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Cayuga Lake Water Quality Monitoring, Related to the LSC Facility: 1998

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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 1). The discharge from Cornell's LSC facility will enter the southern portion (e.g., south of McKinney's Point) of the lake along the east shore (Figure 1).

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.

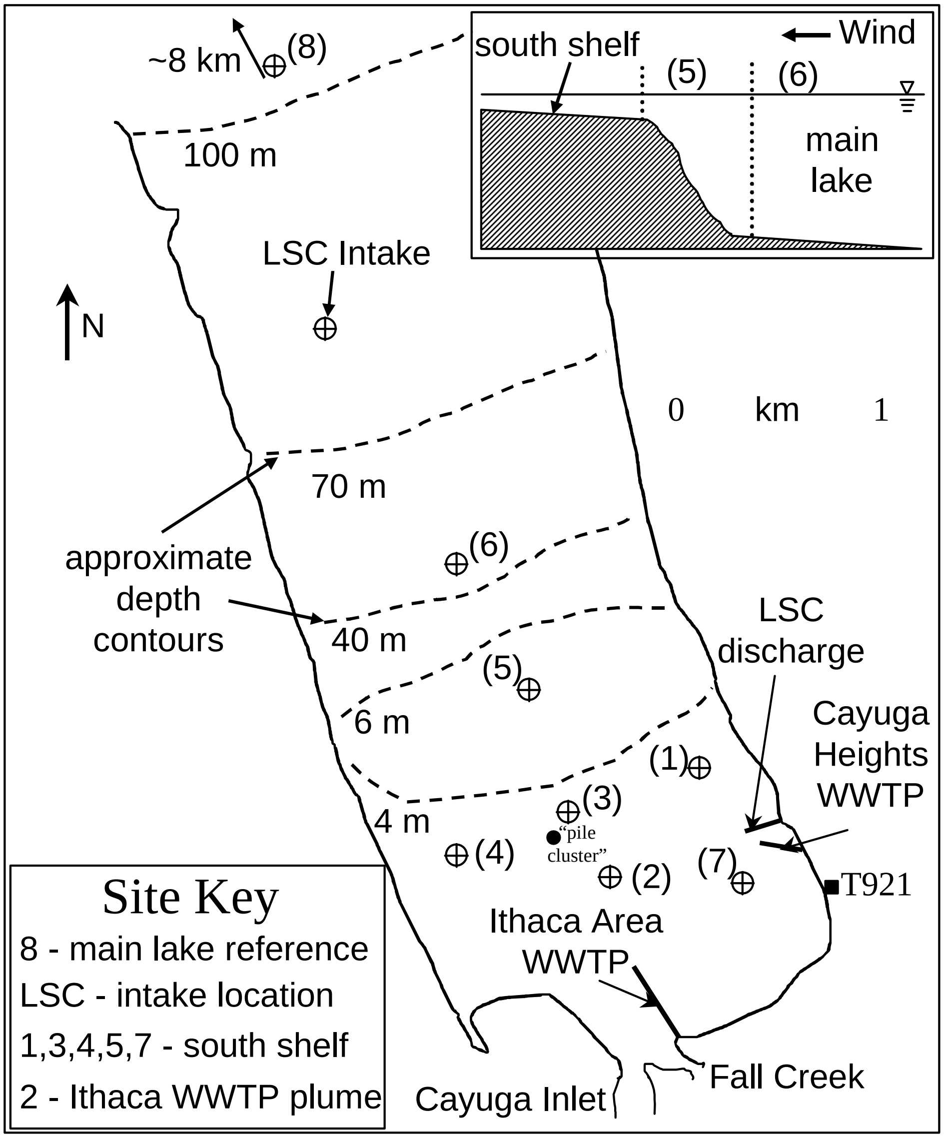

Figure 1a. Sampling sites, setting, approximate bathymetry, for LSC monitoring program, southern end of Cayuga Lake.

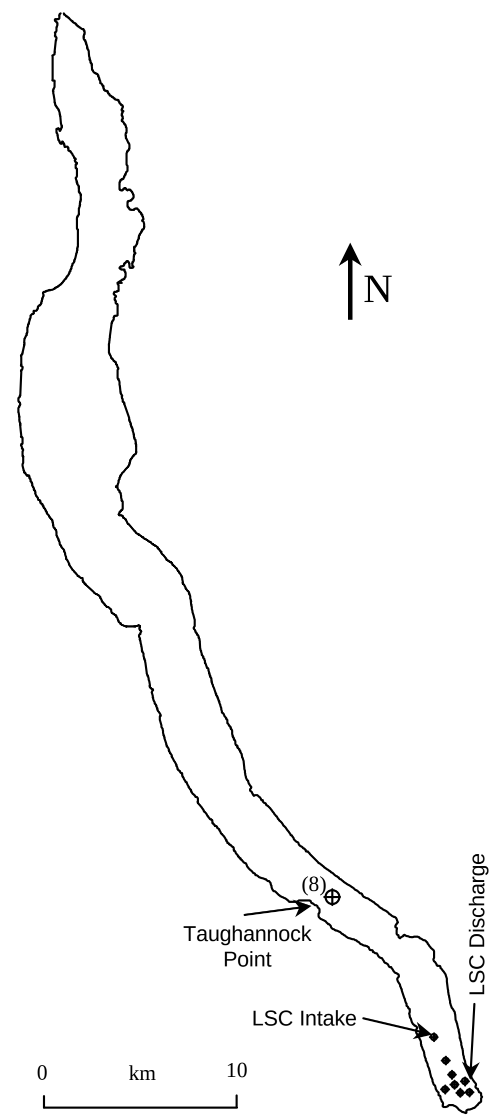

Figure 1b. Sampling sites for LSC monitoring program, within the context of the entire Cayuga Lake basin.

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 are capable of obtaining ("fixing") N from the atmosphere to augment or meet their N requirements. This group of phytoplankton (N-fixing filamentous blue-green algae/cyanobacteria) is generally considered undesirable because they may cause nuisance conditions, such as floating scums.

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

2.1.3. Chloride (Cl^-)/Specific Conductance

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

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

2.1.4. Clarity/Optical Properties

The extent of the penetration of light in water (e.g., ability to see submerged objects), described as clarity, is closely coupled to the public's perception of water quality. Light penetration is particularly sensitive to the concentration, composition and size of particles. In lakes where phytoplankton are the dominant component of the particle population, measures of clarity may be closely correlated to TP concentrations and the concentration of 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 which include not only phytoplankton, but 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 during the summer and fall of 1998, beginning in July and extending through October. Sampling and field measurements were conducted by boat, bi-weekly; a total of 9 monitoring trips were made. Additionally, recording thermistors were deployed continuously at one location; temperature measurements were made hourly over the July – October interval. The thermistors were exchanged biweekly with fresh units for data downloading and maintenance. Deployments made at the end of October (1998) were retrieved at the end of March in 1999. Measurements were recorded on a daily basis over this later interval.

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 1). 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 1). Additionally, two sites (1 and 7) bound the future location of the LSC discharge, paralleling the east shore (Figure 1). The future 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 (Figure 1) 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 1).

Site No.	Latitude	Longitude
1 (discharge boundary)	42°28.3'	76°30.5'
2	28.0'	30.8'
3	28.2'	30.9'
4	28.2'	31.4'
5	28.5'	31.1'
6	28.8'	31.3'
7 (discharge boundary)	28.0'	30.3'
8 (off Taughannock Pt.)	33.0'	35.0'
thermistor "pile cluster"	28.1'	31.0'
LSC Intake	29.4'	31.8'

2.4. Field Measurements/Seabird Profiling

Instrumentation profiles were collected in the field at 9 locations (sites 1 through 8 and the Intake; Figure 1) with a SeaBird profiler. Profiles extended from the surface to within 2m of the lake bottom, or to 20m at deeper sites, for sites, 1 through 8. 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 with a 20 cm diameter black and white quadrant disc (Wetzel and Likens 1991).

Table 2: SeaBird profiler: parameters and utility.

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

2.5. Field Methods

Water samples were collected with a well rinsed Van Dorn sampler or submersible pump, with depths marked on the line/hose. Care was taken that the sampling device was deployed vertically within the water column at the time of sampling. Samples for laboratory analysis (except for coliforms) for sites 1 - 8 were composite-type, formed from equal volumes of sub-samples collected at depths of 0, 2 and 4 meters. The composite-type samples avoid over-representation of the effects of temporary secondary stratification in monitored parameters. Samples (3) for coliform analysis were grab-type; collected from the surface at sites 1 and 7, and as the near-bottom sample at the proposed intake (Figure 1). 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.

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

Analyte	Method No.	Reference	Limit of Detection
total phosphorus	4500-P	APHA (1992)	1 $\mu g \cdot L^{-1}$
soluble reactive phosphorus	4500-P	APHA (1992)	0.5 $\mu g \cdot L^{-1}$
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)	0.5 $\mu g \cdot L^{-1}$
chloride	4500-CL^-	APHA (1992)	0.25 $mg \cdot L^{-1}$
fecal coliform	9222-D	APHA (1992)	-

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.

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 7 on each

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:

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

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 site 7 and another site, that rotated (with the triplicate sampling described above) 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 1998 program (Table 5). The greatest variability was associated with the chlorophyll measurement (Table 5).

Table 5: Precision for triplicate sampling/measurement program for key parameters for 1998, represented by the coefficient of variation.

Parameter	Site 7	Rotating Site
total phosphorus	0.11	0.09
chlorophyll **a**	0.14	0.08
nitrate plus nitrite	0.05	0.03
Secchi disc	0.01	0.01*

* average of Sites 1, 2, 3, 4, 5, 6, 8, LSC

2.7.2. Laboratory Program

The laboratory quality assurance/control program conducted was as specified by the Environmental Laboratory Approval Program (ELAP 1998) of the New York State Health Department. ELAP methods were used to assure precision and accuracy, completeness and comparability (ELAP 1998). 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.

3. Results, 1998

The measurements made in the 1998 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 for selected sites and site groupings. Detailed listings of data are presented in Appendix I. 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" 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 1). 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 WWTP. On several occasions 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 discharge (Figure 1) enriched in these components. This site is omitted in the formation of the "average" from the other sites because the effect is localized, temporally irregular, and is representative of only a relatively small volume of water. Time series for site 2 appear as insets in the time plots (Figure 2) to accommodate the much greater magnitudes of some

Table 6: Summary of results of monitoring program according to site (n=9), 1998.

TP ($\mu gP \cdot L^{-1}$)			
SITE	MEAN	**CV**	**RANGE**
1	29.1	0.58	13.7 – 70.8
2	88.3	0.96	16.6 – 289
3	25.2	0.82	8.7 – 77.9
4	18.2	0.59	6.6 – 34.8
5	16.8	0.32	7.2 – 23.3
6	15.2	0.39	7.0 – 28.8
7	28.7	0.38	9.5 – 44.4
8	13.4	0.20	8.7 – 16.8
LSC	15.2	0.41	7.5 – 28.4

TDN ($mgN \cdot L^{-1}$)			
SITE	MEAN	**CV**	**RANGE**
1	1.52	0.12	1.27 – 1.79
2	2.48	0.81	1.44 – 7.36
3	1.41	0.10	1.20 – 1.64
4	1.38	0.07	1.23 – 1.50
5	1.38	0.09	1.25 – 1.58
6	1.44	0.09	1.27 – 1.65
7	1.40	0.12	1.22 – 1.81
8	1.40	0.11	1.16 – 1.67
LSC	1.37	0.10	1.11 – 1.61

TDP ($\mu gP \cdot L^{-1}$)			
SITE	MEAN	**CV**	**RANGE**
1	6.6	0.43	3.7 – 11.8
2	49.0	1.51	6.5 – 236
3	5.6	0.30	3.0 – 7.6
4	4.9	0.31	2.6 – 7.6
5	4.1	0.50	2.2 – 9.1
6	3.5	0.32	1.7 – 5.8
7	9.7	0.46	5.6 – 16.3
8	4.6	0.49	2.5 – 9.6
LSC	4.9	0.41	2.6 – 9.1

NO_X ($mgN \cdot L^{-1}$)			
SITE	MEAN	**CV**	**RANGE**
1	1.04	0.09	0.95 – 1.23
2	1.20	0.22	0.92 – 1.80
3	1.06	0.09	0.95 – 1.23
4	0.99	0.09	0.84 – 1.14
5	1.02	0.09	0.92 – 1.20
6	1.04	0.07	0.98 – 1.18
7	1.01	0.11	0.93 – 1.30
8	1.02	0.07	0.94 – 1.14
LSC	1.02	0.08	0.89 – 1.16

SRP ($\mu gP \cdot L^{-1}$)			
SITE	MEAN	**CV**	**RANGE**
1	3.0	1.07	0.1 – 8.7
2	40.4	1.67	2.5 – 212
3	1.7	0.61	0.7 – 3.5
4	1.1	0.72	0.4 – 2.4
5	0.7	0.60	0.3 – 1.4
6	0.6	0.46	0.3 – 1.1
7	5.0	0.81	0.4 – 11.0
8	0.7	0.70	0.1 – 1.6
LSC	1.3	1.08	0.3 – 4.7

T-NH_3 ($mgN \cdot L^{-1}$)			
SITE	MEAN	**CV**	**RANGE**
1	0.035	1.15	0.005 – 0.121
2	0.764	1.68	0.053 – 3.852
3	0.103	1.92	0.008 – 0.590
4	0.017	0.55	0.010 – 0.031
5	0.018	0.60	0.006 – 0.033
6	0.016	0.83	0.001 – 0.040
7	0.039	0.37	0.019 – 0.061
8	0.022	1.16	0.001 – 0.073
LSC	0.011	0.69	0.002 – 0.024

Table 6 (cont.): Summary of results of monitoring program according to site (n=9).

CHL A (µg·L^{-1})			
SITE	MEAN	**CV**	**RANGE**
1	5.5	0.78	1.1 – 15.6
2	5.2	0.70	2.1 – 12.5
3	4.2	0.63	1.4 – 10.2
4	3.7	0.65	1.2 – 8.1
5	4.0	0.40	1.4 – 6.4
6	4.7	0.27	1.8 – 6.1
7	5.2	0.68	0.7 – 12.7
8	4.3	0.27	2.3 – 5.7
LSC	4.5	0.29	2.3 – 6.6

Temperature (°C)			
SITE	MEAN	**CV**	**RANGE**
1	19.2	0.23	12.4 – 23.4
2	18.6	0.25	9.8 – 23.7
3	19.1	0.21	12.1 – 23.4
4	19.0	0.22	11.8 – 23.2
5	19.5	0.20	12.9 – 23.7
6	19.8	0.18	14.3 – 23.7
7	18.2	0.28	8.4 – 23.6
8	19.9	0.18	13.9 – 23.9
LSC	19.9	0.17	14.1 – 23.7

Cl (mg·L^{-1})			
SITE	MEAN	**CV**	**RANGE**
1	39.3	0.02	38.2 – 40.3
2	39.7	0.02	38.9 – 40.8
3	39.4	0.02	38.2 – 40.6
4	39.1	0.02	38.2 – 39.9
5	39.0	0.02	38.0 – 40.1
6	39.0	0.02	38.2 – 40.1
7	40.3	0.03	39.2 – 42.1
8	39.1	0.02	38.1 – 39.6
LSC	39.5	0.02	38.2 – 40.3

Beam Attenuation Coeff. (m^{-1})			
SITE	MEAN	**CV**	**RANGE**
1	2.57	0.28	1.32 – 3.85
2	3.65	0.45	1.42 – 6.33
3	2.31	0.33	1.02 – 3.54
4	1.72	0.34	1.08 – 2.82
5	2.29	0.28	1.31 – 2.93
6	2.53	0.65	1.27 – 6.74
7	2.67	0.59	1.22 – 6.47
8	1.94	0.29	1.22 – 2.85
LSC	2.43	0.53	1.31 – 5.31

T_n(NTU)			
SITE	MEAN	**CV**	**RANGE**
1	2.9	1.06	0.7 – 11.2
2	10.2	2.31	1.3 – 75.0
3	6.7	2.35	0.7 – 50.0
4	3.1	1.82	0.6 – 18.4
5	1.6	0.54	0.6 – 3.4
6	2.0	1.02	0.6 – 7.3
7	2.4	0.86	0.8 – 7.0
8	1.4	0.54	0.5 – 2.5
LSC	1.7	1.01	0.5 – 6.2

K_s (m^{-1}) **Attenuation Coeff**			
SITE	MEAN	**CV**	**RANGE**
1	0.61	0.32	0.29 – 0.87
2	0.96	0.32	0.53 – 1.43
3	0.74	0.54	0.42 – 1.71
4	0.56	0.27	0.43 – 0.88
5	0.52	0.28	0.31 – 0.73
6	0.56	0.78	0.24 – 1.69
7	1.06	0.55	0.42 – 2.43
8	0.40	0.29	0.26 – 0.59
LSC	0.52	0.63	0.23 – 1.29

Table 6 (cont.): Coliform results, 1998.

Date 1998	**Coliform Concentrations cfu·100 ml^{-1}***		
	Site 7	**Site 1**	**LSC, bottom**
July 30**	<2	<2	6
August 14	20	30	20
August 27	0	0	0
September 10	100	40	<2
September 24	30	10	20
October 8	20	20	4
October 22	28	12	28

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

** fecal coliforms, results for all other days are total coliforms

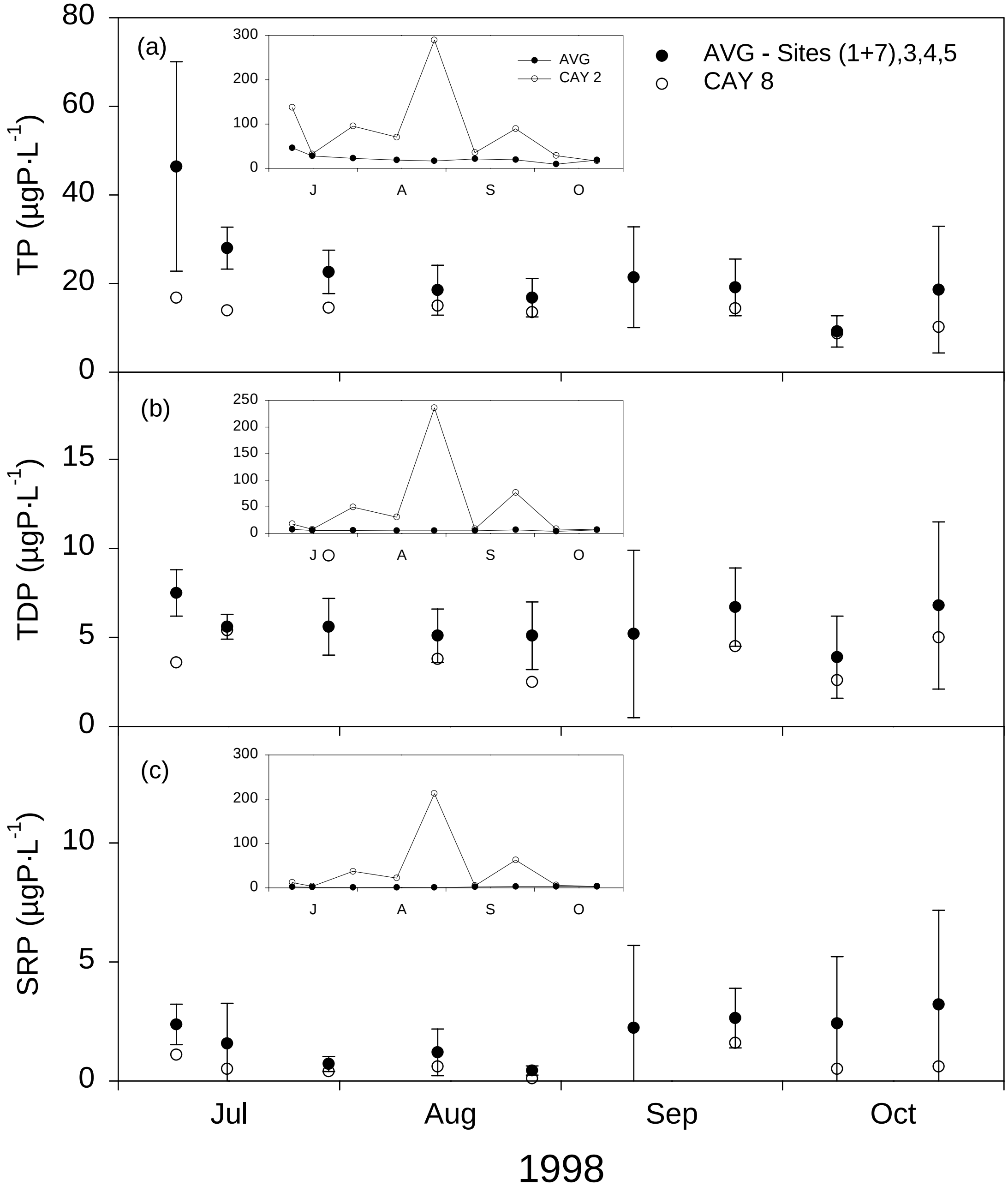

Figure 2 a-c. Time-series of parameter values for Cayuga Lake for 1998: (a) TP, (b) TDP, and (c) SRP. Insets present results for site 2. Results for the "shelf" are averages; the dimensions of the bars are ± 1 standard deviation.

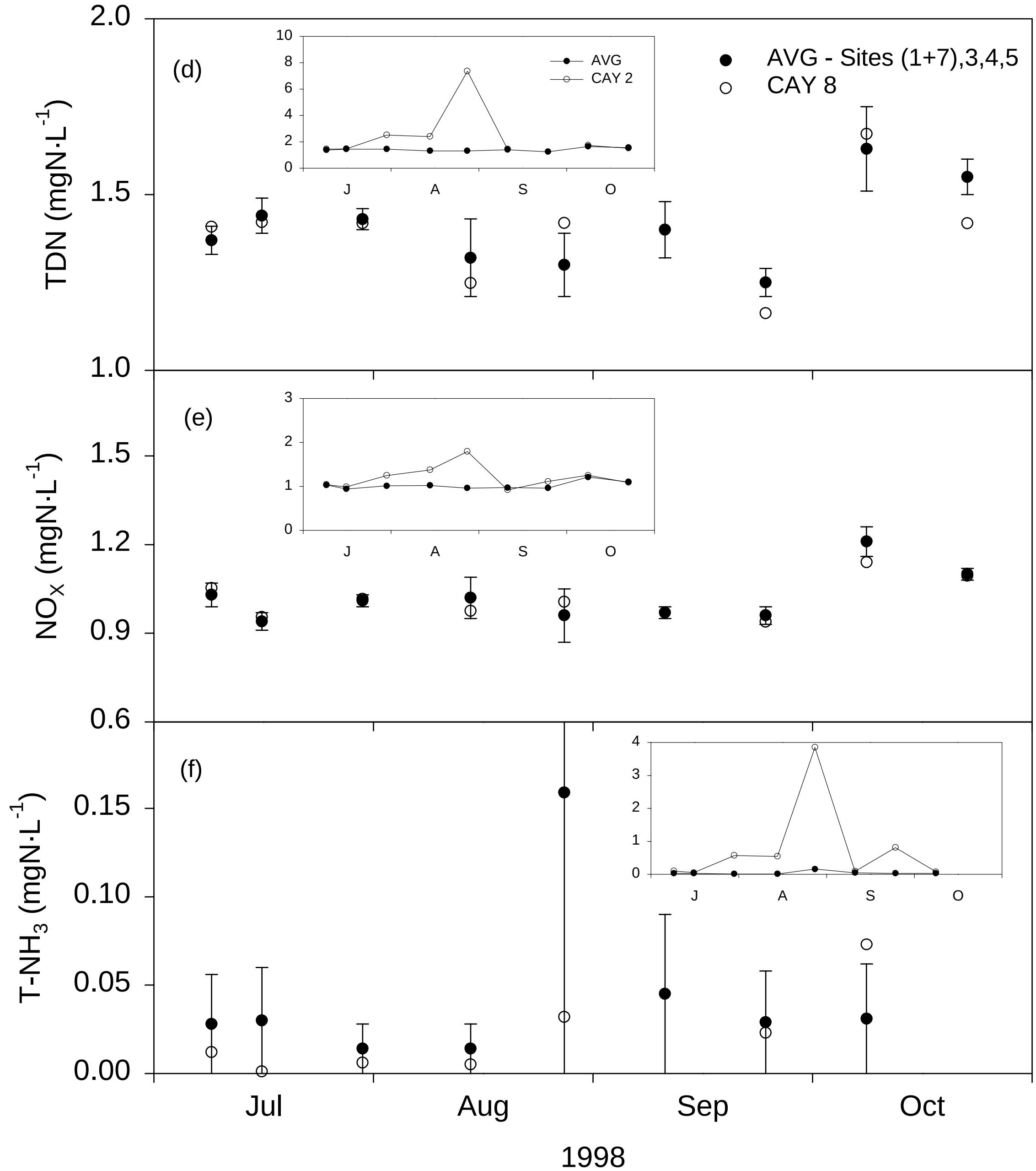

Figure 2 d-f. Time-series of parameter values for Cayuga Lake for 1998: (d) TDN, (e) NO_X, and (f) T-NH_3. Insets present results for site 2. Results for the "shelf are averages; the dimensions of the bars are ± 1 standard deviation.

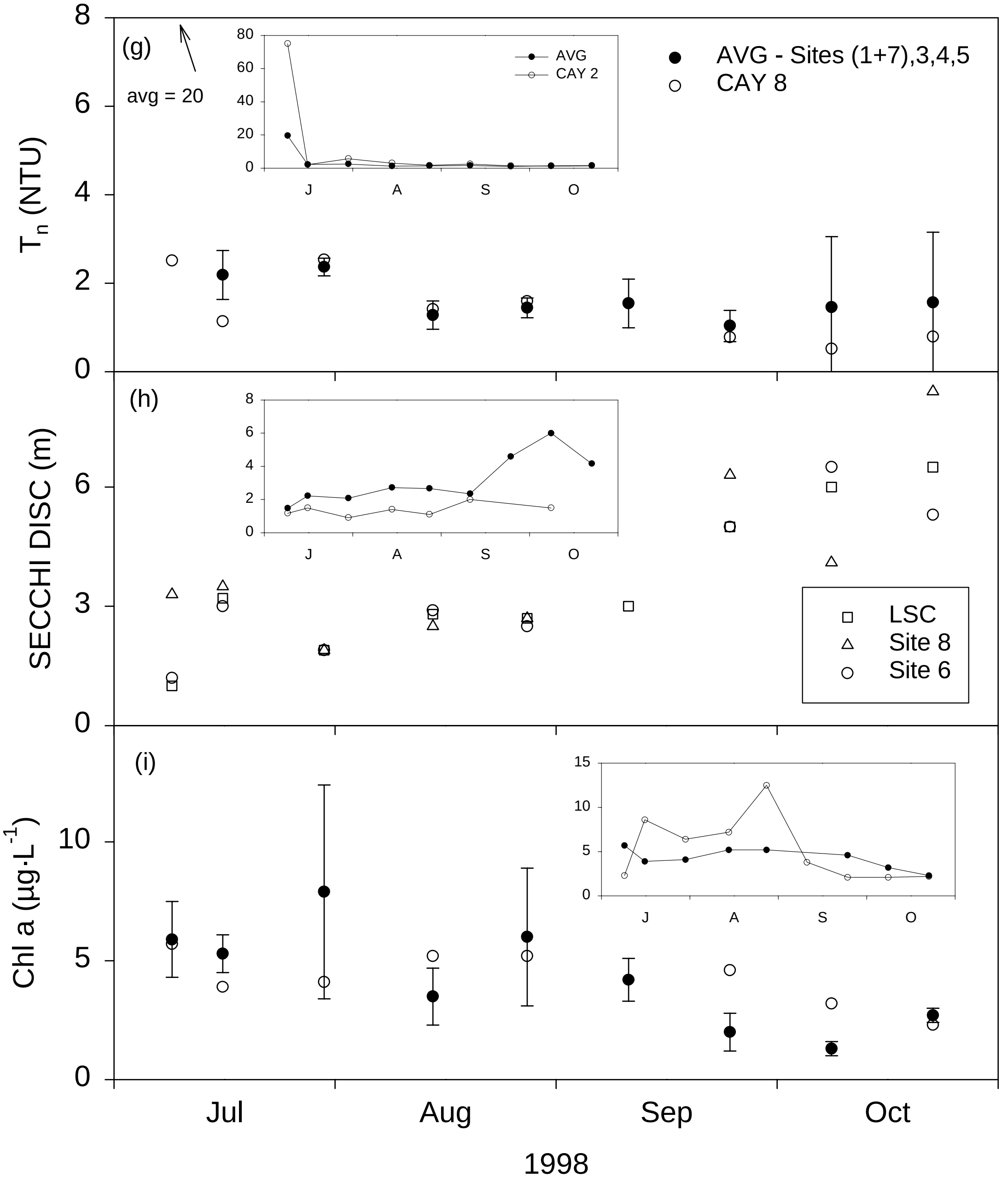

Figure 2 g-i. Time-series of parameter values for Cayuga Lake for 1998: (g) T_n, (h) Secchi disc, and (i) Chl a. Insets present results for site 2. Results for the "shelf" are averages; the dimensions of the bars are ± 1 standard deviation

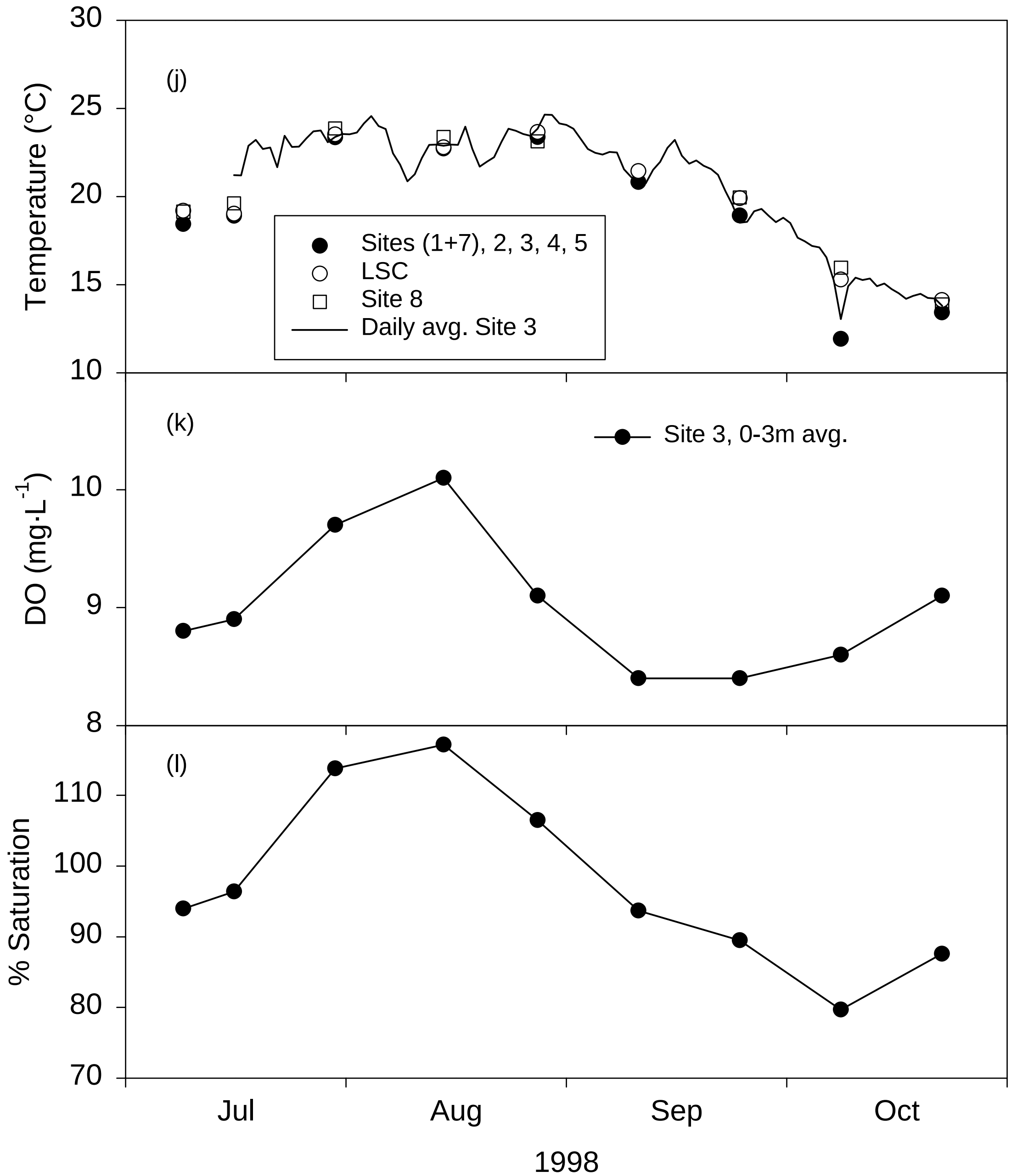

Figure 2 j-l. Time-series of parameter values for Cayuga Lake for 1998: (j) temperature, (k) DO, and (l) % saturation of the observations for this site, and still allow resolution of temporal structure observed for other locations. The Secchi disc plot (Figure 2h) presents observations for the deeper sites (where observations were always < bottom depth); sites 6, LSC, and 8. Paired profiles of temperature, the beam attenuation coefficient (BAC), and fluorescence obtained at LSC on each of the nine monitoring dates of 1998 are also presented (Figure 3).

Noteworthy features of the 1998 observations include (see Figures 2 and 3, and Table 6):

1. site 2 was enriched in all three forms of phosphorus (TP, TDP, and SRP), total dissolved nitrogen (TDN) and ammonia ($T\text{-}NH_3$), and had higher turbidity (T_n) compared to the other monitored sites.

2. site 8 had the lowest concentration of total phosphorus (TP) and turbidity (T_n), on average, of the monitored sites.

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.

4. variance of measures of trophic state (chlorophyll **a**, TP, and T_n) was greater for the south shelf sites than for deep water sites (LSC and site 8).

5. clarity, as measured by Secchi disc transparency (SD) and turbidity (T_n), was the lowest in the southern end of the lake on the first monitoring day (early July).

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

7. two-thirds to three-quarters of the phosphorus was in a particulate form [e.g., (TP-TDP)/TP] over the monitored period (exclusive of site 2).

8. average concentrations of TP, TDP, SRP, and $T\text{-}NH_3$ were higher in the eastern portion (sites 1 and 7), compared to other sites (4 and 5) in the southern end of the lake.

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.

10. temperatures were relatively uniform over the monitored bounds of the upper waters of the lake during the period of measurements, except in early October.

11. dissolved oxygen concentrations were within 20% of saturation (equilibrium with the atmosphere) over the study interval.

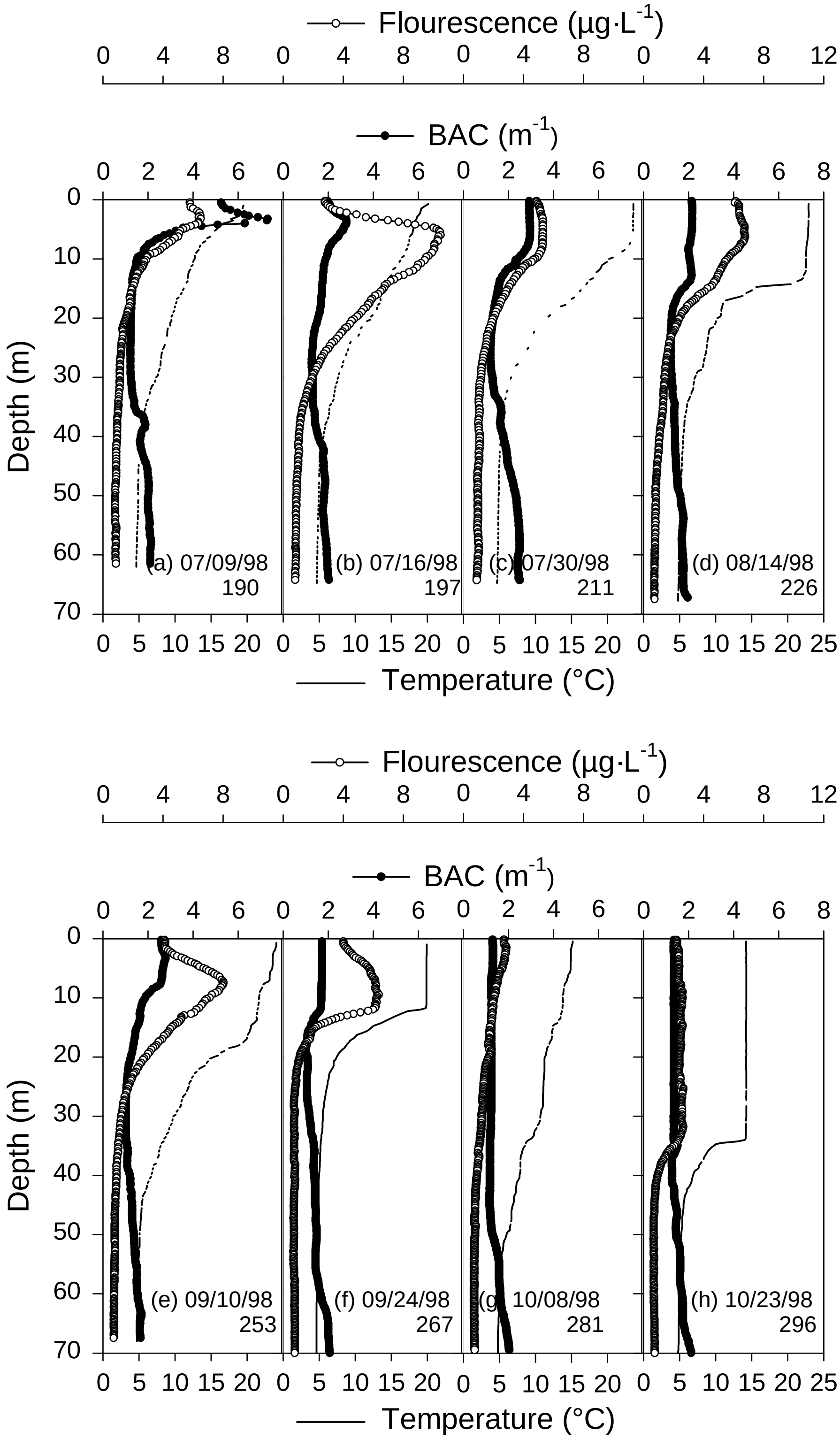

Figure 3. Vertical profiles of temperature, fluorescence, and beam attenuation coefficient for LSC site in 1998: (a) July 9, (b) July 16, (c) July 30, (d) August 14, (e) September 10, (f) September 24, (g) October 8, and (h) October 23.

12. concentrations of coliforms were well below public health limits for contact reaeration at all monitored sites (LSC, and sites 1 and 7) on all monitored dates.

13. there was no evidence for the occurrence of particularly high turbidity layers (benthic nepheloid layers) in the deeper portions of the LSC site.

14. fluorometry profiles indicate subsurface peaks in phytoplankton concentrations occurred at the LSC site during the stratification period of 1998. These peaks occurred above, or at, the maximum temperature (i.e., density) gradient, in depths less than 15 meters.

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 occasionally observed to extend beyond the lake depth at sites 1, 2, 3, 4, 5 and 7 during the 1998 study interval. 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. It may be prudent to consider an alternate representation of clarity that does not have these limitations. Turbidity (T_n) represents a reasonable alternative, in systems where particles regulate clarity (Effler 1988).

The relationship between SD and T_n is evaluated in the inverse format (e.g., Effler 1988) in Figure 4. A linear relationship is expected (Effler 1988) and is manifested in the observations, particularly if the values for site 2 are omitted (Figure 4). Omission of site 2 values is justified based on the likely greater contribution of dissolved (light absorbing) components to SD within the plume of the WWTP. Based on these results (Figure 4), T_n should be considered as an alternate, and apparently more robust, measure of light penetration in shallow portions of the monitored area. The relationship between SD and T_n 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 and loading estimates are presented for the Ithaca and Cayuga Heights wastewater treatment plants (WWTPs) for 1998 (Table 7), based on flow and concentration data made available by these facilities. Discharge flows are measured continuously at these facilities. Concentrations of total phosphorus (TP) in the effluents are measured twice per week at the Ithaca WWTP and once per week at the Cayuga WWTP. The estimates of the monthly loads (Table 7) are the product of the monthly average flows and concentrations.

Other estimation techniques may result in modest differences in these loads. The rather wide differences in loading rate for the Ithaca WWTP (Table 7) in the study interval largely reflect variations in effluent concentration (all observations were below the permit requirement of 1 mg·L^{-1}).

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

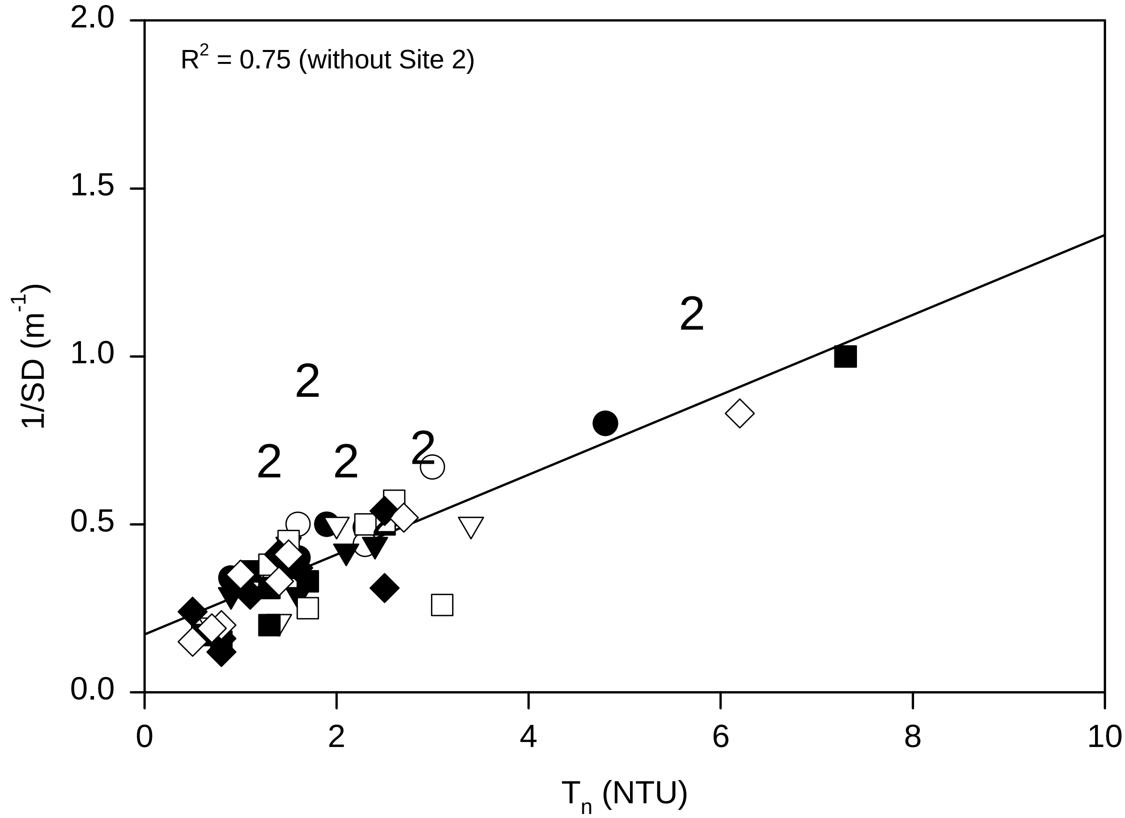

Figure 4. Evaluation of the relationship between Secchi disc transparency (SD) and turbidity in the southern end of Cayuga Lake.

Table 7. These were developed for what was described in that document as an "average hydrologic year". The estimates were based on historic data for these two tributaries. Tributary loads can vary substantially year-to-year, based on natural variations in runoff. Further, the tributary phosphorus loads of Table 7 were not for TP, but rather total soluble phosphorus (see Bouldin (1975) for analytical protocols), to better represent the potential for these inputs to support plant growth.

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

Month	**Ithaca WWTP* ($kg \cdot d^{-1}$)**	**Cayuga Heights WWTP* ($kg \cdot d^{-1}$)**	**Tributary† ($kg \cdot d^{-1}$)**
May	14.1	8.7	29.0
June	5.8	7.5	15.8
July	16.4	4.4	8.8
August	17.0	4.7	6.0
September	32.8	7.7	7.5
October	16.2	9.1	13.1
Mean	*17.1*	*7.0*	*13.3*

* total phosphorus, from facility permit reporting; 1998

† total soluble phosphorus, for average hydrologic year; 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 natural variations in tributary flow and wind speed should be considered 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 1998 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 1). These conditions are placed in a historic perspective by comparison to available records. The record for Fall Creek is quite long, about 75 years; the wind data base reflects 16 years of measurements. Daily measurements of Fall Creek flow and wind speed for 1998 are compared to time-series of daily median values for the available records (Figure 5a and c). Additionally, monthly average flows for the study period are compared to quartiles for the period of record (Figure 5b). Winds out of the north to northwest have been delineated to identify intervals expected to drive the greatest turbulence, and thus resuspension, in the southern end of Cayuga Lake.

Three substantial short-term runoff events occurred in April and May, but usually the flow was less than the historic median level over this interval (Figure 5a). Peak flows were lower in June and July, but elevated flows were much more sustained (Figure 4a); the monthly average flows equaled the 75 percentile level in June and exceeded it in July (Figure 5b). Runoff levels were lower and much less variable over the August – October interval of 1998; these flows were close to the median of long-term observations (Figure 5a). Values for TP (Figure 2a) and T_n (Figure 2g) on the southern "shelf" were conspicuously higher at the start of measurements in July of 1998, soon after the extended runoff interval, compared to the other observations in the monitoring interval.

Major wind events (e.g., protracted intervals of high winds) did not occur over the study interval of 1998 (Figure 5c). Wind velocities were distinctly above average on, or before, the monitoring days of early September and late October (Figure 5c).

4.4 Limitations in Measures of Trophic State on the Shelf

Circumstantial scientific evidence, provided by the findings for 1998 (Figure 2), indicates that T_n and TP are systematically flawed indicators of the trophic state on the south 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 to the measures of TP and T_n on the south shelf. There are at least three lines of circumstantial evidence supporting this position, based on the 1998 observations.

1. the highest TP (Figure 2a) and T_n (Figure 2g) values reported over the study on the south shelf were observed after the prolonged high runoff interval of late June and early July (Figure 5a), at the start of the monitoring program. This suggests greater contributions of non-phytoplankton particles received in runoff to the measurements of TP and T_n.

2. the ratio of chlorophyll **a** to particulate P (PP) was often substantially lower on the south shelf than at the deep stations (Figure 6) 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 below the range of values commonly associated with phytoplankton biomass (e.g., Bowie et al. 1985).

3. 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**

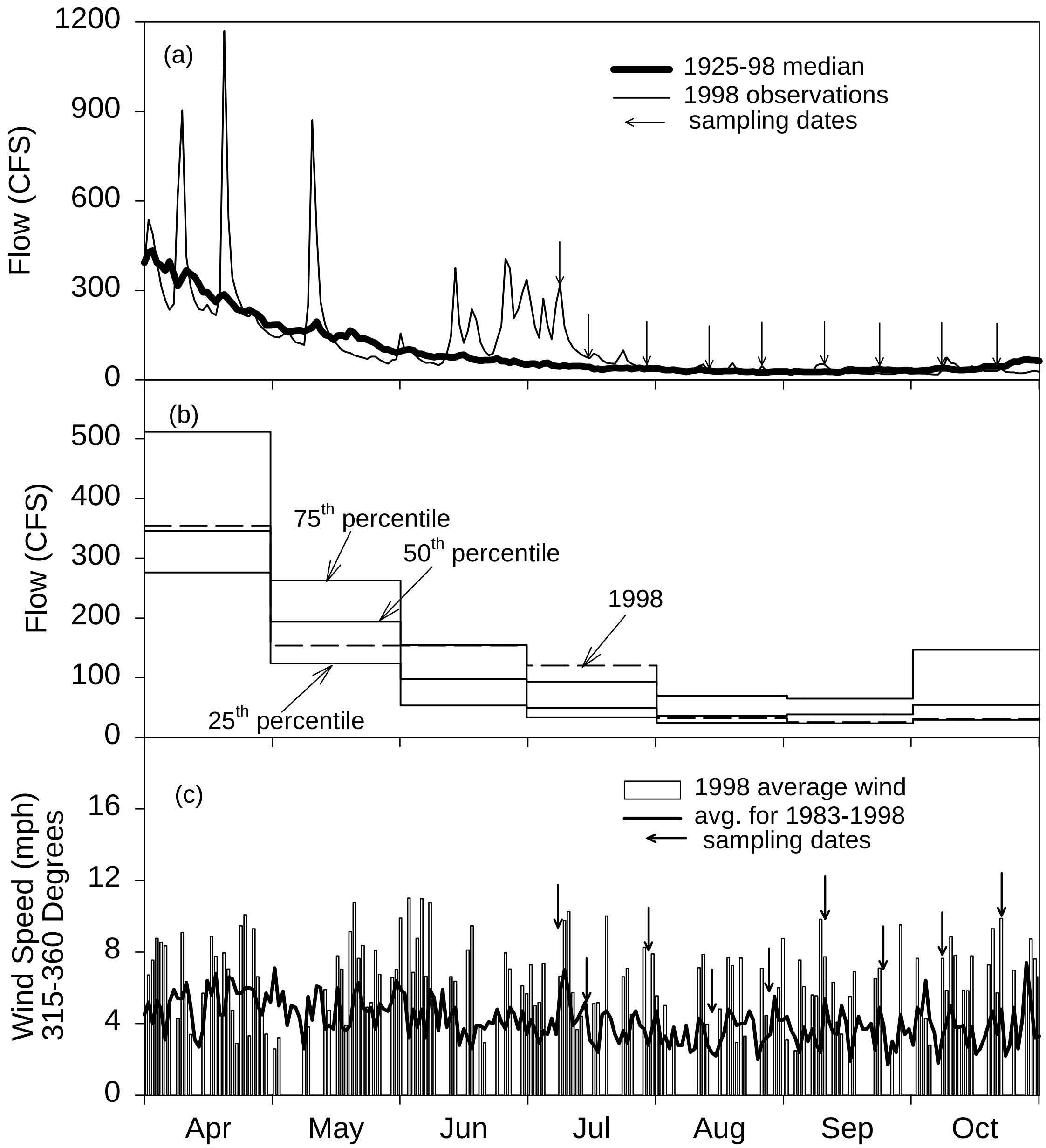

Figure 5. Runoff and wind conditions for the April – October interval of 1998: (a) daily average flows in Fall Creek compared to median daily values for the 1925 – 1998 record, (b) monthly flows in 1998 compared to quartile levels of flow for the 1925 – 1998 record, and (c) daily average wind speed.

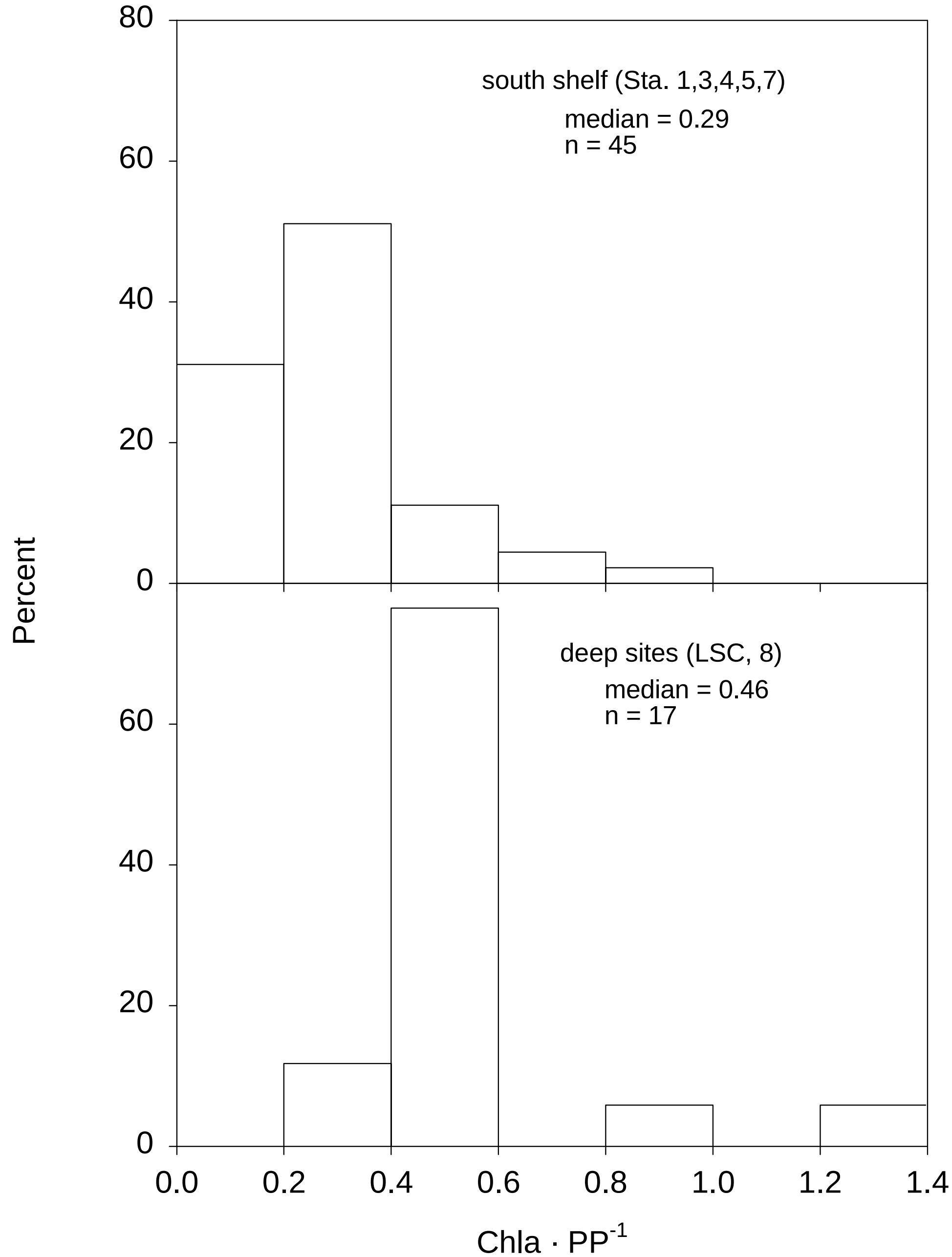

Figure 6. Comparison of distributions of the chlorophyll **a** (Chl **a**) to particulate P (PP) ratio values in Cayuga Lake in 1998: (a) south shelf sites, and (b) deep – water sites

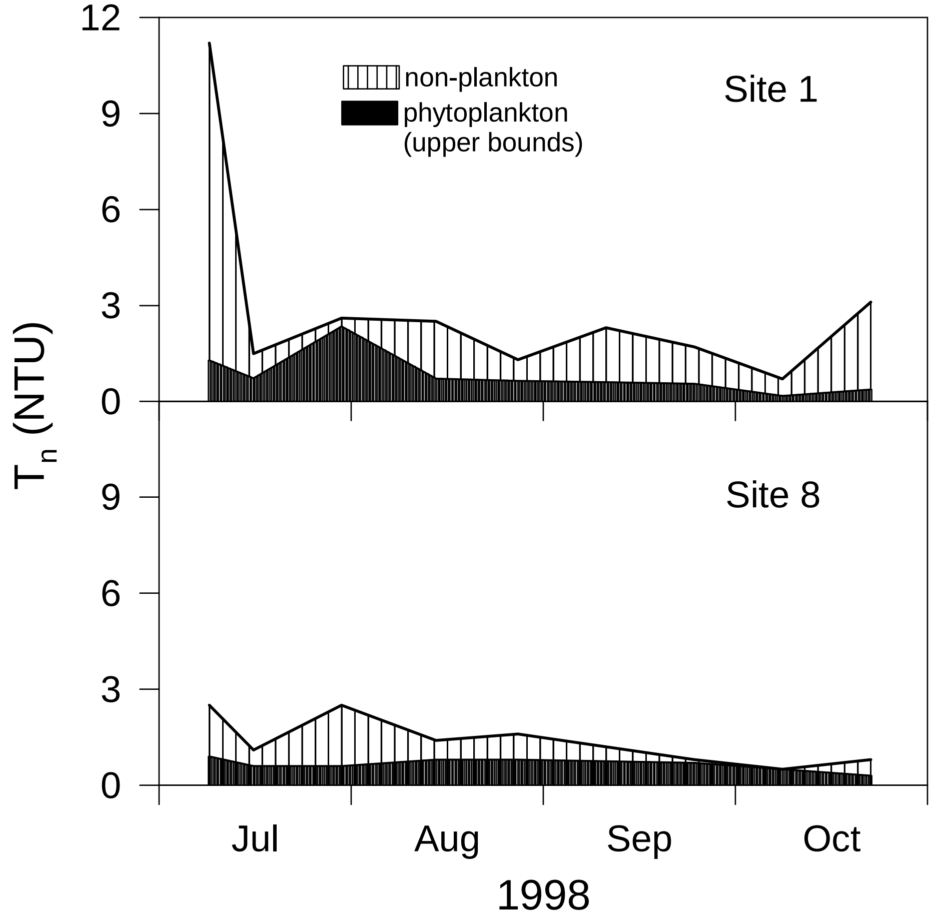

Figure 7. Comparisons of time-series for the July – October interval of 1998, T_n versus the upper bound contribution of phytoplankton : (a) site 1, and (b) site 8.

observations indicate that non-phytoplankton particles make greater contributions to T_n on the south shelf than in deep waters (Figure 7).

The 1998 results suggest substantial seasonal and interannual differences could occur for TP and SD on the south shelf that are uncoupled from the trophic state issue. Additional measurements have been added to the 1999 LSC monitoring program to more comprehensively resolve the constituents/processes regulating the SD and TP measurements. The protocols adopted for these additional analyses have been described in the scientific literature (Effler et al. 1998, Auer et al. 1998). These results will yield insights that will be valuable to water quality managers of this system.

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

Degradation 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 8 and 9). 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 southern shelf and deeper locations (Tables 8 and 9). The record will continue to be updated annually, for both a deep water location and the southern shelf, over the 1998 – 2002 period based on monitoring sponsored by Cornell University related to operation of the LSC facility.

Annual summer (June – August) average concentrations are presented for the lake's upper waters (Tables 8 and 9). Sources of data are included. Higher TP concentrations were observed on the southern shelf compared to deeper portions of the lake in 1994, 1995, 1996 and 1998 (Table 8). 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 in 1998. 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 8: Summer (June - August) average total phosphorus (TP) concentrations for the upper waters of Cayuga Lake.

Year	Total Phosphorus (µg·L^{-1}) Deep-Water Location(s)	Southern Shelf	Source
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	26.5	this report

Δ Myers Point
x one sample, multiple sites and depths
* averages of 0 m observations
+ July – August, 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 9: Summer (June – August) average chlorophyll **a** (Chl **a**) concentrations for the upper waters of Cayuga Lake

Year	Chlorophyll a (µg·L^{-1}) Deep-Water Location(s)	Southern Shelf	Source
1966*	2.8	-	Hamilton 1969
1968**	4.3	-	Wright 1969
1968 – 1970	4.8	-	Oglesby 1978
1970	3.7	-	Trautmann et al. 1982
1972	10.3	-	Olgelsby 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	5.7	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 µg L^{-1} has been used as the demarcation between oligotrophy and mesotrophy (Dobson et al. 1974, National Academy of Science 1972). There is less agreement for the demarcation between mesotrophy and eutrophy; the boundary summer average value reported from different sources (e.g., Dobson et al. 1974, National Academy of Science 1972, Great Lakes Group 1976) ranges from 8 to 12 µg L^{-1}.

The average chlorophyll **a** concentration for Cayuga Lake for this synoptic program (3.5 µg L^{-1}) is compared to the values measured in the other ten Finger Lakes in Figure 8. These data support Cayuga Lake's classification as mesotrophic. Six of the lakes had average concentrations lower than observed for Cayuga Lake (Figure 8). Two of the lakes, Canandaigua and Skaneateles, had concentrations consistent with oligotrophy, while two (Conesus and Honeoye) bordered on eutrophy (Figure 8).

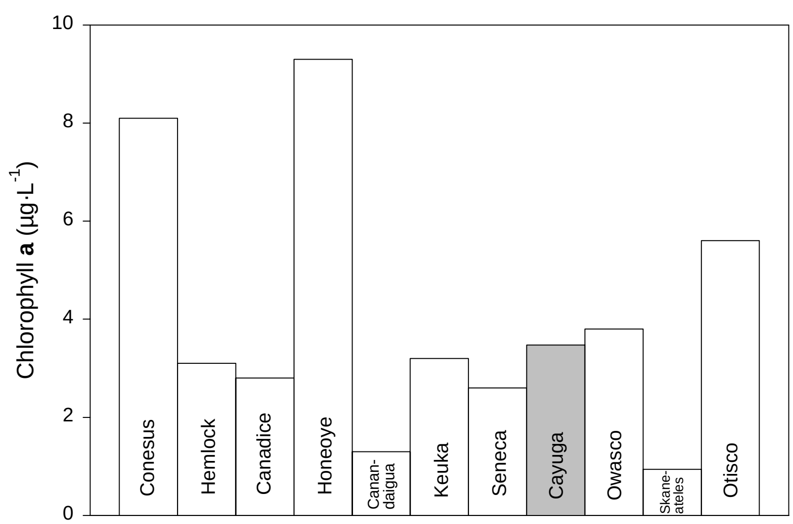

Figure8. Comparison of average chlorophyll **a** concentrations for the spring-early fall interval for the eleven Finger Lakes, based on samples (n=15 to 16) collected over the 1996 through 1999 interval (data from Callinan et al. 2000).

5. Summary

This report presents the design and salient findings of a water quality monitoring study conducted for Cayuga Lake in 1998, sponsored by Cornell University. This study was the precursor of a monitoring program that will be conducted annually, at least through 2002. The primary goal is to support long-term records of trophic state indicators, including concentrations of total phosphorus (TP) and chlorophyll and Secchi disc transparency (SD), and other measures of water quality, for the southern shallow portion of Cayuga Lake ("south shelf"). The program design more than meets the permit obligations associated with the Lake Source Cooling (LSC) facility; e.g., including additional parameters and sites (nine, including one representative of the "main" lake). Thus this program represents a contribution by Cornell to the increased understanding and protection of this invaluable resource and ecosystem. A report of this type will be prepared each year, that will describe seasonal and spatial patterns, noteworthy phenomena, and evaluate the extent to which changes occur between years.

A number of noteworthy findings are reported here for 1998 that have value for lake management. For example, Secchi disc is not a valid measure of clarity on the south shelf as the value is often greater than the lake depth. Turbidity (T_n) is demonstrated to be a viable surrogate measure of this feature of water quality. Features of the data collected provide substantial support for the position that T_n and TP are systematically flawed indicators of the trophic state on the south shelf compared to the open waters of the lake, because of the greater contribution of non-phytoplankton particles to these measures on the south shelf.

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Appendix I

Data Listing

Total Phosphorus (μgP·L^{-1})

Date:	7/9/98	7/16/98	7/30/98	8/14/98	8/27/98	9/10/98	9/24/98	10/8/98	10/22/98
Jd:	190	197	211	226	239	253	267	281	295
Site:									
CAY 1	70.8	19.4	23.8	24.7	13.7	33.0	22.1	19.2	35.6
CAY 2	137.6	32.2	95.1	70.1	289.2	35.5	89.4	28.8	16.6
CAY 3	77.9	30.5	19.3	23.0	22.8	15.6	17.1	8.7	12.2
CAY 4	34.8	33.4	28.0	12.1	13.3	12.2	12.5	6.6	11.1
CAY 5	23.3	23.3	17.7	15.5	14.0	20.1	18.9	7.2	11.0
CAY 6	28.8	14.8	17.0	13.4	14.4	14.7	16.3	7.0	10.6
CAY 7	28.2	30.4	26.7	22.3	20.4	42.6	33.4	9.5	44.4
CAY 8	16.8	13.9	14.5	15.0	13.5	-	14.4	8.7	10.2
LSC	28.4	20.0	18.4	12.8	12.6	13.0	13.6	7.5	10.6

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

Date:	7/9/98	7/16/98	7/30/98	8/14/98	8/27/98	9/10/98	9/24/98	10/8/98	10/22/98
Jd:	190	197	211	226	239	253	267	281	295
Site:									
CAY 1	9.2	5.3	4.3	4.4	3.7	8.0	4.3	8.7	11.8
CAY 2	18.0	7.5	49.5	30.4	236.1	8.1	76.9	8.1	6.5
CAY 3	7.1	5.6	5.0	6.6	7.6	3.3	7.3	3.0	4.9
CAY 4	6.1	5.5	7.6	4.7	5.0	3.1	5.3	2.6	4.4
CAY 5	9.1	4.8	3.8	3.2	3.1	2.2	4.6	2.5	4.0
CAY 6	3.7	5.8	3.9	3.4	3.0	2.7	4.0	1.7	3.4
CAY 7	6.1	7.8	7.7	7.3	5.6	16.3	14.6	6.5	15.9
CAY 8	3.6	5.4	9.6	3.8	2.5	-	4.5	2.6	5.0
LSC	6.4	5.8	4.2	9.1	4.7	2.6	3.2	3.7	4.1

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

Date:	7/9/98	7/16/98	7/30/98	8/14/98	8/27/98	9/10/98	9/24/98	10/8/98	10/22/98
Jd:	190	197	211	226	239	253	267	281	295
Site:									
CAY 1	3.7	0.4	0.4	0.4	0.1	4.8	1.7	8.7	7.3
CAY 2	12.0	3.4	37.1	22.1	212.5	4.6	62.8	6.4	2.5
CAY 3	3.5	1.1	1.1	2.5	0.7	0.8	3.2	1.5	1.2
CAY 4	2.1	0.5	0.7	0.5	0.4	0.4	2.4	1.1	1.4
CAY 5	1.4	0.6	0.3	0.4	0.4	0.3	1.0	0.5	1.1
CAY 6	1.1	0.6	0.3	0.6	0.3	0.4	0.9	0.5	0.6
CAY 7	1.3	7.8	1.0	2.4	0.4	10.1	6.2	4.5	11.0
CAY 8	1.1	0.5	0.4	0.6	0.1	-	1.6	0.5	0.6
LSC	1.3	0.3	0.4	1.8	4.7	0.5	0.9	0.5	1.0

Total Nitrogen Unfiltered (mgN·L^{-1})

Date:	7/9/98	7/16/98	7/30/98	8/14/98	8/27/98	9/10/98	9/24/98	10/8/98	10/22/98
Jd:	190	197	211	226	239	253	267	281	295
Site:									
CAY 1	1.52	1.36	1.45	1.21	1.19	1.85	1.01	1.82	2.07
CAY 2	1.54	1.43	2.57	2.25	7.08	1.56	1.93	1.92	1.53
CAY 3	1.46	1.32	1.48	1.51	1.20	1.54	1.13	1.73	1.55
CAY 4	1.42	1.34	1.60	1.36	1.02	1.54	0.96	1.56	1.61
CAY 5	1.44	1.57	1.43	1.28	1.29	1.55	0.94	1.66	1.62
CAY 6	1.47	1.73	1.38	1.17	1.30	1.60	1.18	1.68	1.85
CAY 7	1.45	1.38	1.44	1.26	1.37	1.59	1.07	2.22	1.55
CAY 8	1.42	1.33	1.43	1.23	1.19	-	0.97	1.66	1.51
LSC	1.45	1.29	1.45	1.18	1.28	1.51	0.98	1.66	1.54
LSCB	-	1.46	1.87	1.39	1.53	1.72	1.17	1.77	1.67

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

Date:	7/9/98	7/16/98	7/30/98	8/14/98	8/27/98	9/10/98	9/24/98	10/8/98	10/22/98
Jd:	190	197	211	226	239	253	267	281	295
Site:									
CAY 1	1.07	0.96	1.01	1.01	1.00	1.02	0.95	1.23	1.15
CAY 2	1.04	0.99	1.25	1.37	1.80	0.92	1.11	1.25	1.09
CAY 3	1.04	0.95	1.04	1.13	1.05	0.96	0.98	1.23	1.13
CAY 4	0.97	0.90	1.01	0.99	0.84	0.95	0.96	1.14	1.10
CAY 5	1.06	0.93	1.00	0.99	0.99	0.99	0.92	1.20	1.10
CAY 6	1.06	0.98	1.01	1.00	1.01	0.98	1.04	1.18	1.12
CAY 7	1.02	0.97	0.99	0.95	0.93	0.96	0.99	1.30	1.03
CAY 8	1.05	0.96	1.02	0.98	1.01	-	0.94	1.14	1.09
LSC	1.04	0.97	1.00	1.00	1.02	0.97	0.89	1.16	1.09
LSCB	-	1.15	1.26	1.24	1.32	1.27	1.27	1.34	1.25

Ammonia Nitrogen (mgN·L^{-1})

Date:	7/9/98	7/16/98	7/30/98	8/14/98	8/27/98	9/10/98	9/24/98	10/8/98	10/22/98
Jd:	190	197	211	226	239	253	267	281	295
Site:									
CAY 1	0.065	0.016	0.005	0.010	0.017	0.121	0.042	0.005	-
CAY 2	0.100	0.053	0.569	0.549	3.852	0.096	0.812	0.078	-
CAY 3	0.020	0.045	0.008	0.026	0.590	0.024	0.020	0.093	-
CAY 4	0.015	0.018	0.015	0.010	0.011	0.031	0.030	0.005	-
CAY 5	0.017	0.026	0.015	0.006	0.011	0.033	0.031	0.005	-
CAY 6	0.018	0.011	0.001	0.008	0.013	0.028	0.040	0.005	-
CAY 7	0.054	0.047	0.033	0.019	0.032	0.061	0.025	0.041	-
CAY 8	0.012	0.001	0.006	0.005	0.032	-	0.023	0.073	-
LSC	0.012	0.006	0.002	0.007	0.011	0.019	0.024	0.005	-
LSCB	-	0.018	0.006	0.005	0.019	0.010	0.024	0.005	-

CHLOROPHYLL A ($\mu g \cdot L^{-1}$)

Date:	7/9/98	7/16/98	7/30/98	8/14/98	8/27/98	9/10/98	9/24/98	10/8/98	10/22/98
Jd:	190	197	211	226	239	253	267	281	295
Site:									
CAY 1	8.6	4.8	15.6	4.8	4.3	4.0	3.7	1.1	2.5
CAY 2	2.3	8.6	6.4	7.2	12.5	3.8	2.1	2.1	2.2
CAY 3	5.2	4.3	5.0	3.2	10.2	4.5	1.4	1.6	2.5
CAY 4	6.5	5.4	8.1	2.0	3.4	3.0	1.4	1.2	2.5
CAY 5	4.1	6.4	4.1	4.8	5.0	5.2	2.3	1.4	2.7
CAY 6	5.0	5.5	5.6	5.1	5.0	6.1	4.8	1.8	3.7
CAY 7	7.2	5.6	12.7	3.1	6.4	4.4	2.4	0.7	3.9
CAY 8	5.7	3.9	4.1	5.2	5.2	-	4.6	3.2	2.3
LSC	5.4	6.6	4.5	4.5	4.7	5.2	4.8	2.3	2.7
LSCB	7.9	0.4	0.5	0.2	0.6	0.4	0.5	0.5	0.4

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

Date:	7/9/98	7/16/98	7/30/98	8/14/98	8/27/98	9/10/98	9/24/98	10/8/98	10/22/98
Jd:	190	197	211	226	239	253	267	281	295
Site:									
CAY 1	-	-	-	-	-	40.3	38.2	39.2	39.6
CAY 2	-	-	-	-	-	38.9	40.8	39.6	39.6
CAY 3	-	-	-	-	-	39.2	38.2	39.6	40.6
CAY 4	-	-	-	-	-	39.9	38.2	38.7	39.6
CAY 5	-	-	-	-	-	40.1	38.0	39.2	38.7
CAY 6	-	-	-	-	-	40.1	38.2	38.7	39.2
CAY 7	-	-	-	-	-	40.6	39.2	42.1	39.3
CAY 8	-	-	-	-	-	-	38.1	39.6	39.6
LSC	-	-	-	-	-	40.3	38.2	39.9	39.6
LSCB	-	-	-	-	-	40.3	38.2	39.6	40.6

TURBIDITY (NTU)

Date:	7/9/98	7/16/98	7/30/98	8/14/98	8/27/98	9/10/98	9/24/98	10/8/98	10/22/98
Jd:	190	197	211	226	239	253	267	281	295
Site:									
CAY 1	11.2	1.5	2.6	2.5	1.3	2.3	1.7	0.7	3.1
CAY 2	75.0	2.1	5.7	2.9	1.7	2.5	1.5	1.3	1.4
CAY 3	50.0	3.0	2.3	1.3	1.6	1.4	0.9	0.7	0.8
CAY 4	18.4	2.1	2.4	0.9	1.6	1.0	0.6	0.6	0.8
CAY 5	3.4	2.0	2.6	1.2	1.5	1.5	1.4	0.6	0.7
CAY 6	7.3	1.3	2.6	1.1	1.5	1.7	1.3	0.6	0.8
CAY 7	1.9	1.9	1.6	0.8	0.9	2.3	0.9	7.0	4.8
CAY 8	2.5	1.1	2.5	1.4	1.6	-	0.8	0.5	0.8
LSC	6.2	1.4	2.7	1.0	1.5	1.1	0.8	0.5	0.7
LSCB	-	2.5	2.5	2.0	2.5	2.0	1.7	2.0	2.0

$CaCO_3$ TURBIDITY (NTU)

Date:	7/9/98	7/16/98	7/30/98	8/14/98	8/27/98	9/10/98	9/24/98	10/8/98	10/22/98
Jd:	190	197	211	226	239	253	267	281	295
Site:									
CAY 1	2.4	0.0	1.5	0.7	0.1	0.8	0.6	0.3	1.6
CAY 2	14.4	0.3	1.2	0.5	0.0	1.0	0.6	0.5	0.4
CAY 3	8.6	0.4	1.3	0.3	0.6	0.2	0.3	0.2	0.2
CAY 4	3.1	0.3	1.4	0.4	0.8	0.3	0.2	0.2	0.2
CAY 5	0.5	0.3	1.7	0.5	0.7	0.5	0.4	0.3	0.1
CAY 6	1.3	0.2	1.6	0.6	0.2	0.6	0.3	0.2	0.2
CAY 7	0.2	0.3	0.6	0.3	0.1	0.6	0.2	6.6	1.2
CAY 8	0.4	0.1	1.8	0.9	0.8	-	0.2	0.0	0.3
LSC	1.1	0.3	1.8	0.6	0.7	0.5	0.2	0.1	0.1
LSCB	-	0.4	0.2	0.4	0.1	0.5	0.5	0.8	0.3

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

Date:	7/9/98	7/16/98	7/30/98	8/14/98	8/27/98	9/10/98	9/24/98	10/8/98	10/22/98
Jd:	190	197	211	226	239	253	267	281	295
Site:									
CAY 1	111.3	109.1	108.4	104.4	100.5	102.1	99.5	125.1	103.4
CAY 2	111.3	108.9	123.1	112.3	133.0	100.5	108.4	128.1	100.1
CAY 3	108.4	-	107.4	103.4	103.4	99.5	99.5	127.1	101.5
CAY 4	110.3	107.8	108.4	99.5	98.5	99.5	98.5	123.1	100.5
CAY 5	109.3	108.7	106.4	103.9	98.5	99.5	99.5	124.1	100.5
CAY 6	109.3	-	107.4	102.4	98.5	100.5	100.5	124.1	101.5
CAY 7	108.0	107.7	106.1	100.1	98.8	97.2	101.8	129.4	103.8
CAY 8	108.4	106.7	107.4	101.0	99.5	-	100.5	120.2	102.4
LSC	110.3	110.8	108.4	103.9	99.2	100.5	100.5	120.5	101.5
LSCB	-	111.1	111.3	107.9	112.3	137.9	113.3	129.0	102.4

SECCHI DISK (m)

Date:	7/9/98	7/16/98	7/30/98	8/14/98	8/27/98	9/10/98	9/24/98	10/8/98	10/22/98
Jd:	190	197	211	226	239	253	267	281	295
Site:									
CAY 1	1.9	2.2	1.8	2.0	2.6	2.0	4.0	B	3.9
CAY 2	1.2	1.5	0.9	1.4	1.1	2.0	B	1.5	B
CAY 3	1.5	1.5	2.3	2.8	2.0	2.5	B	B	B
CAY 4	0.5	2.4	2.3	3.4	3.5	B	B	B	B
CAY 5	2.0	2.0	1.9	2.7	2.3	2.3	4.8	B	5.0
CAY 6	1.0	3.2	1.9	2.8	2.7	3.0	5.0	6.0	6.5
CAY 7	B	2.0	2.5	B	3.0	2.0	B	B	1.3
CAY 8	3.3	3.5	1.9	2.5	2.7	-	6.3	4.1	8.4
LSC	1.2	3.0	1.9	2.9	2.5	-	5.0	6.5	5.3

Temperature (°C) @ 2m

Date:	7/9/98	7/16/98	7/30/98	8/14/98	8/27/98	9/10/98	9/24/98	10/8/98	10/22/98
Jd:	190	197	211	226	239	253	267	281	295
Site:									
CAY 1	18.74	19.13	23.25	22.90	23.42	20.33	-	13.23	12.35
CAY 2	18.46	18.72	22.94	22.40	23.72	19.77	17.78	9.84	13.34
CAY 3	18.76	18.77	23.28	22.54	23.35	20.98	18.32	12.14	13.62
CAY 4	17.71	18.91	23.33	22.70	23.15	21.06	18.94	11.84	13.79
CAY 5	18.89	19.12	23.72	22.90	23.46	21.36	19.28	12.89	14.12
CAY 6	18.82	19.48	23.73	22.90	23.43	21.38	19.76	14.27	14.27
CAY 7	18.14	18.55	22.92	22.56	23.62	19.42	18.30	8.44	11.94
CAY 8	19.15	19.62	23.87	23.39	23.14	-	19.96	15.97	13.89
LSC	19.20	19.03	23.52	22.79	23.65	21.45	19.91	15.30	14.13

Dissolved Oxygen (mg·L^{-1}) Station 3

Date:	7/9/98	7/16/98	7/30/98	8/14/98	8/27/98	9/10/98	9/24/98	10/8/98	10/22/98
Jd:	190	197	211	226	239	253	267	281	295
Depth:									
0	9.95	8.99	9.10	9.18	8.92	8.52	9.14	9.19	9.78
1	9.86	9.04	8.87	9.12	9.12	8.27	8.95	8.62	9.42
2	9.10	9.36	8.83	8.99	9.06	8.13	8.85	8.04	9.32
3	8.60	9.13	8.82	8.94	8.94	8.07	8.83	8.20	9.31
4	8.33	8.65	6.97	8.98	7.76	7.92	8.79	7.63	-