March 31, 2008

Cayuga Lake Water Quality Monitoring, Related to the LSC Facility: 2007

Prepared by:

DeFrees Hydraulics Laboratory

School of Civil and Environmental Engineering

Cornell University

Ithaca, NY 14853-3501

Sponsored by:

Cornell University

Department of Utilities and Energy Management

Table of Contents

Table of Tables

Table of Figures

Preface

This report summarizes the results of water quality monitoring efforts related to the LSC facility in 2007. This monitoring program began in 1998 and was performed annually by the Upstate Freshwater Institute (UFI) until 2006. In 2007 water sample collection and generation of the report was taken over by the DeFrees Hydraulics Laboratory of the School of Civil and Environmental Engineering at Cornell University. UFI continues to carry out all laboratory analysis. This report is largely based on previous annual reports written by UFI.

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-a, 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 enters the southern portion (south of McKinney's Point) of the lake along the east shore (Figure 1). 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 human activity. 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 two forms of P measured in this monitoring program, total P (TP) 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). SRP is measured on filtered (0.45 μm) samples. SRP is a component of the total dissolved phosphorus (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.

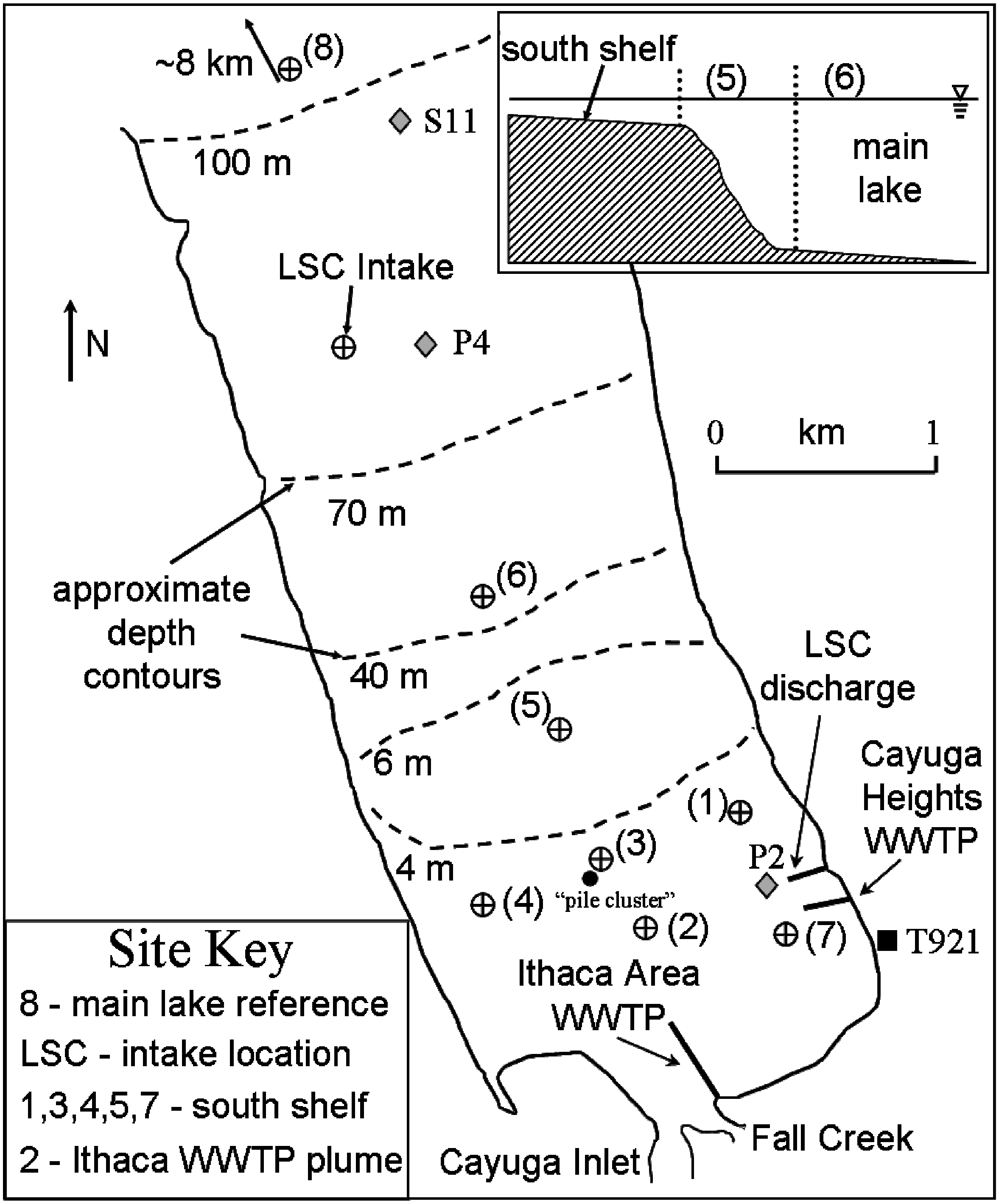

Figure 1: Sampling sites, setting, approximate bathymetry, for LSC monitoring program, southern end of Cayuga Lake. Sites sampled during 1994 – 1996 study (P2, P4 and S11; Stearns and Wheler 1997) are included for reference. Locations of sampling sites and outfalls are approximate.

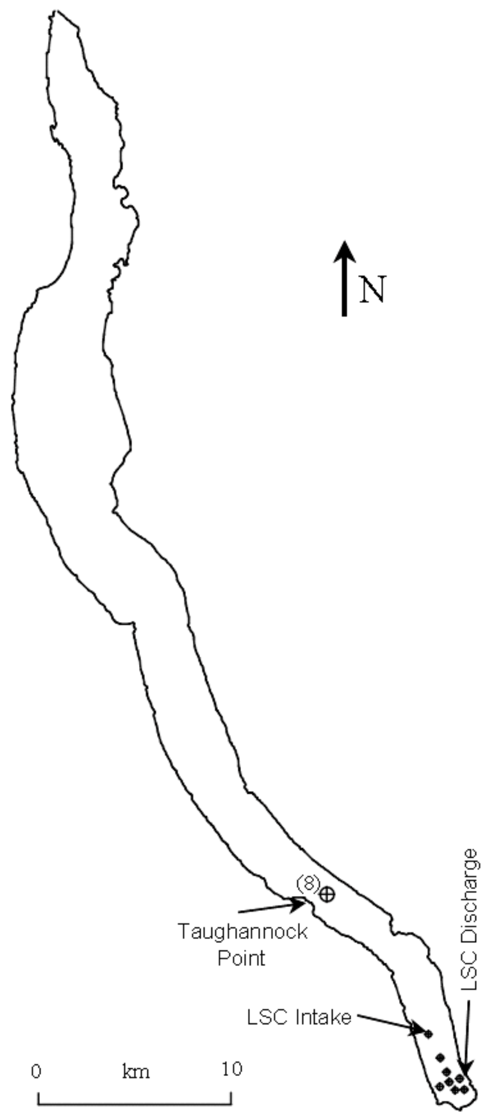

Figure 2: Sampling sites for LSC monitoring program, within the context of the entire Cayuga Lake basin.

2.1.2. Clarity/Optical Properties

The extent of the penetration of light in water (the 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-a). 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.

2.1.3. Chlorophyll/Fluorescence

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

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

2.1.4. Temperature

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

2.2. Timing

Lake sampling and field measurements were conducted by boat during the spring to fall interval of 2007, beginning in mid-April and extending through late October. The full suite of laboratory and field measurements was made for 16 bi-weekly monitoring trips. Additionally, recording thermistors were deployed continuously at one location; temperature measurements were made hourly over the mid-April to late October interval. The thermistors were exchanged periodically with fresh units for data downloading and maintenance. Thermistors deployed in October 2006 were recovered in April 2007. Deployments made in late October 2007 will be retrieved in April 2008. Measurements are recorded on a daily basis over this latter interval. Laboratory measurements of phosphorus concentration (TP and SRP), turbidity (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 (i.e. grid) has been adopted that provides a robust representation of the southern portion of the lake (Figure 1 and Figure 2). 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). Additionally, the intake location for the LSC facility and site 8, located further north as a reference for the main lake conditions, were also sampled. Positions (latitude, longitude) for the nine 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 north-south along the main axis of the lake (Figure 1). Additionally, two sites (1 and 7) bound the location of the LSC discharge, paralleling the east shore (Figure 1). 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 1) was used to assess the accuracy of the GPS for each monitoring trip.

Table 1: Latitude, longitude and lake depth at ambient water quality monitoring program sites (refer to Figure 1). 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

Secchi disc transparency was measured at all sites with a 20 cm diameter black and white quadrant disc (Wetzel and Likens 1991).

2.5. Field Methods

Water samples were collected with a submersible pump, with depths marked on the hose. Care was taken that the sampling device was deployed vertically within the water column at the time of sampling. Samples for laboratory analysis were composite-type, formed from equal volumes of sub-samples collected at depths of 0, 2 and 4 meters for sites 5, 6, LSC Intake, 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 or 0, 2 and near bottom if the depth was between 3 and 4 m. The composite-type samples avoid over-representation of the effects of temporary secondary stratification in monitored parameters. 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 2. Detection limits for these analyses are also included. Most of these laboratory analyses are "Standard Methods". Results below the limit of detection are reported as ½ the limit of detection. Chlorophyll-a concentrations were determined by spectrophotometric assay (Parsons et al. 1984). Specifications adhered to for processing and preservation of samples, containers for samples, and maximum holding times before analyses, are summarized in Table 3.

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 2: 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 $\mu g \cdot L^{-1}$
turbidity	2130-B	APHA (1992)	-
Chlorophyll-a		Parsons et al. (1984)	0.4 $\mu g \cdot L^{-1}$
	445.0	USEPA (1992)	0.4 $\mu g \cdot L^{-1}$

2.7.1. Field Program

Precision of sampling and sample handling was assessed by a program of field replicates. Samples for laboratory analyses were collected in triplicate at site 1 on each sampling day. Triplicate samples were collected at one of the other numbered stations (sites 2-8) each monitoring trip. This station was rotated each sampling trip through the field season. Secchi disc (SD) measurements were made in triplicate by two technicians at all sites throughout the field season, each reported SD value in this report is the mean of all six measurements at each site. Precision was generally high for the triplicate sampling/measurement program, as represented by the average values of the coefficient of variation for the 2007 program (Table 4). At sites where triplicate samples were collected the median value was used for analysis in this report.

2.7.2. Laboratory Program

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

Table 3: Summary of processing, preservation, storage containers and holding times for laboratory measurements; see codes below

Parameter	Processing	Preservation	Container	Holding Time
total phosphorus	c	a	1	1
soluble reactive phosphorus	a	b	1	2
Chlorophyll-a	b	c	2	3
turbidity	c	b	2	2

codes for Table 3**:**

processing:

a - filter with 0.45 µm cellulose acetate filter

b - filter with 0.45 µm cellulose nitrate filter

c - whole water sample

preservation:

a - H_2SO_4 to pH < 2

b - none

c - store filter frozen until analysis

container:

1 - 250 ml acid washed borosilicate boston round

2 - 4L polypropylene container

holding time:

1 - 28 days

2 - 48 hours

3 - 21 days

Table 4: Precision for triplicate sampling/measurement program for key parameters for 2007, represented by the average coefficient of variation (CV=SDev/Mean).

Parameter	Site 1	Rotating Site*
TP	0.10	0.05
Chlorophyll-a	0.11	0.11
Turbidity	0.14	0.14
SRP	0.14	0.16

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

3. Results, 2007

The measurements made in the 2007 monitoring program are presented in two formats here: (1) in tabular form (Table 5) as selected summary statistics for each site, and (2) as time plots (Figure 3 - Figure 6) for selected sites and site groupings. Detailed listings of data are presented in Appendix 1. 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 5). The plots present time series for site 8 and 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 was calculated by taking the mean of values at sites 1 and 7, and then calculating the mean of this single value and the values observed at sites 3, 4 and 5. This is done to avoid over representation of the eastern part of the shelf (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. The Secchi disc plot (Figure 4b) presents observations for sites 6, LSC, and 8; the deeper sites, where observations were always less than the bottom depth. Time series for the LSC influent, the LSC effluent, and the shelf are presented separately (Figure 5 - Figure 6). Flow rates in Fall Creek (Figure 3a) were measured by USGS gage 04234000.

Previous annual reports (UFI 1999–2006) documented occurrences of extremely high concentrations of forms of phosphorus (TP, TDP, and SRP) and nitrogen (TDN and T-NH_3) at site 2. These occurrences are likely associated with the proximity of site 2 to the Ithaca Area WWTP discharge (Figure 1), which is enriched in these components. Due to this localized condition site 2 was not included in the shelf average in those years. However, since 2006 differences between phosphorus concentrations at this site and the shelf average have become less pronounced, most likely due to upgrades to the IAWWTP phosphorus treatment capabilities in recent years (Figure 7). Site 2 is omitted from shelf averages in this report in order maintain consistency with previous reports and allow easier inter annual comparison.

Table 5: Summary of monitoring program results according to site, 2007.

TP [µg/L]			
SITE	**MEAN**	**CV**	**RANGE**
1	16.89	0.44	10.5 – 41.3
2	24.88	0.45	14.9 – 46.7
3	25.63	0.99	10.2 – 101.1
4	16.59	0.35	10.5 – 29.7
5	13.59	0.17	9.3 – 17.4
6	13.58	0.18	10.1 – 17.6
7	24.74	1.02	9.2 – 115.3
8	13.31	0.19	9.0 – 17.0
LSC	14.94	0.98	10.3 – 33.3

Chlorophyll-a a [µg/L]			
SITE	**MEAN**	**CV**	**RANGE**
1	4.26	0.66	1.8 - 12.7
2	4.65	0.99	0.6 - 20.0
3	4.29	0.84	1.2 - 15.1
4	3.88	0.81	0.2 – 10.2
5	4.54	0.55	0.2 – 8.5
6	5.55	0.58	0.3 – 10.8
7	5.49	0.45	1.1 – 33.6
8	6.18	0.59	0.3 – 13.9
LSC	5.99	0.54	0.3 – 11.5

SRP [µg/L]			
SITE	**MEAN**	**CV**	**RANGE**
1	2.48	1.02	0.3 – 9.3
2	3.27	0.94	0.3 – 10.0
3	3.23	1.10	0.15 – 12.6
4	2.91	0.92	0.15 – 9.0
5	1.77	1.44	0.15 – 8.7
6	1.91	1.45	0.15 – 9.5
7	3.64	0.96	0.7 – 13.9
8	2.00	1.42	0.15 – 8.7
LSC	2.37	1.57	0.15 – 13.7

T_n [NTU]			
SITE	**MEAN**	**CV**	**RANGE**
1	2.83	2.36	0.6 – 27.7
2	2.97	1.76	0.7 – 22.1
3	4.82	2.29	0.4 – 42.3
4	1.53	1.35	0.4 – 9.0
5	1.15	0.42	0.4 – 2.2
6	0.94	0.33	0.5 – 1.5
7	3.31	1.98	0.5 – 26.7
8	0.98	0.42	0.5 – 1.7
LSC	0.98	0.37	0.5 – 1.6

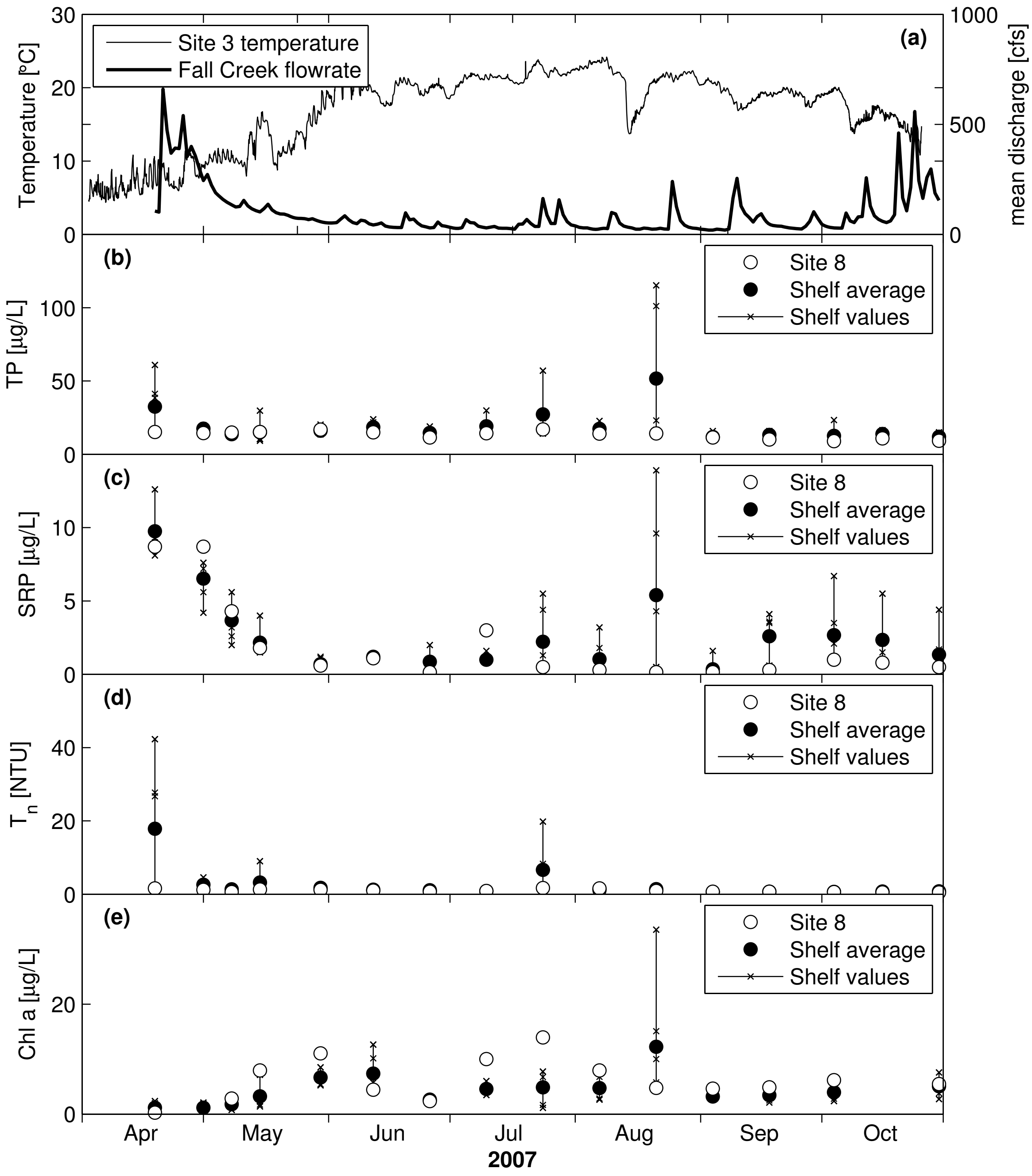

Figure 3: Time series of parameter values for Cayuga Lake for 2007: (a) Temperature at pile cluster (near site 3) and Fall Creek inflow record, (b) TP, (c) SRP, (d) Turbidity, (e) Chlorophyll-a. Values at site 8 are compared with the average value on the shelf. "x" symbols represent individual values measured at separate sites on the shelf.

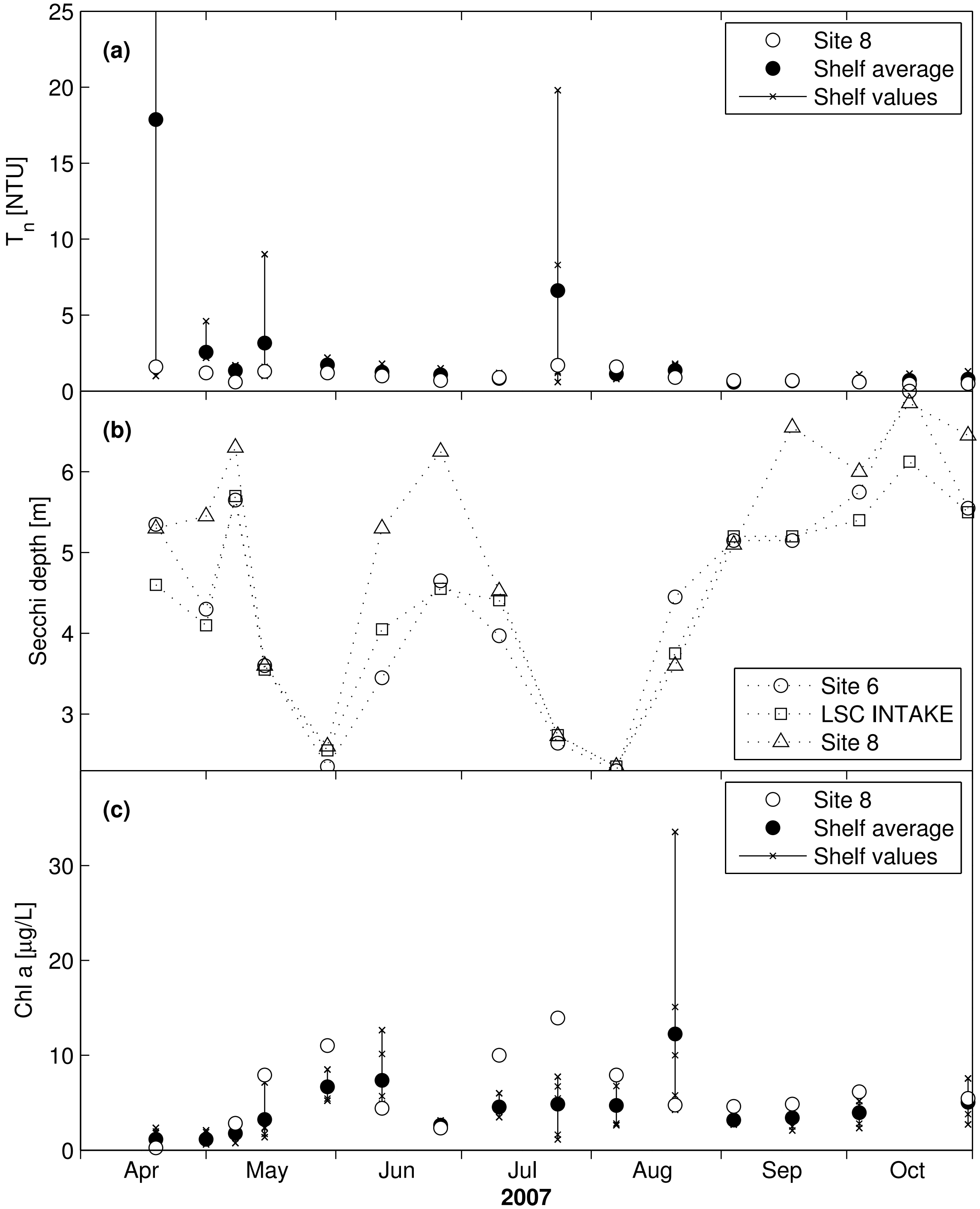

Figure 4: Time series of parameter values for Cayuga Lake for 2007: (a) Turbidity, (b) Secchi disc depth, and (c) Chlorophyll-a. Results for the "shelf" are averages; "x" symbols represent individual values measured at separate sites on the shelf.

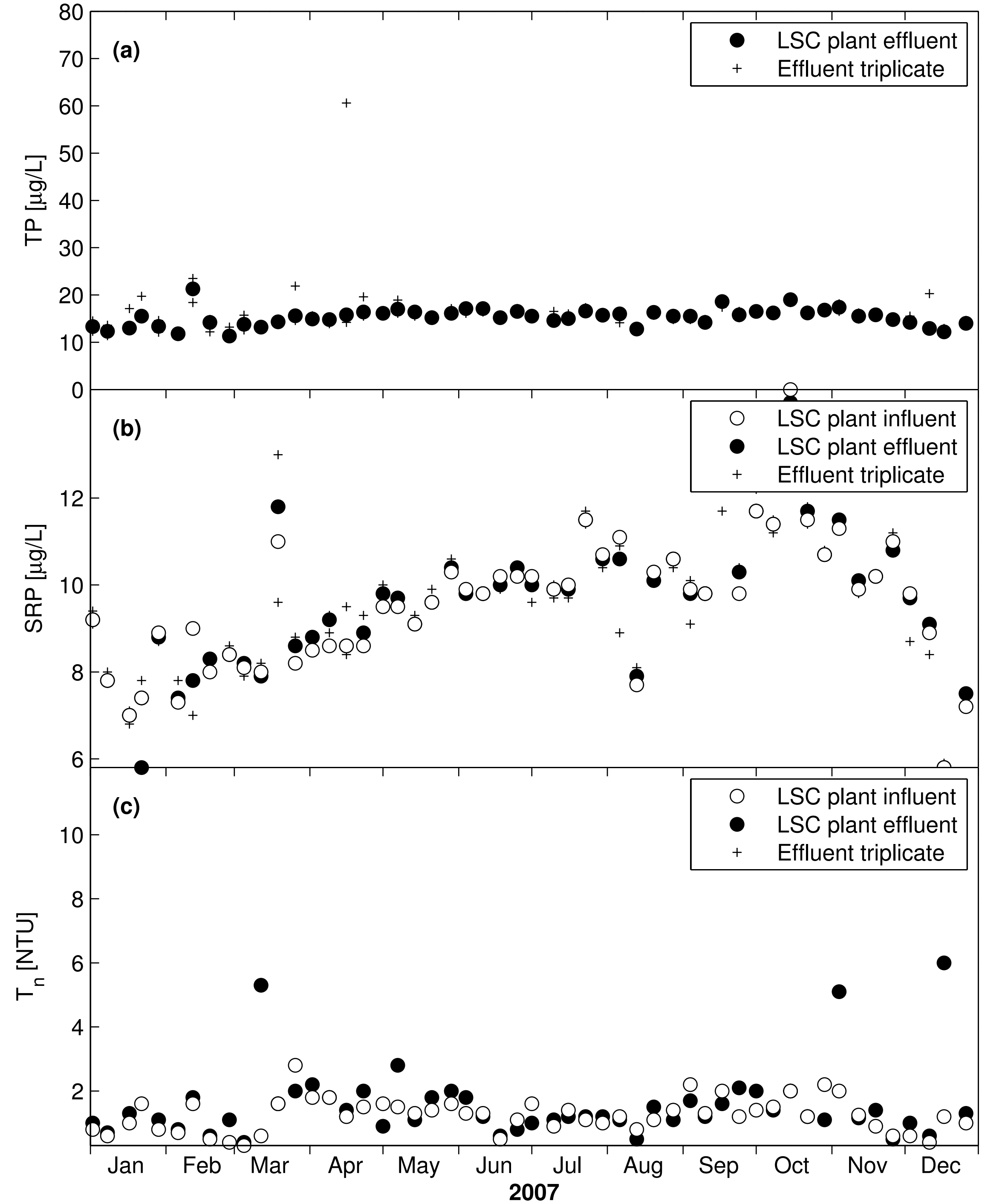

Figure 5: Time series of parameter values for the LSC influent and effluent for 2007: (a) TP (influent was not measured), (b) SRP, and (c) T_n. "+" symbols represent values of additional triplicate samples.

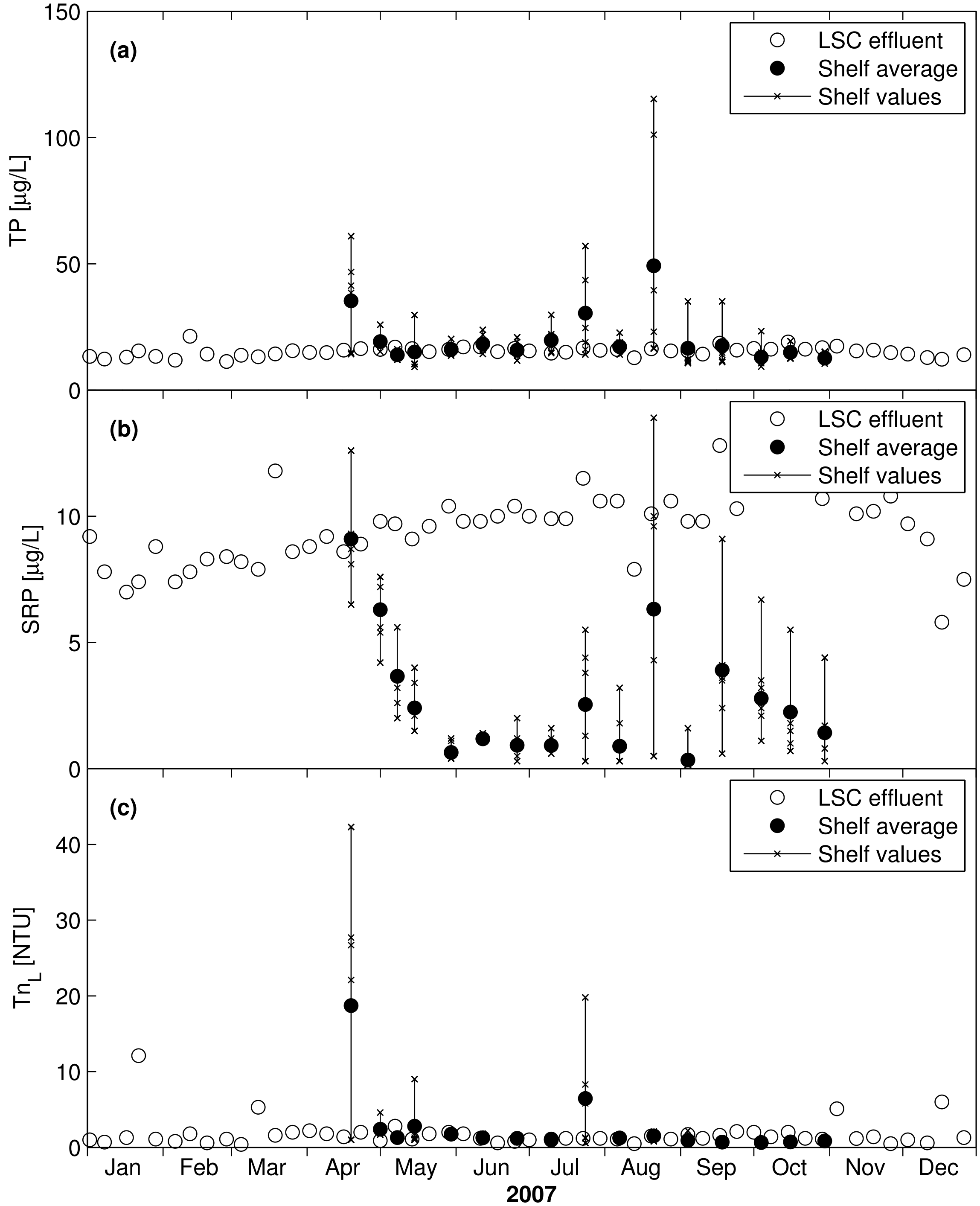

Figure 6: Time series of parameter values for the south shelf and the LSC effluent for 2007: (a) TP, (b) SRP, and (c) Turbidity. Results for the “shelf” are averages; “x” symbols represent individual values measured at separate sites on the shelf.

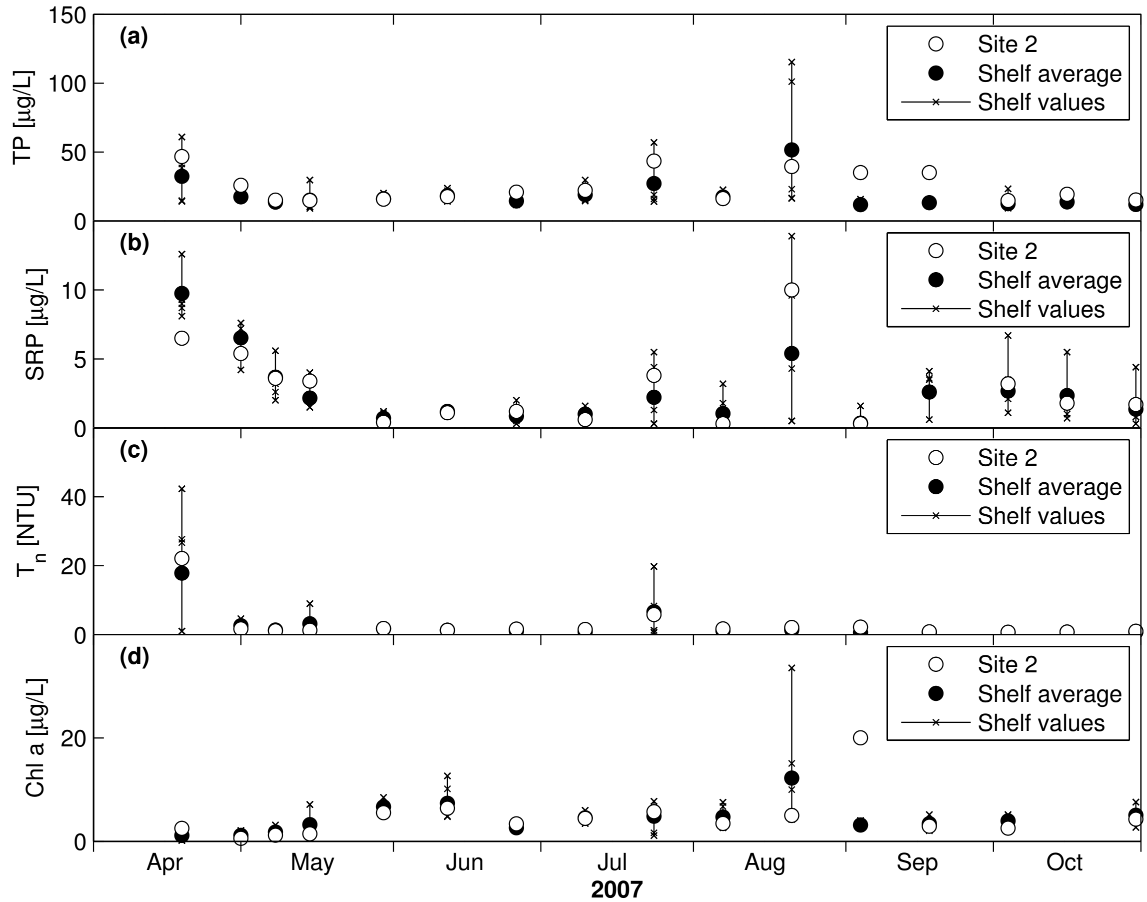

Figure 7: Comparison of observed parameters at site 2 and the shelf average.

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 2007 study interval as was the case in previous years (see Appendix 1). On several dates the disc was obscured by rooted macrophytes before reaching the full transparency depth. 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).

4.2. Inputs of Phosphorus to the Southern End of Cayuga Lake

Phosphorus loading is an important driver of primary production in phosphorus limited lakes. Thus, it is valuable to consider the relative magnitudes of the various sources of phosphorus that enter the southern end of Cayuga Lake. Monthly average loading estimates are presented for the Ithaca Area (IAWWTP) and Cayuga Heights (CHWWTP) wastewater treatment plants (WWTPs) for the 2000–2007 interval (Table 6, Figure 8 - Figure 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 are the product of the monthly average flows and concentrations. Other estimation techniques may result in modest differences in these loads. Rather wide monthly and interannual differences in loading rates have been observed for both WWTPs (Table 6) over the 2000 – 2007 interval. Major decreases in phosphorus loading from IAWWTP were observed since 2006 as a result of the commencement of tertiary treatment for phosphorus. This trend has continued in 2007. Phosphorus loading from IAWWTP in 2007 was 30% less than in 2006, 3 times less than average 2002 – 2005 levels and nearly 5 times less than observed levels in 2000 and 2001 (Table 6). The TP permit limit is 40 pounds per day (18.1 kg per day) for the IAWWTP and 1 $mg{\cdot}L^{-1}$ for the CHWWTP.

Estimates of monthly tributary phosphorus loading presented in the Draft Environmental Impact Statement (DEIS) for the LSC facility for the combined inputs of Fall Creek and Cayuga Inlet for the May – October interval are included for reference in Table 6 and Figure 8. 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 6 and Figure 8 were not for TP, but rather total soluble phosphorus (TSP, see Bouldin 1975 for analytical protocols). Therefore, Table 6 and Figure 8 compare loading of different forms of phosphorus from the different sources. This is done because of the differences in composition of each of the sources (treated wastewater, surface runoff and hypolimnetic water). The comparison in this form was first made in the DEIS for the LSC facility, in an attempt to select the form of phosphorus believed to be most readily available for biological uptake in each loading source. The same comparison has been presented in previous reports and is presented here for consistency. It should be noted however that a comparison of total phosphorus (TP) from each source would result in much higher values from the tributaries and hence a significantly reduced relative loading from the LSC facility.

Estimates of monthly TP loading to the shelf from the LSC facility and the relative contribution of this source during 2007 are presented in Table 6 and Figure 8 - Figure 9. Concentrations of TP were measured weekly at the LSC discharge. The estimates of the monthly loads 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 1.5 $kg{\cdot}d^{-1}$, or 8.2% of the calculated load to the shelf (sum of TP from LSC, IAWWTP and CHWWTP and TSP from tributaries). This is a smaller contribution than the 2.9 $kg{\cdot}d^{-1}$ projected in the DEIS for the LSC facility (Stearns and Wheler 1997). The LSC facility contributed a larger fraction of TP to the shelf in 2007 than the 4.8% projected in the DEIS. This is attributable to substantially lower TP loading from the wastewater treatment facilities in 2007 (3.6 kg·d^{-1}) than was projected in the DEIS (45.4 kg·d^{-1}, the maximum allowed under their combined DEC permits).

The peak relative monthly contribution of the LSC facility to total phosphorus loading to the shelf occurred in August 2007 (12.7%). In this month the loading from LSC was highest for the year (1.8 kg d^{-1}) and loadings from other sources were relatively low, most notably the loading from tributary flow was the lowest of any month. Tributary flow is the most significant source of phosphorus to the shelf, and is the source that shows the most variance between months.

Phosphorus loading rates for LSC were similar during June to September of 2007 and substantially lower in May and October (Table 6, and Figure 8 - Figure 9). From 2000 to 2004 phosphorus loading from the LSC facility to the shelf remained consistent at about 1.1 kg·d^{-1} (May – October average) with a relative contribution of about 3.5% (Table 6). Loading rates and relative contributions from LSC were markedly higher in 2005 and 2006 than in 2000-2004, with average daily loadings around 2 kg·d^{-1} for several of the warmer months of the year. This is likely due to changes in phosphorus concentrations in the lake's hypolimnion in those years (Figure 10). Loading rates declined slightly in 2007 relative to the two previous years, however the relative contributions from the LSC facility remained higher due to very low loading rates from the IAWWTP (Figure 9).

Paired measurements of SRP and T_n for the LSC influent and effluent agreed very well for the vast majority of measurements (Figure 5). This suggests the absence of substantial inputs within the facility. The average concentration of SRP in the LSC effluent in 2007 (April – October average of 10.2 µg L^{-1}) was slightly higher than that observed in 2006 (9.2 µg L^{-1}), and higher than all preceding years of operation, when average SRP concentrations ranged from 4.2 to 8.7 µg L^{-1}. Average levels of TP, SRP and T_n in the LSC effluent and on the shelf are presented in Figure 6 and Table 7. TP and T_n levels observed in the LSC effluent were very close to those measured on the shelf on all but three sampling dates: on April 19 during spring melt runoff, on July 24 after a large rainfall event, and most pronounced on August 21 after a large upwelling event. Levels of TP, SRP and T_n varied widely over time and space on the shelf during 2007. This variability was largely caused by runoff events in July and by a large upwelling event in mid-August that brought phosphorus rich hypolimnetic waters onto the shelf (Figure 3).

Increased TP loading to the shelf from the LSC effluent during 2005-2007 (Table 6) is largely attributable to the increase in effluent TP concentrations relative to 2000-2004. Average TP concentration in the LSC effluent in the years 2004-2007 are 29% higher than in the years 2000-2003 (Figure 10). Average SRP concentrations rose 78% in 2004-2007 relative to 2000-2003 (Figure 10). The increased phosphorus concentrations in the LSC effluent appear to be associated with a change in hypolimnetic water quality that has occurred over the last four to five years. Paired measurements of SRP and T_n in the LSC influent and effluent compared closely in 2007 (Figure 5), as they have throughout operation of the facility (UFI 2001, 2002, 2003, 2004, 2005, 2006, 2007). This supports the position that the increased effluent concentrations were associated with in-lake phenomena rather than a change within the LSC facility.

An unambiguous explanation for the apparent increases in phosphorus concentration in the lake's hypolimnion has not been identified. In large deep lakes such as Cayuga, changes in hypolimnetic water quality are expected to occur over long time scales, on the order of decades rather than years. Temporary increases in T_n and the particulate fraction of TP in bottom waters can be caused by plunging turbid inflows and internal waves or seiches. However, hypolimnetic SRP levels are generally considered to reflect lake-wide metabolism rather than local effects. Soluble reactive phosphorus is produced during microbial decomposition of organic matter and often accumulates in the hypolimnia of stratifying lakes during summer. Increases in primary production (phytoplankton growth) and subsequent decomposition could cause increases in SRP levels. Longer intervals of thermal stratification, increased hypolimnetic temperatures or depletion of dissolved oxygen could also cause higher concentrations of SRP in the bottom waters. The apparent increase in hypolimnetic SRP concentrations may represent a short-term anomaly rather than a long-term trend. It is worth noting that higher levels (>20 $\mu g\ L^{-1}$) of SRP have been observed in Cayuga Lake's hypolimnion in the past at depths near 100 meters (Oglesby, 1979). This metric of lake metabolism should be diligently monitored in the future in order to discern the permanence and significance of these changes.

Table 6: Estimates of monthly loads of phosphorus to the southern portion of Cayuga Lake over the 2000 to 2007 interval.

Year	IAWWTP[a] (TP, kg d^{-1})	CHWWTP[a] (TP, kg d^{-1})	Tributaries[b] (TSP, kg d^{-1})	LSC[c] (TP, kg d^{-1})	Total (TP+TSP, kg d^{-1})	% LSC
2000						
May	24.1	3.5	29.0	-	56.6	-
June	16.6	5.1	15.8	-	37.5	-
July	13.7	3.4	8.8	1.4	27.3	5.1%
August	19.1	4.6	6.0	1.0	30.7	3.3%
September	18.5	4.0	7.5	0.9	30.9	2.9%
October	15.4	4.1	13.1	0.6	33.2	1.8%
Mean	*17.9*	*4.1*	*13.4*	*1.0*	*36.4*	*3.3%*
2001						
May	15.8	5.5	29.0	0.7	51	1.4%
June	11.2	4.0	15.8	1.1	32.1	3.4%
July	15.2	4.2	8.8	1.0	29.2	3.4%
August	15.2	7.1	6.0	1.4	29.7	4.7%
September	22.0	6.6	7.5	1.0	37.1	2.7%
October	16.4	2.8	13.1	0.7	33	2.1%
Mean	*16.0*	*5.0*	*13.4*	*1.0*	*35.4*	*3.0%*
2002						
May	12.4	4.4	29.0	0.6	46.4	1.3%
June	7.9	3.5	15.8	1.0	28.2	3.5%
July	10.4	3.8	8.8	1.8	24.8	7.3%
August	16.2	2.0	6.0	1.2	25.4	4.7%
September	11.4	2.8	7.5	1.0	22.7	4.4%
October	13.6	3.1	13.1	0.7	30.5	2.3%
Mean	*12.0*	*3.3*	*13.4*	*1.1*	*29.7*	*3.9%*
2003						
May	11.0	2.7	29.0	0.6	43.3	1.4%
June	6.0	7.8	15.8	1.2	30.8	3.9%
July	8.5	3.9	8.8	1.2	22.4	5.4%
August	13.8	3.1	6.0	1.2	24.1	5.0%
September	11.9	3.4	7.5	1.3	24.1	5.4%
October	14.5	5.3	13.1	0.9	33.8	2.7%
Mean	*11.0*	*4.4*	*13.4*	*1.1*	*29.8*	*3.9%*

Table 6 (continued)

Year	IAWWTP[a] (TP, kg d^{-1})	CHWWTP[a] (TP, kg d^{-1})	Tributaries[b] (TSP, kg d^{-1})	LSC[c] (TP, kg d^{-1})	Total (TP+TSP, kg d^{-1})	% LSC
2004						
May	11.0	6.6	29.0	1.3	47.9	2.7%
June	11.0	7.2	15.8	1.2	35.2	3.4%
July	11.7	7.1	8.8	0.9	28.5	3.2%
August	11.6	3.4	6.0	1.4	22.4	6.3%
September	11.5	7.9	7.5	1.1	28	3.9%
October	10.9	10.6	13.1	0.6	35.2	1.7%
Mean	*11.3*	*7.1*	*13.4*	*1.1*	*32.9*	*3.5%*
2005						
May	11.0	3.7	29.0	2.1	45.8	4.6%
June	10.3	3.5	15.8	1.9	31.5	6.0%
July	9.4	2.8	8.8	2.0	23	8.7%
August	9.4	2.9	6.0	2.0	20.3	9.9%
September	10.5	3.8	7.5	1.8	23.6	7.6%
October	10.4	5.1	13.1	1.1	29.7	3.7%
Mean	*10.2*	*3.6*	*13.4*	*1.8*	*29.0*	*6.7%*
2006						
May	7.2	1.5	29.0	1.1	38.8	2.8%
June	6.7	4.1	15.8	1.9	28.5	6.7%
July	7.2	3.9	8.8	2.2	22.1	10.0%
August	3.7	3.7	6.0	2.0	15.4	13.0%
September	4.2	2.5	7.5	1.4	15.6	9.0%
October	3.2	2.1	13.1	1.0	19.4	5.2%
Mean	*5.4*	*3.0*	*13.4*	*1.6*	*23.3*	*7.8%*
2007						
May	3.3	0.9	29.0	1.1	34.3	3.2%
June	1.8	1.3	15.8	1.7	20.55	8.3%
July	4.3	2.5	8.8	1.7	17.3	9.8%
August	4.3	2.1	6.0	1.8	14.2	12.7%
September	4.6	3.6	7.5	1.6	17.3	9.2%
October	3.0	4.5	13.1	1.3	21.9	5.9%
Mean	*3.6*	*2.5*	*13.4*	*1.5*	*20.9*	*8.2%*

[a] total phosphorus; from IAWWTP and CHWWTP permit reporting

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

[c] total phosphorus; from facility permit reporting

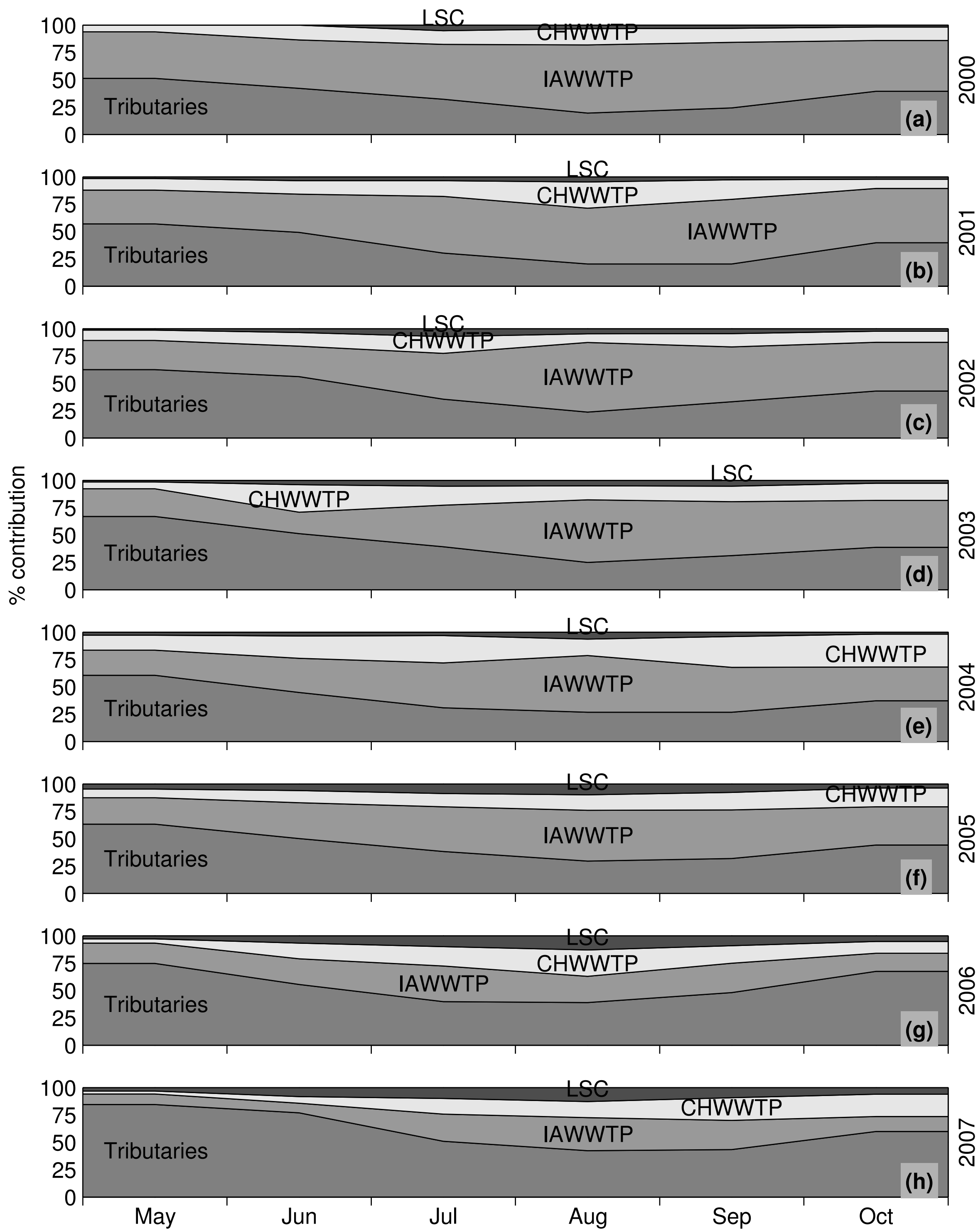

Figure 8: Time series of estimated relative monthly external loads of phosphorus to the southern portion of Cayuga Lake, partitioned according to source: (a) 2000, (b) 2001, (c) 2002, (d) 2003, (e) 2004, (f) 2005, (g) 2006 and (h) 2007. Loads are for total phosphorus with the exception of tributary loading, which is for total soluble phosphorus.

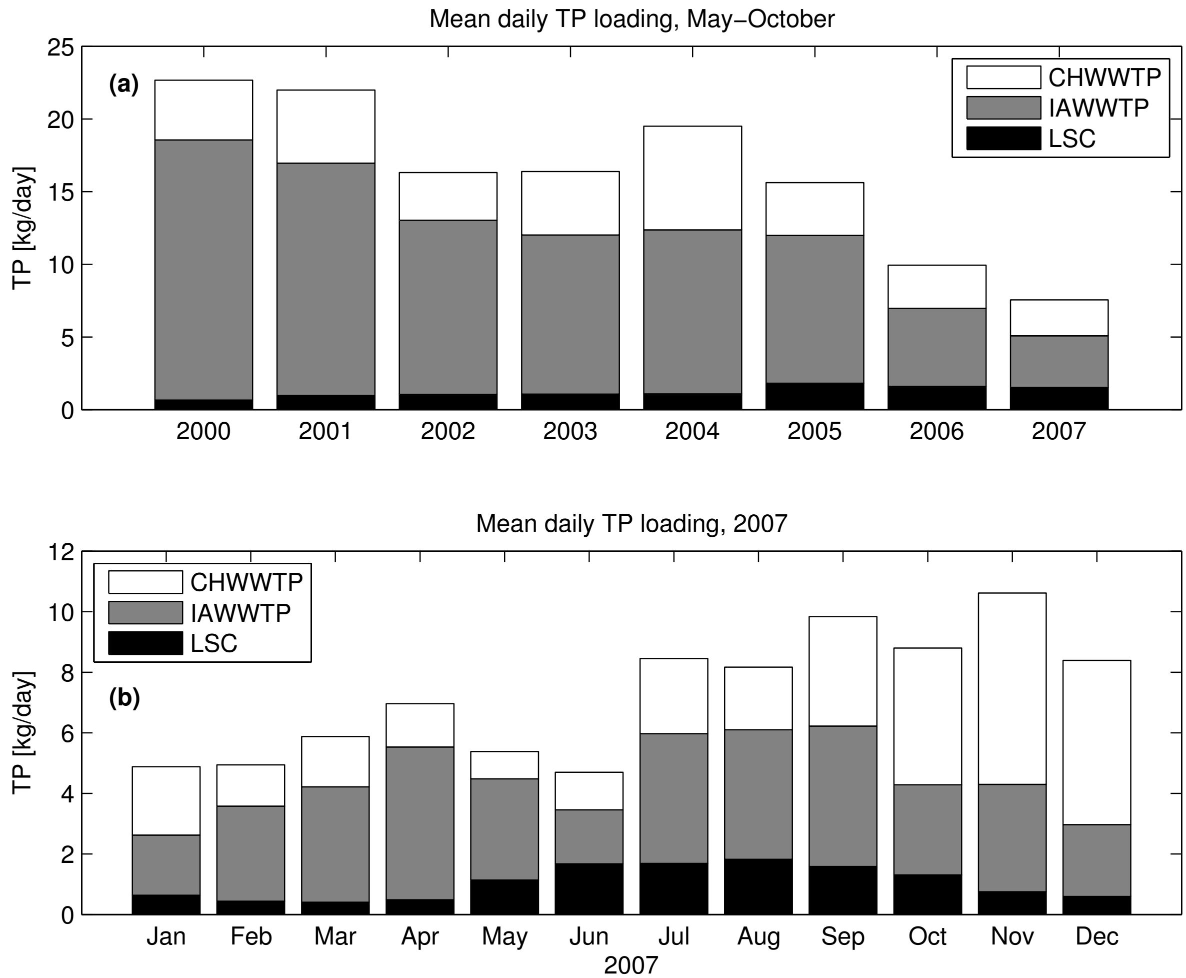

Figure 9: Trends in point source TP loading to the southern shelf: (a) mean daily loading in the May-October period, 2000-2007, (b) monthly mean loading in 2007.

Table 7: Average values and standard deviations for TP, SRP, and Tn in the LSC effluent and on the shelf. Averages determined from observations made during the April – October interval of 2007.

Location	TP ($\mu g \cdot L^{-1}$)	SRP ($\mu g \cdot L^{-1}$)	T_n (NTU)
LSC effluent (n = 31)	16.0 ± 1.2	10.2 ± 1.2	1.4 ± 0.5
Shelf average (n = 16)	20.0 ± 13.3	2.7 ± 2.6	3.0 ± 5.8

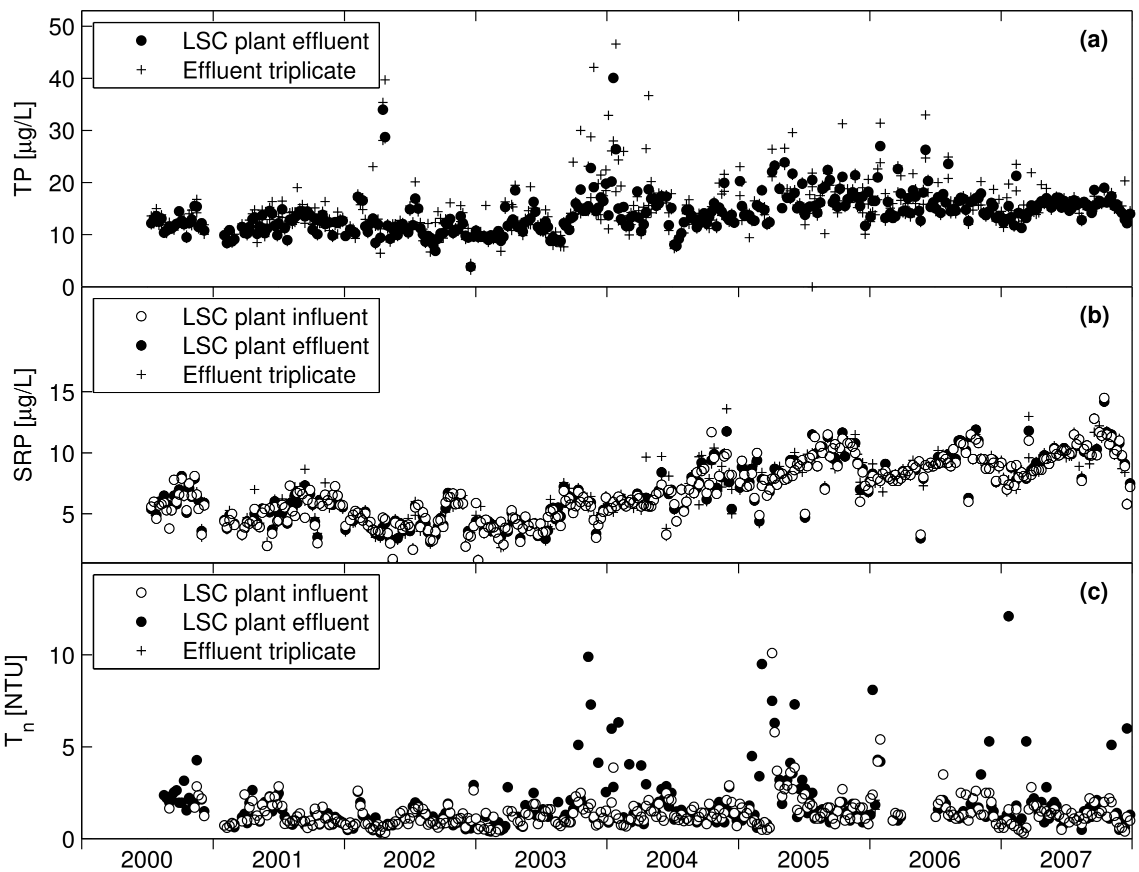

Figure 10: Time series of concentrations measured weekly in the LSC effluent for the 2000–2007 interval: (a) total phosphorus, (b) soluble reactive phosphorus, and (c) turbidity. “+” symbols represent additional triplicate sample values.

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, Rueda and Cowen 2005). Thus the effects of natural variations in these conditions can be mistaken for anthropogenic impacts (e.g., pollution). The setting of the southern end of the lake, including the localized entry of tributary flows and its shallowness, may promote interpretive interferences with the measurements of total phosphorus (TP), Secchi disc transparency (SD), and turbidity (T_n). These interferences are associated with potential influxes of non-phytoplankton particles that would diminish SD and increase T_n and TP concentrations, features that could be misinterpreted as reflecting increases in phytoplankton concentrations. These influxes may be associated with external loads carried by the tributaries, particularly during runoff events, and internal loads associated with sediment resuspension, driven by wind events (e.g., Bloesch 1995). Thus, it is prudent to consider natural variations in tributary flow and wind speed in evaluating seasonal and interannual differences in these parameters for the southern end of Cayuga Lake. Interannual variations in runoff and wind speed are discussed in Section 4.7 – Interannual Comparisons and illustrated in Figure 12 and Figure 14.

Runoff and wind conditions for the study period of 2007 are represented here by daily average flows measured in Fall Creek by the USGS, and daily average wind speed, measured by Cornell University at the Game Farm Road Weather Station (Figure 12). Only the component of the wind along the lake's long axis is presented, as this is the component most important to physical processes such as generation of waves, internal seiches and upwelling events. 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, going back to 1925; the wind database contains measurements since 1987. Daily average flow measurements for Fall Creek and wind speed for 2007 are compared to time-series of daily median values for the available records for the monitoring period (Figure 12).

When compared to the historic record, Fall Creek flows during 2007 were low during June, July and August and near or above average in April, May, September and October (Figure 12). In comparison to previous years since the LSC facility began operating, 2007 was a low runoff year (Figure 12, Figure 14). However, a strong correlation between runoff and measured parameters was seen, with elevated phosphorus and turbidity levels during large runoff in April (spring melt) and on July 24th when a sampling date coincided with a large runoff event. The July 24th sampling day recorded the highest turbidity values outside of the spring snow melt event though the runoff flow at that time was less than 200 cfs – much lower than runoff events recorded in previous years.

4.4. Limitations in Measures of Trophic State on the Shelf

Recurring scientific evidence, provided by the findings of nine consecutive study years (Upstate Freshwater Institute 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007) has demonstrated that T_n and TP are systematically flawed indicators of the trophic state on the shelf. In particular, substantial variations and increases in both parameters on the south shelf appear to be uncoupled at times from patterns and magnitudes of phytoplankton biomass. These features appear to be associated with greater contributions of non-phytoplankton particles (e.g. clay and silt) to the measures of TP and T_n on the south shelf. Four lines of circumstantial evidence supporting this position have been presented in previous annual reports, based on observations from the 1998 - 2006 study years (Upstate Freshwater Institute 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007):

1. high T_n values were observed for the shelf and site 8 following major runoff events. This suggests greater contributions of non-phytoplankton particles to the measurements of T_n following runoff events.
2. elevated T_n values were reported for the 1999, 2000 and 2002 study years (Upstate Freshwater Institute 2000, 2001, 2003) at the deep water sites during "whiting" events in late July and August. These increases in T_n were driven largely by increases in T_c (calcium carbonate turbidity).
3. the ratio of particulate P (PP) to Chlorophyll-a was often substantially higher on the south shelf than at the deep stations, suggesting greater contributions of non-phytoplankton particles to the PP pool at the southern end of the lake. Further, unlike the deep sites, the

ratio was often above the range of values commonly associated with phytoplankton biomass (e.g., Bowie et al. 1985).

4. application of previously reported literature values of light scattering (e.g., T_n) per unit chlorophyll (e.g., Weidemann and Bannister 1986) to the Chlorophyll-a observations indicate that non-phytoplankton particles made greater contributions to T_n on the shelf than in deep waters. Non-phytoplankton particles were found to be responsible for the high T_n levels on the shelf and at site 8 following the major runoff events.

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

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 (Table 8 and Table 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 shelf and deeper locations (Table 8 and Table 9). 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 – 2007, documented here).

Summer (June – August) average concentrations are presented for the lake's upper waters; sources of data are included (Table 8 and Table 9). Higher TP concentrations were observed on the shelf compared to deeper portions of the lake in all years monitored (Table 8). Summer average TP concentrations for 2007 were within the range of interannual variability observed since 1998 for both the deep water site and the shelf (Table 8). Summer average Chlorophyll-a concentrations were higher in 2007 than observed in recent years (Table 9), though not as high as the 2006 values. Chlorophyll-a concentrations were distinctly higher on the shelf than at deeper water sites from 1994 to 1996, though similar levels were observed over the 1998 – 2006 interval (Table 9). In 2006 – 2007, Chlorophyll-a concentrations were slightly higher at the deep water location (Table 9). The 1998 average does not include June observations. Summer average concentrations of TP and Chlorophyll-a for deep water sites are generally 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. June – September averages are included in parentheses for the 1998 – 2006 study years.

Year	Total Phosphorus (µg·L^{-1})		Source
	Deep-Water Location(s)	Southern Shelf	
1968[Δ]	20.2 (n = 19)	-	Peterson 1971
1969[Δ]	15.3 (n = 22)	-	Peterson 1971
1970[Δ]	14.0 (n = 32)	-	Peterson 1971
1972[x]	18.8 (n = 22)	-	USEPA 1974
1973[Δ]	14.5 (n = 88)	-	Godfrey 1973
1994[*,⊕]	21.7	30.8	Stearns and Wheler 1997
1995[*,⊗]	16.5	23.7	Stearns and Wheler 1997
1996[*,⊗]	12.4	21.7	Stearns and Wheler 1997
1998[+]	14.7 (14.7)	26.5 (24.7)	UFI 1999
1999[++]	10.6 (9.8)	15.9 (14.5)	UFI 2000
2000[++]	11.9 (11.6)	19.4 (18.7)	UFI 2001
2001[++]	14.0 (14.2)	21.4 (20.4)	UFI 2002
2002[++]	14.7 (14.1)	22.1 (22.2)	UFI 2003
2003[++]	10.2 (10.4)	13.6 (14.4)	UFI 2004
2004[++]	15.8 (15.3)	21.5 (24.9)	UFI 2005
2005[++]	12.8 (12.6)	17.3 (17.8)	UFI 2006
2006[++]	16.2 (15.2)	30.1 (26.3)	UFI 2007
2007[++]	14.3 (13.4)	26.8 (23.4)	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 8 and shelf average respectively

[⊕] 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 concentrations for the upper waters of Cayuga Lake. June – September averages are included in parentheses for the 1998 – 2007 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	-	Oglesby 1978
1973	8.2	-	Trautmann et al. 1982
1974	8.1	-	Trautmann et al. 1982
1977	8.6	-	Trautmann et al. 1982
1978	6.5	-	Trautmann et al. 1982
1994	5.5	8.9	Stearns and Wheler 1997
1995	4.8	6.8	Stearns and Wheler 1997
1996	3.4	7.6	Stearns and Wheler 1997
1998^{+}	4.8 (4.8)	5.7 (5.2)	UFI 1999
1999^{++}	4.7 (4.6)	4.4 (4.2)	UFI 2000
2000^{++}	4.8 (4.7)	5.5 (5.4)	UFI 2001
2001^{++}	4.7 (4.5)	4.6 (4.4)	UFI 2002
2002^{++}	5.1 (5.2)	4.8 (5.6)	UFI 2003
2003^{++}	5.6 (5.6)	6.0 (5.9)	UFI 2004
2004^{++}	4.7 (5.3)	6.5 (6.9)	UFI 2005
2005^{++}	4.9 (4.7)	4.8 (4.9)	UFI 2006
2006^{++}	7.7 (7.8)	7.2 (7.2)	UFI 2007
2007^{++}	7.2 (6.6)	6.4 (5.6)	this report

* Hamilton 1969, 15 dates

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

$^{+}$ July – August, 0 – 4 m composite samples

$^{++}$ 0 – 4 m composite samples, site 8 and shelf average respectively

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 2).

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 $\mu g \cdot L^{-1}$) is compared to the values measured in the other ten Finger Lakes in Figure 11. These data support Cayuga Lake's classification as mesotrophic. However, the higher Chlorophyll-a concentrations observed in 2007 approached the upper bounds of mesotrophy. Six of the lakes had average concentrations lower than observed for Cayuga Lake (Figure 11). Two of the lakes, Canandaigua and Skaneateles, had concentrations consistent with oligotrophy, while two (Conesus and Honeoye) bordered on eutrophy (Figure 11).

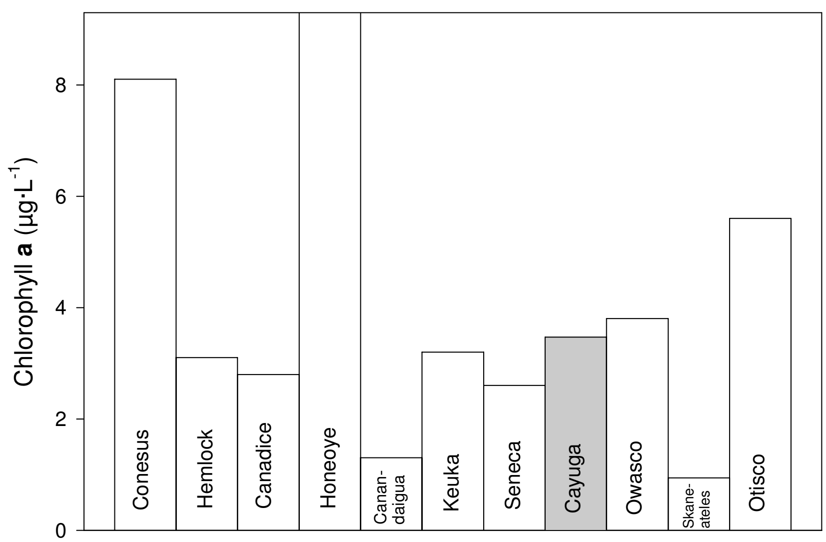

Figure 11: Comparison of average Chlorophyll-a concentrations for the spring-early fall interval for the eleven Finger Lakes, based on samples (n=15 to 16) collected over the 1996 through 1999 interval (data from Callinan et al. 2000).

4.7. Interannual Comparisons

Interannual differences in water quality can occur as a result of both human interventions and natural variations in climate. Because of its location and shallowness, water quality on the south shelf can vary substantially from year to year as a result of changes in forcing conditions. Conditions for runoff, wind speed and summed TP loading from the Ithaca Area WWTP, Cayuga Heights WWTP and the LSC facility for 2007 are compared here to the previous study years (1998 – 2006; Figure 12). When compared to flow conditions of the preceding nine years, the Fall Creek hydrograph for 2007 shows that this was a relatively dry year with only one event during the sampling season reaching 1,000 cfs and two more with flow rates near 500 cfs. In previous years runoff events with flow rates of 2,000 cfs and more were not uncommon (UFI 1999-2007). Also, between May and September of 2007 runoff events had peak flow rates of 250 cfs or less, which is quite low compared to previous study years.

Daily average wind speeds along the lake's long axis are presented in Figure 12b for the 1998 - 2006 interval and the 2007 study period. Wind patterns were within the range of values measured in previous years. In late August steady winds from the south for a period of several days led to an upwelling event as can be seen from the dip in temperature recorded by the deployed thermistors (Figure 3a). Upwelling events such as this result in the advection of hypolimnetic waters onto the southern shelf, which is likely the cause of the increased phosphorus and Chlorophyll-a levels measured after the event (Figure 3b,c,e).

Estimates of monthly average total phosphorus (TP) loads to the shelf from point sources in 2007 are compared to the 2000 - 2006 period in Figure 12c. Monthly estimates of TP loads for 2007 were lower than values observed over the previous nine study years in May – August and higher only than the values observed in 2006 during September and October (Figure 12c). This decrease was caused by the establishment of tertiary treatment for phosphorus at the Ithaca Area WWTP, which resulted in a 50% reduction in phosphorus loading from this facility.

Time series of TP, Chlorophyll-a, and T_n are presented for the April – October interval of the ten study years (Figure 13). Data were not collected during the April – June interval of 1998. Plotted values are intended to represent conditions on the shelf (shelf average – mean of values at sites 3, 4, 5 and the mean of sites 1 and 7). TP concentrations in 2007 were in the upper range of historically observed values in April, were high in late August probably due to the upwelling event near the August 24 sampling date, and were near the long-term average for all other months (Figure 13a). This temporal pattern in TP observed during 2007 was correlated with dynamics in physical processes on the shelf; runoff and upwelling events, and followed the same general seasonal trends observed in previous years.

The seasonal dynamics of Chlorophyll-a concentrations on the shelf in 2007 were generally typical of the previous nine study years (Figure 13b). In general, Chlorophyll-a concentrations have been lowest during spring and fall and highest during mid-summer. Turbidity values measured in 2007 were in general lower than values observed in previous study years (Figure 13c). Historically, high turbidity values were observed on sampling dates that coincided with major runoff events (e.g. early July 1998, early April 2000, mid-June 2000, early April 2001, and late June 2001). In contrast, in low flow years high turbidity values were not observed (e.g. in 1999, an extremely low runoff year, peak turbidity observations were < 5 NTU). 2007 had runoff conditions similar to 1999 and correspondingly low measured turbidity values.

The temporally detailed data presented in Figure 12 and Figure 13 are summarized in Figure 14 as box plots for the ten study years. The dimensions of the boxes are identified in the key located to the right of Figure 14a. Fall Creek flows were highest in 2004; runoff was also relatively high in 2000, 2002, 2003 and 2006 (Figure 14a). Flows were relatively low for the study intervals of 1999, 2001, 2005 and 2007. Average wind speeds were comparable for the nine study years (Figure 14b). Total phosphorus loading from point sources has decreased over the ten years of study, with major decreases since 2006 associated with upgrades in phosphorus treatment at the Ithaca Area WWTP (Figure 14c).

Study period medians (median of all values measured at sites 1, 3, 4, 5 and 7) for TP and T_n on the shelf were lowest in 1999, the driest of the study years (Figure 14d-f). Median Chlorophyll-a on the shelf in 2007 was very low, second only to values observed in 1999. Temporal variability for TP and turbidity was also lowest during the 1999 and 2007 study intervals (Figure 14d,f). Chlorophyll-a concentrations on the shelf have been highest in years with the highest runoff (e.g. 2000, 2003, 2004 and 2006).

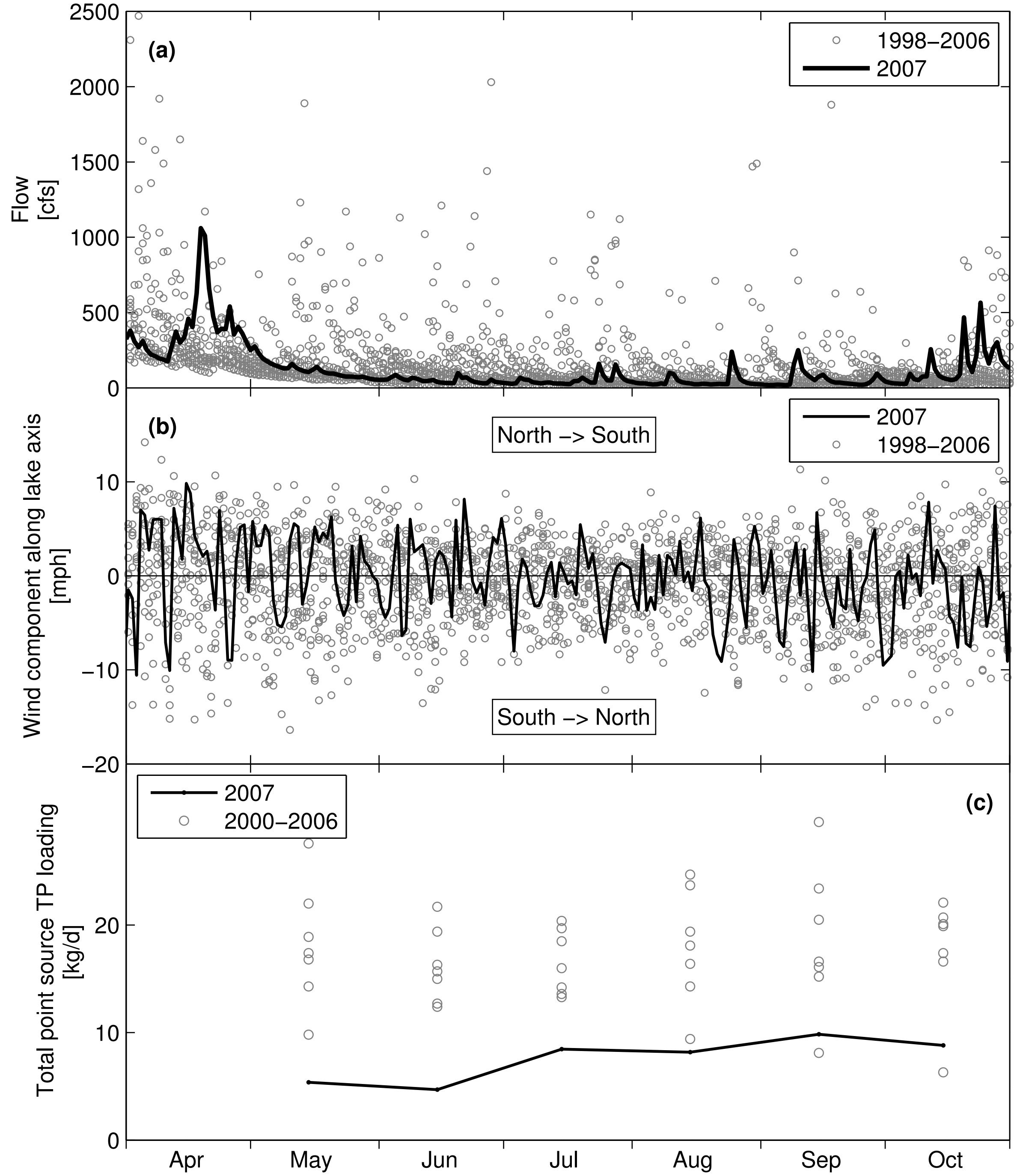

Figure 12: Comparison of 2007 conditions for runoff, wind and total phosphorus loading with conditions from the 1998-2006 interval: (a) daily average flows in Fall Creek, (b) daily average wind component along lake's long axis, and (c) summed monthly loads of total phosphorus (TP) to southern Cayuga Lake from the Ithaca Area WWTP, Cayuga Heights WWTP, and the LSC facility, 2000-2006.

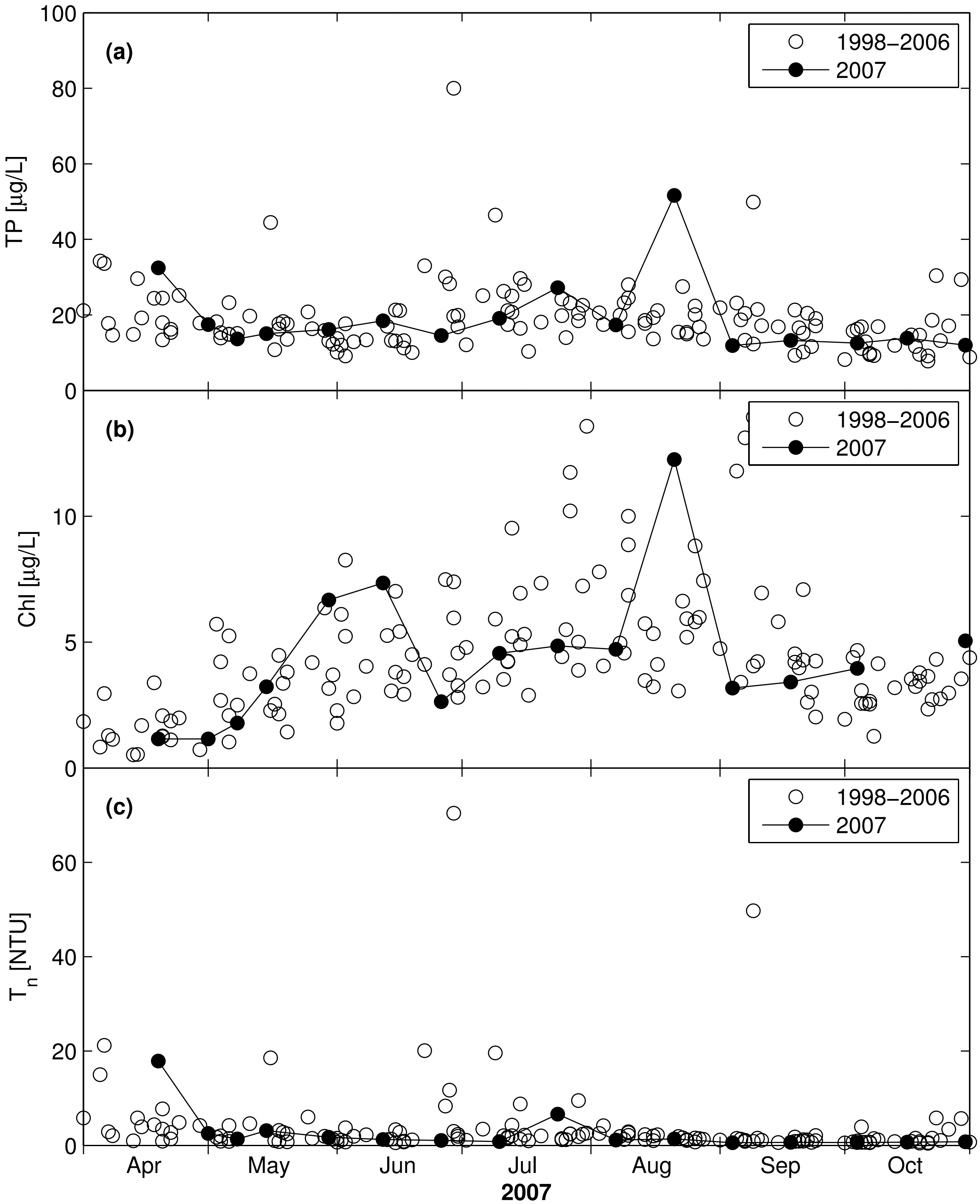

Figure 13: Comparison of 2007 conditions for total phosphorus, Chlorophyll-a, and turbidity on the south shelf of Cayuga Lake with conditions from the 1998- 2006 interval: (a) total phosphorus (TP), (b) Chlorophyll-a, and (c) turbidity (T_n).

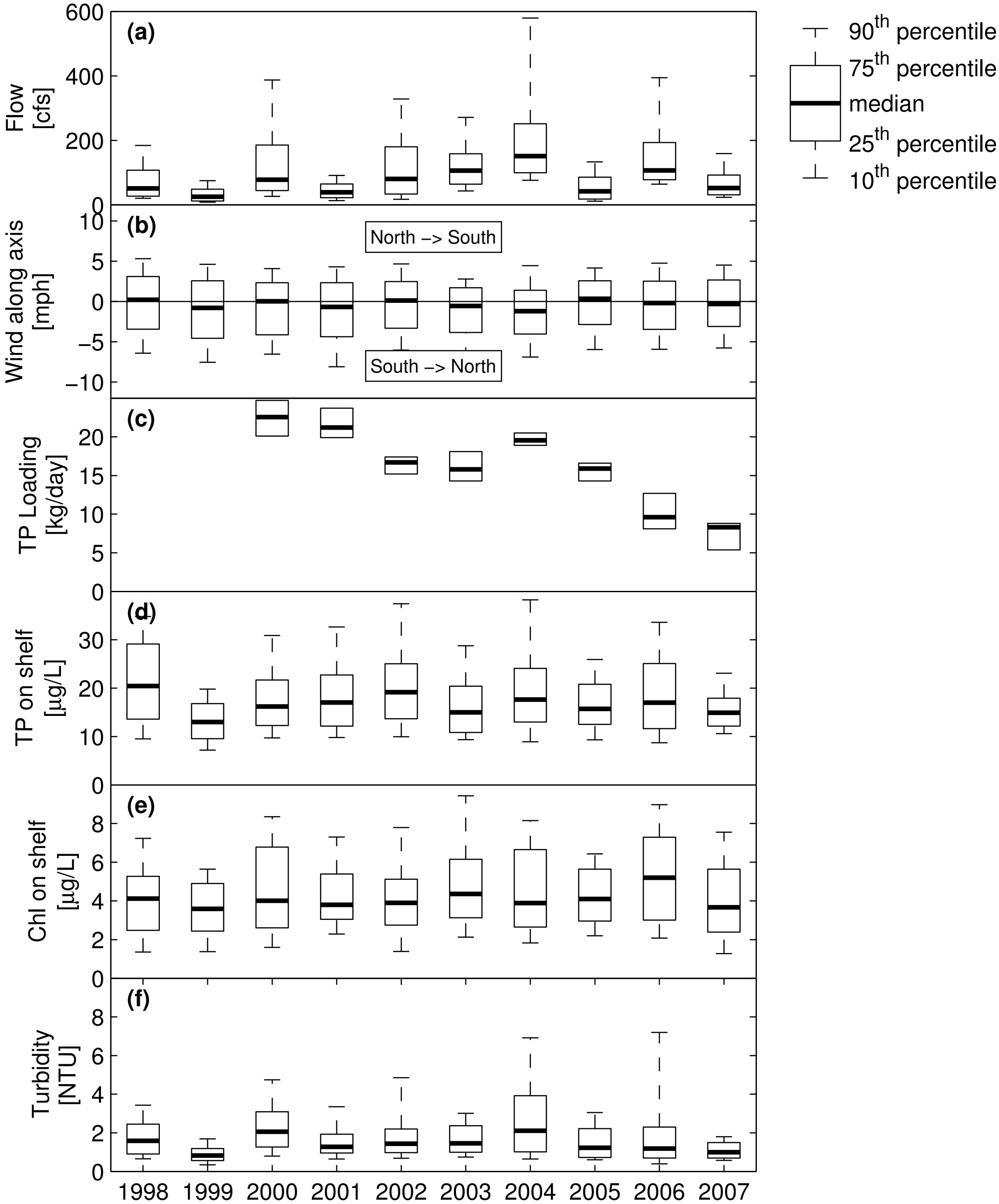

Figure 14: Comparison of study interval averages for runoff, wind, total phosphorus loading, total phosphorus concentration, Chlorophyll-a concentration and turbidity: (a) Fall Creek flow, (b) wind speed, (c) summed loads of total phosphorus (TP) from the Ithaca Area WWTP, Cayuga Heights WWTP and the LSC facility, (d) total phosphorus concentration on the south shelf, (e) Chlorophyll-a concentration on the south shelf, and (f) turbidity on the south shelf. Data plotted are from the May – October interval. Shelf data includes measurements from sites 1, 3, 5 and 7.

5. Noteworthy Observations from the 2007 Data

1. sites 2, 3 and 7 were enriched in both measured forms of phosphorus (TP and SRP) and turbidity compared to the other monitored sites (Table 5). Sites 2 and 7 are located adjacent to wastewater effluents. This effect seems to have diminished somewhat at site 2 relative to previous years, likely as a result of improvements in phosphorus treatment at the Ithaca Area WWTP.
2. Chlorophyll-a (Chl) concentrations were lower on the south shelf than at deep water locations (Table 5).
3. the deep water sites (6, 8 and LSC Intake) had the lowest concentrations of total phosphorus (TP) and turbidity (T_n), on average, of the monitored sites (Table 5).
4. substantial spatial variations were observed within the southern end of the lake ("shelf") for most parameters included in the monitoring program (Figure 3, Table 5).
5. variances of measures of trophic state (Chl, TP, and T_n) were generally greater for the south shelf sites than for deep water sites (sites 6, 8 and LSC; Table 5).
6. the highest turbidity values measured in 2007 were associated with runoff events in April and late July (Figure 3).
7. the highest total phosphorus values measured in 2007 were associated with an upwelling event in late August (Figure 3) and a runoff event in late July (Figure 3).
8. Chlorophyll-a concentrations, on a monitoring period average basis, were similar across the spatial bounds of sampling, though substantial spatial variability was observed on individual days (Figure 4, Table 5).
9. temperatures, measured hourly at the "pile cluster", dropped precipitously on a number of occasions, suggesting the occurrence of relatively cool tributary inflows or seiche activity. Most notably in late August temperatures dropped by more than 5 degrees Centigrade and increased phosphorus and Chlorophyll-a values were observed on the shelf in following samples, indicative of a seiche driven upwelling event (Figure 3).
10. turbidity (T_n) values and concentrations of soluble reactive phosphorus (SRP) were essentially equal in the LSC influent and effluent (Figure 5).
11. total phosphorus (TP) concentrations in the LSC effluent were usually less than 20 $\mu g \cdot L^{-1}$ during 2007 (Figure 5).
12. the concentration of total phosphorus (TP) in the LSC effluent was similar to the concentration on the south shelf on most sampling days (Figure 6). Exceptions to this were during runoff events in April and July and an upwelling event in August. On average, the TP concentration in the LSC effluent was 4 $\mu g \cdot L^{-1}$ lower than the receiving waters of the shelf (Table 7).
13. the concentration of soluble reactive phosphorus (SRP) was routinely higher in the LSC effluent than on the shelf (Figure 6), consistent with projections made in the Draft Environmental Impact Statement (Stearns and Wheler, 1997); on average, the concentration was 7.5 $\mu g \cdot L^{-1}$ higher (Table 7).
14. turbidity (T_n) values for the LSC effluent were similar to values on the shelf on most sampling days (Figure 6). Exceptions to this were during runoff events in

April and July. On average, turbidity was 1.6 NTU lower in the LSC effluent (Table 7).

15. Secchi disc transparency (SD) was observed to extend beyond the lake depth at multiple sites on several occasions during the 2007 study interval (Appendix 1).
16. phosphorus loading from the Ithaca Area WWTP averaged 3.6 kg d^{-1} over the May to October interval of 2007, representing a 33% decrease from 2006 levels, a 68% decrease from 2002-2005 levels and a decrease of nearly 80% from 2000-2001 levels (Table 6). In 2007, phosphorus loading from the Cayuga Heights WWTP (2.5 kg d^{-1}) reached the lowest level of the 2000-2007 period (Table 6).
17. LSC contributed an estimated 8.2% of the TP load to the shelf over the May to October interval of 2007, a larger contribution than projected (4.8%) in the Draft Environmental Impact Statement (Stearns and Wheler 1997; Table 6, Figure 8). This is attributable to smaller inputs from wastewater treatment facilities and higher TP concentrations at the LSC intake location.
18. the average TP loading rate to the shelf from LSC for the May to October interval of 2007 was 1.5 $kg \cdot d^{-1}$, 48% lower than the 2.9 $kg \cdot d^{-1}$ projected in the Draft Environmental Impact Statement. Higher levels of TP loading from LSC since 2005 were caused by increased TP concentrations of the effluent.
19. increases in TP, SRP, and T_n since 2003 have been observed in the LSC effluent (Figure 10) and in the lake adjacent to the LSC intake (UFI 2007). The cause of these increases has not been established.
20. the Fall Creek hydrograph for 2007 depicts relatively dry conditions from May through September, and near average flow rates for April and October (Figure 12).
21. winds aligned with the lake's long axis were near or above long-term average values for extended periods during August and September (Figure 12). Annual average wind speeds have been essentially constant over the 1998-2007 interval (Figure 12).
22. summer average concentrations of TP and Chlorophyll-a for deep water sites continue to be consistent with mesotrophy, an intermediate level of primary productivity (Table 8 and Table 9). However, the summer average concentration of Chlorophyll-a in 2007 (7.1 $\mu g \cdot L^{-1}$) was about 50% higher than observed over the 1998-2005 interval (Table 9). The summer average concentration of TP was also higher in 2007 than during 1998-2005 (Table 8).
23. study period median values for TP on the shelf were lowest in 1999 and similar in the other study years (Figure 14). Median "shelf" TP values for 2007 were relatively low and showed less temporal variance than previous study years (Figure 14).
24. study period median values for Chlorophyll-a on the shelf have exhibited little interannual variability over the 1998 – 2006 interval, though the lowest peak values were observed during the low runoff years of 1999, 2001, 2005 and 2007, with 2007 being the second lowest (Figure 14e).
25. study period median values for T_n on the shelf were lowest for the low runoff years of 1999, 2001, 2005 and 2007 (Figure 14f).

26. no conspicuous changes in water quality have been observed on the shelf since start-up of the LSC facility in July 2000 (Upstate Freshwater Institute 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007).
27. the increase in soluble reactive phosphorus concentrations at the LSC intake since 2003 could represent significant lake-wide changes in water quality. Additional monitoring will be required to assess the persistence and spatial extent of these changes.

6. Summary

This report presents the design and salient findings of a water quality monitoring study conducted for Cayuga Lake in 2007, sponsored by Cornell University Department of Utilities and Energy Management. This is the tenth annual report for a monitoring program that has been conducted annually since 1998. A number of noteworthy findings are reported here for 2007 that have value for lake management. Water quality on the south shelf has been observed to vary substantially from year to year. Potential sources of variation include interannual differences in runoff, loading from WWTPs, and wind. Runoff during the June to October interval of 2007 was substantially lower than the long-term average. This is in stark contrast to the conditions in 2006 when the average flow for Fall Creek over the June to August was the third highest of the 1925 to 2007 record. As a consequence of lower tributary flows, summer average levels of total phosphorus and especially turbidity were lower in 2007 than in 2006. Summer average Chlorophyll-a concentrations on the shelf were among the lowest levels observed over the 1998-2007 interval. Summer average concentrations of total phosphorus and Chlorophyll-a for deep water sites continue to be consistent with mesotrophy, a classification shared by seven of the eleven Finger Lakes. Total phosphorus concentrations and turbidity values were similar in the LSC effluent and the receiving waters of the shelf. Soluble reactive phosphorus concentrations were distinctly higher in the LSC effluent than on the shelf. LSC contributed an estimated 8.2% of the TP load to the shelf over the May – October interval of 2007, a larger contribution than projected (4.8%) in the Draft Environmental Impact Statement. This is attributable to smaller inputs from wastewater treatment facilities and higher total phosphorus concentrations at the LSC intake location. The cause of higher phosphorus concentrations at the LSC intake has not been established. The total phosphorus loading rate to the shelf from LSC was 45% lower 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. The observed increases in soluble reactive phosphorus concentrations at the LSC intake since 2003 appear to be the result of lake-wide phenomena. Additional monitoring will be required to assess the persistence and spatial extent of this trend in water quality.

While the 2006 report noted an apparent increase in lake-wide Chlorophyll-a concentrations this now appears to correlate with the unusually high tributary flows of that year. The low tributary flow conditions of 2007 resulted in Chlorophyll-a levels returning to values more consistent with their long-term average and to levels comparable to those seen in 1999 (before the facility's startup), a similarly dry year.

References

American Public Health Association (APHA). 1992. Standard Methods for the Examination of Water and Wastewater, 18th edition. Washington, DC, American Public Health Association.

Auer, M.T. and S.W. Effler 1989. Variability in photosynthesis: impact on DO models. *J. Environ. Engng. Div. ASCE* 115:944-963.

Auer, M.T., K.A. Tomasoski, M.J. Babiera, M. Needham, S.W. Effler, E.M. Owens and J.M. Hansen. 1998. Particulate phosphorus bioavailability and phosphorus cycling in Cannonsville Reservoir. *Lake and Reserv. Manage.* 14 (2-3):278-289.

Bloesch, J. 1995. Mechanisms, measurement, and importance of sediment resuspension in lakes. *Mar. Freshwat. Res*. 46:295-304.

Bouldin, D.R. 1975. Transport in Streams. In Nitrogen and Phosphorus; Food Production, Waste, in the Environment, edited by K.S. Porter, Ann Arbor Science Publishers, Inc. Ann Arbor, MI.

Bowie, G.L., W.B. Mills, D.B. Porcella, C.L. Campbell, J.R. Pagenkopf, G.L. Rupp, K.M. Johnson, P.W.H. Chan, S.A. Gherini and C. Chamberlain. 1985. Rates, constants, and kinetic formulations in surface water quality modeling, 2nd edition, EPA/600/3-85/040. U.S. Environmental Protection Agency. Athens, GA. 544p.

Chapra, S.C., and H.F.H. Dobson. 1981. Quantification of the Lake Typologies of Naumann (Surface Growth) and Thienemann (Oxygen) with Special Reference to the Great Lakes. *J. Great Lakes Res*. 7:182-193.

Dobson, H.F.H., Gilbertson, M. and P.G. Sly. 1974. A Summary and Comparison of Nutrients and Related Water Quality in Lakes Erie, Ontario and Superior. *J. of the Fisheries Res. Board of Canada*. 31:731-738.

Ebina , J., T. Tsutsui and Shirai. 1983. Simultaneous determination of total nitrogen and total phosphorus in water using peroxidisulfate oxidation. *Wat. Res*. 17:1721-1726.

Effler, S.W. 1988. Secchi disc transparency and turbidity. *Jounal of Environmental Engineering Division*, ASCE 114:1436-1447.

Effler, S.W., M.T. Auer and N.A. Johnson. 1989. Modeling Cl concentration in Cayuga Lake, USA. *Water Air Soil Pollut.* 44:347-362.

Effler, S.W. and D.L. Johnson. 1987. Calcium carbonate precipitation and turbidity measurements in Otisco Lake, N.Y. *Water Resources Bulletin* 23:73-77.

Effler, S. W., M. G. Perkins and D. L. Johnson. 1998. The optical water quality of Cannonsville Reservoir: Spatial and temporal structures, and the relative roles of phytoplankton and inorganic tripton. *Lake and Reservoir Management* 14(2/3):238-253.

Effler, S. W., D. A. Matthews, M. G. Perkins, D. L. Johnson, F. Peng, M. R. Penn and M. T. Auer. 2002. Patterns and impacts of inorganic tripton in Cayuga Lake. *Hydrobiologia* 482:137-150.

Godfrey, P. J. 1977. Spatial and temporal variation of the phytoplankton in Cayuga Lake. Ph.D. Thesis, Cornell University, Ithaca, NY.

Hamilton, D. H. 1969. Nutrient limitation of summer phytoplankton growth in Cayuga Lake. *Limnol. Oceanogr*. 14:579-590.

Oglesby, R.T. 1979. The limnology of Cayuga Lake. In: J.A. Bloomfield (ed.), Lakes of New York State, Vol. I., Ecology of the Finger Lakes, Academic Press, Inc., New York, pp. 2-121.

NELAP (National Environmental Laboratory Approval Program). 2003. Environmental laboratory approval program certification manual. New York State Department of Health.

Parsons, T. R., Y. Maita and C. M. Lalli. 1984. A Manual of Chemical and Biological Methods for Seawater Analysis. Pergamon Press, New York, NY.

Peterson, B. J. 1971. The role of zooplankton in the phosphorus cycle of Cayuga Lake. Ph.D. Thesis, Cornell University, Ithaca, NY.

Rueda, F.J.; Cowen, E.A. 2005. The residence time of a freshwater embayment connected to a large lake. *Limnology & Oceanography* 50:1638-1653.

Stearns and Wheler 1997. Environmental Impact Statement – Lake Source Cooling Project: Cornell University.

Trautmann N. M., C. E. McCulloch and R. T. Oglesby. 1982. Statistical determination of data requirements for assessment of lake restoration programs. *Can. J. Fish. Aquat. Sci*. 39:607-610.

Upstate Freshwater Institute (UFI). 1999. Cayuga Lake Water Quality Monitoring, Related to the LSC Facility: 1998.

Upstate Freshwater Institute (UFI). 2000. Cayuga Lake Water Quality Monitoring, Related to the LSC Facility: 1999.

Upstate Freshwater Institute (UFI). 2001. Cayuga Lake Water Quality Monitoring, Related to the LSC Facility: 2000.

Upstate Freshwater Institute (UFI). 2002. Cayuga Lake Water Quality Monitoring, Related to the LSC Facility: 2001.

Upstate Freshwater Institute (UFI). 2003. Cayuga Lake Water Quality Monitoring, Related to the LSC Facility: 2002.

Upstate Freshwater Institute (UFI). 2004. Cayuga Lake Water Quality Monitoring, Related to the LSC Facility: 2003.

Upstate Freshwater Institute (UFI). 2005. Cayuga Lake Water Quality Monitoring, Related to the LSC Facility: 2004.

Upstate Freshwater Institute (UFI). 2006. Cayuga Lake Water Quality Monitoring, Related to the LSC Facility: 2005.

Upstate Freshwater Institute (UFI). 2007. Cayuga Lake Water Quality Monitoring, Related to the LSC Facility: 2006.

United States Environmental Protection Agency (USEPA). 1974. Report on Cayuga Lake, Cayuga, Seneca, and Tompkins Counties, New York. EPA Region II. Working paper No. 153, EPA National Eutrophication Survey. National Environmental Research Center, Las Vegas. 19 p. and appendices.

United States Environmental Protection Agency (USEPA). 1983. Methods for chemical analysis of water and wastes. Environmental Monitoring and Support Laboratory, Cincinnati, OH, EPA-600/4-79-020.

United States Environmental Protection Agency (USEPA). 1992. *In vitro determination of Chlorophyll-a and phaeophytin in marine and freshwater phytoplankton by fluorescence,*adapted by E. J. Arar and G. B. Collins. In USEPA Methods for the Determination of Chemical Substances in Marine and Estuarine Environmental Samples. Environmental Monitoring Systems Laboratory, Office of Research and Development, USEPA, Cincinnati, OH 45268.

Vollenweider, R.A. 1975. Input-output models with special reference to the phosphorus loading concept in limnology. *Schweiz. J. Hydrol.* 33:53-83.

Weidemann A.D. and T.T. Bannister. 1986. Absorption and scattering coefficients in Irondequoit Bay. *Limnol. Oceanogr*. 31:567-583.

Wetzel, R.G. and G.E. Likens. 1991. Limnological analyses (2nd edition). Springer- Verlag, New York.

Wright, T. D. 1969. Plant pigments (Chlorophyll-a and phaeophytin). In "Ecology of Cayuga Lake and the Proposed Bell Station (Nuclear Powered)" (R.T. Oglesby and Allee, eds.), Publ. No. 27, Chapter XV. Cornell Univ. Water Resour. And Mar. Sci. Cent., Ithaca, New York.

Appendix 1

In Lake Monitoring Data Listing

Total Phosphorus (µgP·L^{-1})

Dates:	4/19/07	5/1/07	5/8/07	5/15/7	5/30/07	6/12/07	6/26/07	7/10/07	7/24/07	8/7/07	8/21/07	9/4/07	9/18/07	10/4/07	10/16/07	10/30/07
Sites:																
1	41.3	18	12	10.5	15.2	21.9	13.6	14.6	24.6	14.1	16.7	12.3	13.9	13	13.6	14.9
2	46.7	25.9	15.1	14.9	15.8	17.7	20.9	22.2	43.5	16.3	39.5	35.1	35.1	14.9	19.3	15.2
3	60.9	17.7	16.1	10.2	14.2	16.8	15.8	21.5	57	16	101.1	11.7	15.8	10.6	12.7	12
4	14.8	18	12	29.7	20.2	23.8	11.7	15.2	14.1	22.7	23.1	10.7	11.7	12.1	15.2	10.5
5	14.2	15.2	13.3	10.5	15.8	14.3	14.3	17.4	16	14.1	16.4	11.1	11.1	9.3	12.4	12
6	14.8	14.8	13.3	12.7	17.4	17.1	12	14.9	17.6	14.1	14.2	11.1	10.1	10.6	11.4	11.1
7	38.5	19.9	14.5	9.2	13.6	15.8	19	29.8	18.9	18.9	115.3	15.8	14.8	23.3	16.5	12
8	15.2	14.5	14.8	15.2	16.8	14.9	11.4	14.3	17	14.1	14.2	11.4	10.1	9	10.8	9.2
LSC Intake	19.6	15.5	15.1	14	17.1	33.3	12.4	12	18.6	12.5	13.9	11.1	11.1	10.3	11.4	11.1

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

Dates:	4/19/07	5/1/07	5/8/07	5/15/7	5/30/07	6/12/07	6/26/07	7/10/07	7/24/07	8/7/07	8/21/07	9/4/07	9/18/07	10/4/07	10/16/07	10/30/07
Sites:																
1	9.3	5.6	2	4	0.6	1.1	0.3	1.2	0.3	0.3	0.5	0.3	4.1	3.5	2.1	4.4
2	6.5	5.4	3.6	3.4	0.4	1.1	1.2	0.6	3.8	0.3	10	0.3	9.1	3.2	1.8	1.7
3	12.6	6.4	3.6	2.3	1.1	1.2	0.9	0.8	4.4	0.3	9.6	0.15	3.6	2.4	1.5	0.8
4	9	7.6	5.6	1.5	0.4	1.4	0.9	0.9	1.3	1.8	4.3	0.15	2.4	2.1	5.5	1.7
5	8.7	7.2	3.2	2.1	0.4	1.1	0.5	0.9	0.3	0.3	0.5	0.15	0.6	1.1	1	0.3
6	9.5	7.9	3.2	2.1	0.6	1.1	0.15	0.8	0.3	0.3	0.5	0.15	0.6	1.3	1.3	0.8
7	8.1	4.2	2.6	1.5	1.2	1.1	2	1.6	5.5	3.2	13.9	1.6	3.5	6.7	0.7	0.8
8	8.7	8.7	4.3	1.8	0.6	1.1	0.15	3	0.5	0.3	0.15	0.15	0.3	1	0.8	0.5
LSC Intake	13.7	8.1	4	2.6	0.6	4.5	0.5	0.5	0.3	0.3	0.3	0.15	0.3	1	0.8	0.3

Chlorophyll-a (µg·L^{-1})

Dates:	4/19/07	5/1/07	5/8/07	5/15/7	5/30/07	6/12/07	6/26/07	7/10/07	7/24/07	8/7/07	8/21/07	9/4/07	9/18/07	10/4/07	10/16/07	10/30/07
Sites:																
1	1.8	1.9	2.25	2.32	6.94	12.65	2.51	4.09	5.45	4.95	5.77	4.04	3.06	2.34	-	3.79
2	2.53	0.58	1.21	1.47	5.56	6.42	3.38	4.43	5.74	3.47	5.02	20.04	2.95	2.57	-	4.3
3	2.35	1.23	1.28	1.37	6.8	4.79	2.56	4.7	7.74	2.63	15.09	2.93	2.5	2.8	-	5.64
4	0.22	0.62	0.76	7.14	5.21	10.15	2.11	3.47	1.64	2.82	10	2.7	3.44	5.18	-	2.72
5	0.17	0.76	2.38	2.39	8.5	5.69	3.13	6	6.72	7.55	4.26	3.54	5.16	4.3	-	7.57
6	0.34	0.59	2.7	5.14	9.91	9.26	1.89	6.64	10.81	7.94	3.83	5.19	5.81	6.06	-	7.06
7	1.97	2.1	3.16	1.71	5.43	4.91	2.97	4.04	1.13	6.76	33.55	3.01	2.08	4.71	-	4.75
8	0.26	-	2.83	7.93	11.03	4.42	2.34	10.01	13.93	7.92	4.75	4.61	4.85	6.15	-	5.45
LSC Intake	0.31	0.48	3.37	6.23	11.4	5.02	6.58	8.82	11.5	7.3	4.6	4.7	5.84	6.41	-	7.25

Turbidity (NTU)

Dates:	4/19/07	5/1/07	5/8/07	5/15/7	5/30/07	6/12/07	6/26/07	7/10/07	7/24/07	8/7/07	8/21/07	9/4/07	9/18/07	10/4/07	10/16/07	10/30/07
Sites:																
1	27.7	2.7	1.7	1.1	1.4	1.8	1	0.9	1.2	1.2	0.9	0.6	0.65	0.6	1.15	0.6
2	22.1	1.7	1.1	1.3	1.8	1.3	1.6	1.5	5.8	1.7	2.1	2.2	0.85	0.7	0.74	1
3	42.3	2.2	1.6	1	1.7	1.4	1.5	0.8	19.8	1.1	0.8	0.4	0.65	0.5	0.6	0.8
4	1	2.2	1	9	2.2	1.2	0.7	0.7	0.6	0.8	1.7	0.7	0.8	0.7	0.82	0.4
5	1	2.2	1.2	1.6	1.6	1	1.2	0.8	1.3	1.5	1.6	0.7	0.58	0.4	0.49	1.3
6	1.2	1.3	0.9	1.1	1.5	0.8	1.1	0.8	1.4	1.1	0.8	0.7	0.58	0.5	0.58	0.7
7	26.7	4.6	1.5	1	1.4	1	0.8	1.2	8.3	1.1	1.8	0.5	0.6	1.1	0.68	0.7
8	1.6	1.2	0.6	1.3	1.2	1	0.7	0.9	1.7	1.6	0.9	0.7	0.7	0.6	0.46	0.5
LSC Intake	1.5	1.3	0.8	1.3	1.1	1.1	1	0.6	1.6	1.3	1	0.8	0.52	0.6	0.51	0.6

Secchi Disc Depth (m)

Dates:	4/19/07	5/1/07	5/8/07	5/15/7	5/30/07	6/12/07	6/26/07	7/10/07	7/24/07	8/7/07	8/21/07	9/4/07	9/18/07	10/4/07	10/16/07	10/30/07
Sites:																
1	0.4	1	2.3	bottom	2.4	1.65	bottom	vegetation	3.25	3	3.55	vegetation	bottom	bottom	bottom	bottom
2	0.3	2.3	bottom	bottom	2.45	bottom	bottom	vegetation	1.7	vegetation	vegetation	1.6	vegetation	bottom	bottom	bottom
3	0.4	1.6	bottom	bottom	2.25	2.85	vegetation	bottom	1.8	vegetation	vegetation	bottom	bottom	bottom	bottom	bottom
4	bottom	2.05	bottom	3.45	2.1	bottom	vegetation	vegetation	vegetation	vegetation	vegetation	vegetation	vegetation	vegetation	bottom	bottom
5	5.35	1.8	4.55	4.1	2.2	3.05	vegetation	vegetation	3.3	2.35	3.35	4.55	bottom	5.45	bottom	bottom
6	5.35	4.3	5.65	3.6	2.35	3.45	4.65	4	2.65	2.3	4.45	5.15	5.15	5.75	7	5.55
7	0.3	0.9	bottom	bottom	2.6	bottom	vegetation	vegetation	bottom	vegetation	vegetation	bottom	bottom	bottom	bottom	bottom
8	5.3	5.45	6.3	3.6	2.6	5.3	6.25	4.5	2.73	2.35	3.6	5.1	6.55	6	6.85	6.45
LSC Intake	4.6	4.1	5.7	3.55	2.55	4.05	4.55	4.4	2.74	2.35	3.75	5.2	5.2	5.4	6.15	5.5

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

Next page

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
Jan-03	8.2	9.2	0.4	0.5	10.64	11.59	7.5	7.7	0.0103	0.0115	0.0037	0.0048
Feb-03	7.8	8.2	0.3	0.3	13.40	13.84	7.8	7.9	0.0095	0.0099	0.0039	0.0044
Mar-03	7.6	9.2	0.3	0.4	12.52	13.00	7.5	7.9	0.0111	0.0155	0.0032	0.0039
Apr-03	8.2	9.4	0.4	0.8	12.75	13.30	7.6	7.9	0.0138	0.0169	0.0045	0.0049
May-03	8.7	9.6	0.6	0.9	12.73	14.60	7.5	7.8	0.0120	0.0131	0.0039	0.0046
Jun-03	9.4	10.6	1.0	1.5	12.05	12.20	7.7	7.9	0.0136	0.0159	0.0038	0.0042
Jul-03	10.4	10.8	1.2	1.6	11.77	12.86	7.6	7.8	0.0111	0.0125	0.0039	0.0051
Aug-03	10.5	11.6	1.6	2.0	11.63	12.40	7.1	7.8	0.0090	0.0093	0.0051	0.0055
Sep-03	9.6	10.6	1.2	1.8	11.09	11.31	7.4	7.7	0.0128	0.0170	0.0062	0.0073
Oct-03	9.1	10.1	0.6	0.9	10.27	10.50	7.6	7.7	0.0166	0.0209	0.0065	0.0070
Nov-03	8.9	9.9	0.6	1.2	10.42	10.61	7.7	7.8	0.0201	0.0252	0.0055	0.0061
Dec-03	8.2	8.8	0.6	1.0	10.61	10.64	7.6	7.9	0.0170	0.0202	0.0048	0.0064
Jan-04	7.7	9.0	0.4	0.5	10.82	11.13	7.7	8.1	0.0320	0.0561	0.0057	0.0061
Feb-04	8.5	8.8	0.2	0.2	11.31	11.66	7.9	8.1	0.0154	0.0178	0.0061	0.0063
Mar-04	7.8	8.5	0.3	0.5	11.72	12.10	7.9	8.0	0.0141	0.0179	0.0061	0.0066
Apr-04	8.4	9.7	0.4	0.9	12.25	12.80	7.9	8.1	0.0163	0.0237	0.0062	0.0074
May-04	9.2	10.2	0.9	1.4	11.88	12.40	7.9	8.2	0.0166	0.0172	0.0064	0.0069
Jun-04	9.6	10.8	0.9	1.5	11.76	12.10	7.9	8.3	0.0157	0.0171	0.0065	0.0086
Jul-04	10.1	11.0	1.2	1.5	11.69	12.00	7.9	7.9	0.0089	0.0104	0.0056	0.0070
Aug-04	9.8	10.9	1.2	1.6	11.70	11.48	7.7	8.3	0.0135	0.0148	0.0066	0.0080
Sep-04	9.5	10.3	1.0	1.4	10.35	11.00	7.0	7.9	0.0127	0.0141	0.0082	0.0093
Oct-04	8.9	9.5	0.5	0.8	10.65	10.80	7.6	8.0	0.0139	0.0161	0.0082	0.0100
Nov-04	8.8	9.4	0.5	0.7	10.35	11.00	7.0	7.9	0.0127	0.0141	0.0082	0.0093
Dec-04	8.6	9.6	0.5	0.6	10.55	11.00	7.8	7.9	0.0130	0.0138	0.0068	0.0079
Jan-05	8.5	8.9	0.3	0.5	10.80	11.10	7.8	8.1	0.0153	0.0203	0.0079	0.0088
Feb-05	8.3	8.9	0.3	0.4	11.28	11.60	7.7	7.8	0.0145	0.0157	0.0072	0.0094
Mar-05	7.9	8.5	0.3	0.4	12.28	13.40	7.8	7.9	0.0145	0.0172	0.0075	0.0079
Apr-05	8.2	9.3	0.5	0.8	12.10	12.60	7.8	7.9	0.0218	0.0233	0.0081	0.0086
May-05	11.4	11.5	1.2	1.2	11.94	12.60	7.5	7.8	0.0200	0.0246	0.0083	0.0093
Jun-05	10.1	10.9	1.3	1.7	11.73	12.10	7.7	7.8	0.0172	0.0199	0.0091	0.0120
Jul-05	10.2	11.1	1.4	1.8	11.80	12.60	7.6	7.7	0.0162	0.0205	0.0097	0.0150
Aug-05	9.9	10.7	1.4	1.7	11.26	11.60	7.8	8.0	0.0164	0.0188	0.0093	0.0105
Sep-05	9.5	10.2	1.1	1.6	11.00	11.10	7.7	8.0	0.0189	0.0222	0.0100	0.0138
Oct-05	9.0	10.0	0.7	1.4	10.48	10.70	7.7	7.9	0.0183	0.0245	0.0104	0.0115
Nov-05	8.3	9.4	0.7	1.1	10.08	10.60	7.7	7.9	0.0183	0.0213	0.0105	0.0136
Dec-05	8.3	9.6	0.5	0.7	10.23	10.70	7.6	8.0	0.0156	0.0183	0.0075	0.0105

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
Jan-06	7.3	7.9	0.5	0.5	10.96	11.70	7.6	8.2	0.0185	0.0274	0.0079	0.0084
Feb-06	7	8.5	0.5	0.5	11.43	11.60	8.0	8.2	0.0151	0.0164	0.0083	0.0091
Mar-06	7.8	9.1	0.4	0.7	11.60	11.90	7.9	8.1	0.0169	0.0213	0.0080	0.0082
Apr-06	8.3	9.1	0.5	0.7	11.90	12.00	7.8	8.0	0.0150	0.0167	0.0083	0.0085
May-06	9.1	10.5	0.8	1.5	11.36	11.70	7.7	8.0	0.0163	0.0190	0.0076	0.0092
Jun-06	9.6	10.5	1.1	1.7	11.18	11.50	7.9	7.9	0.0198	0.0180	0.0090	0.0090
Jul-06	10.2	10.9	1.6	1.9	11.42	12.30	7.8	8.0	0.0161	0.0175	0.0094	0.0097
Aug-06	9.9	11.4	1.4	2.0	10.98	11.40	7.7	7.9	0.0169	0.0231	0.0096	0.0103
Sep-06	9.4	9.8	1.0	1.4	10.50	10.80	7.8	7.9	0.0164	0.170	0.0108	0.0110
Oct-06	9.0	9.6	0.7	1.0	10.68	11.00	7.6	7.7	0.0157	0.0169	0.0100	0.0118
Nov-06	8.9	9.6	0.6	0.8	9.90	10.30	7.6	7.8	0.0151	0.0179	0.0091	0.0095
Dec-06	8.7	9.8	0.6	0.9	10.28	10.80	7.5	7.9	0.0151	0.0166	0.0089	0.0096
Jan-07	8.2	8.9	0.5	0.8	9.78	10.40	7.6	8.0	0.0135	0.0155	0.0080	0.0092
Feb-07	7.8	8.6	0.3	0.5	10.40	11.40	7.8	8.0	0.0147	0.0213	0.0080	0.0084
Mar-07	7.9	8.6	0.3	0.5	10.60	11.60	7.8	7.9	0.0142	0.0156	0.0091	0.0118
Apr-07	8.3	9.3	0.4	0.8	12.00	12.10	8.0	8.1	0.0155	0.0164	0.0089	0.0092
May-07	8.8	9.6	0.8	1.4	10.93	11.30	7.7	8.1	0.0162	0.0170	0.0097	0.0104
Jun-07	9.4	10.7	1.2	1.7	11.07	11.20	7.5	8.0	0.0165	0.0171	0.0100	0.0104
Jul-07	9.6	10.5	1.3	1.7	11.20	11.60	7.9	8.0	0.0155	0.0166	0.0104	0.0115
Aug-07	9.7	10.6	1.4	1.9	11.43	12.00	7.7	8.5	0.0152	0.0163	0.0098	0.0106
Sep-07	9.4	10.4	1.1	1.8	10.65	11.00	7.8	8.0	0.0160	0.0186	0.0107	0.0128
Oct-07	9.1	10.0	0.9	1.5	10.24	11.20	7.6	7.8	0.0169	0.0190	0.0119	0.0142
Nov-07	8.7	9.3	0.5	1.0	10.05	10.90	7.5	7.8	0.0159	0.0174	0.0107	0.0115
Dec-07	8.4	9.5	0.5	0.7	10.65	11.00	7.8	7.9	0.0133	0.0142	0.0080	0.0097

Note: Information regarding QA of these data is available on request.