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Water Quality of Cayuga Lake
1991-1998

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SUMMARY

The water quality of Cayuga Lake has been studied since the early 1900's when secchi disk readings were first taken. At that time, the trophic state of Cayuga Lake was classified as oligotrophic; that is, nutrient concentrations and primary production were low and transparency high. Water clarity remained approximately the same up through the early 1930's. By the late 1950's, water clarity had decreased enough to classify Cayuga Lake as mesotrophic. Total phosphorus concentrations from the 1960's were well within the mesotrophic range and remained so until the late 1960's. Chl-a concentrations also illustrate the trend toward more productive waters in Cayuga Lake in the mid 1960's through the 1970's. By the late 1970's, the transparency of Cayuga Lake had decreased to a nearly eutrophic value. Based on the sampling done by the Seneca County Soil and Water Conservation District in the 1990s, an improvement in water quality of Cayuga Lake is suggested – at least at the north end where the samples were taken. Summer total phosphorus levels have decreased and perhaps as a result, phytoplankton levels have decreased slightly as indicated by the decrease in chlorophyll levels. However, it should be noted that the increase in transparency and the decrease in phytoplankton levels may well be the result of the high filtering capacity of the invading zebra mussels into Cayuga Lake. The monitoring data do not provide an answer to this question. The trophic status of Cayuga Lake is currently best described as mesotrophic. In conclusion, water quality of Cayuga Lake appears to have improved since the early 1970’s and also within the 1991-1998 period of monitoring by the Seneca County Soil and Water Conservation District.

INTRODUCTION

Cayuga and Seneca Lakes represent a major water resource of central New York State of considerable economic, recreational and aesthetic value. Maintenance of water quality, prevention of further deterioration of water quality and restoration of a lake’s health are major concerns of the public. Monitoring the water quality of Cayuga Lake has continued periodically from the early 1900's to the present. This report reviews data collected by the Seneca County Soil and Water Conservation District during the 1991-1998 period from the north end of Cayuga Lake. The water quality data presented are the result of a new strategy to continually monitor Cayuga Lake. Monitoring, as performed, provides the important function of documenting gradual improvements that may result from restoration efforts and remedial action plans. Similarly, monitoring provides evidence of deterioration of water quality and thus the opportunity for a management response and notification of the public of such changes. By considering nutrient and chlorophyll a concentrations and water clarity measurements, we review the current data from Cayuga Lake using the previous historical measurements of the lake.

METHODS

General:

Cayuga Lake was sampled once a week usually from late June or early July to September from 1991 to 1998 by personnel from the Seneca County Soil and Water Conservation District and by volunteers from Seneca County. All samples collected for water quality analysis were taken from Site #2 (Figure 1) with a Van Dorn water bottle. Secchi disk measurements were taken at six different sites along the center axis of Cayuga Lake. Once samples were taken, they were packed in ice and transported to SUNY College at Brockport for water quality analysis within one day. A subsample was filtered on site for soluble nutrient analysis through a 0.45-µm membrane filter. Parameters analyzed included nitrate + nitrite, total phosphorus (TP), soluble reactive phosphorus (SRP), chlorophyll-a (Chl-a), and turbidity.

Water Chemistry:

Nitrate + Nitrite: Dissolved nitrate + nitrite nitrogen analyses were performed by the automated (Technicon Autoanalyser) cadmium reduction method (APHA 1999).

Total Phosphorus: The persulfate digestion procedure was used prior to analysis by the automated (Technicon autoanalyser) colorimetric ascorbic acid method (APHA 1999).

Turbidity: Turbidity was measured using a Turner nephelometer. The turbidimeter was calibrated with a known standard prior to measurements with routine verifications during analysis.

Soluble Reactive Phosphorus: Sample water was filtered through a 0.45-µm membrane filter. The filtrate was analyzed for orthophosphate using a Technicon Autoanalyzer II

(Technicon Industrial Method No. 15-71W). The formation of a phosphomolybdenum blue complex was read colorimetrically at 880 nm.

Chlorophyll a: Chlorophyll a was measured fluorometrically using a Turner Model 111 Fluorometer. Approximately 800 mL aliqouts were filtered through glass fiber filters and extracted with 90% alkaline acetone. Extracted samples were centrifuged and measured fluorometrically (Wetzel and Likens 1994).

Secchi Disk: The secchi disk depth was determined using a black and white 20-cm disk.

Quality Assurance Internal Quality Control: Multiple sample control charts (APHA 1999) were constructed for each parameter analyzed. A prepared quality control solution was placed in the analysis stream for each sampling date. If the control solution was beyond the set limits of the control chart, corrective action was taken and the samples re-run.

External Quality Control: The Water Chemistry Laboratory at SUNY Brockport is certified through the New York State Department of Health's Environmental Laboratory Approval Program (ELAP - # 11439). This program includes biannual proficiency audits, annual inspections and good laboratory practices documentation of all samples, reagents and equipment. Table 1 is a summary of a proficiency audit.

RESULTS

Soluble Reactive Phosphorus (SRP):

Soluble reactive phosphorus provides information on the amount of phosphate ion present in the water column. Phosphate is the form of phosphorus that is readily taken up by phytoplankton and macrophytes and is generally considered the limiting factor to plant growth in lakes in New York. Since 1991, SRP summer average concentrations ranged from a minimum of 0.9 ± 0.2 µg P/L (mean±S.E.) in 1995 to a maximum of 2.8 ± 0.3 µg P/L in 1993 with an average concentration of 1.9 µg P/L for the study period (Table 2). There were no trends during the study period (Fig. 2).

Total Phosphorus (TP):

Total phosphorus provides an estimate of the total amount of phosphorus potentially available to aquatic plants. TP summer average concentrations ranged from a minimum of 7.4 ± 1.0 µg P/L in 1995 to a maximum of 16.6 ± 1.6 µg P/L in 1993 (Table 2). As with SRP, there were no significant differences in TP concentrations or obvious trends over the study period (Fig. 2). Average total phosphorus concentration for the study period was 11.7 µg P/L.

Chlorophyll-a (Chl-a):

Chlorophyll a provides an estimate of algal abundance in lakes. Generally, algal abundance increases with increasing levels of phosphorus in the water column. In fact, a strong correlation (r=0.82) between TP and Chl-a concentrations was observed which suggests that phosphorus plays a role in controlling algal abundance in Cayuga Lake. Over the study period, Chl-a concentrations were variable and ranged from an average summer minimum of 1.6 ± 0.4 µg/L in 1994 and 1995 to a maximum of 6.3 ± 0.7 µg/L in 1991 with no upward or downward trends (Table 2, Fig. 2). Average concentration for the study period was 4.0 µg/L.

Nitrate (NO_3):

Figure 3 represents yearly average nitrate concentrations in Cayuga Lake from 1991 to 1998. Temporal variability in nitrate concentration was similar to other nutrients and ranged from a minimum of 0.04 ± 0.02 mg N/L in 1995 to a maximum of 0.66 ± 0.06 mg N/L in 1992 (Table 2). Average concentration for the study period was 0.29 mg N/L.

Turbidity:

Figure 4 illustrates yearly average turbidity readings of samples taken from Cayuga Lake from 1992 to 1998 (turbidity was not measured in 1991). Minimum mean yearly turbidity was observed in 1995 at 0.52 ± 0.08 NTU. Maximum yearly turbidity measurements occurred in 1997 at 3.09 ± 1.95 NTU. This resulted from high readings associated with a storm with strong southerly winds that mixed sediments into the water column. Mean annual turbidity for the study period was 1.49 NTU (Table 2).

Secchi Disk (Lake Clarity):

Figures 5a (Sites 1, 2 and 3), b (Site 4), and c (Sites 5 and 6) show monthly average secchi disk readings during the summer months from 1991 to 1998. The data suggest that the transparency or clarity of the lake has increased since 1991. At Sites 1, 2 and 3 transparency progressively increased from less than 0.2m in 1991 to 1995 when the bottom of the lake was consistently observed after July 1995. Similarly, transparency increased by a factor of 100% (2m to 4+m) from June 91 to September 1998 at Sites 4, 5, and 6.

DISCUSSION

A lake's health or water quality is often associated with its trophic status. A lake that is oligotrophic is biologically unproductive with high transparency and low nutrient concentrations while a eutrophic lake is biologically productive with low transparency and high nutrient concentrations. A mesotrophic lake is a lake with characteristics intermediate of oligotrophic and eutrophic. With time, soil particles from the watershed are gradually added to the lake, thus decreasing depth. Nutrients from the watershed are also constantly added, increasing concentrations of limiting nutrients such as phosphorus. Biotic productivity increases with the higher nutrient concentrations, sedimentation of dying plankton increases, and transparency of the lake decreases accordingly. This process is natural and is called eutrophication. However, the actions of man in a lake's watershed can increase the loss of soils and nutrients from the watershed into the lake. This cultural eutrophication accelerates the natural process often leading to deteriorating water quality. Reducing cultural effects by decreasing the rate of eutrophication and improving water quality is the goal of many environmental agencies concerned with the health of lakes.

Phosphorus (Table 3)

Barlow (1969) observed yearly average TP concentration in Cayuga Lake to range between 15 and 20 µg P/L. Peterson (1971) observed TP concentrations with a range of 9.1 to 56.7 µg P/L with a mean of 18 µg P/L during the months of June through August from 1969 to 1971. Oglesby and Schaffner (1979) analyzed TP concentrations in all of the Finger Lakes of New York State and reported a winter (1972-73) TP concentration of 21.1 µg P/L for Cayuga Lake. Epilimnetic total phosphorus concentrations from the late 1960s through the early 1970s were around 20 µg P/L. For the 1991-1998 period, the average TP was 11.7 µg P/L with a range of 7.4 to 16.6 µg P/L. There were no clear trends in total phosphorus concentrations over the 1991 to 1998 period (Fig. 2). However, total phosphorus concentrations from the 1991- 1998 period appear to be lower than in those in the late 1960s and 1970s (Fig. 7).

Chlorophyll-a (Table 4)

Chlorophyll-a concentrations show a notable amount of variation temporally (Figs. 2 and 8). Hamilton (1969) in 1966 studied chlorophyll-a concentrations in Cayuga Lake and found concentrations averaging 5.5 µg/L until July 6th, and a mean of 1.5 µg/L from July 20th through August 18th in the surface waters. In general, values in the 2-4 µg/L range were observed in 1966 and 1968 (Table 4) while annual means as high as 9.2 µg/L were observed in 1972 by Oglesby and Schaffner (1975). Average chlorophyll a concentrations dropped from the high values (>6 µg/L) observed by Oglesby and Schaffner in the late 1960s and early 1970s to an average of 4.0 µg/L for the 1991–1998 period. However, the range of values (1.6 to 6.3 µg /L) for the 1991- 1998 period do bracket the levels observed in the 1970s (Figs. 2 and 8).

Transparency (Secchi Disk)(Table 5)

Our early knowledge of Cayuga Lake’s water quality dates from the early 1900s. Birge and Juday (1921) observed a transparency reading of 6.1 meters in the early 1920s while Burkholder (1931) observed a similar transparency reading (5.6m) in the early 1930s (Table 5). By the early 1950s and into the 1970s, transparency appeared to decrease as the mean range reported by Henson et al. (1961) in the 1950s was 3.5 to 4.5m. By 1991, average values at Sites 5 and 6 were reduced to 1.8m but increased progressively and dramatically over the next six years (Table 5) to 4.7m - a value within the range reported in 1950-52 but not near the historical highs from the early 1900s. In general, transparency within the water column of Cayuga Lake has improved considerably over the past seven years (Fig. 6). This may be the result of reduction of nutrient losses from the watershed. However, the improvement in transparency does correlate with the invasion of zebra mussels (<u>Dreissena</u> <u>polymorpha</u>). Zebra mussels were first observed in 1991 in Cayuga Lake and were widespread throughout the lake by 1993 (Jim Malyj, Personal communication). Zebra mussels are known to actively filter out particles from the water column. In the western basin of Lake Erie, transparency increased after the introduction of zebra mussels (Makarewicz <u>et</u> <u>al</u>. 1999).

Carlson's Trophic Status Index (TSI):

Carlson's TSI is used to assess the trophic state of a given lake by analyzing winter TP concentrations and summer Chl-<u>a</u> concentrations, and by measuring summer secchi disk depth. This index is one of several that can be used to evaluate the trophic status of a lake; that is, what is the overall productivity of the lake. Based on the average Chl-<u>a</u> and summer TP concentrations and secchi disk readings for the entire 1991-1998 period, Carlson's TSI was 42.8 (S.E.=2.1)(Table 2) suggesting a mesotrophic status for the lake. This conclusion is reinforced by considering the general relationship of lake productivity with phosphorus, transparency and chlorophyll (Table 6). Chlorophyll and phosphorus concentrations and transparency readings observed during the 1991-98 period also suggest a mesotrophic status for Cayuga Lake. This is particularly evident for epilimnetic total phosphorus.

ACKNOWLEDGEMENTS

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Table 1. Results of the semi-annual New York State Environmental Laboratory Assurance Program (ELAP Lab # 11439, SUNY Brockport) Non-Potable Water Chemistry Proficiency Test, July 1998. Score Definition: 4 (Highest) = Satisfactory, 3 = Marginal, 2 = Poor, 1 = Unsatisfactory.

Analyte	**Mean/Target**	**Result**	**Score**
Residue			
Solids, Total Suspended	54.3 mg/L	53.3 mg/L	4
Hydrogen Ion (pH)			
Hydrogen Ion (pH)	4.63	4.69	4
Organic Nutrients			
Kjeldahl Nitrogen, Total	9.00 mg/L	8.92 mg/L	4
Phosphorus, Total	3.46 mg/L	3.54 mg/L	4
Total Alkalinity			
Alkalinity	429 mg/L $CaCO_3$	438 mg/L $CaCO_3$	4
Inorganic Nutrients			
Nitrate (as N)	7.08 mg/L as N	6.62 mg/L as N	4
Orthophosphate (as P)	1.92 mg/L as P	1.67 mg/L as P	3
Minerals			
Chloride	74.8 mg/L	74.0 mg/L	4
Wastewater Metals I and II			
Calcium, Total	51.5 mg/L	53.7 mg/L	4
Magnesium, Total	5.78 mg/L	6.02 mg/L	4
Potassium, Total	10.7 mg/L	11.3 mg/L	4
Sodium, Total	40.0 mg/L	39.6 mg/L	4

Table 2. Average summer values for total phosphorus (TP), nitrate, soluble reactive phosphorus (SRP), chlorophyll a (Chl a), turbidity (Turb) and transparency (secchi disk). Values are the average for Site 2. The standard error is in parentheses. TSI equals Carlson's Trophic Status Index (TSI). *Not measured.

Cayuga Lake Yearly Averages (Site 2)						
Year	**Nitrate (mg N/L)**	**SRP (µg P/L)**	**TP (µg P/L)**	**Chl-a (µg/L)**	**Turb (NTU)**	**Secchi Disk (m)**
91	0.18 (0.08)	1.9 (0.4)	15.5 (2.0)	6.3 (0.7)	*	1.6 (.2)
92	0.66 (0.06)	2.4 (.05)	9.9 (1.1)	3.5 (0.3)	0.67 (0.11)	2.9 (.3)
93	0.40 (0.12)	2.8 (0.3)	16.6 (1.6)	5.3 (1.0)	1.70 (0.22)	2.0 (.07)
94	0.19 (0.08)	1.9 (0.5)	9.1 (2.5)	1.6 (0.4)	1.47 (0.55)	BOTTOM (0)
95	0.04 (0.02)	0.9 (0.2)	7.4 (1.0)	1.6 (0.2)	0.52 (0.08)	BOTTOM (0)
96	0.57 (0.36)	2.0 (0.5)	13.1 (1.4)	6.0 (1.0)	1.36 (0.25)	2.7 (.2)
97	0.13 (0.07)	1.2 (0.4)	10.4 (0.7)	2.0 (0.3)	3.09 (1.95)	BOTTOM (0)
98	0.17 (0.07)	2.1 (0.9)	11.5 (3.5)	5.8 (1.4)	1.60 (0.37)	BOTTOM (0)
Average	0.29	1.9	11.7	4.0	1.49	2.3 (.4)
			TSI	42.8 (2.1)		48.5 (2.0)

Table 3. Historical comparisons of total phosphorus (µg P/L) concentrations in Cayuga Lake.

Year	**Mean**	**Range**	**Period**	**Author**
1968	20	15-20	Summer	Barlow (1969)
1969-71	18	9.1- 56.7	June –August	Peterson (1971)
1972-73	21.1	NA	Winter	Oglesby and Schaffner (1979)
1991-1998	11.7	7.4-16.6	June-September	This study

Table 4. Historical comparisons of chlorophyll a (µg/L) concentrations in Cayuga Lake. NA=Not available.

Year	**Mean**	**Range**	**Period**	**Author**
1966	2.82	1.5- 5.5	May-August	Hamilton (1969)
1968	3.9	NA	Epilimnion, summer	Barlow (1969)
1969-1971	4.0	NA	Euphotic zone	Peterson (1971)
1968	6.1	NA	Upper 10m	Oglesby and Schaffener (1975)
1972	9.2	NA	Upper 10m	Oglesby and Schaffener (1975)
1991-1998	4.0	1.6-6.3	June-September	This Study

Table 5. Historical comparisons of transparency (secchi disk) in Cayuga Lake. Data for 1991–1998 is for Sites 5 and 6. NA=Not available.

Year	**Mean**	**Range**	**Period**	**Author**
1918	6.1	-	Week in August and September	Birge and Juday (1921)
1930	5.6	4.0–7.0	Summer	Burkholder (1931)
1950-52	3.5-4.5	1.7-7.0	Summer	Henson et al. (1961)
1970-74	NA	2.0-4.5	June-September	Bloomfield (1978)
1991	1.8	1.2-2.8	June-September	This study
1993	2.4	1.5-3.7	June-September	This study
1995	3.9	2.2-6.0	June-September	This study
1997	4.7	4.6-5.0	June-September	This study

Table 6. General relationship of lake productivity in relation to phosphorus, nitrogen, transparency and chlorophyll a. Adapted from Wetzel (1983).

	Epilimnetic Total Phosphorus (µg P/L)	**Annual Total Phosphorus (µg P/L)**	**Chl a (µg/L)**	**Secchi Disk (m)**
Oligotrophic	5-10	3.0-17.7	0.3- 4.5	5.4-28.3
Mesotrophic	10-30	10.9-95.6	3-11.0	1.5-8.1
Eutrophic	30-100	16.0-386	3-78.0	0.8-7.0
Hypereutrophic	>100	750-1200	100-150	0.4-0.5
Cayuga Lake (91-98)	11.7*	NA	4.0*	5.0**

*Average for all sites from 91 to 98

**Average for Site 5 in 1998

Figure 1. Location of sampling sites on Cayuga Lake, 1991-1998.

Figure 5. Average monthly transparency (secchi disk) measurements for Cayuga Lake. 5a: Sites 1, 2, and 3. 5b: Site 4 on the middle graph. 5c: Sites 5 and 6. All error bars represent plus or minus the standard error.

Figure 3. Average nitrate concentrations in Cayuga Lake from 1991 to 1998. The error bars correspond to the standard error.

Figure 4. Average turbidity readings in Cayuga Lake for each summer from 1991 to 1998. The error bars correspond to the standard error.

Figure 2. Average total phosphorus, soluble reactive phosphorus and chlorophyll a concentrations, Cayuga Lake. The error bars correspond to the standard error. The black bar represents TP concentrations, the gray bar represents SRP concentrations, and the white bar represents Chl-a concentrations.

Figure 6. Historical transparency values for Cayuga Lake. Error bars represent the range of values observed. Sources of these data are listed in Table 5.

Figure 7. Historical total phosphorus values for Cayuga Lake. Error bars represent the range of values observed. Sources of the data are listed in Table 3.

Figure 8. Historical chlorophyll a concentrations for Cayuga Lake. Error bars represent the range of values observed. Sources of the data are listed in Table 3.