Cayuga Lake Water Quality Monitoring, Related to the LSC Facility: 2011

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Sponsored by:
Cornell University
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Energy & Sustainability Department

March 30, 2012

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Preface

This report summarizes the results of water quality monitoring efforts related to Cornell University's Lake Source Cooling (LSC) facility in 2011. 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 annual report was taken over by the De Frees 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 facilities also enters this portion of the lake (IAWWTP - Ithaca Area Waste Water Treatment Plant and CHWWTP - Cayuga Heights Waste Water Treatment Plant; 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 photosynthetic cells in 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 phosphorus from human activity. Increases in phosphorus 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 phosphorus from human activities has been described as cultural eutrophication.

The two forms of phosphorus measured in this monitoring program, total phosphorus (TP) and soluble reactive phosphorus (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 ($0.45 \mu m$) samples. SRP is a component of the total dissolved phosphorus (TDP) that is usually assumed to be immediately available to support phytoplankton growth. Particulate phosphorus (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 phosphorus bearing particles that may be resuspended from the bottom or received from stream/river inputs.

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 (Tn), 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 2011, beginning in mid-April and extending through late October. The full suite of laboratory and field measurements were made for 16 monitoring trips. At least two lake sampling runs were performed each month, and every effort was made to spread the sampling dates out evenly throughout the season (approximately bi-weekly).

In addition to the water sample collection, recording thermistors were deployed continuously at one location. Temperature measurements were made at least 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 2010 were recovered in April 2011. Deployments made in late October 2011 will be retrieved in April 2012. Measurements are recorded on a daily basis over this latter interval. Laboratory measurements of phosphorus concentration (TP and SRP), turbidity (Tn), dissolved oxygen concentration (DO), and pH were made on samples from the LSC influent and effluent collected weekly (year round) 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, were also sampled. Positions (latitude, longitude, lake depth at the location) 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).

Site 2, on the southern part of the shelf near the lake's centerline, is located near the discharge of the IAWWTP's effluent, and higher than average concentrations of nutrients have been measured at this location for this reason (see section 3). Sites 1 and 7 bracket the LSC discharge from the north and south. However, site 7 is located near the outfall of the CHWWTP (figure 1) and the water quality at this location can be expected to be influenced by localized effects of this proximity (similarly to site 2).

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.

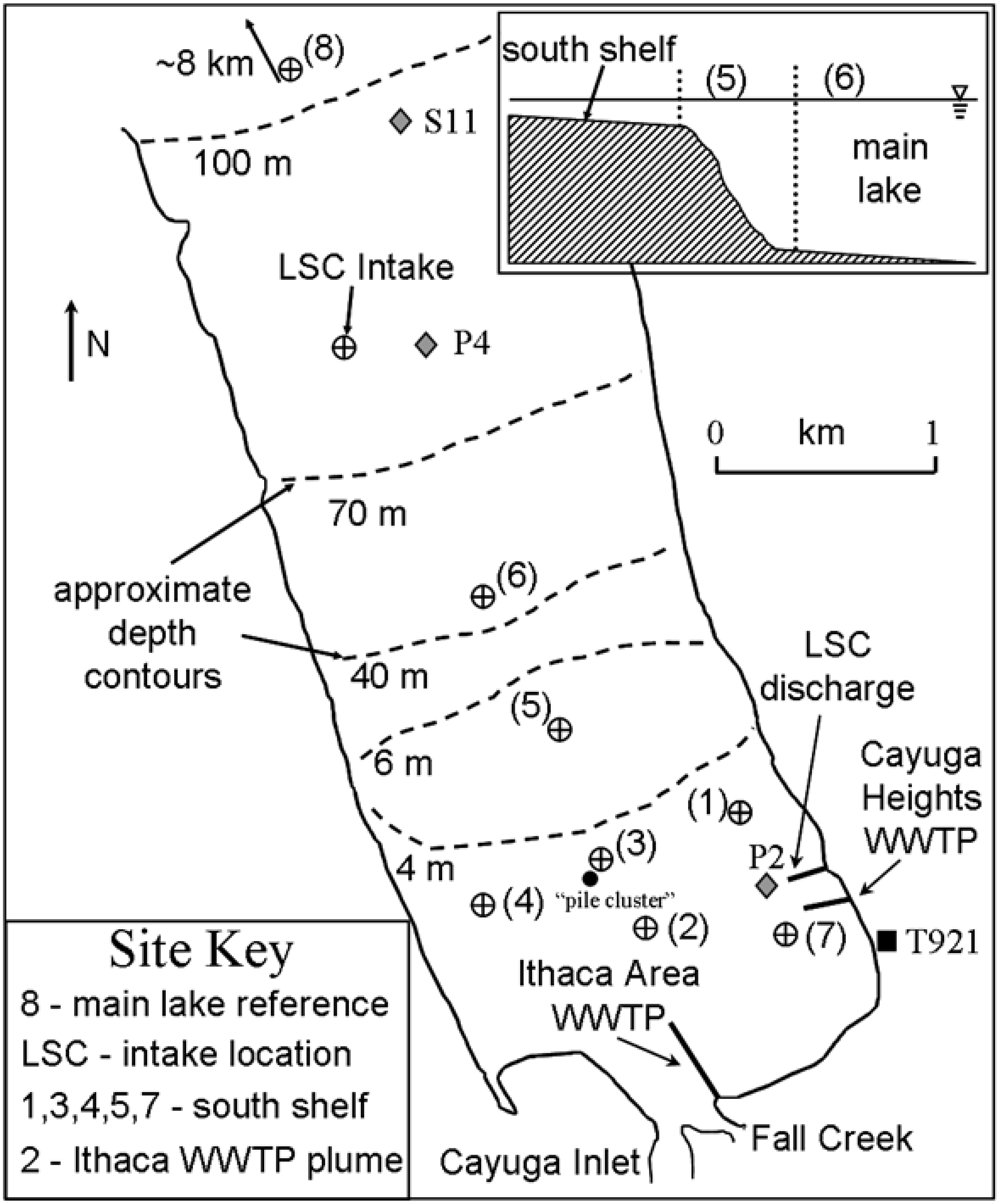

Figure 1: Sampling sites, setting, approximate bathymetry, for LSC monitoring program, southern end of Cayuga Lake. Sites sampled during the 1994 - 1996 study (P2, P4 and S11; Stearns and Wheler 1997) are included for reference. Locations of sampling sites and outfalls are approximate.

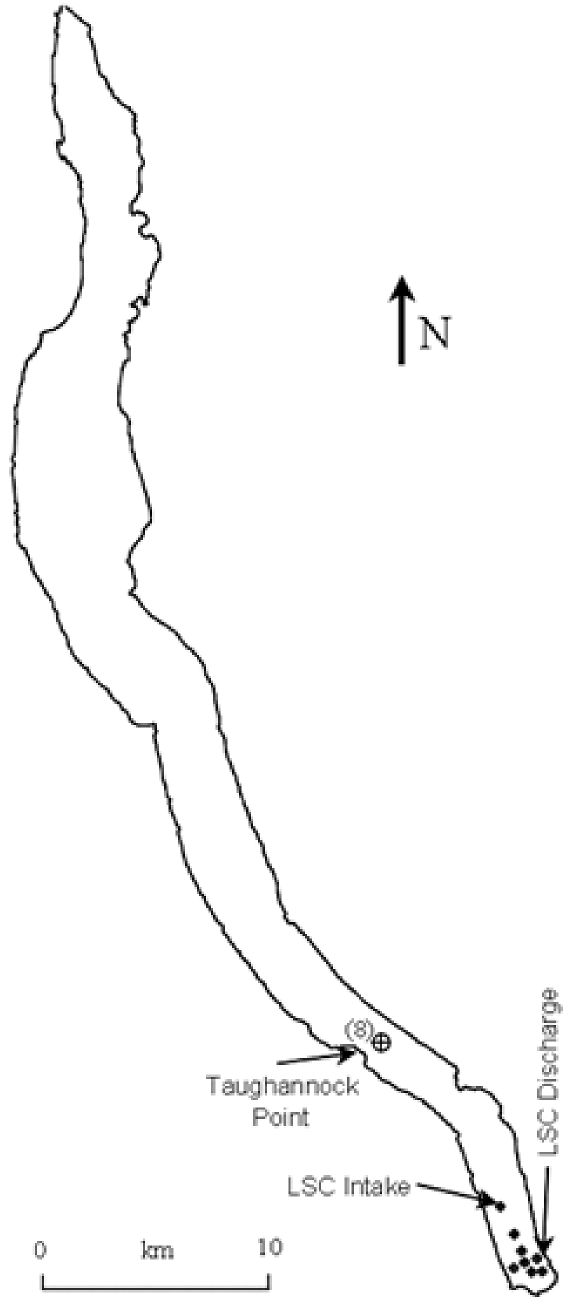

Figure 2: Sampling sites for LSC monitoring program, within the context of the entire Cayuga Lake basin.

Table 1: Latitude, longitude and lake depth at ambient water quality monitoring program sites (refer to figure 1). Sites sampled during the 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 20cm 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 from sites 5, 6, LSC Intake, and 8. Composite samples from sites 1, 2, 3, 4, and 7 were formed from equal volumes of sub-samples collected at depths of 0 and 2 meters. The composite-type samples avoid over-representation of the effects of temporary secondary stratification in monitored parameters. 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	Full Method Name	Reference	Limit of Detection
total phosphorus	SM 18-20 4500-P E	APHA (1998)	1.1 $\mu gP \cdot L^{-1}$
soluble reactive phosphorus	SM 18-20 4500-P E	APHA (1998)	0.4 $\mu gP \cdot L^{-1}$
Chlorophyll-a	USEPA 446.0 Rev. 1.2	USEPA (1997)	0.2 $\mu gChl \cdot L^{-1}$
turbidity	SM 18-20 2130 B	APHA (1998)	0.2 NTU

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 also 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. Median values of triplicate samples collected from the lake, and triplicate samples of the LSC effluent, were used for analysis in this report. 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 2011 program (table 4). Note that 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 2011 - more than 60% of all samples collected during the season had less than 1 µg/Liter SRP and in more than 25% the SRP concentration was below the limit of detection.

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
TP	b	a	1	1
SRP	a	b	1	2
Chlorophyll-a	a	c	2	3
Turbidity	b	b	2	2

processing:
- a - filter with 0.45µm mixed cellulose ester filter
- b - whole water sample

preservation:
- a - H_2SO_4 to pH ≤ 2
- b - none
- c - store filter frozen until analysis

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

holding time:
1 - 28 days
2 - 48 hours
3 - 21 days

Note: The 2010 annual report erroneously indicated that TP analysis was performed on filtered samples. All TP analysis was actually performed on unfiltered samples.

Table 4: Precision for triplicate sampling/measurement program for key parameters for 2011, represented by the average coefficient of variation (CV = standard deviation/mean).

Parameter	**Site 1**	**Rotating Site***
TP	0.04	0.03
Chlorophyll-a	0.17	0.16
Turbidity	0.05	0.09
SRP	0.12	0.02

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

3 Results, 2011

The measurements made in the 2011 monitoring program are presented in two formats here: in tabular form (table 5) as selected summary statistics for each site, and as plots (figure 3 - figure 6) for selected sites and site groupings. Detailed listings of data are presented in Appendix A. LSC Discharge Monitoring Report Data are presented in Appendix B. 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 6m. The "shelf average" 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, i.e.,

$$\text{"Shelf average"} = \frac{\frac{[site\ 1] + [site\ 7]}{2} + [site\ 3] + [site\ 4] + [site\ 5]}{4} \tag{1}$$

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 (>40m; 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 Secchi disc 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 and figure 6). Flow rates in Fall Creek (figure 3a) were measured by USGS gage 04234000.

Previous annual reports (UFI 2000*a*,*b*, 2001, 2002, 2003, 2004, 2005, 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 IAWWTP 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, 2011.

TP $\left(\mu g \cdot L^{-1}\right)$			
Site	**Mean**	**CV**	**Range**
1	19.09	0.35	9.7 - 32.5
2	24.85	0.39	12.4 - 45.3
3	19.31	0.37	8.7 - 38.5
4	18.45	0.57	8.0 - 51.4
5	17.38	0.45	9.4 - 39.9
6	17.22	0.38	9.6 - 35.2
7	22.62	0.28	13.6 - 35.3
8	13.91	0.18	9.9 - 19.1
LSC	14.66	0.24	8.7 - 20.7

Chlorophyll-a $\left(\mu g \cdot L^{-1}\right)$			
Site	**Mean**	**CV**	**Range**
1	5.13	0.62	0.8 - 11.1
2	5.42	0.65	1.8 - 13.8
3	4.29	0.54	1.3 - 8.8
4	3.18	0.53	0.8 - 7.2
5	4.73	0.64	0.1 - 9.5
6	5.97	0.71	0.3 - 14.5
7	4.97	0.81	1.2 - 16.5
8	5.71	0.64	0.8 - 12.3
LSC	6.13	0.66	0.7 - 14.5

SRP $\left(\mu g \cdot L^{-1}\right)$			
Site	**Mean**	**CV**	**Range**
1	2.12	1.49	0.2 - 10.3
2	2.25	1.34	0.2 - 9.7
3	1.72	1.51	0.2 - 9.5
4	1.87	1.51	0.2 - 10.1
5	2.12	1.72	0.2 - 12.0
6	1.93	1.56	0.2 - 9.1
7	2.35	0.99	0.2 - 9.0
8	1.40	1.90	0.2 - 8.3
LSC	1.61	1.77	0.2 - 8.8

$\mathbf{T}_n$ (NTU)			
Site	**Mean**	**CV**	**Range**
1	4.01	1.32	0.7 - 19.1
2	5.08	1.15	1.2 - 19.8
3	4.14	1.33	0.6 - 20.3
4	4.83	2.07	0.4 - 38.0
5	4.00	1.85	0.6 - 29.3
6	3.20	1.80	0.6 - 24.3
7	3.93	1.27	0.8 - 19.7
8	1.27	0.35	0.6 - 2.0
LSC	1.54	0.67	0.6 - 4.6

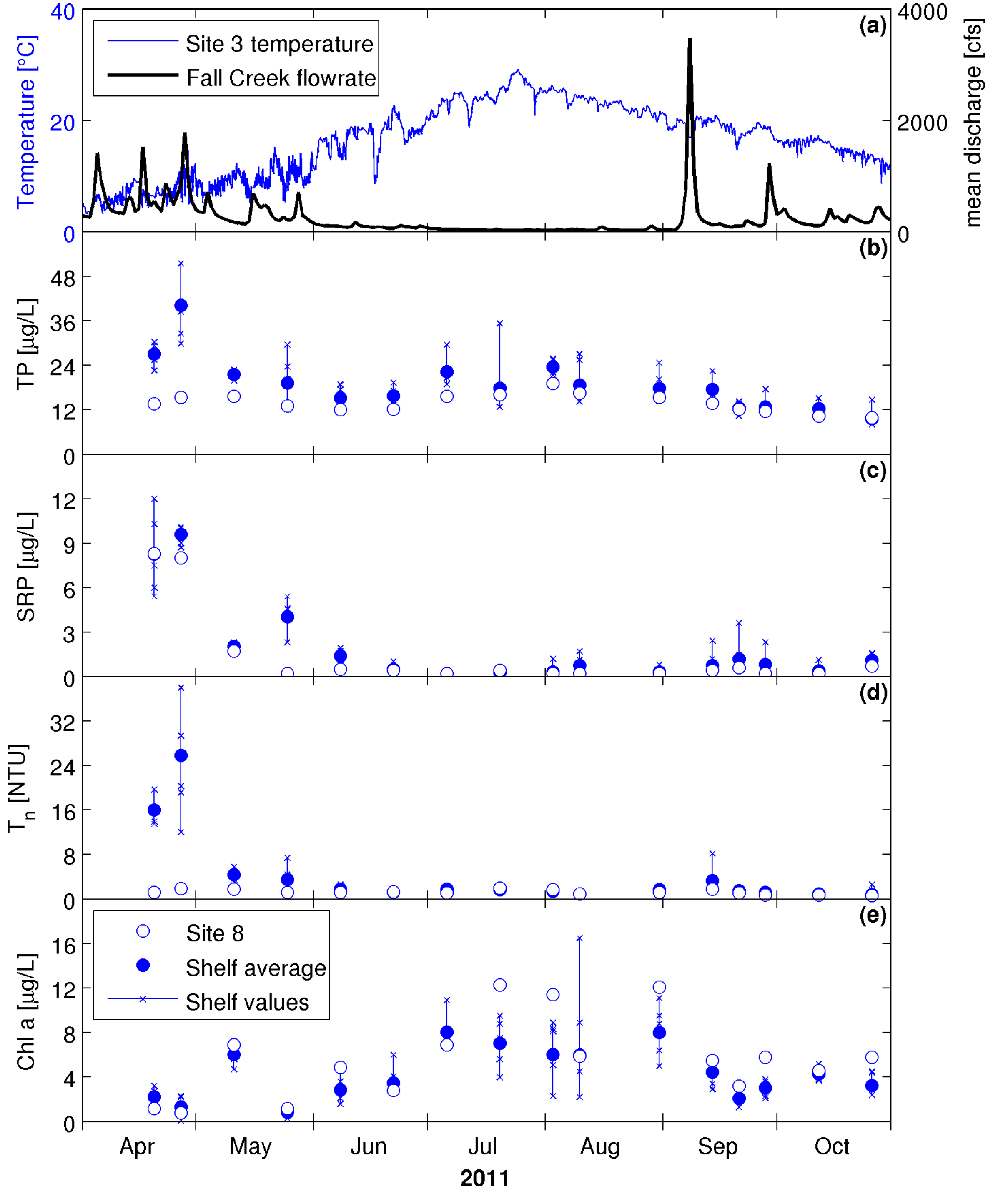

Figure 3: Time series of parameter values for Cayuga Lake for 2011: (a) Temperature at pile cluster (near site 3) and Fall Creek inflow record, (b) TP, (c) SRP, (d) Turbidity, (e) Chlorophyll-a. Values at site 8 are compared with the average value on the shelf. "x" symbols represent individual values measured at separate sites on the shelf.

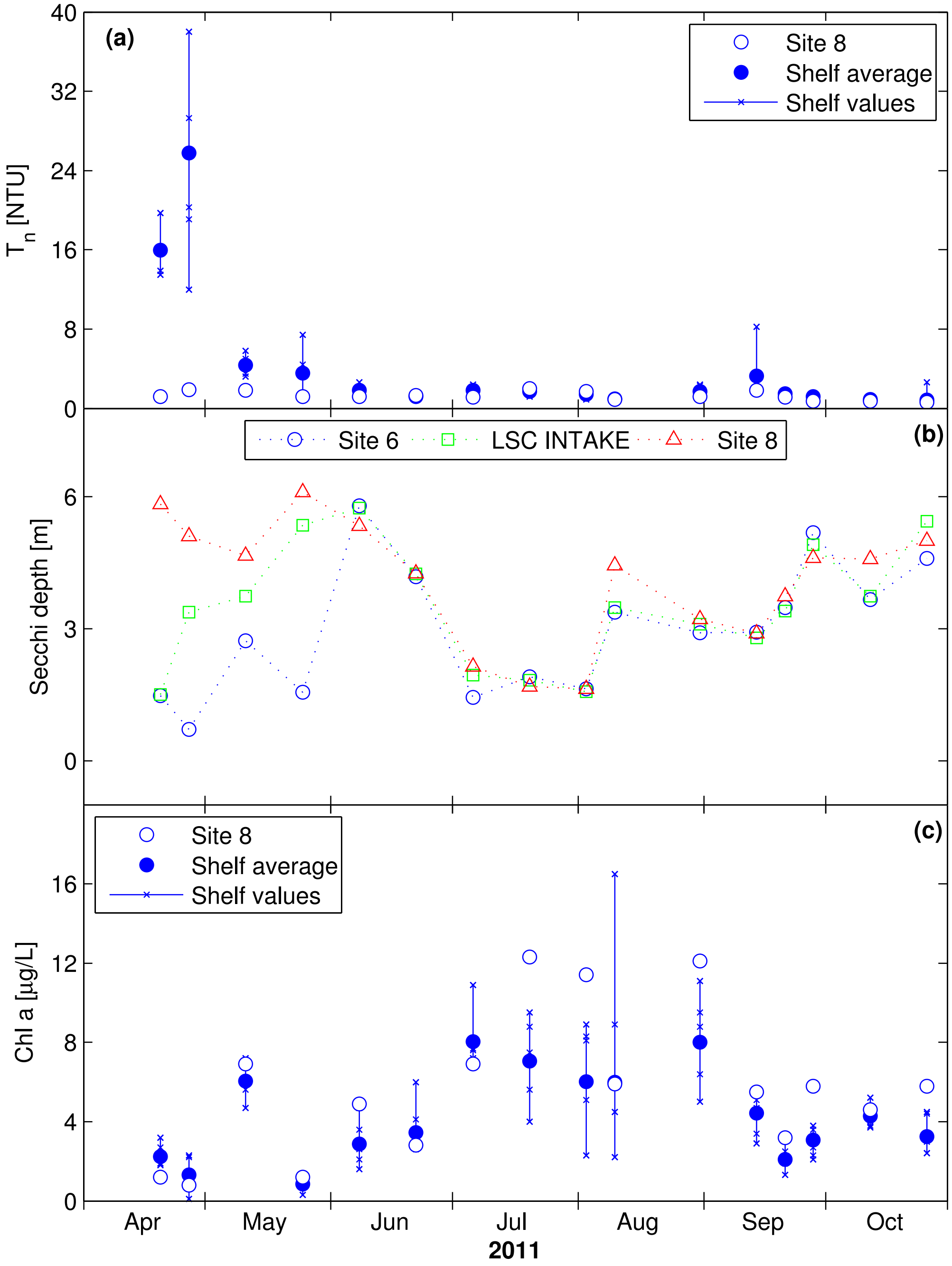

Figure 4: Time series of parameter values for Cayuga Lake for 2011: (a) Turbidity, (b) Secchi disc depth, and (c) Chlorophyll-a. Results for the “shelf” are averages; “x” symbols represent individual values measured at separate sites on the shelf.

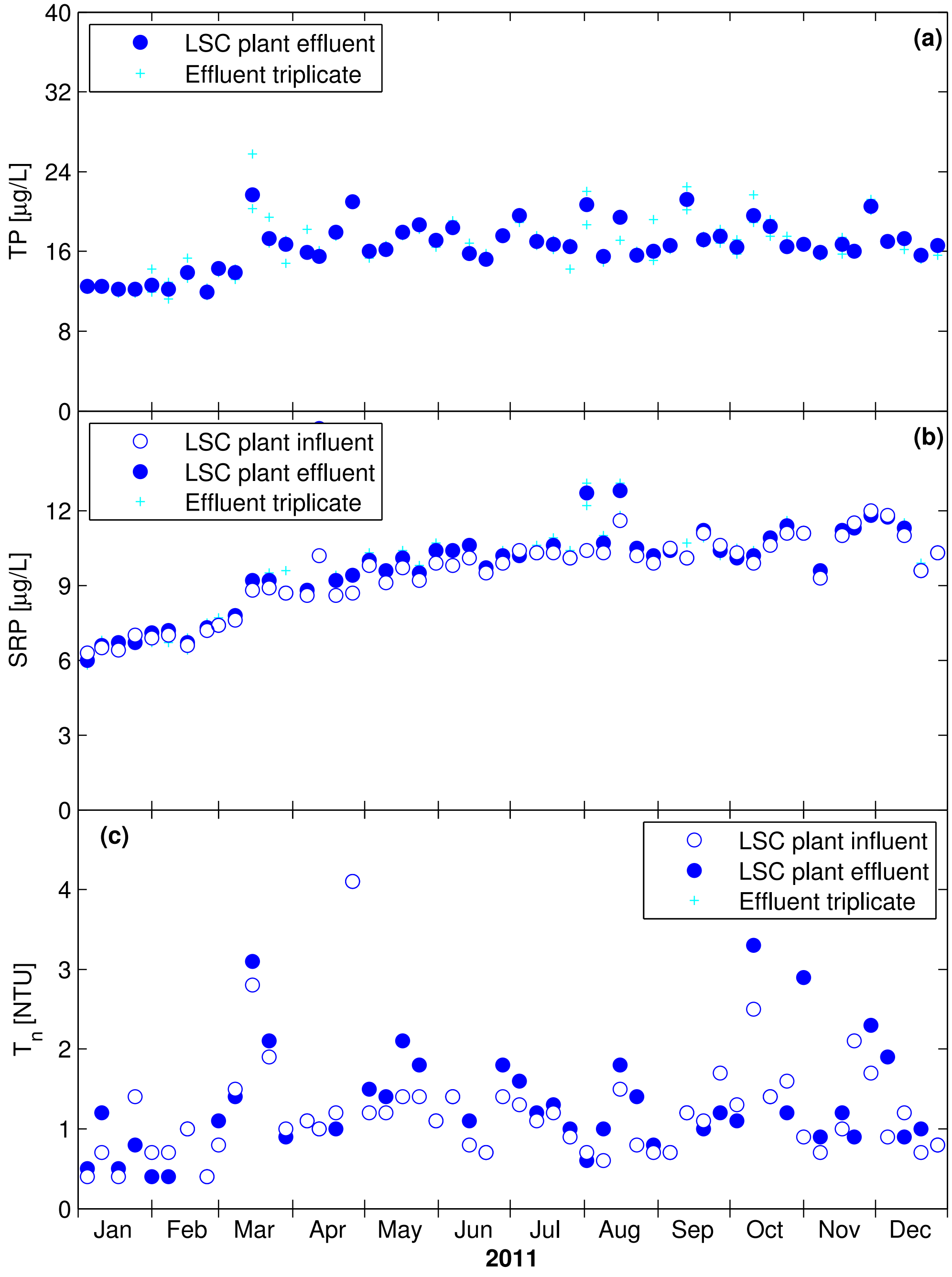

Figure 5: Time series of parameter values for the LSC influent and effluent for 2011: (a) TP (influent was not measured), (b) SRP, and (c) Tn. The median of triplicate samples was used as the representative value. "+" symbols represent values of additional triplicate samples.

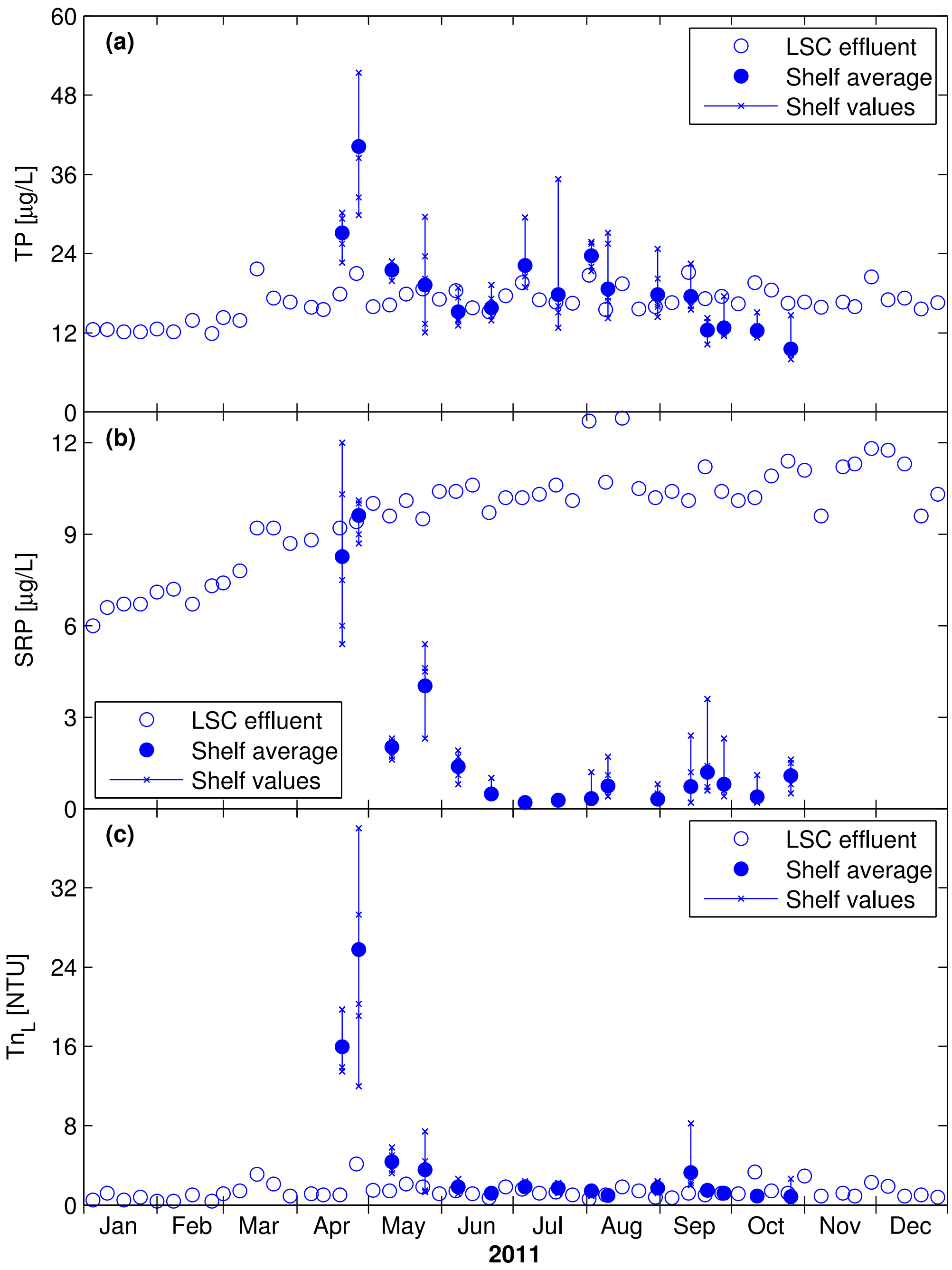

Figure 6: Time series of parameter values for the south shelf and the LSC effluent for 2011: (a) TP, (b) SRP, and (c) Turbidity. Results for the "shelf" are averages; "x" symbols represent individual values measured at separate sites on the shelf.

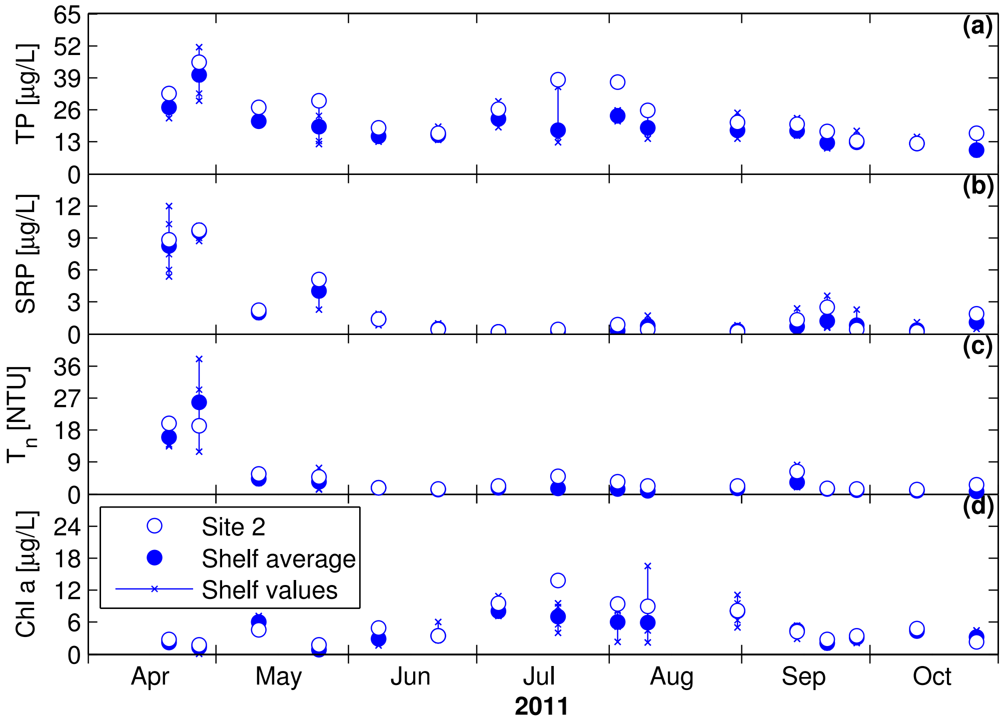

Figure 7: Comparison of observed parameters at site 2 and the shelf average.

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 shallow depth. Secchi disc transparency (SD) was observed to extend beyond the lake depth at sites 2, 4, 5 and 7 on several occasions during the 2011 study interval as was the case in previous years (see Appendix A). Additionally, 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 in cases where the true Secchi disc depth is deeper than the lake's bottom at the location measured. 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 (Tn) 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 IAWWTP and CHWWTP wastewater treatment plants for the 2000 - 2011 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 the facilities. Concentrations of total phosphorus (TP) in the effluents are measured twice per week at the IAWWTP and once per week at the CHWWTP. 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 - 2011 interval.

Major decreases in phosphorus loading from the IAWWTP have been observed since 2006 as a result of the commencement of tertiary treatment for phosphorus. A new phosphorus treatment process installed in the CHWWTP in 2009 further reduced loading from that source. The trend of decreasing phosphorus loading from the WWTPs continued until 2010. Loading from these two point sources was higher in 2011 than in 2010, though still much lower than in years prior to 2006. The higher loading rates from the two WWTP in 2011 relative to 2010 are due to increased flow rates and modifications of the treatment processes (see section 4.7). Average total phosphorus loading from the IAWWTP during May - October 2011 was nearly 70% lower than during 2000-2006 (table 6). Average total phosphorus loading from the CHWWTP during May - October 2011 was nearly 60% lower than in 2000 - 2005 (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 the IAWWTP during May - October of 2011 was 4.2 kg/day, lower than all years prior to 2007. Phosphorus loading from CHWWTP during May - October 2011 was 2 kg/day, higher than in 2010 but lower than in all other preceding years since 2000. The average phosphorus loading from CHWWTP since 2005 is less than half the loading rate in 2004, the year with the highest surface flows and highest loading from CHWWTP during the study period.

Monthly estimates of phosphorus loading from the tributaries were 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 over the May - October interval. These estimates 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 substantially reduced relative loading from the LSC facility and the two WWTPs. Further, tributary loads vary substantially year-to-year, based on natural variations in runoff as well as changes in land-use practices. 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 2011 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 B). The average TP loading rate from LSC during the May - October 2011 period was 1.8 kg/day, approximately 5% higher than the average loading during those months of the preceding year. This is the highest May - October loading rate since the plant began operating but is still nearly 40% less than the loading rate of 2.9 kg/day projected by the DEIS. The relative loading from LSC was approximately 10% of the total estimated load to the shelf (sum of measured TP from LSC, IAWWTP, CHWWTP, and estimated TSP from tributaries), higher than the 4.8% projected in the DEIS. The highest relative monthly contribution of the LSC facility to total phosphorus loading to the shelf in 2011 occurred in July (16.7%) and August (16.4%).

The higher relative loading during these months is mainly due to reduced loading from other sources, especially the estimated loading from tributary flow, though there is some effect from the higher flow rates required to meet LSC cooling demands during the hot summer months. Tributary flow is the most substantial source of phosphorus to the shelf - the estimated average TP loading from the tributaries is nearly double the sum of measured TP loads from LSC and the two WWTPs. It is also the source that shows the most monthly variability. It should be noted that the estimated phosphorus loading from the tributaries used here is based on a multi year average loading calculated in the DEIS (Wheler 1997), and does not reflect inter annual variation due to runoff conditions.

The higher relative loading rate of LSC in 2011 when compared to the projected relative loading in the DEIS is due to lower loadings from the WWTPs than predicted in the DEIS, not higher loadings from LSC. The loading estimates from the two WWTPs 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 substantially lower than this, averaging a total of 6.2 kg/day during May - October 2011 out of the permitted 45.4 kg/day. Absolute phosphorus loading from LSC was also substantially lower in 2011 than predicted in the DEIS (1.8 kg/day discharged vs. 2.9 kg/day predicted in the DEIS).

Phosphorus loading rates for LSC in 2011 followed a similar trend as in previous years, with higher loading during the months with a higher cooling demand from the system, which requires increased flow rates. June to September mean loading was 2.1 kg/day, and loading during the cooler months of May and October was lower, with a mean of 1.2 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 (to 1.8 kg/day, 6.7%). Since 2006 the mean daily May - October loading has been approximately 1.6 kg/day. The increased loading since 2006 is due to changes in phosphorus concentrations in the lake's hypolimnion in those years (figure 10), and increased cooling demand from the system leading to increased flow rates. The relative TP loading from LSC has gradually increased from 6.7% in 2005 to 10% in 2011. However this increase in relative loading is primarily due to decreased loads from the two WWTPs in that period, as the absolute loading from LSC remained fairly stable.

Paired measurements of SRP and Tn 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 µg/Liter, and between Tn pairs was 0.1 NTU. This suggests the absence of substantial inputs within the facility. The median concentration of SRP in the LSC effluent in 2011 (April - October median of 10.3 µg/Liter) was approximately 30% higher than that observed in 2010 (7.9 µg/Liter) and was the highest observed since the plant began operating in 2000. In the preceding study years (2000 - 2010) median April - October effluent SRP concentrations ranged from 3.9 to 10 µg/Liter. Average levels of TP, SRP and Tn in the LSC effluent and on the shelf in 2011 are presented in figure 6 and table 7, and in a historical context going back to when the plant began operating in figure 10 and figure 11. TP and Tn levels measured in the LSC effluent in 2011 were close to those observed on the shelf. As in previous years, levels of TP, SRP and Tn varied widely over time and space on the shelf during 2011.

The increased TP loading to the shelf from the LSC effluent during 2005 - 2011 (table 6) is largely attributable to the increase in TP concentration in the effluent relative to 2000 - 2003 (while the increase in TP concentration in the LSC effluent appears to have began in 2004, the peak increase in loading from the facility was observed in 2005; figure 10, figure 11 and table 6). The mean TP concentration in the LSC effluent in the years 2004 - 2011 (15.5 µg/Liter) was 26% higher than in the years 2000 - 2003 (12.3 µg/Liter; figure 10). The mean SRP concentration was 79% higher in 2004 - 2011 (8.6 µg/Liter) than in 2000 - 2003 (4.8 µg/Liter; figure 10).

After the steep rise in phosphorus concentration during 2004 - 2005, TP and SRP levels appeared to have leveled off or to be declining (figure 11) until 2011. The mean TP concentration in the plant's effluent in 2011 (16.5 µg/Liter) was nearly as high as the highest annual mean recorded (17 µg/Liter in 2005). Annual mean SRP in the plant's effluent in 2011 was 9.8 µg/Liter, slightly higher than the previous highest annual concentration (9.6 µg/Liter, measured in 2007).

The increase in phosphorus loading from LSC since 2005 was more than offset by the reduction in loading from the IAWWTP following upgrades to the plant. Total phosphorus loading to shelf from the three point sources dropped nearly 60% between 2005 - 2011 (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 Tn in the LSC influent and effluent compared closely in 2011 (figure 5), as they have throughout operation of the facility (UFI 2001, 2002, 2003, 2004, 2005, 2006, 2007; Cornell University 2008, 2009, 2010, 2011). 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 Tn 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. Hypolimnetic SRP concentrations measured in 2010 were the lowest since 2005, though still higher than those observed during 2000-2004. However, the mean SRP concentration in the hypolimnion for 2011 (averaged over the entire year) was the highest since the record began with LSC's operation in 2000. A seasonal trend in SRP concentration has been apparent since 2006, with a relatively low concentration of SRP at the beginning of the year, gradually climbing to a peak near the end of the year and then suddenly dropping down to a low concentration. This pattern was even more pronounced in 2011 (figure 10).

It is worth noting that higher levels (>20 µg/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 2011 interval.

Year	**IAWWTP**[a] **TP**, $kg \cdot d^{-1}$	**CHWWTP**[a] **TP**, $kg \cdot d^{-1}$	**Tributaries**[b] **TSP**, $kg \cdot d^{-1}$	**LSC**[c] **TP**, $kg \cdot d^{-1}$	**Total TP+TSP**, $kg \cdot d^{-1}$	**% LSC**
2000						
May	24.1	3.5	29	-	56.6	-
June	16.6	5.1	15.8	-	37.5	-
July	13.7	3.4	8.8	1.4	27.3	5.10%
August	19.1	4.6	6	1	30.7	3.30%
September	18.5	4	7.5	0.9	30.9	2.90%
October	15.4	4.1	13.1	0.6	33.2	1.80%
Mean	*17.9*	*4.1*	*13.4*	*1*	*36.4*	*3.30%*
2001						
May	15.8	5.5	29	0.7	51	1.40%
June	11.2	4	15.8	1.1	32.1	3.40%
July	15.2	4.2	8.8	1	29.2	3.40%
August	15.2	7.1	6	1.4	29.7	4.70%
September	22	6.6	7.5	1	37.1	2.70%
October	16.4	2.8	13.1	0.7	33	2.10%
Mean	*16*	*5*	*13.4*	*1*	*35.4*	*3.00%*
2002						
May	12.4	4.4	29	0.6	46.4	1.30%
June	7.9	3.5	15.8	1	28.2	3.50%
July	10.4	3.8	8.8	1.8	24.8	7.30%
August	16.2	2	6	1.2	25.4	4.70%
September	11.4	2.8	7.5	1	22.7	4.40%
October	13.6	3.1	13.1	0.7	30.5	2.30%
Mean	*12*	*3.3*	*13.4*	*1.1*	*29.7*	*3.90%*

Table 6 (continued)

Year	**IAWWTP**^{a} **TP**, $kg \cdot d^{-1}$	**CHWWTP**^{a} **TP**, $kg \cdot d^{-1}$	**Tributaries**^{b} **TSP**, $kg \cdot d^{-1}$	**LSC**^{c} **TP**, $kg \cdot d^{-1}$	**Total TP+TSP**, kg d^{-1}	**% LSC**
2003						
May	11	2.7	29	0.6	43.3	1.40%
June	6	7.8	15.8	1.2	30.8	3.90%
July	8.5	3.9	8.8	1.2	22.4	5.40%
August	13.8	3.1	6	1.2	24.1	5.00%
September	11.9	3.4	7.5	1.3	24.1	5.40%
October	14.5	5.3	13.1	0.9	33.8	2.70%
Mean	*11*	*4.4*	*13.4*	*1.1*	*29.8*	*3.90%*
2004						
May	11	6.6	29	1.3	47.9	2.70%
June	11	7.2	15.8	1.2	35.2	3.40%
July	11.7	7.1	8.8	0.9	28.5	3.20%
August	11.6	3.4	6	1.4	22.4	6.30%
September	11.5	7.9	7.5	1.1	28	3.90%
October	10.9	10.6	13.1	0.6	35.2	1.70%
Mean	*11.3*	*7.1*	*13.4*	*1.1*	*32.9*	*3.5%*
2005						
May	11	3.7	29	2.1	45.8	4.60%
June	10.3	3.5	15.8	1.9	31.5	6.00%
July	9.4	2.8	8.8	2	23	8.70%
August	9.4	2.9	6	2	20.3	9.90%
September	10.5	3.8	7.5	1.8	23.6	7.60%
October	10.4	5.1	13.1	1.1	29.7	3.70%
Mean	*10.2*	*3.6*	*13.4*	*1.8*	*29*	*6.70%*
2006						
May	7.2	1.5	29	1.1	38.8	2.80%
June	6.7	4.1	15.8	1.9	28.5	6.70%
July	7.2	3.9	8.8	2.2	22.1	10.00%
August	3.7	3.7	6	2	15.4	13.00%
September	4.2	2.5	7.5	1.4	15.6	9.00%
October	3.2	2.1	13.1	1	19.4	5.20%
Mean	*5.4*	*3*	*13.4*	*1.6*	*23.3*	*7.80%*
2007						
May	3.3	0.9	29	1.1	34.3	3.20%
June	1.8	1.3	15.8	1.7	20.55	8.30%
July	4.3	2.5	8.8	1.7	17.3	9.80%
August	4.3	2.1	6	1.8	14.2	12.70%
September	4.6	3.6	7.5	1.6	17.3	9.20%
October	3	4.5	13.1	1.3	21.9	5.90%
Mean	*3.6*	*2.5*	*13.4*	*1.5*	*20.9*	*8.20%*
2008						
May	3.4	6.0	29	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%
Mean	*3.6*	*2.9*	*13.4*	*1.5*	*21.4*	*8.2%*

Table 6 (continued)

Year	**IAWWTP**[a] **TP**, $kg \cdot d^{-1}$	**CHWWTP**[a] **TP**, $kg \cdot d^{-1}$	**Tributaries**[b] **TSP**, $kg \cdot d^{-1}$	**LSC**[c] **TP**, $kg \cdot d^{-1}$	**Total TP+TSP**, kg d^{-1}	**% LSC**
2009						
May	2.5	3.5	29.0	1.1	36.1	2.9%
June	1.5	2.8	15.8	1.8	21.8	8.1%
July	1.6	4.1	8.8	1.9	16.4	11.5%
August	2.0	2.0	6.0	2.2	12.1	17.8%
September	4.0	2.6	7.5	1.5	15.6	9.9%
October	2.3	0.8	13.1	0.8	17.0	4.8%
Mean	*2.3*	*2.6*	*13.4*	*1.5*	*19.8*	*9.2%*
2010						
May	2.4	1.4	29.0	1.3	34.1	3.9%
June	1.5	1.2	15.8	2.1	20.5	10.0%
July	2.1	1.9	8.8	2.0	14.8	13.8%
August	2.4	1.9	6.0	2.0	12.2	16.0%
September	2.3	1.2	7.5	1.6	12.6	12.5%
October	1.7	2.1	13.1	1.0	17.9	5.5%
Mean	*2.1*	*1.6*	*13.4*	*1.7*	*18.7*	*10.3%*
2011						
May	5.9	2.6	29.0	1.4	38.8	3.5%
June	2.4	1.3	15.8	1.8	21.2	8.3%
July	2.3	1.0	8.8	2.4	14.6	16.7%
August	3.8	2.0	6.0	2.3	14.0	16.4%
September	8.9	2.6	7.5	2.0	21.0	9.6%
October	2.0	2.4	13.1	1.0	18.5	5.5%
Mean	*4.2*	*2.0*	*13.4*	*1.8*	*21.4*	*10.0%*

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

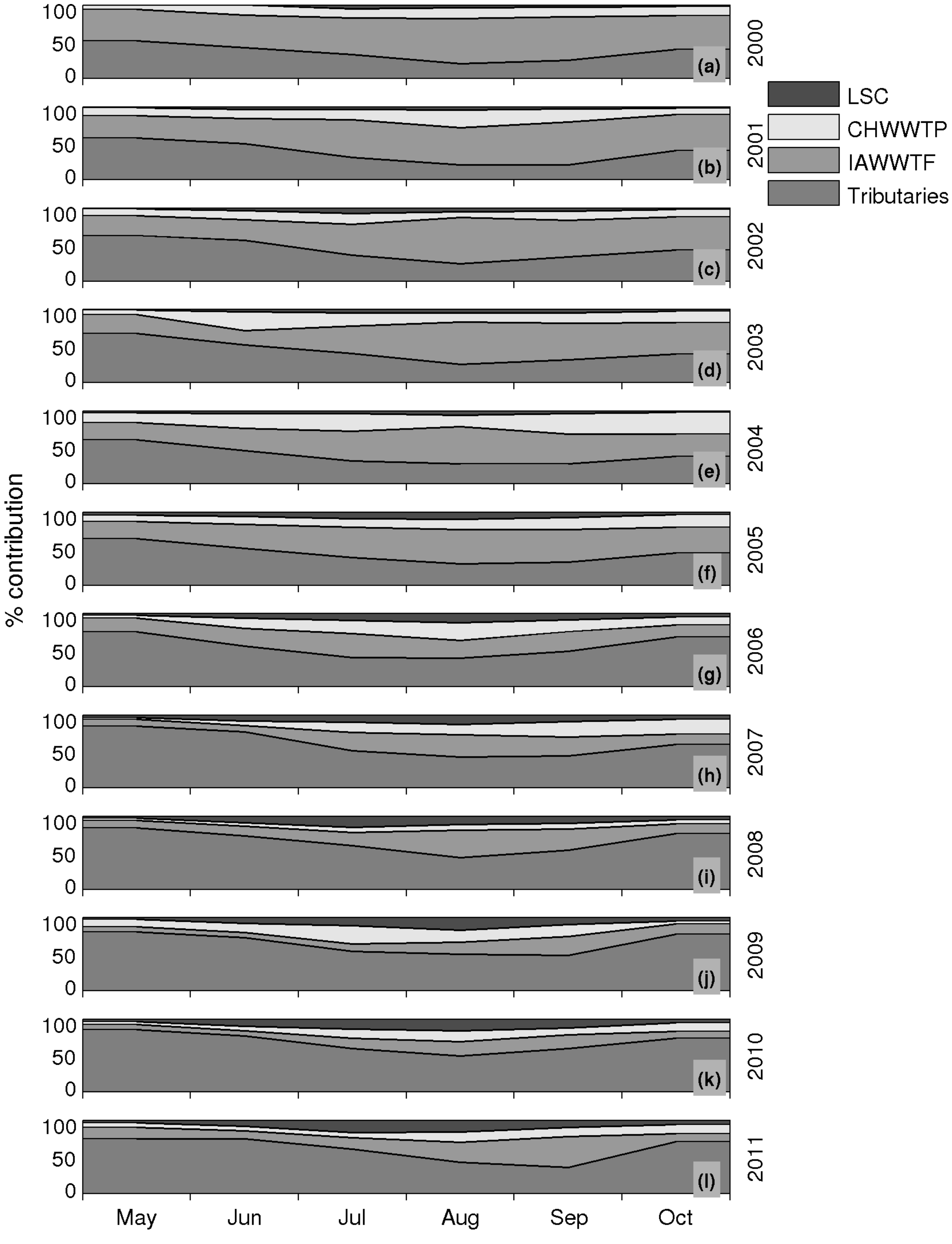

Figure 8: Time series of estimated relative monthly external loads of phosphorus to the southern portion of Cayuga Lake, partitioned according to source: (a) 2000, (b) 2001, (c) 2002, (d) 2003, (e) 2004, (f) 2005, (g) 2006, (h) 2007, (i) 2008, (j) 2009, (k) 2010 and (l) 2011. Loads are for total phosphorus with the exception of tributary loading, which is for total soluble phosphorus.

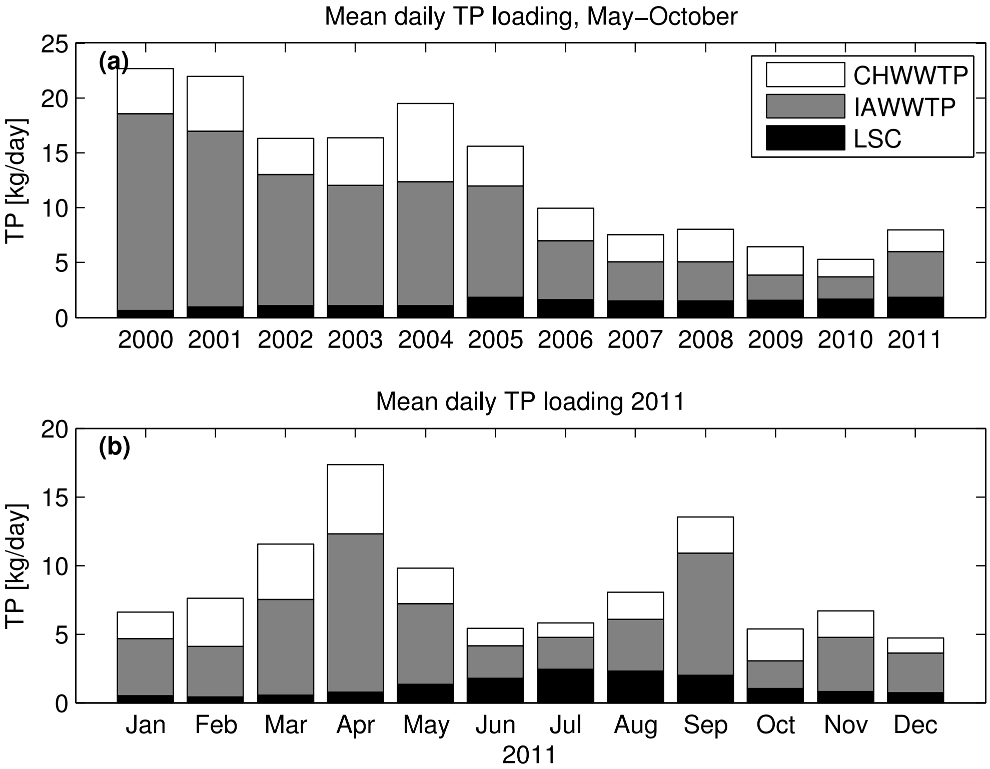

Figure 9: Trends in point source TP loading to the southern shelf: (a) mean daily loading in the May - October period, 2000 - 2011, (b) monthly mean loading in 2011.

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 2011.

Location	**TP** $\left(\mu g \cdot L^{-1}\right)$	**SRP** $\left(\mu g \cdot L^{-1}\right)$	**Tn** (NTU)
LSC effluent (n = 30)	17.5±1.7	10.5±1.2	1.4±0.7
Shelf average (n = 16)	19.2±6.4	2.0±2.9	4.0±5.8

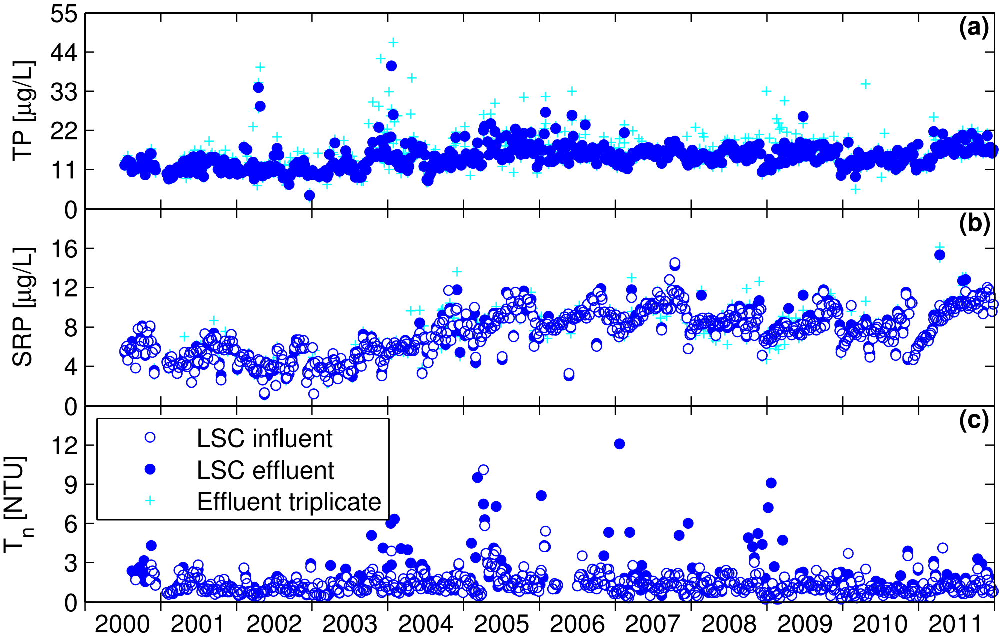

Figure 10: Time series of concentrations measured weekly in the LSC effluent for the 2000 - 2011 interval: (a) total phosphorus, (b) soluble reactive phosphorus, and (c) turbidity. The median of triplicate samples was used as the representative value. “+” symbols represent additional triplicate sample values.

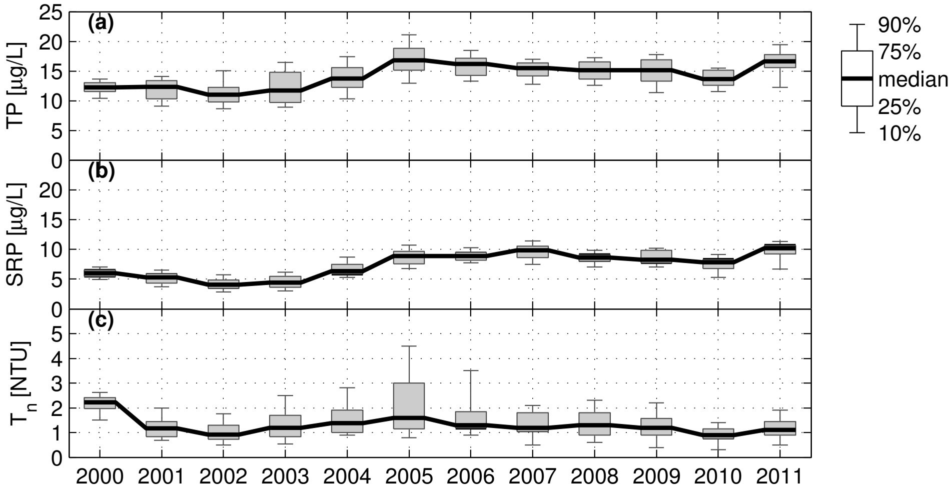

Figure 11: Annual concentrations measured in the LSC effluent for the 2000 - 2011 interval: (a) total phosphorus, (b) soluble reactive phosphorus, and (c) turbidity.

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 factors that can strongly modify measures of water quality (e.g., Lam et al. 1987, Auer and Effler 1989, 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 shallow depth, make it particularly challenging to identify conditions influencing measurements of total phosphorus (TP), Secchi disc transparency (SD), and turbidity (Tn). This challenge is further increased by the lack of a comprehensive data collection effort that measures tributary inputs of sediment or various forms of phosphorus. Therefore, potential tributary contributions of non-phytoplankton particles that would diminish SD values and increase in-lake Tn and TP concentrations are not accounted for and could mistakenly be misinterpreted as reflecting increases in lake 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 or 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 2011 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; figure 13). 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 2011 are compared to time-series of daily mean values for the available records for the monitoring period (figure 13).

Fall Creek flows during 2011 were high compared to the historic record. The total flow volume through Fall Creek during the April - October period of 2011 was nearly double that of 2010. April - October Fall Creek flow in 2011 was the second highest of the years 1998 - 2011 and the second highest since the LSC plant began operating in 2000. Daily flow rates were above the historic median flow rates for much of the season, and several events with very high surface flow occurred during the year, most notably in April, September and October. The heavy runoff in the spring of 2011 lead to near flood levels of the lake during April and May.

4.4 Limitations in Measures of Trophic State on the Shelf

Recurring scientific evidence, provided by the findings of fourteen consecutive study years has demonstrated that Tn and TP are systematically flawed indicators of the trophic state on the shelf (UFI 2000*a*,*b*, 2001, 2002, 2003, 2004, 2005, 2006, 2007; Cornell University 2008, 2009, 2010, 2011). 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 Tn 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 (UFI 2000*a*,*b*, 2001, 2002, 2003, 2004, 2005, 2006, 2007):

1. High Tn 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 Tn following runoff events.

2. Elevated Tn values were reported for the 1999, 2000 and 2002 study years (UFI 2000*b*, 2001,

2003) at the deep water sites during "whiting" events in late July and August. These increases in Tn were driven largely by increases in Tc (calcium carbonate turbidity).

3. The ratio of particulate phosphorus (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., Tn) per unit chlorophyll (e.g., Weidemann and Bannister 1986) to the Chlorophyll-a observations indicate that non-phytoplankton particles made greater contributions to Tn on the shelf than in deep waters. Non-phytoplankton particles were found to be responsible for the high Tn 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 Tn, 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 several 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 - 2011, 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 2011 were near the higher end of 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 - 2011 than in preceding years both on the shelf and at the deep water sites, although not as high as some observations made in the 1970s (in deep water). Chlorophyll-a concentrations in 2011 were lower than the average of the last 5 years on the southern shelf, and higher than observed since 1998 in deep water. Chlorophyll-a concentrations were distinctly higher on the shelf than at deep water sites from 1994 to 1996. However, it should be noted that data for those years were collected as part of the DEIS study at different locations and using different methodology than in the monitoring program that began in 1998. In the years since 1998 observed differences between Chlorophyll-a on the shelf and the deep water locations have not been as large, and in different years Chlorophyll-a was higher on the shelf or in deeper water. 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., Dobson et al. 1974, Vollenweider 1975, Chapra and Dobson 1981).

Slight differences exist between the data presented in table 8 and table 9 and those presented in figure 15. Table 8 and table 9 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 - 2011 study years.

Total Phosphorus $\left(\mu g \cdot L^{-1}\right)$			
Year	Deep-Water Location(s)	Southern Shelf	Source
1968$^{\triangle}$	20.2 (n = 19)	-	Peterson 1971
1969$^{\triangle}$	15.3 (n = 22)	-	Peterson 1971
1970$^{\triangle}$	14.0 (n = 32)	-	Peterson 1971
1972^{x}	18.8 (n = 22)	-	USEPA 1974
1973$^{\triangle}$	14.5 (n = 88)	-	Godfrey 1973
1994$^{*,\oplus}$	21.7	30.8	Stearns and Wheler 1997
1995$^{*,\otimes}$	16.5	23.7	Stearns and Wheler 1997
1996$^{*,\otimes}$	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)	Cornell University 2009
2009^{++}	12.1 (11.6)	20.9 (18.1)	Cornell University 2010
2010^{++}	13.6 (12.9)	16.9 (16.3)	Cornell University 2011
2011^{++}	15.3 (14.5)	18.7 (17.4)	This report

$\triangle$ 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
$^{\oplus}$ site in 62 m of water, south of Myers Point, surface samples
$^{\otimes}$ 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 - 2011 study years.

Chlorophyll-a $\left(\mu g \cdot L^{-1}\right)$			
Year	Deep-Water Location(s)	Southern Shelf	Source
1966*	2.8	-	Hamilton 1969
1968**	4.3	-	Wright 1969
1968 - 1970	4.8	-	Oglesby 1978
1970	3.7	-	Trautmann et al. 1982
1972	10.3	-	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)	Cornell University 2009
2009^{++}	6.2 (6.6)	5.9 (5.7)	Cornell University 2010
2010^{++}	6.5 (5.8)	6.2 (5.4)	Cornell University 2011
2011^{++}	8.0 (7.1)	5.9 (5.1)	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 supports comparison of selected conditions among these lakes. This type of comparative study is important for understanding Cayuga Lake in the context of similar nearby systems. The following section is included to provide some context although data presented in this section are not as current as data presented elsewhere in this report. Annual average Chlorophyll-a values have been variable in Cayuga Lake, and similar changes have occurred in other lakes in the region as well (e.g., Halfman & Franklin 2008).

Chlorophyll-a data (Callinan 2001) collected from the synoptic surveys are reviewed here, as this may be the most trophic state representative indicator from available measurements. Samples (n=15 to 16) were collected in these surveys over the spring to early fall interval during 1996 through 1999.

The sample site for Cayuga Lake for this program coincides approximately with site 8 of the LSC monitoring program (figure 2).

Although no universal agreement is available regarding 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., National Academy of Science 1972, Dobson et al. 1974, 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, and again in 2011 approached the upper bounds of mesotrophy.

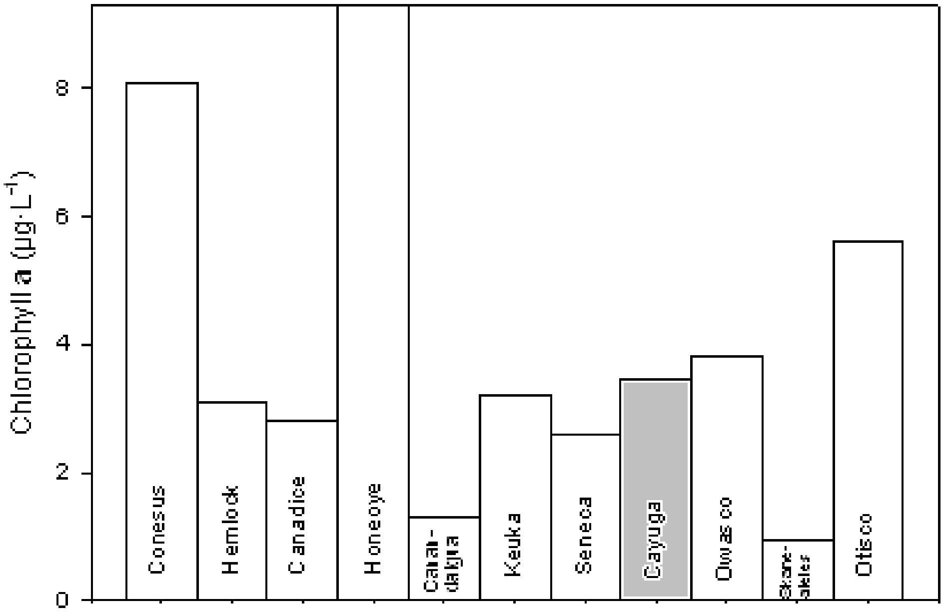

Figure 12: Comparison of average Chlorophyll-a concentrations for the spring-early fall interval for the eleven Finger Lakes, based on samples (n=15 to 16) collected over the 1996 through 1999 interval (data from Callinan 2001).

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 shallow depth, 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 IAWWTP, CHWWTP and the LSC facility for 2011 are compared here to the previous study years (figure 13). When compared to flow conditions of the preceding years, the Fall Creek hydrograph for 2011 shows that this was a year with relatively high flows. Daily flow rates were above the median rate during 1998-2011 most days, and there were several periods of high flow rate, including a major runoff event in September (tropical storm Lee).

Flow rates in Fall Creek were relatively high during most of April 2011 due to spring melt. Flows remained elevated during May, leading to a peak lake level of 384.95 feet above sea level as measured by the USGS gaging station at the Cayuga Inlet (USGS 04233500). This is the fourth highest water level since records began in 1956, and is just below the minor flood damage level of 385 feet defined by the New York State Canal Corporation.

Flow rates were at typically low levels during June to August. However, during a major runoff event in September flow rates peaked at a daily average of nearly 3,500 cfs. This is the second highest daily average flow rate observed in Fall Creek during the month of September since records began in 1925. In contrast, between April and September of 2010 there was only one event with flow rates higher than 500 cfs. The total volume of flow through Fall Creek during the April - October interval of 2011 was the second highest of all years in the study period (1998 - 2011).

Daily average wind speeds along the lake's long axis are presented in figure 13b for the 1998 - 2011 study periods. Wind patterns were generally 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.

Estimates of monthly average total phosphorus (TP) loads to the shelf from point sources in 2011 are compared to the 2000 - 2010 period in figure 13c. Monthly estimates of TP loads for 2011 were among the lowest values observed during all study years except during May and September, months with high flow rates in the tributaries and high loading rates from the two waste water treatment plants (table 6). TP loading to the shelf has decreased substantially since the establishment of tertiary treatment for phosphorus at the IAWWTP, and upgrades to the CHWWTP.

Time series of TP, Chlorophyll-a, and Tn are presented for the April - October interval in the context of historical values measured since 1998 (figure 14, note that data were not collected during the April - June interval of 1998). Plotted values are intended to represent conditions on the shelf (shelf average, defined as the mean of values at sites 3, 4, 5 and the mean of sites 1 and 7; see equation 1 on page 8). TP levels recorded on the shelf in 2011 were near the average of the historic range on most sampling dates (figure 14a).

The seasonal dynamics of Chlorophyll-a concentrations on the shelf in 2011 were generally typical of the previous study years (figure 14b). In general, Chlorophyll-a concentrations have been lowest during spring and fall and highest during mid-summer.

Turbidity values measured in 2011 were typical of 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). This trend continued in 2011, with relatively high turbidity values observed on the shelf during times of high surface runoff in April and early September, and low values at other times of the season.

The temporally detailed data presented in figure 13 and figure 14 are summarized in figure 15 as box plots for each of the 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, 2006 and 2011 (figure 15a). Flows were relatively low for the study intervals of 1999, 2001, 2005, 2007, 2008 and 2009. Average wind speeds were comparable for all 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 IAWWTP and more recently CHWWTP (figure 15c). The increase in point source TP loading observed in 2011 relative to the preceding several years is mainly due to loading from the waste water treatment plants. The efficiency of the treatment process in these plants is reduced at times of high flow, conditions which existed in the spring and fall of 2011 (table 6). Additionally, the IAWWTF is optimizing its treatment process by attempting to obtain the highest removal of phosphates at the lowest dose of ferrous chloride. This may also have contributed somewhat to the increase of the average annual phosphorus concentration in the effluent (J. Lozano, personal communication).

Study period medians (median of all values measured at sites 1, 3, 4, 5 and 7) for TP and Tn on the shelf were lowest in 1999, the driest of the study years (figure 15f). 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 2011 was slightly higher than that observed in 2010 and near the middle of the range of values observed over the entire study period. Variability in observations of TP on the shelf was typical relative to the other study years. Median Chlorophyll-a observed on the shelf in 2011 was slightly higher than in 2010, and was the third highest value of all study years.

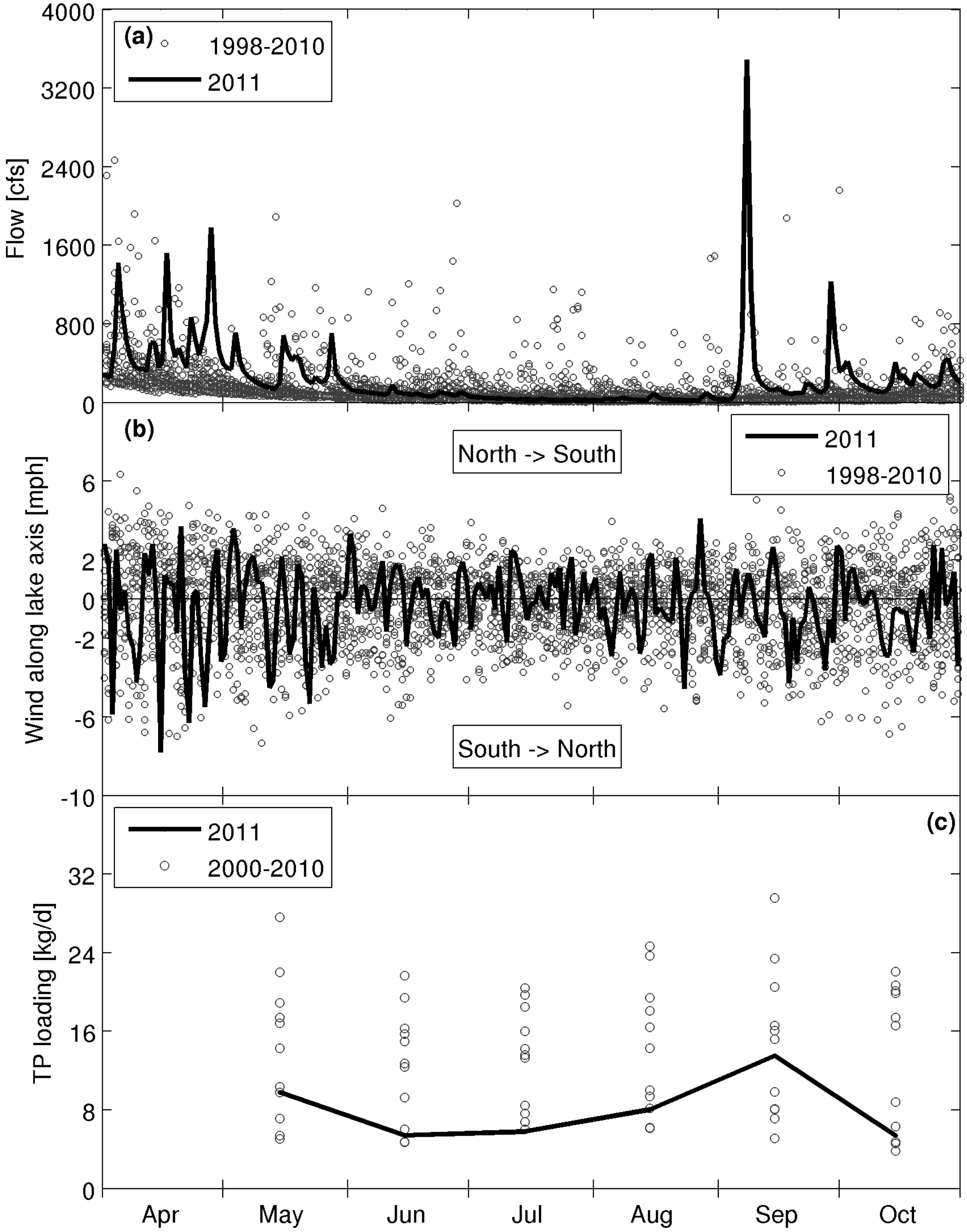

Figure 13: Comparison of 2011 conditions for surface runoff, wind, and total phosphorus loading with conditions from the 1998 - 2010 interval: (a) mean daily flow in Fall Creek, (b) daily average wind component along lake's long axis as measured at Game Farm Road, and (c) summed monthly loads of total phosphorus (TP) to southern Cayuga Lake from the IAWWTP, CHWWTP, and the LSC facility.

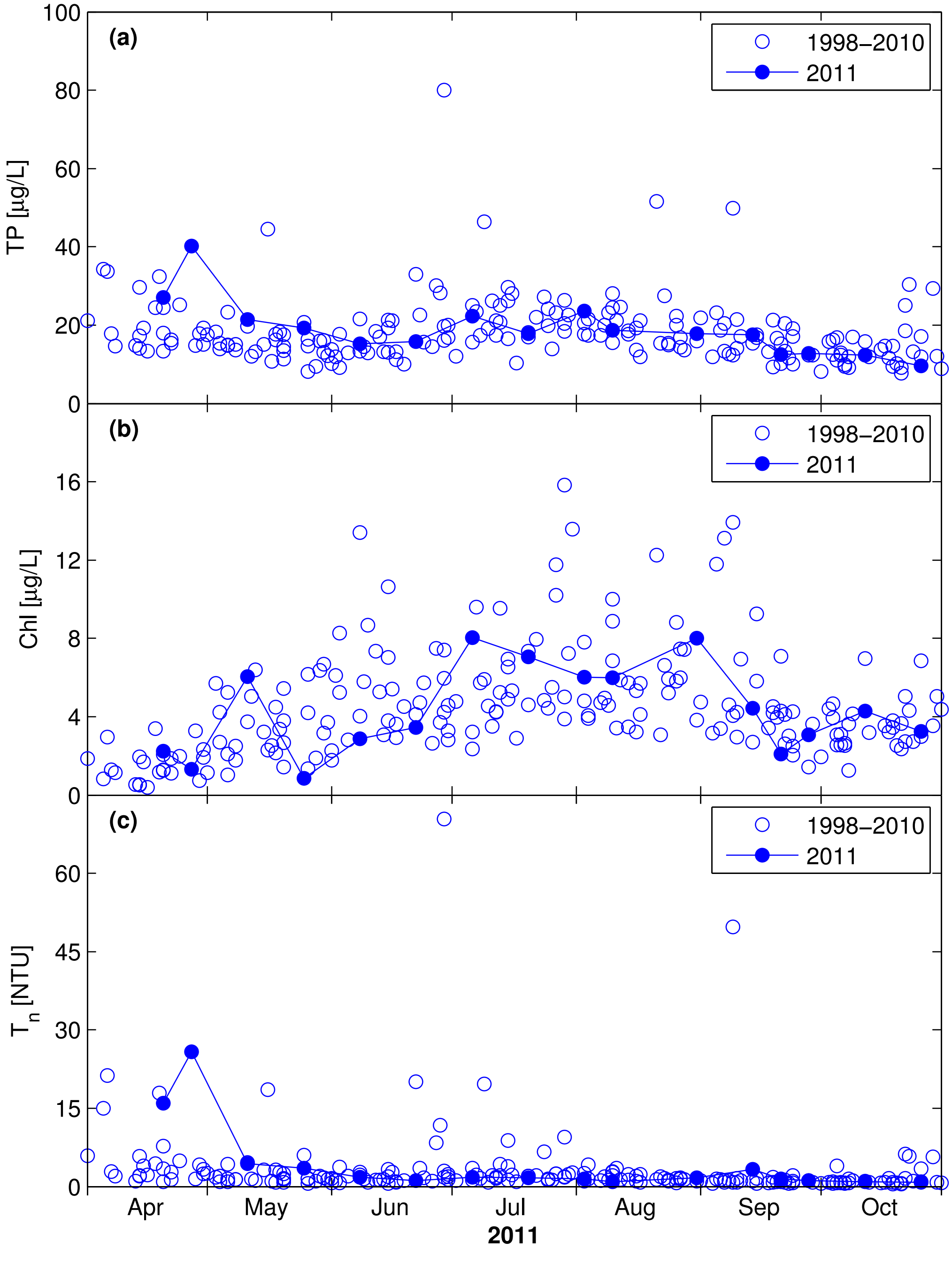

Figure 14: Comparison of 2011 conditions for total phosphorus, Chlorophyll-a, and turbidity on the south shelf of Cayuga Lake with conditions from the 1998 - 2010 interval: (a) total phosphorus (TP), (b) Chlorophyll-a, and (c) turbidity (Tn).

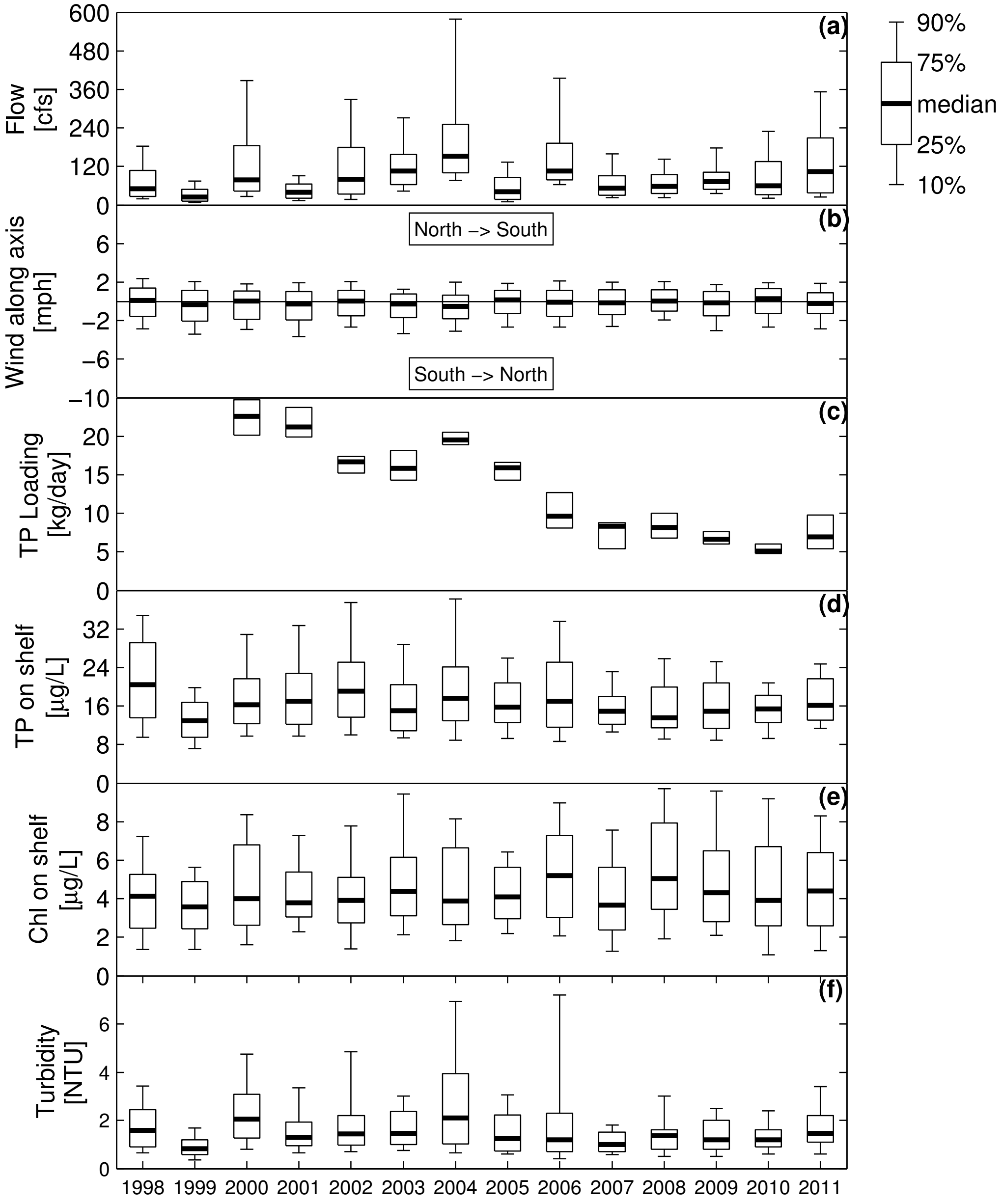

Figure 15: Comparison of study interval runoff, wind, total phosphorus loading, total phosphorus concentration, Chlorophyll-a concentration and turbidity. Legend marks percentile range of data. (a) Fall Creek flow, (b) wind speed, (c) summed loads of total phosphorus (TP) from the IAWWTP, CHWWTP and 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 2011 Data

1. The highest average concentrations of total phosphorus (TP) and turbidity (Tn) were measured at sites 2 and 7 (table 5). Site 2 is located adjacent to the outfall of the IAWWTP and site 7 is nearby the outfall of the CHWWTP. Site 2 is also located directly in the path of the inflows from Fall Creek and the Cayuga Inlet.

2. In previous years extremely high concentrations of phosphorus (TP, TDP, and SRP) and nitrogen (TDN and T-NH_3) were observed at site 2. The highest levels of phosphorus in 2011 were still observed at site 2. However, observed levels of phosphorus at this site have diminished somewhat relative to previous years, likely as a result of improvements in phosphorus treatment at the IAWWTP.

3. The overall temporal trends of observed Chlorophyll-a concentrations were similar on the shelf and at deep water sites (figure 4), suggesting they are controlled by lakewide processes and not local conditions on the shelf.

4. Chlorophyll-a (Chl) concentrations were lower on the south shelf than at deep water locations on average (table 5).

5. 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).

6. Variance of TP was generally greater for the south shelf sites than for deep water sites (sites 6, 8 and LSC; table 5).

7. Variance of Chlorophyll-a (Chl) was similar at most sites and slightly lower at site 4, which had the lowest overall observed concentrations of Chlorophyll-a (table 5).

8. The mean Tn was highest at sites 2 and 4 (table 5).

9. Average Chlorophyll-a concentrations were higher in 2006 - 2008 than in preceding study years. The range of Chlorophyll-a concentrations observed in 2011 was lower than in 2006 - 2008, and was more in line with average Chlorophyll-a concentrations in prior years (table 9 and figure 15). It is possible that these increases in Chlorophyll-a are related to observed changes in phosphorus in the lake’s hypolimnion since 2003 (figure 11).

10. Increases in TP, SRP, and Tn 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, during 2006 - 2010 TP levels in the effluent decreased (though still higher than pre 2003 values) and SRP and Tn have remained fairly stable. In 2011 all three of these quantities increased to near peak levels (figure 11).

11. There appears to be an annual pattern of rising SRP concentration in the LSC outfall during most of the year, followed by a steep drop in concentration in November and December (figure 10). This pattern appears in most years of the plant’s operation, and was most pronounced during 2011. This most likely reflects conditions throughout the lake’s hypolimnion. The cause of this pattern is unknown. It is possible that is related to seasonal dynamics of organisms that cycle phosphorus in the lake, but any such explanation is very speculative due to a lack of relevant data.

12. 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 (figure 3).

13. Turbidity (Tn) values and concentrations of soluble reactive phosphorus (SRP) were essentially equal in the LSC influent and effluent (figure 5).

14. Median total phosphorus (TP) concentrations in the LSC effluent in 2011 was 16.6 µg/Liter. This is the highest annual median TP concentration in the LSC effluent observed in any year except 2005 (median TP in 2005 was 16.8 µg/Liter; figure 11).

15. 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). On average, the TP concentration in the LSC effluent was 1.7 µg/Liter lower than the receiving waters of the shelf (table 7).

16. 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 8.5 µg/Liter higher (table 7).

17. The mean (April - October) concentration of total phosphorus (TP) in the LSC effluent was 3.6 µg/Liter higher in 2011 than in 2010 and the mean (April - October) concentration of soluble reactive phosphorus (SRP) was 2.8 µg/Liter higher than in 2010 (table 7). Median annual TP was 3 µg/Liter higher in the LSC effluent in 2011 than 2010, and median annual SRP was 2.4 µg/Liter higher in 2011 than in 2010 (figure 11). These differences reflect changes in phosphorus concentrations in the lake's hypolimnion.

18. Turbidity (Tn) 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 which caused elevated turbidity on the shelf. On average, turbidity was 2.6 NTU lower in the LSC effluent than on the shelf (table 7).

19. Secchi disc transparency (SD) was observed to extend beyond the lake depth at multiple sites on several occasions during the 2011 study interval (Appendix A).

20. Phosphorus loading from the IAWWTP averaged 4.2 kg/day over the May to October interval of 2011. This is approximately double the loading in 2010, however it represents a 60% decrease from the 2002 - 2005 levels and an 75% decrease relative to 2000 - 2001 (table 6).

21. Phosphorus loading from the CHWWTP averaged 2 kg/day over the May to October interval of 2011. This was the second lowest mean seasonal loading of the 2000 - 2011 period. This loading is 25% higher than the loading in 2010, the year with the lowest loading from this source since 2000, and is 25% lower than the mean loading in 2009 (table 6).

22. In previous years the IAWWTP was the dominant of the three point sources in terms of phosphorus loading to the shelf. However, the loading from the plant has been dropping following improvements in treatment processes. In 2011, mean May - October loading from IAWWTP was the highest of the three point sources. Loading from IAWWTP was more than double the loading from LSC during May - October of 2011. Loading from CHWWTP was slightly higher than the loading from LSC during this period. The tributaries continues to be the dominant source of phosphorus loading, as they have been since 2006 following upgrades to the IAWWTF treatment process (table 6).

23. During years/months with high surface runoff the relative importance of the phosphorus loading from the tributaries is much higher than the combined loading of the three point sources (table 6).

24. Surface flow rates during 2011 were relatively high, causing the lake to reach near flood levels in late April and early May of the year.

25. 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).

26. The TP loading rate to the shelf from LSC peaked in 2005, with a mean 1.8 kg/day over the May - October interval. The loading rate has dropped in subsequent years and was 1.5 kg/day over May - October of each of the years 2007 - 2009. TP loading from LSC again averaged 1.8 kg/day over May - October of 2011. This is due primarily to the increased phosphorus concentration in the lake's hypolimnion since 2005, and also due to increased cooling demands on LSC which require a higher flow rate through the system (table 6).

27. The average TP loading rate to the shelf from LSC for the May to October interval of 2011 was 1.8 kg/day, 38% lower than the 2.9 kg/day projected in the Draft Environmental Impact Statement (table 6).

28. The Fall Creek hydrograph for 2011 reflects relatively high flow conditions for most of the year, with several high flow events (figure 13).

29. Winds aligned with the lake's long axis were near or above long-term average values for several extended periods during the year (figure 13). Annual average wind speeds have been essentially constant over the 1998 - 2011 interval (figure 15).

30. 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). The summer average concentration of Chlorophyll-a in 2011 (8 µg/Liter) was about 60% higher than observed over the 1998 - 2005 interval, and was approximately 10% higher than the summer average values observed during 2006 - 2010 (table 9).

31. Study period yearly median values for TP on the shelf have ranged from 13.0 - 20.4 µg/Liter (figure 15). Median shelf TP in 2011 (16.1 µg/Liter) was near the median value for all study years since 1998 (figure 15).

32. Study period median values for Chlorophyll-a on the shelf have exhibited relatively little interannual variability over the 1998 - 2011 interval, ranging from 3.6 - 5.2 µg/Liter. The median shelf Chlorophyll-a in 2011 was 4.4 µg/Liter (figure 15e) and the summer average Chlorophyll-a on the shelf was 5.9 µg/Liter (table 9). Chlorophyll-a concentrations in deep water sites were higher than those measured on the shelf during much of the 2011 study period, especially during the summer months.

33. Study period median values of Tn on the shelf were lowest during low runoff years. Surface runoff in 2011 was relatively high, as was the median shelf Tn in 2011 (1.5 NTU; figure 15f).

34. The increase in phosphorus concentrations at the LSC intake after 2003 could represent significant lake-wide changes in water quality. Since peaking, TP (2005) and SRP (2007) levels have declined somewhat. However, in 2011 both TP and SRP in the hypolimnion were observed to be near the peak levels (figure 11).

35. No conspicuous changes in water quality have been observed on the shelf since start-up of the LSC facility in July 2000 (UFI 2001, 2002, 2003, 2004, 2005, 2006, 2007; Cornell University 2008, 2009, 2010, 2011).

6 Summary

This report presents the design and salient findings of a water quality monitoring study conducted for Cayuga Lake in 2011, sponsored by Cornell University Department of Energy and Sustainability. This is the fourteenth annual report for a monitoring program that has been conducted since 1998. A number of noteworthy findings are reported here for 2011 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 2011 was relatively high in comparison to other years since 1998, including high runoff in April and May that led to near flooding levels of the lake, and an extreme runoff event in September, following tropical storm Lee. Phosphorus loading from the tributaries is on the order of double the combined loading from the point sources. Phosphorus loading to the shelf from the point sources has been dropping since 2006 following upgrades to the WWTPs, and combined TP loading from LSC and the two WWTPs was much lower in 2011 than any year prior to the WWTP upgrades, though higher than the loading in 2010.

Summer average TP on the shelf has also been lower following the plant upgrades. Summer average Chlorophyll-a concentrations on the shelf in 2011 were on the low end of the range observed during 2006 - 2010, however summer average Chlorophyll-a at site 8 was the highest observed for several decades. It is possible that the higher levels of Chlorophyll-a are related to the increase in phosphorus in the lake's hypolimnion observed since 2004 - 2005, which was observed to be higher in 2011 than in any previous year since 2000. 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 nearly 40% lower than projected in the Draft Environmental Impact Statement.

TP and SRP concentrations in the LSC intake increased sharply from 2003 - 2005. In subsequent years the concentrations declined somewhat, but both TP and SRP concentrations at the LSC intake were higher in 2011 than in any previous year. 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 A In Lake Monitoring Data Listing

Total Phosphorus ($\mu g/Liter$)

Dates:	04/20/11	04/27/11	05/11/11	05/25/11	06/08/11	06/22/11	07/06/11	07/20/11	08/03/11	08/10/11	08/31/11	09/14/11	09/21/11	09/28/11	10/12/11	10/26/11
Sites:																
1	27.1	32.5	22.8	20.2	13.8	19.3	18.9	16.1	25.8	25.5	16.0	22.5	11.9	11.6	11.7	9.7
2	32.5	45.3	27.0	29.6	18.8	16.6	26.2	38.3	37.2	25.8	20.8	20.1	17.2	13.2	12.4	16.6
3	22.6	38.5	22.1	29.6	17.4	17.2	21.6	17.7	22.0	16.8	20.2	16.1	12.6	12.9	13.0	8.7
4	30.2	51.4	21.2	12.1	13.1	13.9	22.6	12.8	25.5	14.2	16.3	16.1	14.2	11.9	11.7	8.0
5	29.3	39.9	19.9	13.4	14.1	14.6	20.6	15.1	21.3	17.4	14.4	15.5	10.3	11.6	11.3	9.4
6	21.4	35.2	19.6	18.8	11.5	13.9	23.6	16.4	20.7	20.4	15.3	14.8	11.6	9.6	12.3	10.4
7	25.5	29.8	22.8	23.6	18.8	15.6	29.5	35.3	25.8	27.1	24.7	22.5	13.6	17.5	15.1	14.7
8	13.7	15.4	15.6	13.1	12.1	12.2	15.6	16.1	19.1	16.5	15.3	13.8	12.2	11.6	10.3	9.9
LSC Intake	19.8	16.5	18.6	12.8	11.8	13.9	17.3	16.4	20.7	16.5	14.0	13.8	12.2	10.3	11.3	8.7

Soluble Reactive Phosphorus ($\mu g/Liter$) values reported as 0.2 are 1⁄2 the limit of detection (0.4/2 = 0.2)

Dates:	04/20/11	04/27/11	05/11/11	05/25/11	06/08/11	06/22/11	07/06/11	07/20/11	08/03/11	08/10/11	08/31/11	09/14/11	09/21/11	09/28/11	10/12/11	10/26/11
Sites:																
1	10.3	8.7	1.6	5.4	0.8	1.0	0.2	0.2	0.2	0.4	0.5	2.4	0.7	0.9	0.2	0.5
2	8.8	9.7	2.2	5.1	1.4	0.4	0.2	0.4	0.9	0.4	0.2	1.3	2.5	0.4	0.2	1.9
3	5.4	9.5	2.3	4.5	1.7	0.4	0.2	0.4	0.2	0.4	0.2	0.2	0.6	0.6	0.2	0.8
4	7.5	10.1	2.2	2.3	1.4	0.4	0.2	0.2	0.2	1.1	0.2	0.7	1.4	0.4	0.2	1.5
5	12.0	10.0	1.7	4.6	1.1	0.4	0.2	0.2	0.2	0.4	0.2	0.2	0.6	0.6	0.5	1.0
6	9.1	8.7	2.8	5.2	0.5	0.4	0.2	0.4	0.5	0.8	0.2	0.4	0.4	0.4	0.2	0.7
7	6.0	9.0	2.2	4.0	1.9	0.4	0.2	0.4	1.2	1.7	0.8	1.2	3.6	2.3	1.1	1.6
8	8.3	8.0	1.7	0.2	0.5	0.4	0.2	0.4	0.2	0.2	0.2	0.4	0.6	0.2	0.2	0.7
LSC Intake	8.8	8.6	2.9	1.3	0.5	0.4	0.2	0.2	0.5	0.4	0.2	0.2	0.4	0.2	0.5	0.5

Chlorophyll-a ($\mu g/Liter$) 04/27/11 value at site 5 reported as 0.1 is ½ the limit of detection (0.2/2 = 0.1)

Dates:	04/20/11	04/27/11	05/11/11	05/25/11	06/08/11	06/22/11	07/06/11	07/20/11	08/03/11	08/10/11	08/31/11	09/14/11	09/21/11	09/28/11	10/12/11	10/26/11
Sites:																
1	1.9	0.8	6.0	0.8	4.7	6.0	7.6	8.8	8.9	8.9	11.1	2.9	3.1	2.3	3.8	4.5
2	2.8	1.8	4.6	1.8	4.9	3.4	9.5	13.8	9.4	9.0	8.2	4.2	2.8	3.4	4.8	2.3
3	1.9	2.3	6.0	1.3	2.1	2.7	7.7	7.5	5.1	4.5	8.8	5.1	2.5	3.6	5.2	2.4
4	2.7	1.3	5.6	0.8	3.6	2.6	7.2	4.0	2.3	2.2	5.0	3.4	1.3	2.7	3.7	2.4
5	1.8	0.1	7.2	0.3	2.6	4.1	8.0	9.5	8.1	4.5	9.5	5.4	1.9	3.8	4.4	4.4
6	0.3	1.0	5.7	0.4	2.2	4.9	7.2	14.5	11.1	9.7	12.5	6.0	3.8	4.8	7.0	4.5
7	3.2	2.2	4.7	1.2	1.6	2.9	10.9	5.6	8.3	16.5	6.4	4.7	2.2	2.1	4.0	3.0
8	1.2	0.8	6.9	1.2	4.9	2.8	6.9	12.3	11.4	5.9	12.1	5.5	3.2	5.8	4.6	5.8
LSC Intake	1.2	1.1	5.5	0.7	6.5	5.2	9.4	12.8	10.5	6.4	14.5	6.5	2.3	4.4	4.4	6.7

Turbidity (NTU)

Dates:	04/20/11	04/27/11	05/11/11	05/25/11	06/08/11	06/22/11	07/06/11	07/20/11	08/03/11	08/10/11	08/31/11	09/14/11	09/21/11	09/28/11	10/12/11	10/26/11
Sites:																
1	13.9	19.1	4.7	3.4	1.7	1.1	2.0	1.8	1.8	1.3	1.3	8.2	1.3	0.9	1.0	0.7
2	19.8	19.2	5.7	4.9	1.8	1.5	2.2	5.0	3.4	2.2	2.3	6.3	1.6	1.5	1.2	2.7
3	13.9	20.3	5.8	7.4	2.6	1.3	1.9	1.6	1.4	0.9	2.4	2.2	1.6	1.2	1.1	0.6
4	19.7	38.0	3.2	1.3	1.1	1.2	1.6	1.2	0.9	0.6	1.2	3.0	1.7	1.4	0.7	0.4
5	13.5	29.3	3.5	1.5	1.6	1.1	1.6	2.2	1.6	1.0	1.3	2.0	1.3	1.2	0.7	0.6
6	5.3	24.3	2.7	3.1	1.1	0.9	2.4	2.0	1.7	1.0	1.2	2.0	1.3	0.6	0.8	0.8
7	19.7	12.0	5.0	4.4	2.1	1.2	2.4	1.6	1.7	1.1	2.3	3.6	1.3	0.8	1.1	2.6
8	1.2	1.9	1.8	1.2	1.2	1.3	1.1	2.0	1.7	0.9	1.2	1.8	1.1	0.7	0.7	0.6
LSC Intake	4.6	1.9	3.0	1.5	1.0	0.7	1.3	1.8	1.7	1.0	1.3	1.9	1.2	0.6	0.6	0.6

Secchi Disc Depth (*m*)

Dates:	04/20/11	04/27/11	05/11/11	05/25/11	06/08/11	06/22/11	07/06/11	07/20/11	08/03/11	08/10/11	08/31/11	09/14/11	09/21/11	09/28/11	10/12/11	10/26/11
Sites:																
1	0.6	0.4	1.1	1.6	3.4	3.1	1.8	2.0	veg.	veg.	veg.	1.1	veg.	veg.	3.4	veg.
2	0.4	0.3	1.0	0.6	bottom	veg.	1.8	1.0	1.9	veg.	2.2	1.4	veg.	veg.	bottom	2.1
3	0.6	0.4	1.0	0.4	2.7	2.8	1.7	veg.	2.6	veg.	2.8	2.4	3.3	veg.	3.3	veg.
4	0.4	0.2	1.8	bottom	bottom	veg.	veg.	veg.	veg.	veg.	veg.	3.0	veg.	veg.	veg.	veg.
5	0.6	0.6	1.4	4.6	2.7	3.9	1.4	1.9	1.7	3.4	3.4	3.0	3.7	3.0	4.3	bottom
6	1.5	0.7	2.7	1.6	5.8	4.2	1.4	1.9	1.6	3.4	2.9	2.9	3.5	5.2	3.7	4.6
7	0.5	0.4	1.3	1.3	2.7	veg.	1.7	veg.	veg.	veg.	veg.	veg.	veg.	veg.	bottom	2.0
8	5.8	5.1	4.7	6.1	5.3	4.2	2.1	1.7	1.6	4.4	3.2	2.9	3.7	4.6	4.6	5.0
LSC Intake	1.5	3.4	3.7	5.3	5.7	4.2	1.9	1.8	1.6	3.5	3.1	2.8	3.4	4.9	3.7	5.4

"bottom" indicates true Secchi disc depth was greater than lake depth
"veg." indicates Secchi disc was obscured by rooted vegetation before reaching the true Secchi disc depth

Appendix B Lake Source Cooling Discharge Monitoring Report Data

	Temperature ($^\circ$**C**)		**Flow rate** $(m^3/second)$		**Dissolved oxygen** (mg/L)		**pH** (SU)		**TP** $(\mu g/L)$		**SRP** $(\mu g/L)$	
Date	**Daily Ave**	**Daily Max**	**Daily Ave**	**Daily Max**	**Daily Ave**	**Daily Max**	**Min**	**Max**	**Daily Ave**	**Daily Max**	**Daily Ave**	**Daily Max**
Jul 2000	10.3	10.9	1.2	1.3	11.0	11.1	8.0	8.1	13.3	13.6	5.0	5.0
Aug 2000	10.2	11.6	1.0	1.3	11.0	11.5	8.0	8.1	11.6	13.0	5.9	6.4
Sep 2000	9.8	11.8	0.8	1.4	10.6	10.9	7.9	8.1	12.2	14.4	6.1	6.9
Oct 2000	9.1	9.8	0.6	0.9	10.4	10.7	7.8	8.1	12.0	14.0	6.7	8.1
Nov 2000	9.0	9.8	0.5	1.0	10.9	12.2	7.7	8.1	14.0	16.0	6.0	8.0
Dec 2000	8.2	9.5	0.5	0.7	12.5	12.5	7.9	7.9	10.9	10.9	5.9	5.9
Jan 2001	7.3	7.6	0.4	0.5	-	-	-	-	-	-	-	-
Feb 2001	8.2	8.6	0.3	0.3	17.6	20.3	7.9	8.1	9.5	11.0	4.4	4.9
Mar 2001	6.6	8.7	0.3	0.4	15.8	18.2	8.0	8.1	10.5	11.6	3.8	4.2
Apr 2001	7.9	9.6	0.5	0.7	15.5	17.6	8.0	8.1	12.0	14.0	8.0	8.0
May 2001	9.1	10.0	0.7	0.9	15.0	18.4	7.9	8.1	11.4	13.9	4.3	5.3
Jun 2001	10.4	11.4	1.0	1.3	12.0	12.3	8.0	8.1	12.7	14.7	4.9	5.8
Jul 2001	10.3	11.8	1.0	1.5	11.5	11.6	7.9	8.0	12.0	15.0	5.0	5.6
Aug 2001	10.7	11.8	1.2	1.5	11.3	11.4	7.8	8.0	13.9	15.4	6.2	6.9
Sep 2001	9.7	10.8	0.8	1.3	10.8	10.9	7.9	8.0	14.1	14.8	6.8	7.3
Oct 2001	9.2	10.7	0.6	1.1	10.6	10.8	7.8	8.1	12.0	13.5	4.9	6.1
Nov 2001	9.5	10.4	0.6	1.0	10.4	10.6	7.9	7.9	12.2	13.7	6.1	6.4
Dec 2001	9.4	10.6	0.5	0.8	10.3	10.4	7.7	7.9	12.5	12.8	6.0	6.4
Jan 2002	9.2	9.4	0.4	0.5	10.6	11.2	7.9	8.0	10.4	11.0	4.3	4.7
Feb 2002	7.9	8.9	0.4	0.4	11.8	12.0	7.7	7.9	15.5	17.3	4.9	5.2
Mar 2002	8.3	9.3	0.4	0.4	12.2	12.6	7.8	7.9	12.1	16.1	3.8	4.3
Apr 2002	9.1	10.9	0.5	1.1	11.7	11.9	7.9	8.0	17.8	32.3	3.7	4.2
May 2002	9.7	10.8	0.7	1.1	11.5	11.8	7.8	8.0	10.8	11.6	2.9	4.4
Jun 2002	10.7	11.8	1.1	1.3	11.1	11.3	7.9	8.1	10.8	12.1	3.9	4.2
Jul 2002	10.7	12.0	1.5	1.9	11.3	12.8	7.8	7.9	14.2	17.8	4.2	5.6
Aug 2002	10.5	11.5	1.4	1.8	12.8	15.6	7.8	7.9	9.5	10.3	3.8	4.7
Sep 2002	10.0	11.0	1.2	1.8	15.2	20.9	8.0	8.0	9.6	11.0	3.7	4.7
Oct 2002	9.4	10.3	0.7	1.8	12.7	24.7	7.8	8.1	11.8	13.6	5.6	6.6
Nov 2002	9.2	10.3	0.6	1.7	10.0	10.4	7.6	8.0	12.2	13.9	6.2	6.5
Dec 2002	8.6	9.1	0.6	1.2	10.5	10.8	7.5	8.1	8.3	10.0	3.3	4.0
Jan 2003	8.2	9.2	0.4	0.5	10.6	11.6	7.5	7.7	10.3	11.5	3.7	4.8
Feb 2003	7.8	8.2	0.3	0.3	13.4	13.8	7.8	7.9	9.5	9.9	3.9	4.4
Mar 2003	7.6	9.2	0.3	0.4	12.5	13.0	7.5	7.9	11.1	15.5	3.2	3.9
Apr 2003	8.2	9.4	0.4	0.8	12.8	13.3	7.6	7.9	13.8	16.9	4.5	4.9
May 2003	8.7	9.6	0.6	0.9	12.7	14.6	7.5	7.8	12.0	13.1	3.9	4.6
Jun 2003	9.4	10.6	1.0	1.5	12.1	12.2	7.7	7.9	13.6	15.9	3.8	4.2
Jul 2003	10.4	10.8	1.2	1.6	11.8	12.9	7.6	7.8	11.1	12.5	3.9	5.1
Aug 2003	10.5	11.6	1.6	2.0	11.6	12.4	7.1	7.8	9.0	9.3	5.1	5.5
Sep 2003	9.6	10.6	1.2	1.8	11.1	11.3	7.4	7.7	12.8	17.0	6.2	7.3
Oct 2003	9.1	10.1	0.6	0.9	10.3	10.5	7.6	7.7	16.6	20.9	6.5	7.0
Nov 2003	8.9	9.9	0.6	1.2	10.4	10.6	7.7	7.8	20.1	25.2	5.5	6.1
Dec 2003	8.2	8.8	0.6	1.0	10.6	10.6	7.6	7.9	17.0	20.2	4.8	6.4

Date	**Temperature** $(^{\circ}\mathbf{C})$		**Flow rate** $\left(m^3/second\right)$		**Dissolved oxygen** (mg/L)		**pH** (SU)		**TP** $(\mu g/L)$		**SRP** $(\mu g/L)$	
	Daily Ave	**Daily Max**	**Daily Ave**	**Daily Max**	**Daily Ave**	**Daily Max**	**Min**	**Max**	**Daily Ave**	**Daily Max**	**Daily Ave**	**Daily Max**
Jan 2004	7.7	9.0	0.4	0.5	10.8	11.1	7.7	8.1	32.0	56.1	5.7	6.1
Feb 2004	8.5	8.8	0.2	0.2	11.3	11.7	7.9	8.1	15.4	17.8	6.1	6.3
Mar 2004	7.8	8.5	0.3	0.5	11.7	12.1	7.9	8.0	14.1	17.9	6.1	6.6
Apr 2004	8.4	9.7	0.4	0.9	12.3	12.8	7.9	8.1	16.3	23.7	6.2	7.4
May 2004	9.2	10.2	0.9	1.4	11.9	12.4	7.9	8.2	16.6	17.2	6.4	6.9
Jun 2004	9.6	10.8	0.9	1.5	11.8	12.1	7.9	8.3	15.7	17.1	6.5	8.6
Jul 2004	10.1	11.0	1.2	1.5	11.7	12.0	7.9	7.9	8.9	10.4	5.6	7.0
Aug 2004	9.8	10.9	1.2	1.6	11.7	11.5	7.7	8.3	13.5	14.8	6.6	8.0
Sep 2004	9.5	10.3	1.0	1.4	10.4	11.0	7.0	7.9	12.7	14.1	8.2	9.3
Oct 2004	8.9	9.5	0.5	0.8	10.7	10.8	7.6	8.0	13.9	16.1	8.2	10.0
Nov 2004	8.8	9.4	0.5	0.7	10.4	11.0	7.0	7.9	12.7	14.1	8.2	9.3
Dec 2004	8.6	9.6	0.5	0.6	10.6	11.0	7.8	7.9	13.0	13.8	6.8	7.9
Jan 2005	8.5	8.9	0.3	0.5	10.8	11.1	7.8	8.1	15.3	20.3	7.9	8.8
Feb 2005	8.3	8.9	0.3	0.4	11.3	11.6	7.7	7.8	14.5	15.7	7.2	9.4
Mar 2005	7.9	8.5	0.3	0.4	12.3	13.4	7.8	7.9	14.5	17.2	7.5	7.9
Apr 2005	8.2	9.3	0.5	0.8	12.1	12.6	7.8	7.9	21.8	23.3	8.1	8.6
May 2005	11.4	11.5	1.2	1.2	11.9	12.6	7.5	7.8	20.0	24.6	8.3	9.3
Jun 2005	10.1	10.9	1.3	1.7	11.7	12.1	7.7	7.8	17.2	19.9	9.1	12.0
Jul 2005	10.2	11.1	1.4	1.8	11.8	12.6	7.6	7.7	16.2	20.5	9.7	15.0
Aug 2005	9.9	10.7	1.4	1.7	11.3	11.6	7.8	8.0	16.4	18.8	9.3	10.5
Sep 2005	9.5	10.2	1.1	1.6	11.0	11.1	7.7	8.0	18.9	22.2	10.0	13.8
Oct 2005	9.0	10.0	0.7	1.4	10.5	10.7	7.7	7.9	18.3	24.5	10.4	11.5
Nov 2005	8.3	9.4	0.7	1.1	10.1	10.6	7.7	7.9	18.3	21.3	10.5	13.6
Dec 2005	8.3	9.6	0.5	0.7	10.2	10.7	7.6	8.0	15.6	18.3	7.5	10.5
Jan 2006	7.3	7.9	0.5	0.5	11.0	11.7	7.6	8.2	18.5	27.4	7.9	8.4
Feb 2006	7.0	8.5	0.5	0.5	11.4	11.6	8.0	8.2	15.1	16.4	8.3	9.1
Mar 2006	7.8	9.1	0.4	0.7	11.6	11.9	7.9	8.1	16.9	21.3	8.0	8.2
Apr 2006	8.3	9.1	0.5	0.7	11.9	12.0	7.8	8.0	15.0	16.7	8.3	8.5
May 2006	9.1	10.5	0.8	1.5	11.4	11.7	7.7	8.0	16.3	19.0	7.6	9.2
Jun 2006	9.6	10.5	1.1	1.7	11.2	11.5	7.9	7.9	19.8	18.0	9.0	9.0
Jul 2006	10.2	10.9	1.6	1.9	11.4	12.3	7.8	8.0	16.1	17.5	9.4	9.7
Aug 2006	9.9	11.4	1.4	2.0	11.0	11.4	7.7	7.9	16.9	23.1	9.6	10.3
Sep 2006	9.4	9.8	1.0	1.4	10.5	10.8	7.8	7.9	16.4	17.0	10.8	11.0
Oct 2006	9.0	9.6	0.7	1.0	10.7	11.0	7.6	7.7	15.7	16.9	10.0	11.8
Nov 2006	8.9	9.6	0.6	0.8	9.9	10.3	7.6	7.8	15.1	17.9	9.1	9.5
Dec 2006	8.7	9.8	0.6	0.9	10.3	10.8	7.5	7.9	15.1	16.6	8.9	9.6
Jan 2007	8.2	8.9	0.5	0.8	9.8	10.4	7.6	8.0	13.5	15.5	8.0	9.2
Feb 2007	7.8	8.6	0.3	0.5	10.4	11.4	7.8	8.0	14.7	21.3	8.0	8.4
Mar 2007	7.9	8.6	0.3	0.5	10.6	11.6	7.8	7.9	14.2	15.6	9.1	11.8
Apr 2007	8.3	9.3	0.4	0.8	12.0	12.1	8.0	8.1	15.5	16.4	8.9	9.2
May 2007	8.8	9.6	0.8	1.4	10.9	11.3	7.7	8.1	16.2	17.0	9.7	10.4
Jun 2007	9.4	10.7	1.2	1.7	11.1	11.2	7.5	8.0	16.5	17.1	10.0	10.4
Jul 2007	9.6	10.5	1.3	1.7	11.2	11.6	7.9	8.0	15.5	16.6	10.4	11.5
Aug 2007	9.7	10.6	1.4	1.9	11.4	12.0	7.7	8.5	15.2	16.3	9.8	10.6
Sep 2007	9.4	10.4	1.1	1.8	10.7	11.0	7.8	8.0	16.0	18.6	10.7	12.8
Oct 2007	9.1	10.0	0.9	1.5	10.2	11.2	7.6	7.8	16.9	19.0	11.9	14.2

Date	**Temperature** (°**C**)		**Flow rate** $\left(m^3/second\right)$		**Dissolved oxygen** (mg/L)		**pH** (SU)		**TP** $(\mu g/L)$		**SRP** $(\mu g/L)$	
	Daily Ave	**Daily Max**	**Daily Ave**	**Daily Max**	**Daily Ave**	**Daily Max**	**Min**	**Max**	**Daily Ave**	**Daily Max**	**Daily Ave**	**Daily Max**
Nov 2007	8.7	9.3	0.5	1.0	10.1	10.9	7.5	7.8	15.9	17.4	10.7	11.5
Dec 2007	8.4	9.5	0.5	0.7	10.7	11.0	7.8	7.9	13.3	14.2	8.0	9.7
Jan 2008	7.4	8.5	0.5	0.6	11.2	11.8	7.7	8.1	14.3	16.5	8.0	8.2
Feb 2008	6.5	6.8	0.5	0.5	11.5	12.2	7.7	7.8	14.8	15.4	9.3	11.2
Mar 2008	6.0	6.6	0.5	0.6	11.6	11.9	7.6	7.8	14.5	15.4	8.6	8.9
Apr 2008	7.8	8.9	0.7	1.1	11.8	12.1	7.6	7.8	13.1	13.7	8.0	8.7
May 2008	8.6	9.5	0.7	1.2	11.5	11.9	7.6	7.9	14.6	15.2	8.4	8.9
Jun 2008	9.7	10.6	1.4	2.0	11.7	12.0	7.8	7.9	17.1	18.0	8.4	8.9
Jul 2008	9.9	10.7	1.5	1.9	11.6	11.9	7.7	7.8	17.0	18.0	9.2	9.8
Aug 2008	9.6	10.3	1.3	1.7	10.9	11.1	7.7	7.9	14.9	15.6	9.1	10.1
Sep 2008	9.4	10.7	1.1	1.8	10.4	11.1	7.6	7.7	15.0	16.4	8.3	9.5
Oct 2008	9.0	10.4	0.6	1.0	9.8	10.3	7.5	7.7	16.1	17.4	8.7	9.8
Nov 2008	8.7	9.3	0.6	0.9	9.6	10.2	7.5	7.8	17.2	18.2	10.0	10.7
Dec 2008	8.5	9.1	0.5	0.5	10.8	11.1	7.1	7.7	12.0	15.4	7.0	9.8
Jan 2009	8.4	9.3	0.3	0.5	10.2	11.1	7.5	7.8	12.1	14.0	7.0	7.1
Feb 2009	7.0	7.5	0.3	0.4	11.9	12.1	7.6	7.7	13.7	16.8	7.4	7.8
Mar 2009	6.9	7.2	0.3	0.5	12.1	12.6	7.7	7.9	14.6	18.4	8.1	8.5
Apr 2009	7.9	9.8	0.6	1.2	11.6	12.2	7.7	7.8	16.7	17.2	8.7	9.9
May 2009	9.0	10.0	0.8	1.3	12.1	12.6	7.5	7.7	15.1	15.9	7.9	8.0
Jun 2009	9.5	10.1	1.1	1.6	11.4	11.6	7.5	7.8	18.1	25.9	8.4	11.2
Jul 2009	9.6	10.3	1.4	1.8	12.0	12.5	7.4	8.0	16.1	18.1	8.7	9.2
Aug 2009	9.8	10.7	1.7	2.0	10.9	11.3	7.3	7.6	15.1	17.7	8.5	8.7
Sep 2009	9.2	10.4	1.1	1.7	10.8	11.7	7.4	7.6	16.5	18.2	10.1	11.8
Oct 2009	9.1	9.4	0.6	0.8	10.4	10.5	7.4	7.8	15.8	16.8	9.8	10.7
Nov 2009	9.0	9.7	0.6	1.8	10.0	10.3	7.7	7.8	15.6	16.2	10.2	10.3
Dec 2009	8.4	9.1	0.6	1.1	10.8	12.0	7.7	8.0	13.6	17.2	8.2	10.0
Jan 2010	8.2	7.4	0.5	0.6	11.4	11.5	7.8	8.0	13.5	18.7	6.6	7.2
Feb 2010	9.5	7.5	0.4	0.5	11.8	13.1	7.8	7.9	13.1	13.6	7.8	8.2
Mar 2010	8.0	7.2	0.5	0.6	11.8	12.3	7.8	7.9	12.3	15.8	7.7	8.0
Apr 2010	9.5	8.8	0.6	1.0	11.8	12.0	7.6	8.1	13.5	14.4	8.2	8.8
May 2010	10.2	8.9	1.1	1.8	11.7	12.3	8.0	8.2	13.6	15.0	6.5	7.8
Jun 2010	11.0	10.1	1.6	2.0	11.4	12.0	7.9	8.0	15.3	16.2	7.9	8.3
Jul 2010	11.0	10.3	1.8	2.0	11.3	11.6	7.8	8.1	13.5	13.9	7.5	7.9
Aug 2010	10.9	10.1	1.7	2.0	10.8	11.0	7.7	8.0	13.6	14.8	7.7	8.7
Sep 2010	10.6	9.5	1.3	1.9	10.4	10.6	7.7	7.8	13.9	16.5	7.9	9.6
Oct 2010	9.8	8.8	0.8	1.3	10.6	11.8	7.6	7.8	13.5	15.1	8.8	9.2
Nov 2010	9.4	8.2	0.8	1.6	10.0	10.2	7.6	7.9	15.2	15.8	9.0	11.5
Dec 2010	8.9	7.7	1.1	1.6	10.7	11.4	7.8	9.2	14.8	18.1	6.5	10.4
Jan 2011	7.3	8.4	0.5	0.5	11.5	12.0	7.8	7.9	12.4	12.5	6.5	6.7
Feb 2011	7.7	9.3	0.4	0.5	11.6	12.3	7.7	8.1	12.7	13.9	7.1	7.3
Mar 2011	7.7	8.7	0.4	0.4	11.8	12.2	7.8	9.4	16.8	21.7	8.5	9.2
Apr 2011	8.3	11.8	0.5	1.3	11.9	12.1	7.6	7.8	17.6	21.0	10.7	15.3
May 2011	9.6	11.0	0.9	1.6	11.9	12.2	7.6	8.0	17.2	18.7	9.9	10.4
Jun 2011	10.1	11.1	1.2	1.9	11.5	11.7	6.7	7.7	16.8	18.4	10.2	10.6
Jul 2011	10.2	11.1	1.6	2.0	11.7	12.0	7.5	9.1	17.5	19.6	10.3	10.6
Aug 2011	9.9	10.8	1.5	1.9	14.4	16.1	7.4	7.7	17.4	20.7	11.4	12.8

Date	Temperature ($^\circ$C)		Flow rate ($m^3/second$)		Dissolved oxygen (mg/L)		pH (SU)		TP ($\mu g/L$)		SRP ($\mu g/L$)	
	Daily Ave	**Daily Max**	**Daily Ave**	**Daily Max**	**Daily Ave**	**Daily Max**	**Min**	**Max**	**Daily Ave**	**Daily Max**	**Daily Ave**	**Daily Max**
Sep 2011	9.6	10.8	1.3	1.9	13.6	22.9	7.6	7.6	18.1	21.2	10.5	11.2
Oct 2011	9.1	9.7	0.7	1.1	10.2	10.5	7.5	7.7	17.8	19.6	10.7	11.4
Nov 2011	9.0	9.5	0.5	0.7	10.2	10.6	7.2	7.4	17.2	20.5	11.0	11.8
Dec 2011	8.7	9.2	0.5	0.6	10.3	10.5	7.4	7.6	16.6	17.3	10.7	11.8

Notes:

- *In previous reports the maximum daily TP from the LSC effluent for Sep. 2006 was erroneously reported as 170* ($\mu g/L$) *instead of 17* ($\mu g/L$)*. This has been corrected in the present report.*
- *Information regarding QA of these data is available on request.*