16/02	5/30/02	6/13/02	6/27/02	7/11/02	7/25/02	8/8/02	8/22/02	9/5/02	9/19/02	10/3/02	10/17/02	10/31/02
Site:																
1	1.648	1.516	1.754	1.364	1.506	1.509	1.263	1.376	1.517	1.624	1.398	1.421	-	1.470	1.891	1.416
2	1.432	1.770	1.606	1.487	1.606	1.762	1.309	1.274	1.936	2.421	1.737	2.130	-	1.416	1.436	1.705
3	1.510	1.526	1.610	1.358	1.403	1.446	1.024	1.248	1.378	1.517	1.285	1.424	-	1.492	1.539	1.361
4	1.492	1.580	1.452	1.224	1.469	1.608	1.266	1.309	1.501	1.441	1.244	1.284	-	1.354	1.499	1.330
5	1.511	1.494	1.679	1.370	1.377	1.563	1.827	1.173	1.560	1.497	1.346	1.318	-	2.318	1.514	1.337
6	1.653	1.543	1.595	1.428	1.425	1.472	1.055	1.212	1.376	1.495	1.336	1.270	-	1.386	1.532	1.253
7	1.437	1.658	1.685	1.180	1.800	1.530	1.363	1.354	1.692	1.454	1.480	1.380	-	1.399	1.631	1.335
8	1.678	1.565	1.680	1.471	1.402	1.550	1.352	1.259	1.530	1.406	1.348	1.270	-	1.298	1.498	1.347
LSC T	1.582	1.636	1.511	1.481	1.405	1.361	1.318	1.229	1.380	1.391	1.262	1.270	-	1.348	1.523	1.409
LSC B	-	1.762	1.649	1.580	1.587	1.610	1.379	1.333	1.750	1.599	1.601	1.502	-	1.545	1.550	1.466
LSC3B	-	1.777	1.631	1.497	1.551	1.545	1.410	1.319	1.480	1.758	1.502	1.512	-	1.487	1.587	1.486

Nitrate + Nitrite Nitrogen (mgN·L⁻¹)

Date:	4/1/02	4/18/02	5/6/02	5/16/02	5/30/02	6/13/02	6/27/02	7/11/02	7/25/02	8/8/02	8/22/02	9/5/02	9/19/02	10/3/02	10/17/02	10/31/02
Site:																
1	1.142	1.045	1.315	0.886	1.111	1.109	1.025	1.182	1.056	0.972	0.874	0.996	-	0.946	1.212	1.226
2	1.099	0.937	1.327	1.165	1.165	1.246	1.000	1.016	1.176	1.546	1.099	1.283	-	0.941	1.009	1.468
3	1.114	0.903	1.343	1.042	1.019	1.079	0.979	1.117	1.048	0.982	0.849	1.005	-	0.979	1.115	1.209
4	1.212	1.099	1.312	0.816	1.074	1.041	0.908	1.054	1.052	0.890	0.731	0.931	-	1.016	1.104	1.210
5	1.197	1.191	1.411	0.980	1.116	1.056	0.959	1.085	1.066	0.902	0.862	-	-	0.989	1.103	1.233
6	1.175	1.079	1.340	1.093	1.055	1.001	0.813	1.058	1.010	0.688	0.865	0.770	-	0.866	1.067	1.185
7	0.943	1.068	1.334	0.738	1.078	1.000	0.962	1.059	1.225	0.760	0.938	0.933	-	0.994	1.121	1.242
8	1.219	1.355	1.464	1.253	1.038	1.061	0.986	1.109	1.125	0.767	0.881	0.911	-	0.947	1.079	1.269
LSC T	1.190	1.176	1.430	1.276	1.107	1.023	0.985	1.102	1.094	0.787	0.853	0.868	-	0.980	1.079	1.268
LSC B	-	1.289	1.571	1.309	1.137	1.094	1.047	1.289	1.386	1.053	1.305	1.175	-	-	1.194	1.403
LSC3B	-	1.302	1.504	1.299	1.171	1.078	1.064	1.270	1.318	1.000	1.221	1.162	-	-	1.163	1.438

Ammonia Nitrogen (mgN·L⁻¹) values reported as 0.005 are ½ the limit of detection (0.01*0.5 = 0.005)

Date:	4/1/02	4/18/02	5/6/02	5/16/02	5/30/02	6/13/02	6/27/02	7/11/02	7/25/02	8/8/02	8/22/02	9/5/02	9/19/02	10/3/02	10/17/02	10/31/02
Site:																
1	0.173	0.059	0.084	0.060	0.042	0.032	0.025	0.114	0.024	0.066	0.076	0.035	-	0.096	0.430	0.070
2	0.032	0.280	0.101	0.050	0.034	0.012	0.017	0.128	0.431	0.174	0.165	0.461	-	0.082	0.086	0.187
3	0.079	0.054	0.109	0.049	0.044	0.005	0.031	0.055	0.022	0.038	0.051	0.033	-	0.057	0.048	0.034
4	0.020	0.042	0.053	0.049	0.029	0.010	0.033	0.026	0.029	0.033	0.043	0.018	-	0.047	0.031	0.034
5	0.020	0.024	0.089	0.044	0.026	0.005	0.028	0.025	0.016	0.030	0.064	0.012	-	0.048	0.040	0.031
6	0.018	0.019	0.062	0.028	0.024	0.005	0.025	0.022	0.019	0.036	0.036	0.005	-	0.048	0.029	0.028
7	0.061	0.118	0.135	0.081	0.258	0.012	0.026	0.260	0.022	0.100	0.089	0.014	-	0.130	0.079	0.058
8	0.016	0.014	0.026	0.005	0.015	0.011	0.005	0.022	0.012	0.022	0.048	0.005	-	0.030	0.023	0.027
LSC T	0.016	0.018	0.055	0.005	0.015	0.005	0.005	0.021	0.019	0.029	0.051	0.005	-	0.045	0.023	0.024
LSC B	-	0.013	0.015	0.014	0.019	0.005	0.005	0.027	0.021	0.020	0.033	0.005	-	0.028	0.024	0.021

LSC3B	-	0.005	0.023	0.014	0.014	0.005	0.257	0.025	0.020	0.024	0.028	0.005	-	0.025	0.022	0.020
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Chlorophyll a ($\mu\text{g}\cdot\text{L}^{-1}$)

Date:	4/1/02	4/18/02	5/6/02	5/16/02	5/30/02	6/13/02	6/27/02	7/11/02	7/25/02	8/8/02	8/22/02	9/5/02	9/19/02	10/3/02	10/17/02	10/31/02
Site:																
1	1.8	2.5	0.8	2.7	3.3	5.0	6.2	4.9	4.8	8.1	3.7	9.2	8.6	2.5	2.9	3.7
2	0.9	3.8	0.8	2.3	3.1	6.2	8.6	2.3	7.4	2.7	3.5	16.7	4.1	3.3	4.7	3.9
3	1.0	2.5	1.1	2.3	2.3	4.5	8.2	1.4	3.4	3.3	4.2	7.1	2.7	3.3	3.1	6.0
4	0.6	3.9	0.8	1.8	2.8	4.1	7.2	2.5	3.2	3.9	1.9	14.0	3.1	4.8	4.5	3.6
5	1.0	4.1	1.3	2.7	4.3	4.4	8.5	5.5	4.8	8.0	3.5	5.1	5.1	6.3	3.4	4.1
6	1.2	5.3	1.2	3.5	4.5	4.5	9.1	4.9	5.5	6.9	5.8	5.1	6.9	6.5	4.6	5.9
7	7.8	3.3	1.2	1.9	3.3	11.0	5.8	4.4	7.8	2.6	1.7	32.9	4.1	3.9	3.4	4.0
8	1.2	1.9	1.8	3.3	6.5	2.9	6.8	3.7	5.0	6.8	5.4	4.5	6.0	5.2	3.7	5.3
L SCT	1.2	5.0	2.1	3.0	4.3	4.1	7.2	4.2	5.3	7.6	8.0	3.9	7.5	7.0	3.4	4.3
L SCB	-	0.2	0.2	0.7	0.4	0.2	0.2	0.2	0.2	0.5	0.2	0.5	0.2	0.6	0.9	0.2
L SC3B	-	0.2	0.2	0.9	0.4	0.2	0.2	0.2	0.2	0.5	0.4	0.4	0.4	0.6	0.9	0.2

Chloride ($\text{mg}\cdot\text{L}^{-1}$)

Date:	4/1/02	4/18/02	5/6/02	5/16/02	5/30/02	6/13/02	6/27/02	7/11/02	7/25/02	8/8/02	8/22/02	9/5/02	9/19/02	10/3/02	10/17/02	10/31/02
Site:																
1	37.2	41.4	45.0	34.4	41.7	41.8	41.3	47.2	45.2	44.9	44.1	45.7	44.0	43.3	46.1	43.7
2	38.5	36.0	43.6	34.8	38.3	42.3	41.2	46.5	46.2	45.2	45.7	46.0	46.7	41.3	43.8	43.7
3	37.2	40.1	44.1	30.0	42.7	41.8	38.5	44.2	44.8	43.8	43.0	43.2	44.7	43.3	43.9	43.7
4	24.8	41.4	43.1	32.9	42.2	44.7	44.0	46.5	47.2	43.3	42.1	42.7	41.7	43.3	43.4	43.7
5	39.4	41.1	43.8	31.9	41.1	46.2	42.5	46.5	44.3	43.3	43.9	42.7	44.7	43.3	43.9	43.7
6	35.6	43.7	45.1	35.9	41.7	46.2	45.5	45.5	45.2	44.8	42.4	43.7	44.7	43.3	44.4	44.4
7	28.8	38.0	46.6	29.0	43.7	43.8	43.0	44.1	46.2	44.8	46.6	45.7	44.7	43.3	44.4	42.7
8	34.6	41.1	44.6	42.6	43.2	47.4	44.0	44.6	43.8	43.8	43.9	44.6	43.4	45.3	49.3	43.7
L SCT	31.7	40.9	45.6	43.1	29.0	45.2	43.5	45.5	46.7	43.8	41.2	43.7	39.7	43.3	45.4	43.4
L SCB	-	44.2	45.6	42.6	45.1	46.6	48.0	47.5	50.2	46.7	43.9	42.7	43.7	44.3	48.4	42.7
L SC3B	-	40.1	46.6	43.1	42.7	44.7	47.0	47.5	48.2	46.7	42.1	42.2	44.7	44.3	44.4	43.7

Turbidity (NTU)

Date:	4/1/02	4/18/02	5/6/02	5/16/02	5/30/02	6/13/02	6/27/02	7/11/02	7/25/02	8/8/02	8/22/02	9/5/02	9/19/02	10/3/02	10/17/02	10/31/02
Site:																
1	6.2	4.4	1.3	21.5	1.8	1.5	3.7	2.7	1.4	3.9	4.6	2.5	4.9	1.1	1.0	0.7
2	4.5	5.8	1.2	14.2	2.4	2.0	10.2	3.3	4.8	1.8	1.6	3.3	1.5	0.9	4.3	0.7
3	5.0	4.9	1.2	14.9	2.2	1.1	15.8	2.1	1.8	1.6	2.0	1.2	1.0	0.7	0.7	0.7
4	2.9	3.9	1.0	17.9	1.1	1.5	4.1	1.2	1.1	0.9	0.9	1.8	1.3	0.6	0.5	0.6
5	3.3	3.8	1.1	15.4	1.8	1.2	10.3	1.8	1.3	2.3	1.9	0.9	1.8	0.8	0.9	0.7
6	2.9	3.7	1.2	8.1	1.7	1.2	4.9	1.2	1.4	1.7	2.5	0.8	1.2	0.7	0.6	0.5
7	18.2	5.6	3.5	30.2	1.3	0.7	2.6	3.7	1.7	1.5	0.7	2.2	1.2	1.1	1.6	0.9
8	3.2	1.2	0.7	3.4	1.7	0.9	1.9	1.4	1.1	1.5	2.4	0.9	1.1	0.7	0.7	0.4
L SCT	4.3	3.5	1.1	1.2	1.7	1.3	2.2	1.0	1.2	2.5	2.8	2.1	1.1	0.9	0.5	0.5
L SCB	-	0.6	1.2	1.8	2.0	2.1	2.9	2.0	2.2	2.1	1.6	1.3	1.1	1.7	1.3	1.2

LSC3B	-	0.9	1.2	1.5	1.4	1.8	1.8	1.3	1.6	2.1	1.3	1.1	1.1	2.0	0.7	0.9
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CaCO₃ Turbidity (NTU)

Date:	4/1/02	4/18/02	5/6/02	5/16/02	5/30/02	6/13/02	6/27/02	7/11/02	7/25/02	8/8/02	8/22/02	9/5/02	9/19/02	10/3/02	10/17/02	10/31/02
Site:																
1	0.6	1.0	0.3	3.3	0.3	0.3	1.0	0.4	0.3	0.8	1.9	0.7	1.4	0.4	0.2	0.2
2	0.7	1.4	0.6	2.5	0.6	0.4	2.3	0.7	0.9	0.4	0.5	0.9	0.2	0.1	1.3	0.1
3	0.5	0.7	0.4	1.1	0.4	0.2	3.2	0.4	0.5	0.4	1.1	0.1	0.0	0.1	0.2	0.1
4	0.3	0.7	0.4	1.7	0.1	0.5	1.2	0.2	0.2	0.1	0.3	1.1	0.2	0.0	0.1	0.2
5	0.2	0.4	0.1	2.3	0.3	0.3	2.0	0.5	0.2	0.7	1.0	0.3	0.2	0.2	0.2	0.3
6	0.2	1.0	0.1	1.1	0.2	0.3	1.1	0.2	0.3	0.8	1.5	0.1	0.2	0.0	0.2	0.0
7	2.7	2.6	1.5	1.2	0.3	0.1	0.5	0.8	0.1	0.2	0.3	0.7	0.3	0.3	0.7	0.4
8	0.1	0.3	0.1	2.3	0.3	0.1	0.2	0.4	0.3	0.3	1.7	0.2	0.2	0.2	0.4	0.0
L SCT	0.4	0.2	0.2	0.1	0.3	0.2	0.3	0.1	0.3	1.3	1.8	1.4	0.2	0.3	0.1	0.0
L SCB	0.0	0.1	0.2	0.5	0.8	0.5	1.0	0.3	1.0	0.7	0.7	0.3	0.3	0.8	0.3	0.5
L SC3B	0.0	0.3	0.4	0.3	0.5	0.4	0.5	0.5	0.6	0.8	0.5	0.4	0.3	1.2	0.2	0.3

Alkalinity (mg CaCO₃ · L⁻¹)

Date:	4/1/02	4/18/02	5/6/02	5/16/02	5/30/02	6/13/02	6/27/02	7/11/02	7/25/02	8/8/02	8/22/02	9/5/02	9/19/02	10/3/02	10/17/02	10/31/02
Site:																
1	97.4	103.8	108.2	96.7	108.5	107.9	109.9	111.1	105.4	103.8	99.0	103.8	103.5	104.8	118.7	107.9
2	100.1	105.9	108.3	97.7	113.7	109.3	110.4	118.0	121.9	103.5	97.7	105.4	103.5	104.5	125.4	110.3
3	100.3	104.5	108.3	95.8	112.2	106.4	113.7	105.8	104.5	101.6	96.7	104.5	102.5	104.5	107.4	106.1
4	105.4	109.3	107.4	96.2	106.4	106.4	110.8	102.5	103.9	102.5	94.3	103.5	104.5	101.6	106.4	105.4
5	104.5	104.9	110.6	97.7	108.3	107.4	110.3	107.4	104.9	104.1	97.7	104.5	104.0	104.0	106.4	104.5
6	106.9	103.0	109.3	101.4	107.4	107.4	113.2	105.9	105.4	102.5	97.5	102.5	102.5	103.5	106.4	104.5
7	94.8	104.9	109.3	93.8	109.8	110.3	109.3	124.8	107.9	104.5	96.7	104.8	103.0	105.4	108.3	108.3
8	106.4	107.4	106.9	107.4	106.4	104.9	107.9	106.4	104.9	104.5	97.2	103.5	103.2	101.6	105.4	103.5
L SCT	105.4	104.5	109.8	105.9	105.9	107.4	106.4	105.9	103.0	103.5	97.7	102.5	102.5	103.3	106.4	104.5
L SCB	-	106.4	108.3	107.4	107.4	105.4	106.4	104.5	104.5	110.3	106.4	114.1	113.7	110.3	110.3	111.2
L SC3B	-	106.4	107.9	106.4	107.4	107.4	106.4	104.5	105.4	109.3	106.4	113.2	112.2	111.2	109.3	111.2

Secchi Disc (m)

Date:	4/1/02	4/18/02	5/6/02	5/16/02	5/30/02	6/13/02	6/27/02	7/11/02	7/25/02	8/8/02	8/22/02	9/5/02	9/19/02	10/3/02	10/17/02	10/31/02
Site:																
1	1.2	1.6	3.3	0.3	2.7	3.0	1.3	2.1	3.0	2.5	2.1	4.0	3.1	3.5	bottom	bottom
2	1.9	1.5	bottom	0.4	2.0	2.3	0.3	1.9	1.2	2.9	bottom	bottom	bottom	3.0	2.5	bottom
3	-	1.6	3.2	0.4	2.2	3.2	0.3	2.6	3.0	bottom	2.8	3.5	bottom	bottom	bottom	bottom
4	bottom	1.8	bottom	0.4	bottom	3.1	0.8	bottom	bottom	bottom	bottom	bottom	3.3	bottom	bottom	bottom
5	2.9	1.6	4.1	0.5	2.4	3.0	0.3	2.6	2.7	2.8	3.0	3.9	3.2	3.7	bottom	bottom
6	4.9	1.6	4.0	0.8	2.6	3.1	0.8	3.9	3.2	2.8	2.0	4.0	3.6	4.0	7.0	7.5
7	0.6	1.8	2.9	0.3	bottom	2.1	1.8	1.7	2.5	bottom	bottom	bottom	bottom	bottom	bottom	bottom
8	-	6.2	6.0	4.0	2.8	5.0	2.6	4.0	4.4	2.8	2.4	4.0	4.0	5.0	6.8	7.0
L SCT	5.1	1.7	4.2	3.1	3.3	3.1	2.7	3.9	4.0	2.8	2.1	3.9	3.7	3.8	7.0	9.0
L SCB	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

LSC3B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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Temperature (°C) @ 2m

Date:	4/1/02	4/18/02	5/6/02	5/16/02	5/30/02	6/13/02	6/27/02	7/11/02	7/25/02	8/8/02	8/22/02	9/5/02	9/19/02	10/3/02	10/17/02	10/31/02
Site:																
1	7.92	11.77	8.74	9.97	11.27	17.28	18.29	22.22	23.89	23.31	21.98	21.41	19.38	18.17	12.95	10.31
2	-	11.95	8.05	8.42	8.95	17.67	17.04	22.00	23.50	22.56	24.05	21.73	20.13	18.20	11.01	9.16
3	6.41	11.09	9.52	10.09	8.69	16.76	17.11	22.19	23.71	23.31	23.84	21.45	19.87	18.10	13.55	9.21
4	5.83	12.15	9.60	7.86	8.78	16.81	16.80	22.33	24.02	23.72	23.97	20.71	20.34	18.13	13.80	10.92
5	5.62	11.71	8.53	8.29	10.24	16.15	16.64	22.47	24.17	24.15	23.87	21.41	19.57	18.20	13.91	12.30
6	4.98	11.30	8.27	8.90	10.65	16.00	16.56	22.51	24.10	24.19	23.86	21.87	19.62	18.23	13.88	12.36
7	8.20	11.75	9.32	10.36	9.16	18.14	17.35	22.38	23.43	22.45	23.77	21.87	19.33	18.50	12.56	9.74
8	-	7.35	7.18	7.71	12.96	15.53	19.21	22.02	23.82	23.80	23.60	21.89	19.72	18.37	14.70	12.46
L SCT	4.93	11.88	8.02	7.73	10.70	15.72	18.77	22.51	23.79	24.24	23.78	21.78	19.65	18.18	14.01	12.34

Dissolved Oxygen (mg·L⁻¹) Site 3

Date:	4/1/02	4/18/02	5/6/02	5/16/02	5/30/02	6/13/02	6/27/02	7/11/02	7/25/02	8/8/02	8/22/02	9/5/02	9/19/02	10/3/02	10/17/02	10/31/02
Depth:																
0	-	10.7	11.2	10.6	10.2	9.7	8.5	8.7	9.4	8.6	9.1	9.0	-	8.5	9.0	9.8
1	-	10.5	11.2	10.6	10.5	9.6	8.5	8.6	9.4	8.6	9.1	9.0	-	8.5	8.9	9.8
2	11.7	11.2	11.3	10.6	10.7	9.1	11.1	8.5	9.6	8.6	9.0	9.0	8.2	8.5	8.9	10.0
3	-	10.6	11.4	11.3	10.8	9.6	10.7	8.5	9.6	8.5	9.0	7.7	-	8.5	8.3	10.4
4	-	11.1	11.6	11.4	10.8	8.8	7.3	8.5	-	8.5	9.0	7.1	-	8.0	8.3	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

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Lake Source Cooling Discharge Monitoring Report Data

DMR Notes:

^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 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.