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Cayuga Lake Water Quality Monitoring, Related to the LSC Facility: 2008

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Preface

This report summarizes the results of water quality monitoring efforts related to the LSC facility in 2008. 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. The format of 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, Chlorophyll-a, 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 human 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.

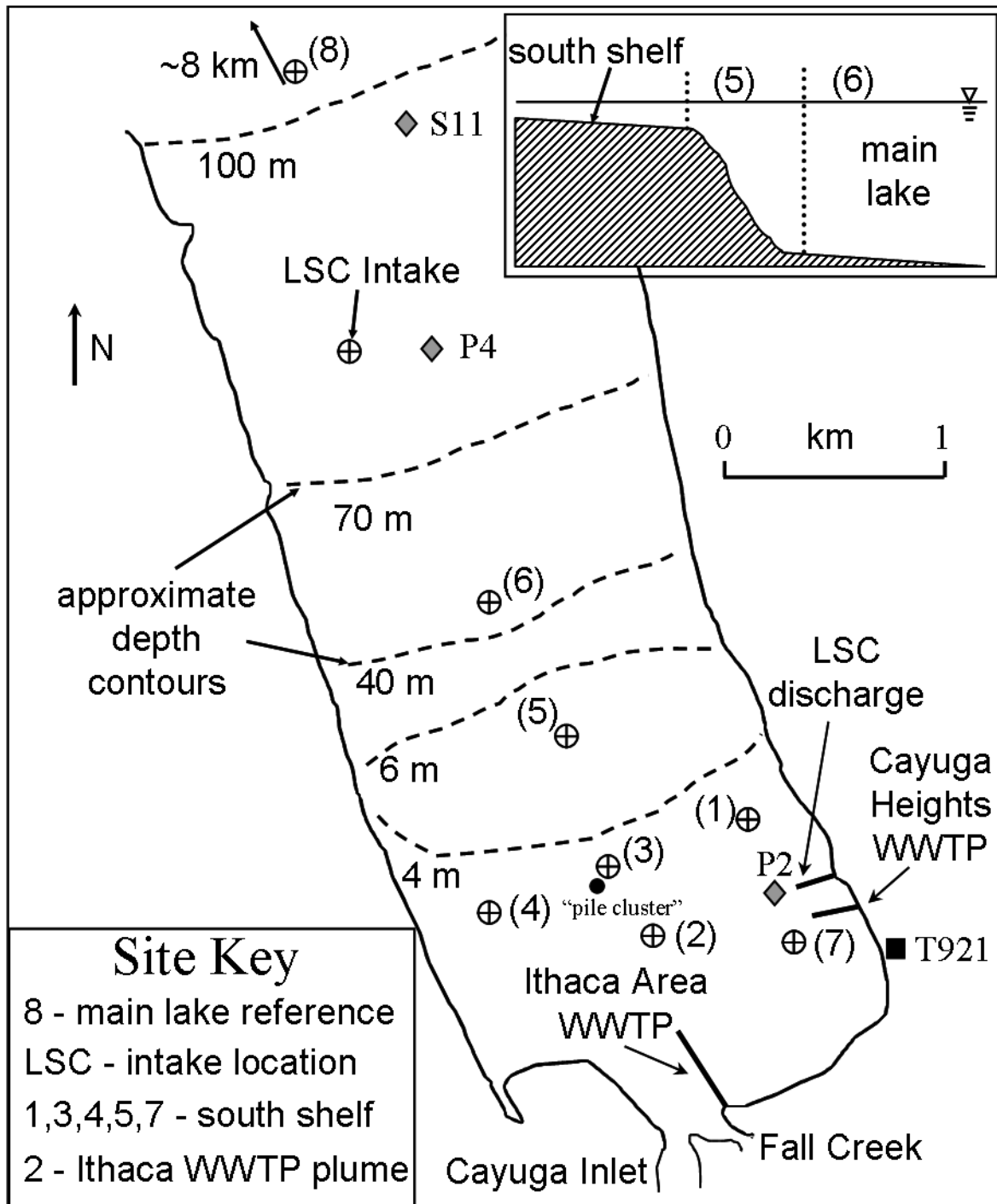


Figure 1: Sampling sites, setting, approximate bathymetry, for LSC monitoring program, southern end of Cayuga Lake. Sites sampled during 1994 – 1996 study (P2, P4 and S11; Stearns and Wheler 1997) are included for reference. Locations of sampling sites and outfalls are approximate.

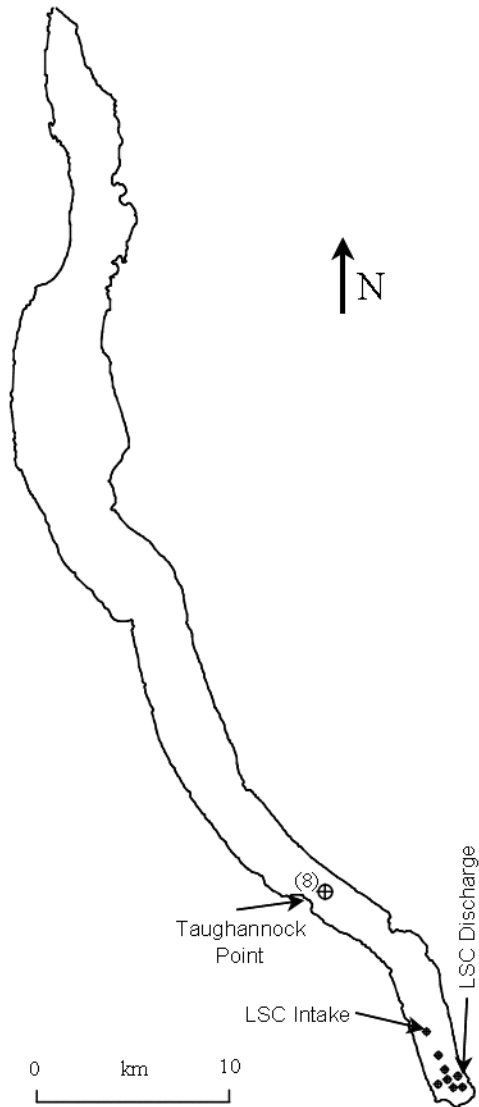


Figure 2: Sampling sites for LSC monitoring program, within the context of the entire Cayuga Lake basin.

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 (T_n), 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 2008, 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. Samples were not collected from site 8 on the last sampling date of the season, October 22, due to high winds and lake conditions that did not allow safe access to this site. All other sites were sampled as per the normal program on this date.

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 2007 were recovered in April 2008. Deployments made in late October 2008 will be retrieved in April 2009. 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 in an effort to provide 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 imparted by the various inputs/inflows that enter this portion of the lake and contribute to a fair representation of average conditions for this part 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, was 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 (sites 1, 3, 4), the other with 4 sites running approximately north-south along the main axis of the lake (sites 2, 3, 5, 6). An additional site (site 7) in the southeastern corner of the shelf brackets the location of the LSC discharge from the south, while site 1 is located at a similar distance to the north of the discharge (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 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 (USEPA 1997). 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 (1998)	0.7 $\mu\text{g}\cdot\text{L}^{-1}$
soluble reactive phosphorus	4500-P	APHA (1998)	0.5 $\mu\text{g}\cdot\text{L}^{-1}$
turbidity	2130-B	APHA (1998)	0.07 NTU
Chlorophyll-a	446.0 Rev. 1.2	USEPA (1997)	0.4 $\mu\text{g}\cdot\text{L}^{-1}$

2.7.1. Field Program

Precision of sampling and sample handling was assessed by a program of field replicates. Samples for laboratory analyses were collected in triplicate at site 1 on each sampling day. Triplicate samples were collected at one of the other sampling locations (sites 2-8 and the LSC intake) 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 2008 program (Table 4). The relatively high CV value of 0.29 for SRP at site 1 was largely the result of a single high value in one triplicate sample. If this value is omitted from the record the resulting mean CV for SRP at site 1 becomes 0.19. Further, the CV as it is defined here (standard deviation / mean) is sensitive to low mean values. SRP values were very low in most samples collected in 2008 – approximately 60% of all samples collected during the season had less than 1 $\mu\text{g}/\text{Liter}$ SRP and in approximately 30% the SRP concentration was below the limit of detection. At sites where triplicate samples were collected the median value was used for analysis.

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 - H₂SO₄ 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 2008, represented by the average coefficient of variation (CV=SDev/Mean).

Parameter	Site 1	Rotating Site*
TP	0.04	0.04
Chlorophyll-a	0.09	0.10
Turbidity	0.07	0.12
SRP	0.29	0.16

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

3. Results, 2008

The measurements made in the 2008 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 which are 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-NH₃) 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 nutrients. 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 interannual comparison.

Table 5: Summary of monitoring program results according to site, 2008.

TP [$\mu\text{g/L}$]			
SITE	MEAN	CV	RANGE
1	19.03	0.58	9.7 - 53.5
2	24.22	0.58	7.1 - 54.2
3	17.46	0.59	8.7 - 50.5
4	12.76	0.32	8.8 - 24.4
5	12.81	0.28	7.7 - 23.1
6	12.83	0.25	8.1 - 20.1
7	25.19	0.64	12.1 - 63.6
8	12.47	0.28	8.3 - 20.4
LSC	12.29	0.21	8.8 - 18.6

Chlorophyll-a a [$\mu\text{g/L}$]			
SITE	MEAN	CV	RANGE
1	5.82	0.76	0.4 - 16.2
2	4.13	0.78	0.1 - 11.7
3	4.39	0.70	0.3 - 10.4
4	4.28	0.76	0.4 - 9.7
5	5.38	0.61	0.5 - 11.6
6	7.01	0.60	0.4 - 14.6
7	9.05	1.19	0.3 - 47.3
8	6.49	0.54	0.5 - 13.3
LSC	6.74	0.51	0.6 - 12.8

SRP [$\mu\text{g/L}$]			
SITE	MEAN	CV	RANGE
1	1.56	1.47	0.3 - 6.6
2	2.64	0.96	0.5 - 8.1
3	1.88	1.21	0.3 - 6.9
4	2.07	1.48	0.3 - 11.3
5	1.11	1.50	0.3 - 6.0
6	1.00	1.79	0.3 - 7.0
7	1.22	1.49	0.3 - 6.7
8	1.04	1.92	0.3 - 8.1
LSC	1.02	1.96	0.3 - 7.9

T_n [NTU]			
SITE	MEAN	CV	RANGE
1	1.99	0.84	0.6 - 7.6
2	3.88	1.55	0.6 - 24.3
3	2.37	1.18	0.5 - 10.1
4	1.04	0.55	0.4 - 2.6
5	1.11	0.36	0.6 - 1.7
6	1.15	0.46	0.5 - 2.3
7	3.64	1.42	0.8 - 21.7
8	1.04	0.39	0.5 - 1.7
LSC	0.95	0.38	0.5 - 1.7

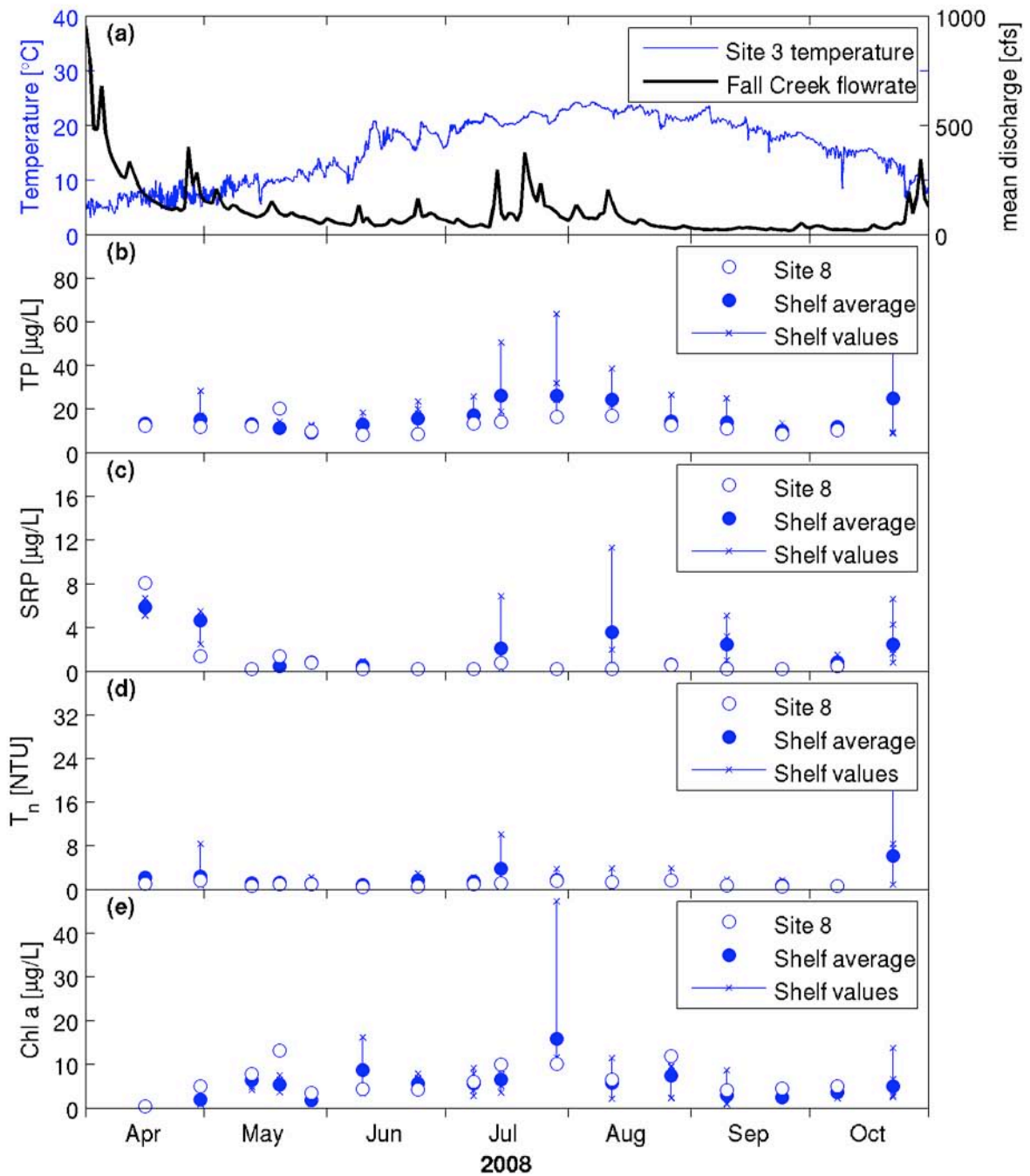


Figure 3: Time series of parameter values for Cayuga Lake for 2008: (a) Temperature at pile cluster (near site 3) and Fall Creek inflow record, (b) TP, (c) SRP, (d) Turbidity, (e) Chlorophyll-a. Values at site 8 are compared with the average value on the shelf. “x” symbols represent individual values measured at separate sites on the shelf. No samples were collected from site 8 on October 22 due to lake conditions.

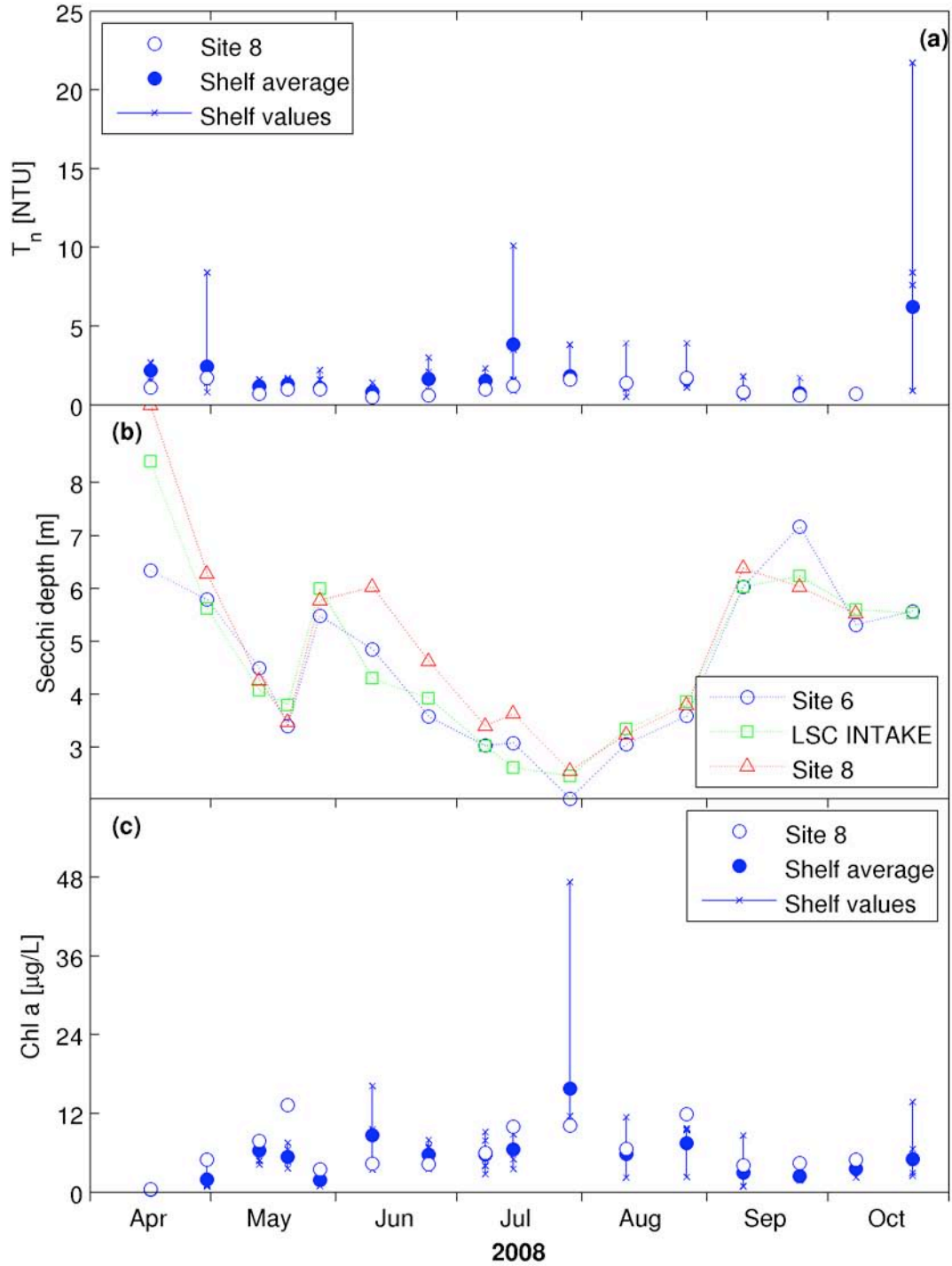


Figure 4: Time series of parameter values for Cayuga Lake for 2008: (a) Turbidity, (b) Secchi disc depth, and (c) Chlorophyll-a. Results for the “shelf” are averages; “x” symbols represent individual values measured at separate sites on the shelf.

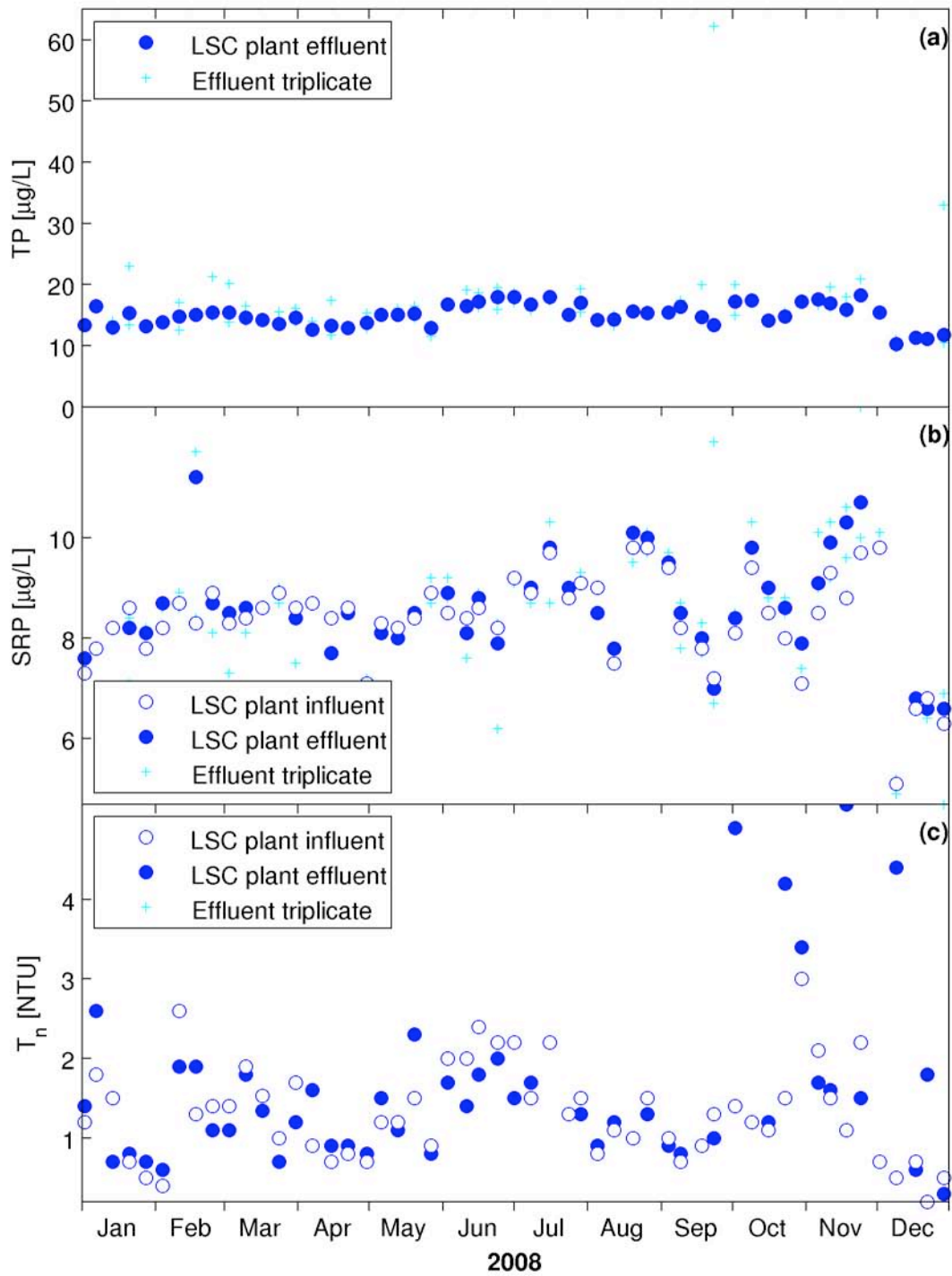


Figure 5: Time series of parameter values for the LSC influent and effluent for 2008: (a) TP (influent was not measured), (b) SRP, and (c) T_n . “+” symbols represent values of additional triplicate samples.

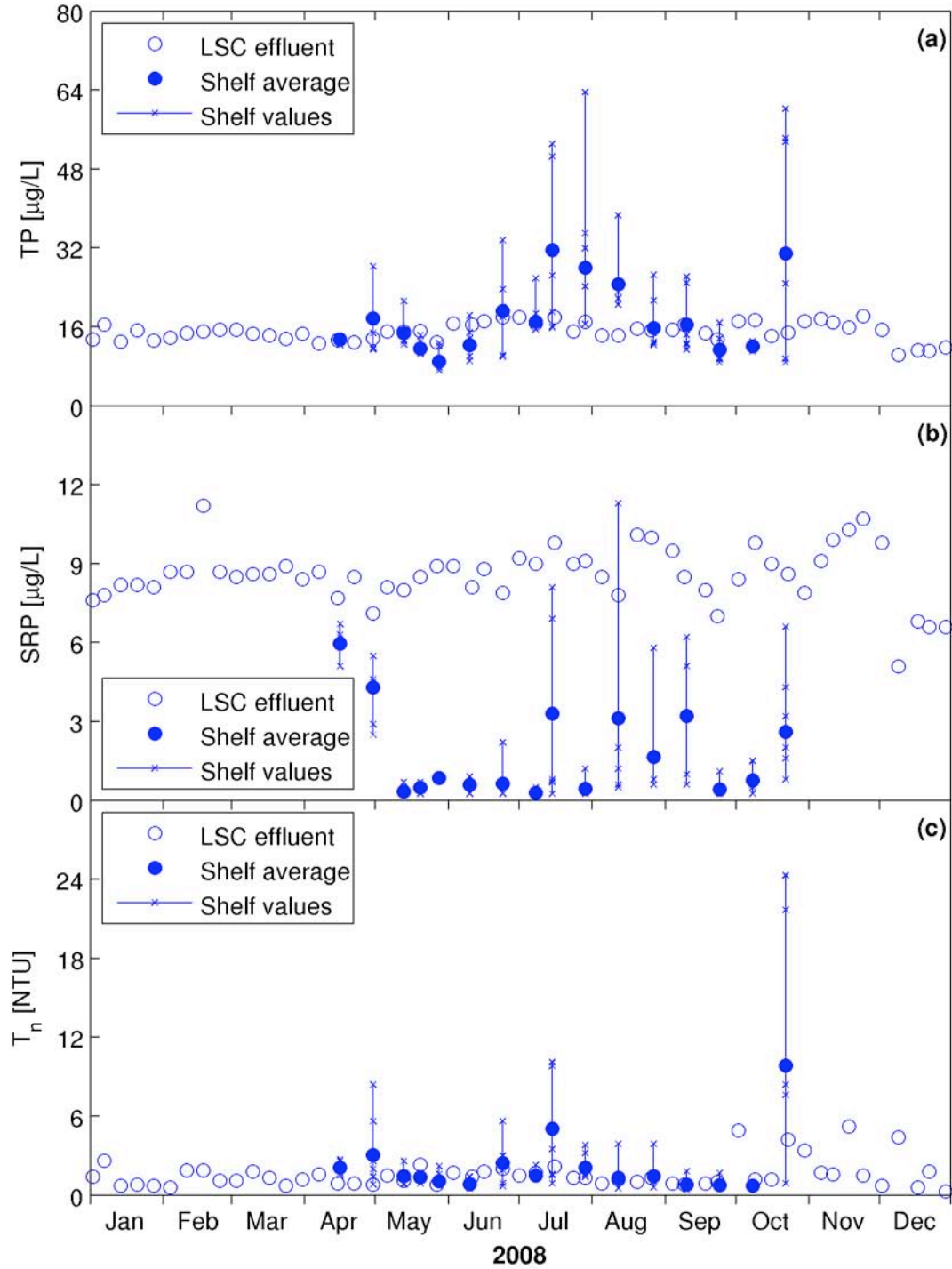


Figure 6: Time series of parameter values for the south shelf and the LSC effluent for 2008: (a) TP, (b) SRP, and (c) Turbidity. Results for the “shelf” are averages; “x” symbols represent individual values measured at separate sites on the shelf.

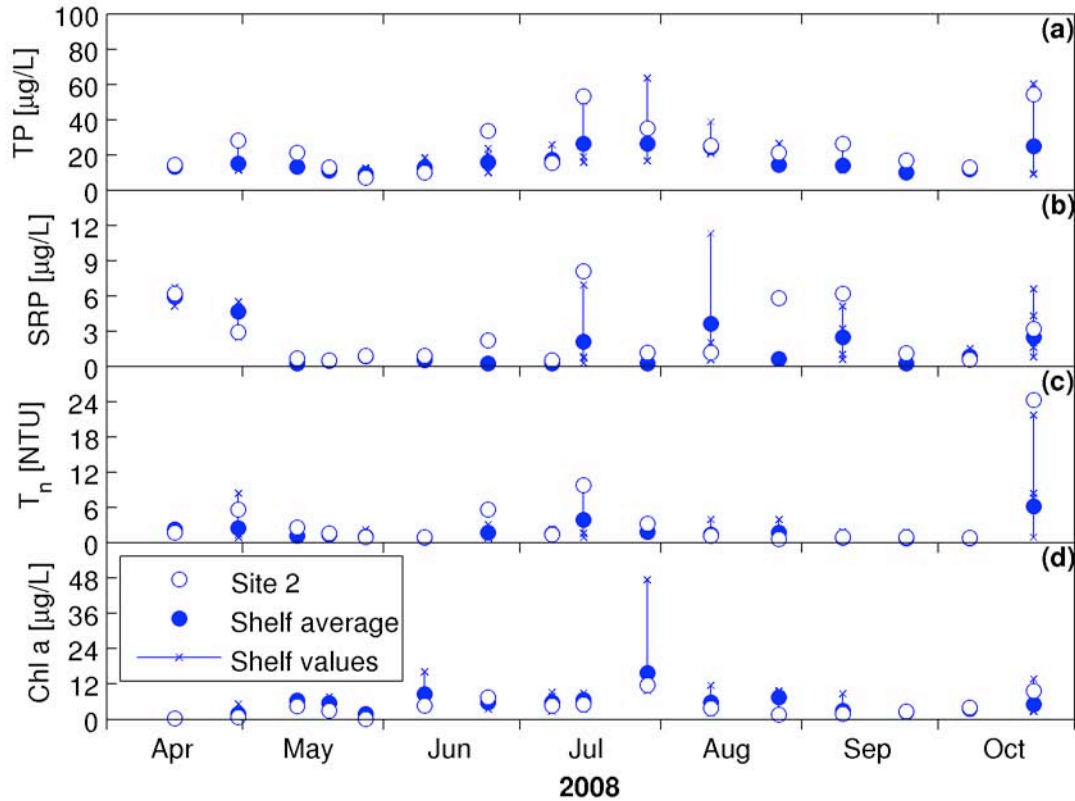


Figure 7: Comparison of observed parameters at site 2 and the shelf average.

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 the southern shelf's 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 2008 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 – 2008 interval (Table 6, Figure 8 and 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. Estimates of the monthly loads are the product of 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 – 2008 interval. Major decreases in phosphorus loading from IAWWTP were observed since 2006 as a result of the commencement of tertiary treatment for phosphorus. Phosphorus loading from IAWWTP during May – October 2008 was similar to the loading in 2007 over the same period. 2007-2008 loading levels were 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 37.8 kg per day for the IAWWTP and 7.6 kg per day for the CHWWTP. Average daily TP loading from IAWWTP during May – October of 2008 was 3.6 kg/day. Phosphorus loading from CHWWTP during May – October 2008 was 2.9 kg/day, similar to but slightly higher than the loading in 2007. Loading levels from CHWWTP have also decreased over the study period: 2005-2008 loading levels were 30% less on average than loadings in 2000-2003 (Table 6). In 2004, the year with the highest surface flows of the study period, phosphorus loading from CHWWTP was more than double the average loading rate since 2005.

Estimates of monthly tributary phosphorus loading presented in the Draft Environmental Impact Statement (DEIS) for the LSC facility (Stearns and Wheler 1997) for the combined inputs of Fall Creek and Cayuga Inlet for the May – October interval are included for reference and comparison with other loading sources in Table 6 and Figure 8. The tributary loading estimates were developed for what was described in the DEIS as an “average hydrologic year”, based on historic data for these two tributaries. 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 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 annual 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. Further, tributary loads vary substantially year-to-year, based on natural variations in runoff. This interannual variation is not accounted for in the data presented in Figure 8 and Table 6.

Estimates of monthly TP loading to the shelf from the LSC facility and the relative contribution of this source during 2008 are presented in Table 6, Figure 8 and Figure 9. Concentrations of TP were measured weekly in 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 1.51 kg/day, slightly lower than the average of 1.53 kg/day in 2007 and approximately half of the loading rate of 2.9 kg/day projected by the DEIS. The relative loading from LSC was approximately 8.2% of the total estimated load to the shelf (sum of measured TP from LSC, IAWWTP and CHWWTP and estimated TSP from tributaries), higher than the 4.8% projected in the DEIS. The peak relative monthly contribution of the LSC facility to total phosphorus loading to the

shelf in 2008 occurred in July (14.4%). In this month the loading from LSC was the highest for the year (2.2 kg/day) and loadings from other sources were relatively low, including loading from tributary flow. Tributary flow is the most significant source of phosphorus to the shelf, and is the source that shows the most variance between months.

The higher relative loading rate of LSC in 2008 when compared to the projected relative loading in the DEIS is due to lower loadings from the WWTP than predicted in the DEIS, not higher loadings from LSC. The loading estimates from the two WWTP in the DEIS were based on the plants discharging at their maximum permitted TP concentrations and flow rates during the entire year. The actual loadings from both plants are significantly lower than this, averaging a total of 6.5 kg/day during May – October 2008 out of the permitted 45.4 kg/day. Absolute phosphorus loading from LSC (as well as from the two WWTP) was significantly lower in 2008 than predicted in the DEIS (1.5 kg/day discharged vs. 2.9 kg/day predicted).

Phosphorus loading rates for LSC were similar during June to September of 2008 (mean 1.8 kg/day) and substantially lower in May and October (mean 0.9 kg/day; Table 6, Figure 8 and Figure 9). From 2000 to 2004 phosphorus loading from the LSC facility to the shelf remained consistent at about 1.1 kg/day (May – October average) with a relative contribution of about 3.5% (Table 6). In 2005 loading rates and the relative contributions from LSC increased significantly (to 1.8 kg/day, 6.7%). Since 2006 the mean daily May - October loading has been approximately 1.5 kg/day or about 8% of the total estimated loading. This is due to changes in phosphorus concentrations in the lake's hypolimnion in those years (Figure 10). Loading rates declined slightly in 2008 relative to the three 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). The median difference between SRP pairs was 0.2 $\mu\text{g/Liter}$, and between T_n pairs was 0.2 NTU. This suggests the absence of substantial inputs within the facility. The average concentration of SRP in the LSC effluent in 2008 (April – October average of 8.6 $\mu\text{g/Liter}$) was 15% lower than that observed in 2007 (10.2 $\mu\text{g/Liter}$), which was the year with the highest observed levels. Between 2000-2006 average April – October effluent SRP concentrations ranged from 4.2 to 8.7 $\mu\text{g/Liter}$. 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 four sampling dates in July, August and October. These dates were immediately following upwelling or surface flow events which led to higher levels on the shelf than in the effluent. As in previous years, levels of TP, SRP and T_n varied widely over time and space on the shelf during 2008. However this variance was not as pronounced during 2008, a low surface flow year, as it has been during high flow years.

The increased TP loading to the shelf from the LSC effluent during 2005 - 2008 (Table 6) is largely attributable to the increase in TP concentration in the effluent relative to 2000-2004. Average TP concentration in the LSC effluent in the years 2004 - 2008 are 28% higher than in the years 2000 - 2003 (Figure 10). Average SRP concentrations were 78% higher in 2004 - 2008 than in 2000-2003 (Figure 10). However, after the steep rise in phosphorus concentration in 2004 – 2005, TP levels have been declining and SRP levels appear to have leveled off (Figure 11). The increase in phosphorus loading from the LSC since 2005 was completely offset by the reduction in loading from IAWWTP following upgrades to the plant. Total phosphorus loading to shelf from point sources dropped approximately 50% between 2005 – 2008 (Figure 15c).

The increased phosphorus concentrations in the LSC effluent appear to be associated with a change in hypolimnetic water quality that has occurred beginning around 2004. Paired measurements of SRP and T_n in the LSC influent and effluent compared closely in 2008 (Figure 5), as they have throughout operation of the facility (UFI 2001, 2002, 2003, 2004, 2005, 2006, 2007, Cornell University 2008). 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 in 2004 and 2005 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 stratified 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 ($>20 \mu\text{g/Liter}$) of SRP have been observed in Cayuga Lake's hypolimnion in the past at depths near 100 meters (Oglesby, 1979).

Table 6: Estimates of monthly loads of phosphorus to the southern portion of Cayuga Lake over the 2000 to 2008 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%
<i>Mean</i>	<i>17.9</i>	<i>4.1</i>	<i>13.4</i>	<i>1.0</i>	<i>36.4</i>	<i>3.3%</i>
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%
<i>Mean</i>	<i>16.0</i>	<i>5.0</i>	<i>13.4</i>	<i>1.0</i>	<i>35.4</i>	<i>3.0%</i>
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%
<i>Mean</i>	<i>12.0</i>	<i>3.3</i>	<i>13.4</i>	<i>1.1</i>	<i>29.7</i>	<i>3.9%</i>
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%
<i>Mean</i>	<i>11.0</i>	<i>4.4</i>	<i>13.4</i>	<i>1.1</i>	<i>29.8</i>	<i>3.9%</i>
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%
<i>Mean</i>	<i>11.3</i>	<i>7.1</i>	<i>13.4</i>	<i>1.1</i>	<i>32.9</i>	<i>3.5%</i>

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
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%
<i>Mean</i>	<i>10.2</i>	<i>3.6</i>	<i>13.4</i>	<i>1.8</i>	<i>29.0</i>	<i>6.7%</i>
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%
<i>Mean</i>	<i>5.4</i>	<i>3.0</i>	<i>13.4</i>	<i>1.6</i>	<i>23.3</i>	<i>7.8%</i>
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%
<i>Mean</i>	<i>3.6</i>	<i>2.5</i>	<i>13.4</i>	<i>1.5</i>	<i>20.9</i>	<i>8.2%</i>
2008						
May	3.4	6.0	29.0	0.9	39.3	2.3%
June	3.8	3.5	15.8	2.0	25.1	8.0%
July	2.7	1.8	8.8	2.2	15.6	14.4%
August	5.3	3.2	6.0	1.6	16.0	10.0%
September	4.1	1.6	7.5	1.4	14.6	9.7%
October	2.8	1.4	13.1	0.9	17.7	4.9%
<i>Mean</i>	<i>3.6</i>	<i>2.9</i>	<i>13.4</i>	<i>1.5</i>	<i>21.4</i>	<i>8.2%</i>

^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

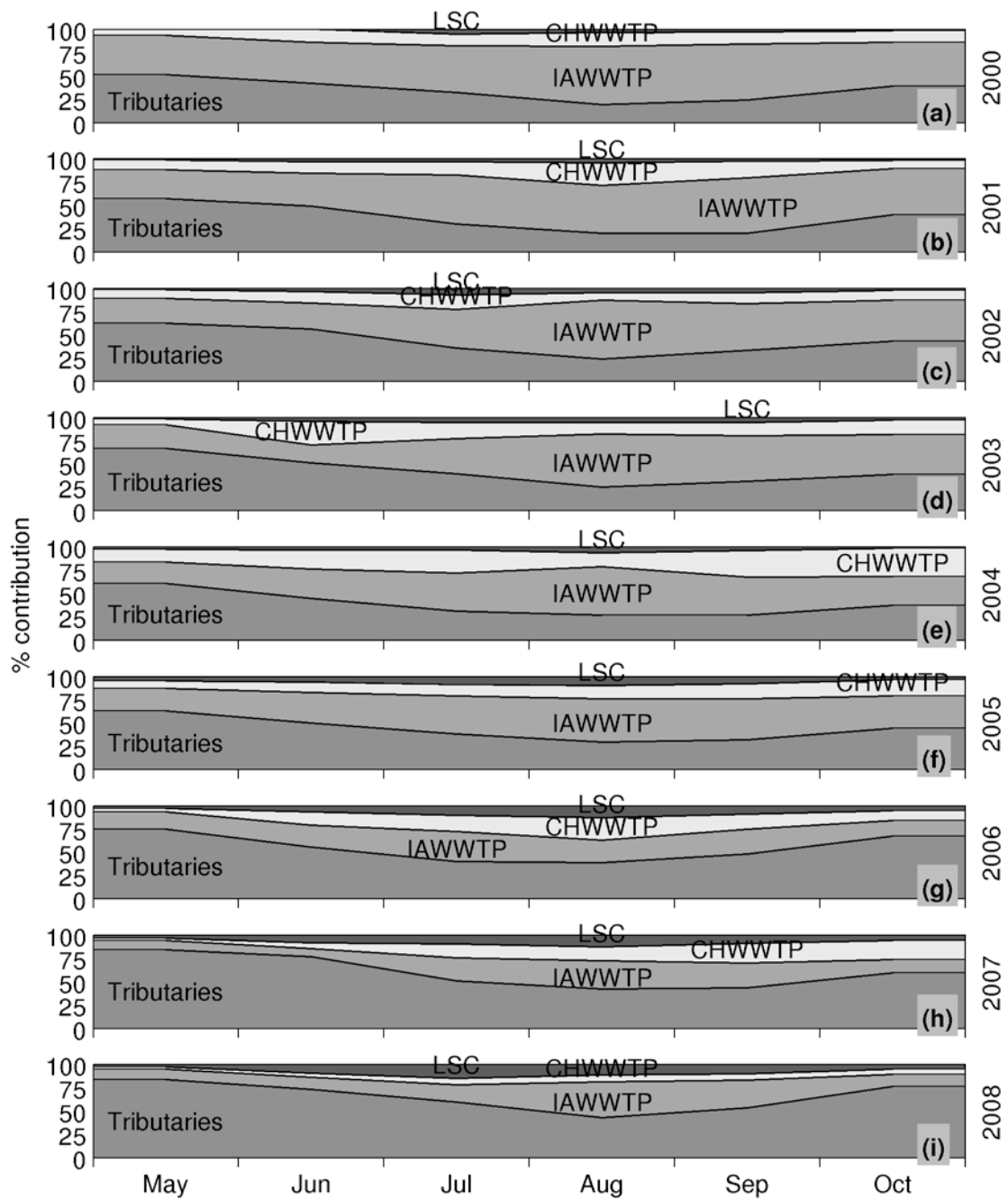


Figure 8: Time series of estimated relative monthly external loads of phosphorus to the southern portion of Cayuga Lake, partitioned according to source: (a) 2000, (b) 2001, (c) 2002, (d) 2003, (e) 2004, (f) 2005, (g) 2006, (h) 2007 and (i) 2008. Loads are for total phosphorus with the exception of tributary loading, which is for total soluble phosphorus.

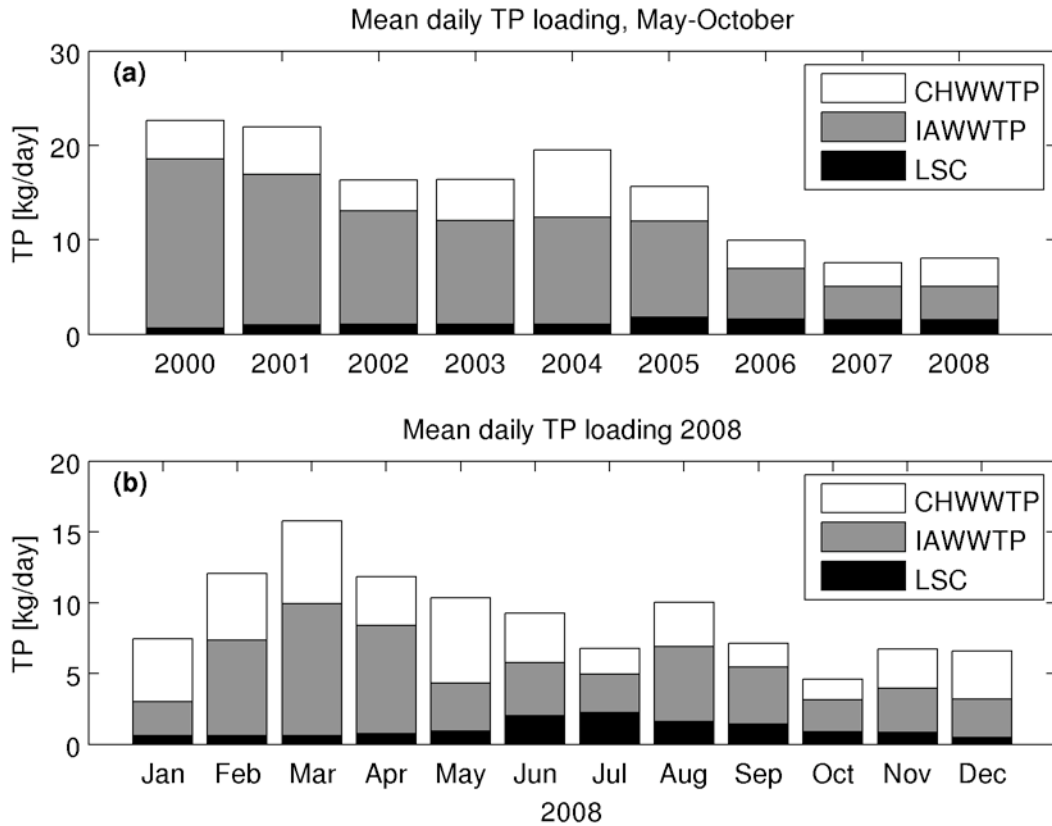


Figure 9: Trends in point source TP loading to the southern shelf: (a) mean daily loading in the May-October period, 2000-2008, (b) monthly mean loading in 2008.

Table 7: Average values and standard deviations for TP, SRP, and T_n in the LSC effluent and on the shelf. Averages determined from observations made during the April – October interval of 2008.

Location	TP ($\mu\text{g}\cdot\text{L}^{-1}$)	SRP ($\mu\text{g}\cdot\text{L}^{-1}$)	T_n (NTU)
LSC effluent (n = 30)	15.5 ± 1.7	8.6 ± 0.8	1.6 ± 1.0
Shelf average (n = 16)	17.5 ± 7.1	1.5 ± 1.8	2.1 ± 1.8

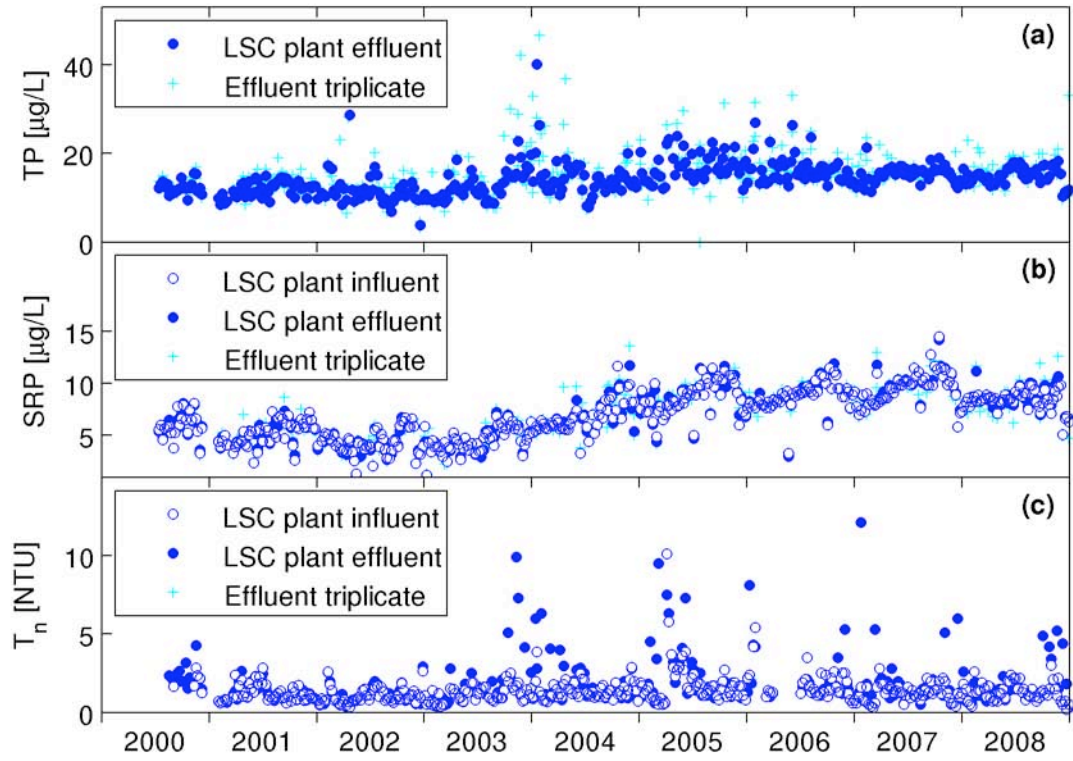


Figure 10: Time series of concentrations measured weekly in the LSC effluent for the 2000 – 2008 interval: (a) total phosphorus, (b) soluble reactive phosphorus, and (c) turbidity. “+” symbols represent additional triplicate sample values.

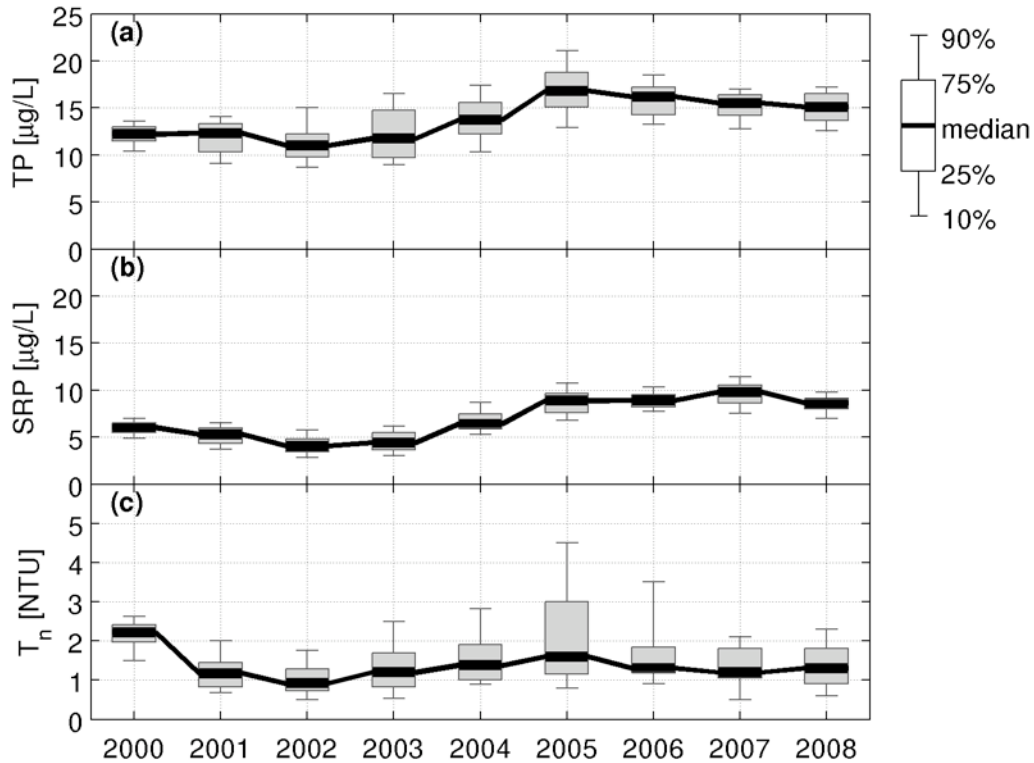


Figure 11: Annual statistics of concentrations measured in the LSC effluent for the 2000–2008 interval: (a) total phosphorus, (b) soluble reactive phosphorus, and (c) turbidity.

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 13 and Figure 15.

Runoff and wind conditions for the study period of 2008 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 (GFR) or the RUSS station

(Figure 13). Wind data presented here were taken from the GFR station when available, however such data were not available from 8/27/2008 – 9/24/2008 due to technical issues at the station. In this interval the wind data was supplemented by measurements taken at the RUSS station, an automated weather and water quality monitoring buoy operated by the DeFrees Hydraulics Laboratory and moored near site 6. It should be noted that slight differences between measurements from these sources can be expected to exist, due to different elevations of the wind sensor above the ground or water surface, and due to the surrounding topography. 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 2008 are compared to time-series of daily median values for the available records for the monitoring period (Figure 13).

When compared to the historic record, Fall Creek flows during 2008 were very low. The total flow volume through Fall Creek during the April – October period of 2008 was the second lowest of the years 1998 – 2008 and the lowest since the LSC plant began operating in 2000. Daily flow rates were below the historic median flow rates for most of the season, and high flow events were infrequent and characterized by lower peak flows relative to previous years. Sampling days on which above average for the year phosphorus and turbidity were measured correlated with higher flow events (July 15, 29; August 12) or upwelling events (October 22). However, these elevated levels were lower than peak values observed in previous years during strong forcing events.

4.4. Limitations in Measures of Trophic State on the Shelf

Recurring scientific evidence, provided by the findings of ten consecutive study years (Upstate Freshwater Institute 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007; Cornell University 2008) 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 – 2008, documented here).

Summer (June – August) average TP and Chlorophyll-a concentrations are presented for the lake's upper waters in Table 8 and Table 9. Higher TP concentrations were observed on the shelf compared to deeper portions of the lake in all years monitored. Summer average TP concentrations for 2008 were within the range of interannual variability observed since 1998 for both the deep water site and the shelf. Summer average Chlorophyll-a concentrations were higher in 2006-2008 than in preceding years both on the shelf and at the deep water sites, although not as high as some observations made in the 1970's. Chlorophyll-a concentrations were distinctly higher on the shelf than at deep water sites from 1994 to 1996. 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).

It should be noted that data from 1994 – 1996 were collected as part of the DEIS study. The collection sites and averaging methods were different than those used since 1998. Also, slight differences exist between the data presented in Table 8 and Table 9 and those presented in Figure 15. Table 8 and Table 9 aim to present each year as a single value, to facilitate simple interannual comparison. Values in the two tables were calculated by first calculating the shelf averaged value of TP or Chlorophyll-a concentration for each sampling date, and then averaging those numbers to a single value for the season. Figure 15 presents the range of variability of the different metrics, both temporally and spatially within the shelf. Data presented in this figure are not averaged, but are statistics of individual observations at the various sites. Further, Table 8 and Table 9 present data from June-September, the peak productive months, while Figure 15 presents May – October data.

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 – 2008 study years.

Year	Total Phosphorus ($\mu\text{g}\cdot\text{L}^{-1}$)		Source
	Deep-Water Location(s)	Southern Shelf	
1968 ^Δ	20.2 (n = 19)	-	Peterson 1971
1969 ^Δ	15.3 (n = 22)	-	Peterson 1971
1970 ^Δ	14.0 (n = 32)	-	Peterson 1971
1972 ^x	18.8 (n = 22)	-	USEPA 1974
1973 ^Δ	14.5 (n = 88)	-	Godfrey 1973
1994 ^{*,⊕}	21.7	30.8	Stearns and Wheler 1997
1995 ^{*,⊗}	16.5	23.7	Stearns and Wheler 1997
1996 ^{*,⊗}	12.4	21.7	Stearns and Wheler 1997
1998 ⁺	14.7 (14.7)	26.5 (24.7)	UFI 1999
1999 ⁺⁺	10.6 (9.8)	15.9 (14.5)	UFI 2000
2000 ⁺⁺	11.9 (11.6)	19.4 (18.7)	UFI 2001
2001 ⁺⁺	14.0 (14.2)	21.4 (20.4)	UFI 2002
2002 ⁺⁺	14.7 (14.1)	22.1 (22.2)	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)	24.7 (21.7)	Cornell University 2008
2008 ⁺⁺	12.9 (12.2)	19.6 (17.9)	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

Note: Shelf values reported here are weighted spatial averages (see section 3). This weighted average was not used in Table 8 of the 2007 report for that year's data only. The 2007 entry has been adjusted in this document for consistency with the other years.

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 – 2008 study years.

Year	Chlorophyll-a ($\mu\text{g}\cdot\text{L}^{-1}$)		Source
	Deep-Water Location(s)	Southern Shelf	
1966*	2.8	-	Hamilton 1969
1968**	4.3	-	Wright 1969
1968 – 1970	4.8	-	Oglesby 1978
1970	3.7	-	Trautmann et al. 1982
1972	10.3	-	Oglesby 1978
1973	8.2	-	Trautmann et al. 1982
1974	8.1	-	Trautmann et al. 1982
1977	8.6	-	Trautmann et al. 1982
1978	6.5	-	Trautmann et al. 1982
1994	5.5	8.9	Stearns and Wheler 1997
1995	4.8	6.8	Stearns and Wheler 1997
1996	3.4	7.6	Stearns and Wheler 1997
1998 ⁺	4.8 (4.8)	5.7 (5.2)	UFI 1999
1999 ⁺⁺	4.7 (4.6)	4.4 (4.2)	UFI 2000
2000 ⁺⁺	4.8 (4.7)	5.5 (5.4)	UFI 2001
2001 ⁺⁺	4.7 (4.5)	4.6 (4.4)	UFI 2002
2002 ⁺⁺	5.1 (5.2)	4.8 (5.6)	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)	6.1 (5.4)	Cornell University 2008
2008 ⁺⁺	7.6 (6.9)	8.0 (6.8)	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

Note: Shelf values reported here are weighted spatial averages (see section 3). This weighted average was not used in Table 9 of the 2007 report for that year's data only. The 2007 entry has been adjusted in this document for consistency with the other years.

4.6. Comparison to Other Finger Lakes: Chlorophyll-a

A synoptic survey of all eleven Finger Lakes was conducted in the late 1990's (NYSDEC, with collaboration of the Upstate Freshwater Institute) that support comparison of selected conditions among these lakes. This type of comparative study is important for understanding Cayuga Lake in the context of similar systems nearby. The following section is included to allow some context although data presented in this section are not as current as data presented elsewhere in this report. Variations in annual average Chlorophyll-a have been recorded in Cayuga Lake, and likely exist in other lakes in the region as well.

Chlorophyll-a data (Callinan et al., 2000) collected from the synoptic 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 µg/Liter 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/Liter.

The average Chlorophyll-a concentration for Cayuga Lake during the synoptic survey (3.5 µg/Liter) is compared to the values measured in the other ten Finger Lakes in Figure 12. These data support Cayuga Lake's classification as mesotrophic. In 1996 - 1999 Six of the lakes had average concentrations lower than observed for Cayuga Lake. Two of the lakes, Canandaigua and Skaneateles, had concentrations consistent with oligotrophy, while two (Conesus and Honeoye) bordered on eutrophy. However, the higher Chlorophyll-a concentrations observed in Cayuga Lake in 2006 - 2008 approached the upper bounds of mesotrophy.

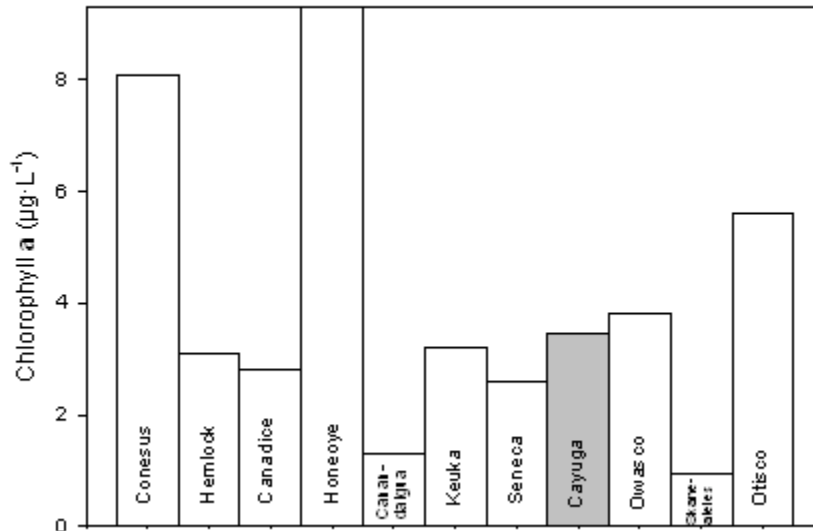


Figure 12: Comparison of average Chlorophyll-a concentrations for the spring-early fall interval for the eleven Finger Lakes, based on samples (n=15 to 16) collected over the 1996 through 1999 interval (data from Callinan et al. 2000).

4.7. Interannual Comparisons

Interannual differences in water quality can occur as a result of both human interventions and natural variations in climate. Because of its location and shallowness, water quality on the south shelf can vary substantially from year to year as a result of changes in forcing conditions. Conditions for runoff, wind speed and summed TP loading from the Ithaca Area WWTP, Cayuga Heights WWTP and the LSC facility for 2008 are compared here to the previous study years (1998 – 2007; Figure 13). When compared to flow conditions of the preceding ten years, the Fall Creek hydrograph for 2008 shows that this was a relatively dry year with only one event during the sampling season reaching a daily mean flow of 800 cfs and only two more with daily flow rates above 350 cfs. Average daily flow in Fall Creek was below 200 cfs 90% of the time. In previous years runoff events with flow rates of 2,000 cfs or higher were not uncommon (UFI 1999-2007).

Daily average wind speeds along the lake's long axis are presented in Figure 13b for the 1998 - 2008 study periods. Wind patterns were within the range of values measured in previous years. Sustained winds from the south for a period of several days can lead to upwelling events as is evident in the temperature record taken by the deployed thermistors (Figure 3a). Upwelling events result in the advection of hypolimnetic waters onto the southern shelf and increased vertical mixing in the water column as well as altering the residence time of nutrient loads on the shelf. This is most likely the reason for the increased phosphorus and turbidity measured on October 22 (Figure 3b,c,e).

Estimates of monthly average total phosphorus (TP) loads to the shelf from point sources in 2008 are compared to the 2000 - 2007 period in Figure 13c. Monthly estimates of TP loads for 2008 were consistently among the lowest values observed over all study years. TP loading to the shelf has decreased significantly since the establishment of tertiary treatment for phosphorus at the Ithaca Area WWTP.

Time series of TP, Chlorophyll-a, and T_n are presented for the April – October interval of the eleven study years in the context of historical values measured since 1998 (Figure 14, 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 levels recorded on the shelf in 2008 were on the lower end of the historic range on all but four sampling days (Figure 14a). TP concentrations were in the upper range of historically observed values on three consecutive sampling dates in July and August and on October 22. These sampling dates correspond to natural forcing events – elevated tributary flow rates on or before the July and August dates and an upwelling event on the October date (Figure 3a).

The seasonal dynamics of Chlorophyll-a concentrations on the shelf in 2008 were generally typical of the previous ten study years, although they were in the higher range of historic values throughout most of May - July (Figure 14b). In general, Chlorophyll-a concentrations have been lowest during spring and fall and highest during mid-summer. Turbidity values measured in 2008 were in general lower than values observed in previous study years (Figure 14c). 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). 2008 had runoff conditions similar to 1999 and correspondingly low measured turbidity values.

The temporally detailed data presented in Figure 13 and Figure 14 are summarized in Figure 15 as box plots for the eleven study years. The dimensions of the boxes are identified in the key located to the right of Figure 15a. Fall Creek flows were highest in 2004; runoff was also relatively high in 2000, 2002, 2003 and 2006 (Figure 15a). Flows were relatively low for the study intervals of 1999, 2001, 2005, 2007 and 2008. Average wind speeds were comparable for the eleven study years (Figure 15b). Total phosphorus loading from point sources has decreased over the study period, with major decreases since 2006 associated with upgrades in phosphorus treatment at the Ithaca Area WWTP (Figure 15c).

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 15). Variability of TP and turbidity were lowest during the 1999 and 2007 study intervals, which were characterized by low surface flow. Median shelf TP in 2008 was the second lowest of the entire study period, only slightly above that of 1999. Median shelf turbidity and the variability of TP and turbidity in 2008 were higher than in 1999 and 2007 but still in the range typical of low surface flow years. Conversely, median Chlorophyll-a on the shelf in 2008 was relatively high, second only to values observed in 2006.

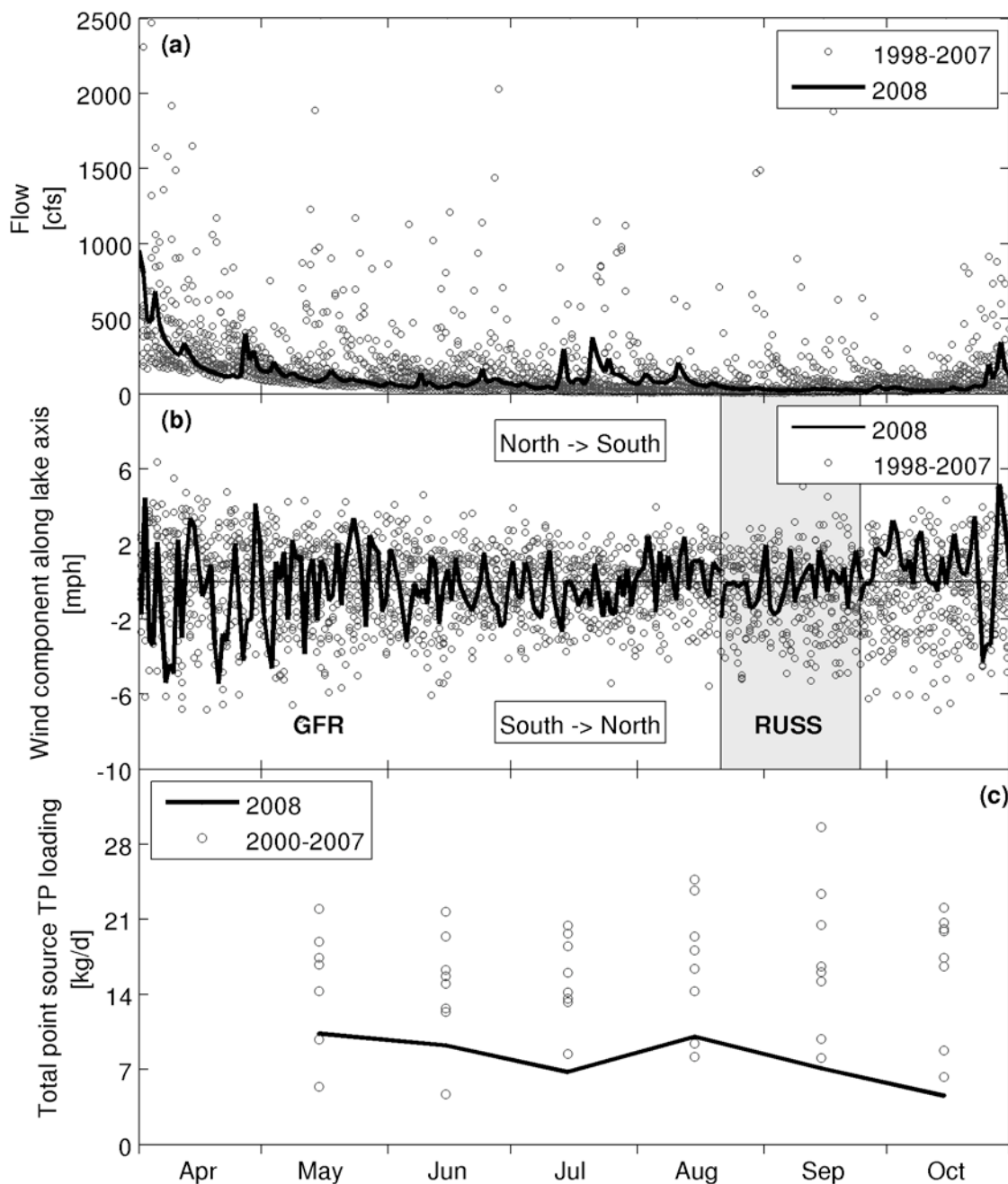


Figure 13: Comparison of 2008 conditions for runoff, wind and total phosphorus loading with conditions from the 1998-2007 interval: (a) median daily flows in Fall Creek, (b) daily average wind component along lake's long axis as measured at Game Farm Road or the RUSS station, and (c) summed monthly loads of total phosphorus (TP) to southern Cayuga Lake from the Ithaca Area WWTP, Cayuga Heights WWTP, and the LSC facility.

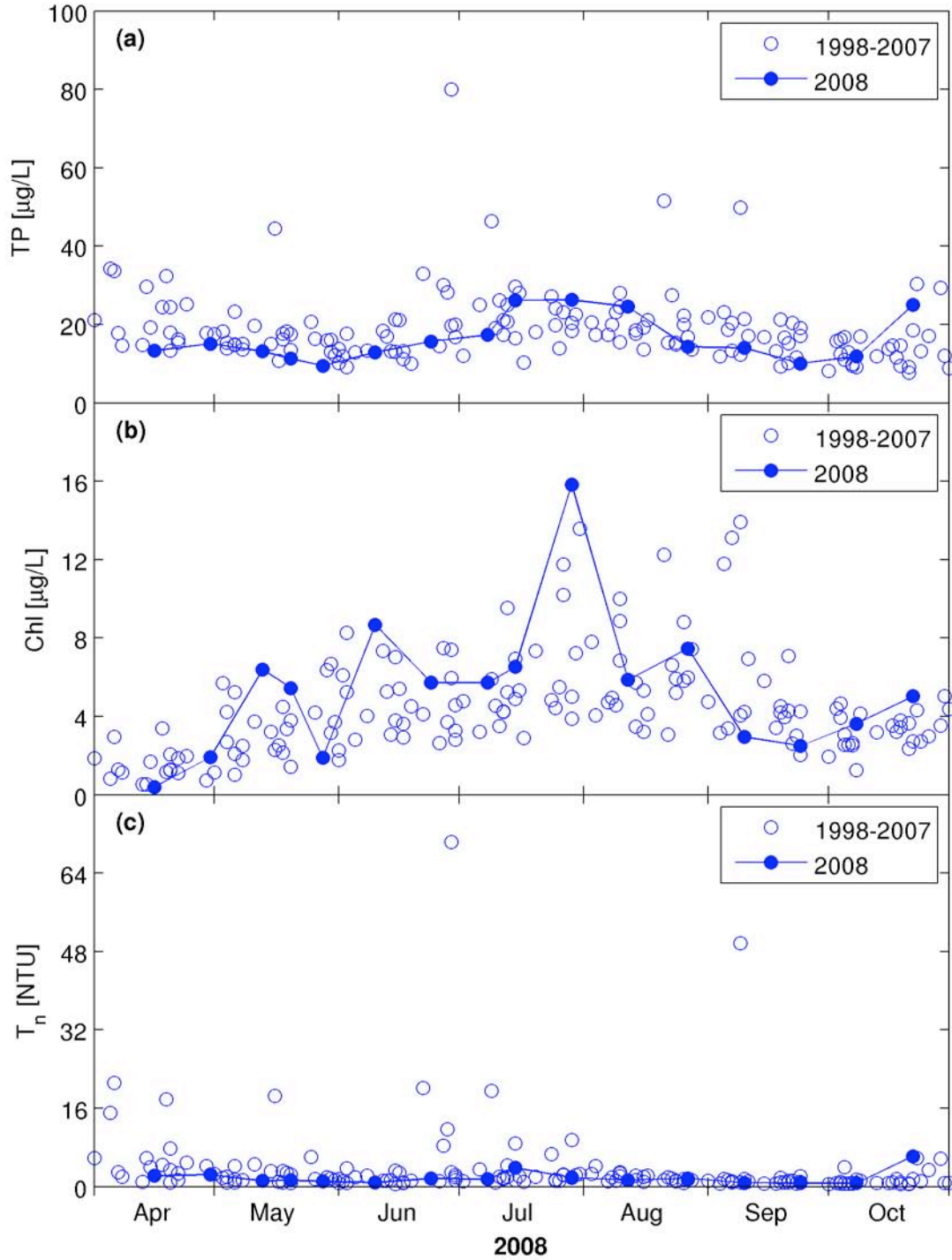


Figure 14: Comparison of 2008 conditions for total phosphorus, Chlorophyll-a, and turbidity on the south shelf of Cayuga Lake with conditions from the 1998 - 2007 interval: (a) total phosphorus (TP), (b) Chlorophyll-a, and (c) turbidity (T_n).

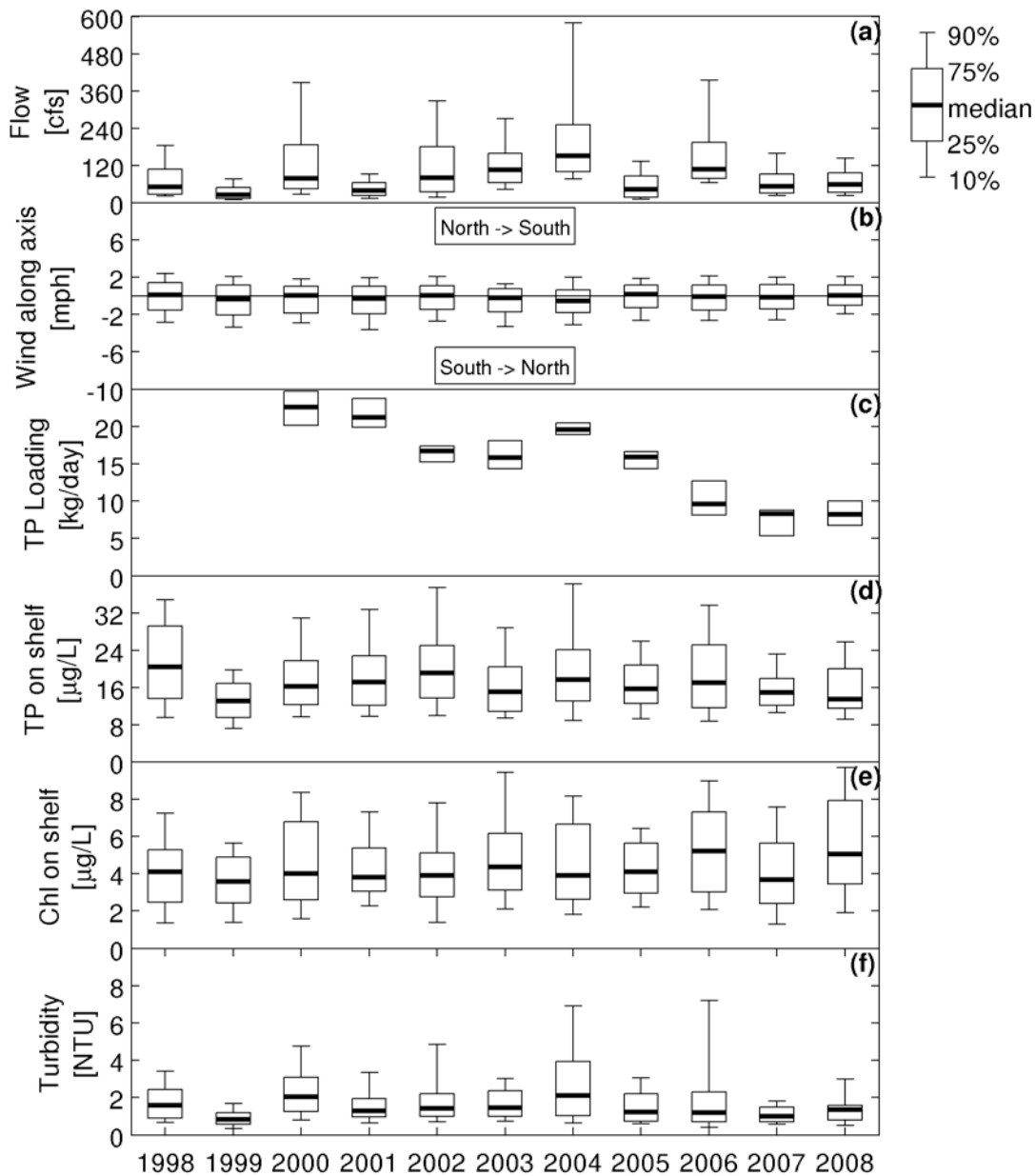


Figure 15: Comparison of study interval runoff, wind, total phosphorus loading, total phosphorus concentration, Chlorophyll-a concentration and turbidity. Legend marks percentile range of data. (a) Fall Creek flow, (b) wind speed, (c) summed loads of total phosphorus (TP) from the Ithaca Area WWTP, Cayuga 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, 4, 5 and 7.

5. Noteworthy Observations from the 2008 Data

1. Sites 1, 2, 3 and 7 were enriched in total phosphorus (TP) and turbidity (T_n) compared to the other monitored sites (Table 5). These sites are located adjacent to wastewater treatment plant 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, with the exception of site 7 which had the highest overall average Chlorophyll-a value (Table 5).
3. The highest average concentrations of total phosphorus (TP) and turbidity (T_n) were measured at sites 1, 2, 3 and 7, the sites closest to the natural and anthropogenic loading sources of the shelf (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 2008 were associated with runoff events in April and July and a wind event in late October (Figure 3).
7. The highest total phosphorus values measured in 2008 were associated runoff events in July and August and with a wind event in late October (Figure 3).
8. Average Chlorophyll-a concentrations were higher in 2006 - 2008 than in preceding study years. The range of Chlorophyll-a concentrations observed in 2008 was more representative of previous years with higher flow rates in the tributaries (e.g. 2000, 2004, 2006) than years with flow rates similar to 2008 (Figure 15).
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 October such an event coincided with a sampling day on which increased phosphorus, turbidity and Chlorophyll-a values were observed on the shelf. This is indicative of a seiche driven upwelling event, especially since tributary flow levels were not significantly elevated during or before this date (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 equal to or less than 18 $\mu\text{g/Liter}$ in all but one weekly sample taken during 2008 (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 July and August and a storm event in October. At these times TP concentrations in the LSC effluent were lower than on the shelf. On average, the TP concentration in the LSC effluent was 2 $\mu\text{g/Liter}$ 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 7.1 µg/Liter higher (Table 7).

14. On average, the concentration of total phosphorus (TP) in the LSC effluent was 0.5 µg/Liter lower in 2008 than in 2007 and the concentration of soluble reactive phosphorus (SRP) was 1.6 µg/Liter lower than in 2007 (Table 7).
15. 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 and a storm event in October which caused elevated turbidity on the shelf. On average, turbidity was 0.5 NTU lower in the LSC effluent than on the shelf (Table 7).
16. Secchi disc transparency (SD) was observed to extend beyond the lake depth at multiple sites on several occasions during the 2008 study interval (Appendix 1).
17. Phosphorus loading from the Ithaca Area WWTP averaged 3.6 kg/day over the May to October interval of 2008, consistent with 2007 and 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 2008, phosphorus loading from the Cayuga Heights WWTP (2.9 kg/day) was the second lowest of the 2000-2007 period (Table 6).
18. The Ithaca Area WWTP is the dominant of the three point sources in terms of phosphorus loading to the shelf (Table 6). In years with low surface runoff (such as 2008) its relative importance as a loading source is even more significant.
19. The improvements in the IAWWTP treatment processes and subsequent reduction in phosphorus loading to the shelf are more significant than any observed increase in loading from LSC due to changes in hypolimnetic phosphorus concentrations (Figure 15c).
20. The average TP loading rate to the shelf from LSC for the May to October interval of 2008 was 1.5 kg/day, 48% lower than the 2.9 kg/day projected in the Draft Environmental Impact Statement.
21. Increases in TP, SRP, and T_n since 2003 have been observed in the LSC effluent (Figure 10, Figure 11) and in the deep waters of the lake adjacent to the LSC intake (UFI 2007). The cause of these increases has not been established. However, since 2005 TP levels in the effluent have decreased (although they are still higher than pre 2003 values) and SRP and T_n have remained fairly stable (Figure 11).
22. The Fall Creek hydrograph for 2008 depicts relatively dry conditions for most of 2008. Flow rates were generally below average for most of April and October and nearly all of May, June and September. (Figure 13).
23. Winds aligned with the lake's long axis were near or above long-term average values for extended periods during October (Figure 13). Annual average wind speeds have been essentially constant over the 1998-2008 interval (Figure 15).
24. 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 2008 (7.6 µg/Liter) was about 50% higher than observed over the 1998-2005 interval (Table 9). This value is consistent with summer average values since 2006 (Table 8).

25. Study period yearly median values for TP on the shelf have ranged from 13.0 – 20.4 $\mu\text{g/Liter}$. Median shelf TP in 2008 (13.5 $\mu\text{g/Liter}$) was lower than all previous study years aside from 1999 (13.0 $\mu\text{g/Liter}$; Figure 15).
26. Study period median values for Chlorophyll-a on the shelf have exhibited relatively little interannual variability over the 1998 – 2008 interval, ranging from 3.6 – 5.2 $\mu\text{g/Liter}$. The median shelf Chlorophyll-a in 2008 was the second highest of the study period (5.0 $\mu\text{g/Liter}$; Figure 15e) and the summer average Chlorophyll-a was the highest since 1995 (8.0 $\mu\text{g/Liter}$; Table 9). Chlorophyll-a concentrations in deep water sites were similar to those measured on the shelf.
27. Study period median values for T_n on the shelf were lowest for the low runoff years of 1999, 2001, 2005 and 2007. Median shelf T_n in 2008 was below average for the study period, but was higher than in other low runoff years (Figure 15f).
28. The increase in phosphorus concentrations at the LSC intake after 2003 could represent significant lake-wide changes in water quality. Since 2005 TP levels have declined and SRP levels have remained fairly constant (Figure 11).
29. 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; Cornell University 2008).

6. Summary

This report presents the design and salient findings of a water quality monitoring study conducted for Cayuga Lake in 2008, sponsored by Cornell University Department of Utilities and Energy Management. This is the eleventh annual report for a monitoring program that has been conducted annually since 1998. A number of noteworthy findings are reported here for 2008 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 surface runoff, loading from WWTPs, and wind. Runoff during the April - June and September - October intervals of 2008 was substantially lower than the long-term average. As a consequence of lower phosphorus loading of the shelf from the point sources, summer average levels of total phosphorus have been dropping since 2006. However, summer average Chlorophyll-a concentrations during 2006 - 2008 were among the highest levels observed over the 1998-2008 interval. This is the case both on the shelf and in the deeper part of the lake and therefore does not appear to indicate a localized affect on the shelf. Summer average concentrations of total phosphorus and Chlorophyll-a for deep water sites continue to be consistent with mesotrophy. 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. The total phosphorus loading rate to the shelf from LSC was 45% lower than projected in the Draft Environmental Impact Statement. After increasing sharply from 2003 – 2005 the TP concentration in the LSC intake appears to be declining. The cause of higher phosphorus concentrations at the LSC intake has not been established. The correlation of dates on which higher levels of phosphorus have been measured on the shelf with dates on which there were either elevated tributary flows, upwelling events or temporarily increased loading from the two WWTPs indicates that these are the dominant factors in determining the water quality on the shelf. No conspicuous changes in water quality have been observed on the shelf since start-up of the LSC facility in July 2000.

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Appendix 1

**In Lake Monitoring
Data Listing**

Total Phosphorus (µgP/Liter)																
Dates:	4/16/08	4/30/08	5/13/08	5/20/08	5/28/08	6/10/08	6/24/08	7/8/08	7/15/08	7/29/08	8/12/08	8/27/08	9/10/08	9/24/08	10/8/08	10/22/08
Sites:																
1	13.9	17	13	10.8	12.7	18.3	18	18.7	26.4	31.9	21.8	12.6	14.4	9.7	11.7	53.5
2	14.2	28.3	21.2	13	7.1	10	33.6	15.4	53.1	35	25.1	21.3	26.2	16.8	13	54.2
3	13.9	14.8	13	10.5	8.7	13.6	23.6	15.4	50.5	24.2	20.5	12.3	12.7	8.8	12	24.8
4	13.3	11.7	13.4	10.5	9	9.1	9.9	16.4	15.7	16.6	24.4	12.6	12.4	9.4	11	8.8
5	12.3	11.4	12.4	11.5	7.7	12.2	10.2	15.4	16	16.6	23.1	12.9	11.4	10.4	12	9.5
6	12	12	11.8	14	11.8	8.6	11.5	12.2	15.1	20.1	19.5	13.9	12	10.4	12.3	8.1
7	13.6	28.3	14.6	14.3	12.1	14.9	20	25.8	19	63.6	38.6	26.5	24.9	13.6	13	60.2
8	12.3	12	12.1	20.4	9.9	8.3	8.6	13.5	14.1	16.6	16.9	12.6	11	8.5	10.3	-
LSC Intake	12.3	12	12.1	13.7	10.2	9.2	11.8	13.1	14.4	16	18.6	13.3	10.4	8.8	11	9.8

Soluble Reactive Phosphorus (µgP/Liter) values reported as 0.25 are 1/2 the limit of detection ($0.5 \times 0.5 = 0.25$)																
Dates:	4/16/08	4/30/08	5/13/08	5/20/08	5/28/08	6/10/08	6/24/08	7/8/08	7/15/08	7/29/08	8/12/08	8/27/08	9/10/08	9/24/08	10/8/08	10/22/08
Sites:																
1	6.3	5.5	0.25	0.5	0.9	0.9	0.25	0.25	0.7	0.25	0.5	0.6	1	0.25	0.25	6.6
2	6.2	2.9	0.7	0.5	0.9	0.9	2.2	0.5	8.1	1.2	1.2	5.8	6.2	1.1	0.6	3.2
3	6	5.5	0.25	0.5	0.8	0.7	0.25	0.25	6.9	0.25	2	0.6	3.2	0.25	0.6	2
4	5.1	4.6	0.25	0.25	0.9	0.6	0.25	0.25	0.25	0.25	11.3	0.6	5.1	0.25	1.5	1.6
5	6	4.5	0.25	0.7	0.8	0.25	0.25	0.25	0.8	0.25	0.6	0.6	0.6	0.25	0.8	0.8
6	7	3.5	0.25	0.5	0.5	0.6	0.25	0.25	0.25	0.25	0.25	0.6	0.5	0.8	0.25	0.25
7	6.7	2.5	0.25	0.5	0.9	0.25	0.25	0.25	0.25	0.25	0.6	0.8	1	0.25	0.5	4.3
8	8.1	1.4	0.25	1.4	0.8	0.25	0.25	0.25	0.8	0.25	0.25	0.6	0.25	0.25	0.5	-
LSC Intake	7.9	3.4	0.25	0.25	0.6	0.25	0.25	0.5	0.25	0.25	0.5	0.6	0.5	0.25	0.25	0.25

Chlorophyll a (µg/Liter)																
Dates:	4/16/08	4/30/08	5/13/08	5/20/08	5/28/08	6/10/08	6/24/08	7/8/08	7/15/08	7/29/08	8/12/08	8/27/08	9/10/08	9/24/08	10/8/08	10/22/08
Sites:																
1	0.42	1.22	4.79	6.49	2.91	16.15	6.72	2.77	5.04	15.84	6.25	7.22	3.54	2.78	4.48	6.57
2	0.43	0.86	4.49	2.93	0.05	4.57	7.44	4.66	5.14	11.68	3.86	1.73	1.8	2.72	3.99	9.68
3	0.32	0.89	6.14	3.63	2.36	9.59	7.92	4.01	6.14	10.43	5.51	2.34	0.86	1.78	3.85	4.53
4	0.43	1.03	7.29	7.54	1.64	3.44	3.52	7.86	6.84	9.7	2.2	9.41	0.94	1.91	2.22	2.52
5	0.49	2.5	7.67	4.64	0.95	9.22	4.64	5.04	8.84	11.6	6.91	9.73	3.93	3	3.96	2.89
6	0.44	3.93	8.61	14.23	3.66	5.81	5.88	8.21	9.57	14.59	8.74	12.87	4.33	4.36	3.3	3.62
7	0.28	5.29	4.23	5.4	2.21	8.84	6.88	9.19	3.52	47.26	11.44	9.56	8.61	3.81	4.46	13.75
8	0.51	5.01	7.86	13.26	3.53	4.41	4.32	6.03	10.01	10.19	6.61	11.91	4.13	4.49	5.01	-
LSC Intake	0.56	3.85	8.88	12.79	3.18	6.8	6	6.49	8.53	11.11	9.26	12.05	4.37	5.44	4.93	3.57

Turbidity (NTU)																
Dates:	4/16/08	4/30/08	5/13/08	5/20/08	5/28/08	6/10/08	6/24/08	7/8/08	7/15/08	7/29/08	8/12/08	8/27/08	9/10/08	9/24/08	10/8/08	10/22/08
Sites:																
1	2.1	2.6	1.6	0.9	2.2	1.4	2.1	1.5	3.5	1.9	1.1	1.1	1	0.6	0.7	7.6
2	1.7	5.6	2.6	1.6	0.9	0.9	5.6	1.4	9.8	3.2	1.2	0.6	0.9	0.9	0.8	24.3
3	2.7	2	1.4	1.4	0.8	1	3	1.5	10.1	1.4	1	1.3	0.6	0.5	0.8	8.4
4	2.6	1.4	0.9	0.9	0.8	0.5	0.7	1.4	1.6	1.4	0.5	1.5	0.4	0.7	0.5	0.9
5	1.7	0.8	0.8	1.7	0.8	0.7	0.9	1.3	1.5	1.6	1.5	1.4	0.7	0.6	0.8	0.9
6	2.3	1.6	0.8	1.3	0.9	0.5	0.8	1	1.3	1.9	1.3	1.8	0.8	0.7	0.9	0.5
7	1.5	8.4	1.6	1.6	1.6	0.8	1.9	2.3	0.9	3.8	3.9	3.9	1.8	1.7	0.8	21.7
8	1.1	1.7	0.7	1	1	0.5	0.6	1	1.2	1.6	1.4	1.7	0.8	0.6	0.7	-
LSC Intake	0.8	0.8	1.2	0.8	0.7	0.5	0.8	1	1.4	1.7	1.2	1.6	0.7	0.7	0.7	0.6

Secchi Disc Depth (m)																
Dates:	4/16/08	4/30/08	5/13/08	5/20/08	5/28/08	6/10/08	6/24/08	7/8/08	7/15/08	7/29/08	8/12/08	8/27/08	9/10/08	9/24/08	10/8/08	10/22/08
Sites:																
1	3.73	2.06	3.14	bottom	3	2	2	vegetation	1.48	1.82	vegetation	3.85	vegetation	bottom	bottom	0.88
2	bottom	1.16	2.06	bottom	bottom	bottom	0.92	2.57	0.63	1.42	vegetation	bottom	vegetation	bottom	bottom	0.28
3	bottom	2.78	bottom	bottom	bottom	3.08	1.42	vegetation	0.79	vegetation	vegetation	vegetation	vegetation	bottom	bottom	0.95
4	2.53	bottom	bottom	bottom	bottom	bottom	bottom	3.12	2.69	2.42	vegetation	vegetation	vegetation	bottom	bottom	0.75
5	bottom	bottom	3.98	2.89	bottom	2.93	3.31	vegetation	2.73	2.21	3.08	3.78	Bottom	bottom	5.09	4.35
6	6.34	5.79	4.49	3.4	5.48	4.85	3.58	3.03	3.08	2.03	3.06	3.59	6.03	7.17	5.31	5.57
7	bottom	0.73	2.55	2.96	bottom	bottom	1.78	vegetation	vegetation	1.62	vegetation	1.36	2.64	bottom	bottom	0.3
8	9.47	6.28	4.26	3.47	5.77	6.03	4.62	3.4	3.63	2.55	3.24	3.8	6.38	6.03	5.52	-
LSC Intake	8.4	5.62	4.08	3.8	6	4.3	3.93	3.02	2.62	2.45	3.34	3.86	6.03	6.23	5.6	5.53

“bottom” indicates true Secchi disc depth was greater than lake depth

“vegetation” indicates Secchi disc was obscured by rooted vegetation before reaching the true Secchi disc depth

No water samples were collected and no Secchi disc measurements were made at site 8 on 10/22/08 due to lake and weather conditions

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	10.9c	12.2c	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-02f	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
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

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
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
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

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
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
Jan-08	7.4	8.5	0.5	0.6	11.22	11.80	7.7	8.1	0.0143	0.0165	0.0080	0.0082
Feb-08	6.5	6.8	0.5	0.5	11.48	12.20	7.7	7.8	0.0148	0.0154	0.0093	0.0112
Mar-08	6.0	6.6	0.5	0.6	11.60	11.90	7.6	7.8	0.0145	0.0154	0.0086	0.0089
Apr-08	7.8	8.9	0.7	1.1	11.78	12.10	7.6	7.8	0.0131	0.0137	0.0080	0.0087
May-08	8.6	9.5	0.7	1.2	11.53	11.90	7.6	7.9	0.0146	0.0152	0.0084	0.0089
Jun-08	9.7	10.6	1.4	2.0	11.65	12.00	7.8	7.9	0.0171	0.0180	0.0084	0.0089
Jul-08	9.9	10.7	1.5	1.9	11.56	11.90	7.7	7.8	0.0170	0.0180	0.0092	0.0098
Aug-08	9.6	10.3	1.3	1.7	10.87	11.10	7.7	7.9	0.0149	0.0156	0.0091	0.0101
Sep-08	9.4	10.7	1.1	1.8	10.40	11.10	7.6	7.7	0.0150	0.0164	0.0083	0.0095
Oct-08	9.0	10.4	0.6	1.0	9.78	10.30	7.5	7.7	0.0161	0.0174	0.0087	0.0098
Nov-08	8.7	9.3	0.6	0.9	9.63	10.20	7.5	7.8	0.0172	0.0182	0.0100	0.0107
Dec-08	8.5	9.1	0.5	0.5	10.80	11.10	7.1	7.7	0.0120	0.0154	0.0070	0.0098

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