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# Cayuga Lake Water Quality Monitoring, Related to the LSC Facility: 2001

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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 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.

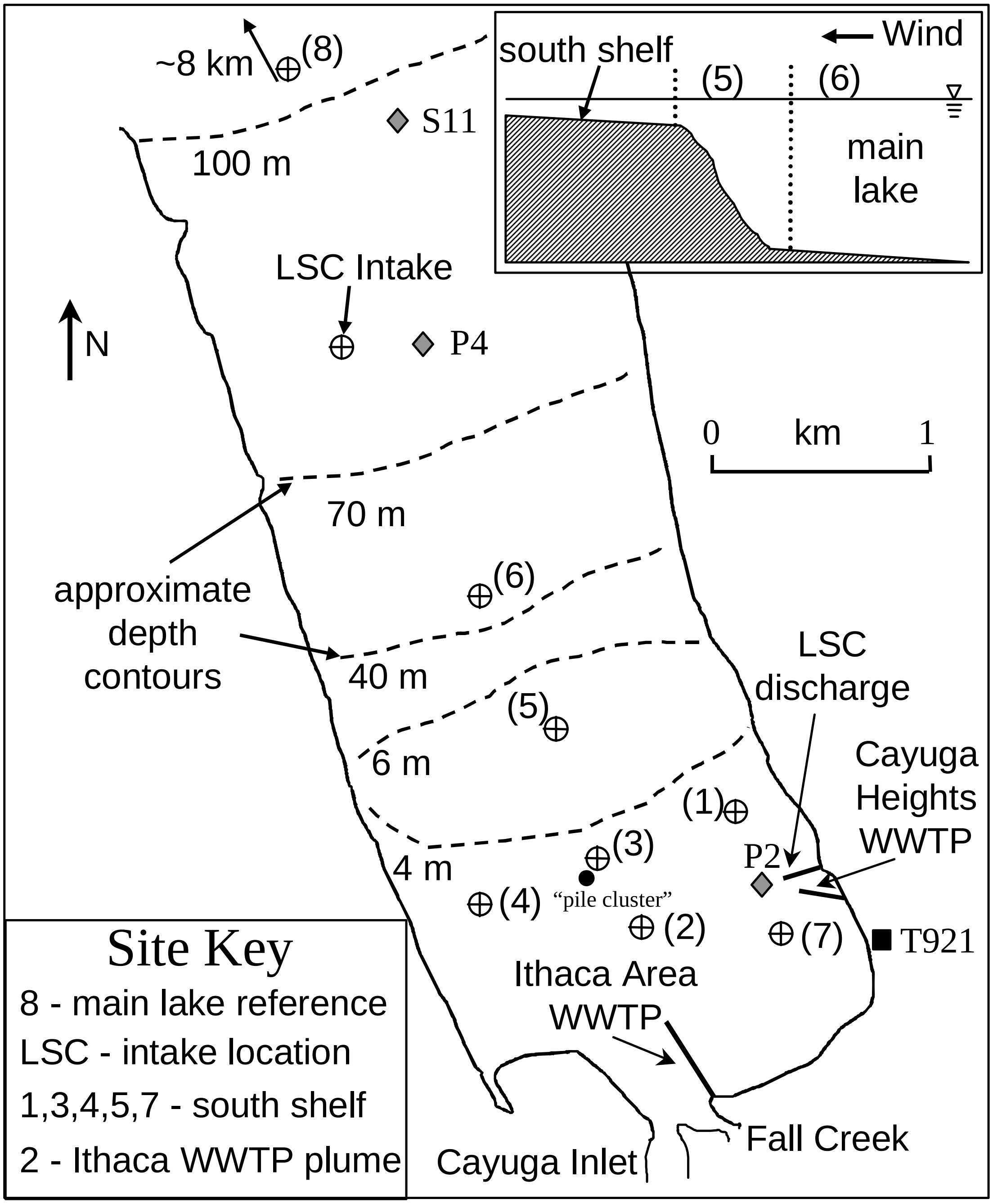

Figure 1a. Sampling sites, setting, approximate bathymetry, for LSC monitoring program, southern end of Cayuga Lake. Sites sampled during 1994 – 1996 study (P2, P4 and S11; Stearns and Wheler 1997) are included for reference.

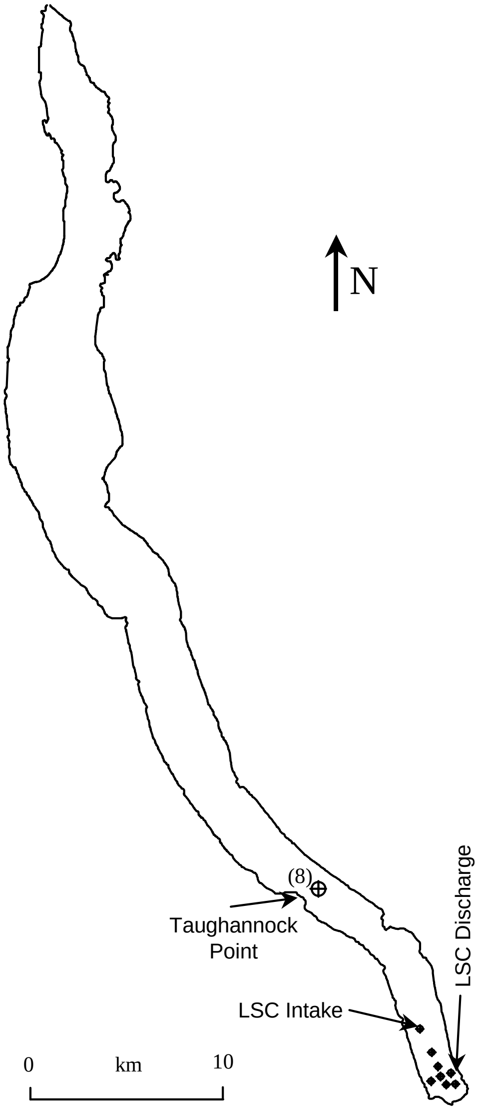

Figure 1b. Sampling sites for LSC monitoring program, within the context of the entire Cayuga Lake basin.

### *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 ($T\text{-}NH_3$), 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 $T\text{-}NH_3$ and $NO_x$ is an estimate of the concentration of dissolved organic N (DON). Biochemical processes can cause the conversion of DON to $T\text{-}NH_3$, and $T\text{-}NH_3$ 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 2001, beginning in April and extending to the end of 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 in November (2001) were retrieved in April (2002). Measurements were 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). An eighth (site 8) point was located further north as a reference for the main lake conditions. 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 intake location for the LSC facility was also sampled. 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 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 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<br>Scalar<br>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 (except for coliforms) 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). Samples (3) for coliform analysis were grab-type; collected from the surface at sites 1 and 7, and near-bottom at the LSC intake (Figure 1a). 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”. 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 $\mu g \cdot L^{-1}$ |
| 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) | - |
| total dissolved nitrogen | | Ebina et al. 1983 | 0.01 $mg \cdot L^{-1}$ |
| ammonia nitrogen | 350.1 | USEPA (1983) | 0.01 $mg \cdot L^{-1}$ |
| nitrate and nitrite nitrogen | 353.2 | USEPA (1983) | 0.01 $mg \cdot L^{-1}$ |
| chlorophyll **a** | | Parsons et al. (1984) | 0.4 $\mu g \cdot L^{-1}$ |
| chloride | 4500-$CL^-$ | APHA (1992) | 0.05 $mg \cdot L^{-1}$ |
| fecal coliform | 9222-D | APHA (1992) | - |

### *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 2001 program (Table 5). The greatest variability was associated with the total phosphorus 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 | a | 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 |
| fecal coliform | c | d | 3 | 5 |

**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
d - none sample kept at < 4° C, and in the dark

container:
1 - 250 ml acid washed borosilicate boston round
2 - 4L polypropylene container
3 - sterilized, glass or plastic

holding time:
1 - 28 days
2 - 24 hours
3. - 200 days
4 - unpreserved 48 hours, preserved 28 days
5 - 30 hours

**Table 5:** Precision for triplicate sampling/measurement program for key parameters for 2001, represented by the average coefficient of variation.

| Parameter | Site 1 | Rotating Site* |
|---|---|---|
| total phosphorus | 0.13 | 0.13 |
| chlorophyll **a** | 0.10 | 0.10 |
| nitrate plus nitrite | 0.04 | 0.02 |
| Secchi disc | < 0.01 | < 0.01 |

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

## 3. Results, 2001

The measurements made in the 2001 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). Additionally, the individual observations for coliforms are presented (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 < 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 LSC on each of 12 monitoring dates in 2001 are also presented (Figure 3).

On several occasions during each of the last four study years (1998 – 2001), concentrations of forms of phosphorus (TP, TDP, and SRP) and nitrogen (TDN and T-$NH_3$) were much higher at site 2 than at any other location (Table 6, Figure 2), consistent with the proximity to the Ithaca Area WWTP discharge (Figure 1a) enriched in these components. 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. Occurrences of high TDP and

$T\text{-}NH_3$ concentrations on the shelf are summarized in Table 7 for observations made during the 1998 – 2001 interval. Concentrations of TDP greater than 10 µg·$L^{-1}$ have been much more common for site 2 than for any other site sampled on the shelf. Concentrations of TDP between 10 and 20 µg·$L^{-1}$ occurred rarely at sites 1 and 7, which bracket the Cayuga Heights WWTP discharge and at site 3, located just northwest of site 2 (Table 7, Figure 1a). Concentrations of TDP greater than 20 µg·$L^{-1}$ have been observed 14 times for site 2 and never at the other sites on the shelf. The frequency and spatial distribution of high concentrations on the shelf is very similar for TDP and $T\text{-}NH_3$ (Table 7, Figure 2, see also Upstate Freshwater Institute 1999, 2000, 2001). Extremely high concentrations of TDP (> 20 µg·$L^{-1}$) and $T\text{-}NH_3$ (> 200 µg·$L^{-1}$) have not been observed for sites 4 and 5 (Table 7). Distributions of the ratios of paired concentrations for site 2 and the shelf are presented in Figure 4 for TDP and $T\text{-}NH_3$. Concentrations of TDP at site 2 were at least twice as large as TDP concentrations for the shelf for nearly 50 % of the paired samples and more than 5 times larger than TDP concentrations for the shelf for about 20 % of the paired samples (Figure 4a). Concentrations of $T\text{-}NH_3$ at site 2 were at least twice as large as $T\text{-}NH_3$ concentrations for the shelf for about 55 % of the paired samples and more than 5 times larger than $T\text{-}NH_3$ concentrations for the shelf for about 30 % of the paired samples (Figure 4b). Much higher ratios ( > 10) have been observed irregularly for both TDP and $T\text{-}NH_3$ during the 1998 – 2001 interval (Figure 4).

**Table 6**: Summary of results of monitoring program according to site, 2001.

**TP** ($\mu gP\cdot L^{-1}$)

| **SITE** | MEAN | **CV** | **RANGE** |
|---|---|---|---|
| **1** | 21.7 | 0.38 | 11.1 – 35.8 |
| **2** | 36.2 | 0.66 | 8.2 – 83.5 |
| **3** | 21.2 | 0.45 | 8.8 – 39.6 |
| **4** | 14.7 | 0.45 | 6.4 – 29.8 |
| **5** | 17.4 | 0.49 | 9.1 – 45.4 |
| **6** | 15.4 | 0.47 | 8.5 – 35.5 |
| **7** | 25.6 | 0.33 | 11.1 – 39.8 |
| **8** | 13.1 | 0.27 | 7.7 – 19.1 |
| **LSC** | 12.9 | 0.35 | 8.4 – 21.2 |

**TDN** ($mgN\cdot L^{-1}$)

| **SITE** | MEAN | **CV** | **RANGE** |
|---|---|---|---|
| **1** | 1.44 | 0.10 | 1.22 – 1.80 |
| **2** | 1.82 | 0.40 | 1.19 – 3.77 |
| **3** | 1.50 | 0.13 | 1.23 – 1.83 |
| **4** | 1.40 | 0.11 | 1.20 – 1.77 |
| **5** | 1.43 | 0.11 | 1.19 – 1.72 |
| **6** | 1.40 | 0.10 | 1.18 – 1.69 |
| **7** | 1.40 | 0.13 | 1.15 – 1.88 |
| **8** | 1.38 | 0.09 | 1.20 – 1.59 |
| **LSC** | 1.42 | 0.13 | 1.16 – 1.90 |

**TDP** ($\mu gP\cdot L^{-1}$)

| **SITE** | MEAN | **CV** | **RANGE** |
|---|---|---|---|
| **1** | 5.8 | 0.50 | 1.8 – 9.9 |
| **2** | 14.6 | 1.04 | 0.7 – 53.8 |
| **3** | 6.2 | 0.77 | 0.3 – 16.7 |
| **4** | 5.1 | 0.56 | 0.7 – 9.8 |
| **5** | 4.9 | 0.67 | 1.1 – 13.6 |
| **6** | 3.7 | 0.54 | 0.7 – 7.6 |
| **7** | 6.9 | 0.47 | 1.3 – 12.5 |
| **8** | 4.0 | 0.48 | 1.3 – 9.0 |
| **LSC** | 3.6 | 0.45 | 1.4 – 7.1 |

**$NO_X$** ($mgN\cdot L^{-1}$)

| **SITE** | MEAN | **CV** | **RANGE** |
|---|---|---|---|
| **1** | 1.05 | 0.11 | 0.83 – 1.20 |
| **2** | 1.35 | 0.43 | 1.00 – 3.12 |
| **3** | 1.12 | 0.07 | 0.96 – 1.25 |
| **4** | 1.03 | 0.10 | 0.85 – 1.21 |
| **5** | 1.03 | 0.10 | 0.82 – 1.20 |
| **6** | 0.98 | 0.11 | 0.74 – 1.12 |
| **7** | 1.00 | 0.14 | 0.76 – 1.24 |
| **8** | 1.02 | 0.12 | 0.83 – 1.18 |
| **LSC** | 1.02 | 0.10 | 0.85 – 1.15 |

**SRP** ($\mu gP\cdot L^{-1}$)

| **SITE** | MEAN | **CV** | **RANGE** |
|---|---|---|---|
| **1** | 2.1 | 1.02 | 0.2 – 7.0 |
| **2** | 9.8 | 1.35 | 0.2 – 46.8 |
| **3** | 2.3 | 1.58 | 0.2 – 12.2 |
| **4** | 1.6 | 1.23 | 0.2 – 6.5 |
| **5** | 1.5 | 1.83 | 0.2 – 10.4 |
| **6** | 1.0 | 1.59 | 0.2 – 5.6 |
| **7** | 2.3 | 0.98 | 0.2 – 7.7 |
| **8** | 0.8 | 1.66 | 0.2 – 4.5 |
| **LSC** | 0.8 | 1.72 | 0.2 – 4.3 |

**T-$NH_3$** ($mgN\cdot L^{-1}$)

| **SITE** | MEAN | **CV** | **RANGE** |
|---|---|---|---|
| **1** | 0.040 | 0.83 | 0.005 – 0.104 |
| **2** | 0.171 | 1.49 | 0.005 – 0.813 |
| **3** | 0.053 | 1.43 | 0.005 – 0.267 |
| **4** | 0.027 | 1.00 | 0.005 – 0.093 |
| **5** | 0.024 | 1.07 | 0.005 – 0.092 |
| **6** | 0.017 | 0.64 | 0.005 – 0.035 |
| **7** | 0.055 | 0.68 | 0.005 – 0.131 |
| **8** | 0.011 | 0.77 | 0.005 – 0.027 |
| **LSC** | 0.011 | 0.70 | 0.005 – 0.026 |

**Table 6 (cont.)**: Summary of results of monitoring program according to site, 2001.

| **CHL a** (µg·L$^{-1}$) | | | |
|---|---|---|---|
| **SITE** | MEAN | **CV** | **RANGE** |
| **1** | 4.2 | 0.58 | 0.9 – 11.1 |
| **2** | 4.8 | 0.75 | 0.6 – 15.6 |
| **3** | 3.9 | 0.67 | 0.7 – 12.0 |
| **4** | 2.8 | 0.56 | 0.2 – 5.6 |
| **5** | 3.9 | 0.41 | 0.7 – 7.3 |
| **6** | 4.3 | 0.49 | 0.6 – 8.0 |
| **7** | 5.3 | 0.69 | 0.7 – 13.5 |
| **8** | 4.3 | 0.48 | 0.7 – 7.9 |
| **LSC** | 3.9 | 0.57 | 0.4 – 8.2 |

| **Temperature** (°C) @ 2m | | | |
|---|---|---|---|
| **SITE** | MEAN | **CV** | **RANGE** |
| **1** | 14.3 | 0.45 | 3.4 – 23.5 |
| **2** | 15.4 | 0.44 | 4.4 – 23.6 |
| **3** | 14.4 | 0.43 | 4.8 – 23.5 |
| **4** | 14.6 | 0.45 | 4.5 – 23.5 |
| **5** | 14.5 | 0.43 | 4.7 – 23.7 |
| **6** | 14.7 | 0.42 | 3.5 – 23.7 |
| **7** | 14.7 | 0.46 | 3.3 – 23.5 |
| **8** | 14.7 | 0.48 | 2.7 – 25.4 |
| **LSC** | 14.6 | 0.47 | 2.9 – 24.1 |

| **Cl** (mg·L$^{-1}$) | | | |
|---|---|---|---|
| **SITE** | MEAN | **CV** | **RANGE** |
| **1** | 41.5 | 0.06 | 35.7 – 43.8 |
| **2** | 44.2 | 0.12 | 34.6 – 56.0 |
| **3** | 41.7 | 0.07 | 33.3 – 46.7 |
| **4** | 41.8 | 0.06 | 36.1 – 45.3 |
| **5** | 42.1 | 0.05 | 39.6 – 47.2 |
| **6** | 41.4 | 0.07 | 32.2 – 45.3 |
| **7** | 42.7 | 0.05 | 36.1 – 45.3 |
| **8** | 42.3 | 0.05 | 36.5 – 45.6 |
| **LSC** | 41.9 | 0.04 | 38.5 – 44.8 |

| **Beam Attenuation Coeff.** (m$^{-1}$) | | | |
|---|---|---|---|
| **SITE** | MEAN | **CV** | **RANGE** |
| **1** | 2.45 | 0.74 | 0.69 – 6.49 |
| **2** | 2.96 | 0.92 | 0.67 – 9.00 |
| **3** | 2.21 | 0.93 | 0.70 – 8.08 |
| **4** | 1.78 | 0.94 | 0.51 – 6.28 |
| **5** | 2.85 | 1.71 | 0.82 – 20.89 |
| **6** | 1.75 | 0.77 | 0.90 – 5.80 |
| **7** | 2.93 | 0.74 | 1.01 – 8.33 |
| **8** | 1.13 | 0.40 | 0.75 – 2.51 |
| **LSC** | 1.40 | 0.49 | 0.77 – 3.41 |

| **$T_n$** (NTU) | | | |
|---|---|---|---|
| **SITE** | MEAN | **CV** | **RANGE** |
| **1** | 3.2 | 1.11 | 0.8 – 14.0 |
| **2** | 3.6 | 1.31 | 0.9 – 15.5 |
| **3** | 3.3 | 1.36 | 0.6 – 14.7 |
| **4** | 2.4 | 1.34 | 0.3 – 11.2 |
| **5** | 3.6 | 1.87 | 0.6 – 26.7 |
| **6** | 2.0 | 1.23 | 0.6 – 9.7 |
| **7** | 3.8 | 1.14 | 0.8 – 15.0 |
| **8** | 1.3 | 0.70 | 0.6 – 3.7 |
| **LSC** | 1.5 | 0.93 | 0.5 – 5.9 |

| **$K_s$ Attenuation Coeff.** (m$^{-1}$) | | | |
|---|---|---|---|
| **SITE** | MEAN | **CV** | **RANGE** |
| **1** | - | - | - |
| **2** | - | - | - |
| **3** | - | - | - |
| **4** | - | - | - |
| **5** | - | - | - |
| **6** | 0.44 | 0.53 | 0.19 – 1.11 |
| **7** | - | - | - |
| **8** | 0.38 | 0.24 | 0.29 – 0.63 |
| **LSC** | 0.37 | 0.32 | 0.21 – 0.65 |

**Table 6 (cont.)**: Coliform results, 2001.

| Date<br>2001 | Fecal Coliform Concentrations (cfu·100 ml$^{-1}$)*<br>Site 1 | <br>Site 7 | <br>LSC, bottom |
|---|---|---|---|
| April 5 | 8 | < 2 | 6 |
| April 19 | < 2 | < 2 | - |
| May 3 | 12 | 4 | < 4 |
| May 17 | 2 | 2 | - |
| May 31 | 2 | 12 | 2 |
| June 14 | < 2 | < 2 | < 2 |
| June 28 | 20 | 100 | < 4 |

* cfu·100 ml$^{-1}$ – colony forming units per 100 ml

Fecal coliform standard for bathing beaches (Chapter I. State Sanitary Code, Part 6, Subpart 6-2, bathing beaches (1988):

> “The fecal coliform density from the five successive sets of samples collected daily on five different days shall not exceed a logarithmic mean of 200 per ml. When fecal coliform density of any sample exceeds 1,000 per 100 ml, consideration shall be given to closing the beach and daily samples shall immediately be collected and analyzed for fecal coliform for at least two consecutive days”

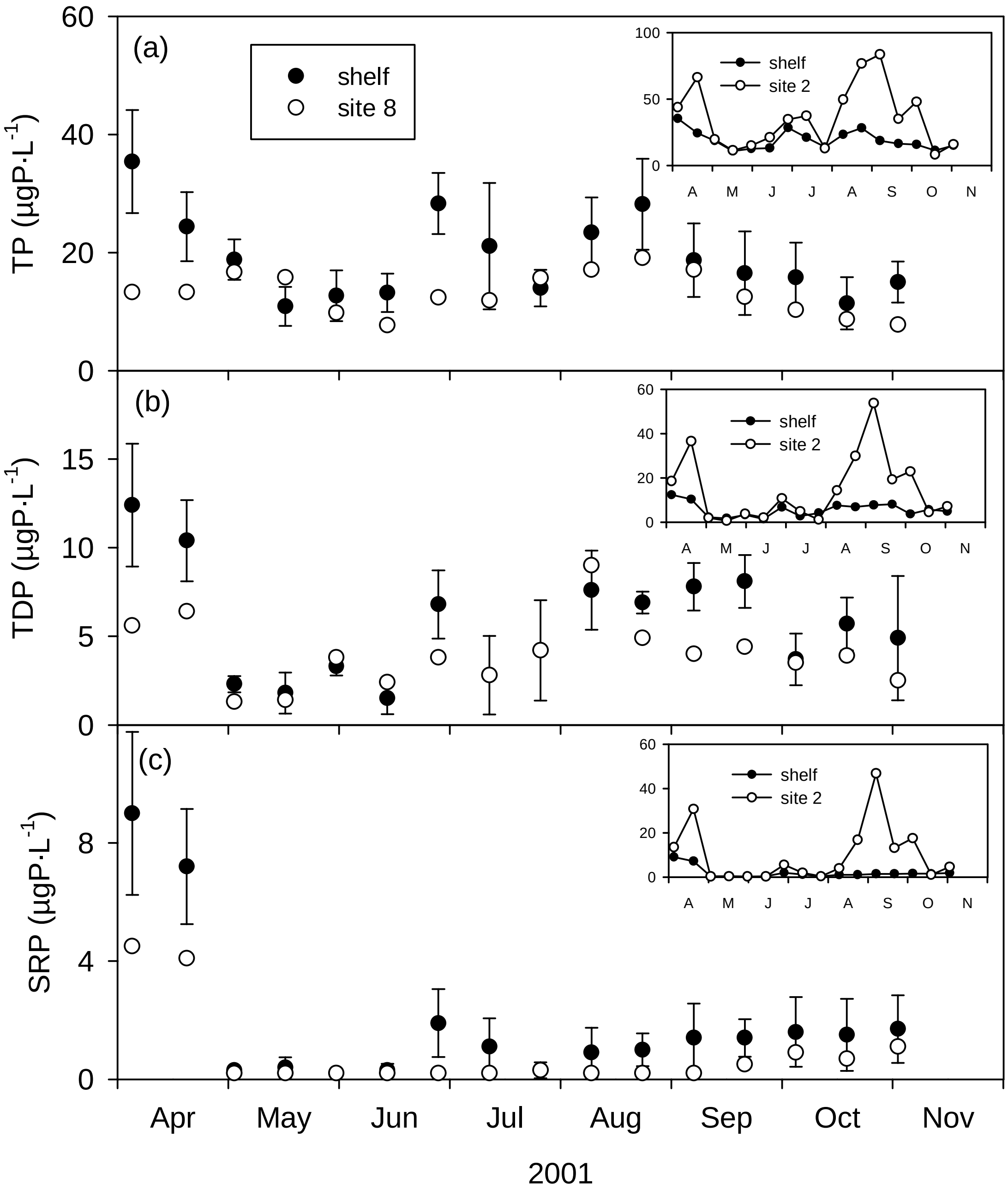

Figure 2a-c. Time-series of parameter values for Cayuga Lake for 2001: (a) TP, (b) TDP, and (c) SRP. Insets present results for site 2. Results for the “shelf” are averages; the dimensions of the bars are ± 1 standard deviation.

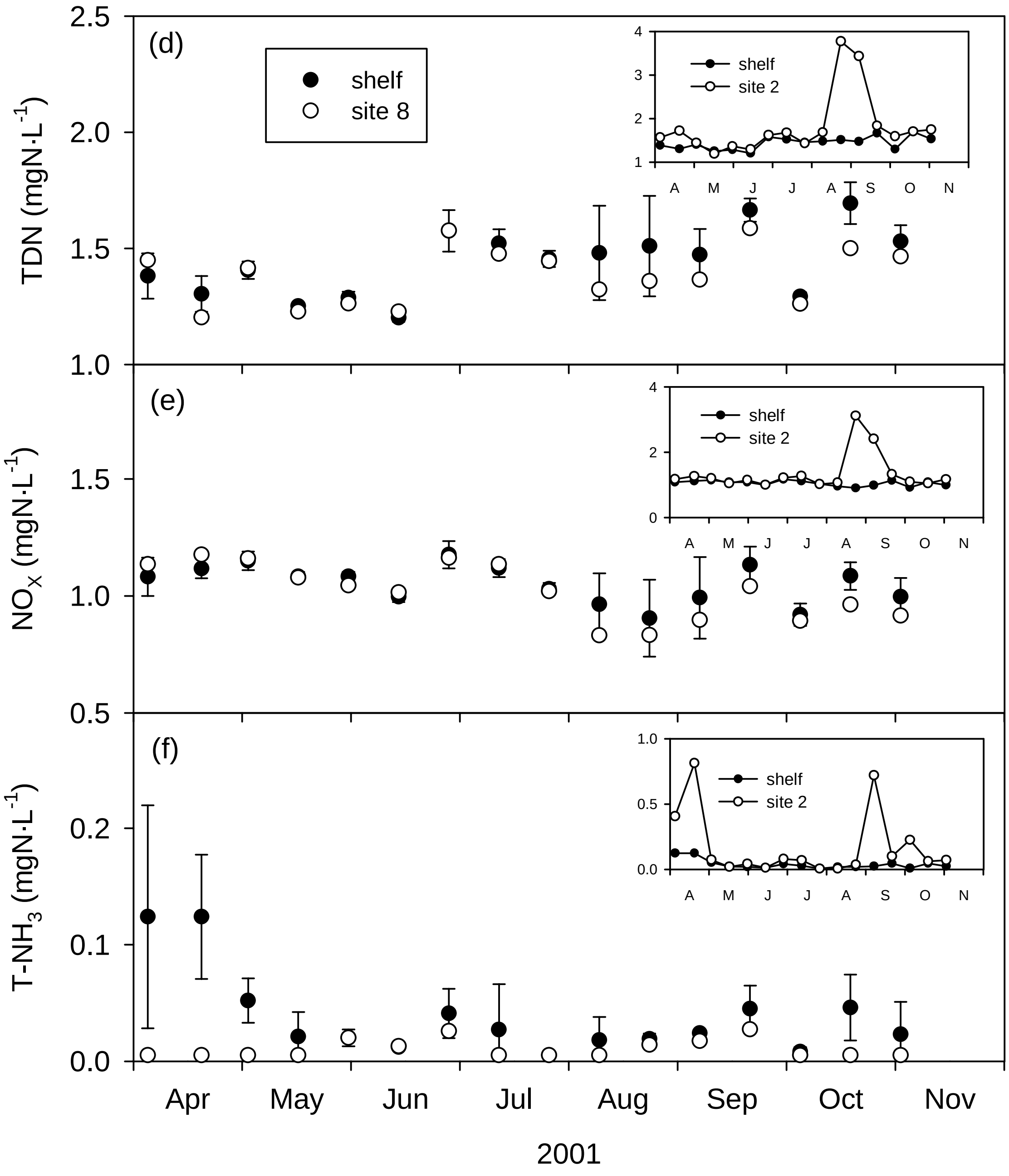

Figure 2d-f. Time-series of parameter values for Cayuga Lake for 2001: (d) TDN, (e) $NO_X$, and (f) T-$NH_3$. Insets present results for site 2. Results for the "shelf" are averages; the dimensions of the bars are ± 1 standard deviation.

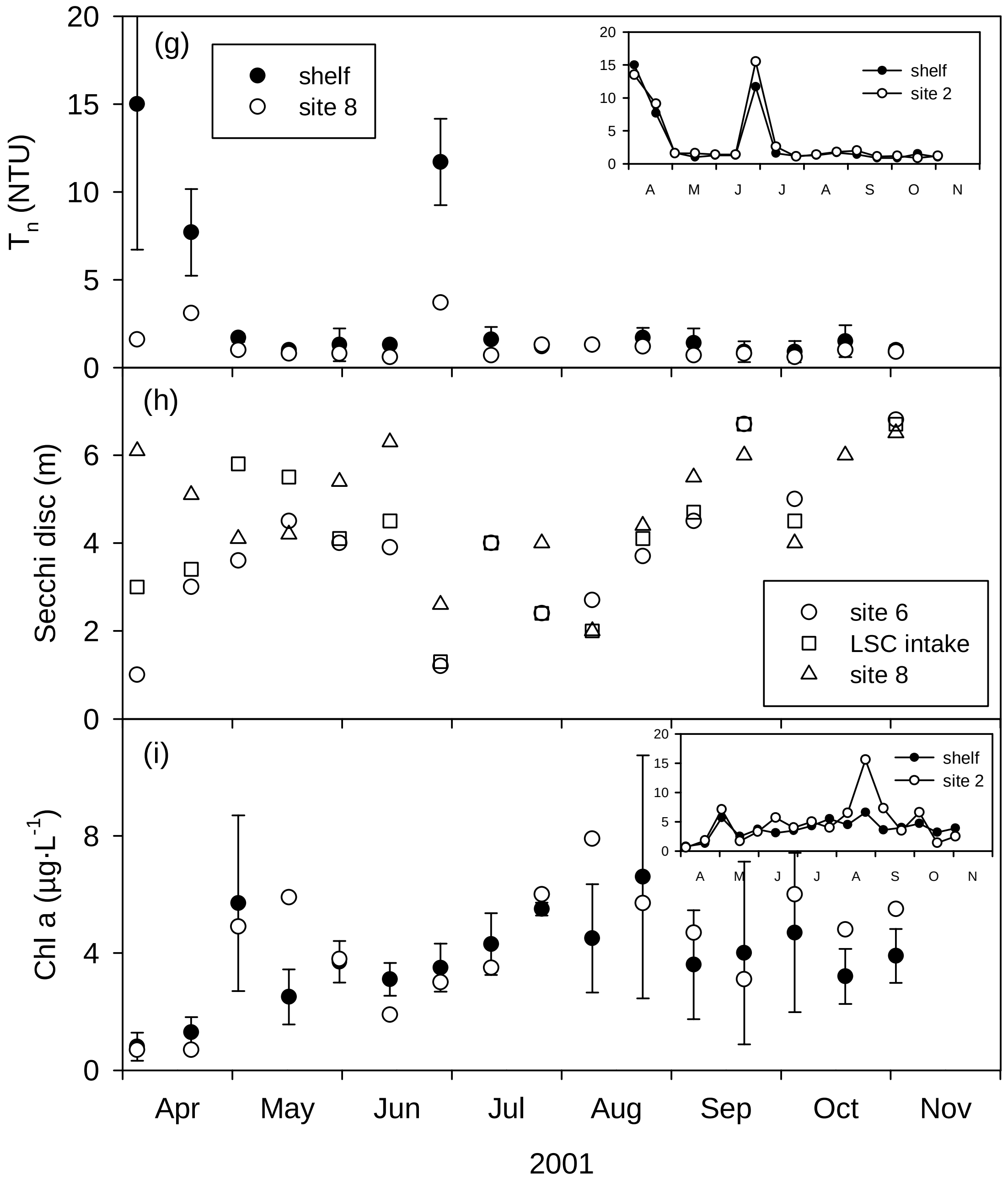

Figure 2g-i. Time-series of parameter values for Cayuga Lake for 2001: (g) $T_n$, (h) Secchi disc, and (i) Chl a. Insets present results for site 2. Results for the “shelf” are averages; the dimensions of the error bars are ± 1 standard deviation.

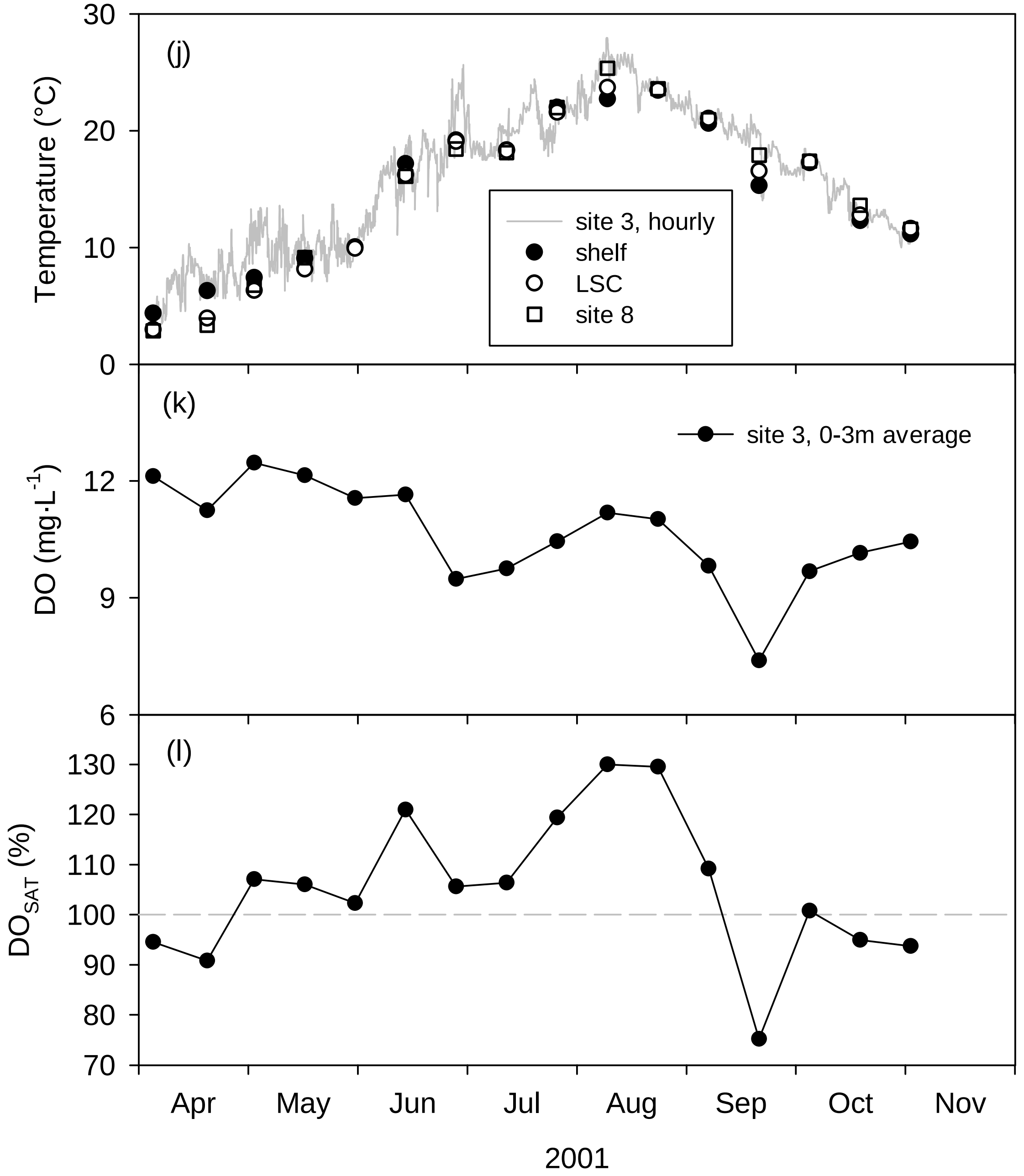

Figure 2j-l. Time-series of parameter values for Cayuga Lake for 2001: (j) temperature, (k) DO, and (l) $DO_{SAT}$.

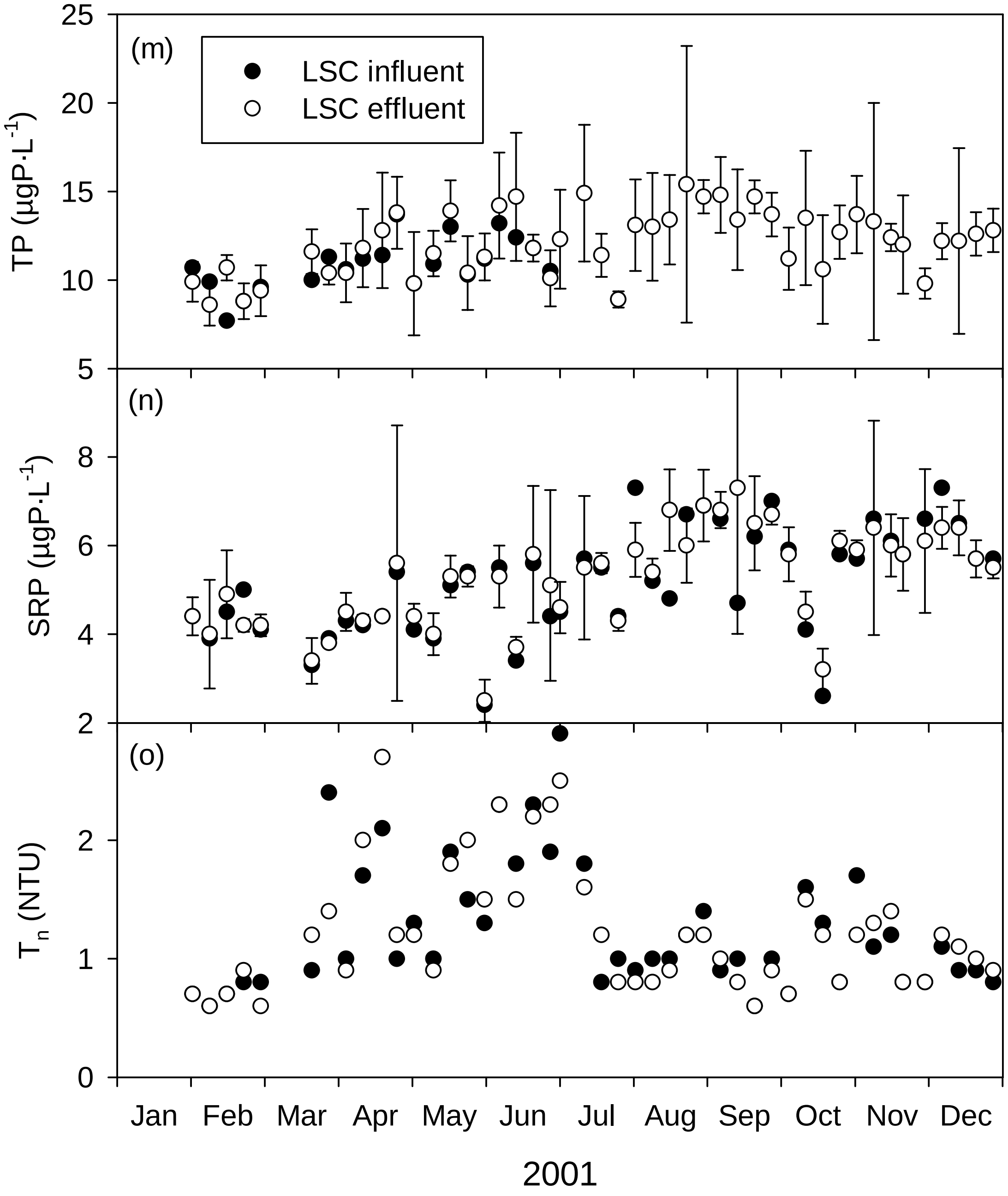

Figure 2m-o. Time series of parameter values for the LSC influent and effluent for 2001: (m) TP, (n) SRP, and (o) $T_n$. Error bars represent 95 % confidence intervals determined from analyses of field triplicates.

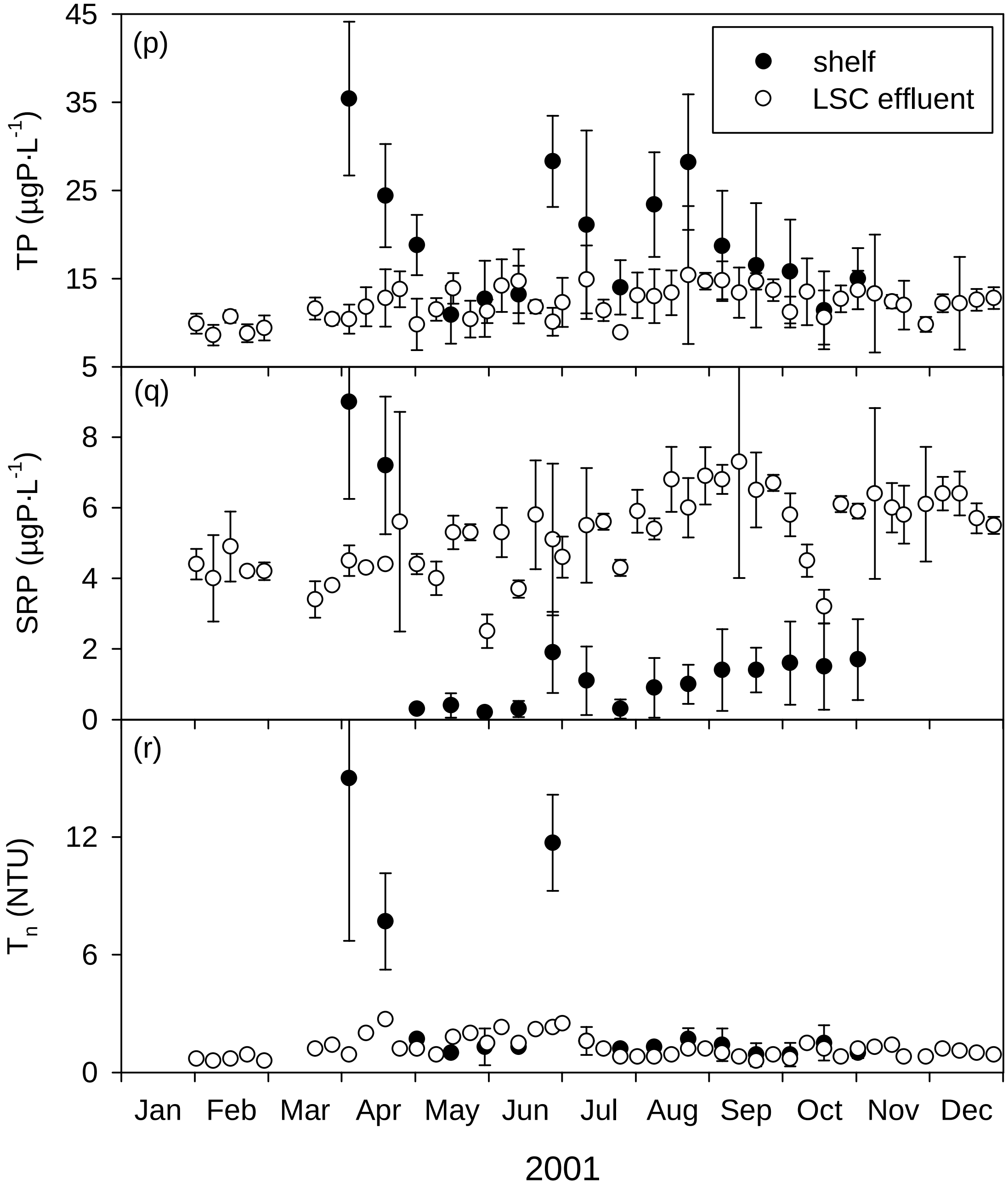

Figure 2p-r. Time series of parameter values for the south shelf and the LSC effluent for 2001: (p) TP, (q) SRP, and (r) $T_n$. Results for the "shelf" are averages; the dimensions of the error bars are ± 1 standard deviation. Error bars for the LSC effluent represent 95 % confidence intervals determined from analyses of field triplicates.

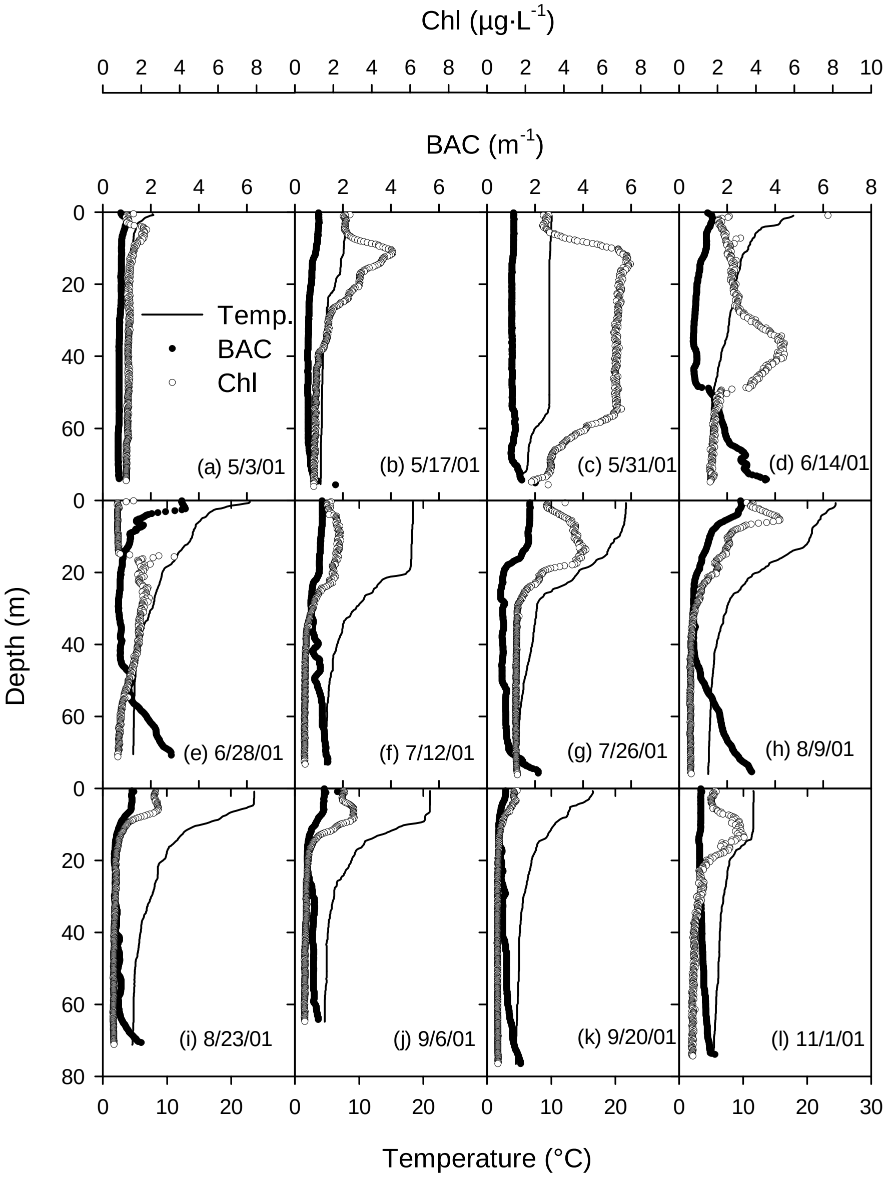

Figure 3. Vertical profiles of temperature, chlorophyll fluorescence, and beam attenuation coefficient (BAC) for LSC site in 2001: (a) May 3, (b) May 17, (c) May 31, (d) June 14, (e) June 28, (f) July 12, (g) July 26, (h) August 9, (i) August 23, (j) September 6, (k) September 20, (l) November 1.

**Table 7:** Occurrences of high TDP and T-$NH_3$ concentrations for sampling locations on the shelf for observations made during the 1998 – 2001 study periods.

| Site | TDP | | T-$NH_3$ | |
|---|---|---|---|---|
| | > 10 $\mu g \cdot L^{-1}$ | > 20 $\mu g \cdot L^{-1}$ | > 100 $\mu g \cdot L^{-1}$ | > 200 $\mu g \cdot L^{-1}$ |
| 1 | 5 | 0 | 4 | 1 |
| 2 | 30 | 14 | 23 | 19 |
| 3 | 7 | 0 | 7 | 5 |
| 4 | 0 | 0 | 1 | 0 |
| 5 | 1 | 0 | 0 | 0 |
| 7 | 8 | 0 | 8 | 2 |

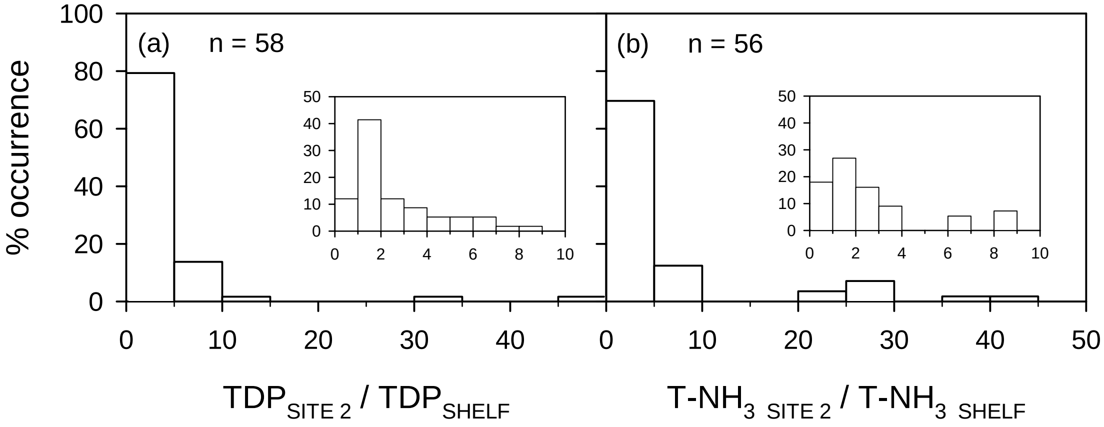

Figure 4. Distributions of ratios of paired observations for site 2 and the shelf for: (a) total dissolved phosphorus (TDP) and (b) total ammonia (T-$NH_3$). Ratios are for samples collected on the same day during the 1998 – 2001 study periods.

**Table 8:** Average values for TP, SRP, and $T_n$ in the LSC effluent and on the shelf. Averages determined from paired observations made during the April – November interval of 2001.

| **Location** | **TP ($\mu g \cdot L^{-1}$) n=16** | **SRP ($\mu g \cdot L^{-1}$) n=16** | **$T_n$ (NTU) n=16** |
|---|---|---|---|
| **LSC effluent** | 12.5 | 5.0 | 1.3 |
| **Shelf** | 19.2 | 1.9 | 3.2 |

# 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 2001 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 5. A linear relationship is expected (Effler 1988), and has been observed for the observations of 1998, 1999, 2000 and 2001 (Figure 4). Based on these results (Figure 5), $T_n$ 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 $T_n$ will continue to be evaluated in future years of this monitoring program.

## 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 1998, 1999, 2000 and 2001 (Table 9), 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 9) 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 9) over the 1998 – 2001 interval. The TP permit requirement is 40 pounds per day (18.1 kg per day) for the Ithaca Area WWTP and 1 $mg \cdot L^{-1}$ 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 9. 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 9 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 2001 are presented in Table 9. Concentrations of TP are measured weekly at the LSC discharge. The estimates of the monthly loads (Table 9) 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 1.0 kg·d$^{-1}$, or 3.0 % 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).

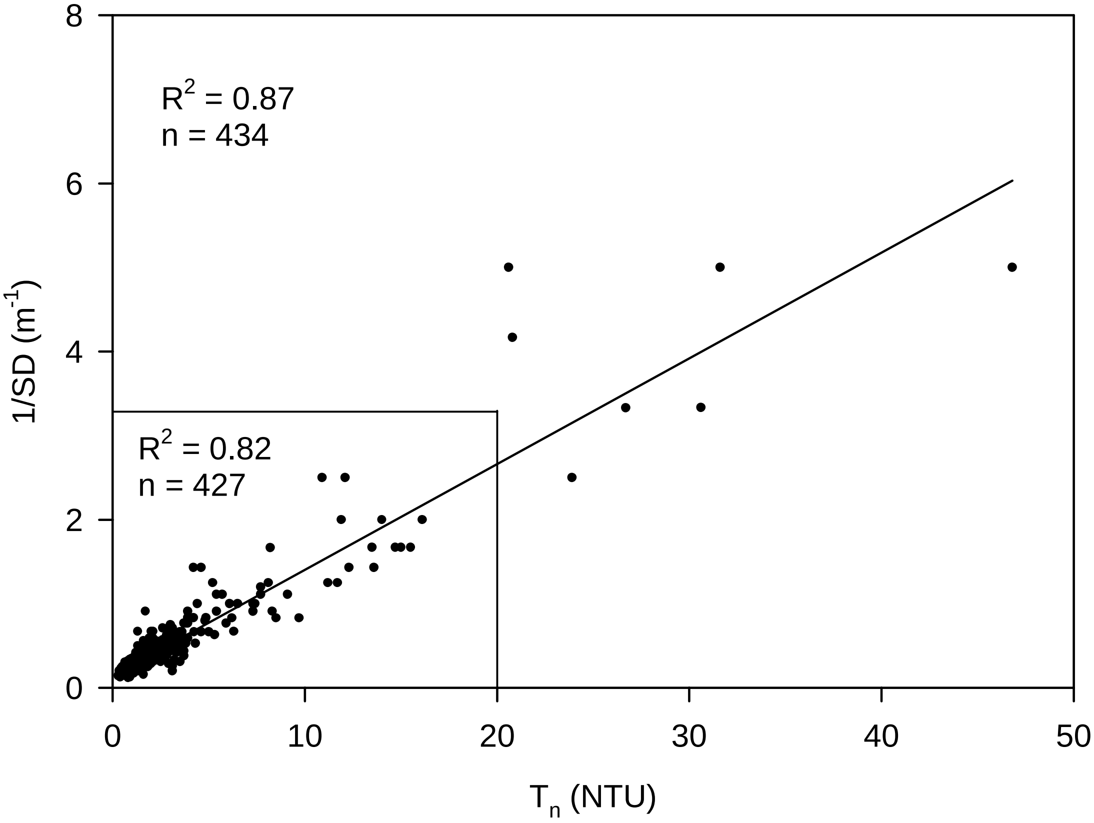

Figure 5. Relationship between Secchi disc transparency (SD) and turbidity in the southern end of Cayuga Lake based on paired observations in 1998, 1999, 2000 and 2001.

**Table 9:** Estimates of monthly external loads of phosphorus to the southern portion of Cayuga Lake.

| **Month** | **Ithaca Area WWTP* (kg·d$^{-1}$)** | | | | **Cayuga Heights WWTP✚ (kg·d$^{-1}$)** | | | |
|---|---|---|---|---|---|---|---|---|
| | **1998** | **1999** | **2000** | **2001** | **1998** | **1999** | **2000** | **2001** |
| May | 14.1 | 19.7 | 24.1 | 15.8 | 8.7 | 3.7 | 3.5 | 5.5 |
| June | 5.8 | 9.1 | 16.6 | 11.2 | 7.5 | 4.3 | 5.1 | 4.0 |
| July | 16.4 | 11.4 | 13.7 | 15.2 | 4.4 | 2.6 | 3.4 | 4.2 |
| August | 17.0 | 12.5 | 19.1 | 15.2 | 4.7 | 1.5 | 4.6 | 7.1 |
| September | 32.8 | 20.0 | 18.5 | 22.0 | 7.7 | 1.8 | 4.0 | 6.6 |
| October | 16.2 | 9.4 | 15.4 | 16.4 | 9.1 | 1.7 | 4.1 | 2.8 |
| *Mean* | *17.1* | *13.7* | *16.5* | *16.0* | *7.0* | *2.6* | *4.1* | *5.0* |

| **Month** | **Tributary† (kg·d$^{-1}$)** | **LSC* (kg·d$^{-1}$)** | | **Total (kg·d$^{-1}$)** | | **% LSC** | |
|---|---|---|---|---|---|---|---|
| | **average year** | **2000** | **2001** | **2000** | **2001** | **2000** | **2001** |
| May | 29.0 | - | 0.7 | 56.6 | 51.0 | - | 1.4 |
| June | 15.8 | - | 1.1 | 37.5 | 32.1 | - | 3.4 |
| July | 8.8 | 1.4 | 1.0 | 27.3 | 29.2 | 5.1 | 3.4 |
| August | 6.0 | 1.0 | 1.4 | 30.7 | 29.7 | 3.3 | 4.7 |
| September | 7.5 | 0.9 | 1.0 | 30.9 | 37.1 | 2.9 | 2.7 |
| October | 13.1 | 0.6 | 0.7 | 33.2 | 33.0 | 1.8 | 2.1 |
| *Mean* | *13.3* | *1.0* | *1.0* | *34.9* | *35.4* | *2.9* | *3.0* |

* total phosphorus, from facility permit reporting

✚ total phosphorus; personal communication with Brent Cross, Village Engineer

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

## 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.

Runoff and wind conditions for the study period of 2001 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, about 75 years; the wind database reflects 17 years of measurements. Daily average measurements of Fall Creek flow and wind speed for 2001 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.

With the exception of three major runoff events that occurred in early April, the end of June, and the end of September, Fall Creek flows were generally low in 2001 compared to long-term median values (Figure 6a). Monthly average flows were above the 75-percentile level in April and well below the 25-percentile level in May (Figure 6b). Monthly average flows were elevated for June and September, near the long-term average for July, and rather low for August and October (Figure 6b).

Major wind events (e.g., protracted intervals of high winds) did not occur over the study interval of 2001 (Figure 6c). However, winds were above average for extended periods during early April, early May, late May, mid-July, August, and mid-September (Figure 6c). Wind velocities were distinctly above average on, or before, the monitoring days of April 5, May 3, and July 12 (Figure 6c).

### 4.4 Limitations in Measures of Trophic State on the Shelf

Circumstantial scientific evidence, provided by the findings for 1998, 1999, 2000 (Upstate Freshwater Institute 1999, 2000, 2001) and 2001, indicates 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 1998 - 2000 observations (Upstate Freshwater Institute 1999, 2000, 2001). Observations from the 2001 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 reported over the study interval for the shelf and the main lake were observed after the major runoff events of early April and late June (Figure 6a). This suggests greater contributions of non-phytoplankton particles received in runoff to the measurements of $T_n$.

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). Increases in $T_c$ indicative of a "whiting" event were not observed during the summer of 2001 (Figure 7).

3. the ratio of particulate P (PP) to chlorophyll **a** was often substantially higher on the south shelf than at the deep stations (Figure 8) 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 9). Non-phytoplankton particles were responsible for high $T_n$ on the shelf and in the main lake following runoff events in early April and late June (Figure 9).

The 2001 results suggest substantial seasonal differences 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 regulator 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.

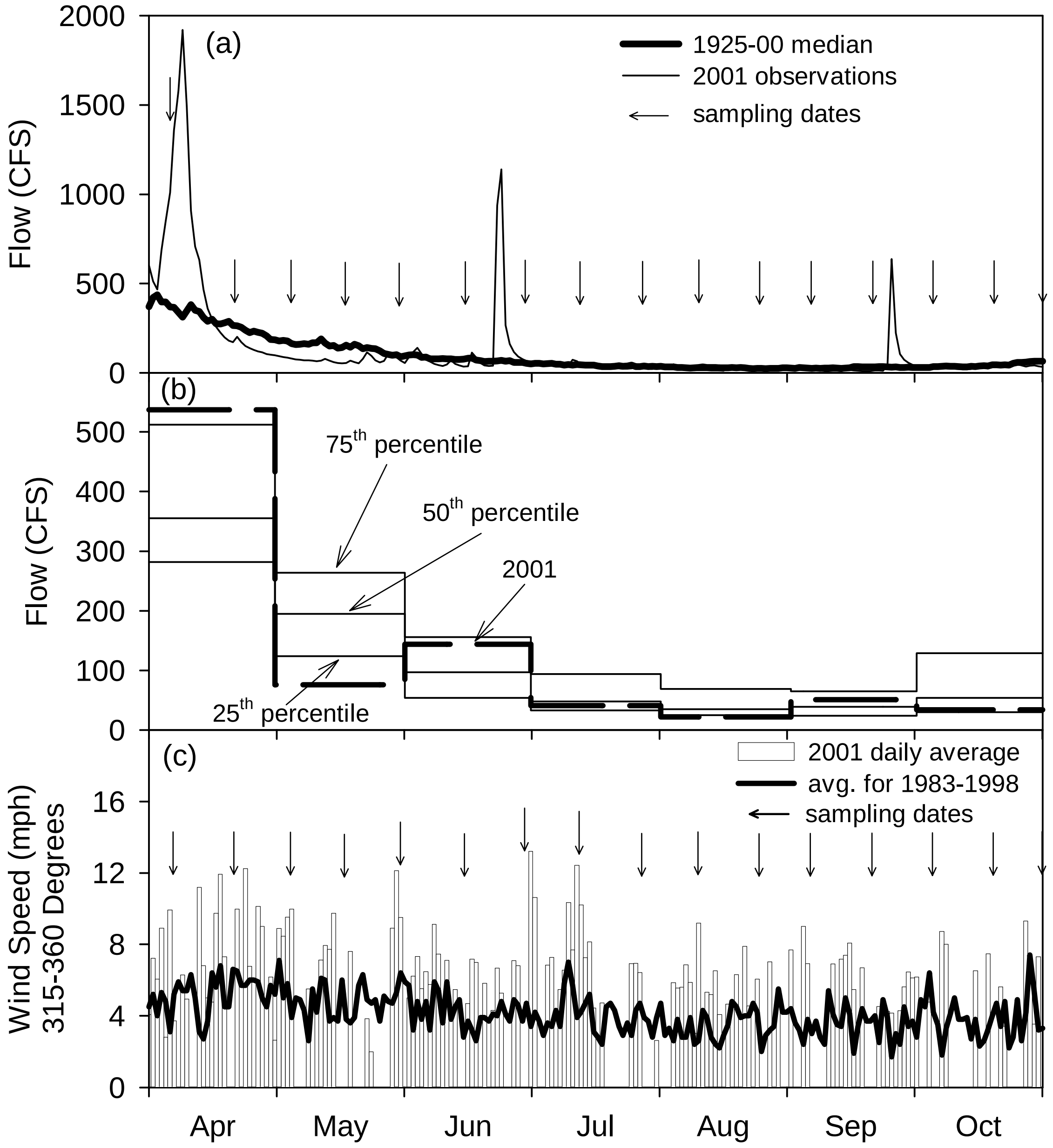

Figure 6. Runoff and wind conditions for the April – October interval of 2001: (a) daily average flows in Fall Creek compared to median daily values for the 1925 – 2000 record, (b) monthly flows in 2001 compared to quartile levels of flow for the 1925 – 2000 record, and (c) daily average wind speed out of the north to northwest.

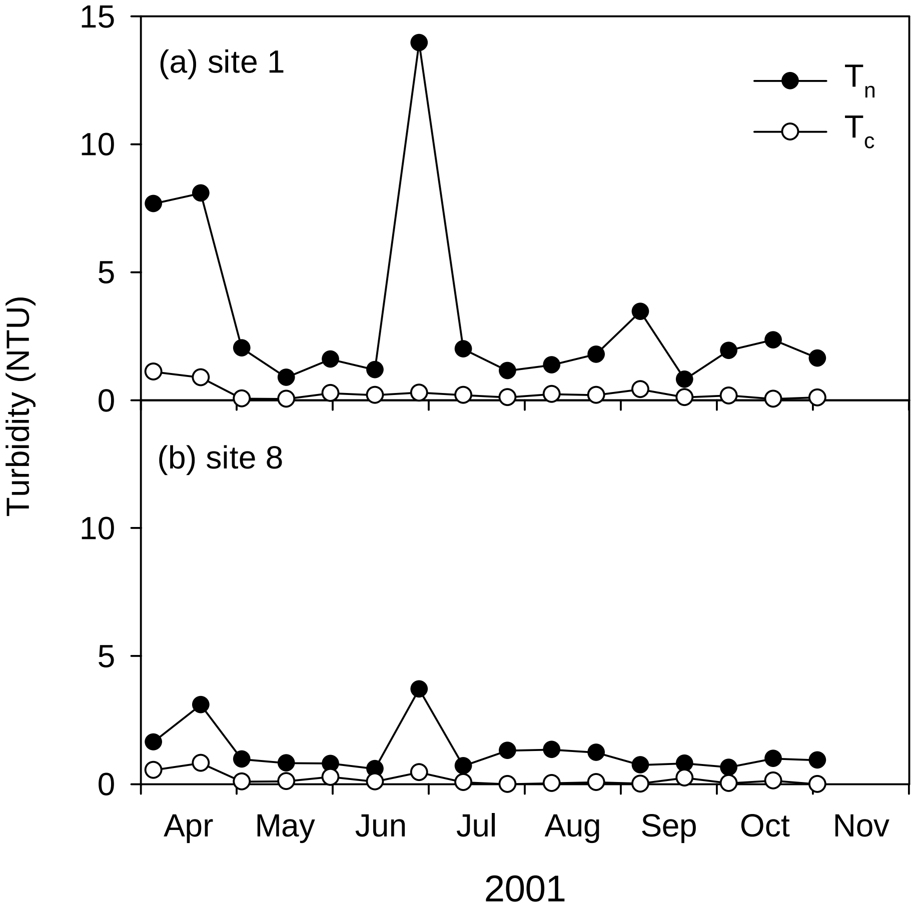

Figure 7. Distributions of total turbidity ($T_n$) and calcium carbonate turbidity ($T_c$) in the upper waters of Cayuga Lake in 2001: (a) site 1, (b) site 8.

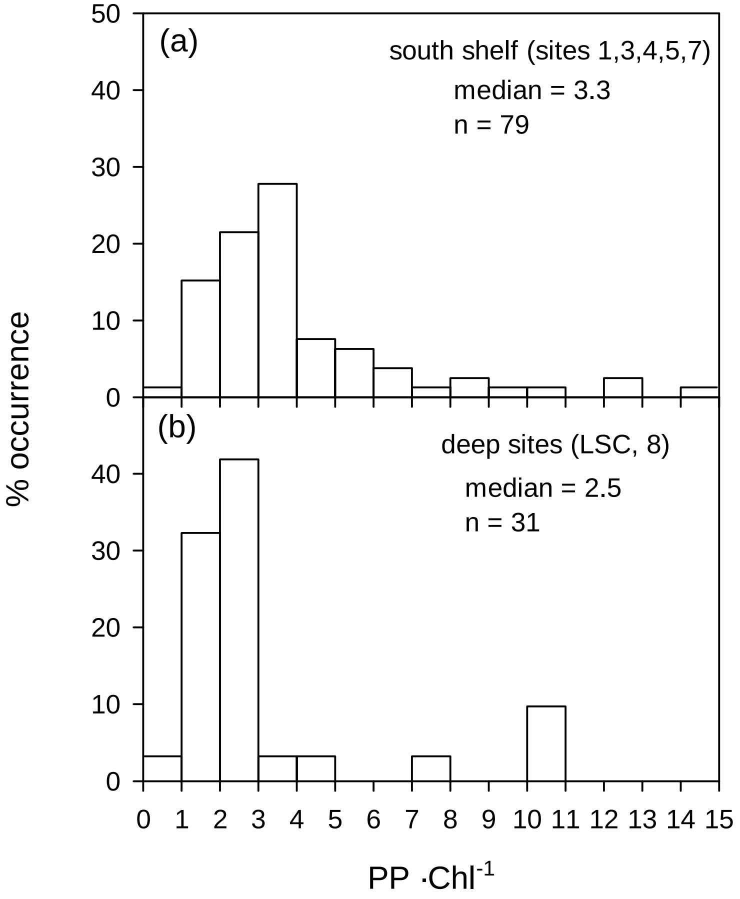

Figure 8. Distributions of the particulate P (PP) to chlorophyll **a** (Chl **a**) ratio values in Cayuga Lake in 2001: (a) south shelf sites, and (b) deep water sites.

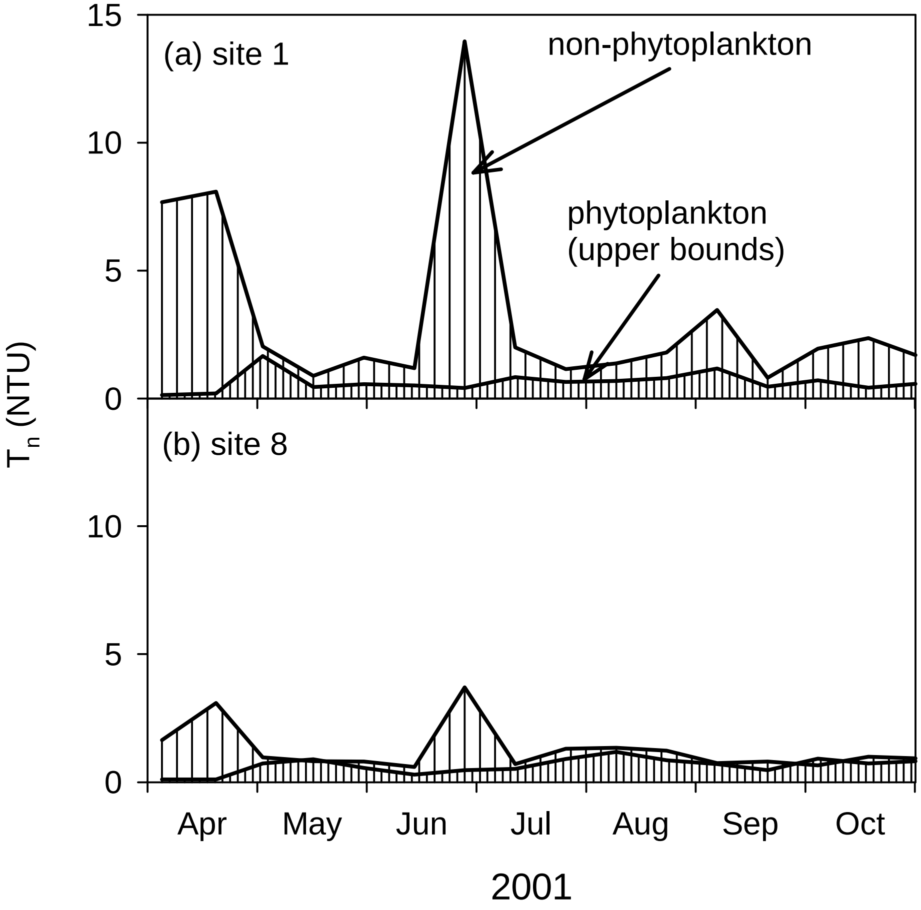

Figure 9. Time-series for the April – October interval of 2001, $T_n$ versus the upper bound contribution of phytoplankton: (a) site 1, and (b) site 8.

## 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 10 and 11). 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 10 and 11). 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 – 2001, documented here).

Summer (June – August) average concentrations are presented for the lake's upper waters; sources of data are included (Tables 10 and 11). Higher TP concentrations were observed on the shelf compared to deeper portions of the lake in all years monitored since 1994 (Table 10). 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 – 2001 interval (Table 11). 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 10:** 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 – 2001 study years.

| Year | Total Phosphorus ($\mu g \cdot L^{-1}$) | | 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) | 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 11:** Summary (June – August) average chlorophyll **a** (Chl **a**) concentrations for the upper waters of Cayuga Lake. June – September averages are included in parentheses for the 1998 – 2001 study years.

| Year | Chlorophyll a ($\mu g \cdot L^{-1}$) | | 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 | - | Olglesby 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) | 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 $\mu g \cdot L^{-1}$ 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 $\mu g \cdot L^{-1}$.

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 10. These data support Cayuga Lake's classification as mesotrophic. Six of the lakes had average concentrations lower than observed for Cayuga Lake (Figure 10). Two of the lakes, Canandaigua and Skaneateles, had concentrations consistent with oligotrophy, while two (Conesus and Honeoye) bordered on eutrophy (Figure 10).

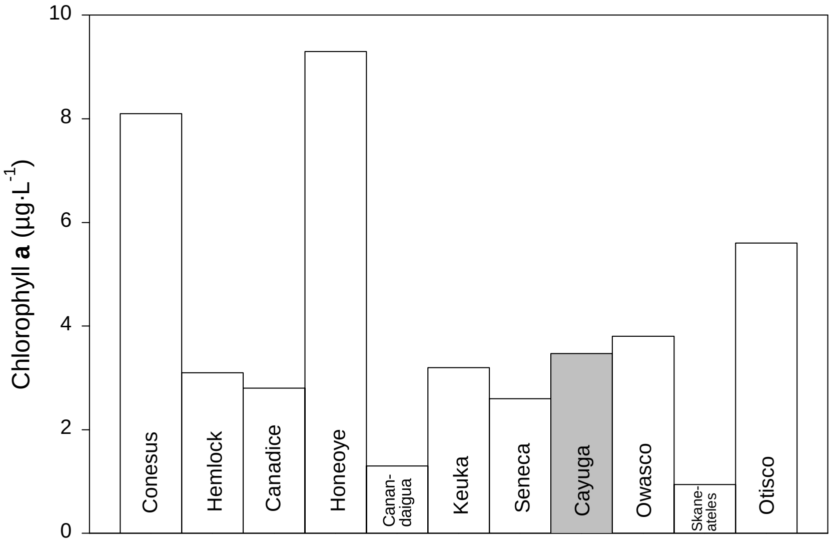

Figure 10. Comparison of average chlorophyll **a** concentrations for the spring-early fall interval for the eleven Finger Lakes, based on samples (n=15 to 16) collected over the 1996 through 1999 interval (data from Callinan et al. 2000).

## 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 TP loading from the Ithaca Area WWTP are compared here for 1998, 1999, 2000 and 2001 (Figure 11). Daily average flows measured in Fall Creek (Figure 10a) over the April – October interval of 2001 were generally lower than in 1998 and 2000 and higher than in 1999. Major runoff events occurred in early April, late June, and late September of 2001. Flows remained low during the May – August interval of 1999; no significant runoff events occurred from late April through mid-September. Flow conditions during 1998 were similar to those of 2000; major runoff events occurred during April and May, and flows were elevated during much of June and July.

Daily average wind speeds, out of the north to northwest, for 1998, 1999, 2000 and 2001 are presented in Figure 11b. Average wind speeds greater than 10 mph were less common in 1998 compared to the other study years. Major year-to year differences have not been observed for this metric (Figure 11b). Estimates of monthly average total phosphorus (TP) loads for the Ithaca Area WWTP are compared here for 1998, 1999, 2000 and 2001 (Figure 11c). Monthly TP loading from the Ithaca Area WWTP followed the same general trends that have been observed since 1998. Loading of TP from the Ithaca Area WWTP was lowest during June 2001 and highest during September 2001.

Time series for TP, chlorophyll **a**, and $T_n$ are presented for the July – October interval of 1998, and the April – October interval of 1999, 2000 and 2001 (Figure 12). 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 generally highest in 1998 and lowest in 1999 (Figure 12a). The high TP concentrations (e.g., > 30 $\mu g \cdot L^{-1}$; Figure 12a) observed on the shelf during the 1998, 2000 and 2001 study intervals were associated with major runoff events (Figure 11a). High TP concentrations (e.g., > 30 $\mu g \cdot L^{-1}$) were not observed during the1999 study interval. Chlorophyll **a** concentrations were similar during the four study years with the exception of the higher values observed during the late July – early August interval of 2000 (Figure 12b). In general, chlorophyll **a** concentrations have been highest during mid-summer. 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 12c). High turbidity values (e.g., > 5 NTU) were not observed during the 1999 study interval.

The temporally detailed data presented in Figures 11 and 12 are summarized in Figure 13 as averages for the four study years. Fall Creek flows were highest in 2000 and lowest in 1999 (Figure 13a). Average wind speeds were essentially equal for the four study years (Figure 13b). Total phosphorus loading from the Ithaca Area WWTP was lowest in 1999 and essentially equal in 1998, 2000 and 2001 (Figure 13c). Greater month-to-month variability in TP loading was observed in 1998 than in the other study years (Figures 11c and 13c). Study period averages for TP and $T_n$ on the shelf were similar for 1998, 2000 and 2001, and substantially lower for 1999 (Figure 13d-e). Chlorophyll **a** concentrations were higher in 1998 and 2000 and lower in 1999 and 2001 (Figure 13f).

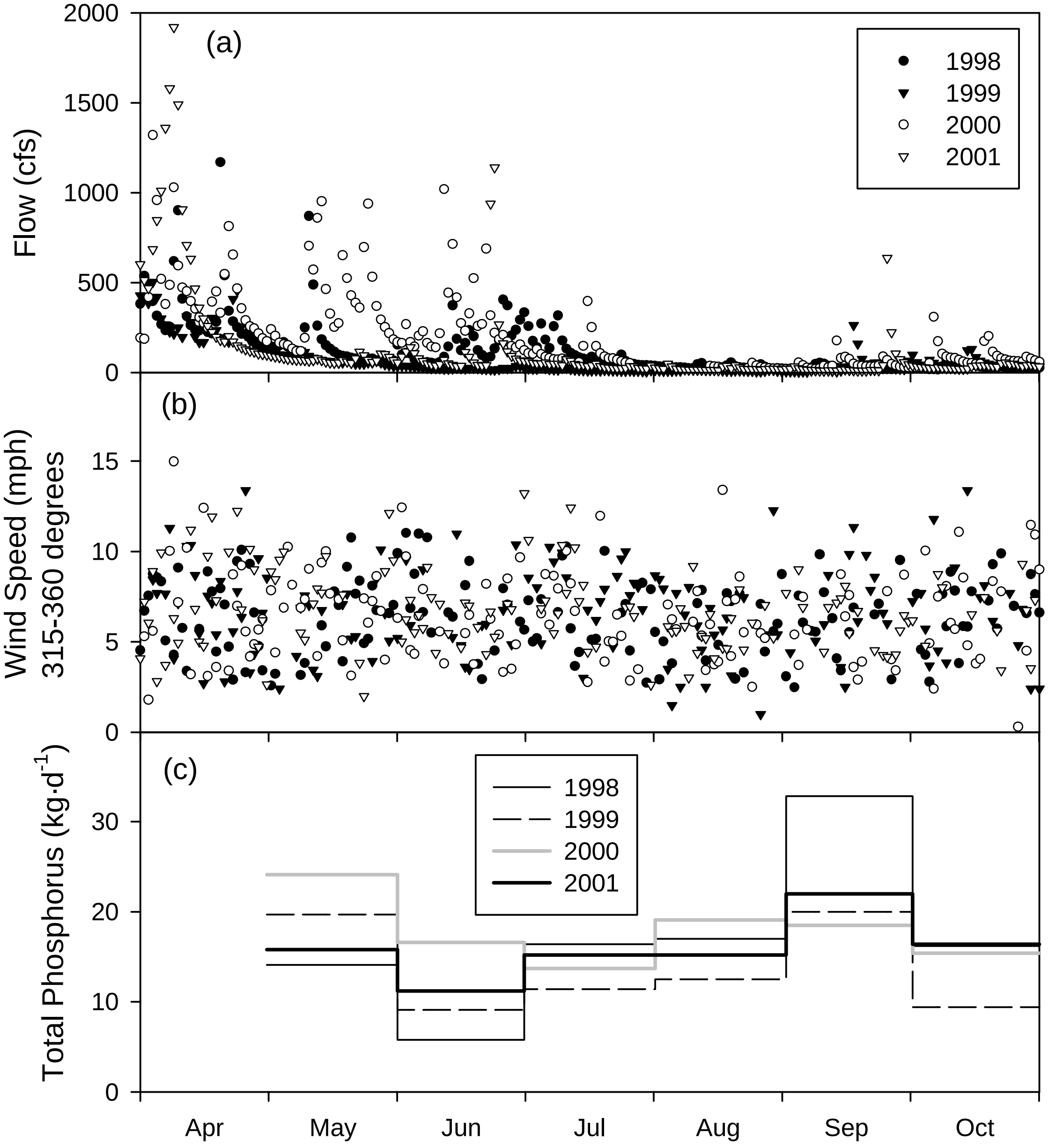

Figure 11. Comparison of 1998, 1999, 2000 and 2001 conditions for runoff, wind and total phosphorus loading for the April – October interval: (a) daily average flows in Fall Creek, (b) daily average wind speed, and (c) monthly loads of total phosphorus (TP) from the Ithaca Area WWTP.

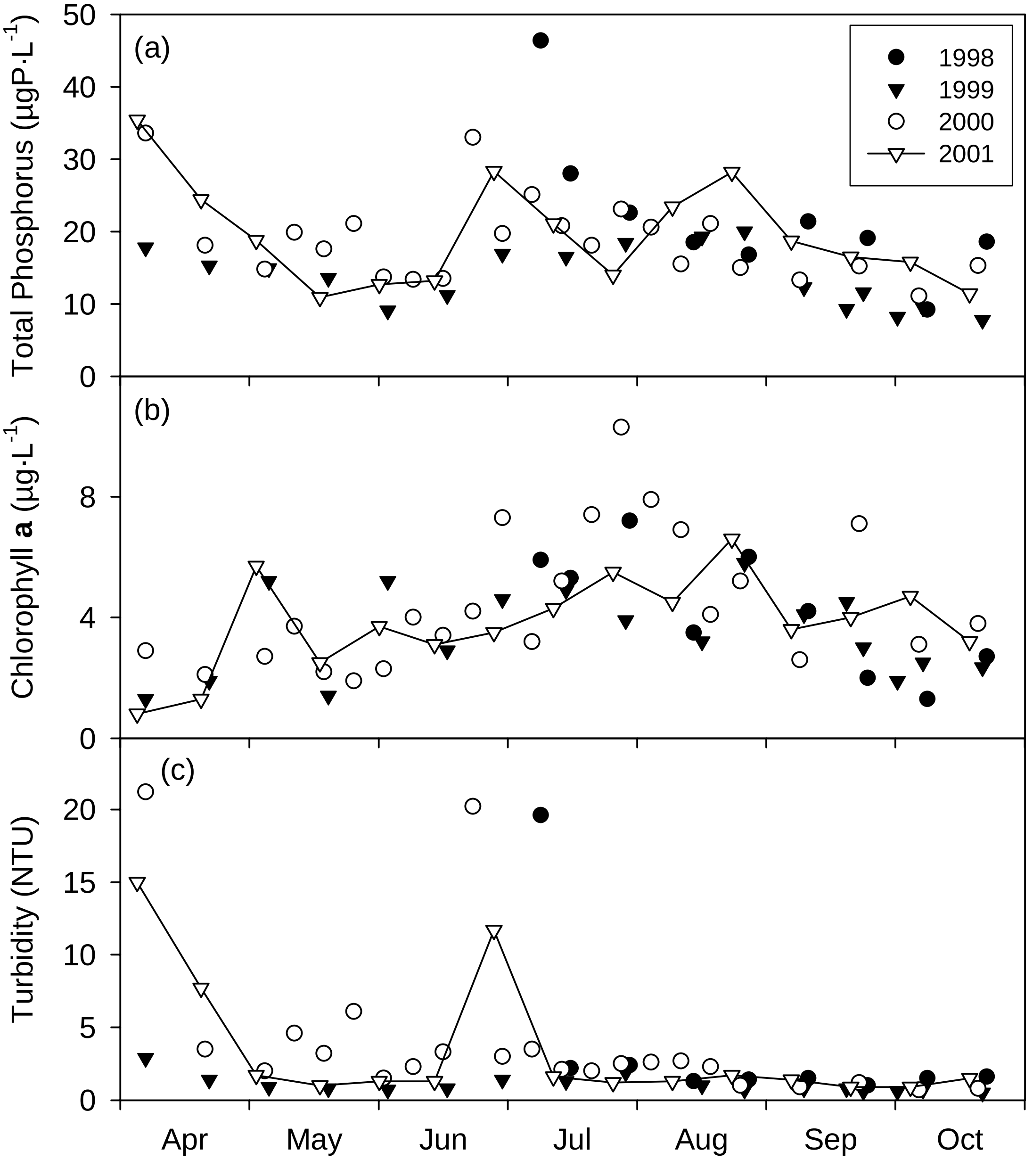

Figure 12. Comparison of 1998, 1999, 2000 and 2001 conditions for total phosphorus, chlorophyll **a**, and turbidity on the south shelf of Cayuga Lake for the April – October interval: (a) total phosphorus (TP), (b) chlorophyll **a** (Chl **a**), and (c) turbidity ($T_n$).

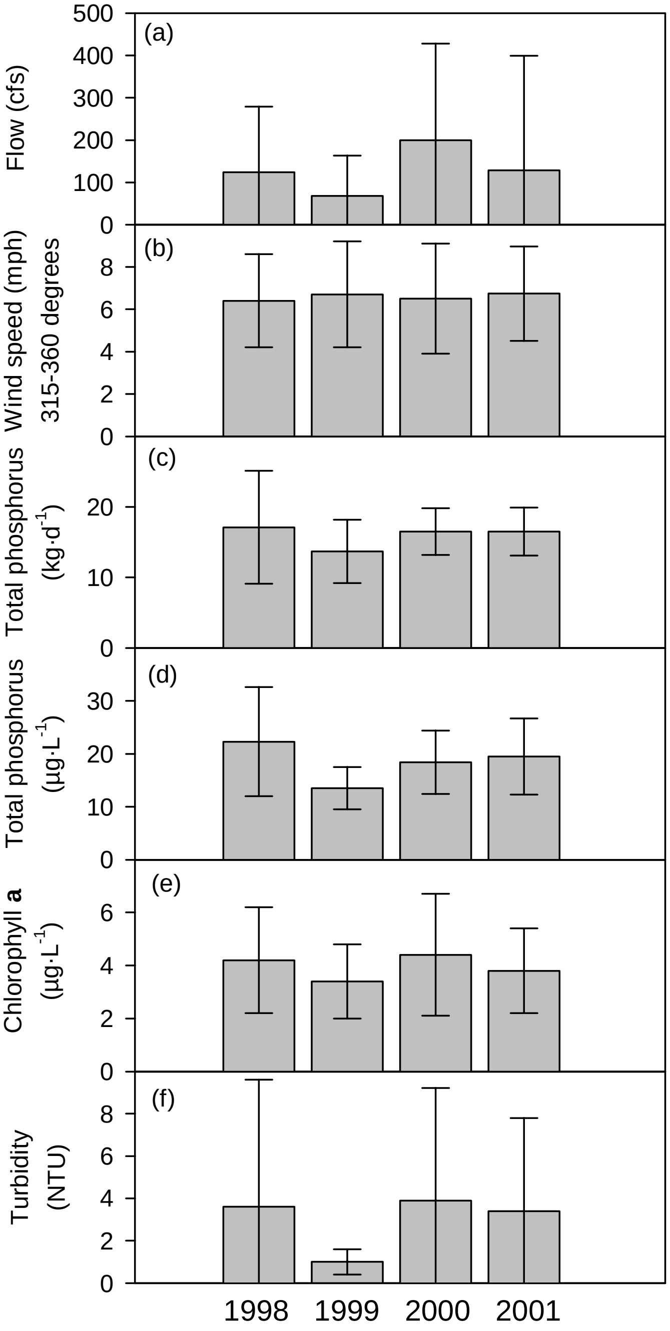

Figure 13. Comparison of 1998, 1999, 2000 and 20001 averages for runoff, wind, total phosphorus loading, total phosphorus concentration, chlorophyll **a** concentration and turbidity: (a) Fall Creek flow, (b) wind speed, (c) loads of total phosphorus (TP) from the Ithaca Area WWTP, (d) total phosphorus concentration on the south shelf, (e) chlorophyll **a** (Chl **a**) concentration on the south shelf, and (f) turbidity ($T_n$) 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. The dimensions of the error bars are ± 1 standard deviation.

Noteworthy observations from the 2001 data include:

1. site 2 was enriched in all three forms of phosphorus (TP, TDP, and SRP), all three forms of nitrogen (TDN, $NO_X$, and T-$NH_3$), chloride (Cl), and had a higher average temperature compared to the other monitored sites (Figure 2, Table 6).

2. 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).

3. 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).

4. variances of measures of trophic state (chlorophyll **a**, 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).

5. clarity, as measured by Secchi disc transparency (SD) and turbidity ($T_n$), was low on the south shelf on the first two monitoring days (April 5 and April 20) and lake-wide on June 28 (Figure 2g-h).

6. chloride concentrations were spatially and temporally uniform compared to other parameters measured in the monitoring program (Table 6).

7. more than 60 % of the phosphorus was in a particulate form [e.g., (TP-TDP)/TP] over the monitored period.

8. average concentrations of TP, TDP, SRP, and T-$NH_3$ were higher in the eastern portion (sites 1 and 7), compared to other sites (4 and 5) on the shelf (Table 6).

9. 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).

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

11. turbidity ($T_n$) values and concentrations of total phosphorus (TP) and soluble reactive phosphorus (SRP) were essentially equal in the LSC influent and effluent (Figure 2m-o).

12. higher $T_n$ values for the LSC influent and effluent during April and June (Figure 2o) coincided with major runoff events (Figure 6a) that caused high $T_n$ values throughout southern Cayuga Lake (Figure 2g).

13. 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 6.7 $\mu g \cdot L^{-1}$ lower (Table 8).

14. 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 3.1 $\mu g \cdot L^{-1}$ higher (Table 8).

15. 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 1.9 NTU (Table 8).

16. 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 super-saturation (~130 %) in August and under-saturation (< 80%) in September.

17. concentrations of fecal coliforms were below public health limits for contact recreation at monitored sites (LSC, and sites 1 and 7) on all monitored dates (Table 6).

18. 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).

19. chlorophyll fluorescence profiles indicate subsurface peaks in phytoplankton concentrations occurred at the LSC intake site during the stratification period of 2001 (Figure 3). These peaks usually occurred above, or at, the maximum temperature (i.e., density) gradient, at depths $\leq$ 20 meters. Deeper peaks were observed on May 31 (Figure 3c) and June 14 (Figure 3d).

20. Secchi disc transparency (SD) was observed to extend beyond the lake depth at multiple sites on several occasions during the 2001 study interval (Appendix 1).

21. the 2001 results continue to support turbidity ($T_n$) as an alternate measure of light penetration in shallow portions of the shelf (Figure 5).

22. phosphorus loading from the Ithaca Area WWTP was lower in 2001 than in 1998 or 2000, but not as low as in 1999 (Table 9).

23. LSC contributed ~ 3 % of the TP load to the shelf over the May – October interval of 2001, a smaller contribution than projected (4.8 %) in the **Draft Environmental Impact Statement** (Stearns and Wheler 1997; Table 9).

24. the Fall Creek hydrograph for 2001 was dominated by three major runoff events that occurred in April, June and September (Figure 6a). Compared to long-term median values, Fall Creek flows were high during April and June and low during May, August and October (Figure 6a-b).

25. major wind events did not occur over the study interval of 2001 (Figure 6c) and annual average wind speeds were essentially equal in 1998, 1999, 2000 and 2001 (Figure 13b).

26. the 2001 results continue to support the position that TP and $T_n$ are systematically flawed indicators of trophic state on the shelf.

27. the 2001 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.

28. summer average concentrations of TP and Chl **a** for deep water sites continue to be consistent with mesotrophy, an intermediate level of primary productivity (Tables 10 and 11).

29. study period average values for TP and $T_n$ on the shelf were similar for 1998, 2000 and 2001, and distinctly lower for 1999 (Figure 13d-f).

30. 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).

## 5. Summary

This report presents the design and salient findings of a water quality monitoring study conducted for Cayuga Lake in 2001, sponsored by Cornell University. This is the fourth annual report for a monitoring program that will be conducted annually through 2002. A number of noteworthy findings are reported here for 2001 that have value for lake management. Water quality on the south shelf apparently varies substantially from year to year. Potential sources of variation include interannual differences in runoff, loading from WWTPs, and wind. For example, Fall Creek flows were high in 2000 compared to long-term median values and were distinctly higher than 1999 flows. Major runoff events occurred throughout the April – July interval of 2000 and in April, June and September of 2001. No significant runoff events occurred from late April through mid-September 1999. Phosphorus loadings from the Ithaca and Cayuga Heights WWTPs were similar in 1998, 2000 and 2001, but lower in 1999. Although north to northwest wind speeds greater than 10 mph were more common in 1999, 2000 and 2001 than in 1998, study average wind speeds were essentially equal for the four study years. Study period average values for TP and $T_n$ on the shelf were similar for 1998, 2000 and 2001, and lower in 1999. Chlorophyll a concentrations were slightly lower in 1999 and 2001 than in 1998 and 2000. The 2001 results continue to support the position (Effler et al. 2002), that inorganic particles, rather than phytoplankton, are the primary regulator of $T_n$ and SD on the shelf. Summer average concentrations of TP and Chl **a** for deep water sites continue to be consistent with mesotrophy, a classification shared by seven of the eleven Finger Lakes. Total phosphorus (TP) concentrations and turbidity ($T_n$) values were generally lower, and SRP (soluble reactive phosphorus) concentrations were generally higher, in the LSC effluent than on the shelf. LSC contributed ~ 3 % of the TP load to the shelf over the May – October interval of 2001, 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 (μgP·L$^{-1}$)

| Date: | 4/5/01 | 4/20/01 | 5/3/01 | 5/17/01 | 5/31/01 | 6/14/01 | 6/28/01 | 7/12/01 | 7/26/01 | 8/9/01 | 8/23/01 | 9/6/01 | 9/20/01 | 10/4/01 | 10/18/01 | 11/1/01 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site: | | | | | | | | | | | | | | | | |
| 1 | 35.8 | 23.9 | 22.1 | 12.3 | 15.0 | 12.6 | 29.4 | 33.2 | 15.5 | 26.4 | 28.4 | 32.6 | 16.3 | 16.1 | 16.9 | 11.1 |
| 2 | 43.8 | 66.4 | 19.6 | 11.4 | 15.0 | 21.1 | 34.7 | 37.4 | 12.9 | 49.6 | 76.7 | 83.5 | 35.0 | 48.0 | 8.2 | 16.0 |
| 3 | 39.6 | 30.9 | 22.9 | 11.8 | 11.9 | 17.1 | 31.3 | 20.2 | 13.1 | 28.0 | 37.5 | 18.0 | 16.4 | 15.4 | 8.8 | 16.8 |
| 4 | 26.2 | 19.5 | 16.8 | 6.4 | 8.4 | 10.1 | 29.8 | 13.4 | 12.2 | 16.4 | 21.1 | 11.2 | 10.9 | 9.3 | 9.8 | 13.1 |
| 5 | 45.4 | 19.5 | 15.3 | 11.1 | 12.1 | 11.1 | 20.6 | 14.4 | 12.2 | 20.5 | 22.7 | 19.1 | 12.2 | 15.1 | 9.1 | 18.8 |
| 6 | 22.7 | 13.8 | 10.2 | 12.8 | 8.7 | 8.8 | 23.3 | 15.1 | 13.8 | 21.2 | 35.5 | 17.1 | 13.7 | 10.0 | 11.1 | 8.5 |
| 7 | 25.0 | 31.8 | 18.3 | 16.2 | 22.4 | 17.1 | 33.3 | 39.8 | 21.8 | 30.6 | 34.5 | 20.3 | 36.6 | 31.1 | 19.2 | 11.1 |
| 8 | 13.3 | 13.3 | 16.7 | 15.8 | 9.8 | 7.7 | 12.4 | 11.9 | 15.7 | 17.1 | 19.1 | 17.1 | 12.5 | 10.3 | 8.7 | 7.8 |
| LSCT | 15.1 | 15.0 | 12.5 | 11.4 | 9.4 | 8.4 | 21.2 | 12.3 | 14.1 | - | 18.4 | 16.4 | 10.5 | 11.7 | 8.5 | 8.5 |
| LSCB | 10.0 | - | 8.9 | - | 11.5 | 14.7 | 13.5 | 12.0 | 12.5 | 12.0 | 12.8 | 12.8 | 13.8 | 8.6 | 7.8 | 11.5 |
| LSC3B | 9.9 | - | 8.9 | - | 9.4 | 12.4 | 13.5 | 12.3 | - | 12.0 | 16.4 | 12.2 | 12.8 | 8.3 | 11.7 | 11.5 |

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

| Date: | 4/5/01 | 4/20/01 | 5/3/01 | 5/17/01 | 5/31/01 | 6/14/01 | 6/28/01 | 7/12/01 | 7/26/01 | 8/9/01 | 8/23/01 | 9/6/01 | 9/20/01 | 10/4/01 | 10/18/01 | 11/1/01 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site: | | | | | | | | | | | | | | | | |
| 1 | 9.3 | 7.7 | 3.2 | 1.8 | 3.1 | 3.1 | 9.5 | 5.5 | 2.5 | 9.6 | 6.1 | 9.9 | 7.8 | 3.2 | 7.1 | 3.7 |
| 2 | 18.6 | 36.6 | 2.0 | 0.7 | 3.8 | 2.1 | 10.8 | 4.9 | 1.2 | 14.4 | 29.9 | 53.8 | 19.3 | 22.9 | 4.6 | 7.2 |
| 3 | 16.7 | 13.8 | 2.7 | 0.2 | 2.8 | 1.7 | 7.5 | 2.1 | 1.3 | 9.7 | 6.9 | 7.9 | 7.6 | 2.1 | 5.5 | 10.1 |
| 4 | 9.8 | 8.9 | 2.6 | 1.7 | 3.1 | 0.7 | 4.4 | 1.1 | 8.0 | 5.2 | 6.4 | 7.6 | 7.9 | 4.9 | 5.2 | 3.5 |
| 5 | 13.6 | 9.5 | 1.7 | 2.2 | 3.2 | 1.1 | 6.5 | 1.8 | 4.2 | 6.2 | 6.5 | 6.3 | 6.6 | 2.8 | 4.2 | 2.5 |
| 6 | 7.3 | 6.5 | 0.7 | 2.0 | 2.8 | 1.7 | 5.0 | 2.1 | 1.3 | 5.2 | 5.9 | 4.0 | 4.8 | 2.8 | 4.9 | 2.1 |
| 7 | 9.4 | 11.3 | 1.3 | 4.0 | 4.9 | 2.4 | 8.5 | 6.6 | 3.9 | 9.0 | 9.5 | 9.2 | 12.5 | 7.0 | 8.5 | 3.8 |
| 8 | 5.6 | 6.4 | 1.3 | 1.4 | 3.8 | 2.4 | 3.8 | 2.8 | 4.2 | 9.0 | 4.9 | 4.0 | 4.4 | 3.5 | 3.9 | 2.5 |
| LSCT | 5.7 | 7.1 | 2.0 | 1.4 | 3.8 | 4.1 | 4.1 | 1.8 | 1.6 | 4.9 | 4.2 | 3.7 | 5.0 | 2.5 | 3.9 | 2.1 |
| LSCB | 5.2 | - | 6.6 | - | 3.8 | 5.4 | 5.9 | 5.9 | 4.5 | 9.0 | 10.5 | - | 9.9 | - | 3.6 | 6.8 |
| LSC3B | 5.9 | - | 5.6 | - | 3.1 | 5.7 | 5.9 | 5.9 | - | 8.6 | 9.5 | 9.2 | 9.2 | 7.9 | 4.9 | 6.5 |

## Soluble Reactive Phosphorus (μgP·L$^{-1}$)

| Date: | 4/5/01 | 4/20/01 | 5/3/01 | 5/17/01 | 5/31/01 | 6/14/01 | 6/28/01 | 7/12/01 | 7/26/01 | 8/9/01 | 8/23/01 | 9/6/01 | 9/20/01 | 10/4/01 | 10/18/01 | 11/1/01 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site: | | | | | | | | | | | | | | | | |
| 1 | 7.0 | 6.2 | 0.3 | 1.5 | 0.2 | 0.2 | 3.4 | 1.8 | 0.3 | 2.5 | 0.5 | 3.4 | 0.7 | 0.8 | 3.1 | 1.3 |
| 2 | 13.4 | 30.7 | 0.2 | 0.3 | 0.2 | 0.2 | 5.5 | 1.9 | 0.3 | 3.9 | 16.8 | 46.8 | 13.1 | 17.5 | 1.0 | 4.5 |
| 3 | 12.2 | 10.0 | 0.3 | 0.2 | 0.2 | 0.5 | 2.6 | 0.2 | 0.2 | 1.5 | 1.2 | 0.9 | 1.4 | 0.7 | 1.1 | 3.4 |
| 4 | 6.5 | 5.5 | 0.4 | 0.7 | 0.2 | 0.5 | 0.5 | 0.4 | 0.2 | 0.2 | 1.1 | 1.4 | 2.1 | 3.4 | 1.0 | 1.2 |
| 5 | 10.4 | 6.3 | 0.3 | 0.2 | 0.2 | 0.2 | 1.5 | 1.5 | 0.2 | 0.2 | 0.2 | 0.4 | 0.5 | 1.4 | 0.6 | 0.8 |
| 6 | 5.6 | 4.2 | 0.3 | 0.2 | 0.2 | 0.2 | 0.8 | 0.2 | 0.2 | 0.3 | 1.7 | 0.2 | 0.2 | 0.7 | 0.5 | 0.9 |
| 7 | 6.8 | 7.7 | 0.3 | 0.2 | 0.2 | 0.2 | 2.8 | 2.7 | 1.1 | 0.8 | 2.3 | 2.7 | 2.4 | 1.4 | 3.5 | 1.5 |
| 8 | 4.5 | 4.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.2 | 0.2 | 0.2 | 0.5 | 0.9 | 0.7 | 1.1 |
| LSCT | 4.2 | 4.3 | 0.6 | 0.2 | 0.2 | 0.2 | 0.4 | 0.2 | 0.3 | 0.2 | 0.2 | 0.2 | 0.5 | 0.2 | 0.5 | 0.8 |
| LSCB | 4.0 | - | 4.2 | - | 1.7 | 4.4 | 3.2 | 4.6 | 4.2 | 5.5 | 5.9 | 6.3 | 6.8 | 2.9 | 0.6 | 5.2 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LSC3B | 4.0 | - | 4.6 | - | 0.2 | 4.2 | 2.9 | 4.0 | - | 5.2 | 5.4 | 5.4 | 6.8 | 3.2 | 1.8 | 5.2 |

## Total Dissolved Nitrogen (mgN·L$^{-1}$)

| Date: | 4/5/01 | 4/20/01 | 5/3/01 | 5/17/01 | 5/31/01 | 6/14/01 | 6/28/01 | 7/12/01 | 7/26/01 | 8/9/01 | 8/23/01 | 9/6/01 | 9/20/01 | 10/4/01 | 10/18/01 | 11/1/01 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site: | | | | | | | | | | | | | | | | |
| 1 | 1.449 | 1.307 | 1.391 | 1.274 | 1.323 | 1.219 | 1.474 | 1.599 | 1.441 | 1.420 | 1.437 | 1.488 | 1.800 | 1.348 | 1.636 | 1.409 |
| 2 | 1.565 | 1.718 | 1.441 | 1.190 | 1.361 | 1.291 | 1.618 | 1.675 | 1.432 | 1.684 | 3.771 | 3.431 | 1.834 | 1.589 | 1.703 | 1.746 |
| 3 | 1.488 | 1.349 | 1.430 | 1.250 | 1.278 | 1.227 | 1.589 | 1.481 | 1.433 | 1.755 | 1.832 | 1.633 | 1.700 | 1.290 | 1.660 | 1.596 |
| 4 | 1.262 | 1.230 | 1.351 | 1.266 | 1.321 | 1.198 | 1.529 | 1.479 | 1.418 | 1.277 | 1.450 | 1.459 | 1.623 | 1.285 | 1.775 | 1.538 |
| 5 | 1.351 | 1.389 | 1.431 | 1.244 | 1.260 | 1.194 | 1.694 | 1.515 | 1.474 | 1.489 | 1.378 | 1.402 | 1.716 | 1.277 | 1.582 | 1.555 |
| 6 | 1.370 | 1.379 | 1.459 | 1.297 | 1.256 | 1.178 | 1.485 | 1.391 | 1.452 | 1.456 | 1.280 | 1.349 | 1.565 | 1.233 | 1.687 | 1.511 |
| 7 | 1.398 | 1.187 | 1.434 | 1.211 | 1.259 | 1.155 | 1.503 | 1.621 | 1.547 | 1.379 | 1.327 | 1.297 | 1.441 | 1.288 | 1.883 | 1.458 |
| 8 | 1.448 | 1.202 | 1.415 | 1.228 | 1.262 | 1.227 | 1.576 | 1.477 | 1.445 | 1.322 | 1.359 | 1.365 | 1.586 | 1.261 | 1.500 | 1.465 |
| LSCT | 1.338 | 1.164 | 1.466 | 1.235 | 1.321 | 1.223 | 1.512 | 1.493 | 1.431 | 1.287 | 1.896 | 1.435 | 1.662 | 1.258 | 1.502 | 1.463 |
| LSCB | 1.406 | - | 1.421 | - | 1.350 | 1.284 | 1.661 | 1.698 | 1.461 | 1.711 | - | 1.706 | 1.712 | 1.606 | 1.499 | 1.727 |
| LSC3B | 1.364 | - | 1.330 | - | 2.299 | 1.264 | 1.621 | 1.662 | - | 1.820 | 1.728 | 1.694 | 1.795 | 1.593 | 1.696 | 1.674 |

## Nitrate + Nitrite Nitrogen (mgN·L$^{-1}$)

| Date: | 4/5/01 | 4/20/01 | 5/3/01 | 5/17/01 | 5/31/01 | 6/14/01 | 6/28/01 | 7/12/01 | 7/26/01 | 8/9/01 | 8/23/01 | 9/6/01 | 9/20/01 | 10/4/01 | 10/18/01 | 11/1/01 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site: | | | | | | | | | | | | | | | | |
| 1 | 1.147 | 1.103 | 1.180 | 1.098 | 1.107 | 1.016 | 1.089 | 1.200 | 1.041 | 0.887 | 0.828 | 0.905 | 1.205 | 0.916 | 1.100 | 0.972 |
| 2 | 1.174 | 1.268 | 1.201 | 1.046 | 1.148 | 1.002 | 1.218 | 1.272 | 1.022 | 1.070 | 3.120 | 2.408 | 1.325 | 1.095 | 1.047 | 1.172 |
| 3 | 1.180 | 1.175 | 1.201 | 1.055 | 1.103 | 1.027 | 1.205 | 1.102 | 1.019 | 1.155 | 1.150 | 1.252 | 1.224 | 0.963 | 1.060 | 1.105 |
| 4 | 1.004 | 1.088 | 1.114 | 1.097 | 1.087 | 0.977 | 1.206 | 1.095 | 1.005 | 0.882 | 0.853 | 0.917 | 1.114 | 0.914 | 1.070 | 1.005 |
| 5 | 1.026 | 1.120 | 1.124 | 1.094 | 1.054 | 0.983 | 1.205 | 1.102 | 1.030 | 0.956 | 0.822 | 0.915 | 1.157 | 0.948 | 1.039 | 0.919 |
| 6 | 0.979 | 1.120 | 1.087 | 1.032 | 1.027 | 0.959 | 1.070 | 1.056 | 1.007 | 0.834 | 0.738 | 0.857 | 1.124 | 0.855 | 1.036 | 0.954 |
| 7 | 1.088 | 1.068 | 1.143 | 1.072 | 1.067 | 0.979 | 1.087 | 1.153 | 1.088 | 0.842 | 0.761 | 0.860 | 0.873 | 0.796 | 1.241 | 0.936 |
| 8 | 1.136 | 1.176 | 1.160 | 1.078 | 1.044 | 1.015 | 1.163 | 1.136 | 1.020 | 0.831 | 0.833 | 0.897 | 1.041 | 0.893 | 0.963 | 0.916 |
| LSCT | 1.118 | 1.086 | 1.154 | 1.100 | 1.064 | 1.022 | 1.107 | 1.122 | 1.022 | 0.854 | 0.855 | 0.929 | 1.147 | 0.897 | 0.976 | 0.912 |
| LSCB | 1.126 | - | 1.166 | - | 1.127 | 1.133 | 1.406 | 1.355 | 1.287 | 1.263 | 1.271 | 1.325 | 1.356 | 1.261 | 1.119 | 1.089 |
| LSC3B | 1.125 | - | 1.161 | - | 1.150 | 1.136 | 1.407 | 1.285 | - | 1.228 | 1.216 | 1.317 | 1.352 | 1.211 | 1.038 | 1.055 |

## Ammonia Nitrogen (mgN·L$^{-1}$)

| Date: | 4/5/01 | 4/20/01 | 5/3/01 | 5/17/01 | 5/31/01 | 6/14/01 | 6/28/01 | 7/12/01 | 7/26/01 | 8/9/01 | 8/23/01 | 9/6/01 | 9/20/01 | 10/4/01 | 10/18/01 | 11/1/01 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site: | | | | | | | | | | | | | | | | |
| 1 | 0.104 | 0.084 | 0.062 | 0.012 | 0.026 | 0.012 | 0.076 | 0.079 | 0.005 | 0.005 | 0.017 | 0.032 | 0.057 | 0.010 | 0.058 | 0.005 |
| 2 | 0.407 | 0.813 | 0.073 | 0.019 | 0.041 | 0.011 | 0.080 | 0.069 | 0.005 | 0.005 | 0.036 | 0.719 | 0.099 | 0.225 | 0.061 | 0.070 |
| 3 | 0.267 | 0.203 | 0.073 | 0.013 | 0.016 | 0.011 | 0.028 | 0.012 | 0.005 | 0.013 | 0.013 | 0.026 | 0.038 | 0.005 | 0.054 | 0.064 |
| 4 | 0.071 | 0.093 | 0.027 | 0.005 | 0.017 | 0.010 | 0.026 | 0.005 | 0.005 | 0.005 | 0.022 | 0.020 | 0.046 | 0.013 | 0.060 | 0.005 |
| 5 | 0.068 | 0.092 | 0.055 | 0.013 | 0.017 | 0.012 | 0.037 | 0.005 | 0.005 | 0.005 | 0.018 | 0.025 | 0.024 | 0.005 | 0.005 | 0.005 |
| 6 | 0.027 | 0.021 | 0.011 | 0.013 | 0.022 | 0.009 | 0.035 | 0.005 | 0.005 | 0.025 | 0.018 | 0.029 | 0.030 | 0.005 | 0.005 | 0.005 |
| 7 | 0.075 | 0.130 | 0.043 | 0.092 | 0.035 | 0.015 | 0.068 | 0.091 | 0.005 | 0.089 | 0.030 | 0.018 | 0.086 | 0.005 | 0.077 | 0.028 |
| 8 | 0.005 | 0.005 | 0.005 | 0.005 | 0.020 | 0.013 | 0.026 | 0.005 | 0.005 | 0.005 | 0.014 | 0.017 | 0.027 | 0.005 | 0.005 | 0.005 |
| LSCT | 0.014 | 0.005 | 0.005 | 0.005 | 0.018 | 0.013 | 0.026 | 0.005 | 0.005 | 0.005 | 0.013 | 0.017 | 0.024 | 0.005 | 0.005 | 0.005 |
| LSCB | 0.005 | - | 0.012 | - | 0.022 | 0.028 | 0.022 | 0.005 | 0.005 | 0.005 | 0.012 | 0.010 | 0.016 | 0.005 | 0.005 | 0.005 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LSC3B | 0.010 | - | 0.013 | - | 0.023 | 0.018 | 0.024 | 0.005 | - | 0.005 | 0.005 | 0.016 | 0.019 | 0.005 | 0.005 | 0.005 |

## Chlorophyll a (µg·L$^{-1}$)

| Date: | 4/5/01 | 4/20/01 | 5/3/01 | 5/17/01 | 5/31/01 | 6/14/01 | 6/28/01 | 7/12/01 | 7/26/01 | 8/9/01 | 8/23/01 | 9/6/01 | 9/20/01 | 10/4/01 | 10/18/01 | 11/1/01 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site: | | | | | | | | | | | | | | | | |
| 1 | 0.9 | 1.3 | 11.1 | 3.0 | 3.6 | 3.4 | 2.7 | 5.5 | 4.3 | 4.5 | 5.3 | 7.8 | 3.0 | 4.7 | 2.8 | 3.9 |
| 2 | 0.6 | 1.8 | 7.1 | 1.7 | 3.3 | 5.7 | 4.0 | 5.0 | 4.0 | 6.5 | 15.6 | 7.3 | 3.5 | 6.6 | 1.4 | 2.5 |
| 3 | 0.7 | 1.4 | 5.7 | 1.3 | 2.8 | 3.3 | 3.8 | 3.6 | 5.4 | 3.6 | 12.0 | 4.3 | 3.9 | 5.8 | 2.4 | 3.0 |
| 4 | 0.3 | 1.0 | 3.3 | 3.5 | 3.8 | 2.3 | 3.0 | 3.7 | 5.6 | 3.4 | 2.4 | 1.0 | 0.8 | 1.0 | 4.2 | 4.5 |
| 5 | 1.5 | 0.7 | 3.9 | 2.6 | 3.7 | 3.0 | 4.5 | 3.9 | 5.7 | 7.3 | 4.7 | 3.7 | 3.0 | 4.6 | 3.8 | 4.9 |
| 6 | 0.9 | 0.6 | 2.9 | 3.7 | 5.1 | 2.7 | 3.9 | 4.2 | 7.1 | 7.0 | 8.0 | 3.0 | 3.3 | 5.7 | 4.7 | 5.3 |
| 7 | 0.7 | 2.5 | 8.9 | 2.3 | 5.3 | 3.8 | - | 6.1 | 6.2 | 3.1 | 9.4 | 3.0 | 13.5 | 10.1 | 2.1 | 2.9 |
| 8 | 0.7 | 0.7 | 4.9 | 5.9 | 3.8 | 1.9 | 3.0 | 3.5 | 6.0 | 7.9 | 5.7 | 4.7 | 3.1 | 6.0 | 4.8 | 5.5 |
| LSCT | 0.9 | 1.1 | 2.3 | 4.2 | 4.5 | 2.1 | 0.4 | 4.3 | 6.5 | 8.2 | 6.0 | 4.5 | 2.0 | 5.5 | 4.4 | 5.6 |
| LSCB | 0.6 | - | 0.4 | - | 1.3 | 0.5 | 0.4 | 0.3 | 0.4 | 0.5 | 0.8 | 0.3 | 0.2 | 0.3 | 4.5 | 0.6 |
| LSC3B | 0.9 | - | 0.4 | - | - | 0.4 | 2.9 | 0.3 | - | 0.6 | 0.6 | 0.3 | 0.2 | 0.3 | 1.6 | 0.5 |

## Chloride (mg·L$^{-1}$)

| Date: | 4/5/01 | 4/20/01 | 5/3/01 | 5/17/01 | 5/31/01 | 6/14/01 | 6/28/01 | 7/12/01 | 7/26/01 | 8/9/01 | 8/23/01 | 9/6/01 | 9/20/01 | 10/4/01 | 10/18/01 | 11/1/01 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site: | | | | | | | | | | | | | | | | |
| 1 | - | 36.2 | 41.0 | 42.9 | 43.1 | 41.7 | 35.7 | 43.0 | 42.6 | 43.2 | 41.8 | 43.8 | 43.6 | 43.4 | 41.0 | 39.7 |
| 2 | - | 34.6 | 40.6 | 42.3 | 43.5 | 42.0 | 36.9 | 43.3 | 42.9 | 44.4 | 56.0 | 54.1 | 45.2 | 46.6 | 43.1 | 46.9 |
| 3 | - | 33.3 | 40.6 | 40.4 | 42.6 | 42.0 | 37.9 | 41.0 | 42.6 | 44.4 | 43.5 | 43.3 | 42.8 | 42.2 | 42.2 | 46.7 |
| 4 | - | 36.1 | 39.8 | 43.3 | 43.1 | 42.0 | 39.7 | 41.9 | 42.1 | 44.0 | 39.5 | 41.9 | 43.3 | 44.2 | 41.2 | 45.2 |
| 5 | - | 40.4 | 39.6 | 41.5 | 42.9 | 41.5 | 39.7 | 41.9 | 42.1 | 42.5 | 41.0 | 41.1 | 44.2 | 43.7 | 42.6 | 47.2 |
| 6 | - | 32.2 | 40.6 | 41.4 | 42.6 | 41.4 | 38.8 | 41.9 | 42.1 | 43.0 | 41.0 | 40.4 | 44.1 | 43.7 | 42.2 | 45.2 |
| 7 | - | 42.3 | 41.0 | 43.3 | 43.5 | 42.0 | 36.1 | 43.8 | 44.5 | 44.0 | 41.0 | 43.8 | 44.7 | 43.4 | 41.2 | 45.2 |
| 8 | - | 40.9 | 42.0 | 43.7 | 43.5 | 42.5 | 36.4 | 42.5 | 43.1 | 42.0 | 42.5 | 40.9 | 42.8 | 45.6 | 43.0 | 43.3 |
| LSCT | - | 38.5 | 41.0 | 41.4 | 43.2 | 43.0 | 39.3 | 42.4 | 43.1 | 42.5 | 41.0 | 40.4 | 43.3 | 44.7 | 40.7 | 44.8 |
| LSCB | - | - | 41.5 | - | 42.1 | 42.0 | 42.1 | 42.4 | 42.6 | 42.0 | 40.0 | 39.5 | 43.3 | 43.2 | 41.2 | 42.8 |
| LSC3B | - | - | 41.5 | - | 42.6 | 42.5 | 41.6 | 41.9 | - | 42.0 | 41.5 | 40.9 | 40.9 | 43.2 | 41.2 | 43.3 |

## Turbidity (NTU)

| Date: | 4/5/01 | 4/20/01 | 5/3/01 | 5/17/01 | 5/31/01 | 6/14/01 | 6/28/01 | 7/12/01 | 7/26/01 | 8/9/01 | 8/23/01 | 9/6/01 | 9/20/01 | 10/4/01 | 10/18/01 | 11/1/01 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site: | | | | | | | | | | | | | | | | |
| 1 | 7.7 | 8.1 | 2.0 | 0.9 | 1.6 | 1.2 | 14.0 | 2.0 | 1.1 | 1.4 | 1.8 | 3.5 | 0.8 | 1.9 | 2.4 | 1.6 |
| 2 | 13.5 | 9.1 | 1.6 | 1.6 | 1.4 | 1.4 | 15.5 | 2.6 | 1.1 | 1.4 | 1.8 | 2.0 | 1.1 | 1.2 | 0.9 | 1.2 |
| 3 | 14.7 | 8.3 | 1.9 | 1.3 | 1.1 | 1.6 | 12.3 | 1.6 | 1.2 | 1.4 | 2.4 | 0.8 | 0.6 | 0.8 | 1.0 | 1.2 |
| 4 | 11.2 | 6.3 | 1.7 | 0.9 | 0.9 | 1.4 | 8.5 | 1.2 | 1.1 | 1.0 | 1.2 | 0.5 | 0.6 | 0.3 | 1.3 | 0.8 |
| 5 | 26.7 | 5.3 | 1.4 | 0.9 | 0.7 | 1.1 | 11.7 | 1.0 | 1.2 | 1.4 | 1.3 | 2.0 | 0.6 | 0.8 | 1.0 | 0.8 |
| 6 | 6.5 | 3.2 | 1.1 | 0.8 | 0.8 | 0.8 | 9.7 | 1.0 | 1.3 | 1.4 | 1.8 | 1.2 | 0.6 | 0.7 | 0.9 | 0.9 |
| 7 | 7.4 | 13.6 | 1.9 | 1.2 | 3.8 | 1.3 | 15.0 | 3.1 | 1.6 | 1.2 | 1.8 | 0.8 | 2.7 | 1.6 | 3.3 | 1.1 |
| 8 | 1.6 | 3.1 | 1.0 | 0.8 | 0.8 | 0.6 | 3.7 | 0.7 | 1.3 | 1.3 | 1.2 | 0.7 | 0.8 | 0.6 | 1.0 | 0.9 |
| LSCT | 2.3 | 2.9 | 0.9 | 0.6 | 1.1 | 0.7 | 5.9 | 0.8 | 1.2 | 2.4 | 1.2 | 0.8 | 0.5 | 0.7 | 0.8 | 0.9 |
| LSCB | 1.4 | - | 1.3 | - | 2.2 | 3.3 | 3.5 | 1.7 | 1.5 | 1.4 | 1.5 | 1.4 | 1.2 | 0.8 | 0.8 | 2.3 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LSC3B | 1.4 | - | 1.1 | - | 1.4 | 2.4 | 3.0 | 1.7 | - | 1.4 | 1.7 | 1.6 | 1.1 | 0.8 | 2.5 | 2.0 |

## $CaCO_3$ Turbidity (NTU)

| Date: | 4/5/01 | 4/20/01 | 5/3/01 | 5/17/01 | 5/31/01 | 6/14/01 | 6/28/01 | 7/12/01 | 7/26/01 | 8/9/01 | 8/23/01 | 9/6/01 | 9/20/01 | 10/4/01 | 10/18/01 | 11/1/01 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site: | | | | | | | | | | | | | | | | |
| 1 | 1.1 | 0.9 | 0.1 | 0.0 | 0.3 | 0.2 | 0.3 | 0.2 | 0.1 | 0.2 | 0.2 | 0.4 | 0.1 | 0.2 | 0.1 | 0.1 |
| 2 | 1.1 | 0.4 | 0.1 | 0.3 | 0.1 | 0.1 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | 0.1 | 0.0 | 0.1 |
| 3 | 1.5 | 0.5 | 0.0 | 0.2 | 0.2 | 0.5 | 0.0 | 0.1 | 0.0 | 0.2 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4 | 1.4 | 0.3 | 0.1 | 0.1 | 0.3 | 0.7 | 0.0 | 0.2 | 0.0 | 0.1 | 0.2 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 |
| 5 | 2.0 | 0.2 | 0.1 | 0.1 | 0.1 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 | 0.0 | 0.1 | 0.0 |
| 6 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.1 | 0.1 | 0.4 | 0.4 | 0.2 | 0.1 | 0.1 | 0.2 | 0.1 |
| 7 | 0.4 | 1.2 | 0.1 | 0.3 | 1.1 | 0.2 | 0.5 | 0.6 | 0.1 | 0.0 | 0.2 | 0.1 | 0.4 | 0.1 | 0.4 | 0.0 |
| 8 | 0.5 | 0.8 | 0.1 | 0.1 | 0.3 | 0.1 | 0.5 | 0.1 | 0.0 | 0.0 | 0.1 | 0.0 | 0.2 | 0.0 | 0.1 | 0.0 |
| LSCT | 0.3 | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |
| LSCB | 0.1 | - | 0.0 | - | 0.2 | 0.6 | 0.3 | 0.6 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.4 |
| LSC3B | 0.0 | - | 0.1 | - | 0.1 | 0.1 | 0.1 | 0.2 | - | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 | 0.3 | 0.3 |

## Alkalinity (mg $CaCO_3 \cdot L^{-1}$)

| Date: | 4/5/01 | 4/20/01 | 5/3/01 | 5/17/01 | 5/31/01 | 6/14/01 | 6/28/01 | 7/12/01 | 7/26/01 | 8/9/01 | 8/23/01 | 9/6/01 | 9/20/01 | 10/4/01 | 10/18/01 | 11/1/01 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site: | | | | | | | | | | | | | | | | |
| 1 | 98.4 | 98.4 | 108.5 | 105.6 | 110.0 | 106.0 | 104.6 | 108.3 | 104.9 | 98.2 | 93.7 | 96.6 | 102.3 | 98.5 | 103.0 | 100.7 |
| 2 | 90.7 | 102.9 | 105.7 | 109.1 | 107.8 | 109.7 | 101.1 | 106.8 | 105.1 | 96.3 | 103.0 | 101.5 | 99.1 | 101.5 | 100.6 | 103.0 |
| 3 | 89.1 | 97.2 | 108.1 | 112.9 | 110.2 | 106.8 | 102.0 | 107.8 | 106.8 | 97.4 | 93.4 | 94.3 | 100.1 | 99.1 | 101.1 | 103.0 |
| 4 | 91.0 | 93.9 | 106.2 | 105.2 | 107.8 | 104.0 | 103.0 | 104.9 | 106.4 | 95.8 | 91.0 | 96.3 | 101.1 | 99.1 | 100.1 | 100.1 |
| 5 | 81.5 | 98.6 | 105.2 | 109.0 | 108.3 | 104.9 | 102.5 | 106.4 | 106.4 | 101.1 | 92.9 | 96.7 | 102.0 | 97.2 | 99.6 | 100.1 |
| 6 | 100.5 | 101.4 | 102.9 | 107.1 | 107.8 | 105.2 | 102.0 | 106.8 | 105.4 | 97.7 | 92.9 | 96.3 | 100.9 | 97.7 | 100.1 | 101.5 |
| 7 | 97.6 | 95.3 | 106.2 | 112.8 | 112.1 | 107.8 | 102.7 | 109.7 | 105.4 | 99.1 | 93.9 | 92.4 | 94.8 | 96.9 | 104.0 | 101.1 |
| 8 | 107.1 | 104.3 | 104.3 | 104.3 | 109.2 | 104.0 | 104.0 | 106.5 | 106.4 | 94.8 | 92.4 | 96.3 | 100.6 | 98.2 | 99.9 | 100.1 |
| LSCT | 104.8 | 101.4 | 102.4 | 106.8 | 108.3 | 103.0 | 104.0 | 106.4 | 105.9 | 97.2 | 94.3 | 98.2 | 102.0 | 97.2 | 101.1 | 100.6 |
| LSCB | 107.1 | - | 105.2 | - | 108.3 | 104.0 | 105.4 | 107.8 | 107.8 | 105.9 | 105.9 | 106.4 | 107.3 | 105.9 | 101.1 | 105.9 |
| LSC3B | 105.2 | - | 104.3 | - | 106.8 | 104.0 | 106.8 | 105.9 | - | 104.9 | 105.9 | 106.4 | 105.9 | 105.9 | 104.9 | 104.9 |

## Secchi Disc (m)

| Date: | 4/5/01 | 4/20/01 | 5/3/01 | 5/17/01 | 5/31/01 | 6/14/01 | 6/28/01 | 7/12/01 | 7/26/01 | 8/9/01 | 8/23/01 | 9/6/01 | 9/20/01 | 10/4/01 | 10/18/01 | 11/1/01 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site: | | | | | | | | | | | | | | | | |
| 1 | 0.9 | 0.8 | 1.5 | 3.7 | 2.6 | 3.3 | 0.5 | 2.1 | 3.0 | 2.5 | 2.8 | 3.2 | bottom | 3.7 | bottom | 4.0 |
| 2 | 0.6 | 0.9 | 1.8 | 2.5 | 2.6 | 2.9 | 0.6 | 1.4 | 3.0 | bottom | bottom | bottom | bottom | bottom | bottom | bottom |
| 3 | 0.6 | 1.1 | 1.8 | 3.8 | 3.1 | 2.9 | 0.7 | 2.1 | 3.0 | 3.3 | bottom | bottom | bottom | bottom | bottom | bottom |
| 4 | 0.8 | 1.5 | 3.9 | bottom | bottom | bottom | 1.2 | bottom | bottom | 3.0 | bottom | bottom | bottom | bottom | bottom | bottom |
| 5 | 0.3 | 1.6 | 2.5 | 4.0 | 4.3 | 3.5 | 0.8 | 3.1 | 2.5 | 2.3 | 3.9 | 3.1 | bottom | 5.2 | bottom | bottom |
| 6 | 1.0 | 3.0 | 3.6 | 4.5 | 4.0 | 3.9 | 1.2 | 4.0 | 2.4 | 2.7 | 3.7 | 4.5 | 6.7 | 5.0 | 8.0 | 6.8 |
| 7 | 1.0 | 0.7 | 1.7 | bottom | 1.3 | bottom | 0.6 | 1.4 | 2.2 | 3.2 | bottom | - | bottom | bottom | bottom | bottom |
| 8 | 6.1 | 5.1 | 4.1 | 4.2 | 5.4 | 6.3 | 2.6 | - | 4.0 | 2.0 | 4.4 | 5.5 | 6.0 | 4.0 | 6.0 | 6.5 |
| LSCT | 3.0 | 3.4 | 5.8 | 5.5 | 4.1 | 4.5 | 1.3 | 4.0 | 2.4 | 2.0 | 4.1 | 4.7 | 6.7 | 4.5 | 8.0 | 6.7 |
| LSCB | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LSC3B | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

## Temperature (°C) @ 2m

| Date: | 4/5/01 | 4/20/01 | 5/3/01 | 5/17/01 | 5/31/01 | 6/14/01 | 6/28/01 | 7/12/01 | 7/26/01 | 8/9/01 | 8/23/01 | 9/6/01 | 9/20/01 | 10/4/01 | 10/18/01 | 11/1/01 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site: | | | | | | | | | | | | | | | | |
| 1 | 3.35 | 5.46 | 6.77 | 8.96 | 10.05 | 15.13 | 17.84 | 19.72 | 22.11 | 22.05 | 23.51 | 20.53 | 12.85 | 17.07 | 12.06 | 11.63 |
| 2 | 4.41 | 6.13 | 6.60 | - | 10.10 | - | 17.08 | 20.05 | 22.15 | 23.58 | 23.53 | 20.39 | 16.87 | 17.23 | 12.25 | 10.93 |
| 3 | 4.79 | 6.32 | 6.19 | 9.36 | 10.08 | 14.49 | 16.93 | 19.45 | 21.87 | 22.90 | 23.54 | 20.42 | 14.44 | 17.35 | 12.55 | 10.39 |
| 4 | 4.52 | 4.63 | 6.53 | 8.67 | 10.31 | 13.19 | 16.92 | 18.86 | 21.41 | 22.85 | 23.52 | 20.72 | 16.08 | 17.32 | 12.79 | 10.41 |
| 5 | 4.68 | 5.65 | 6.64 | 8.54 | 9.95 | 16.31 | 16.46 | 19.08 | 21.89 | 22.35 | 23.68 | 20.68 | 13.93 | 17.38 | 12.79 | 11.58 |
| 6 | 3.46 | - | 6.37 | 8.43 | 9.83 | 15.66 | 16.52 | 18.95 | 21.56 | 23.58 | 23.72 | 20.95 | 16.01 | 17.28 | 12.85 | 11.58 |
| 7 | 3.26 | 6.34 | 7.23 | 9.54 | 10.45 | - | 17.02 | 20.57 | 22.32 | 22.74 | 23.54 | 20.38 | 19.21 | 16.85 | 11.32 | 9.99 |
| 8 | 2.69 | 3.23 | 6.75 | 8.79 | 10.15 | 15.14 | 16.99 | 18.19 | 22.13 | 25.36 | 23.74 | 20.97 | 17.89 | 17.49 | 13.75 | 11.59 |
| LSCT | 2.87 | 3.82 | 6.25 | 7.98 | 10.07 | 16.14 | 19.01 | 18.41 | 21.63 | 24.07 | 23.54 | 21.03 | 16.25 | 17.46 | 12.95 | 11.65 |

## Dissolved Oxygen (mg·L$^{-1}$) Site 3

| Date: | 4/5/01 | 4/20/01 | 5/3/01 | 5/17/01 | 5/31/01 | 6/14/01 | 6/28/01 | 7/12/01 | 7/26/01 | 8/9/01 | 8/23/01 | 9/6/01 | 9/20/01 | 10/4/01 | 10/18/01 | 11/1/01 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth: | | | | | | | | | | | | | | | | |
| 0 | 12.2 | 11.1 | 12.0 | 12.1 | 11.5 | 11.1 | 9.1 | 9.8 | 10.6 | 10.6 | 11.1 | 9.9 | 8.3 | 9.7 | 10.1 | 10.4 |
| 1 | 12.2 | 11.1 | 12.7 | 12.1 | 11.9 | 11.1 | 9.3 | 9.8 | 10.5 | 11.2 | 11.0 | 9.9 | 8.0 | 9.7 | 10.1 | 10.4 |
| 2 | 12.1 | 11.0 | 12.6 | 12.2 | 11.6 | 11.3 | 10.1 | 9.8 | 10.4 | 11.3 | 11.0 | 10.0 | 6.7 | 9.7 | 10.2 | 10.5 |
| 3 | 12.1 | 11.7 | 12.6 | 12.2 | 11.3 | 13.1 | 9.4 | 9.5 | 10.3 | 11.5 | 11.0 | 9.5 | 6.6 | 9.7 | 10.2 | 10.5 |
| 4 | 12.0 | 11.7 | 12.7 | 12.2 | 11.6 | 12.8 | - | 9.4 | - | 8.7 | 10.4 | 8.3 | 6.6 | 9.5 | 10.2 | 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 (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 |

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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.