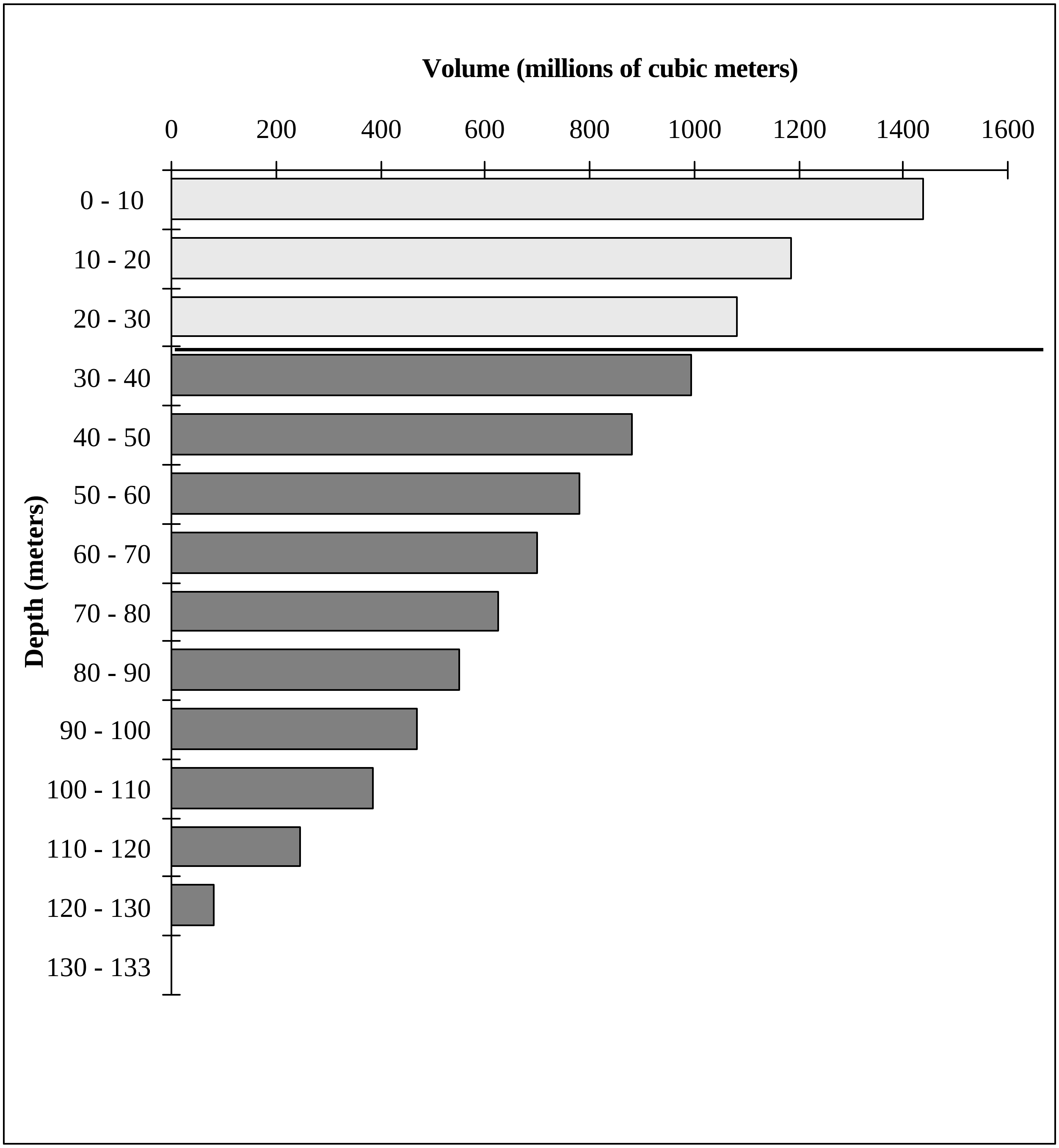
4.3 Lake Characteristics

4.3.1 Physical Characteristics of Cayuga Lake

4.3.1.1 Bathymetry

Cayuga Lake is the second largest of New York's Finger Lakes based on water volume and surface area. It is situated in a glacially carved valley at the northern edge of the Appalachian Uplands physiographic region of New York State. Water surface elevation is 116.4 m (382 ft.) above mean sea level and maximum depth is 132 m (435 ft.); the lake bottom extends well below sea level. The great depth of Cayuga Lake, second only to Seneca among the Finger Lakes, is attributed to rock scour from glaciation. The Cayuga Lake basin appears to have originated as a preglacial stream valley that was overdeepened by glacial erosion. Based on seismic surveys, bedrock may lie as much as 242 m (794 ft.) below sea level, and the rock basin has been infilled by as much as 226 m (741 ft.) of glacial and postglacial sediment (Mullins 1998).



Note: Depth of epilimnion is 12-15 meters by late August. Size of metalimnion (which includes the thermocline) is variable.
m^3: cubic meters

FIGURE 4.3.1
VOLUME OF CAYUGA LAKE WITH DEPTH,
LATE SUMMER CONDITIONS

Morphometric statistics for the Lake are summarized in Oglesby (1978). The Cayuga Lake basin is long and narrow, extending approximately 60 km (38 miles) from Ithaca in the southern basin to the Seneca River outlet. Mean width is 2.8 km (1.75 miles). At its widest point, Cayuga Lake is 5.6 km (3.5 miles) across. Volume is estimated at 9380 million cubic meters (331,080 million cubic ft.) at a lake elevation of 116 m. Surface area is 172.1 sq. km. (66.4 sq. miles).

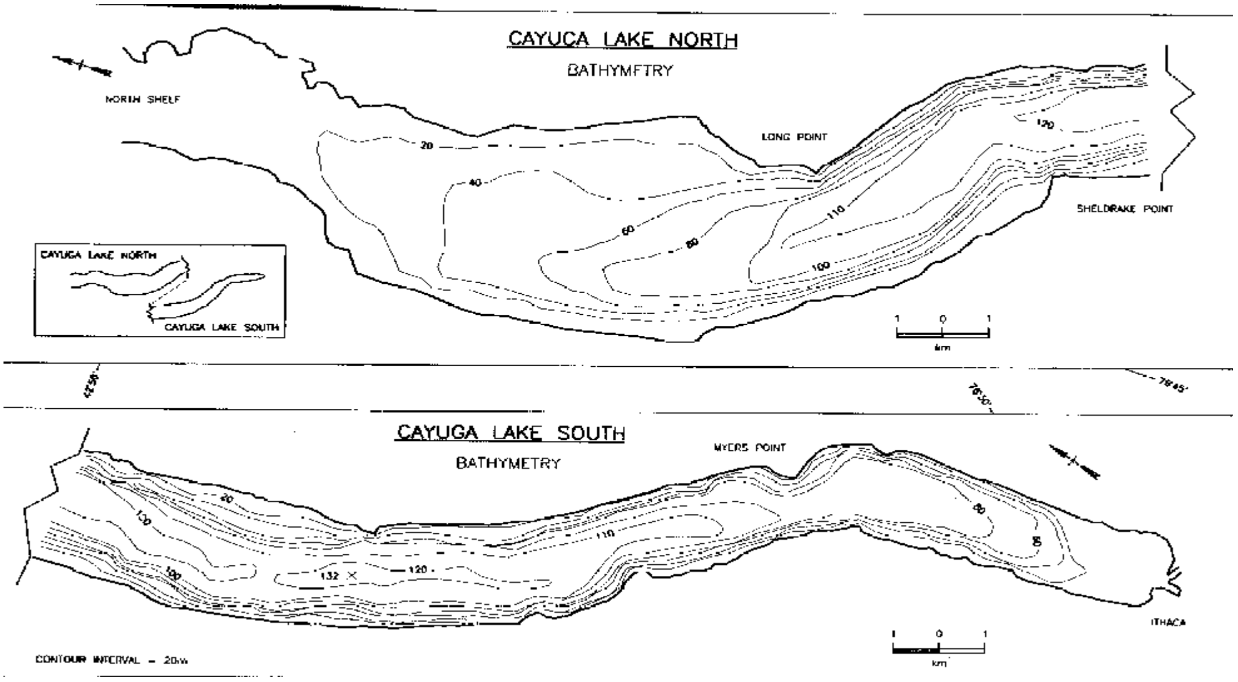


Figure 4.3.2 Bathymetric map of Cayuga Lake
Source: Edward Hinchey

Bathymetric data (depth and volume) for Cayuga Lake were first reported by Birge and Juday in 1912. These investigators used a base map surveyed by Cornell University engineering students and measured water depth with a steel sounding wire. Position of each depth measurement was controlled by transit instruments on shore and a sextant in the boat. Results of this early survey are plotted in Figure 4.3.1, which displays the water volume associated with each depth stratum. Note the large volume of deep water in Cayuga Lake. Median depth of the Lake is 40 meters (131 ft.); mean depth is 54.5 meters (179 ft.).

Between 1986 and 1988, Henry Mullins of Syracuse University and colleagues collected high-resolution seismic reflection profiles of the major Finger Lakes, including Cayuga Lake. The seismic reflection profiles allowed the researchers to quantify and map water depth, total sediment thickness, and depth to bedrock. They identified a sequence of six depositional events associated with the retreat of the Laurentide ice sheet that transported large volumes of fine-grained sediments into the Finger Lakes basins. The sediment deposits created the relatively flat lake bottom in the V-shaped basin.

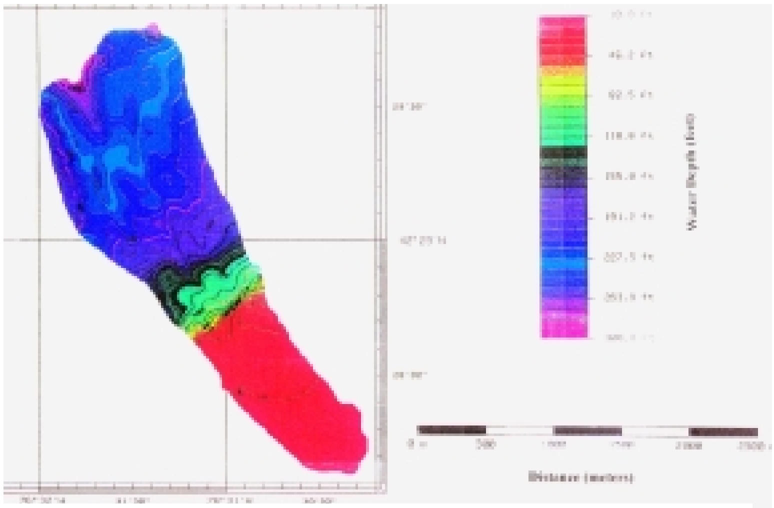


Figure 4.3.3. Lake Bottom

A bathymetric map of Cayuga Lake indicates that the lake is relatively shallow at its northern end, deepens towards the south and has a relatively small, shallow shelf at its southern end (Figure 4.3.2). The deepest part of Cayuga Lake is a trough extending north from Myers Point to Long Point.

A detailed bathymetric survey of southern Cayuga Lake was completed in 1996 to support design of the pipeline route for the Lake Source Cooling (LSC) intake. This survey was completed using differential-corrected Global Positioning System (GPS) technology coupled with side-scan sonar and hydroacoustics to map the lake bottom. Results are displayed in Figure 4.3.3.

4.3.1.2 Hydraulic Retention Time

The hydraulic retention time (water residence time) of a lake is defined as the average time water remains in the lake. In Cayuga Lake, various investigators have estimated hydraulic retention time between 5 – 12 years. This range in estimation reflects natural variability in weather conditions as well as the methodology of the estimate.

Several methods are used to estimate water residence time of a lake. The most accurate approach is to measure all the flows into and from a lake. Only in rare cases is this level of detail available. The most common method of calculating residence time is to assign a unit runoff coefficient to the watershed and estimate the volume of water entering the lake, then divide the volume of influent water by the lake volume. Recently, investigators from USGS have used tritium levels to estimate retention time of the Finger Lakes.

The work of Likens (1974) remains the most direct approach to estimating the water residence time in Cayuga Lake. He calculated the hydrologic budget for the period of August 1970 through July 1971 based on detailed measurements of precipitation, streamflow, discharge, and change in water surface elevation. Likens calculated that 18% of the Lake’s volume flowed out to the Seneca River; which translated to an average hydraulic retention time of 5.1 years (100% lake volume / 18% per year =5.1years). However, this calculation included the inflow and outflow of the Seneca River, which enters Cayuga Lake close to the lake outlet. It is reasonable to assume that river waters do not mix south throughout the long lake. If the contribution of the Seneca River were excluded, the hydraulic retention time based on 1970 – 1971 data would be estimated at 7.4 years.

These values are about 50% smaller than hydraulic retention time estimates compiled by Wright (1969). The study period in 1970 – 1971 was relatively wet, which affects the estimates. Likens emphasized the theoretical nature of the flushing rate estimates, which are based on the total volume of the lake as if mixing were complete throughout the year. These calculations do not account for seasonal differences in hydrologic input, nor do they consider current patterns in the lake.

Oglesby (1978) estimated that the average hydraulic retention time of Cayuga Lake was 12.8 years, with a range of 8.1 to 24.1 years, based on 36 years of record of inflow and outflow data, excluding contribution of the Seneca River. Another estimate of Cayuga Lake’s hydraulic retention time was prepared by Schaffner and Oglesby (1978) using detailed hydrologic calculations from Owasco Lake and assuming that unit runoff throughout the Finger Lakes was proportional to watershed size. This method yielded a retention time of 9.5 years. USGS estimated Cayuga Lake’s hydraulic retention time at 10 years based on statewide runoff data (Michel and Kraemer 1995).

Investigators from USGS have used tritium, a radioactive isotope of hydrogen, to estimate hydraulic retention time in the Finger Lakes (Michel and Kraemer 1995). The concentration of tritium in rainfall peaked in the mid-1960’s during atmospheric weapons testing. Tritium concentration in surface waters has decreased since this time period due to radioactive decay, mixing with older water masses, and dilution with rainfall with lower tritium concentration. Michel and Kraemer used this method to estimate hydraulic retention time of Cayuga Lake as 10 years. These results confirm that groundwater inflow to the lake is minimal.

4.3.1.3 Heat Budget

The temperature of Cayuga Lake reflects the net result of heat inputs, losses, and exchange. The sun is the ultimate natural source of heat to the lake, heating the water through shortwave solar radiation, longwave solar radiation and conduction of heat from the atmosphere to the water. Other heat inputs include municipal or industrial sources such as noncontact cooling water. There have been several attempts to estimate an annual heat budget for Cayuga Lake. An annual heat budget is an accounting of the total heat entering a lake between dates of its least and greatest heat content. Cayuga Lake contains the least heat in March and the greatest in August.

Early in the 20th century, Birge and Juday estimated a heat budget for Cayuga Lake based on isolated temperature data collected in winter and summer. Henson used this approach in the early 1950's, with similar findings. Two subsequent heat budgets were drawn using models of lakewide temperature and circulation. Both models were developed to quantify the thermal impacts of a proposed industrial cooling water discharge to Cayuga Lake. Sunderman et al (1968) developed a model of lake temperature as part of the environmental assessment of the Bell Station, and J. E. Edinger Associates, Inc. (1997) applied their model CE-QUAL-W2 to quantify potential lake-wide thermal impacts of Cornell Lake Source Cooling. The four estimated heat budgets are summarized in Table 4.3-1.

Table 4.3.1. Heat Budgets developed for Cayuga Lake

Investigator	Years Used as Basis of Calculation	Annual Heat Budget *	
		(Btu/ft^2)	(J/m^2)
Birge and Juday	1910, 1911	144,000	1.6E+09
Henson	1950 -1953	137,000	1.6E+09
Sunderam et al.	1968	185,000	2.1E+09
John E. Edinger Associates, Inc.	1986 – 1995		
	Mean	123,000	1.4E+09
	Minimum	115,000	1.3E+09
	Maximum	130,000	1.5E+09

Source: Stearns & Wheler 1997

* The annual heat budget is defined as the gain in heat storage in Cayuga Lake from the time of minimum heat storage (March) to the time of maximum heat storage (August).

Btu/ft^2 British thermal units per square ft.
J/m^2 joules per square meter

The annual heat budgets demonstrate periods during which the lake gains and loses heat. Monthly heat storage data (summarized in Table 4.3-2) indicate that, in an average year, the lake gains heat from March through mid-August and loses heat the remainder of the year. During the heating season, Cayuga Lake gains an average of 2.3 E+07 joules per square meter of lake surface per day (2,000 Btu per square foot per day). The net heat energy enters the lake surface primarily from solar radiation and is distributed through the water column by currents, seiche oscillations, and internal waves. On a long-term basis, the amount of heat gained by the lake each year is lost to the atmosphere during the prolonged period of winter mixing. There may, however, be disequilibrium in any given 12-month period.

With the exception of the Birge and Juday calculations, the heat budgets include the input from AES-Cayuga (formerly known as Milliken Station). AES Cayuga is a 387-megawatt (MW) coal-fired power plant located on the east shore of Cayuga Lake approximately 13 miles north of Ithaca. Cooling water is withdrawn at a depth of 14 m (46 ft.) through an intake located 183 m (600 ft.) offshore. The plant is permitted to reject heat at a maximum rate of 1.3 E+09 Btu/hr (2.42 watts/m^2-day) based on its permitted flow of 169,000 gallons/minute and an 8.3 °C (15 °F) heat rise through the condensers. On a cumulative annual basis, AES Cayuga is permitted to reject heat at 1.1 E+13 Btu/yr. AES Cayuga contributes approximately 15 Btu/ft^2/day, which is less than 1% of the natural heat gain (2,000 Btu/ft^2/day)

Table 4.3.2 Monthly Heat Storage in Cayuga Lake per Unit Surface Area			
Month	**Average Heat Content (joules/m^2)**	**Minimum Heat Content (joules/m^2)**	**Maximum Heat Content (joules/m^2)**
January	6.69E+08	5.82E+08	8.01E+08
February	5.39E+08	4.74E+08	6.29E+08
March	5.33E+08	4.16E+08	6.12E+08
April	7.01E+08	5.28E+08	7.86E+08
May	1.08E+09	9.48E+08	1.18E+09
June	1.50E+09	1.37E+09	1.63E+09
July	1.81E+09	1.68E+09	1.88E+09
August	1.93E+09	1.81E+09	1.98E+09
September	1.90E+09	1.85E+09	1.94E+09
October	1.69E+09	1.64E+09	1.75E+09
November	1.37E+09	1.31E+09	1.48E+09
December	9.89E+08	8.82E+08	1.12E+09
Source: JEEAI, as presented in Stearns & Wheler 1997			

The JEEAI heat budget also includes heat rejected from Cornell’s Lake Source Cooling project (LSC) which began operation in summer 2000. The LSC project is a second source of noncontact cooling water to Cayuga Lake. Water for LSC is drawn from a depth of 76 m (250 ft) through an intake located approximately 2 miles north of Stewart Park and circulated through a shoreline heat exchange facility. Plate and frame heat exchangers in this facility transfer chill from the lake water to a closed loop of water circulating from the Cornell University campus. Warmed water is returned to southern Cayuga Lake through a submerged multiport diffuser located approximately 500 ft offshore. Temperature of the return flow is relatively constant throughout the year as compared to the temperature of the shallow southern basin where the flow is returned. Temperature of the return flow will be 8.9 °C in winter and 13.3 °C in summer. Volume of the LSC return flow fluctuates in response to demand for campus cooling. The plate and frame heat exchanger is designed so that the circulating lake water system will never mix with the closed-loop campus chilled water system.

The two noncontact cooling water systems are compared in Table 4.3-3. The LSC system will add a daily maximum of 0.434 watts/m^2 to the lake surface during peak summer operating conditions and 0.07 watts/m^2 during winter when demand for campus cooling will be very low. As a basis for comparison, the sun can deliver 400 watts/m^2 to the lake surface during a clear summer day. The daily heat input from LSC is equivalent to heat from approximately 9 seconds of sunlight in summer (assuming 14 hours of sunlight) and 20 seconds during winter (assuming 9 hours of sunlight). On an annual basis, the LSC system represents approximately 8 percent of the heat load (to Cayuga Lake) from AES-Cayuga.

The effects of the LSC project on Cayuga Lake’s thermal regime were examined at two scales: nearfield (in the region of the outfall) and lakewide. Near-field impacts were projected using the model CORMIX2, which simulates mixing of the return flow from the heat exchangers with ambient lake water (Jirka et al. 1996). The model projects dimensions of a “plume” of cooler or warmer water created in the region of the submerged outfall diffuser. The two-dimensional hydrothermal model CE-QUAL-W2 was used to simulate effects of LSC on Cayuga Lake’s seasonal temperature structure. Site-specific data were used to define parameters, initialize the models, and (in the case of the lakewide model) verify model performance by comparing predicted and observed temperature profiles.

Table 4.3.3. Comparison of Heat Loads, Noncontact Cooling Water Discharges to Cayuga Lake

Permit Conditions	**Cornell LSC**	**AES-Cayuga (*Formerly known as Milliken Station)***
Heat input to Lake (W/m^2-day)		
Summer	0.434	2.42
Winter	0.07	
Btu/hr (peak summer)	0.24×10^{9}	1.3×10^{9}
Btu/yr (cumulative)	0.09×10^{13}	1.1×10^{13}
Average Heat Rejection (MW$_{thermal}$)	29.4	387
Depth of Intake	76 m (250 ft)	13.7 m (45 ft)
Depth of Return Flow/Distance Offshore of Outfall	2.7 m (9 ft)/150m (500 ft)	**Surface**/At Shoreline
Recirculated Volume (peak flow)	2 m^3/sec (32,000 gpm)	10.6 m^3/sec (169,000 gpm)
Temperature of return flow	Ambient plus 7 – 15 degrees F (return flow temperature relatively constant at 48 – 56 °F)	Ambient plus 15 degrees F (return flow temperature is variable due to fluctuating temperature of intake water)
Recirculated volume (annual average flow)	1.2 m^3/sec (19,200 gpm)	10.6 m^3/sec (169,000 gpm)

W/m^2-day	Watts per square meter per day
Btu/hr	British thermalunits per hour
gpm	Gallons per minute

Source: Cornell Utilities for LSC
NYSEG for Millken

The CORMIX2 model projections assume that the LSC facility operates at its maximum permit capacity, 24 hours each day. In fact, flows through the system will vary in response to the demand for campus cooling. Actual flows will always be less. Projections indicate that the LSC return flow will have minimal impact on water temperature in southern Cayuga Lake (Stearns & Wheler 1997). Water temperatures are projected to return to within 2 °C of background within a short distance of the outfall diffuser. During most months, temperature returns to within 0.5 °C of ambient within several hundred meters of the outfall. The largest plume (a plume of cooler water) is projected to occur in August when the gradient between the temperature of the return flow and background conditions is greatest.

The lakewide model was used to simulate temperature regime, which included stratification and ice cover, over the ten-year period from 1986 – 1995. To apply CE-QUAL-W2, bathymetry was mapped onto a grid dividing Cayuga Lake into segments in two dimensions: with depth (vertical) and from south to north (longitudinal). The grid, with a total of 1103 model cells, was designed to provide more spatial resolution in the southern end and in the epilimnion. A continuous simulation of water temperature over the ten-year period was run using site-specific inputs of meteorological conditions and streamflow.

Model projections for 1995, the final year of the continuous simulation, were compared with field measurements recorded at 15-minute intervals by a series of thermistors suspended at 10-m intervals from the lake's surface to 70-

m depth. The string of thermistors was placed in the region of the proposed intake for LSC; predicted water temperature in this model segment was used as the basis for comparison. The model performed well, reproducing both the short-term variability associated with the lake's prominent seiches as well as the longer-term development of thermal structure. Root mean square (RMS) difference between predicted and observed temperature was always less than 2.4 $^{\text{o}}$C; 55% of RMS differences were less than 1 $^{\text{o}}$C.

Once model performance was established, it was used to simulate 10 years of thermal behavior with the LSC system online. This 10-year simulation period also provided an opportunity to examine whether there would be any thermal impacts that might carry over from year to year. Results indicate that lakewide impacts of LSC will be negligible. The maximum projected changes in water temperature are small (on the order of 0.08 $^{\text{o}}$C) and well below natural spatial and temporal variations. These subtle changes in water temperature are projected to occur in the region of the LSC intake. The greatest temperature changes are projected for shallow waters, and effects will be greatest in the winter. The project is projected to have no impact on the duration of stratification or ice cover.

Both the nearfield and lakewide models project that circulation of water and addition of heat by LSC will only slightly affect temperature in a very limited region of the lake. These temperature changes are well within the natural variability of the lake. Heat added to the lake will be lost to the atmosphere each winter during the prolonged period of complete mixing typical from December through May. There is projected to be no discernible impact on the spawning, nursery or migratory habitat for lake fishes and other aquatic life.

The potential impact of the Lake Source Cooling project on the phosphorus budget of southern Cayuga Lake has been an issue of concern to the community. Additional discussion of this issue is included in Sections 4.2.4 (permitted discharges) and 4.3.2.2 (materials budget).

4.3.1.4 Stratification and Mixing

Deep lakes at temperate latitudes develop relatively predictable patterns of water temperature each year. Water temperatures vary with depth in response to seasonal changes in atmospheric temperatures and radiant heating. There are significant differences in the water temperature of Cayuga Lake during the stratified period (June through November), in both horizontal and vertical dimensions. Differences in the vertical dimension are pronounced, due to solar radiation to the lake surface, wind patterns, poor heat conductance of water, and depth and morphometry of the lake basin. Differences in the horizontal dimension are present, although less evident, due to tributary inflows, effluent discharges, return of noncontact cooling water, and localized microclimatic differences (Stearns & Wheler 1997).

Considering winter as the beginning of the annual cycle, Cayuga Lake water temperature and density are relatively uniform throughout the water column. Water reaches its maximum density at 4 °C (39 °F). Without density stratification, winds are able to mix the lake waters from top to bottom, north to south.

As the sun's energy increases in spring, the lake gains heat and the upper waters begin to warm. Heating causes the water to expand and warmer less dense water floats on top of the cooler water. More work is needed for winds to overcome density stratification and mix warmer water throughout the water column. Depending on meteorological conditions (in particular, solar radiation and wind) Cayuga Lake alternates between isothermal and weakly stratified conditions.

By June of a typical year, Cayuga Lake waters stratify into the three layers associated with classic thermal stratification: warm upper waters (epilimnion), cool lower waters (hypolimnion) and a transition layer between the two (metalimnion, which includes the thermocline). The thermocline is defined as the plane in the metalimnion exhibiting maximum rate of change in temperature with depth. Density differences during stratification are strong enough to impede wind-induced mixing between the epilimnion and hypolimnion; the hypolimnion remains isolated from the atmosphere. The extent of mixing in the spring influences the temperature of the hypolimnion for the rest of the year. In some years, the lake warms quickly and lower waters are isolated relatively early, leading to colder temperature in the hypolimnion. In years with cool, windy springs the lake stratifies later and the temperature of the bottom waters is warmer. The temperature of the hypolimnion varies between 4.1 °C and 5.5 °C (Oglesby, 1978).

Detailed thermal measurements of the hypolimnion obtained between 1994 – 1996 were consistent with this reported range (Table 4.3.4).

Table 4.3.4. Water Temperature in Hypolimnion, Cayuga Lake

	1994	1995	1996
Depth	60 m	70 m	70 m
Period of Measurement	September - December	May - November	May - November
Mean Temp °C (°F)	4.55 (40.2)	5.0 (41)	4.3 (39.7)
Maximum Temp °C (°F)	5.97 (42.7)	5.9 (42.6)	5.5 (41.9)
Standard Deviation	0.22	0.48	0.57

Source: Stearns & Wheler 1997

By August, Cayuga Lake ceases to gain heat and the waters begin to cool. The cooling process is manifested in a steady deepening of the epilimnion and gradual decrease in its temperature. As the epilimnion cools, the metalimnion warms due to wind-induced mixing of warmer surface waters deeper into the lake. Heat loss continues through the fall. Eventually, the temperature of the upper water cools to the temperature of the hypolimnion, and thermal stratification breaks down. There is no density impediment to complete mixing of the lake by winds. During most winters Cayuga Lake remains well mixed and essentially isothermal; stratification is rare and transient.

The annual thermal cycle of Cayuga Lake is illustrated in Figure 4.3.4. This is a plot of water temperature recorded every 15 minutes at 10-m depth intervals in southern Cayuga Lake. Note that on May 1, 1995 there was very little temperature difference between the depths; temperature varied from 4 – 7 °C. Warming of the upper waters is evident as the summer progressed. Water temperature at the surface was above 26°C by July, while the temperature below 50 – 60 meters remained relatively constant. Cooling was evident after August. In the late fall, distinctions between the water layers broke down as cooler water mixed deeper into the lake (Stearns & Wheler 1997)

4.3.1.5 Hydrodynamic Motions (Currents, Seiches and Waves)

In Cayuga Lake, water moves primarily in response to winds. The long fetch of the lake and the steep-sided valley combine to channel winds down the lake surface. Wind action on the lake's surface causes circulation and mixing of the lake water. Three types of hydrodynamic motions are evident in response to the wind-induced turbulence created at the water surface: wind-induced drift current, internal seiche oscillations, and internal waves (Stearns & Wheler 1997).

Wind-induced drift current is created by wind blowing over the water surface, moving surface water in the direction of the wind at a rate two to three percent of the wind speed. A return current flows beneath the water surface in the direction opposite the wind. During unstratified conditions, the return current may be found at any depth in the water column.

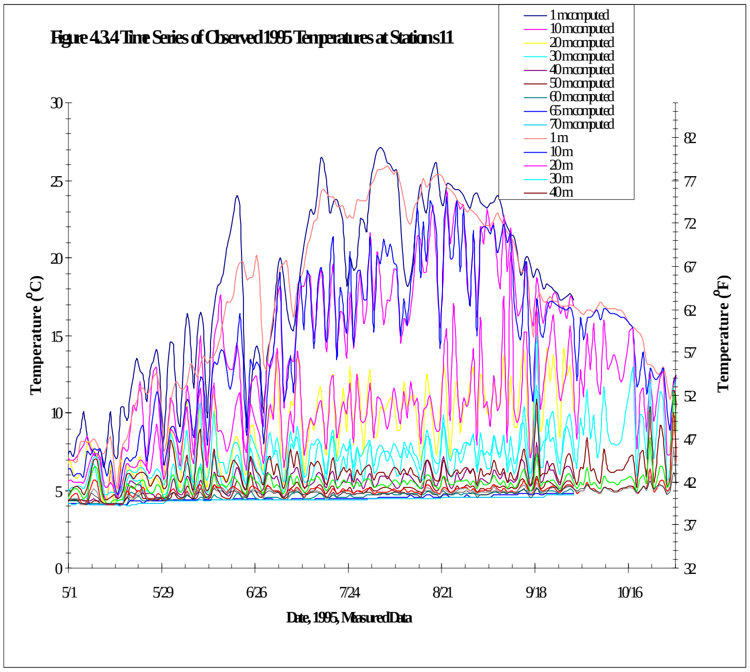


Figure 4.3.4 Time Series of Observed 1995 Temperatures at Stations 11

During stratified conditions, the return flow is relatively shallow, restricted to the upper waters and metalimnion. The return flow moves at its highest velocity, half the velocity of the surface flow (one to one and one-half percent of wind speed), at the depth of the thermocline (Sunderam et al. 1969).

As the wind-induced drift current moves water in the direction of the wind, a slight tilt in the water surface is created. This tilt deepens the epilimnion and causes a slight depression in the metalimnion. In response, the metalimnion at the opposite end of the lake tilts upward. The tilt remains stable as long as the wind maintains its velocity and direction. When the wind stops or changes, the force maintaining the tilt is removed, causing the water to rock (oscillate) in the lake basin. These oscillations are called seiches.

Amplitude of the seiche oscillation in Cayuga Lake increases linearly towards the northern and southern ends of the lake. The effect of seiche activity on the lake's thermal structure is evident in Figure 4.3.4. Data measured at 10 and 20 meters show a pronounced periodicity in temperature. Note how the oscillations in temperature are dampened as the lake water deepens; only rarely are the temperature fluctuations so prominent in the shallow water evident at depths below 50 meters. Fluctuations in temperature of deeper water are more evident during fall when thermal stratification is weakening.

The third type of water motion in Cayuga Lake is the progressive internal wave, where all water moves through the same distance, differing only in phase. These waves are created by irregularities in the lake bottom profile or short-term atmospheric disturbances. Sunderam et al. (1969) reported the presence of internal waves in Cayuga Lake with a short period (5 minutes) during stratified conditions.

Two investigations of lake currents have been completed in recent years. As part of an environmental analysis of relocating the outfall of the Ithaca Area Wastewater Treatment Plant from Cayuga Inlet to southern Cayuga Lake, Dr. William Ahrnsbrak of Hobart William Smith Colleges installed a current meter near the proposed location. For the period between May – September 1985 lake currents in this region were very slow. The mean scalar current speed was 2.12 cm/sec. More than 50% of the observations had current speed less than 2 cm/sec and more than 80% of the observations had current speed less than 5 cm/sec (Ahrnsbrak 1986).

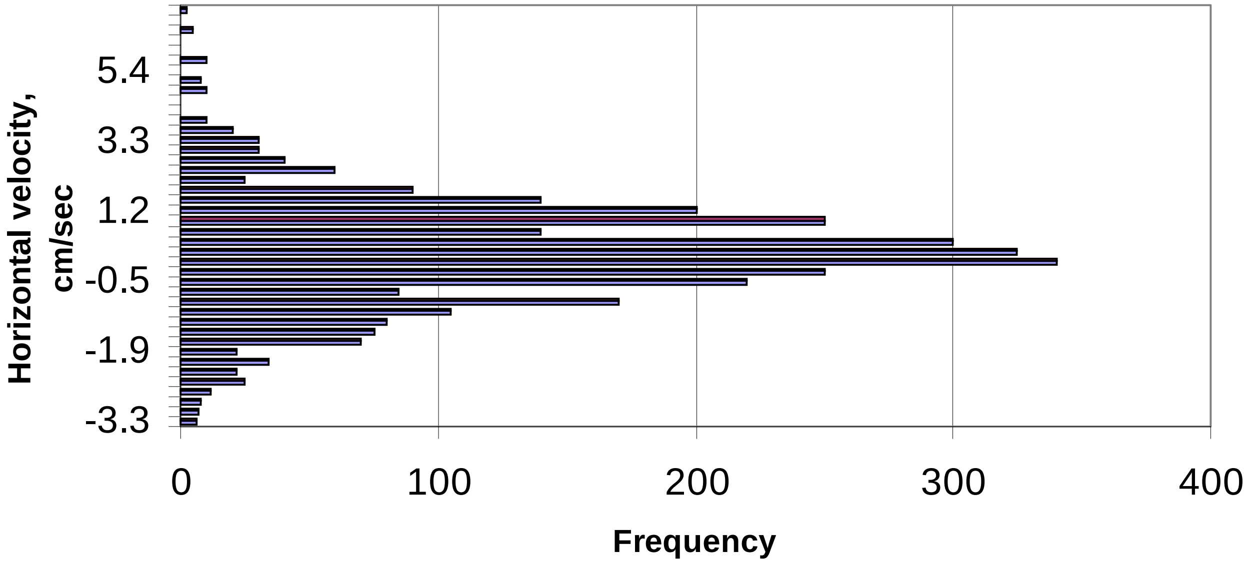
The current meter deployed in southern Cayuga Lake recorded water temperature as well. There were significant fluctuations in water temperature in southern Cayuga Lake that appear to be associated with movement of much colder water from deeper in the lake. Ahrnsbrak (1986) concluded that these incursions of lake water probably represent fairly complete flushing of the shallow southern lake basin. Based on the detailed temperature data collected in 1995, seiche activity is the likely explanation for the periodic abrupt changes in water temperature.

The second effort to quantify currents in Cayuga Lake was made as part of the environmental impact assessment and design phase of the LSC project. John E. Edinger Associates Inc. (JEEAI) applied the hydrodynamic model CE-QUAL-W2 to Cayuga Lake to examine any potential changes in the lake's temperature, mixing, or stratification. The model is constructed by dividing Cayuga Lake into a series of grid cells and tracking the transfer of water and heat between the cells. A ten-year simulation was run using site-specific streamflow and meteorological data from 1986 – 1995. Model performance was verified using the continuous 1995 temperature data measured in Cayuga Lake. Model accuracy for Cayuga Lake was confirmed through statistical comparisons of predicted and observed temperature data (Stearns & Wheler 1997).

Results of the hydrodynamic model can also be used to examine current velocity in each grid cell. LSC design engineers were interested in current velocity near the lake bottom along the route of the intake pipeline, to calculate the amount of anchoring required. Project scientists were interested in near-bottom currents in the region of the LSC intake to estimate potential for scour and entrainment of aquatic organisms. Results of the model simulation indicate that current velocity in the region of the LSC intake is on the order of 1.5 – 1.8 cm/sec. Higher velocities (in the range of 6 – 7 cm/sec) are typically northward (towards the lake outlet). A histogram of current velocity near the lake bottom at a depth of 75 m as predicted by the JEEAI model is included as Figure 4.3.5. Note that positive values are towards the north and negative values are towards the south.

Figure 4.3.5 Histogram of current velocity at LSC intake depth and location

{ based on simulation using CE-QUAL-W2, JEEAI}



4.3.1.6 Light Penetration

Light penetration through the water column is one of the most important physical factors affecting distribution and abundance of phytoplankton and macrophytes (rooted aquatic plants and algae). Materials dissolved and suspended in water act to absorb and scatter incident radiation. As reported in Oglesby (1978) several investigators have measured light penetration through the water column of Cayuga Lake and used the results to calculate an extinction coefficient. Data on solar radiation and extinction coefficients were calculated by Peterson; a modified Table 17 from Oglesby (1978, pg. 46) is included as Table 4.3.5. The higher values of light extinction correspond to shallower light penetration through the water column. Light extinction in water is described by Beers Law, $I_z = I_0 * e^{-CZ}$ where I_0 is light intensity (irradiance) at the water surface, I_z is irradiance at depth z, and c is the light extinction coefficient.

Table 4.3.5 Light Extinction Coefficients Measured in 1968 – 1970

Month	Light Extinction Coefficient (N= number of observations)
January	0.250 (N=1)
February	0.292 (N=1)
March	0.250 (N=1)
April	0.463 (N=2)
May	0.301 (N=4)
June	0.370 (N=3)
July	0.854 (N=4)
August	0.598 (N=10)
September	0.403 (N=4)
October	0.321 (N=2)
November	0.286 (N=3)
December	No observations

Source: Ogelsby 1978 (pg. 46)

Additional measurements of light extinction were made during the environmental investigations for the LSC project. These data (summarized in Table 4.3.6) indicate that the light extinction coefficient is higher in shallower waters, where light is scattered by phytoplankton, than in deeper waters (Stearns & Wheler 1997).

Upstate Freshwater Institute measured wavelength-specific light extinction coefficients in June 1996 as part of the LSC field program. An underwater spectroradiometer (irradiance meter) was used to measure intensity of light of different wavelength through the water column.. Data are presented in two depth categories: the surface layer 0.5 – 4.5 m depth) and a subsurface layer (to 23 m). Approximately 98% of the surface illumination was attenuated within 4.5 m. Wavelengths between 500 and 600 nm had the lowest extinction coefficient; this portion of the visible spectrum penetrates deepest into the lake water.

Table 4.3.6 Light Extinction Coefficients by Depth* Measured in 1996

Date Sampled	0-10 m	11-20 m	21-30 m	Greater than 30 m
6/12/96	0.464	0.408	0.380	Not measured
6/20/96	0.721	0.386	0.340	0.236
7/24/96 (*near LSC Intake*)	0.667	0.583	Not measured	Not measured
7/24/96 (*off Myers Point)*	0.584	0.447	0.397	Not measured
8/21/96 *(1400 hours)*	0.388	0.397	0.384	Not measured
8/21/96 *(1640 hours)*	0.489	0.424	0.356	0.326

*Each reported extinction coefficient is the average of data obtained at 1 m depth intervals.

Unless specified, measurements were obtained in mid-basin, Southern Cayuga Lake near Station S-11.

Source. Stearns & Wheler 1997. Appendix C-2 (Volume 2)

Secchi disk transparency (SDT) is another measure of light penetration in water. SDT is easily measured and is used by lake managers as a rapid index of water clarity that is easily compared over time and among lakes. Historical SDT data for Cayuga Lake including 1910 measurements of Birge and Juday were compiled by Wright and compared with measurements he made in 1968. No statistically significant trend in SDT was detected when data were stratified into twoweek time periods by location. However, when comparable data were available, SDT values measured after 1950 tended to be lower than values measured from 1910 – 1927 (Oglesby 1978).

SDT measurements in southern Cayuga Lake were obtained in 1994 – 1996 as part of the LSC field program. These data (summarized in Table 4.3.7) indicate that the lake water is more turbid closer to shore, as a result of tributary inflows and resuspension of bottom sediments. The recent invasion of Cayuga Lake by the zebra mussel (*Dreissena polymorpha*) is likely to affect water clarity. These benthic organisms filter water and remove particles, thus increasing water clarity.

Table 4.3.7 Recent Secchi Disk Transparency Data

	Southern Basin, Class A (nearshore)	Southern Basin *Class A* **(mid-basin)**	**Northern basin Class B(T) (nearshore)**	**Northern basin Class A(T) (mid-basin)**
Years of measurement	1994 – 1996, 1998	1994 – 1996, 1998	1991 – 1998	1991 – 1998
Summer average SDT (meters)	1.8 m (site P2)	2.3 m (site S11/P4)	2.7 m (site 1)	3.4 m (sites 5 and 6)
Standard deviation	0.52	0.82	0.90	1.3
Number of observations N	24	24	60	95
Percent of observations at lake bottom	0%	0%	48%	6%
Program and reference	Lake Source Cooling Stearns & Wheler 1997 Cornell Utilities 1999		Makarewicz et al. 1999 Seneca County Aquatic Vegetation Control Program	

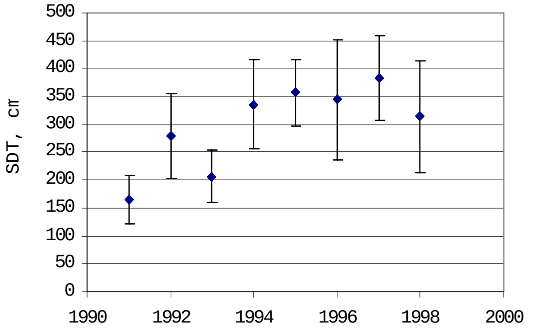
The Seneca County Soil and Water Conservation District has routinely monitored SDT in a network of six shallow sites in the northern basin since 1991. These data also demonstrate an improvement in water clarity after 1993 (Figures 4.3.6 and 4.3.7). The number of sites with light penetration to the lake bottom (sediment surface) has increased from less than 10% in 1991 – 1993 to greater than 50% after 1995.

4.3.1.7 Sedimentation rate and sediment texture

Cayuga Lake sediments are mixtures of fluvial silts, sand, clay, gravel, shale fragments, and detrital organic material. Sediment composition at any given site reflects the nature and proximity of tributary inflows coupled with the lake's hydrodynamic regime. Coarser texture sediments (larger particle size) tend to be present closer to the shoreline and near the mouths of tributaries. Preliminary analysis of sediment cores obtained in 1994 suggests that coarser sediments are being trapped in the shallow water complex of inlets and shelf (Karig et al. 1996).

Sediment deposition in the lake is variable along the north-south axis, with higher rates in the southern basin reflecting the large hydrologic input from tributaries and the mixture of land use in the

Figure 4.3.6
Secchi Disk Transparency
Nothern Cayuga Lake, 1991 - 1998
Annual Mean and Standard Deviaton
of Six Stations



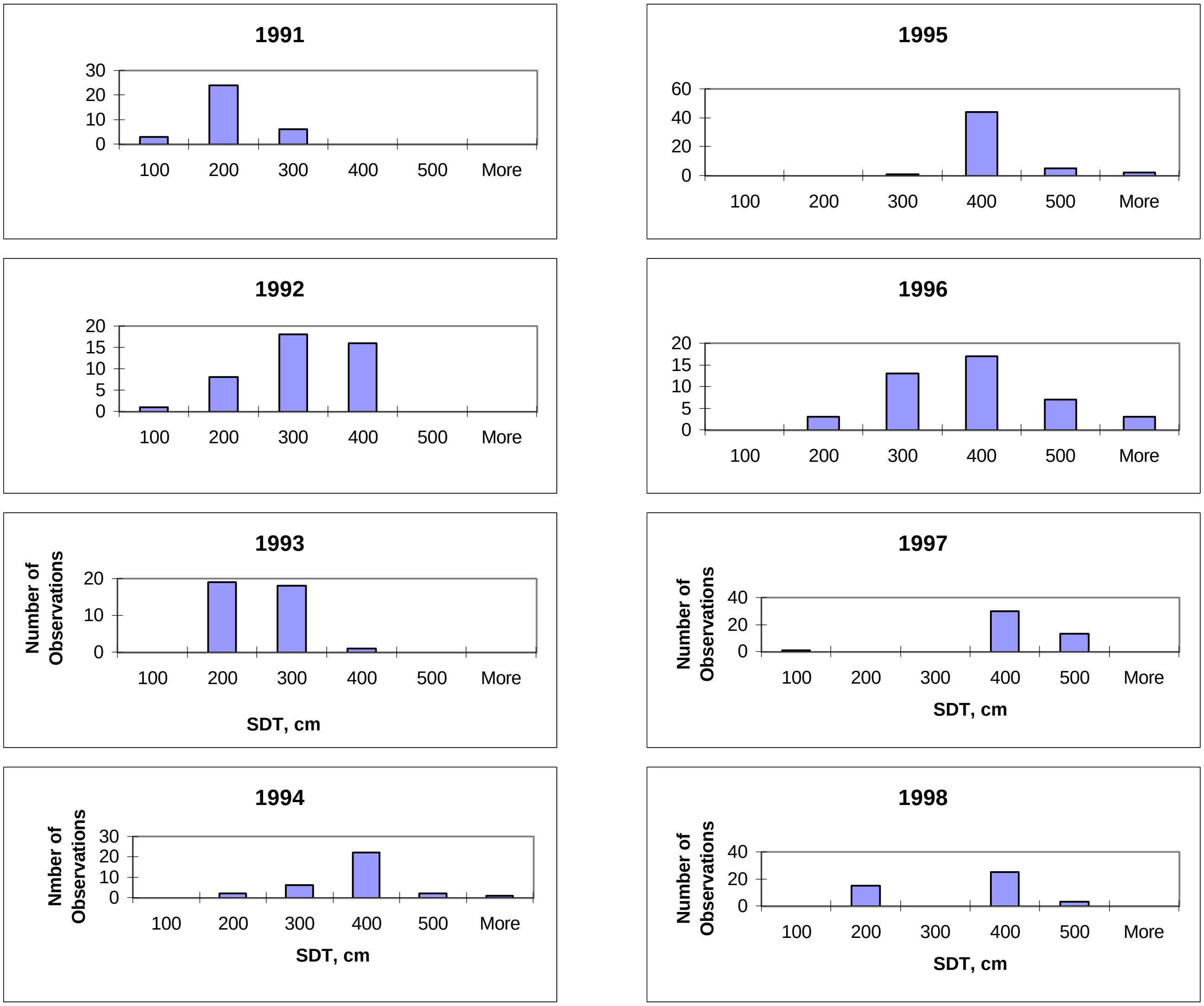


Figure 4.3.7. Histogram of Secchi disk transparency data, northern Cayuga Lake.

Source: Seneca County Soil and Water Conservation District subwatersheds. The estimated sedimentation rate ranges from 0.2 – 1.6 cm/yr (Yaeger 1999).

There have been several investigations of sediment quality in southern Cayuga Lake. The Environmental Measurements Laboratory of the U.S. Dept. of Energy and the Center for Climatic Research investigated the distribution of polycyclic aromatic hydrocarbons in lake sediment cores to assess changes in atmospheric transport and deposition in relation to fossil fuel combustion (Heit et al. 1986). The sediment cores were dated and peaks of polycyclic aromatic hydrocarbons were linked to forest clearing and coal combustion.

As part of the environmental impact assessment of the proposed Bell Station, New York State Electric and Gas collected sediment cores along the southeastern shoreline, in the region of Milliken Station (NUS 1973). In 1973, Al Vogel collected 33 samples of surficial sediments in the lake's littoral zone and analyzed them for texture (particle size distribution), pH, percent organic matter and major nutrients. He determined that littoral zone sediments are composed of 10 – 20% clay, 45 – 80% silt, and up to 80% sand (Vogel 1973).

Ludlam (1964) collected samples of Cayuga Lake sediments and determined that distinct banded pairs (varves) were present in core samples. The pairs of bands were approximately 2 cm thick in the top 1.5 m of lake sediment, and were considered to represent an annual deposition cycle.

A cooperative sediment coring effort was carried out in 1994. Researchers from USGS, Cornell University, Hobart William Smith Colleges, Tompkins County Water Quality Coordinating Committee, Syracuse University, and the U.S. Dept. of Energy participated in this effort. Cores were obtained throughout the lake and analyzed for geochemical composition, sediment texture, presence of microfossils, and sedimentation rate (dating). Results were presented at a symposium in October 1999.

4.3.2 Chemical Characteristics of Cayuga Lake

4.3.2.1 Ionic composition, pH, alkalinity

Cayuga Lake waters are moderately hard and well buffered, consistent with the predominance of calcareous parent material and soil in the watershed. Bicarbonate alkalinity is approximately 100 – 110 mg/l as $CaCO_3$. Major anions include chloride and bicarbonate, with relatively low amounts of sulfate; major cations include calcium and sodium, with relatively low concentrations of potassium and magnesium (Figure 4.3.8). Specific conductance, which is an indicator of total dissolved salts, is consistently in the range of 380 – 480 μmhos/cm in the lake's open waters, away from the influence of tributary and wastewater inflows (Stearns & Wheler 1994). Measurements in 1969 indicated significant seasonal and spatial variability in specific conductance, attributed to tributary and groundwater inflows (Oglesby 1978). Specific conductance of the epilimnion increased from 475 μmhos/cm in July to nearly 600 μmhos/cm in October. Increases with depth were also noted.

Chloride concentrations in surface waters reflect underlying geology, proximity to oceans, extent of road salting practices in the watershed, and any industrial or municipal discharge. Chloride concentrations in Seneca and Cayuga Lakes are elevated compared with the other Finger Lakes, and also compared with chloride concentrations in tributaries to these lakes. Likens (1974) reported a significant chloride imbalance in Cayuga Lake; export of chloride from the lake was 95% higher than the sum of the influents. The data indicate a significant

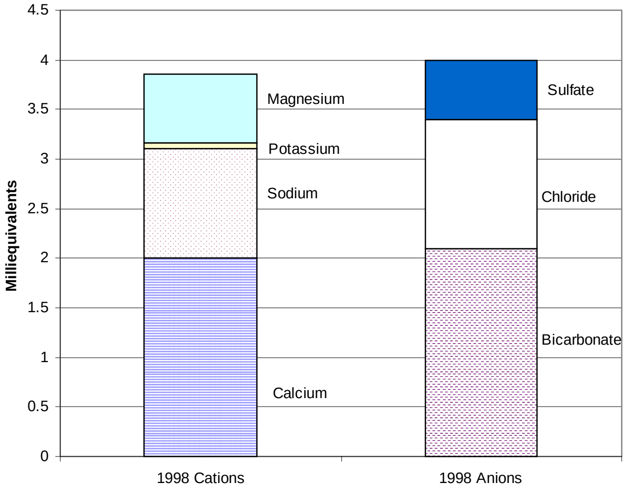
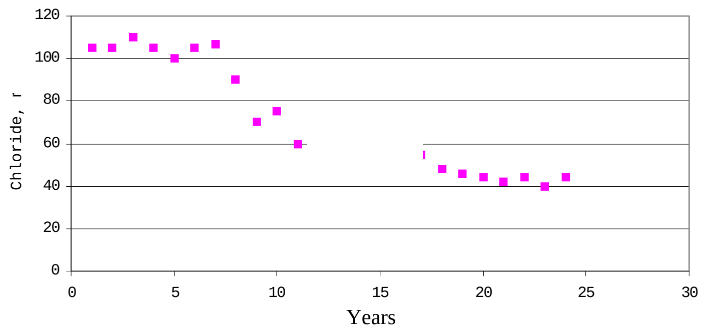


Figure 4.3.8. Charge Balance, Cayuga Lake (1998 Data)

source, or sources, of chloride within the lake basin.

Several hypotheses have been advanced to explain the elevated chloride levels. Berg (1966) considered that saline groundwater might enter Cayuga and Seneca Lakes, based on the depth of the lake bottoms. Wing et al. (1995) measured elevated sodium chloride (NaCl) concentrations in sediment pore water (concentrations as high as 30% NaCl) and concluded that the NaCl in interstitial water was due to intrusion of saline groundwater from underlying Silurian evaporites.

Figure 4.3.9 Chloride Concentrations, Cayuga Lake



1965-85: Effler, et. al. 1989, 1994: Sterns & Wheler. 1997, 1999 Southern Cayuga Lake Intermunicipal Water Commission

However, the concentration of chlorides in Cayuga Lake have been decreasing since 1970 (Figure 4.3.9) which corresponds to the virtual elimination of an industrial discharge of chlorides from the salt mining operation at Portland Point. Effler et al. (1989) modeled Cayuga Lake chloride concentrations and concluded that concentrations would continue to decline to steady-state (approximately 32 mg/l by the year 2000) as lake water is gradually replaced by precipitation and runoff. Chloride levels in 1987 averaged 46 mg/l (Effler et al. 1989); in 1994 chloride averaged 41 mg/l (Stearns & Wheler 1997). Southern Cayuga Lake Intermunicipal Water Commission reported average chloride concentration of 44 mg/l between January and July 1999. Elimination of the point source of chlorides reduced ambient lake water concentrations since 1970. However, groundwater intrusion does appear to be a continuing source.

Measurements of pH vary both diurnally and seasonally, but are consistently in the alkaline range. The highest pH values (in the range of 8.5 – 8.85) are measured in the upper waters during summer periods of algal activity as CO_2 is incorporated into biomass during photosynthesis. In the lower waters, where organic material is decomposed and CO_2 released, values between 7.2 and 7.9 have been reported (Stearns & Wheler 1997).

4.3.2.2 Major nutrients

Phosphorus. In the vast majority of lakes in the Northeast, phosphorus is the most important nutrient limiting the growth of algae suspended in the water column. Given favorable light and temperature conditions, algal growth continues until the supply of phosphorus is depleted. Phosphorus has been established as the limiting nutrient for algal growth in Cayuga Lake (Peterson, Barlow and Savage, 1974). The supply of phosphorus to Cayuga Lake depends on natural processes and human activities within the watershed such as erosion, fertilization, and discharge of wastewater. Sources of wastewater are discussed in Chapter 3.

Scientists and lake managers classify lakes according to their level of productivity (abundance of algae, plants, and other aquatic life forms) on a scale of “trophic state”. Oligotrophic lakes are nutrient-poor and low in productivity. Eutrophic lakes are well supplied with nutrients and support an abundance of algae and plants. Excessive algae will make a lake appear turbid or green, and diminish its attractiveness for recreational use. Decay of algae and aquatic plants reduces the concentration of dissolved oxygen in a lake’s lower waters. Mesotrophic lakes are intermediate in nutrient supply and algal abundance.

Concentrations of phosphorus have been measured in Cayuga Lake and its tributaries at irregular intervals since the 1960s. Several fractions of phosphorus (P) have been measured: total phosphorus (TP), total soluble phosphorus (TSP) and soluble reactive phosphorus (SRP, equivalent to molybdate reactive phosphorus or MRP) are most common. These fractions of phosphorus are operationally defined by sample handling and analytical methodologies. TP is all the P in an unfiltered sample that reacts with the chemical reagent molybdate after the sample has been digested. It includes P incorporated into algal biomass or adsorbed to soil particles. TSP is all the P in a filtered (or centrifuged) sample that reacts with molybdate after digestion. SRP (or MRP) is all the P in a filtered sample that reacts with molybdate, without digestion. SRP includes dissolved inorganic P, some P associated with small particles, and some organic P which reacts with molybdate. Most investigators consider SRP to represent biologically available P, that is, readily taken up by algal cells.

TABLE 4.3.8

Historical Measurements of Summer and Winter Phosphorus Concentrations
Cayuga Watershed Characterization Report

Year	**Investigator**	**Station**	**Summer (June – September)**			**Winter**		
			Average TP µg/l (0 – 10 m)	**N**	**Std Error of mean**	**Average TP (Water Column)**	**N**	**Std Error of mean**
1968	Peterson	Myers Pt.	20.2	19	Not reported	Not measured	-	-
1969	Peterson	Myers Pt.	15.3	22	Not reported	Not measured	-	-
1970	Peterson	Myers Pt.	14.0	32	Not reported	Not measured	-	-
1972	EPA	Myers Pt.	18.8	22	0.87	20.7	5	2.4
1973	P. Godfrey	Myers Pt.	14.5	88	0.71	22.2	3	Not reported
1994	LSC	mid-southern lake basin	22.4	12	8.4	Not measured	-	-
1995	LSC	mid-southern lake basin	16.3	12	1.0	15.7	15	1.6
1996	LSC	mid-southern lake basin	13.2	12	1.3	21.7	16	0.97
1998	LSC	mid-southern lake basin	17	7	1.9	Data not available	-	-
1991	Makarewicz	Northern basin	15.5	6	2.0	Not measured	-	-
1992	Makarewicz	Northern basin	9.1	9	1.1	Not measured	-	-
1993	Makarewicz	Northern basin	16.6	7	1.6	Not measured	-	-
1994	Makarewicz	Northern basin	9.1	8	2.5	Not measured	-	-
1995	Makarewicz	Northern basin	7.4	9	1.0	Not measured	-	-
1996	Makarewicz	Northern basin	13.1	9	1.4	Not measured	-	-
1997	Makarewicz	Northern basin	10.4	8	0.7	Not measured	-	-
1998	Makarewicz	Northern basin	11.5	8	3.5	Not measured	-	-

References:

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

Godfrey, Paul. 1977. Spatial and temporal variation in the phytoplankton in Cayuga Lake. Ph.D. thesis, Cornell University. Ithaca, NY

EPA. 1974. Report on Cayuga Lake: Cayuga, Seneca, and Tompkins Counties, New York. USEPA Region 2. Working paper 153. EPA National Eutrophication Survey.

Makarewicz, J. M. et al. Water quality of Cayuga Lake, 1991 – 1998. Prepared for Seneca County Soil and Water Conservation District.

µg/l micrograms per liter
TP total phosphorus

Results of P monitoring conducted through the 1970's are presented in Oglesby (1978). Additional data have been collected as part of graduate theses, special research programs, the Aquatic Vegetation Control Program, and in support of the environmental impact assessment of Cornell's LSC initiative. In May 1996, NYSDEC began a long-term monitoring program of 11 Finger Lakes for limnological parameters, including measurements of TP, TSP and SRP through the water column at the lakes' deepest point. Data from the NYSDEC monitoring program will be available in mid-2000.

Direct comparisons of historical and recent data are complex, even when equivalent fractions of P have been measured. The objectives and design of each monitoring program differ. Samples have been collected at various depths, stations, and time intervals. Three measures of P in Cayuga Lake are relevant to this analysis of trophic status and use impairment. First, summer average TP in the upper waters is used to assess compliance with NYSDEC guidance value for phosphorus in lakes, based on aesthetics. Second, TP concentration in the winter indicates the supply of TP throughout the water column and appears to be correlated to algal abundance the following summer (Dillon and Rigler 1974). Third, SRP profiles with depth indicate the uptake of phosphorus from the upper waters during algal growth, and any accumulation of SRP in the lower waters as algal cells are decomposed.

Summer average TP measured at a mid-lake station at one-meter depth is used as an index of a lake's trophic state and suitability for use in water supply and recreation. NYSDEC has adopted a guidance value for TP in lakes of 20 μg/l summer average (defined as the four months of June – September). This guidance value was derived from opinion survey data relating measured TP to perceived water quality for recreational use. Table 4.3.8 summarizes historical and recent TP data in the upper waters. Note that phosphorus concentrations are higher in the northern and southern basins as compared to the mid-lake station.

Winter or early spring TP data are also summarized in Table 4.3.8. The range of concentrations indicates that Cayuga Lake is mesotrophic, exhibiting moderate levels of primary productivity. The third index, phosphorus concentrations measured at discrete depths through the water column (profiles), is also typical of a mesotrophic lake. As summarized in Table 4.3.9 SRP concentrations are variable with depth. Concentration at any time is a dynamic balance between many biological and physical processes. Overall, the concentration of SRP in the upper waters tends to decrease as the lake warms each year, thermal stratification develops, and phytoplankton grow in the upper waters. The concentration of SRP in the lower waters tends to increase as algae settle through the water column and are decomposed.

As discussed below in the section on dissolved oxygen, Cayuga Lake remains well-oxygenated throughout the stratified period. Dissolved oxygen levels remain above 70% of saturation even in the deepest waters throughout the year. In contrast with other mesotrophic lakes, regeneration of P from bottom sediments is not an additional (internal) source of P. The well-oxygenated hypolimnion and iron-rich sediments prevent diffusive flux of SRP to the hypolimnion.

Table 4.3.9 Soluble Reactive Phosphorus (SRP), μg/l, Profiles Measured in Cayuga Lake, 1968 – 1969

Depth (m)	**1968**									**1969**	
	July		**August**		**Sept.**	**Oct**		**Nov**		**Jan**	**Feb**
	1-2	**15-16**	**1-2**	**19-20**	**19-20**	**16-17**	**29-30**	**11-14**	**26**	**21**	**17**
00-09	2.1	3.7	2.1	1.3	1.0	1.0	1.4	1.8	4.7	12.2	11.4
10-19	3.5	3.3	2.0	3.2	2.6	1.2	-	.6	-	-	-
20-29	3.2	4.5	3.5	4.0	1.4	1.3	2.1	5.7	-	-	-
30-39	4.5	5.4	5.8	6.0	5.7	3.1	2.0	7.3	6.1	16.0	12.7
40-49		6.2	7.2	6.2	6.0	6.6	3.6	4.4	6.4	12.5	10.3
50-59			8.3	-	-	9.6	8.8	8.1	-	-	12.1
60-69			10.7	11.4	10.8	13.3	-	10.0	11.7	13.1	13.0
70-79			13.1	12.9	10.5	-	13.1	17.7	9.8	12.2	12.6
80-89					10.2	14.0	13.7	20.1	-	-	-
90-99					9.7		17.9	21.9	13.4	12.7	11.6
100-109									15.9	12.9	12.7

Source: Ogelsby 1978 (pg. 52)
μg/l micrograms per liter

Nitrogen, another macronutrient for plant and algal growth, is detected at relatively high concentrations in Cayuga Lake. Oglesby reports that nitrate N is found consistently at all stations, all depths, throughout the year at an average concentration of 1 mg/l (Oglesby 1978). Data collected in 1994 for the LSC investigations were consistent with the historical data. Ammonia N concentrations are variable spatially in the lake, with elevated concentrations in regions of the southern lake basin directly affected by outfalls from the two wastewater treatment plants (Stearns & Wheler 1997; Moran 1984).

The ratio of nitrogen to phosphorus in lakes is used to predict the relative competitive success of phytoplankton groups. Nitrogen-fixing cyanobacteria (blue-green algae) are reported to be favored when the ratio of total N to total P decreases; nitrogen-fixing blue-greens are rare when the ratio exceeds 29:1 (Smith 1983). On a molar ratio basis, cyanobacteria generally comprise less than a few percent of phytoplankton biomass when the total N: total P ratio exceeds 65:1 (Howarth et al. 1988). The N:P ratio in Cayuga Lake is well over 100:1, indicating that nitrogen-fixing blue green algae are not favored. As discussed in the section on phytoplankton, cyanobacteria comprise only a small proportion of the algal community. The dominant species of cyanobacteria present in Cayuga Lake are not nitrogen-fixing organisms.

4.3.2.3 Trace metals and micronutrients

There are limited data on trace metals and micronutrients in Cayuga Lake. When substances are present in trace concentrations it can be difficult to differentiate ambient concentrations from contamination of sampling equipment or bottles, atmospheric deposition in the field or laboratory, or impurities in laboratory reagents. Based on an evaluation of historical data collected throughout the United States, limit of detection and contamination problems limit the quality of historical data for the metals cadmium, copper, lead, nickel, silver, zinc, and mercury (Windom et al. 1991). Analytical methods for monitoring metals in water and wastewater are inadequate for determining ambient concentrations of some metals in some surface waters (EPA Office of Water, October 1993).

Historical Cayuga Lake water column metals data (prior to the late 1980s) should be considered “estimated” due to these limit of detection and contamination problems. The NYSDEC Finger Lakes monitoring program analyzes water samples for selected metals. These data will be available in mid-2000.

The Southern Cayuga Lake Intermunicipal Water Commission operates the Bolton Point water supply. This agency serves the towns of Ithaca, Dryden, and Lansing and is a back-up supply to Cornell University and the City of Ithaca. The commission measures a suite of inorganic parameters in Cayuga Lake water as part of their permit-required monitoring of the public water supply. These data, summarized in Table 4.3.10, indicate that concentrations of metals in the water column are low.

Table 4.3.10 Summary of Monitoring Data for Inorganic Parameters, Bolton Point, 1994 - 1998

Analyte	Mean Concentration (mg/l)	Number of Detectable Observations
Arsenic	<0.001	0 : 5
Barium	0.031	4 : 5
Antimony	<0.003	0 : 3
Beryllium	<0.002	0 : 3
Cadmium	<0.001	0 : 5
Chromium	<0.001	0 : 5
Cyanide	<0.001	0 : 2
Fluoride	0.21	3 : 3
Mercury	<0.0004	0 : 5
Nickel	<0.01	0 : 3
Nitrate	1.29	3 : 3
Selenium	<0.001	0 : 5
Sodium	25.5	5 : 5
Sulfate	28.5	20 : 20
Thallium	< 0.005	0 : 3

Source: Southern Cayuga Lake Intermunicipal Water Commission, Ithaca NY

4.3.2.4 Dissolved oxygen

Dissolved oxygen (DO) concentrations are a significant factor affecting distribution, species composition, and abundance of the biological community. The founder of the science of limnology, G. Evelyn Hutchinson, concluded that a limnologist can learn more about the nature of a lake from a series of oxygen measurements than from any other type of chemical data (Hutchinson 1957). DO concentrations in Cayuga Lake are typical of those of a cold, deep, moderately productive lake (Ogelsby 1978). Variations in DO concentration occur seasonally and with depth.

When Cayuga Lake is stratified into layers of different temperature and density (thermal stratification) DO gradients develop through the water column. Concentrations of DO in the epilimnion (upper waters) are almost always near saturation levels due to atmospheric exchange. During daylight hours in summer, DO can be supersaturated as a result of photosynthesis. The epilimnion is isolated from the hypolimnion (deeper cooler layer) by the transition zone known as the metalimnion. As a consequence, the hypolimnion remains isolated from atmospheric exchange during stratification. The hypolimnion's supply of oxygen is used by aerobic organisms during decomposition of organic material and is not replenished. Oxygen concentrations in the hypolimnion gradually decrease with depth and as the stratified period progresses.

The rate of DO depletion is an important indicator of trophic status. As algal biomass increases the rate of DO depletion increases and DO concentrations can decline in the lower waters. If DO falls below critical levels for aquatic life (4 – 5 mg/l) the habitat for cold water fishes such as salmonids is lost. Cayuga Lake remains well-oxygenated throughout the stratified period. Dissolved oxygen levels remain above critical levels even in the deepest waters during the approximately six months of thermal stratification.

Temperature and DO profiles collected in late August 1995 are included as Figure 4.3-10 to illustrate the DO status of Cayuga Lake. Note the well-defined epilimnion to a depth of 10 m, and the supersaturated DO conditions. The metalimnion extends from the bottom of the epilimnion at 10 m to an approximate depth of 30 m. Below 30 m is the hypolimnion, where temperatures are cool and uniform. Note that DO concentrations remain close to 90% of saturation through the deepest waters.

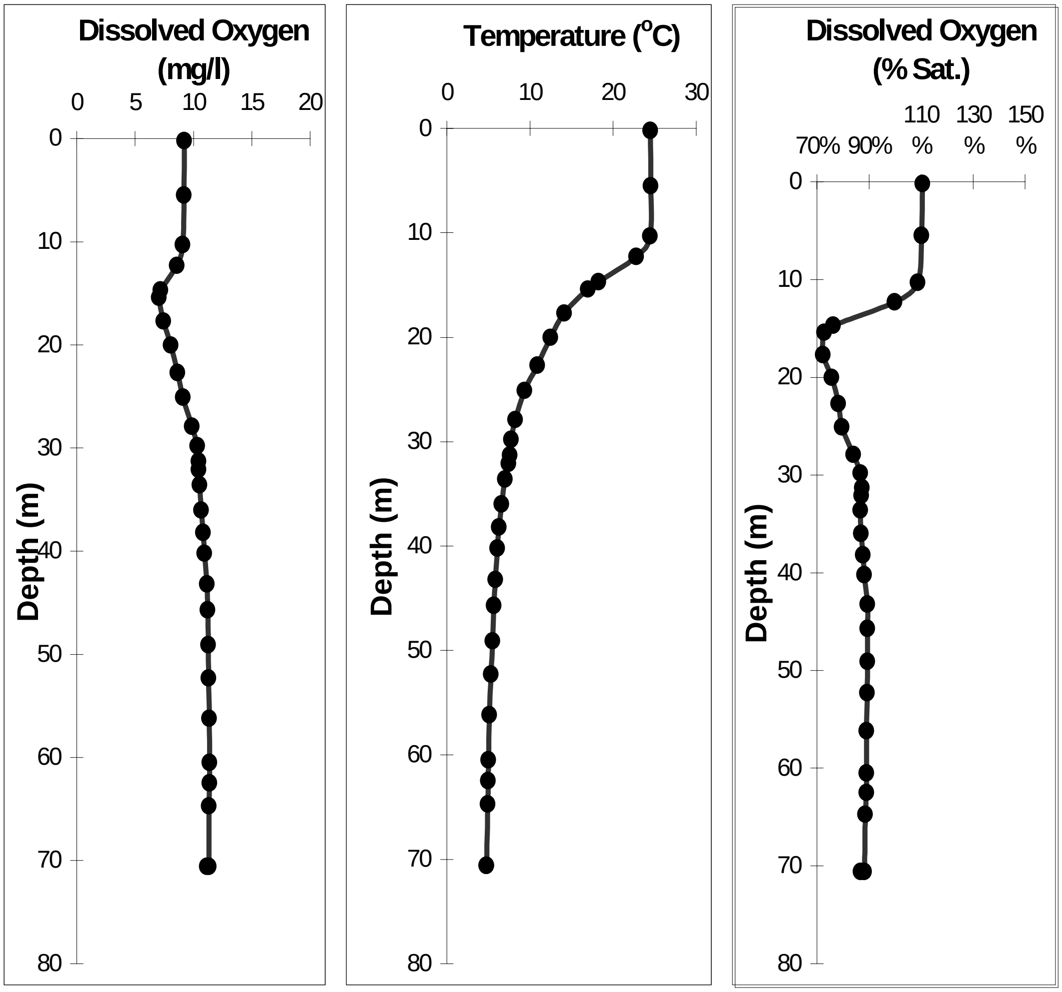
When the lake mixes again late in the year, DO is replenished throughout the water column. Concentrations remain near saturation at all depths until the following summer when the sun's energy once again drives thermal stratification.

There have been no major changes in the DO levels since the earliest measurements obtained in 1910. This important finding is based on intensive investigations of the lake's water quality conducted by NYSDEC, USGS, and researchers from Cornell University.

4.3.2.5 Concentrations of organic compounds (including pesticides)

Public suppliers of lake water are required by the NYS Dept. of Health to monitor for a comprehensive list of inorganic chemicals, organic chemicals, particulate matter, and microbiological organisms (pathogens and indicator organisms). In addition to the routine required monitoring, Cayuga Lake is included in several special statewide investigations of pesticides in water. These special investigations are notable for the use of analytical methods with extremely low limits of detection. Pesticide compounds are precisely and accurately measured at concentrations in the part per trillion or nanogram per liter range (10^{-9}).

The Bolton Point water supply (managed by the Southern Cayuga Lake Intermunicipal Water Authority) is included in the NYSDEC/USGS statewide survey for pesticides in water. Results of five synoptic surveys of 64 surface water sites throughout NY conducted between May 1997 and July 1998 have been published by USGS. Filtered samples were tested for the presence of 47 pesticides using the analytical techniques with very low limits of detection. Eight pesticides have been detected in the samples collected at Bolton Point (Table 4.3.11). Most of the analytes present are herbicides used on cornfields. Concentrations detected were below any state or federal standard or guidance value developed to protect human health and the environment (Philips et al. 1998).



mg/l: milligrams per liter
% Sat.: percent saturation

FIGURE 4.3.10
DO, TEMPERATURE, AND PERCENT
SATURATION PROFILES WITH DEPTH,
SOUTHERN CAYUGA LAKE, 8/22/95

Table 4.3-11. 1997-1998 NYSDEC/USGS Synoptic Sampling Results
Statewide Pesticide Survey: Bolton Point Water Intake

Pesticide Detected [1]	Number of Detectable Results	Maximum Concentration Detected (μg/l)	Data Qualifier [2]	Ambient Water Quality Criteria or Standard (μg/l) [3]
Simazine	5/5	0.031		0.5
Prometon	3/5	0.004	E	50
Metolachlor	5/5	0.066		50
Diethylatrazine	5/5	0.107	E	50
DCPA	1/5	0.001	E	50
Cyanazine	5/5	0.022		1
Alachlor	2/5	0.003	E	0.3
Atrazine	5/5	0.178		3

Notes:

5 Samples were analyzed for 47 pesticides on five dates (5/6/97, 7/2/97, 9/9/97, 2/3/98, 7/17/98). Pesticides that were always less than the limit of detection are not reported.

6 Data qualifier of E signifies that the chemical was present below the method detection limit. Identity of the compound is confirmed; concentration is estimated.

7 Lowest value of federal maximum contaminant level, federal lifetime health advisory limit, NY maximum contaminant level, NY standard for Class GA waters, NY surface water quality standard.

Source: USGS Water Resources Report

Table 4.3-12. 1997-1998 NYSDEC/USGS Synoptic Sampling Results
Statewide Pesticide Survey: Cayuga Lake off Taughannock Park

Pesticide Detected [1]	Number of Detectable Results	Maximum Concentration Detected (μg/l)	Data Qualifier [2]	Ambient Water Quality Criteria or Standard (μg/l) [3]
Alachlor	2/3	0.005		0.3
Atrazine	3/3	0.239		3
Diethylatrazine	3/3	0.104	E	50
Cyanazine	3/3	0.033		1
Metalochlor	3/3	0.120		50
Prometon	2/3	0.006	E	50
Propanil	1/3	0.004		7
Simazine	2/3	0.028		0.5

Notes:

8 Samples were analyzed for 47 pesticides in 8/96, 9/97 and 7/98. Samples were collected at a 2-m depth. Pesticides that were always less than the limit of detection are not reported.

9 Data qualifier of E signifies that the chemical was present below the method detection limit. Identity of the compound is confirmed; concentration is estimated.

10 Lowest value of federal maximum contaminant level, federal lifetime health advisory limit, NY maximum contaminant level, NY standard for Class GA waters, NY surface water quality standard.

Source: USGS Water Resources Report

NYSDEC and USGS also cooperative on an annual pesticide monitoring program including the 11 Finger Lakes, Oneida Lake, and Onondaga Lake. Cayuga Lake samples were collected at a 2-m depth at the NYSDEC sampling station off Taughannock State Park. Results of the 1996, 1997, and 1998 pesticide testing have been released by USGS. These data (summarized in Table 4.3.12) indicate that the pesticides present in the 2-m depth samples are generally consistent with the Bolton Point monitoring data. The major pesticides in both data sets are herbicides used in corn cultivation (atrazine, alachlor, metalochlor, diethylatrazine and cyanazine).

In June 1998, USGS and NYSDEC measured two herbicides in stormflow samples of three tributaries to Cayuga Lake (see section 4.2.4). Researchers then sampled Cayuga Lake at 12 cross-sections on two consecutive weeks one month after the storm. Results of this program indicated that concentrations of atrazine and metolachlor were generally uniform throughout the lake. Atrazine concentration ranged from 0.2-0.6 μg/l; metolachlor was detected at 0.05-0.3 μg/l. Concentration of the two herbicides was more uniform in the hypolimnion. Concentrations in the epilimnion appeared more responsive to changes in seasonal loading. Higher concentrations of chemicals were detected near mouths of tributaries draining agricultural areas (Eckhardt et al. 1999)

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4.3.2.6 Sediment chemistry

Sediment testing is conducted throughout the Finger Lakes as part of the NYSDEC monitoring program. Results will be available in mid-2001.

Chemical composition of sediments in southern Cayuga Lake was assayed as part of the Lake Source Cooling field investigations to determine environmental impacts associated with dredging to install the intake and outfall pipes. Sediment cores were analyzed for presence and concentration of heavy metals and organic compounds that might affect water quality during excavation, or limit disposal options for dredged material.

Results of the sediment testing were compared to guidelines adopted by New York State Dept. Environmental Conservation (NYSDEC). Regulatory guidelines have been developed to protect four uses of surface water resources: human health, wildlife health and reproduction, benthic and water column organisms (acute toxicity) and benthic and water column organisms (chronic toxicity). A separate NYSDEC guidance document provides disposal options based on chemical content of sediments to be removed.

Two rounds of sediment sampling were completed for this project. Surficial sediments were collected in 1994 as part of the feasibility screening for the Lake Source Cooling proposal. Additional sampling was completed in 1996 to support permit acquisition and design of best management practices during construction. The two rounds used different analytical laboratories and different sediment core depths.

Sediment samples were collected by box core on July 21 and 22, 1994 in the nearshore region where sediments will be excavated to install pipelines and in the region of the LSC intake structure. The box core sampled the upper 20 cm of the sediment profile. These samples were analyzed for Target Compound List analytes (as provided in Comprehensive Environmental Response, Compensation, and Liability Act [CERCLA] [1980]), total organic carbon, and acid volatile sulfides (AVS) in order to evaluate the chemical quality of the material.

Concentrations of cobalt, copper, lead, nickel, and zinc ranged from 1.16 micromoles per gram (μmol/g) to 1.35 μmol/g. Acid volatile sulfides were analyzed as well, because their relationship to concentrations of metals is an indicator of the potential for exposure of benthic organisms to potentially toxic concentrations of some divalent metals. When the ratio of metals to AVS is greater than one, biological toxicity may occur (DiToro et al. 1991). The molar ratios of total metal to AVS were calculated and range from 0.0711 to 0.0653. The AVS calculations indicate that the potential for toxicity to benthic and water column organisms from the metals detected in the Cayuga Lake sediments in 1994 is low.

Additional testing of sediment chemistry was completed in 1996. The specialty laboratories used in the 1996 sampling program applied analytical techniques designed to detect chemicals at trace concentrations. Sediment samples were collected by split spoon and hand core on June 18, 19, and 20, 1996. Split-spoon core samples were taken to a depth of 2 - 3 m based on anticipated dredging depths for each section of the excavation. The hand core samples were taken to a depth of 1 m, selected to represent 60 to 100 years of sedimentation (assuming a sedimentation rate of 1.0 - 1.6 cm/yr). These sediments would likely reflect any elevated concentrations of contaminants associated with industrial activity and/or atmospheric deposition.

Results of the sediment sampling for metals are summarized in Table 4.3.13. Complete results can be found in appendices C-12 and C-15 (volume IV) to the Environmental Impact Statement prepared for the LSC project (Stearns & Wheler 1997). Metals are part of the natural soil matrix, so their detection at low levels in sediments is to be expected. Elevated concentrations can reflect industrial inputs through effluent discharges, watershed runoff, and atmospheric deposition.

Risks associated with exposure to metals (inorganic compounds) are addressed in NYSDEC guidance with two separate thresholds for protection: the "lowest effect level" and the "severe effect level." The severe effect level corresponds to acute toxicity thresholds for aquatic organisms, while the lowest effect level "indicates a level of sediment contamination that can be tolerated by the majority of benthic organisms, but still causes toxicity to a few species" (NYSDEC 1994a).

Table 4.3.13 Summary of Cayuga Lake Sediment Metal Data, 1994 – 1996

Analyte	Number of Samples	Mean (mg/kg) dry weight	Median (mg/kg) dry weight	Maximum (mg/kg) dry weight	Number of Observations over Guidance Value Derived for Various Receptors and Disposal Options			
					Lowest Effect Level	Severe Effect Level	Class A Threshold	Class B Threshold
Cadmium	16	0.54	0.71	0.8	5	0	5	0
Chromium	16	19.62	14.05	75.7	3	0	na	na
Copper	16	15.49	16.05	30.8	8	0	na	na
Lead	16	25.35	17	123	2	1	8	0
Mercury	16	0.16	0.17	0.227	7	0	2	1
Nickel	16	19.27	18.1	46.6	9	0	8	0
Arsenic	16	4.41	4.1	9.1	1	0	na	na
Silver	16	0.67	0.88	0.99	0	0	na	na
Zinc	16	69.44	64.95	143	4	0	na	na

The NYSDEC published guidelines for managing sediment materials in its 1994 Interim Guidance: Freshwater Navigational Dredging (NYSDEC 1994b). These guidelines provide a sediment classification system and associated disposal options that are based on measured chemical concentrations. Class A sediments are considered "clean" and suitable for most uses, including in lake disposal. Class B sediments are moderately contaminated with organic and/or inorganic compounds that have the potential for negative environmental and human health impacts. Class C sediments are considered hazardous and must be disposed of as hazardous waste.

Data presented in Table 4.3.13 indicate that nearshore sediments in the southeastern region of Cayuga Lake contain concentrations of certain metals above regulatory guidelines. The NYSDEC "lowest effect level" thresholds for cadmium, copper, mercury, and nickel were exceeded in many samples. Class A sediment thresholds for cadmium, copper, and mercury were exceeded as well.

Because these sediments were to be disturbed during dredging, the LSC project team estimated the potential for contaminants adsorbed to soil particles to be released into the water column. The amount of metals released and their biological availability depends in the nature of the disturbance and the properties of the lake water such as pH, alkalinity, temperature, dissolved and particulate organic carbon, and hardness. The acid volatile sulfide (AVS) results discussed above indicate that AVS levels prevent biological availability of sediment metals to benthic organisms. However, as sediments are disturbed and come into contact with the well-oxygenated water column the metal sulfides will become oxidized. Each metal sulfide oxidizes at a different rate, and each solubilized metal has a unique affinity for repartitioning onto solid phase particulates in the water column and sediment surface (Stearns & Wheler 1997).

The chemical equilibrium model MINEQL+ (Schecher and McAvoy 1992) was used to evaluate speciation of metals potentially mobilized from the Cayuga Lake sediments. Trace metals in lake water are largely associated with carbonate complexes in a high alkalinity hard water lake such as Cayuga. Most metals exhibit relatively low concentrations of the aquo (uncomplexed) form. Results of this analysis (summarized in Stearns & Wheler 1997 pg. 2.3.5.18) indicate that the majority of trace metals mobilized from the sediments during dredging would not be in a biologically available form. Exceptions include zinc (100% uncomplexed) and silver (30% uncomplexed). Dredging was conducted using closed-bucket techniques to minimize exchange with the overlying water column, and sediments were removed from the lake for disposal.

Sediments were analyzed for organic compounds; results are summarized in Table 4.3.14. Just as with the metals results, measured concentrations may be compared with regulatory guidelines established to protect designated uses of the lake ecosystem or regulate disposal. Pesticides were detected in several of the nine sediment samples at concentrations exceeding thresholds for human health bioaccumulation, chronic toxicity for benthic life, and wildlife bioaccumulation. The highest frequency of detectable pesticide results was associated with DDT and its breakdown products. Three samples of the top meter of sediment collected in nearshore areas exhibited elevated concentrations of polyaromatic hydrocarbons. These compounds are associated with fossil fuel combustion.

The New York State Department of Health monitors fish for the presence and concentration of metals and organic compounds. No contaminants have been detected in Cayuga Lake fish at concentrations above human health guidelines.

4.3.3 Biological Characteristics

4.3.3.1 Phytoplankton

Microscopic algae suspended in the water column (phytoplankton) form the base of the food web in Cayuga Lake.

A number of researchers have studied various aspects of the Cayuga Lake phytoplankton community since completion of the first comprehensive biological survey in the early part of this century (Birge and Juday 1914). Oglesby’s (1978) monograph on Cayuga Lake provides a comprehensive review of species composition, biomass, and annual succession of phytoplankton through the early 1970s. The Lake Source Cooling environmental impact statement (Stearns & Wheler 1997) summarizes historical data and findings of field investigations conducted from 1994 – 1996. The objective of this section of the watershed characterization report is to describe the current status of the phytoplankton community from the perspective of trends and use impairment.

Phytoplankton growth rate, abundance, and species composition are affected by the availability of light and nutrients and the temperature of the water. Other factors such as grazing by organisms in the water column and benthos also affect the phytoplankton community. In Cayuga Lake, phosphorus is the limiting nutrient for algal growth. Other essential nutrients include carbon, hydrogen, oxygen, nitrogen, sulfur, (needed in relatively large supply) and silica, iron, manganese, copper, zinc, molybdenum and cobalt (needed in trace amounts).

Cornell graduate student Paul Godfrey completed a detailed evaluation of spatial and temporal variation of the Cayuga Lake phytoplankton based on extensive sampling in 1972 – 1973 (Godfrey 1977). He concluded that annual succession dynamics dominated the observed variation in phytoplankton community structure. Four distinct periods were clearly evident in the annual data. In spring, the phytoplankton community was dominated (both numbers and biomass) by diatoms and cryptophytes. Chlorophyll *a* concentrations typically reached their annual maximum during this period. During a brief period in July large numbers of extremely small cyanophytes (blue-green algae) dominated the phytoplankton community in terms of numbers, but not biomass. From late summer through the fall mixing period, chlorophytes (green algae) dominated both numbers and biomass of the phytoplankton community. Blue-green algae gradually increased in importance over this period. During winter the community was dominated by cryptophytes.

TABLE 4.3.14

Summary of Organic Compounds in Cayuga Lake Sediments, 1996 LSC Data *
Cayuga Watershed Characterization Report

Analyte	Number of Samples (1996)	Samples with Detectable Results	Highest Concentration		Number of Observations over Guidance Value Derived for Various Receptors and Disposal Options				
			(µg/g organic carbon)	(µg/g total solids)	Human health (bioaccumulation)	Benthic (acute)	Benthic (chronic)	Wildlife (bioaccumulation)	Class A Sediment
aldrin	9	2	0.1133	0.0021	1	0	0	0	0
alpha-BHC	9	1	0.100	0.0027	0	0	0	0	0
beta-BHC	9	3	0.16296	0.0044	0	0	0	0	0
delta-BHC	9	2	0.18889	0.0051	0	0	0	0	0
gamma-BHC	9	1	0.111	0.003	0	0	0	0	0
BHC (total)	9	4	0.563	0.0152	2	0	1	0	0
alpha-chlordane	6	0	Non detect	Non detect	0	0	0	0	0
gamma-chlordane	6	1	0.03843	0.00088	0	0	0	0	0
chlordane (total)	9	1	0.03843	0.00088	1	0	1	1	0
4,4’ DDD	9	7	0.5424	0.00922	7	0	0	0	1
4,4’ DDE	9	5	0.2553	0.00434	5	0	0	0	0
4,4’ DDT	9	5	0.08519	0.0023	5	0	0	0	0
dieldrin	9	3	0.1056	0.001901	1	0	0	0	0
endosulfan I	9	1	0.09630	0.0026	0	0	1	0	0
endosulfan II	9	3	0.03704	0.001	0	0	1	0	0
endosulfan sulfate	9	0	Non detect	Non detect	0	0	0	0	0
endrin	9	3	0.08384	0.00093	0	0	0	0	0
heptachlor	6	1	0.10370	0.0028	1	0	1	1	0
heptachlor epoxide	6	1	0.07407	0.002	1	0	0	1	0
methoxychlor	9	4	0.17778	0.0048	0	0	0	0	0
Total PCB	9	0	Non detect	Non detect	0	0	0	0	0
toxaphene	9	0	Non detect	Non detect	0	0	0	0	0
acenaphthene	3	3	3.5529	0.0604	0	0	0	0	0
phenanthrene	3	3	37.1176	0.6310	0	0	0	0	0
fluoroanthene	3	3	56.5294	0.96100	0	0	0	0	0
benzo(a)pyrene	3	3	36.5882	0.6220	3	0	0	0	0
Bis(2-ethylhexyl)phthalate	3	3	12.444	0.2240	0	0	0	0	0
Total PAH	3	3	140.8471	2.3944	0	0	0	0	2
mirex	3	0	Non detect	Non detect	0	0	0	0	0

Seasonal succession of the phytoplankton community was evaluated again in 1994 - 1996 and the findings were remarkably consistent with the data set collected more than two decades earlier. Diatoms and dominated the community in the spring, green algae were increasingly important as the summer progressed, peaking in late August Blue-green algae comprised a significant fraction of the community in terms of numbers by late July and August, but were a negligible fraction of the total algal biomass. Crypotophytes became increasingly dominant as the fall advanced. (Figure 4.3.11).

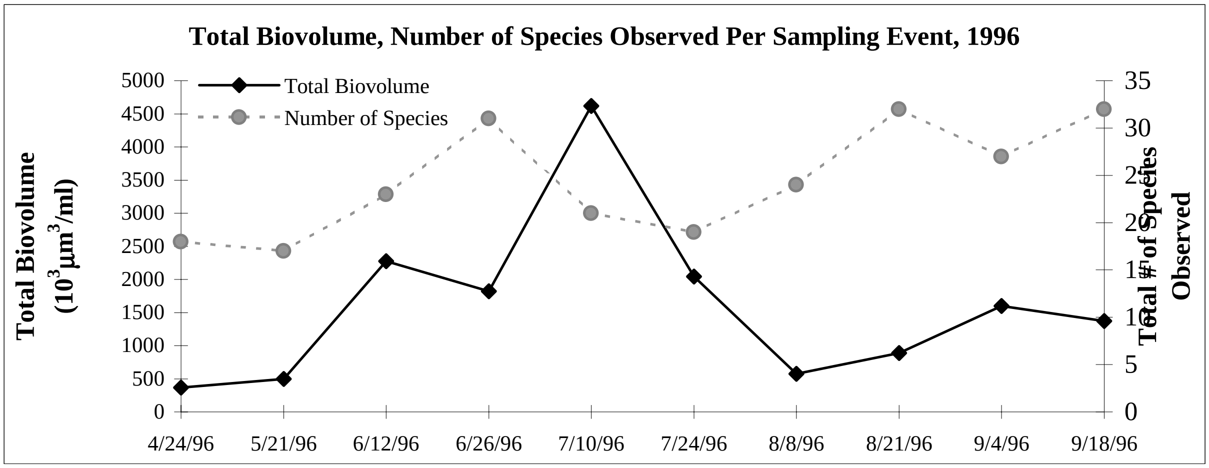
According to Oglesby (1978), the most complete investigations of phytoplankton species assemblages had been performed by Godfrey, Barlow and Dahlberg. Direct comparisons of data gathered by the three investigators are not meaningful due to differences in methods used to collect, preserve, identify, and count the samples and in the taxonomic skills of the investigators. Oglesby considered the Godfrey data set to be most representative of conditions in Cayuga Lake. The phytoplankton species reported by Godfrey as relatively important over the course of his investigation are summarized in Table 4.3.15. Also noted in this table are the findings of the phytoplankton survey work completed in 1994 – 1996 by Dr. William Schaffner for the Lake Source Cooling environmental impact assessment. Dr. Schaffner concluded that the species composition and community structure of the 1994 – 1996 phytoplankton assemblage were generally consistent with the historical Cayuga Lake data (Schaffner, 1997).

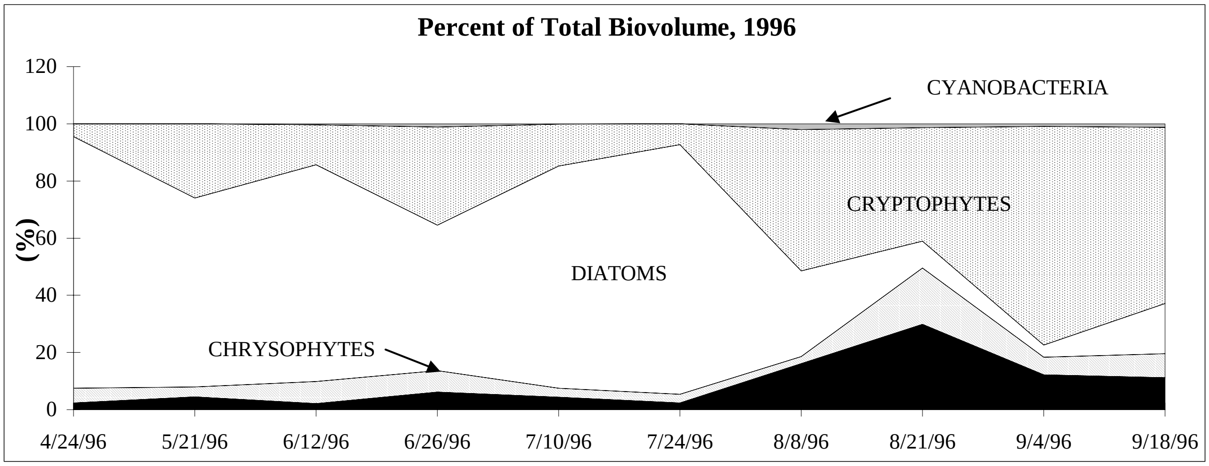
Another index of phytoplankton abundance is chlorophyll *a*, a photosynthetic pigment present in algal cells. Summer average chlorophyll *a* concentration is used as one index of a lake's trophic status, or degree of enrichment by nutrients. Lake managers use summer average chlorophyll a as an indicator of use impairment; for example, NYSDEC derived their guidance value for phosphorus in lakes to correspond to a low frequency of perceived "algal greenness". Upper waters, summer average chlorophyll *a* concentrations less than 6 µg/l correspond to a low frequency of perceived use impairment. When summer average chlorophyll *a* exceeds 13 µg/l more than 50% of lake users would perceive definite algal greenness and find at least slight impairment in use (NYSDEC Fact Sheet, Ambient Water Quality Value for Protection of Recreational Uses, Oct. 22, 1993). The summer averaging period is defined as the four months from June 1 – September 30 to encompass the major recreational period for New York lakes.

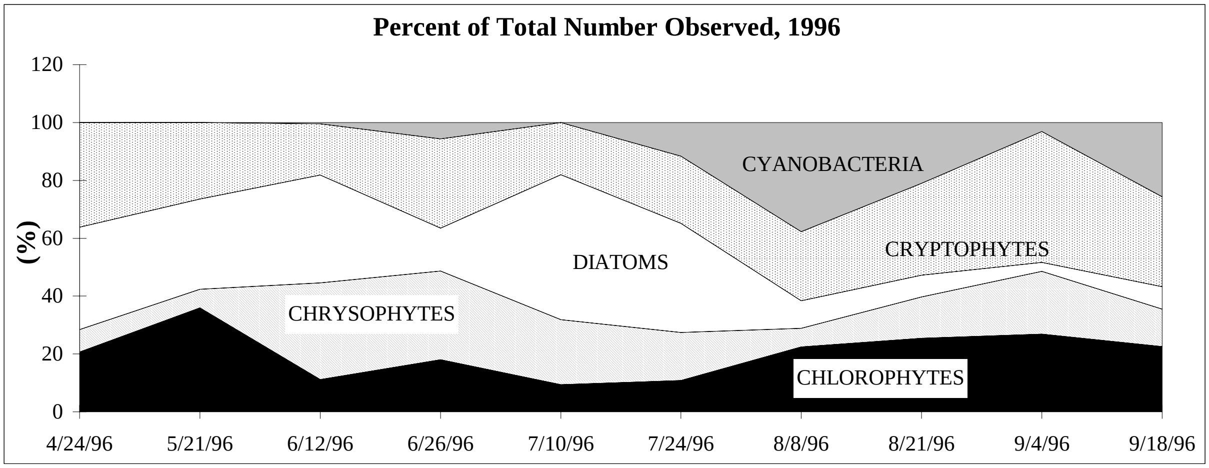
Table 4.3.16 Summer Average Chlorophyll *a* Concentration, Cayuga Lake

Year	**Chlorophyll a (µg/l)**	**Standard Error**	**Location**	**Reference**
1968 - 1970	4.8	Not reported	Myers	Peterson, B. 1971
1970	3.7	Not reported	Myers	Peterson, B. 1971
1972	10.3	0.2	Myers	Godfrey, P. 1977
1973	8.2	0.2	Myers	Godfrey, P. 1977
1974	8.1	0.2	Myers	EPA 1974
1977	8.6	Not reported	Myers	Ogelsby and Schaffner 1978
1978	6.5	Not reported	Myers	Ogelsby and Schaffner 1978
1994	4.1	1.1	Southern basin	Stearns & Wheler 1997
1995	4.8	1.0	Southern basin	Stearns & Wheler 1997
1996	3.4	0.96	Southern basin	Stearns & Wheler 1997
1998	5.1	0.25	Southern basin	Cornell Utilities 1999
1991 - 1998	4.0	0.66	Northern basin	Makarewicz et al. 1999

Similar to other water quality parameters of the Cayuga Lake ecosystem, chlorophyll *a* has been assayed by a number of investigators over the past decades. Measurements fluctuate over the annual cycle; maximum values tend to occur in the spring and minimum values in the winter. Summer average chlorophyll *a* data for Cayuga Lake are summarized in Table 4.3.16. These data represent samples of the upper waters collected during the months of June – September. Note that in recent years the chlorophyll *a* data are consistently below the 6 µg/l threshold for perceived







Data are averages of duplicate samples.
mm3/ml: cubic micrometers per milliliter

FIGURE 4.3.11
SEASONAL PHYTOPLANKTON
SUCCESSION, 1996
Source: Stearns & Wheler 1997

Table 4.3.15 Summary of phytoplankton species present in Cayuga Lake, 1972 – 1974 (Godfrey 1977) and 1994 – 1996 (Schaffner 1997)

Phytoplankton	Present in 1972 – 1974	Present in 1994 – 1996
CHLOROPHYTA		
Actinastrum	No	Yes
Ankistrodesmus	Yes	Yes
Arthrodesmus	No	Yes
Carteria	Yes	Yes
Chlamydomonas	Yes	Yes
Closteriopsis	Yes	Yes
Closterium	No	Yes
coccoids	Yes	Yes
Coelastrum	Yes	Yes
Coronastrum	No	Yes
Cosmarium	Yes	Yes
Crucigenia	No	Yes
Dictyosphaerium	No	Yes
Dimorphococcus	Yes	No
Eudorina	No	Yes
Francia	No	Yes
Gloeocystis	No	Yes
Golenkinia	Yes	Yes
Gonium	No	Yes
Kirchneriella spp.	Yes	Yes
Lagerheimia	Yes	Yes
Micractinium	No	Yes
Nannochloris	Yes	Yes
Oocystis pusilla/parva	Yes	Yes
Oocystis spp.	Yes	Yes
Pediastrum	Yes	Yes
Scenedesmus bijuga	Yes	Yes
Scenedesmus spp.	Yes	Yes
Schroederia	No	Yes
Selenastrum minutus	Yes	Yes
Selenastrum spp.	Yes	Yes
Sphaerocystis	Yes	Yes
Staurastrum	Yes	Yes
Treubaria	No	Yes
Tetraedron	Yes	Yes
Tetraspora	No	Yes
EUGLENOPHYTA		
Euglena	No	Yes
Phacus	No	Yes
Trachelmonas	No	Yes
CHRYSOPHYTA		
Biocoeca	Yes	No
Chromulina	Yes	Yes
Chrysococcus	No	Yes
Chrysochromulina	No	Yes
colonial flagellate	Yes	Yes
coccoid	Yes	Yes
Dinobryon	Yes	Yes
Erkenia	No	Yes

Flagellate w/spines	Yes	Yes
u flagellates	Yes	Yes
uu flagellates	Yes	Yes
Mallomonas	No	Yes
Ochromonas	Yes	Yes
Uroglenopsis americana	No	Yes
DIATOMS		
Achnanthes	No	Yes
Amphipora	No	Yes
Asterionella formosa	Yes	Yes
Cosinodiscus/Stephanodiscus	Yes	Yes
centrics	Yes	Yes
Cymbella	No	Yes
Diatoma	Yes	Yes
Eunotia	No	Yes
Fragilaria	Yes	Yes
Melosira	No	Yes
Meridion	No	Yes
Navicula	No	Yes
Nitzschia	Yes	No
Opephora	No	Yes
pennates	Yes	Yes
Rhizosolenia	No	Yes
Synedra	Yes	Yes
Tabellaria	Yes	Yes
CRYPTOPHYTA		
Chroomonas/Rhodomonas	Yes	Yes
Cryptomonas spp.	Yes	Yes
CYANOPHYTA		
Anabaena	Yes	Yes
Aphanizomenon	Yes	No
coccoid	Yes	Yes
Chrococcus	Yes	Yes
Coelosphaerium	Yes	No
Gomphosphaeria	Yes	Yes
Lyngbya	Yes	No
Merismopedia	Yes	Yes
Microcystis	Yes	Yes
Oscillatoria	No	Yes
PYRROPHYTA		
Ceratium	Yes	Yes
Glenodinium	Yes	No
Peridiniales	Yes	Yes

use impairment. It is likely that the reduction in chlorophyll a concentration is a direct result of the invasion of the lake by zebra mussels.

4.3.3.2 Macrophytes (rooted aquatic plants and algae)

Aquatic macrophytes provide a number of important functions to lake ecosystems including stabilization, food, and habitat value. Macrophytes physically stabilize soft sediments with their root structure and help dissipate the energy of wind and wave action with their stems and leaf structure. Macrophyte beds act as traps for inorganic and organic particulate materials (Foote and Kadlec 1988; Barko et al. 1991). Aquatic vegetation also provides food for other aquatic organisms; in addition to the phytoplankton, macrophytes capture photosynthetic energy and serve as a base to the aquatic and terrestrial food web. For example, *Vallisneria americana* is an important food source for waterfowl.

The presence of macrophytes in the littoral zone is correlated with higher diversity and abundance of invertebrates, which are essential food sources for many life stages of organisms found in Cayuga Lake. Macrophytes provide shelter and forage for waterfowl, invertebrates and fish. They provide habitat areas for insects and other organisms and for the spawning of many fish species. In addition, macrophytes provide habitat for young-of-the-year fish (Dewey and Jennings 1992) and adult sport fishes (Savino and Stein 1989; Crowder and Cooper 1982).

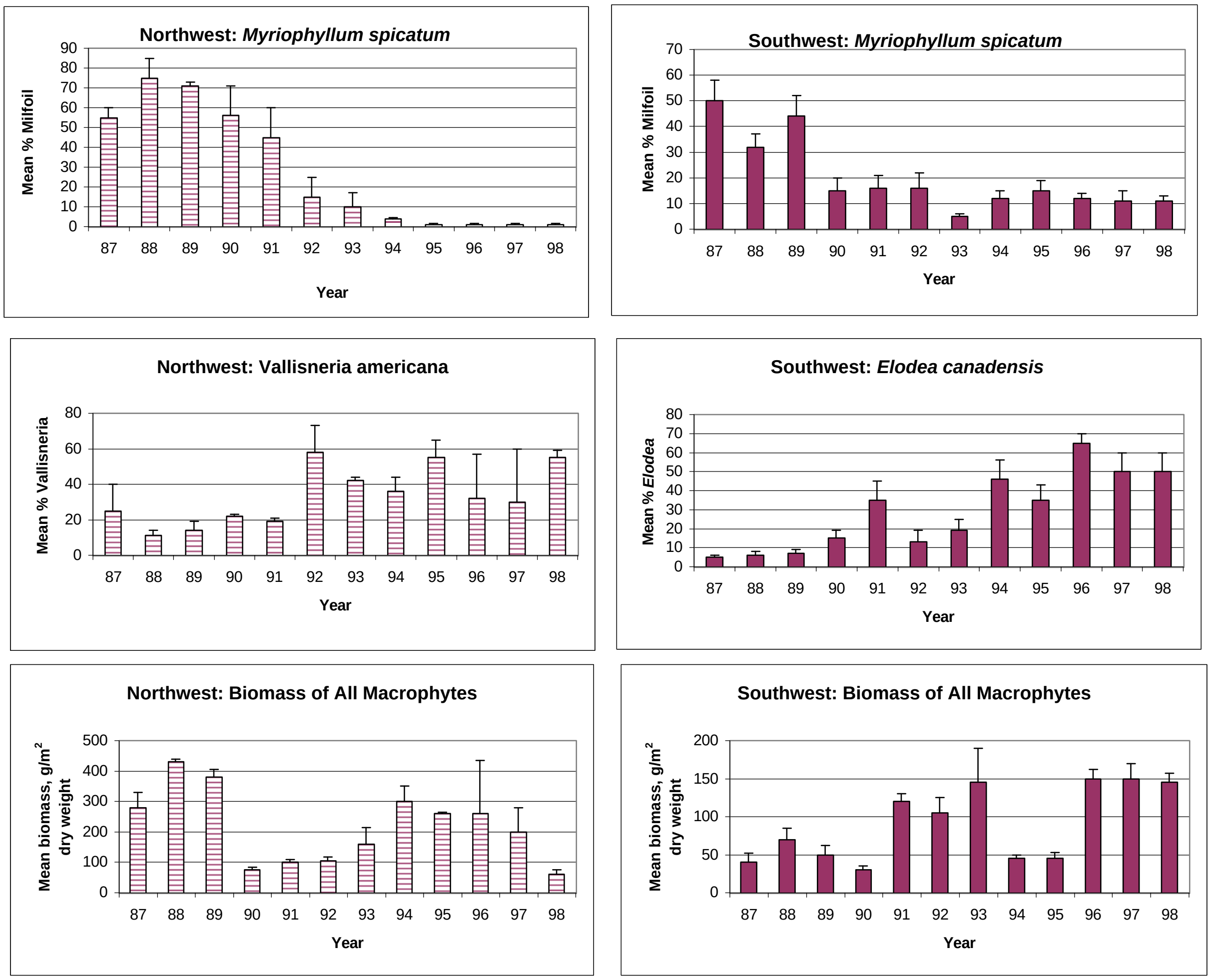
While important to the lake ecosystem, macrophytes can interfere with recreational uses of a lake if they become too abundant or if nuisance species dominate the flora. The species assemblage of macrophytes in Cayuga Lake has been documented at various intervals since the 1920s. Beginning in 1987 (south end) and 1990 (north end), a comprehensive program has been carried out each year to estimate the species composition and biomass of macrophytes. The program is led by Robert L. Johnson of Cornell University's Department of Ecology and Evolutionary Biology, with funding through the Finger Lakes Lake Ontario Watershed Protection Alliance (funding source, NYSDEC) and the Hatch Program (funding source, U.S. Dept. of Agriculture).

The shallow shelf areas at the southern and northern ends of Cayuga Lake represent the vast majority of the lake's littoral zone, which is the habitat for macrophytes. The littoral, or shoreline, zone is defined as the shallow area extending from the water's edge to the maximum depth of light penetration. Because of the steeply sloped basin, the long axis of Cayuga Lake provides only limited littoral habitat. According to data presented in Oglesby (1978) approximately 20% of the lake surface area overlies water of 5 m or less. The majority of this littoral zone (more than 80% of the total) is at the northern end of the lake, north of Union Springs.

The macrophyte species currently found in Cayuga Lake are listed in Table 4.3.17. The number of species present in Cayuga Lake (16 species as of 1998) is comparable to other New York lakes (see, for example, Auer et al. 1996). As discussed in Oglesby (1978) the number of macrophyte species present has fluctuated over time: 21 species were reported in southern Cayuga Lake in 1921, 18 in 1942 – 1943, and 10 in 1970.

Significant changes in total biomass and species composition of macrophytes have occurred over the 12-year study period (Figure 4.3.12). The abundance and dominance of *Myriophyllum spicatum* (eurasian watermilfoil), a nuisance exotic species, have declined in the northern and southern study areas of Cayuga Lake. The precipitous decline in eurasian watermilfoil in the study areas has been accompanied by an increase in two native species, *Elodea canadensis* in the southern lake basin and *Vallisneria americana* in the northern shelf.

It is very interesting to note the fluctuations in total biomass and the contrast between the two regions of the lake. In the northwest area, total biomass was high from 1987 – 1998 and eurasian watermilfoil dominated the flora. Total biomass fell to low levels in the early 1990's accompanied by a decline in eurasian watermilfoil. As biomass has recovered since 1994, *Vallisneria americana* is the dominant species. In contrast, total biomass was relatively low in southern Cayuga Lake in the early part of the record, and increased in 1991 – 1993. 1994 and 1995 were low, but total plant biomass has recovered in recent years. Peak biomass in the northern study area has always been higher than in the southern lake. The one consistent signal lakewide is the decline in dominance of eurasian watermilfoil and the renewed success of native species. This decline in dominance of eurasian watermilfoil was concurrent with the observation of the moth *Acentria ephemerella* feeding on apical meristematic tissue of this macrophyte (Gross et al. 1999 in review).



Northwest: *Myriophyllum spicatum*

Southwest: *Myriophyllum spicatum*

Northwest: Vallisneria americana

Southwest: *Elodea canadensis*

Northwest: Biomass of All Macrophytes

Southwest: Biomass of All Macrophytes

Figure 4.3.12. Relative abundance of selected species and total biomass of macrophytes, northern and southern basins, Cayuga Lake

Source: Robert L. Johnson, P. J. Van Dusen, J.A. Toner and N. G. Hairston, Jr. 1999. Eurasian water milfoil biomass associated with insect herbivores in New York. Submitted for review, Journal of Aquatic Plant Management

Table 4.3.17 Macrophyte species present in Cayuga Lake

Scientific name	Common Name	Distribution
Ceratophyllum demersum	Coontail	North, south
Chara vulgaris	Muskgrass	North, south
Elodea canadensis	Elodea, Canadian waterweed	North, south
Heteranthera dubia	Water stargrass	North, south
Myriophyllum spicatum	Eurasian Watermilfoil	North, south
Najas minor	Brittle naiad	North
Najas flexilis	Bushy naiad	North, south
Potomogeton pectinatus	Sago pondweed	North, south
Potomogeton pusillus	Slender pondweed	North, south
Potomogeton richardsonii	Clasping-leaf pondweed	North, south
Potomogeton zosteriformis	Flat-stemmed pondweed	North, south
Potomogeton vaginatus	Bigsheath pondweed	South
Potomogeton crispus	Curlyleaf pondweed	North, south
Vallisneria americana	Eelgrass, wild celery	North, south
Ranunculus trichophyllus	White water buttercup	South
Zannichellia palustris	Horned pondweed	South

Sources:
Robert L. Johnson, Cornell University. June 1997. Project Completion Report for the Seneca County Soils and Water Conservation District.
Tompkins County Planning Dept. Oct. 1998. Project Completion Report for the Finger Lakes- Lake Ontario Watershed Protection Alliance.

Additional sampling and experiments have focused on the role of this aquatic lepidopteran larva in the observed shift in species composition. Johnson and his colleagues (Elisabeth Gross and Nelson Hairston, Jr.) have developed experimental evidence that the shift in dominance from *Myriophyllum spicatum* to *Elodea canadensis* may be explained by the preference of larval *Acentria ephemerella* for feeding on meristematic tissue of *Myriophyllum spicatum* (Johnson et al. 1998a). In laboratory and mesocosm studies these researchers have demonstrated that the larval stage of *Acentria ephemerella* clearly prefer *Myriophyllum spicatum* over *Elodea canadensis*.

Grazing on the apical meristematic tissue (the growing tip) prevents milfoil from elongating towards the water surface, thus eliminating a major advantage this species has held over native flora. More desirable native species of submersed macrophytes have been able to outcompete milfoil and now comprise a significant fraction of the flora. These native species do not elongate towards the water surface and form a canopy; consequently, there is less perceived impairment of the resource for recreational and aesthetic uses.

In addition to herbivory, there are many environmental factors influencing the total biomass and species composition of macrophytes in Cayuga Lake. Significant storm events that deliver large amounts of sediment to the lake can affect light penetration and the littoral habitat. For example, the number of macrophytes present in southern Cayuga lake dropped from 11 to 5 following tropical storm Agnes in June 1972. Biomass decreased by 44 – 100%. By the following summer, eurasian watermilfoil had greatly increased its relative dominance of the macrophyte community (Oglesby et al. 1976).

Invasion of lakes by the zebra mussel *Dreissena polymorpha* is associated with an increase in water clarity and expansion of littoral habitat (Fahnenstiel et al. 1995). Zebra mussels invaded Cayuga Lake through the Seneca River system and have spread from north to south. Recall that Secchi disk transparency data for northern Cayuga Lake collected by Seneca County Soil and Water Conservation District shows an increase in water clarity concurrent with the mussel invasion. By 1996, significant numbers of zebra mussels were present throughout the lake.

Finally, mechanical harvesting can influence the species composition along with abundance of macrophytes. Survey work performed by Robert Johnson and colleagues at Cornell University suggest an association between lakes intensively managed to control eurasian watermilfoil and low abundance of herbivores (Johnson et al. 1998b).

Apparently, mechanical harvesting removes sufficient numbers of herbivorous larvae to suppress their effectiveness as a natural control for *Myriophyllum spicatum*.

4.3.3.3 Zooplankton (including *Mysis relicta*)

The zooplankton community is another important component of the Cayuga Lake ecosystem; these small, motile, water column organisms graze on phytoplankton and are consumed by various life stages of fish. Oglesby (1978) has reviewed historical data extending back to 1910 describing the abundance and species composition of zooplankton and concluded that the Cayuga Lake community is typical of a moderately productive north temperate lake.

The most recent zooplankton data were collected between June and September 1994 at three stations extending from shallow southern Cayuga (station P2, depth 4m), two miles north (station P4, depth 65 m) to a site off Myers Point (station R, depth 90 m). Dr. William Schaffner analyzed samples as part of the Lake Source Cooling environmental assessment. A total of 37 species were identified in the collections, 21 at P2, 19 at P4 and 25 at R (Table 4.3.18). Oglesby (1978 pg. 89) includes a list of zooplankton species found during field sampling in the early 1970s by Chamberlain and Dahlberg. The species lists are relatively consistent, with a few notable exceptions. The rotifer *Ascomorpha sultans*, dominant in the early 1970's community, was not found in 1994. Both Chamberlain and Dahlberg listed the cyclopoid copepod *Tropocyclops parsinus* and the rotifer *Notholca acuminata* as abundant in the 1970's; these organisms were not present in the 1994 samples. In 1994 the deeper sites had significant numbers of the cyclopoid copepod *Diacyclops*, which was not part of the zooplankton community two decades earlier.

Table 4.3.18. Zooplankton taxa found in Cayuga Lake, Summer 1994

ROTIFERA
Asplanchna priodonta
Brachionus sp.
Cephalodella sp.
Collotheca sp.
Conochilus unicornis
Filinia longeseta
Gastropus hytopus
Kellicottia longispina
Keratella cochlearis
Keratella quadrata
Ploesoma sp.
Polyarthra spp.
Synchaeta sp.
Trichocerca multicrinis

CLADOCERA
Bosmina longirostris
Camptocercus rectirostris
Ceriodaphnia
Chydorus
Daphnia galeata
Daphnia retrocurva
Diaphanosoma brachyurum
Eubosmina coregoni
Holopedium gibberum
Leptodora kindtii
Ilyocryptus sp.
Polyphemus pediculus
Sida crystallina

CALANOIDA
Senecella calanoides
Diaptomus minutus m.
Diaptomus minutus f.
Diaptomus oregonensis m.
Diaptomus oregonensis f.
Diaptomus spp. CI-CV
Diaptomus spp. NI-NVI

CYCLOPOIDA
Cyclops scutifer m.
Cyclops scutifer f.
Cyclops vernalis m.
Cyclops vernalis f.
Diacyclops bicuspidatus m.
Diacyclops bicuspidatus f.
Mesocyclops edax m.
Mesocyclops edax f.
Cyclopoid sp. m.
Cyclopoid sp. f.
Cyclopoid CI-CV
Cyclopoid NI-NV

AMPHIPODA
Diporia affinis

MYSIDACEA
Mysis relicta

Source: Stearns & Wheler 1994

Rotifers were the most abundant group at all sites, followed by cladocerans and copepods. Diversity and density of rotifers and cladocerans decreased with water depth (i.e. the highest numbers of species and individuals were present at the shallowest station P2). This pattern was reversed for copepods; the highest numbers of individuals and species were present at the deepest station R. Abundance of the major taxa present in the 1994 samples is plotted in Figure 4.3.13.

The zooplankton community of Cayuga Lake also includes a large number of the hypolimnetic crustacean *Mysis relicta*, the opossum shrimp. Due to their unique behavioral adaptations, *Mysis relicta* can be difficult to capture using traditional plankton sampling techniques. Their presence and abundance in the zooplankton community can be easily underestimated. These small pelagic crustaceans migrate vertically through the water column over each 24-hour day. During daylight hours, the animals are found at or near the bottom of lakes. In very deep waters, *Mysis relicta* are suspended in the lower regions of the hypolimnion during the day (Brownell 1970; Robertson, Powers, and Anderson 1968; Holmquist 1959). As daylight fades, the animals begin to ascend to shallower depths to feed. This daily migration behavior enables *Mysis relicta* to forage high in the water column during the night making the animals less visible to predators. During the daytime, when light penetrates further into the water column, *Mysis relicta* avoid visual predators by traveling to the deeper, darker waters. In addition to offering protection from predators, the lower temperatures of the deep water may minimize metabolic costs. The benthos also provides an additional food source.

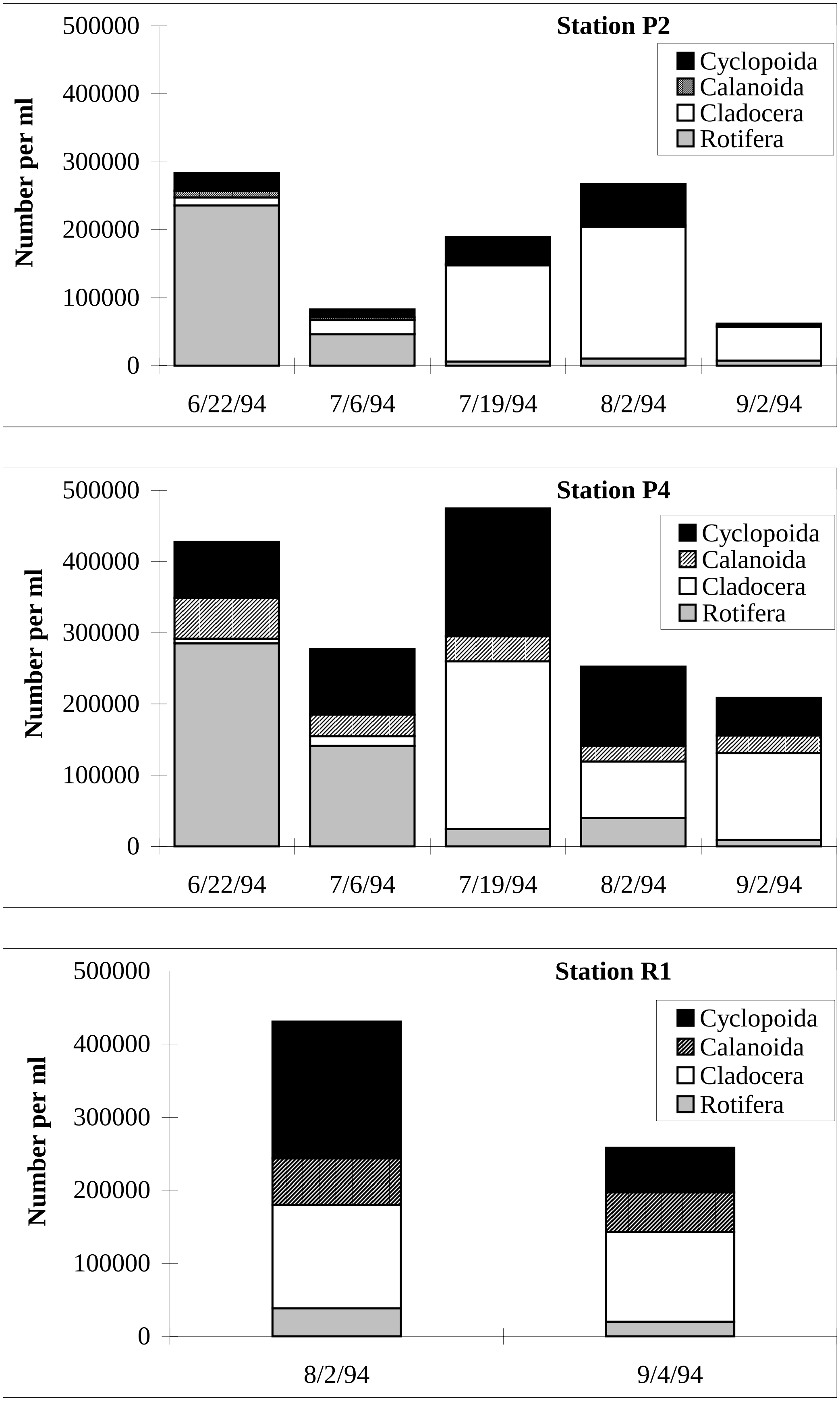


Figure 4.3.13 : Zooplankton densities at stations P2, P4 and R1, Cayuga Lake, New York,
Summer 1994. Source: Stearns & Wheler 1994

Mysis relicta is an important component of the Cayuga Lake food web. The species is a food source for juvenile lake trout (*Salvelinus namaycush*), alewife (*Alosa psuedoharengus*), and smelt (*Osmerus mordax*) (Brownell 1970). Chiotti (1980) considers that abundance of *Mysis relicta* limits growth rate of juvenile lake trout. *Mysis relicta* is an opportunistic omnivore feeding on detritus, benthic invertebrates, phytoplankton and zooplankton (Lasenby, Northcote, and Furst 1986).

Because of the potential vulnerability of this organism to entrainment by a deep-water intake, *Mysis relicta* was a focus of environmental investigations of Cornell's Lake Source Cooling project. Field investigations were carried out from 1994 – 1996 to define the distribution and abundance of *Mysis relicta* in Cayuga Lake, expand the scientific understanding of the animal's life history, and assess the effectiveness of artificial light as a means to keep the animal from being drawn into the intake. Dr. Lars Rudstam of Cornell's Biological Field Station at Shackleton Point on Oneida Lake was the lead investigator. Investigations were conducted using high frequency hydroacoustics and nets.

Significant findings of these investigations are as follows (Stearns & Wheler 1997):

Life History

- The Cayuga Lake population of *Mysis relicta* is composed of two overlapping generations or cohorts. Each cohort has a generation time of 18 to 24 months. The animals are released as 3 to 4 mm juveniles between October and April, and reach sexual maturity in July to October of the following year. Thus, at any one time, there are three cohorts that overlap in size: the winter cohort, the yearling (age one), and the adults. Some females may also spawn a second time in the summer.

- The summer growth rate is estimated at 1 to 1.5 mm/month or 0.033 to 0.050 mm/day. Winter growth rate is approximately one-third to one-half of the summer value, thus retarding growth and sexual maturity to maintain an 18- to 24-month cycle.

- The average length at sexual maturity for the species is 12 to 14 mm for males and 14 to 16 mm for females. Males die shortly after mating. Individuals can reach sexual maturity in 13 to 16 months, and females have a gestation time of 2 to 3 months before releasing young. Life span in Cayuga Lake is 16 to 24 months.

Distribution and Abundance

- *Mysis relicta* are distributed throughout all suitable habitats in Cayuga Lake. Due to patchiness in distribution, variance between samples collected in different regions of the lake is high. The animals are not significantly more abundant in the southern basin as compared with the rest of Cayuga Lake. For example, based on an intensive survey completed in spring 1996 lakewide abundance of *Mysis relicta* was 86 organisms per square meter of lake surface (N= 58, standard deviation = 64). In southern Cayuga Lake, abundance was estimated at 103 organisms/m^2 (N=36, st.dev = 57).

- The pigments in the eyes of the Cayuga Lake *Mysis relicta* population are most sensitive to light of wavelength 520 nm (Rudstam and Lowe, unpublished data 1996). This finding, coupled with measured wavelength-specific light extinction coefficients, has enabled researchers to estimate the depth to which the critical wavelengths of light penetrate into Cayuga Lake. This calculated light level is correlated with the depth at which *Mysis relicta* are found during daylight conditions.

- Daily variations in irradiance, and perhaps seasonal illumination patterns, dictate the depth to which *Mysis relicta* descend. During summer conditions, organisms were off the bottom at water depths of 70 m to 90 m. During the spring survey, the animals were suspended off the bottom at water depths between 50 and 65 m. These water depths correspond to a light intensity in the range of 10^{-4} lux.

- Diurnal migrations were tracked to estimate the swimming speed of *Mysis relicta* through the water column. Based on detailed data from an August 1995 survey, the organisms can swim at a rate of 36 – 60 meters per hour.

Effectiveness of Light

- In a series of experiments conducted in 1995 and 1996, investigators demonstrated that artificial light is an effective deterrent to *Mysis relicta.* Increasing wattage excluded the organism to a greater distance from the light source. The intake for Lake Source Cooling has been designed with sufficient illumination to repel the animals from a region corresponding to the induced flow field around the LSC intake. The potential for entrainment is therefore greatly reduced.

4.3.3.4 Macroinvertebrates (zoobenthos)

Benthic invertebrates spend all or most of their life cycle in or on the lake sediments. The most common taxa are crustaceans, insect larvae, oligochaetes, and mollusks. These organisms convert particulate detritus they use as a food source into protein that can be used for other animals in the food web. Benthic invertebrates exhibit spatial zonation along gradients related to depth of the overlying water. In general, benthic communities are more dense and diverse in shallower water, probably due to the higher quantities of nutrients and higher diversity of microhabitat created by macrophytes (Thorpe and Covich 1991). There are exceptions; littoral areas that are drawn down or experience significant ice scour or wave action tend to have lower diversity and abundance of benthic organisms.

Benthic macroinvertebrates (the benthos) of Cayuga Lake have been sampled at irregular intervals since Birge and Juday collected two samples in 1918. Oglesby (1978) summarized investigations of 1918, 1952 – 1953 and 1972. Additional sampling of the benthos was completed in 1994 as part of the Lake Source Cooling environmental investigations. All samples were collected in late July or early August.

Based on the analysis presented in Oglesby (1978), species composition and abundance of the major benthic invertebrate taxa in the profundal zone have remained relatively consistent over time. Quantitative comparisons are difficult to draw, as sampling methodologies and locations have changed with the objectives of each investigation. Benthic invertebrates tend to be distributed in a non-random (patchy) manner. Replicate samples were not collected in 1918 and 1972. Additional complexity is introduced by changes in taxonomy.

Given these caveats, a comparison of dominant species and density of benthic organisms is summarized in Table 4.3.19. The deepest station (station R) from the 1994 survey is included as most comparable to the earlier stations. The abundance of organisms was higher in 1994 than in the earlier surveys, although the 1972 sampling by Dahlberg might have produced comparable numbers had oligochaetes been enumerated.

Data from all five stations sampled in 1994 by Dr. Mills for the Lake Source Cooling investigations are graphed in Figure 4.3.14. Note the much greater abundance of organisms in the shallower samples.

4.3.3.5 Fish community

The primary data source for this section of the Watershed Characterization Report is the Environmental Impact Statement prepared for Cornell University Lake Source Cooling (Stearns & Wheler 1997). The principal author of the section is Myriam Ibarra, co-author Elizabeth Moran. Lars Rudstam of Cornell University provided extensive review.

Cayuga Lake contains two relatively distinct fish communities: the cold water community utilizing the extensive region of deep, well-oxygenated hypolimnion, and the warm water community utilizing the littoral zone and epilimnion. Historically, a total of 57 fish species have been reported within Cayuga Lake. Of these, 11 are believed to be no longer present due to habitat changes or competition from introduced species. The current fish community includes 46 species (Table 4.3.20) (Chiotti 1980).

Table 4.3.19 Comparison of Benthic Macroinvertebrate Sample Results

Date of Collection	**Station**	**Depth**	**Investigator**	**Taxa**	**Abundance (organisms / m^2)**
July 28, 1918	King Ferry	113 m	Birge and Juday	Chironomus	3863
				Pontoporeia	710
				Oligochaetes	1288
				Sum	**5861**
July 23, 1952	Taughannock	98-105 m	Henson	Pontoporeia	1459
				Oligochaetes	2525
				Pisidium	460
				Heterotrissocladius	325
				Ostracods	98
				Sum	**4867**
August 6, 1953	Taughannock	98-105 m	Henson	Pontoporeia	949
				Oligochaetes	7593
				Pisidium	221
				Heterotrissocladius	161
				Ostracods	304
				Sum	9228
July 25, 1972	King Ferry	Est 100 m	Dahlberg	*Pontoporeia*	2016
				Chironomids (including *Heterotrissocladius*	66
				Oligochaetes	Not enumerated
				sum	>2082
July 25, 1972	Taughannock	Est 100 m	Dahlberg	*Pontoporeia*	4506
				Chironomids (including *Heterotrissocladius*	20
				Oligochaetes	Not enumerated
				Sum	**>4526**
July 22, 1994	Meyers	90 m	Mills for LSC	Pontoporeia	1765
				Oligochaetes	3187
				Chironomids	184
				Ostracods	7084
				Sum	**12,220**

Source: Ogelsby 1978 pg 96
Stearns & Wheler 1997

4.3.3.5.1 Deep Water Fish Community

As discussed in Section 4.1, Physical Characteristics, approximately half of the volume of Cayuga Lake is deeper than 40 meters. The deep water supports a thriving fish community including water column (pelagic) and bottom oriented (benthic) species. The fish community is dominated by four salmonid species as the top predators: lake trout, rainbow trout, brown trout, and landlocked Atlantic salmon. Only the lake trout is native to Cayuga Lake; the other three salmonid species have been introduced. As described in the Strategic Fisheries Management Plan for Cayuga Lake (Chiotti 1980), the populations of all four salmonids are maintained by

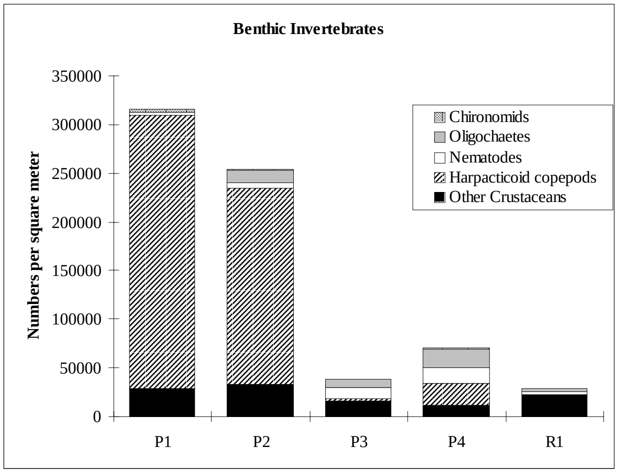


Figure 4.3.14 Abundance of benthic macroinvertebrates, Cayuga Lake, July 22, 1994. Source: Sterns & Wheler, 1994

Table 4.3.20 Fish Species Present in Cayuga Lake

Family	Species (Scientific Name)	Species (Common Name)
Petromyzontidae	*Petromyzon marinus*	sea lamprey
Acipenseridae	*Acipenser fulvescens*	lake sturgeon
Lepisosteidae	*Lepisosteus osseus*	longnose gar
Amiidae	*Amia calva*	bowfin
Anguillidae	*Anguilla rostrata*	american eel
Clupeidae	*Alosa psuedoharengus*	alewife
	Dorosoma cepedianum	gizzard shad
Cyprinidae	*Cyprinus carpio*	common carp
	Cyprinella analostanus	satinfin shiner
	Notropis hudsonius	spottail shiner
	Notemigonus crysoleucas	golden shiner
	Rhinicthys atratulus	blacknose dace
	Rhinicthys cataractae	longnose dace
	Semotilus atromaculatus	creek chub
	Semotilus corporalis	fallfish
Catostomidae	*Catostomus commersoni*	white sucker
	Hypentelium nigricans	northern hog sucker
	Moxostoma sp.	redhorse
Ictaluridae	*Ameiurus nebulosus*	brown bullhead
	Ictalurus punctatus	channel catfish
	Notorus flavus	stonecat
Esocidae	*Esox lucius*	northern pike
	Esox niger	chain pickerel
Osmeridae	*Osmerus mordax*	rainbow smelt
Salmonidae	*Coregonus artedi*	cisco
	Coregonus clupeaformis	lake whitefish
	Oncorhynchus mykiss	rainbow trout
	Salmo salar	Atlantic salmon
	Salmo trutta	brown trout
	Salvelinus namaycush	lake trout
Percopsidae	*Percopsis omiscomaycus*	troutperch
Gasterosteidae	*Culaea inconstans*	brook stickleback
Cottidae	*Cottus cognatus*	slimy sculpin
Percichthyidae	*Morone americana*	white perch
	Morone chrysops	white bass
Family	**Species (Scientific Name)**	**Species (Common Name)**
Centrarchidae	*Ambloplites rupestris*	rock bass
	Lepomis gibbosus	pumpkinseed
	Lepomis macrochirus	bluegill
	Micropterus dolomieui	smallmouth bass
	Micropterus salmoides	largemouth bass
	Pomoxis nigromaculatus	black crappie
	Pomoxis annularis	white crappie
Percidae	*Etheostoma olmstedi*	tesselated darter
	Perca flavescens	yellow perch
	Percina caprodes	logperch
	Stizostedion vitruem	walleye

Source: Chiotti, 1977, 1980, personal communication 1999 stocking. Stocking is needed due to failure of natural reproduction or high mortality of early-life stages.

Distribution of fishes in the water column is a result of species and size-specific responses to temperature, light, and predator-prey interactions. Distribution consequently varies with size and life stage of fish, time of day, and time of year. Juvenile salmonids prey on zooplankton while adult salmonids are largely piscivorous, eating alewives, rainbow smelt, troutperch, and slimy sculpin. Deep water species migrate to streams and littoral areas to spawn and, when water temperatures are low, to feed. At some times of the year (usually late fall through early spring when the lake is isothermal) deep water species can be found in littoral regions of the lake.

Daytime and nighttime hydroacoustical surveys were conducted to estimate distribution and abundance of the deep water fish community as part of the field investigations for Cornell's Lake Source Cooling initiative. Surveys were conducted in April, August, and October. High-frequency hydroacoustical equipment was applied; this technology uses split-beam sound waves to determine the target strength of individual fish and then applies the target strength of an individual fish to the total integrated echo response to estimate the absolute abundance of fish. Gill nets were set to confirm the hydroacoustical findings.

Results of the hydroacoustical surveys demonstrate that most fish are found in upper waters during the stratified period (Figures 4.3.15). Fish are more abundant closer to shore than towards the middle of the lake, and smaller fish are found at shallower depths. Few fish (less than 3% of the total biomass) were found in water deeper than 50 m in August or October. A subtle difference between night and day distribution was observed. Although the acoustical signal was concentrated in the top 40 m during day and night surveys, fish were generally found higher in the water column during the day. Two peaks of distribution were evident in the day surveys. One layer of schooling fish was present in shallow water (less than 10 m). A higher number of non-schooling (dispersed) fish was found at 40 m. The majority of the larger fish (which were presumably salmonids based on their size) were found below 20 m during both the August and October surveys.

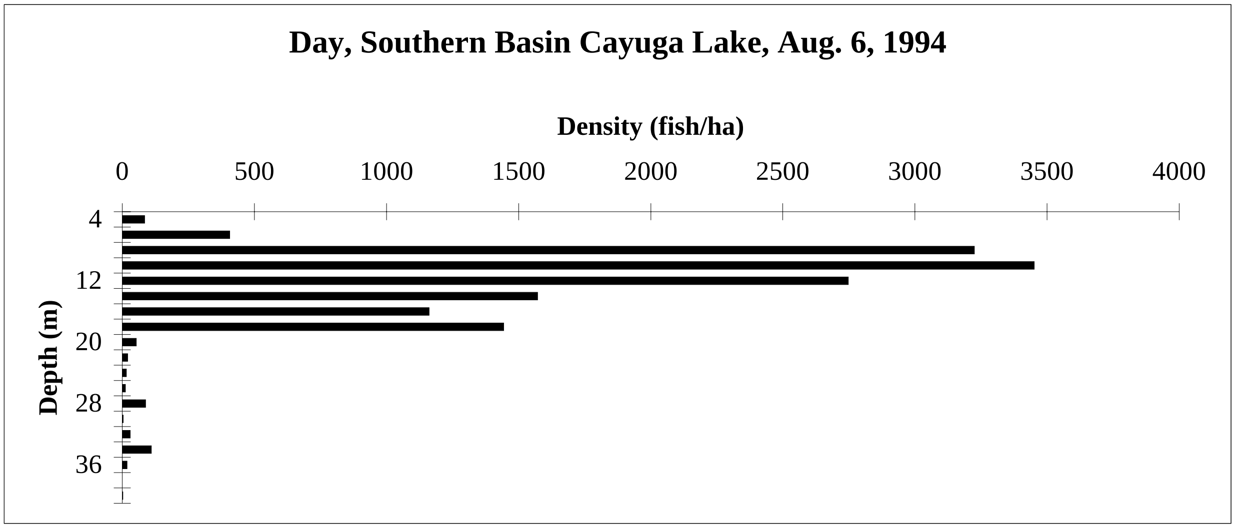
Based on the presence of some fish at the depth of the LSC intake during winter, the intake has been screened. This will prevent drawing fish into the cooling waterloop.

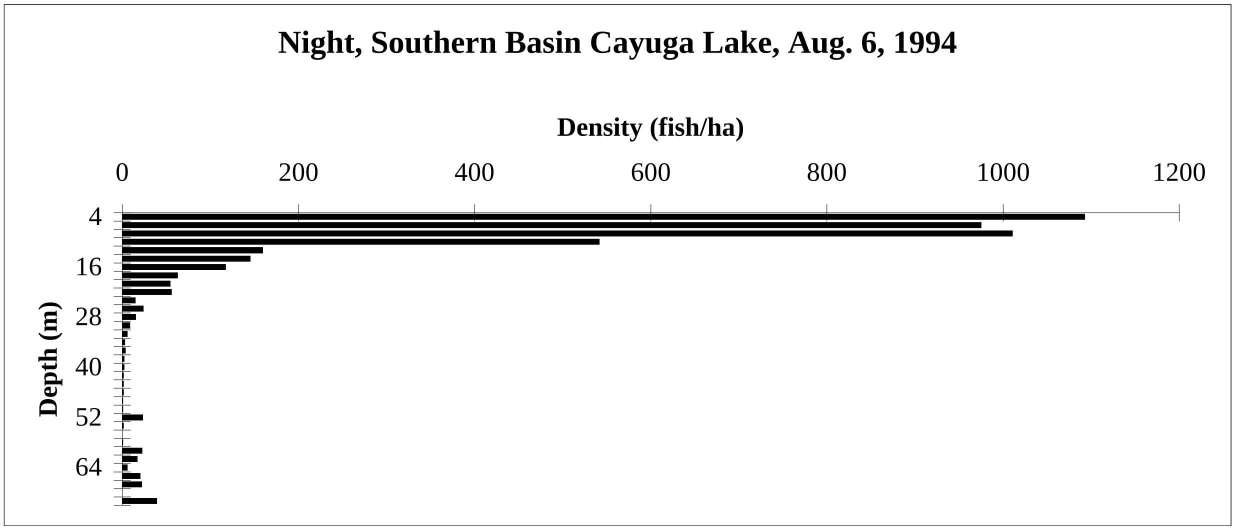
The April survey detected fish deeper in the water column, consistent with the limited historical data regarding winter distribution. Approximately 60% of the fish were present at depths shallower than 40 m during the April survey when the lake was isothermal. In contrast, recall that close to 90% of fish were at water depths shallower than 40 m during the April and October surveys when the lake was thermally stratified. Another one-third of the population was located between 40 and 60 m during the April survey and the remaining 7 % was found below 60 m.

The strength of hydroacoustical signal provided an indication of the size of fish detected during the April survey. Fish smaller than alewife and rainbow smelt formed the majority of the population to 20 m, and rapidly diminished with increasing water depth. Alewives and smelt formed an increasing percentage of the population as depth increased. Fish larger than alewife and smelt, including salmonids, were concentrated from 40 to 60 m, slightly deeper than the peak of 20 – 40 m during the stratified period.

Several graduate student theses have examined the depth distribution of Cayuga Lake fishes over portions of the annual cycle, and discussed the observations with respect to thermal preferences, predator-prey relationships, and reproductive behavior. Galligan (1951) focused on the distribution of lake trout and alewife. His data were collected using gill nets set during various seasons (primarily summer), depths, and locations in Cayuga Lake. He drew the following conclusions from his field program:

- During summer months, lake trout are most abundant in a relatively narrow band between 24 and 30 m. Distribution of this fish is consistent across size and age class.
- As the water cools in the fall, lake trout move towards shallower water.
- Distribution of the alewife is markedly similar to the distribution of lake trout.
- Alewives move to shallower waters to spawn (peak spawning period is late June-early July). Large schools can be observed in the evenings in near-shore areas.
- Beginning in October and November, alewives are found deeper in the lake. No alewives were found in water less than 13 m during winter sampling events.





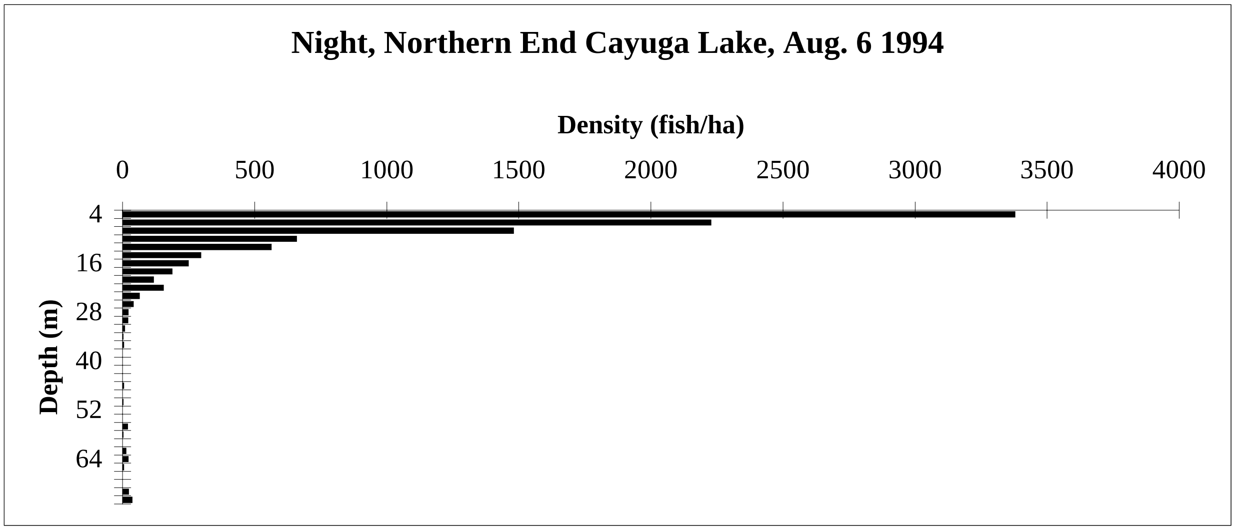


Figure 4.3.15 Fish densities, Cayuga Lake, New York, August 1994

Cayuga Watershed Characterization Report

Source: Stearns & Wheler 1997.

Another graduate student examined life history and distribution of the alewife in Cayuga Lake and concluded as follows (Rothschild 1962):

- Population of the alewife in Cayuga Lake fluctuates greatly from year to year.
- Mature alewives move into littoral areas in early summer, spawning takes place in mid-summer.
- Alewives are positively phototactic (attracted to light) except when exhibiting spawning behavior
- Young-of-year alewives are present in net catches by late August. They remain inshore into fall, but are recruited into the offshore (pelagic) population as fall progresses

Finally, Gibson (1981) used hydroacoustics and limited gill-netting to document depth distribution, temperature preference, and schooling behavior of Cayuga Lake alewife. He concluded that schools of alewives move progressively deeper in the lake as the water cools in the fall. Distribution appeared generally consistent with the upper limit of the thermocline and associated deep layers of *Mysis relicta* and other planktonic organisms. However, there appeared to be a well-defined limit to the depth distribution of the alewife; no fish were detected at water depths below 75 m.

Table 4.3.21 summarizes information on temperature preferences and summer distribution of Cayuga Lake cold water fishes. Table 4.3.22 provides a summary of reproductive biology.

Lake Trout

The dominant sport fishery in Cayuga Lake is for lake trout. Despite the fact that the lake trout is native to Cayuga Lake, the species is no longer able to reproduce naturally within the lake. The lack of reproductive success is manifested in the “Cayuga Syndrome” an early life mortality syndrome evident in salmonids in several Finger Lakes and Great Lakes. Several days after hatching, close to 100% of the swim-up fry die during yolk absorption. Various explanations for the mortality have been advanced including contamination by chemicals or infectious diseases (Fynn-Aikins et al. 1998). The hypothesis with the strongest experimental support is that the mortality is due to thiamin deficiency in the parent (brood) stock of salmonids caused by consumption of forage fish that contain thiaminase (Fisher et al. 1995). The Cayuga Syndrome is found in Finger Lakes with alewife and rainbow smelt, both of which contain the enzyme thiaminase.

Table 4.3.21 Thermal Preferences, Deep Water Fishes

Species	Preferred Temperature
lake trout	10 °C
rainbow trout	young > 19 °C
	adult 15 °C
brown trout	10 – 18 °C
Atlantic salmon	10 – 13 °C
yellow perch	young 15 – 20 °C
	adult 15 – 16 °C
alewife	young 15 – 20 °C
	adult 11 – 14 °C
smelt	larvae: 10 – 14 °C
	adult 7 – 12 °C
troutperch	14 – 18 °C
slimy sculpin	< 6°C

Sources: Smith 1985, Brandtt et al. 1980

The lake trout population has been maintained through a stocking program that started as early as 1897 (Chiotti 1980). Abundance has fluctuated due to variations in stocking rates and the abundance of forage fish. Relatively high stocking rates and high recruitment allowed a rapid increase of the lake trout population in the 1950’s. The fishery was less productive in the 1970’s (Chiotti 1980), but recovered again in the 1980’s (Bishop 1992). Since the 1980’s, 72,000 yearling equivalents have stocked annually in the lake. However, in the late 1980’s, there was an inverse relationship between adult densities and growth rates of juveniles. This suggests that the lake trout population in Cayuga Lake is approaching carrying capacity (Bishop 1992).

Table 4.3.22 Spawning Requirements, Deep Water Fishes

Fish Species	Habitat	Spawning Period	Temperature (°C)	Reproductive Population
lake trout	Lake, 30 – 50 m	Sept. – Oct	10 °	no
rainbow trout	Streams, gravel	April – June	10 – 15 °	yes
brown trout	Streams, gravel	Nov. - Jan	4-8 °	no
Atlantic salmon	Streams, rocky	Oct. – Nov	6 – 8 °	no
cisco	Lake, rocky shoals	Late fall	Ice forming	yes (limited)
alewife	Lake shores	May – Aug	10 – 21 °	yes
smelt	Streams, crevices	Feb. – March	9 °	yes
troutperch	Streams, rocky	Feb. – march	19 °	yes
slimy sculpin	Lake-streams, crevices	April – May (streams)	2 – 13 °	yes
sea lamprey	Streams, riffles	April – Aug.	10 – 21 °	yes

Sources: Smith 1985, Becker 1983, Scott and Crossman 1973, Chiotti 1980

The lake trout spends most its life in deep water. The preferred temperature of lake trout is about 10 °C. (Youngs and Oglesby 1972; Chiotti 1980). In the Great Lakes, this species is most abundant between 30 and 90 m. The fish mostly stay on or near the lake bottom, but a few may occur in the open water offshore (Becker 1983). In Cayuga Lake, the NYSDEC samples the lake trout population in August using gill nets set below the thermocline, typically between 30 and 55 m (Bishop 1992).

Lake trout smaller than 25 cm feed primarily on the hypolimnetic crustacean *Mysis relicta* (Youngs and Oglesby 1972) and occasionally on the benthic amphipod *Diporeia affinis*, sculpin, and small alewives. Fish larger than 25 cm prey mostly on alewives (Youngs and Oglesby 1972, Chiotti, Sage, and Emerson 1977, Bishop 1992), especially during the summer months. Slimy sculpin, rainbow smelt and troutperch are also part of the diet. Lake trout prey on smelt during the spring when the surface waters are cool and smelt congregate near the mouths of tributaries to spawn. As the trout get larger, the proportion of alewives in the diet increases (Chiotti, Sage, and Emerson 1977). This finding is consistent with observations of lake trout in the Great Lakes (Stewart et al. 1983).

Rainbow Trout

Another important sport fish in Cayuga Lake is the rainbow trout, an introduced species. Rainbow trout is one of the most tolerant of the salmonids to a wide range of temperatures. Juveniles prefer to be at about 19° C (Rand et al. 1993). In Lakes Michigan and Superior, rainbow trout prefer shoal water that is 4.6 to 10.7 m deep (15 to 35 ft) (Becker 1983). Little is known of their distribution in Cayuga Lake, but extensive movement in the lake is suspected (Youngs and Oglesby 1972).

The first introduction of rainbow trout to Cayuga Lake in the 1800's was apparently unsuccessful. Introductions between 1954 and 1958 led to the establishment of a self-sustaining population in Cayuga Inlet and Salmon Creek. The population has apparently been stable since 1965 (Chiotti 1980). However, the wild populations are not large enough to provide a strong lakewide fishery. The limiting factor for more natural reproduction is the availability of nursery areas in tributaries. For this reason NYSDEC has been stocking Cayuga Lake with rainbow trout since 1975. In the 1980's, some 40,000 yearlings were stocked annually and accounted for 30 to 40 percent of the harvested fish.

Rainbow trout spawn in the spring in tributaries to Cayuga Lake. Younger and mostly male spawners migrate to the streams in the fall and remain there until spring when the majority of spawners join them. Migrant fish have been trapped in the Cayuga Inlet fishway from October to April (Boreman 1974). Spawning occurs on gravely substrate, usually in riffles. The juveniles reside in the stream up to three years, migrate to the lake where they stay for two years, and then return to spawn in their stream of origin (Youngs and Oglesby 1972). Less than 10 percent of the females and even fewer males survive to spawn the following year.

Rainbow trout in the Great Lakes feed on aquatic and terrestrial insects, zooplankton, and macroinvertebrates; as they grow larger, they eat progressively more rainbow smelt and alewives (Rand et al. 1993). Food habits of the Cayuga Lake rainbow trout population have not been examined, but there is no reason to believe that they would differ greatly from those found in the Great Lakes.

Brown Trout

Brown trout were first introduced to Cayuga Lake in 1917 (Chiotti, Sage, and Emerson 1977). A recreational fishery is maintained by annual stocking of 15,000 yearlings. There are no published data on distribution of brown trout in Cayuga Lake. Because their preferred temperature is 10 to 18.3 °C (Becker 1983), brown trout probably inhabit the metalimnion Cayuga Lake. Young brown trout feed on zooplankton and benthic invertebrates. Adults feed mostly on fish.

Landlocked Atlantic Salmon

Landlocked salmon were re-introduced to the lake in 1957, and small populations are maintained by stocking. Throughout the 1980’s, about 15,000 yearlings and 270,000 spring fingerlings were stocked annually in tributaries. Apparently, relatively low proportions of these fish return to spawn in the tributaries. Most of the catch occurs in the lake. In recent years, Cayuga Lake has supported a popular fishery for the landlocked salmon (Chiotti, personal communication, November 1996).

Alewife

The alewife is the most important forage species for salmonids in Cayuga Lake. It is not known whether the alewife invaded the lake through the canal system, was introduced by anglers, or has been present since the last glacial recession (Youngs and Oglesby 1972). Mills et al. (1993) report that the alewife was discovered in Lake Ontario in 1873, and either expanded through the canal system from the Atlantic drainage or was native in the Great Lakes, but its numbers were depressed by salmonids.

Thermal distribution of the alewife differs significantly between day and night and between young and adults. Mature individuals move inshore from June to August. During spawning, they crowd the shore, and during the winter they may be found at depths up to 75 m. They also tend to move inshore at night and return to deeper waters during the day. After spawning, they move to the sublittoral waters. In Lake Michigan, young alewives prefer temperatures greater than 15 °C, while adults are most abundant at 11 to 14 °C (Brandt, Maguson, and Crowder 1980). Rothschild (1962) reported that alewives in Cayuga Lake attain a maximum length of 15 cm (6 inches) and a maximum life span of five to six years.

Janssen and Brandt (1980) investigated vertical distribution and feeding habits of alewives over the 24-hour cycle in Lake Michigan. A vertical migration was documented. Adult alewives concentrated near the bottom (in 50 m of water) during the day, and migrated to mid-water depths at night. The upper limit of vertical migration was closely linked to the distribution o *Mysis relicta* and to the depth of the thermocline during stratified periods (Janssen and Brandt 1980). Alewife appears to avoid the steep thermal gradient associated with the thermocline (O’Gorman 1997).

Bergstedt and O’Gorman (1989) have documented winter distribution of the alewife in Lake Ontario near Oswego. Just as in Cayuga Lake, alewife moves deeper into the water column as the thermocline deepens in the fall. Results indicate that alewives are pelagic during the winter period, and are distributed in a stratum 40-80 m below the water surface. Distribution of the fish was quite uniform between the survey dates, suggesting little migration during winter. Warmer water habitat was available deeper than 40-80 m in Lake Ontario during the winter survey, but alewives were not common below 100 m depth. The preferred depth of 40-80 m is consistent with the distribution of alewife in its native oceanic environment, when southerly migration each winter leads the species to warmer water (Bergstedt and O’Gorman 1989; O’Gorman personal communication 1997).

The young alewife feeds almost exclusively on zooplankton, while the older fish also include *Mysis relicta* and *Diporeia affinis* in their diet (Hewett and Stewart 1989). In Lake Michigan, adult alewives closely followed *Mysis relicta* migrations at night and preyed on them (Janssen and Brandt 1980). Larger alewives also appear to be effective predators of the early life stages of many fishes, especially those with pelagic larvae, such as yellow perch and the coregonines, including cisco and whitefish (Crowder 1980; Eck and Wells 1987). In Cayuga Lake during the fall, the alewife reportedly feeds on the water column invertebrates *Bosmina*, *Daphnia*, and *Diaptomus*.

Hennick (1973) examined the growth rate of alewife and its relationship to zooplankton biomass and water temperature. Alewives were collected in experimental gill nets, set vertically at a station just north of Salmon Creek at Myers Point. He concluded that the growth rate of yearling alewives could be explained by fluctuations in food supply.

Rainbow Smelt

Rainbow smelt were introduced to Cayuga Lake in 1920. Populations remained low until the mid-1940's, when there was a marked increase of spawners. In Cayuga Lake, smelt are found at depths between 20 and 45 m in the summer. In the fall they move to shore, and during winter, they are found inshore at water depths of about 15 m. During stratification, young-of-year smelt are above the thermocline, where temperatures are 8 to 15 °C, segregated from older fish, which remain below the thermocline where temperatures are less than 10 °C (Lantry and Stewart 1993). Optimum temperatures for smelt are 6.1 to 13.3 °C (Becker 1983). Smelt spawn in March and April in all tributary streams. Three southern tributaries (Fall, Salmon, and Taughannock Creeks) support a popular dip netting fishery for the spring spawning run (Chiotti 1980).

In Cayuga Lake, young smelt prey primarily on *Mysis relicta* and secondarily on *Diporeia affinis* (Youngs and Oglesby 1972). Adult smelt are highly cannibalistic and also prey heavily on young alewives, which move offshore during the fall (Becker 1983).

Troutperch

Troutperch are native to Cayuga Lake, where they occur in shallow to intermediate depths. During the day, their preferred temperature is 7 °C and at night they expand their range to 15 to 16 °C (Brandt, Magnuson, and Crowder 1980). Troutperch probably migrate to spawn in tributary streams to Cayuga Lake from May to July (Smith 1985).

Young troutperch consume zooplankton, and older individuals eat *Mysis relicta*, *Diporeia affinis,* and chironomids. Lake trout, other salmonids, yellow perch, and northern pike prey on troutperch (Becker 1983).

Slimy Sculpin

This cold water species is typically distributed below the thermocline in Cayuga Lake, but also occurs in cooler tributaries. Although there is information on the reproductive habits of the population in Cayuga Inlet, little is known about the biology of the lake's population (Smith 1985). Sculpin are preyed upon by lake trout and probably by other salmonids as well (Youngs and Oglesby 1972, Chiotti, Sage and Emerson 1977). The fish feeds primarily on insect larvae; however, the stomachs of a few large individuals have been found with small fish and fish eggs (Koster 1936, cited in Smith 1985). In Lake Michigan, they also feed on *Diporeia affinis* and *Mysis relicta* (Kraft and Kitchell 1986).

Cisco

Ciscoes are native fishes whose population declined after the establishment of the alewife in Cayuga Lake (Youngs and Oglesby 1972). They are found in waters 25 to 43 m deep and are usually below the thermocline in the summer. In the fall, ciscoes move into shallow areas and spawn when ice is forming along the shores. Ciscoes are zooplanktivores throughout their lives.

4.3.3.5.2 Shallow Water Fish Community

Due to its morphology Cayuga Lake has a relatively small area of littoral habitat to support the warm water fish community. The majority of habitat is found at the extended shelf on the northern end of the lake; the small shelf in the southern lake provides additional habitat. These areas are home to warm water fish assemblages. Dominant predators include smallmouth bass, largemouth bass, and northern pike. These fish prey on yellow perch, pumpkinseed, bluegill, rock bass, and various minnows. With the exception of largemouth bass, all these fish are indigenous. Largemouth bass were introduced with construction of the canal system. In the southern end, there is a population of white sucker that spawn in Cayuga Inlet and other southern tributaries. Reproductive requirements of the common littoral fishes are summarized in Table 4.3.23.

Table 4.3.23 Spawning Requirements, Littoral Fishes

Fish Species	Habitat	Spawning Period	Temperature
Smallmouth bass	Gravel	May – July	17 – 18 °C
Largemouth bass	Vegetation	May – June	> 15 °C
Northern pike	Vegetation	March – April	10 °C
Chain pickerel	Vegetation	April – May	8 - 11°C
Yellow perch	Vegetation	April – May	7 – 11 °C
Black crappie	Vegetation	May - July	20 °C
Bluegill	Gravel	May – July	>21 °C
Golden shiner	Vegetation	May - August	>20 °C
Rock bass	Gravel	April – June	20-23 °C
Pumpkinseed	Vegetation	May – August	>15 °C
White sucker	Gravel	April – June	5 – 12 °C
Carp	Vegetation	May - August	17 °C
Brown bullhead	Crevices	May - June	17 °C
Spottail shiner	Sand	June - July	Undocumented, probably 15-. 20 °C
Tesselated darter	Undersides of rocks	April	Undocumented, probably. 5 - 10 °C

Sources: Smith 1985, Becker 1983, Scott and Crossman 1973

Smallmouth Bass

A large population of smallmouth bass provides an excellent fishery at the northern end of the lake (Youngs and Oglesby 1972). Spawning takes place in the southern tributaries from May to July. Tag return data suggest extensive movement of smallmouth bass in the lake. Smallmouth bass are found at 2 to 9 m along the shore and in the autumn to depths of 13 m. The fish prefer temperatures of 20 to 27 °C; waters below 10 °C make the fish lethargic. In the winter, smallmouth bass seek refuge among rocks and ledges where they remain semidormant until spring (Becker 1983).

Smallmouth bass are opportunistic predators. Small fish eat zooplankton. As they grow, their diet shifts to insects, crayfish, frogs, and a variety of small fish, particularly yellow perch (Smith 1985).

Other Species

Historically, largemouth bass, chain pickerel, northern pike, yellow perch and bullhead have been less abundant than smallmouth bass in Cayuga Lake. In the past, these warm water fishes were objects of small local fisheries. They prefer warm weedy areas in the lake. Draining and filling of wetlands in the northern and southern ends of the lake have been detrimental to the habitat and populations of these fish. Active fisheries currently exist for largemouth bass, smallmouth bass, yellow perch and white crappie.

The southern end of the lake has a relatively large population of white suckers. These benthic feeders spawn in Cayuga Inlet in late April and May. Another common benthic feeder is the common carp.

An important species in Cayuga Lake is the sea lamprey. Like the alewife, the sea lamprey is considered an exotic species that may have invaded the lake through the canal system; however, there are scientists who believe it to be a relict of the last ice age and glacial retreat. Lamprey is a parasite of all large fish in the lake, but particularly of trout (Youngs and Oglesby 1972). Since 1969, the sea lamprey population has been partially controlled by removal of spawning adults at the fishway in Cayuga Inlet. A lampricide treatment applied in 1986 in Cayuga Inlet appears to have reduced the population of sea lamprey.

4.3.3.6 Exotics

The invasion of ecosystems by nonindigenous (exotic) species has become a problem worldwide (Enserink 1999). Travel and trade have facilitated introductions of species of plants and animals into new environments. Most imports die quickly, but an estimated one species in ten survive in the new environment. An even smaller percentage of the invaders (less than 1%) actually thrive and can outcompete native species; in many cases, invasive species alter the processing of energy and nutrients throughout the food web. Biological invasions are the second largest cause of the loss of biodiversity, second only to habitat destruction.

The Great Lakes have been repeatedly invaded by plants and animals. Since the 1800s, at least 136 exotic aquatic organisms of all types: plants, fish, zooplankton, mollusks, and algae have been introduced. More than one-third have been introduced in the last 30 years, coinciding with opening of the St. Lawrence Seaway. Because of the hydrologic connection, many species introduced to the Great Lakes ultimately are found in the Finger Lakes.

Some nonindigenous species have long been part of the Cayuga Lake ecosystem. Rainbow smelt, alewife, white perch, common carp, and sea lamprey were introduced to Cayuga Lake as were rainbow trout and brown trout. Introduced plant species include eurasian watermilfoil, curly-leaf pondweed, and purple loosestrife. Eurasian watermilfoil *Myriophyllum spicatum* is highly visible to lake users. As discussed in the section on macrophytes, abundance and dominance of this macrophyte have declined precipitously in recent years. The decline was concurrent with the discovery of herbivory by another nonindigenous species, *Acentria ephemerella*. Experiments with biological control of the purple loosestrife are underway; two leaf-eating beetles and a flower-feeding weevil are being tested for their effectiveness in controlling the spread of this wetland plant.

The water chestnut, *Trapa natans*, is a nonindigenous nuisance species of macrophyte. It has been present in Sodus Bay of Lake Ontario for a number of years and was recently detected in the Seneca and Oswego Rivers and the western area of Oneida Lake. Montezuma wetland at the northern end of Cayuga Lake is vulnerable to invasion by this species.

Some of the most recent invaders to the ecosystem are among the most visible. *Dreissena polymorpha* (zebra mussel) was first detected in Lake St. Clair in 1986. This small freshwater mussel has spread throughout the Great Lakes and their connecting waterways, the Finger Lakes, and many major river systems of the northeast. Zebra mussels entered Cayuga Lake through the Seneca River in the early 1990s and have spread from north to south. By 1996, zebra mussels were widely distributed throughout the lake, with dense populations in nearshore areas. Water suppliers, utilities, and other water users with intakes less than 10 m have found it necessary to employ control measures to minimize or prevent fouling.

A closely related species *Dreissena bugensis*, quagga mussel, was identified in Cayuga Lake in 1994 (Mills et al. 1995). Quagga mussels thrive in the same water quality conditions as zebra mussels except that their reproductive temperature limit is lower (8 °C as compared to 12 °C for the zebra mussel) and their preferred temperature range is wider (4 – 20 °C as compared to 12 – 20 °C for zebra mussel). The shape of the shells is different; quagga mussels are more rounded and appear to be better adapted for softer substrates (Mills et al. 1993).

In Lake Ontario, quagga mussels are more abundant than zebra mussels in deeper water. According to Mills (1996a) quagga mussels are displacing zebra mussels at depths greater than 25 m and their numbers are increasing. Mills (1996b) expects that quagga mussels will ultimately be the more dominant species in the Great Lakes and Finger Lakes. Native mollusks (clams and snails) are outcompeted in the presence of dreissenid mussels.

Long-term effects of zebra mussels on lakes include increased water clarity and an enriched benthos. Mussels feed by filtering particles suspended in the water column; large quantities of organic material is pulled down from the water column to the benthos. One result is an increase in the diversity and production of all groups of benthic organisms. Periphytin and macrophytes benefit from the improved water clarity and, like zoobenthos, benefit from the increased nutrients and organic carbon found at the sediment surface. Many benthic macroinvertebrates benefit from the increased surface area created by the mussel shells. Production of benthic feeding fish can increase from the improved food supply.

Two exotic crustaceans, the predatory cladoceran zooplankton *Bythotrephes cederstroemi* (spiny waterflea) and *Cercopagis pengoi* (predatory waterflea) are recent invaders of the Great Lakes with the potential for altering the aquatic ecosystem. By October 1999, *Cercopagis* was confirmed present in Cayuga Lake, while *Bythotrephes* was not. Predation by these zooplankton on smaller cladocerans has the potential to affect the size distribution and composition of the phytoplankton community. These organisms may also affect fish populations by competing with young-of the-year fish for prey, or by becoming prey for older fish.

Two exotic fish have recently been confirmed in the Great Lakes and may eventually find their way to Cayuga Lake. The round goby, *Neogobius melanostomus*, is an aggressive bottom-dwelling fish considered a voracious feeder. A native of the Caspian Sea, the goby was probably introduced in ballast water and is now found throughout the Great Lakes and in major river basins of the Midwest. The goby can take over prime spawning sites and will compete with native fish for habitat. The river ruffe (*Gymnocephalus cernuus*) is a small spiny perch with a high reproductive rate. This fish has been found in Lake Superior and connecting waterways.

The National Invasive Species Act of 1996 is the federal legislation to address the issue of nonindigenous species. This bill reauthorizes and expands the original 1990 legislation. A key provision is management of ballast waters, which limits the discharge of water from overseas ecosystems.

4.3.3.7 Pathogens and indicator organisms

Pathogens (disease causing microorganisms) originate from untreated or inadequately treated human sewage and wild and domestic animal waste. Pathogens can enter Cayuga Lake from point and nonpoint sources such as stormwater runoff and septic tank leachate. Human exposure to pathogens can occur from direct contact with or ingestion of contaminated waters. Elevated concentrations are more likely to occur in nearshore areas and at the mouths of tributaries, since microorganisms die once introduced to the aquatic environment.

The potential presence and abundance of many pathogenic microorganisms (including viruses) are assayed using indicator organisms such as coliform or streptococcal bacteria. Indicator organisms are easily measured by standardized protocols and their presence and abundance are correlated with the presence and abundance of pathogens. When the abundance of indicator organisms indicates that pathogens may be present over acceptable threshold levels, human use of the resource for drinking or water contact recreation may be restricted. Other pathogens such as *Giardia* and *Crypotsporidia* are assayed using direct measurements.

Existing data on pathogens and indicator organisms in Cayuga Lake are relatively limited. Distribution of microorganisms in the lake is extremely variable in time and space, and conditions in other areas or time periods cannot be inferred from the few results available

Monitoring for pathogens and indicator organisms is required of public water suppliers as part of their Dept. of Health permit. Concentrations of microorganisms in the intake water for the water treatment plants are consistently low.

Wastewater treatment plants discharging to the Lake and tributaries monitor their effluent for indicator organisms to comply with SPDES permit requirements. Effluent from the wastewater treatment plants is disinfected on a year-round basis. The treatment plants are in compliance with their requirement to maintain fecal coliform bacteria concentrations less than 200 cells per 100 ml (the standard for water contact recreation).

Monitoring is also required for bathing beaches Cayuga County Health Department routinely monitors bathing beaches for fecal coliform bacteria. According to Eileen A. O’Connor, Environmental Health Director, no beaches on Cayuga Lake have been closed in recent history. 1994 – 1998 monitoring data for four beach areas (at two water depths) are presented in (Table 4.3.24).

Tompkins County Health Dept. occasionally monitors the area around Stewart Park for fecal coliform bacteria. Because there is no public swimming beach at this park, monitoring is not conducted on a routine basis. Monitoring has occasionally demonstrated elevated levels of fecal coliform bacteria in nearshore areas. The relative contribution of waterfowl, urban stormwater, and effluent from the wastewater treatment plants is not known.

A microbial source tracking study was done on nearby Owasco Lake (Samadpour, 1999). Genetic fingerprinting data from a total of 335 E. coli isolates from 11 sampling stations (site samples) and various sources of microbial pollution in the Owasco Lake Watershed were analyzed.

Table 4.3.24 Results of Cayuga County Health Dept. Monitoring for Fecal Coliform Bacteria, 1994 – 1998

Location and Date	**Fecal Coliform Bacteria (cells/100 ml)**	
	Sample at 18 inches	**Sample at 60 inches**
Wells College Dock (Aurora)		
7/30/98	20	2
7/15/98	11	18
6/23/98	15	12
8/6/97	30	44
7/16/97	41	20
7/1/97	23	31
7/9/96	11	8
6/20/96	380	10
7/26/95	670	160
8/8/94	327	<10
Frontenac Park		
7/30/98	51	45
7/15/98	22	71
6/23/98	29	
8/6/97	123	76
7/1/97	35	54
8/14/96	41	5
6/27/96	100	10
8/16/94	83	167
8/8/94	345	227
Harris Park		
7/15/98	13	54
6/23/98	31	29
8/6/97	175	210
6/30/97	120	
6/27/96	44	
8/14/96	<10	
7/13/95	10	7
Camp Gregory		
7/30/98	66	15
7/15/98	21	18
6/23/98	16	11
8/8/94	5600	2800
8/16/94	100	
7/18/94	173	27

Source: Cayuga County Health Dept. March 1999

The sampling stations included four of the major tributaries to the lake, the Owasco Outlet, and four lake sites (beaches). The tributaries had 60 E. coli strains analyzed with 42% matching to known sources. The major sources matched to agriculture (cows) and wildlife (waterfowl and deer). The minor sources matched to humans and pets. The beaches and Owasco Outlet had 119 E. coli strains analyzed with 38% matching to known sources. The major sources matched to wildlife (largely waterfowl). The intermediate sources matched to agriculture. The minor sources matched to humans and pets.

4.3.4 Compliance with ambient water quality standards and guidance values

In New York, the DEC classifies surface waters according to their designated "best use". Cayuga Lake is classified into four distinct segments, reflecting differences in the lake's morphometry (shape and depth of the basin) and water quality. South of McKinneys Point, Cayuga Lake is Class A, with a designated best use for water supply (with filtration). The main, deep body of the lake is Class AA (T), with a designated best use for water supply (without filtration). The T designation indicates that the waters support a salmonid fish community. Another Class A (T) segment begins at the northern shelf. The northernmost segment of the lake, including the Seneca-Cayuga Canal and the lake outlet, is Class B (T) with a designated best use for water contact recreation. These segments are displayed in Figure 4.3.16

Each designated use has an associated set of ambient water quality standards and guidance values designed to protect the ecological community and human uses associated with the use. These standards and guidance values are based on the best available scientific information relating water quality to human health and ecological integrity.

Monitoring data are used to evaluate whether water quality supports the designated use of the surface water resource, by comparing measured values to ambient water quality standards and guidance values. When monitoring detects adverse water quality conditions, that may affect a designated use, DEC adds the lake or stream to its list of “priority waterbodies” (the PWL). Waterbodies are ranked on a scale of increasing severity: *Threatened* (conditions indicate potential impairment to best use), *Stressed* (evidence of adverse water quality conditions), *Impaired* (designated use only partially met), and *Precluded* (designated use not met).

Two segments of Cayuga Lake are included on the NYSDEC 1998 305(b) Report. Southern Cayuga Lake in Tompkins County {5000 acres of Class A and a portion of the Class AA (T) segments} is considered “threatened” by silts. The affected use is water supply, and the primary source is identified as streambank erosion. 6000 acres of the Class A (T) segment northern Cayuga Lake, Seneca and Cayuga Counties, is considered “impaired” by nutrients. The affected use is recreational, boating and swimming, and the primary source is listed as on-site septic systems.

A subset of the PWL is the 303d list, named for the section of the federal Clean Water Act requiring states to report to EPA those waterbodies requiring a watershed approach to water quality protection or restoration. A watershed approach examines all point and nonpoint sources of nutrients and develops an integrated strategy for improvement. In April 1998, New York added Cayuga Lake to the 303d list, noting a need for additional information.

Overall, the waters of Cayuga Lake are in compliance with applicable ambient water quality standards and guidance values developed to protect the designated use. There are gaps; however, data we have examined show that the lake supports its designated uses. The standards and associated data supporting this statement are summarized in Table 4.3.25. Recent improvements in water clarity in northern Cayuga Lake are documented in the Secchi disk transparency data of Seneca County Soil and Water Conservation District (refer to Figures 4.3.6 and 7). The improved water clarity, a likely result of the zebra mussel invasion, may alter the listing of this water segment on the next revision of the PWL.

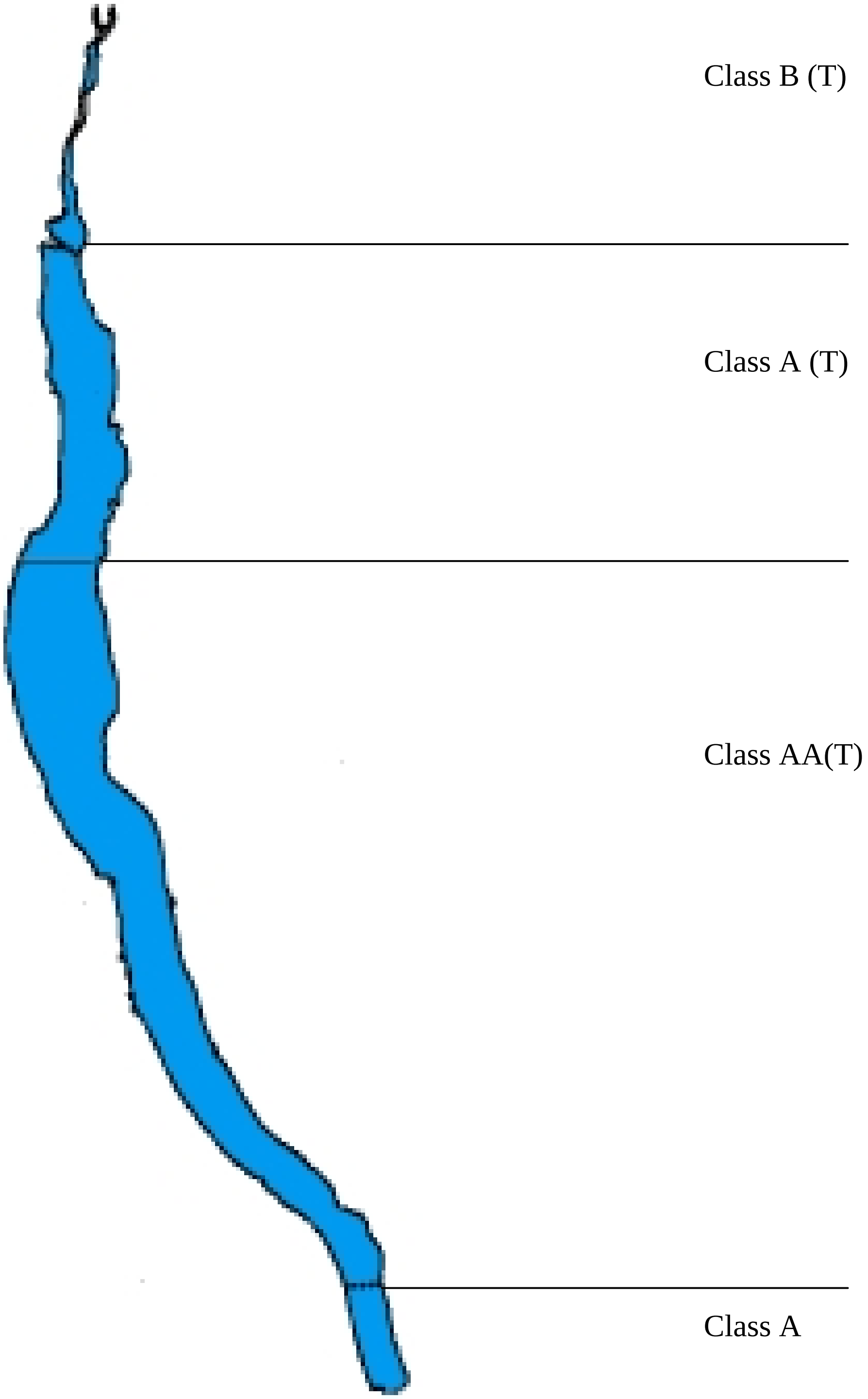


Figure 4.3.16. Classification segments of Cayuga Lake

TABLE 4.3.25

Regulatory Compliance, Cayuga Lake Waters

Cayuga Watershed Characterization Report

Parameter (units)	**NYSDEC Standard**	**Reported Data**
pH (standard units)	Shall not be less than 6.5 nor more than 8.5	Upper water summer pH occasionally exceeds 8.5
Dissolved Oxygen (mg/l)	Minimum daily average 5.0 mg/l, at no time shall DO be < 4.0 mg/l	No violations throughout water column
Dissolved Solids (mg/l)	Shall be kept as low as practicable to maintain the best usage of waters but in no case shall it exceed 500 mg/l.	No violations
Fecal Coliform (cells/100 ml)	The monthly geometric mean, from a minimum of five examinations, shall not exceed 200 cells/100ml.	Limited data available at required temporal frequency. Occasional single measurements exceed 200 cells/100 ml
Ammonia-N (mg/l)	Varies with pH and temperature.	Elevated NH3 in mixing zone at IAWWTP outfall. Occasional exceedance chronic toxicity, no exceedance acute toxicity.
Arsenic * (1) (µg/l)	190 µg/l	Required monitoring at water intakes; No violations
Cyanide * (µg/l)	5.2 µg/l (Free CN)	Limited data No violations
Nitrite-N (µg/l)	100 µg/l (Warm water fishery) 20 µg/l (Cold water fishery)	Limited data No violations
Organic compounds	Variable for individual compounds	No violations

Parameter (units)	**NYSDEC Standard** (at hardness = 150 mg/l)	**Reported Data**
Copper (µg/l)	0.96 exp (0.8545 [ln (ppm hardness)] - 1.702) Standard: 12.7 µg/l	Required monitoring at water intakes; No violations
Mercury (µg/l)	0.2 µg/l	Required monitoring at water intakes; No violations
Lead (µg/l)	{1.46203 -[(ln hardness) 0.145712)]} exp (1.273 [ln harness)] - 4.297 Standard: 4.88 µg/l	Required monitoring at water intakes; No violations
Cadmium (µg/l)	0.85 exp (0.7852 [ln (ppm hardness)] - 2.715) Standard: 2.88 µg/l	Required monitoring at water intakes; No violations
Zinc (µg/l)	exp (0.85 [ln (ppm hardness)] + 0.50) Standard: 117 µg/l	Required monitoring at water intakes; No violations
Chromium (µg/l)	0.86 exp (0.819 [ln (ppm hardness)] + 0.6848) Standard: 248 µg/l	Required monitoring at water intakes; No violations
Iron (µg/l)	300 µg/l	Required monitoring at water intakes; No violations
Nickel (µg/l)	0.997 exp (0.846 [ln (ppm hardness)] + 0.0584) Standard: 73 µg/l	Required monitoring at water intakes; No violations
Total Phosphorus (µg/l)	None in amounts that will result in growths of algae, weeds, and slimes that will impair the waters for their best usages. Guidance value of 20 mg/l, *upper waters summer average.*	Mid-lake stations in compliance Southern, nearshore TP close to upper limit of guidance
Secchi Disk Transparency (m	NYSDOH guidance for bathing beaches 1.2 m June - Aug.	Limited data, no violation Mid-lake data in compliance

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