Chapter 5: Results and Findings

Results and findings from the Synoptic Water Quality Investigation will be presented in the following four sections: (a) thermal stratification and vertical profiles; (b) lake trophic indicators - Secchi Disk depths, total phosphorus, chlorophyll *a*, and dissolved oxygen levels; (c) major ions, specific conductivity, and pH; and (d) other analytes (nitrogen, silica, trace metals, etc.). Interpretation of study results will involve three components: (1) spatial comparison between the 11 Finger Lakes; (2) temporal trends for each lake based upon the current investigation and previous systematic investigations of the Finger Lakes, and (3) discussion of pertinent ambient water quality criteria and possible issues of concern.

As acknowledged by Birge and Juday nearly a decade ago, the Finger Lakes offer an excellent opportunity for comparative studies between similar lake systems. The lakes share similar origins and features, however, there are significant differences with respect to ecosystem structure, land use practices, management activities, etc., which can provide valuable insight regarding system response. This discussion will attempt to look for similarities and dissimilarities between this unique series of lakes.

Temporal comparisons will be limited to the two previous systematic water quality investigations of the Finger Lakes - the pioneering work of Birge and Juday (1914), and collaborative efforts from the late 1960s and early 1970s (Bloomfield, 1978) - and findings from the current investigation. On a cautionary note, comparisons of environmental data sets, collected by different researchers at different times, are notoriously difficult. Variations in station locations, sampling depths, sampling frequency, and analytical methods can confound attempts to detect water quality trends. These issues often interfere with rigorous statistical interpretation. That said, temporal comparisons of environmental data sets is an important process, and can provide some measure of the changes occurring within lake systems.

While the later two objectives (spatial and temporal comparisons) are primarily scientific concerns, it is also important to evaluate ambient water quality conditions within the context of a regulatory context. Thus, findings will be compared to applicable ambient water quality criteria as shown in Table 5.1. The specific criteria will be discussed within the relevant section. Instances of departure from applicable water quality criteria will be highlighted, as will other issues of potential concern within the Finger Lakes.

Table 5.1: Applicable water quality criteria

Parameter	Numerical Limit	Comments
Dissolved Oxygen	water class specific	NYSDEC water quality standard
pH	6.5 – 8.5	NYSDEC water quality standard
Total Phosphorus	20 ug/l	NYSDEC water quality guidance value
Water Clarity	1.2 m	Department of Health criteria for public beaches
Ammonia	based on Temp. & pH	NYSDEC water quality standard
Nitrate + Nitrite	10 mg/l	NYSDEC water quality standard
Sodium	See discussion	Department of Health drinking water criteria
Chloride	250 mg/l	NYSDEC water quality standard
Arsenic	50 ug/l	NYSDEC water quality standard
Lead	50 ug/l	NYSDEC water quality standard
Magnesium	35 mg/l	NYSDEC water quality standard

a. Thermal Characteristics and Vertical Profiles

Thermal stratification is a physical phenomenon which occurs in many lakes and/or reservoirs, and refers to the formation of distinct temperature layers within a water body. The process of thermal stratification is a consequence of the relationship between the temperature of water and its associated density (see further discussion in box below).

While thermal stratification is a physical phenomenon, it has profound effects on (other) physical, chemical, and biological processes within a lake. These effects are largely due to the formidable mixing constraints imposed by thermal stratification. Obviously, mixing constraints strongly influence circulation patterns (physical process) within a lake – in fact, in many ways, the stratified lake begins to behave like two distinct water bodies. The upper portion (or epilimnion) behaves much like a shallower version of the previously unstratified lake with well mixed conditions and efficient gas and thermal exchange with the atmosphere, while the lower portion of the lake (or hypolimnion) begins to "wall off" with little gas and/or thermal exchange with the overlying waters. This transformation from a non-stratified system into a stratified system, results in a cascade of secondary effects (chemical and biological) within the system. For example, this thermal barrier to vertical mixing can play a critical role in determining the level of dissolved oxygen available within the deep waters of a lake. In effect, thermal stratification forms a physical barrier to mixing between the upper layer of the lake (which can receive oxygen from the atmosphere) and the lower layer of the lake (which is unable to receive oxygen input from the atmosphere), thus, precluding oxygen replenishment of the deep waters. If dissolved oxygen demand within the hypolimnion is relatively low, then dissolved oxygen levels remain sufficient to sustain a diverse biota, however, if oxygen demand is high the lower waters become depleted of dissolved oxygen which can adversely effect resident biotic communities and modify chemical cycling within the lake. From a positive perspective, thermal stratification plays a central role in maintaining appropriate temperatures for certain thermally-sensitive organisms (e.g., salmonids). The same thermal barrier responsible for inhibiting oxygen exchange between upper and lower waters also works to limit thermal gain by the lower waters, thus maintaining lower temperatures at depth.

Each of the Finger Lakes, with the exception of Honeoye Lake, undergo prolonged thermal stratification during the growing season. The onset of thermal stratification varies somewhat between the lakes, but usually occurs between mid June and early July. In general, the smaller lakes (Otisco, Canadice, Hemlock and Conesus) stratify earlier in the season, and the larger lakes (Skaneateles, Owasco, Cayuga, Seneca, Keuka and Canandaigua) somewhat later. The reason(s) for this disparity are: (a) the larger lakes require larger thermal inputs than the smaller lakes, (b) the larger lakes are more susceptible to wind induced mixing due to greater widths and longer fetches, which tends to inhibit the process of thermal stratification, and (c) the larger lakes are capable of establishing internal waves, termed seiches, which can also thwart development of stratification. De-stratification, or the break down of thermal stratification, follows a similar pattern during the late fall or early winter in that the smaller lakes de-stratify earlier than do the larger lakes. The governing factor in de-stratification is the rate of thermal loss and the relative quantity of heat stored within the system. De-stratification usually occurs by mid October to early November in the smaller lakes, with the larger lakes following suite by late November to early December. The exact timing of both stratification and de-stratification varies from year to year depending upon the prevailing weather conditions during the given year.

Honeoye Lake, due to its relatively shallow depth and exposure to wind-induced mixing, tends to fluctuate between weakly stratified conditions and de-stratified conditions during the growing season.

Thermal Stratification

The density of water is dependent upon temperature (see figure 5.1 below). The maximum density of water occurs at slightly less than 4 °C. Thus, water with a temperature above or below 4 °C will tend to rise above or float on the denser, underlying water. In addition, on an incremental basis, the density of water changes more quickly as the temperature moves away from 4 °C (see Figure 5.2). These relationships set the stage for a process known as thermal stratification, or the formation of distinct water layers. During thermal stratification the water column “separates” into three distinct layers. The *epilimnion,* or upper layer of water, is characterized by uniform and relatively warm temperatures, continual mixing, and gas exchange with the atmosphere – the depth of this layer is determined by the depth of light penetration. The *metalimnion* (also known as the *thermocline*), or middle layer, is characterized by rapid temperature change per unit change in depth. The *hypolimnion*, or lower layer, is characterized by uniformly low temperatures, limited mixing, and minimal gas exchange with the adjoining layer.

The process of thermal stratification is a “battle” between competing physical processes. At northern latitudes the temperature of a lake during the winter and early spring is fairly uniform, due to low air temperatures and limited solar insolation. This relatively meager solar heating means that any temperature differentials which might arise are easily thwarted by wind-induced mixing. [Some lakes will, on occasion, undergo a period of weak thermal stratification during the winter as a result of ice cover inhibition of mixing.] As the year progresses into late spring and/or early summer, solar input to the lake increases and begins to warm the upper waters. In the absence of sufficient mixing to disperse the heat, this differential warming of the upper waters begins to establish a thermally-induced density barrier between the increasingly warm upper waters (epilimnion) and the colder lower waters (hypolimnion). At this juncture, Mother Nature, becomes the deciding factor on which camp wins out – if the weather turns cloudy, windy, and cold than mixing wins out, whereas, if the weather turns clear, calm, and warm then thermal stratification wins out. Ultimately, however, thermal stratification sets up, and once firmly established, it is able to enhance its edge (e.g., positive feedback mechanism) by increasing the temperature differential between the epilimnion and the hypolimnion. As the year progresses into late fall/early winter and solar input begins to wane, the epilimnion begins to cool and eventually approaches the temperature of the hypolimnion, leading to de-stratification, or the break down of the thermal layers. With the physical barrier to mixing removed, mixing once again dominates the entire system and the water column becomes homogeneous until the cycle is repeated in the spring.

Figure 5.1: Density vs Temperature

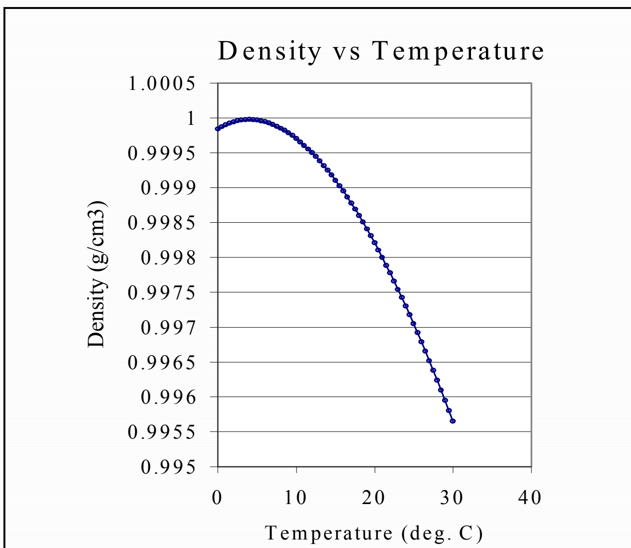
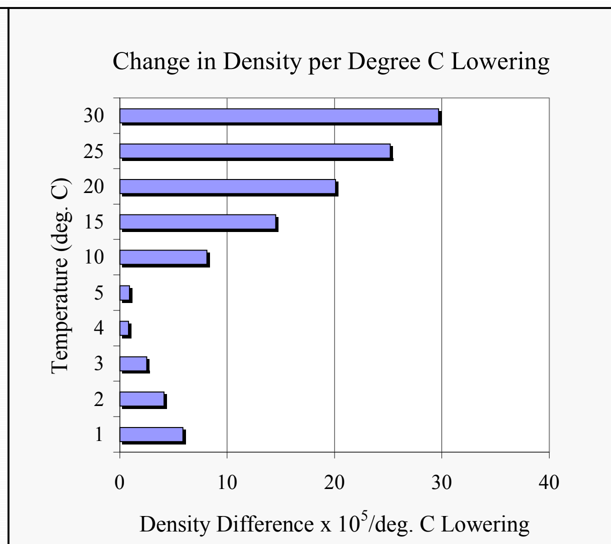


Figure 5.2: Change in density per degree C



Vertical profiles of temperature and dissolved oxygen representing late spring and mid summer conditions for each of the lakes are presented in Figures 5.3 – 5.6. For purposes of this discussion the reader should focus on the temperature profiles (blue lines). A subsequent section will discuss dissolved oxygen findings (green lines). With the exception of the late summer Skaneateles Lake profile, the measurements presented are from June and August of 1996, and while conditions vary from year to year, these measurements are representative of conditions found during similar time periods in subsequent years. The Skaneateles Lake profile for August is from 1997 due to equipment malfunctions during August, 1996.

The vertical profiles for Conesus, Honeoye, and Otisco Lakes during June and August of 1996 are shown in Figure 5.3. The Conesus Lake and Otisco Lake profiles provide a good illustration of the progressive enhancement of thermal stratification with time. The June profiles indicate some level of thermal stratification in both lakes, however, the two profiles are somewhat different in structure. Conesus Lake exhibits a more classic profile with a nearly uniform epilimnetic temperature (~ 17 °C) and hypolimnetic temperature (~ 10 °C) and a pronounced thermocline (~ 7 °C change over ~ 3 m). In contrast, Otisco Lake shows a somewhat unusual profile with temperature falling at approximately the same rate throughout the water column - thus, exhibiting a poorly defined thermocline. The August profiles for both Conesus and Otisco Lakes show an enhancement of thermal stratification with a larger differential between epilimnetic and hypolimnetic temperatures, however, as with the June profiles, the Conesus Lake profile is more characteristic of a true thermocline than is the Otisco Lake profile. As expected, given its relatively shallow depths, the Honeoye Lake profiles exhibit only weak thermal stratification during both June and August, with a temperature differential of only about 4 °C between the "epilimnion" and "hypolimnion" during each time period. The terms epilimnion and hypolimnion are probably not appropriate for Honeoye Lake during much of the year.

The vertical profiles for Owasco, Cayuga, and Seneca Lakes during June and August of 1996 are shown in Figure 5.4. The June profiles, for each lake, indicate the early stages of thermal stratification as evidenced by the small reduction of temperature with depth. However, thermal stratification in Owasco and Seneca Lakes is somewhat more advanced (note the beginnings of a defined thermocline) than in Cayuga Lake. The Owasco Lake thermocline begins at about 5 m and the Seneca Lake thermocline begins at about 8 m, likely reflecting the relative differences in water clarity (Secchi Disk depths for June, 1996: Owasco = 2.5, Seneca = 4.1). By August, thermal stratification is well established in each of the lakes. The Cayuga Lake and Seneca Lake profiles are nearly identical with the exception that surface temperatures in Seneca are slightly higher. Note the following similarities between the two temperature profiles: (1) boundary between the hypolimnion and the metalimnion (~ 35 m); and (2) lack of a well defined epilimnion – nearly uniform decline in temperature from the surface to the thermocline. The August profile for Owasco Lake is also noteworthy due to the appearance of a secondary thermocline. The primary thermocline starts at ~ 9 m, however, there is a secondary thermocline beginning at ~ 2 m. Secondary thermoclines while not the rule, are not uncommon in freshwater lakes.

The vertical profiles for Skaneateles, Keuka, and Canandaigua Lakes are shown in Figure 5.5. Note that the August profile for Skaneateles Lake is taken from 1997, due to equipment malfunction in August, 1996 sampling run. The June profiles provide an interesting illustration of the progression of thermal stratification, although it is important to note that this is not a real progression in that the profiles are from different water bodies. Skaneateles Lake is in the very early stages of stratification (note the absence of a discernable thermocline), whereas, stratification on Keuka Lake and Canandaigua Lake is fairly well established as evidenced by well defined thermoclines. A further distinction to be drawn from the latter two profiles is that thermal stratification on Canandaigua Lake is somewhat more advanced than on Keuka Lake in that the thermocline "flattens out". Also, while both lakes show approximately the same temperature differential between epilimnion and hypolimnion (~ 7 – 8 °C), the incremental depth over which this change occurs is substantially different – the temperature change occurs over approximately 8 m of depth for Keuka Lake versus approximately 4 m of depth for Canandaigua Lake.

Figure 5.3: Vertical profiles (temperature and dissolved oxygen) for Conesus, Honeoye and Otisco Lakes.

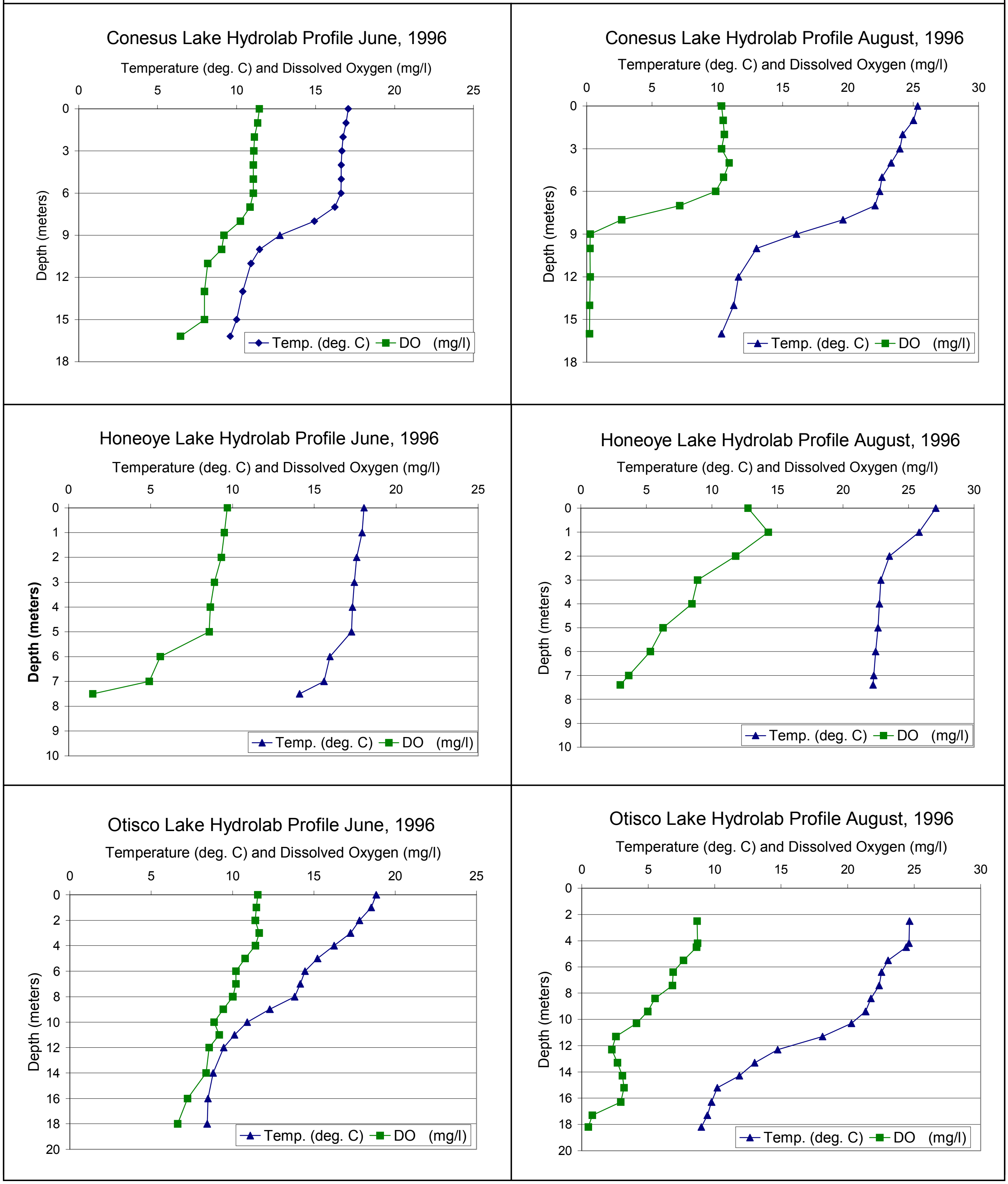


Figure 5.4: Vertical profiles (temperature and dissolved oxygen) for Owasco, Cayuga and Seneca Lakes

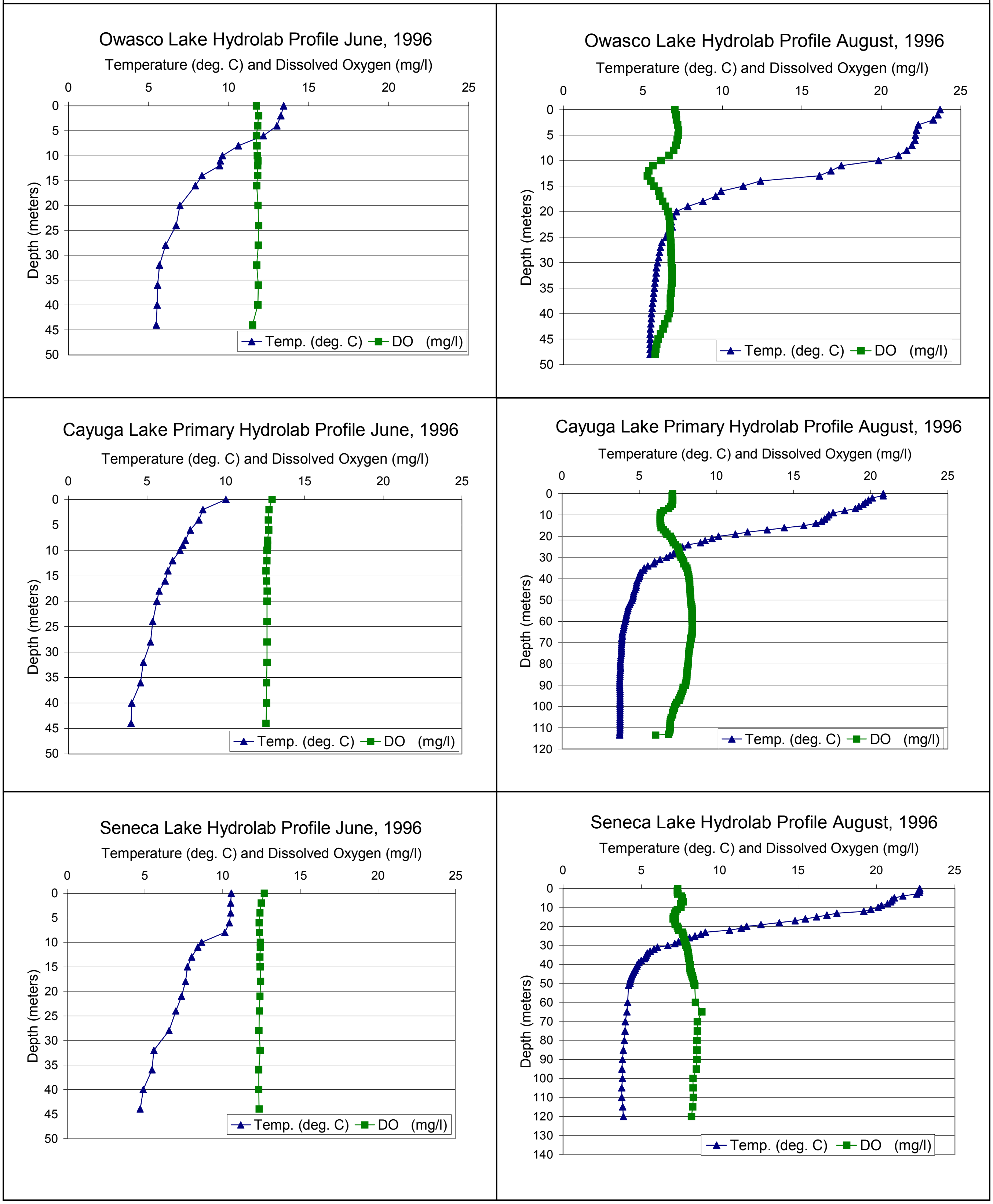
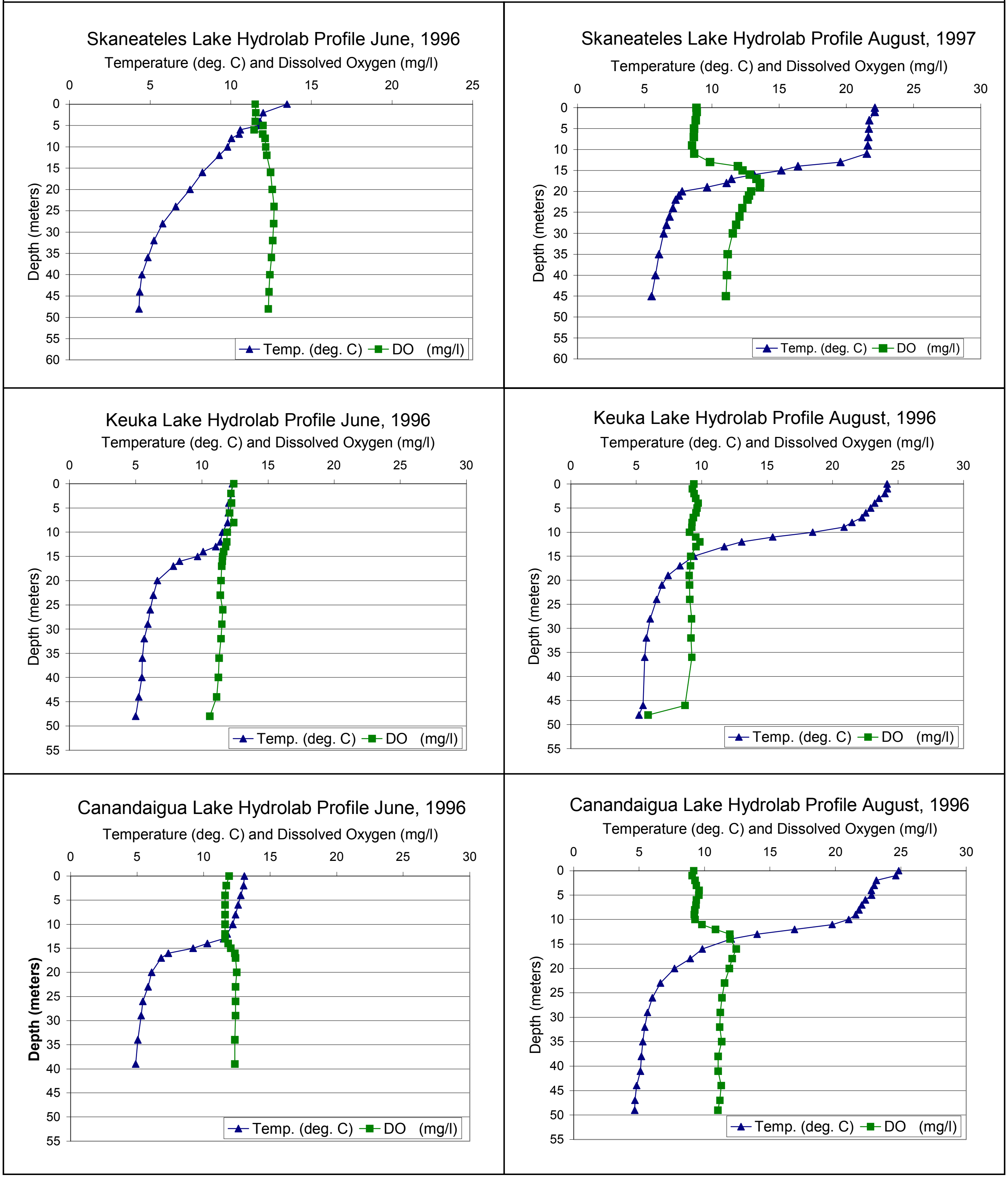


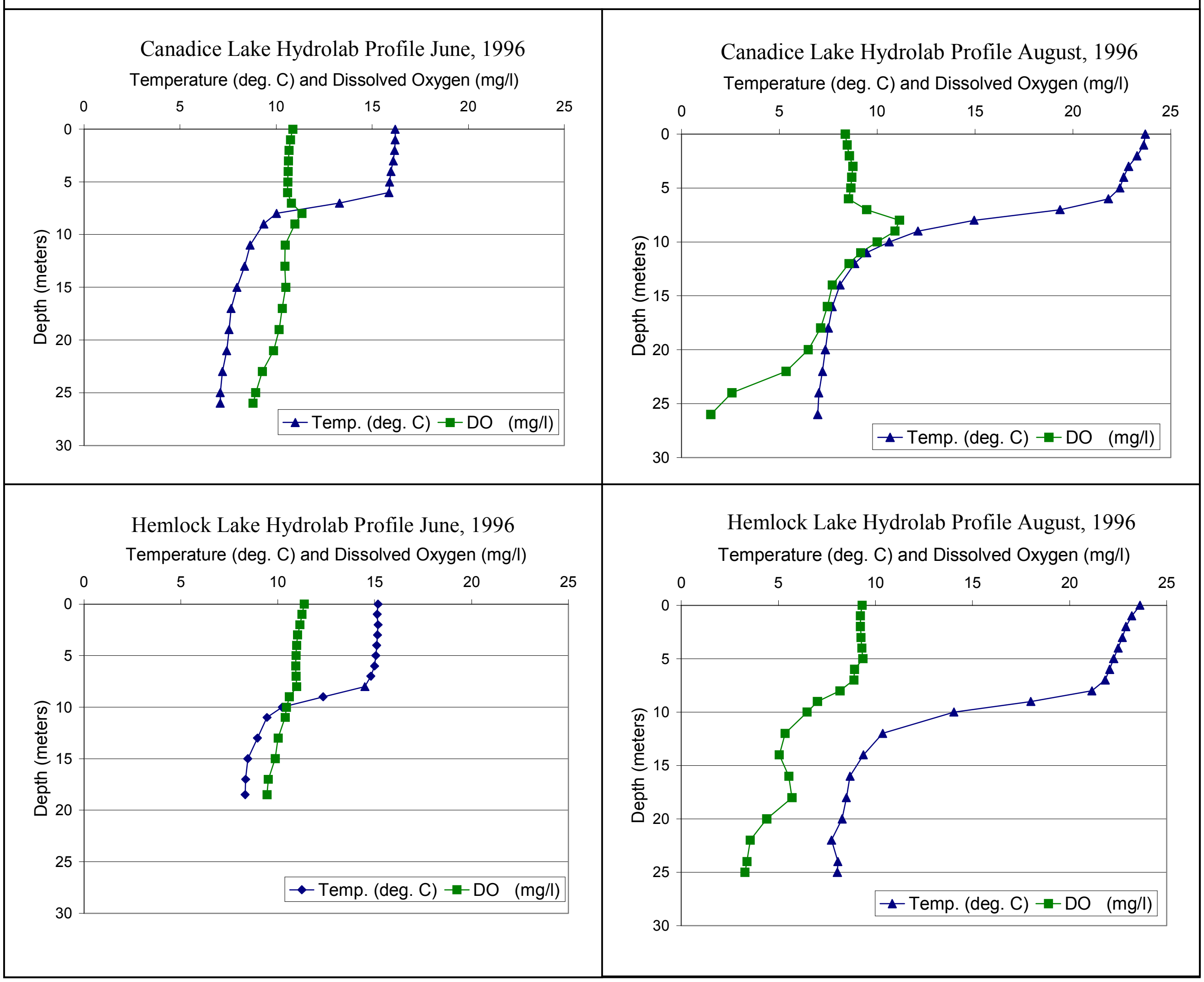
Figure 5.5: Vertical profiles (temperature and DO) for Skaneateles, Keuka and Canandaigua Lakes



The apparent lag in development of thermal stratification in Skaneateles Lake is likely the result of its remarkable water clarity, and the resultant dispersal of incoming solar heat. By August, thermal stratification is firmly established in each of the lakes, and the temperature profiles are quit similar in each of these lakes, with the exception that Canandaigua Lake exhibits a secondary thermocline within the upper few meters of water.

Vertical profiles for Canadice and Hemlock Lakes during June and August of 1996 are shown in Figure 5.6. The June profiles for both lakes indicate that thermal stratification is fairly well established – note the well defined thermoclines. The thermocline during June is located at approximately 6-9 m and 8-12 m for Canadice and Hemlock Lakes, respectively, with a temperature differential of ~ 5-6 °C between the epilimnion and hypolimnion. The August profiles indicate that thermal stratification remains firmly established within both waterbodies, and that the temperature differential has increased to 12-15 °C.

Figure 5.6: Vertical profiles (temperature and dissolved oxygen) for Canadice and Hemlock Lakes



b. Lake Trophic Indicators

Trophic state is the primary metric used to assess the relative health of freshwater lakes. Trophic state refers to the level of primary productivity for a given water body. Primary productivity, defined as the mass of algae produced within a water body, is estimated by measurements of chlorophyll *a*, the main photosynthetic pigment in algal cells. There is a natural progression in the "life" of a lake from oligotrophy to eutrophy, which is generally measured in thousands of years. However, anthropogenic (human) activities can greatly accelerate the natural "aging" process in what is termed cultural eutrophication. Cultural eutrophication is characterized by increases in nutrient loading and primary productivity. The process can lead to declines in water quality (e.g., decreased water clarity, increased occurrence of algal blooms, and increase production of trihalomethanes in water treatment processes).

Primary productivity in most freshwater lakes in New York State is limited by the macro-nutrient phosphorus (P) - other macro-nutrients include carbon (C) and nitrogen (N). This situation, referred to as "phosphorus limiting conditions", is due to: (1) supply issues: the relative availability of carbon, nitrogen and phosphorus within freshwater aquatic environments; and (2) demand issues: the physiological requirements of these macro-nutrients by phytoplankton. This is analogous to a manufacturing process (e.g., bicycles) in that the number of bikes a company can produce is limited by the *component* in shortest supply. If there are many bicycle frames, handle bars, and so forth, but a limited number of wheels available, the wheel inventory will limit the number of bikes produced. If you increase the wheel supply you can build more bicycles. The supply side of the equation favors phosphorus limitation in lakes. While carbon (in the form of CO_2) and nitrogen (in the form of N_2) are relatively abundant and available in the atmosphere, phosphorus must be derived from terrestrial sources or from internal lake sources. The processes of photosynthesis and nitrogen fixation enable certain organisms to exploit atmospheric sources of carbon and nitrogen, respectively. In apparent contrast, the demand side of the equation would seem to be attempting to balance the situation of phosphorus scarcity by requiring relatively less of this macronutrient. On a weight basis the ratio of carbon, nitrogen, and phosphorus in typical aquatic plant material (algae and macrophytes) is approximately *40 C: 7 N: 1 P* (Wetzel, 1983). Thus, from a physiological perspective, aquatic plants require significantly less phosphorus than carbon and/or nitrogen. However, in the final analysis, phosphorus is most often the limiting nutrient in northern latitude freshwater systems.

While carbon limitations within freshwater lakes are virtually nonexistent, nitrogen limitations can occur. On an empirical basis, studies suggest the following with respect to N:P ratios: (1) N:P > 20 – phosphorus is most likely the limiting nutrient; (2) N:P < 10 – nitrogen is most likely the limiting nutrient; and (3) N:P between 10-20 – difficult to determine the limiting nutrient, and depends upon other factors such as light availability, presence/absence of nitrogen-fixing algae (cyanobacteria), and the forms of nutrients present (Thomann and Mueller, 1987). N:P ratios also play an important role in determining the species of phytoplankton present in a given lake. For example, a low N:P ration provides a selective advantage to nitrogen-fixing algae (e.g., anabaena, etc.) which are generally considered undesirable – these organisms can cause noxious odors and produce toxins which can lead to fish mortality, etc.

Table 5.2 provides summary information regarding N:P and C:P ratios for each of the Finger Lakes. The findings indicate that, on most occasions, phosphorus is the limiting nutrient for primary productivity within the Finger Lakes. Note that the N:P means and the C:P means are all above 20:1 and 40:1, respectively. Furthermore, the findings clearly indicate that carbon is not the limiting nutrient within the Finger Lakes – note that all of the C:P ratio minimums are greater than the stoichiometric ratio of 40:1. However, there do appear to be instances, albeit limited, when nitrogen may become the limiting nutrient in certain of the lakes. This is most probable in some the smaller lakes, namely, Conesus, Canadice, and Honeoye Lakes, as evidenced by the N:P ratio minimums of 14:1, 8:1, and 9:1, respectively. While not presented in the Table 2.3, the N:P ratios for the southern Cayuga Lake site varied significantly, ranging from 13:1 to 151:1, which suggests that the southern-shelf could also, on occasion, be susceptible to blooms of blue-green algae.

Table 5.2: Carbon, nitrogen, phosphorus ratios.				
Lake	*Nitrogen:Phosphorus*		*Carbon:Phosphorus*	
	Mean	Range	Mean	Range
Conesus	22:1	14:1 – 39:1	245:1	152:1 – 458:1
Hemlock	50:1	19:1 – 121:1	338:1	192:1 – 980:1
Canadice	41:1	8:1 – 192:1	373:1	250:1 – 560:1
Honeoye	22:1	9:1 – 59:1	188:1	92:1 – 269:1
Canandaigua	78:1	32:1 – 124:1	682:1	254:1 – 2,433:1
Keuka	118:1	15:1 – 155:1	444:1	267:1 – 650:1
Seneca	93:1	18:1 – 266:1	435:1	85:1 – 1160:1
Cayuga	130:1	89:1 – 174:1	348:1	183:1 – 675:1
Owasco	95:1	22:1 – 154:1	316:1	131:1 – 600:1
Skaneateles	241:1	93:1 – 520:1	660:1	150:1 – 1,400:1
Otisco	43:1	23:1 – 71:1	293:1	163:1 – 471:1
cell stoichiometry	7:1		40:1	

Several systems are available for classifying the trophic status of a lake. The conventional system involves segmenting lakes into one of three possible categories (oligotrophic, mesotrophic, and eutrophic) based upon ambient levels of nutrients, primary productivity, water clarity, and hypolimnetic dissolved oxygen levels. Oligotrophic lakes are characterized by low levels of phosphorus, low levels of primary productivity, excellent water clarity, and a well-oxygenated hypolimnion throughout the year. Eutrophic lakes are characterized by high phosphorus levels, elevated levels of primary productivity, poor water clarity, and hypolimnetic dissolved oxygen (DO) depletion - either hypoxia (low DO) or anoxia (no DO). Mesotrophic lakes fall between the other two categories, and are characterized by intermediate levels of phosphorus and primary productivity, moderate water clarity, and moderate levels of hypolimnetic dissolved oxygen. Table 5.3 provides a conventional interpretation of trophic status based upon the most common measures of lake trophic state (EPA, 1974). A significant limitation within the conventional system of classification is the limited number of trophic categories available. This limitation in the conventional trophic system led to the introduction of additional categories (e.g., hypereutrophic) in an effort to further delineate lake trophic status.

Table 5.3: Conventional trophic status indicators (EPA, 1974)

Indicator	**Oligotrophic**	**Mesotrophic**	**Eutrophic**
Total Phosphorus (ug/l)	< 10	10 - 20	>20
Chlorophyll a (ug/l)	< 4	4 - 10	> 10
Secchi Depth (m)	> 4	2 - 4	< 2
Hypolimnetic Oxygen (% of saturation)	> 80	10 – 80	< 10

The Trophic State Index (TSI), a more recent incarnation of lake trophic categorization (Carlson, 1978), was designed to improve upon the previous trophic scheme in several ways, including: (1) a numerical system which provides for a large number of lake classes, thus, more realistically representing the continuum of lake trophic conditions; (2) a numerical approach is also less ambiguous than one based on nomenclature; and (3) linkages are established between the three principal trophic indices (Secchi Disk depth, total phosphorus, and chlorophyll *a*), thus, enabling determination of trophic status from any of the three indicators. The TSI is based on a unitless scale from 0 to 100, with each 10 point increment representing a doubling of biomass. Thus, in certain instances, the TSI can convey a change in lake trophic state where the conventional three-tiered system might not.

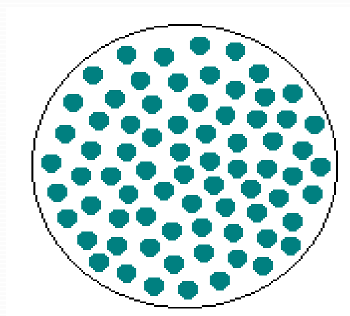
Trophic Indicators

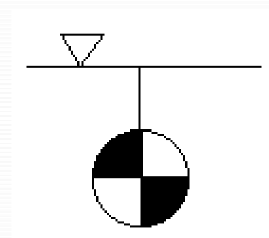
There are four common trophic indicators for freshwater lacustrine systems: (1) phosphorus; (2) chlorophyll a; (3) Secchi Disk depth; and (4) hypolimnetic dissolved oxygen. These four parameters are linked to varying degrees.

The *presumed* linkage between the four trophic indicators (phosphorus, algae, water clarity, and dissolved oxygen) is as follows. *Phosphorus*, assumed to be the limiting nutrient within a lake (see earlier discussion), determines the level of algal productivity within a lake. *Algal* abundance (chlorophyll a), presumed to be the primary limitation on light transmission through the water column, determines *water clarity* (Secchi Disk depth) within the lake. Algal senescence, deposition, and decay, combined with fixed levels of *dissolved oxygen* in the hypolimnion due to thermal stratification, results in the depletion of dissolved oxygen within the hypolimnion. The two possible scenarios for system response are depicted in the figure below: Case 1 - phosphorus levels increase, leading to an increase in algal productivity, which causes a decline in water clarity; and Case 2 - phosphorus levels decline, leading to a reduction in algal productivity, resulting in an increase in water clarity.

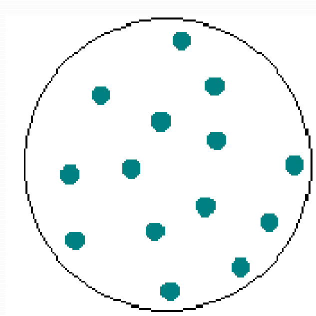
The validity of these linkages is dependant upon the strength of the underlying assumptions. Problems can arise when: (a) phosphorus is not the limiting factor for algal productivity – this would result in a higher TSI (TP) than TSI (chl a); (b) water clarity is controlled by other than algae (e.g., abiotic particulate matter) – this would lead to a higher TSI (SD) than TSI (chl. a) and possibly TSI (TP); and (d) the phosphorus dynamics within the system are significantly disrupted (e.g., Zebra mussel short circuiting) whereby algae productivity is significantly constrained – this would result in a higher TSI (TP) than TSI (SD) and TSI (chl. a').

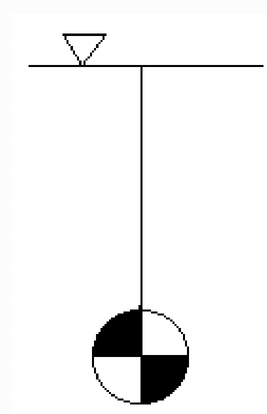
Case 1: P ↑ Chlorophyll a ↑ Secchi Disk ↓





Case 2: P ↓ Chlorophyll a ↓ Secchi Disk ↑





Total Phosphorus

Total phosphorus (TP) levels from the early 1970s and the mid to late 1990s are summarized in Table 5.4. The data represent mean epilimnetic values for the given study periods. The 1990s period excludes 1998 due to analytical irregularities. The 1970s data is derived from Bloomfield (1978) and represents this authors best attempt to summarize data from this period. The individual data points from the 1990s study period are shown in Figure 5.7 and 5.8.

Table 5.4: Mean epilimnetic total phosphorus (ug/l).

Lake Name	1996-99 [1]	Early 1970's [2]
Otisco lake	13.0	9.6
Skaneateles Lake	4.0	6.1
Owasco	12.0	12.0
Cayuga Lake main	9.7	18.0 (1968-70)
Cayuga Lake south	17.2	na
* Seneca Lake	9.8 (7.3)	13.1
Keuka Lake	8.0	13.6
Canandaigua Lake	6.2	11.4
Honeoye Lake	24.2	19
Canadice Lake	8.3	10.2
Hemlock Lake	10.0	9.9
Conesus Lake	22.2	21

1: Current Study – excludes 1998 data due to lab problems.
2: Bloomfield (1978)
*: parenthetical value excludes substantial outlier from 8-97

Spatial comparisons of TP levels within the Finger Lakes indicate substantial variations between the lakes. Mean TP levels range from 4 ug/l in Skaneateles Lake to the greater than 24 ug/l in Conesus Lake. There are no apparent geographic (east – west) patterns to the findings. However, there is some indication of a size-related pattern to the findings, in that the smaller lakes tend to have higher TP levels than do the larger lakes.

In general, temporal trends in TP concentrations within the Finger Lakes over the last several decades indicate that levels have declined in the larger lakes and have increased or remained static within the smaller lakes. Specific results indicate substantial *reductions* (> 25 percent) in epilimnetic phosphorus levels in Skaneateles, Cayuga (main lake), Seneca, Keuka, Canandaigua, and Canadice Lakes, and substantial *increases* (> 25 percent) in Otisco and Honeoye Lakes. Phosphorus levels have remained *static* in Owasco, Hemlock, and Conesus Lakes. Historical phosphorus data for the southern end of Cayuga Lake was not available, however, the levels observed on the southern-shelf area were significantly higher than those observed during the same time period at the main lake site proximate to Taughannock Point.

New York State has adopted a guidance value for total phosphorus of 20 ug/l in ponded waters. The value applies to all Class A, A-S, AA, AA-S and B ponded waters that are indexed, except Lakes Erie, Ontario and Champlain. As currently written, the guidance value "is applied as the mean summer, epilimnetic total phosphorus concentration". This number is the average total phosphorus concentration that would be collected from a minimum of one mid-lake, sampling station during the summer growing months." (NYSDEC, 1993).

Honeoye Lake and Conesus Lake currently exceed the guidance value for total phosphorus in certain years. Honeoye Lake exceeded the guidance value in 1996 (26.5 ug/l) and 1999 (28 ug/l), while Conesus Lake exceeded 20 ug/l in 1997 (22.8 ug/l) and 1999 (20.5 ug/l). As discussed above, the total phosphorus levels in Honeoye Lake have increased significantly over the past two decades, while total phosphorus levels in Conesus Lake have remained nearly constant. Possible reasons for the observed nutrient pattern changes within the Finger Lakes will be explored below – see trophic state discussion.

The southern-shelf area of Cayuga Lake is also of concern with respect to total phosphorus levels. The issue of “where” to apply the total phosphorus guidance value should be addressed first. As written, the total phosphorus guidance value is most often applied at the mid-point of a lake. However, given the length of Cayuga Lake (~ 60 m) and the distinct morphology and water classification of the southern terminus, it is deemed appropriate to apply the guidance value to this segment individually. While total phosphorus levels observed within this section of the lake during this study were, on average, slightly below the current NY State guidance value of 20 ug/l, results from other studies (Sterns and Wheeler, 1997 and Upstate Freshwater Institute, 2000) show exceedence of the 20 ug/l guidance value during several years. Data from this investigation were likely biased low due to the location of the monitoring sites (west of lake centerline). The most extensive data on trophic conditions in the south lake is the Upstate Freshwater Institute (UFI) data being collected in association with the Cornell Lake Source Cooling Project. This data set offers the best spatial resolution of total phosphorus levels within the southern shelf. Results from 1998, 1999, and 2000 indicate total phosphorus levels of 26.5 ug/l, 15.9 ug/l, and 19.4 ug/l, respectively (UFI, 2000). It is also apparent that total phosphorus levels observed at the south end of the lake are substantially higher (approximately 2 fold) than those observed at the main lake site to the north. This longitudinal phosphorus gradient, which was also apparent in previous studies (e.g., Sterns and Wheeler, 1997), is due to the spatial pattern of total phosphorus loading to the lake which is heavily influenced by loading to the southern-shelf area. Finally, it is possible that total phosphorus levels within the south lake are exhibiting a downward trend - possibly due to an increase in Zebra mussel infestation within the south lake. While not quantified, field observations indicated a major increase in Zebra mussel population numbers in 1998 and 1999 – significant numbers of young Zebra mussels were observed adhering to aquatic macrophytes within the south lake.

Figure 5.7: Epilimnetic total phosphorus levels for 6 western Finger Lakes – note scale differences

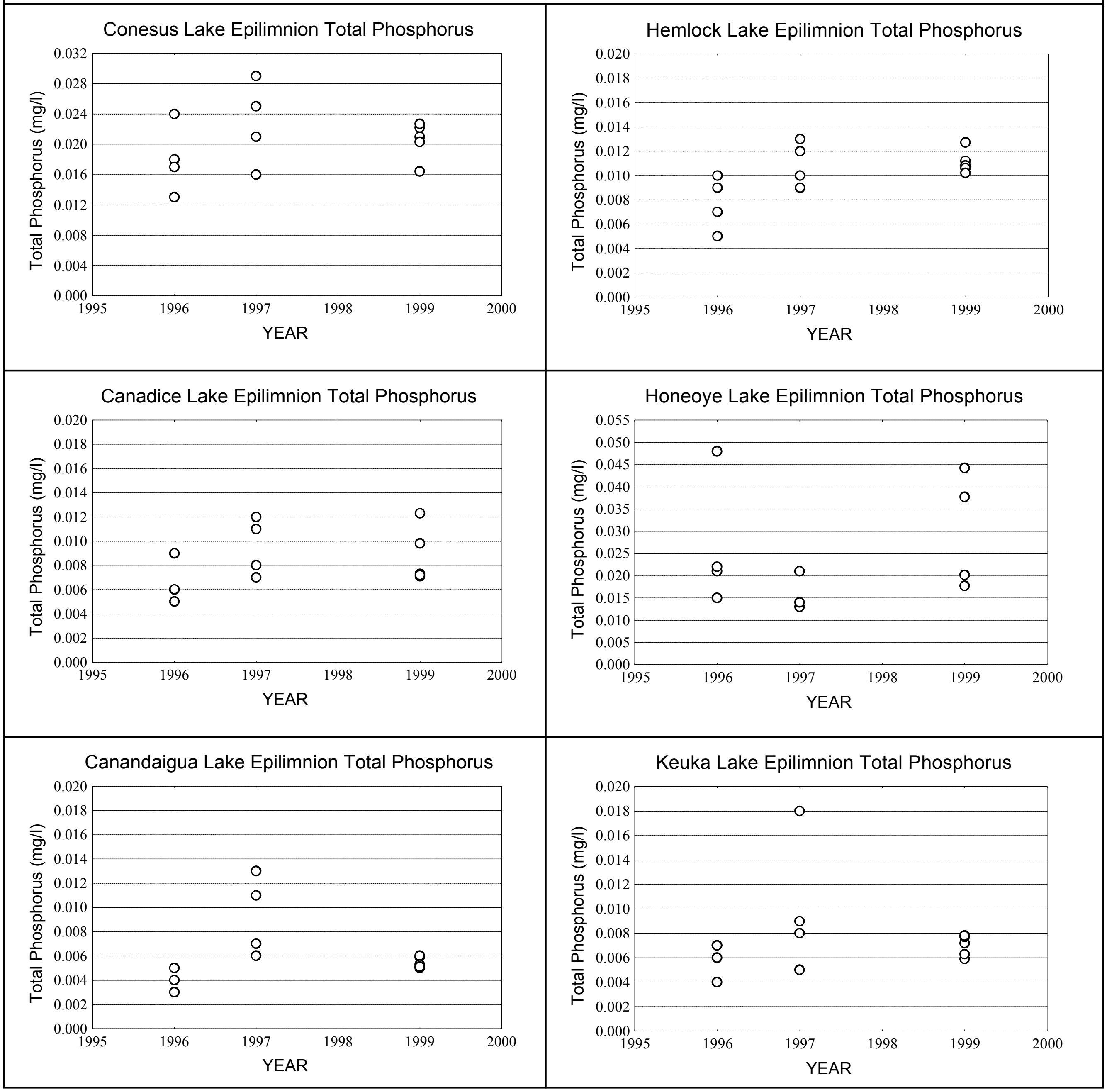
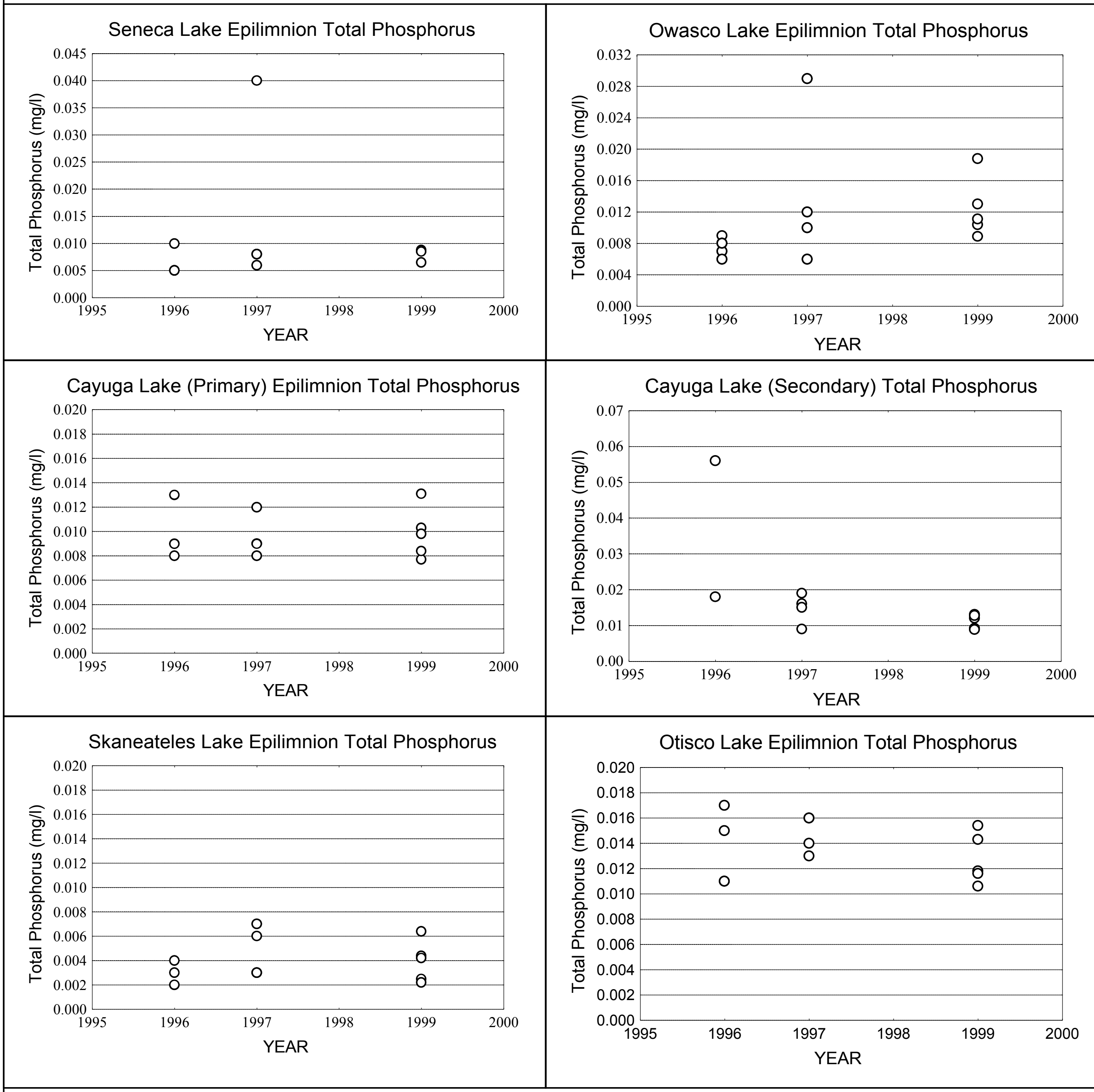


Figure 5.8: Epilimnetic total phosphorus levels for 5 eastern Finger Lakes – note scale differences



Chlorophyll a

Chlorophyll *a* levels for the two most recent study periods are presented in Table 5.5. The data represent mean epilimnetic values for the given study periods. The 1970s data is derived from Bloomfield (1978) and represents this authors best attempt to summarize data from this time period. Individual data values from the current investigation are presented in Figures 5.9 and 5.10.

Table 5.5: Mean chlorophyll a (ug/l) concentrations

Lake Name	1990s [1]	1970's [2]
Otisco lake	5.3	1.8
Skaneateles Lake	0.7	1.95
Owasco	3.8	5.5
Cayuga Lake main	3.5	4.2
Cayuga Lake secondary	3.1	na
Seneca Lake	2.4	8.8
Keuka Lake	2.8	4.9
Canandaigua Lake	1.0	2
* Honeoye Lake	8.4	25.7
Canadice Lake	2.5	2
Hemlock Lake	3.0	6
Conesus Lake	7.9	na

[1]: Current Investigation
[2]: Bloomfield (1978)
*: questionable value from 1970s

As with TP levels, chlorophyll *a* levels vary substantially across the Finger Lakes. Mean annual chlorophyll *a* concentrations range from less than 1 ug/l in Skaneateles Lake to over 8 ug/l in Honeoye Lake. There is no apparent geographic patterns in the data. However, as with phosphorus levels, there is some indication of a size related pattern in the findings. In general, the larger lakes exhibit lower chlorophyll *a* levels than do the smaller lakes.

Temporal trends for chlorophyll *a* levels also vary between the lakes. Chlorophyll *a* results indicate substantial reductions (> 25 percent) in Skaneateles, Owasco, Cayuga, Seneca, Keuka, Canandaigua, and Hemlock Lakes, a moderate increase (approximately 25 percent) in Canadice Lake, and a substantial increase (> 200 percent) in Otisco Lake. The value reported from the 1970s for Honeoye Lake appears substantially higher than what would have been expected given the phosphorus and Secchi Disk depths from that era (see discussion of Trophic State Index, below), and would appear suspect.

The chlorophyll *a* levels observed in the southern end of Cayuga Lake were, on average, slightly lower than those observed at the main lake site. This is somewhat at odds with the phosphorus findings shown above. However, during the first year (1996) of the investigation, chlorophyll levels were significantly elevated – in fact, the highest recorded value during the study period occurred in the first season. It is hypothesized that these observations are the result of an increase in Zebra mussel populations within the southern end of Cayuga Lake.

There are no numeric water quality criteria for chlorophyll *a*. However, as discussed previously, chlorophyll *a* (or more appropriately phytoplankton density) can have a significant effect on water clarity. Thus, water clarity criteria may, in certain instances, act as a surrogate criteria for chlorophyll *a* concerns.

Another issue of concern with respect to phytoplankton populations within the Finger Lakes relates to species composition. As discussed above for the south end of Cayuga Lake, observations suggest that several of the Finger Lakes have experienced a significant increase in Zebra mussel (Dreissena polymorpha) populations during the past several years. An additional water quality concern raised by the presence of Zebra mussels within the lakes is the potential for these organisms to impart a selective advantage to blue-green algae by consuming most other forms of algae but selectively rejecting blue-green algae. Several types of blue-green algae (e.g., Microcystis) produce toxins that can have deleterious effects on aquatic and terrestrial organisms. Microcystis has been associated with bird and fish mortality, as well as instances of gastrointestinal upsets in humans. Thus, it will be important to monitor the progression of Zebra mussels within the lakes and possible changes in phytoplankton composition.

Figure 5.9: Epilimnetic chlorophyll *a* for 6 western Finger Lakes – note scale differences

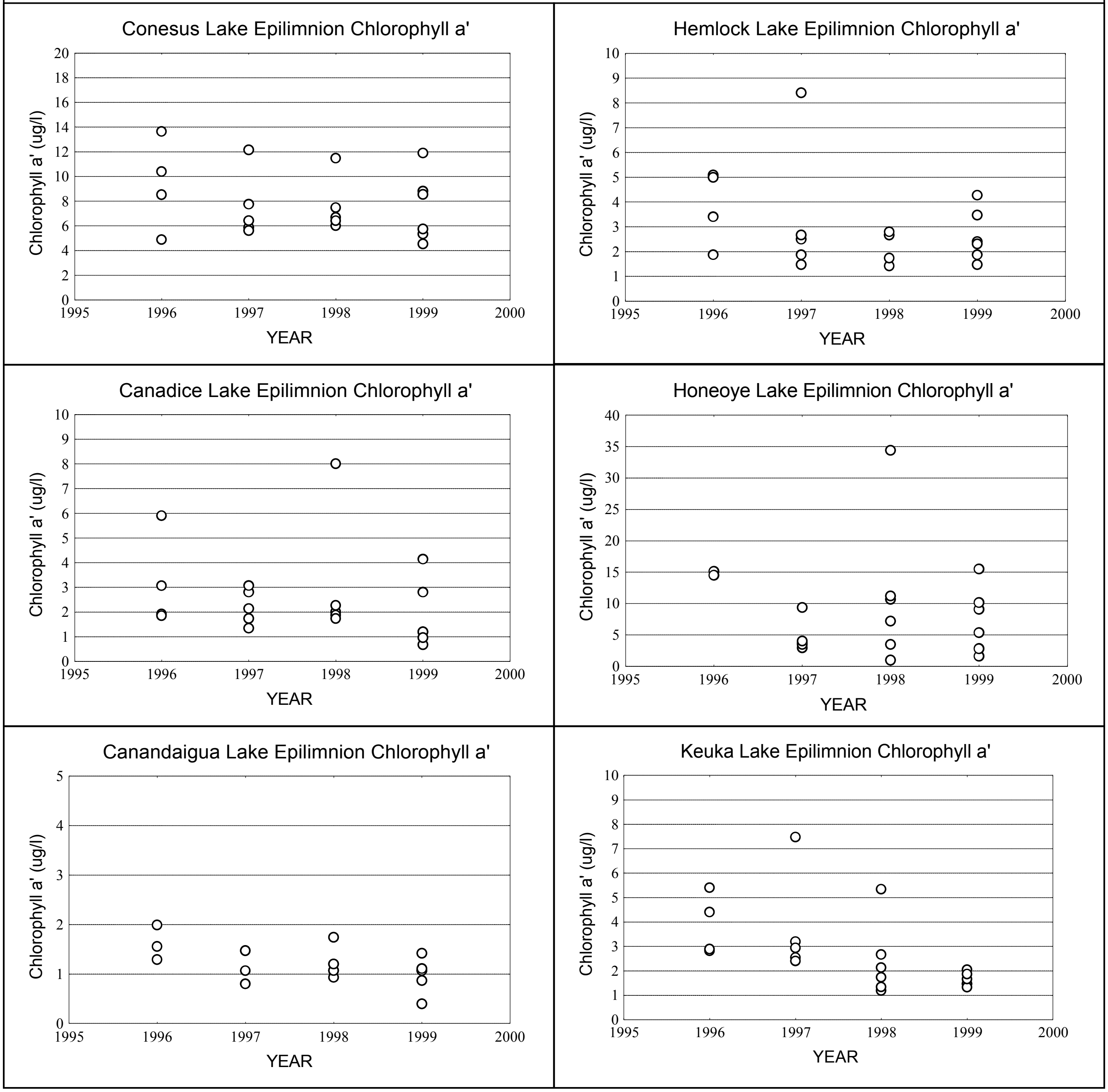
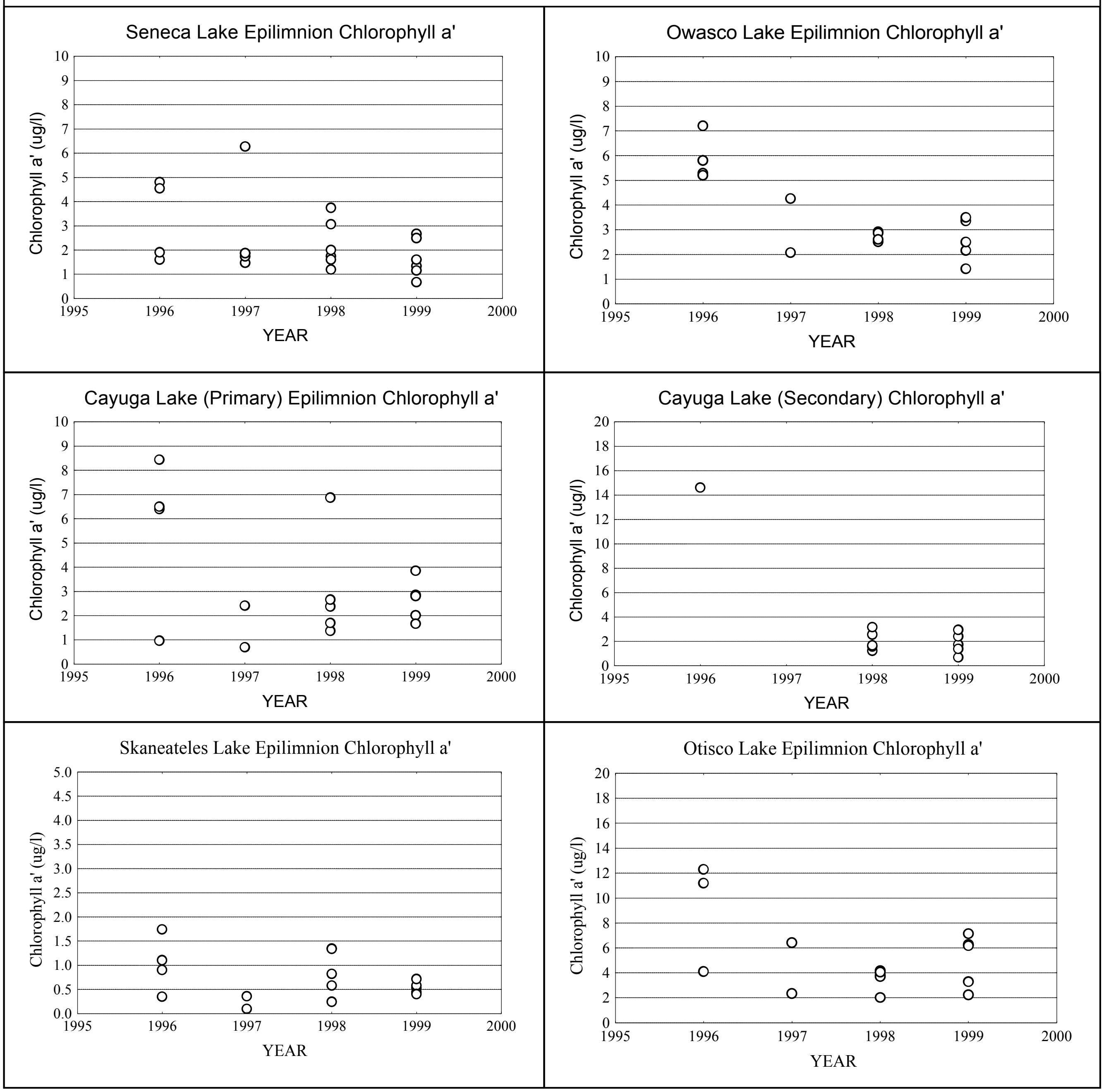


Figure 5.10: Epilimnetic chlorophyll *a* for 5 eastern Finger Lakes – note scale differences



Secchi Disk Depth

Secchi Disk depth values, for the early 1970s and the mid to late 1990s, as well as from 1910, are shown in Table 5.6. The data from the earliest time period (Birge and Juday, 1914), while quite limited (single measurement taken in August of 1910), provides valuable insight concerning historical conditions within the Finger Lakes. However, given the limited number of observations from the 1910 effort, temporal interpretations will be limited to the latter two time periods. Scatter plots of Secchi Disk depth measurements for the 1990s are shown in Figures 5.11 and 5.12.

Table 5.6: Mean Secchi Disk depths (m).

Lake Name	1996-98 [1]	1970's [2]	1910 [3]
Otisco lake	2.0	5.2 *	3.0
Skaneateles Lake	7.6	6.6	10.3
Owasco	2.8	3.1	na
Cayuga Lake main	4.0	3.6	5.1
Seneca Lake	6.0	2.8	8.3
Keuka Lake	5.6	4.7	na
Canandaigua Lake	7.7	4.2	3.7
Honeoye Lake	3.7	3.0	na
Canadice Lake	5.0	5.2	4.0
Hemlock Lake	4.7	3.3	4.7
Conesus Lake	3.7	4.9	6.3

[1]: Current Study
[2]: Bloomfield (1978)
[3]: Birge & Juday (1914) – limited to a single measurement in August, 1910
*: Thought to be anomalous (Effler, 1989)

As with TP and chlorophyll *a* levels discussed earlier, spatial comparisons of mean Secchi Disk depths indicate significant differences in water clarity levels across the Finger Lakes. Mean Secchi Disk depths range from 2 m in Otisco Lake to in excess of 7 m in Skaneateles and Canandaigua Lakes.

Temporal comparisons of Secchi Disk depth trends over the last several decades are generally consistent with the other two trophic indicators presented above (although inversely related), in that the larger lakes show marked increases in water clarity over the intervening time frame while the smaller lakes indicate stable or declining levels of water clarity. Lake specific findings are as follows. Seneca, Canandaigua, and Hemlock Lakes have shown a *substantial increase* (> 30 percent) in water clarity during the intervening time period. Skaneateles, Cayuga (primary site), Keuka, and Honeoye Lakes underwent more *modest increases* (10 – 20 percent) in water clarity. Owasco Lake and Candice Lake remain basically unchanged, and Conesus Lake has shown a *substantial reduction* (~ 30 percent) in water clarity.

There are two caveats which should be noted in the discussion of water clarity trends. First, the Secchi Disk depth reported for Otisco Lake during the 1970s, while listed, is thought to be anomolous (Effler, 1989a) given historical observations in the lake. For example, note that the Secchi Disk depth recorded in 1910 is significantly lower than the 1970s value. Second, the Secchi Disk measurements for the south Cayuga site were compromised due to shallow water depths. On several occasions, the Secchi Disk depth exceeded the station depth, thus, precluding accurate measurement of Secchi Disk depth.

The New York State Department of Health requires a minimum water clarity of 4 feet (1.2 m) for *new* public swimming beaches within the state. As is apparent in Figure 5.12,, both Otisco Lake and the south end of Cayuga Lake (Cayuga Secondary), on occasion, show Secchi Disk depths of less than 1.2 m. As was the case with total phosphorus and chlorophyll *a*, the southern Cayuga site appears to be experiencing a significant change (greater water clarity) likely due to Zebra mussel infestation. There are no public swimming beaches currently in place on either Otisco Lake or at the south end of Cayuga Lake. In the case of Cayuga Lake, the public beach at the southern end of the lake was officially closed approximately 40 years ago due to water clarity issues and other concerns, and remains closed today.

During the first two years of this investigation a team of scientists from the Upstate Freshwater Institute conducted an intensive study of the optical properties of the Finger Lakes (Effler, et al., 2000).

Figure 5.11: Secchi Disk Depths during the 1990s for 6 western Finger Lakes

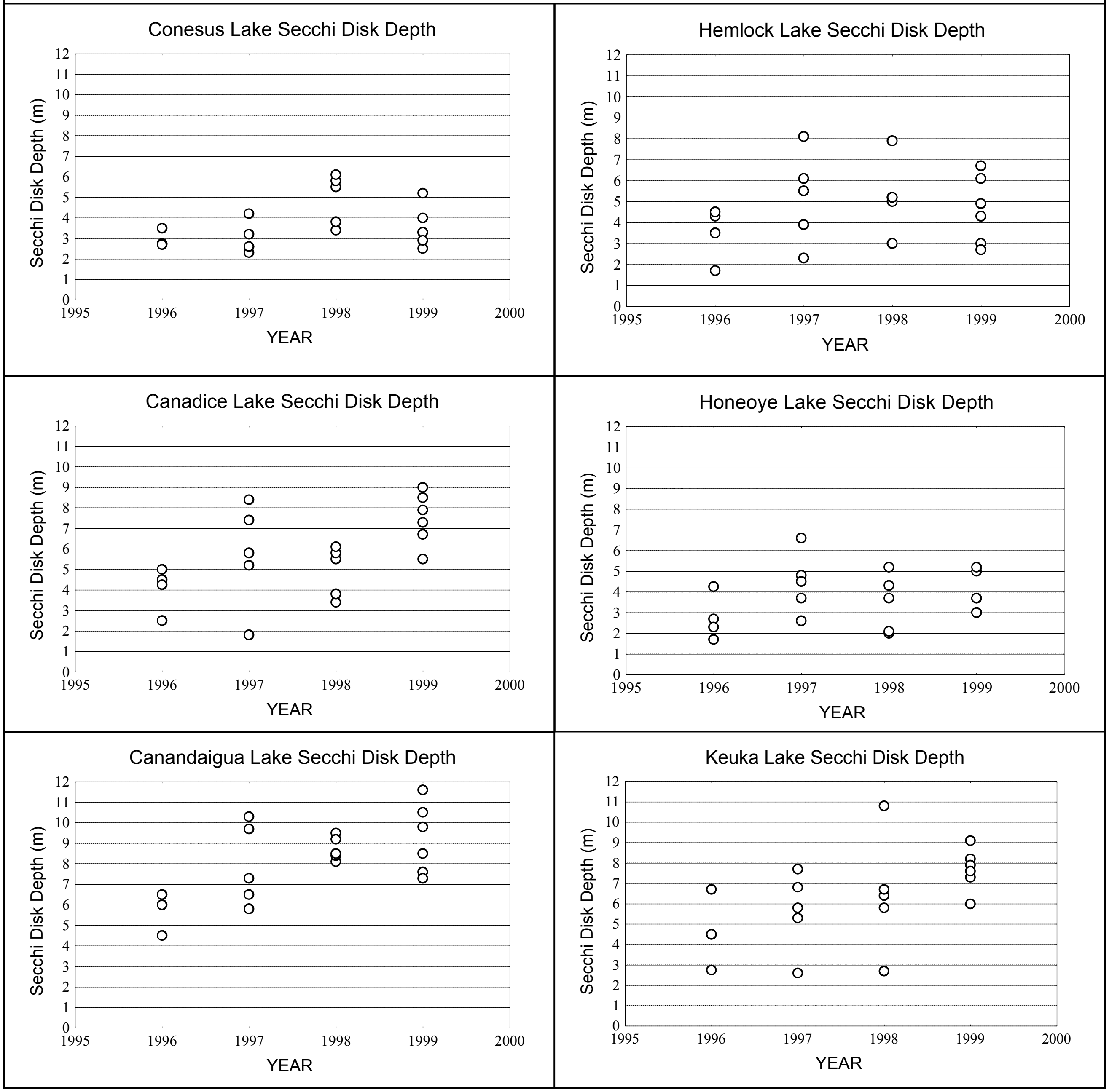
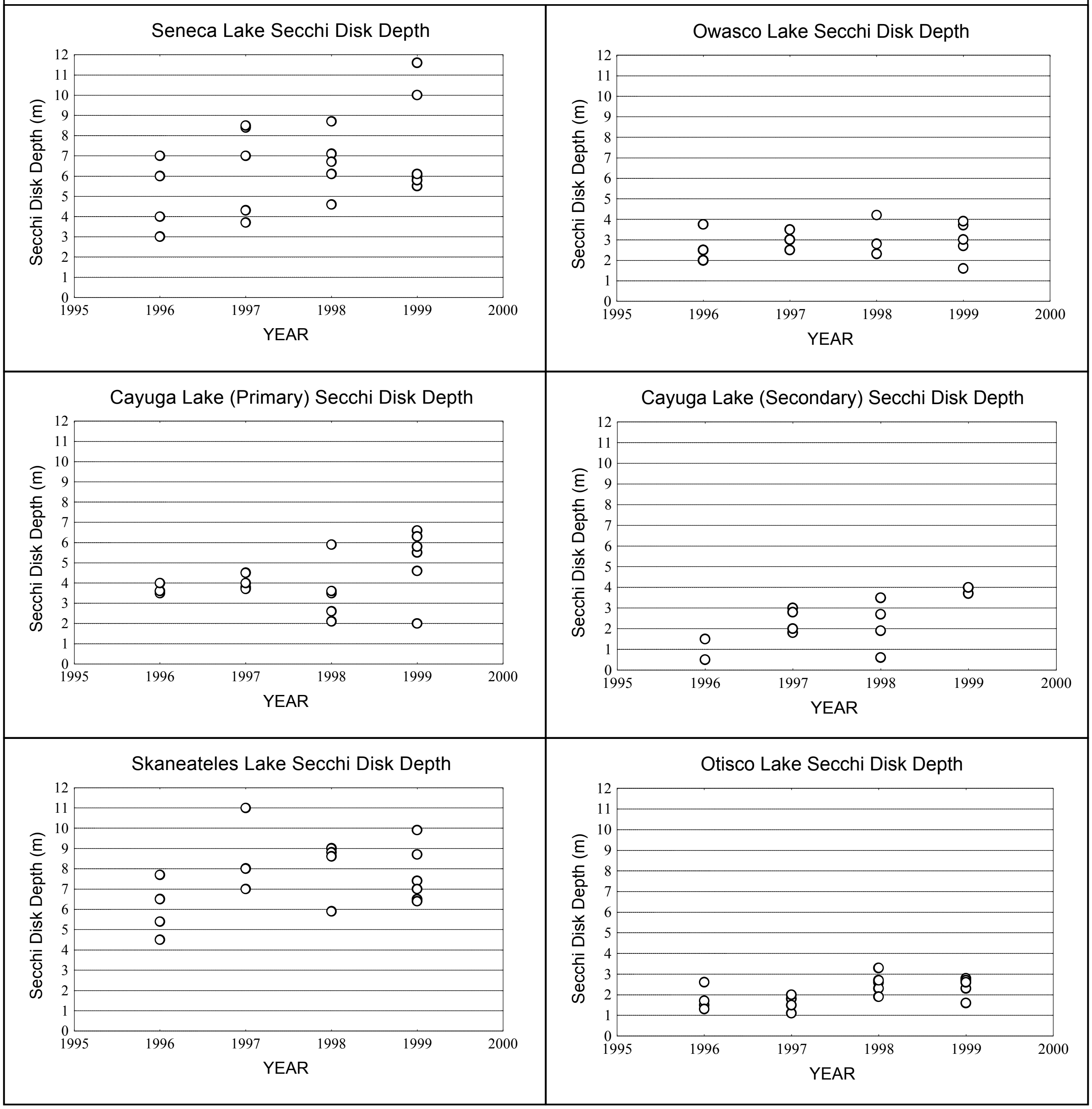


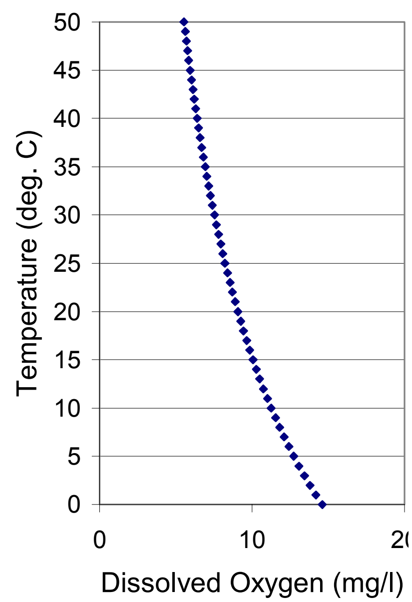
Figure 5.12: Secchi Disk Depths during the 1990s for 5 eastern Finger Lakes



Hypolimnetic Dissolved Oxygen

The final parameter which is frequently used to determine the trophic status of a lake is the level of dissolved oxygen (DO) in the hypolimnion. Oxygen is more soluble in cold water than in warm water (see Figure 5.13). Thus, all other factors being equal, the colder the water the higher the level of dissolved oxygen. However, increasing trophic levels can lead to decreasing dissolved oxygen levels in the hypolimnion (colder waters) in a process referred to as DO depletion.

Figure 5.13: DO vs Temperature



The nomenclature for dissolved oxygen depletion include the terms: (1) *anoxia* – which is defined as a complete absence of oxygen; and (2) *hypoxia* – which is defined as reduced levels of oxygen. DO depletion within the hypolimnion of a lake is the result of several factors, including: (a) lake stratification - which creates a thermal/density barrier to oxygen transfer between the epilimnion and the hypolimnion of a lake – thus, inhibiting reoxygenation of hypolimnetic waters; (b) algal senescence - which results in the settling of organic matter, decay, and exertion of DO demand within the hypolimnion; (c) benthic sediment oxygen demand – which exerts additional DO demand within hypolimnetic waters; and (d) morphological factors such as the volume of the hypolimnion relative to the epilimnion – cone shaped basins are more susceptible to hypolimnetic DO depletion than are box shaped basins.

The dissolved oxygen curve for a given lake will fall between two possible extremes. An *orthograde curve*, characteristic of oligotrophic lakes, which shows increasing DO levels with depth (see the August DO profiles for Skaneateles and Canandaigua Lakes in Figure 5.5 above) and is indicative of the inherent relationship between DO and temperature. On the other extreme, is the *clinograde* curve, characteristic of eutrophic lakes, which shows decreasing DO levels with depth (see the August DO profiles for Otisco and Conesus Lakes in Figure 5.3 above) and is indicative of hypolimnetic DO depletion.

As indicated, Otisco Lake and Conesus Lake (see August profiles in Figure 5.3) both exhibit a sustained clinograde dissolved oxygen curve from early summer through mid-fall, with well established anoxic conditions occurring within the hypolimnion from mid-summer until fall turnover. Honeoye Lake also exhibits a fairly consistent clinograde dissolved oxygen curve (see Figure 5.3) from early-summer until mid-fall, although DO levels do not fall quite as low as in Otisco and Conesus Lakes, and are best characterized as hypoxic conditions.

Owasco, Cayuga, and Seneca Lakes (see Figure 5.4) all exhibit nearly uniform dissolved oxygen levels with depth, or a slight orthograde curve, with fairly high DO levels throughout the growing season. Both Owasco Lake and Cayuga Lake show a somewhat pronounced DO minima within the metalimnion. This is not atypical of mesotrophic lakes (see discussion to follow) and is indicative of reduced settling rates and resultant levels of DO depletion due to density differences as discussed above.

Skaneateles Lake and Canandaigua Lake once again demonstrate their similarities in that both lakes exhibit classic orthograde dissolved oxygen curves (see Figure 5.5) characterized by a distinct increase in dissolved oxygen levels within the hypolimnion reflecting the relationship between water temperature and oxygen solubility (absent significant DO depletion). The dissolved oxygen profile for Keuka Lake during August (see Figure 5.5) is more consistent with those of Owasco, Cayuga and Seneca Lakes (see Figure 5.4) in that DO levels remain nearly constant throughout the water column.

The dissolved oxygen levels observed during the present investigation are similar to levels observed during the late 1960s and early 1970s.

The dissolved oxygen standard for class AA, A, B, C, AA-special waters (portions of which are applicable to all of the Finger Lakes) reads as follows:

> "For cold waters suitable for trout spawning, the DO concentration shall not be less than 7.0 mg/L from other than natural conditions. For trout waters, the minimum daily average shall not be less than 6.0 mg/L, and at no time shall the concentration be less than 5.0 mg/L. For nontrout waters, the minimum daily average shall not be less than 5.0 mg/L, and at no time shall the DO concentration be less than 4.0 mg/L.." (NYSDEC, 1999).

A strict interpretation of the dissolved oxygen standard (e.g., throughout the entire water column) would indicate that each of the smaller Finger Lakes (Otisco, Honeoye, Canadice, Hemlock, and Conesus Lakes) contravene the dissolved oxygen standard within the hypolimnion during late summer. However, at least in the case of Candice and Hemlock Lakes, which have quite restrictive watershed controls, the observed DO depletion might well be a natural phenomenon. The case is not as clear for the other three lakes in that watershed controls are less restrictive than for Hemlock and Canadice Lakes. Furthermore, in the case of Otisco Lake and Conesus Lake the DO depletion rate is more pronounced than in Honeoye, Canadice and Hemlock Lakes. The cause(s) of dissolved oxygen depletion (natural versus human induced) can not be determined at this juncture.

The consequences (ecological, chemical, etc.) of DO depletion within the hypolimnion of freshwaters is not entirely clear. Significant concerns have recently been expressed regarding DO depletions in coastal saline waters (e.g., Gulf of Mexico, Long Island Sound, etc.), and a significant body of information has been developed concerning this issue in coastal waters (Annin, 1999). Unfortunately, similar information concerning DO depletion in freshwater lakes is not available. Some of the issues which may be of concern include: (a) chemical concerns - such as solubilization of certain compounds (e.g., sulfides, arsenic, etc.) which are more soluble under reduced conditions, and (b) biological concerns such as increased production of methyl-mercury, effects on resident biota, etc.

Trophic State Discussion

Trophic states within the Finger Lakes vary significantly, ranging from clearly oligotrophic conditions within Canandaigua and Skaneateles Lakes to eutrophic conditions within Otisco, Honeoye, and Conesus Lakes. Using the conventional classification scheme outlined earlier, the trophic state of the individual Finger Lakes break out as shown in Table 5.7. For the most part, this would suggest little change in trophic status for the lakes since the 1970s. However, this conclusion is due, to some degree, to the relatively coarse nature of the conventional trophic scheme (see previous discussion). Use of the more finely scaled Carlson Trophic State Index indicates some significant changes in some of the lakes.

Table 5.7: Trophic state of the Finger Lakes based on conventional trophic classifications

Oligotrophic		**Mesotrophic**	**Eutrophic**
Skaneateles	Cayuga		Otisco
Canandaigua	Seneca	Owasco	Honeoye
	Keuka		Conesus
	Hemlock		
	Canadice		

TSI values derived from trophic indicator measurements of the 1970s and the 1990s are presented in Table 5.8. The table presents both parameter-specific mean TSI values and the variation is TSI values for individual observations. For example, Skaneateles Lake had a mean TSI (SD) of 31 during the late 1990s, while individual TSI (SD) values ranged from 25-38 during that timeframe. The range provides an indication of how the TSI has varied over the given timeframe. However, it is also influenced by the number of observations available at the monitoring site – in general, the more observations the greater the variability. Thus, it would be best to limit inter-lake comparisons to the later time period as they involved approximately the same number of observations.

Table 5.8: Historical comparison of Carlson Trophic State Indices

	TSI (SD)		TSI (TP)		TSI (chl. a')	
Lake	1971-73 [1]	1996-99	1971-73 [1]	1996-99	1971-73 [1]	1996-99
Otisco	36 *	49 (43-59)	37	41 (38-44)	36	47 (37-52)
Skaneateles	35 (30-36)	31 (25-38)	30 (26-48)	24 (14-32)	37 (32-40)	27 (8-36)
Owasco	44 (41-47)	45 (39-53)	42 (33-41)	40 (30-53)	47 (46-49)	44 (34-50)
Cayuga (main)	42	40 (33-50)	46	37 (34-41)	45	43 (27-51)
Seneca	45 (42-52)	33 (25-44)	44 (33-44)	37 (27-57)	52 (46-56)	39 (27-49)
Keuka	38 (32-47)	34 (26-46)	42 (37-38)	34 (24-46)	46 (36-51)	41 (32-50)
Canandaigua	39	30 (25-35)	39	30 (20-41)	37	31 (22-38)
Honeoye	44	50 (33-50)	42	50 (40-60)	62	51 (30-65)
Canadice	36	35 (28-52)	38	35 (27-41)	37	40 (27-51)
Hemlock	43 (39-46)	37 (30-48)	37 (32-34)	37 (27-41)	48 (46-50)	41 (34-51)
Conesus	37	42 (34-48)	48	49 (41-55)	27	51 (45-56)

Note: mean value with range, where appropriate, in parentheses

[1] From Lakes of New York State (1978)

* There are some indications that this value may be biased low (Effler, 1989).

In general, results indicate that trophic conditions in the Finger Lakes have followed one of two possible scenarios over the past 30 years. The trend in most of the larger lakes has been toward lower nutrient levels, greater water clarity, and lower levels of primary productivity over the intervening period – this is generally viewed as a positive development. In contrast, the trend in the smaller lakes is indicative of either static or somewhat more productive conditions. Exceptions to these trends are Owasco Lake for the larger lakes and Hemlock Lake for the smaller lakes. In the case of Owasco Lake, trophic conditions are nearly the same as were observed in the early 1970s. In the case of Hemlock Lake, current findings indicate increased water clarity and decreased productivity, although phosphorus levels appear to have remained nearly constant. The obvious question raised by this apparent bifurcation in lake trends is "*what factors are responsible for the observed divergence in lake trophic trends* ?".

It is hypothesized that the trend differences observed in trophic state within the Finger Lakes over the past several decades are attributable, in part, to the relative role of *external* and *internal* phosphorus loading in the given lakes. Furthermore, it is proposed that *hypolimnetic dissolved oxygen depletion* in the smaller Finger Lakes acts to constrain trophic reductions in those lakes by triggering the release of phosphorus from the benthic sediments.

Phosphorus inputs to a lake can come from either external sources (watershed and or atmosphere) or internal sources (benthic sediments). External sources of phosphorus can be of natural (e.g., geological) and/or anthropogenic (e.g., agricultural runoff and municipal wastewater) origins. For phosphorus limited lakes, the phosphorus load to the lake, coupled with other factors (e.g., lake morphology, dissolved oxygen levels, etc.) determine the trophic state of the lake. The magnitude of phosphorus loading to a lake, the identification of contributory sources, and the relative contribution from external and internal sources are all important factors in the management of lake water quality.

Over the past several decades a number of factors have contributed to reductions in *external* loading of phosphorus to waterbodies in New York State. *First*, the construction and improvement of wastewater treatment facilities has brought significant reductions in the discharge of phosphorus to receiving waters. There have been significant improvements in the chemical, biological, and physical methods of phosphorus removal from domestic and industrial wastewater. Basic secondary treatment is capable of removing up to 30 percent of the phosphorus in domestic sewage, while advanced treatment can achieve significantly higher levels of phosphorus removal. *Second*, many states, including New York, instituted phosphorus detergent bans during the last few decades, which have also exerted a downward trend in phosphorus loading to receiving waters. For example, in 1976, New York State implemented the following restrictions on the use of phosphorus (Part 659 ECL - NYSDOS, 1999):

"No household cleansing product except those used in dishwashers, food and beverage processing equipment and dairy equipment shall be distributed, sold, offered or exposed for sale in this State which shall contain a phosphorus compound in concentrations in excess of a trace quantity measured as elemental phosphorus".

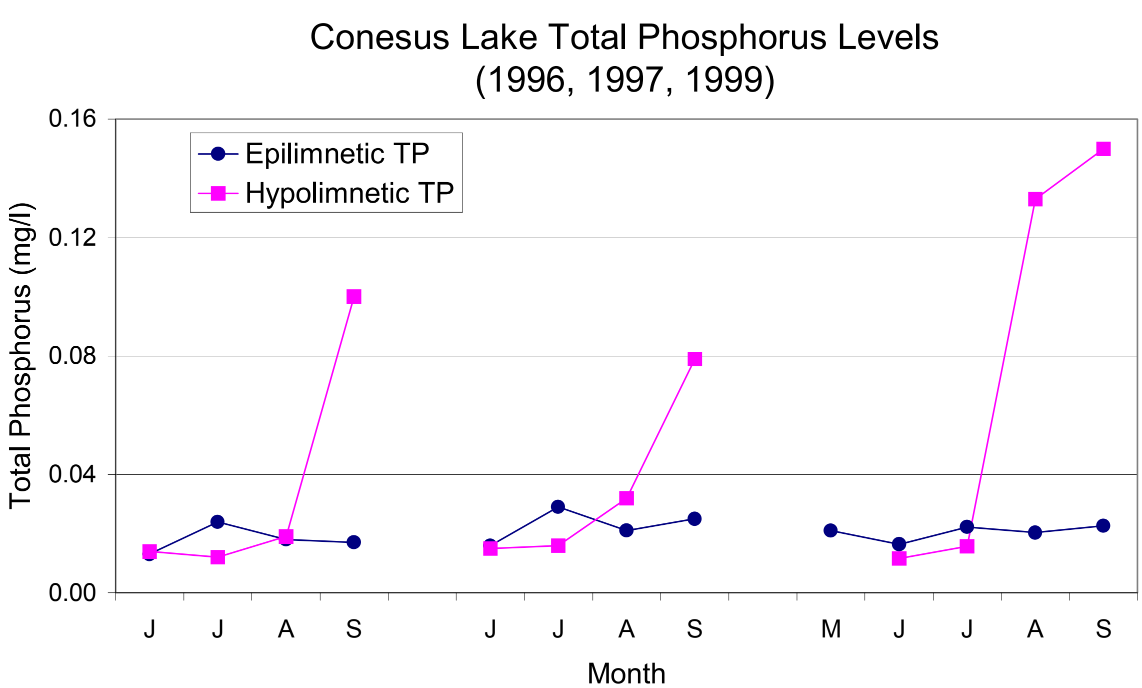
Third, the implementation of Best Management Practices (BMPs) in agricultural operations have also contributed to reductions in phosphorus loading from diffuse, or non-point sources. Other factors, such as land use changes also influence nutrient loading to the lakes, although the direction of change probably varies. In aggregate, it is probable that external phosphorus loading to the Finger Lakes has declined over the past 30 years.

It is possible that the water quality management measures described above have conspired to cause the observed divergence in trophic state changes within the Finger Lakes over the past several decades. However, given the apparent correlation between trophic state trend and hypolimnetic dissolved oxygen conditions, it would seem more probable that the observed trends are a function of both external controls, such as those mentioned above, and internal system dynamics.

It is fairly well established that eutrophic lakes which experience extensive episodes of hypolimnetic dissolved oxygen depletion, exhibit substantial phosphorus release (internal loading) from benthic sediments (Mortimer, 1941). This phenomenon, believed to be biochemically mediated, is the result of reduction/oxidation (redox) related processes occurring at the sediment-water interface. Phosphorus tends to bind with iron and other cations under oxidative conditions, and thus, tends to precipitate out of solution. However, reducing conditions can trigger a de-coupling of phosphorus, and allow it to reenter solution. The end result is that under depressed DO conditions phosphorus is "released" from the bottom sediments to the overlying water column. Thus, while external loading to the Finger Lakes have likely declined over the past 30 years, internal phosphorus loading within the smaller eutrophic lakes may be acting to offset declines in the smaller lakes. This internal phosphorus cycle is quite apparent in Conesus Lake as evidenced by the difference in mean phosphorus levels in the epilimnion versus the hypolimnion (see Figure 5.14). The average phosphorus level within the epilimnion of Conesus Lake during the past several years is 22 ug/l, while the average phosphorus level within the hypolimnion over the same time period is approximately 50 ug/l.

In contrast to Conesus Lake, the other two eutrophic lakes (Honeoye and Otisco Lakes) showed little difference between epilimnetic and hypolimnetic phosphorus concentrations. This is not surprising for Honeoye Lake given the tenuous nature of thermal stratification within the lake and the fact that our operational definition of epilimnion (Secchi Disk depth) and hypolimnion (two thirds the water depth) often resulted in an overlap of the "epilimnion" and "hypolimnion". The lack of a difference in phosphorus concentrations (epilimnion versus hypolimnion) in Otisco Lake was somewhat more surprising given the fairly strong thermal stratification observed in this lake. One possible explanation for this could be that our operational definition of hypolimnion (e.g., 2/3 the station depth) was above the area of phosphorus elevation. In fact, Effler, et al. found significant phosphorus elevation of soluble reactive phosphorus within the hypolimnion of Otisco Lake in earlier studies (Effler, et al., 1989a).

Figure 5.14: Conesus Lake epilimnetic and hypolimnetic total phosphorus levels



One significant uncertainty in the assessment of trophic conditions within the Finger Lakes relates to the recent introduction of Zebra mussels (Dreissena polymorpha) to the lakes (see Figure 5.15). The introduction of this non-native bivalve is thought to be causing significant changes in water chemistry within the Finger Lakes, including increasing water clarity, and decreasing levels of phosphorus and chlorophyll *a*. In other words, Zebra mussels can mimic the effects of nutrient reductions and the resultant decrease in algal productivity. For example, this could explain the apparent dissimilarity in trophic trends within Hemlock and Canadice Lakes. Both Hemlock and Canadice Lakes are relatively small Finger Lakes with fairly well protected watersheds, and each lake exhibits hypolimnetic hypoxia/anoxia during the late summer. However, trophic state trends in Canadice Lake and Hemlock Lake appear to be following differing tracks. Findings from Hemlock Lake suggest a substantial decline in trophic state as indicated by substantial increases in water clarity, and reductions in both total phosphorus and chlorophyll *a* levels between the early 1970s and the late 1990s. In contrast, trophic conditions in Canadice Lake have remained largely constant over the past several decades, as evidenced by nearly constant levels of chlorophyll a and total phosphorus, and consistent levels of water clarity. As it turns out, Canadice lake is the only Finger Lake in which Zebra mussels have not become established. As will be discussed more fully below (see discussion of calcium levels levels), it is conceivable that levels of calcium within Canadice Lake are inhibiting the establishment of Zebra mussels within the system. This would be consistent with the premise that Zebra mussels are exerting some influence on trophic indicators within the Finger Lakes.

Figure 5.15: Zebra mussel - *Dreissena polymorpha*

from: http://www.zeestop.com/adult_mussel.html *c. Major Ions*

An ion is an atom, or molecule, that has gained or lost one or more electrons and acquired a net negative or positive charge. Positively charged ions are termed cations, while negatively charged ions are termed anions. The major ion species present in freshwater lakes (including the Finger Lakes) are as follows: (1) **cations**: calcium [Ca $^{2+}$], magnesium [Mg $^{2+}$], sodium [Na $^{+}$], and potassium [K^{+}]; and (2) **anions**: bicarbonate [HCO $^{3-}$], carbonate [$CO_3{}^{2-}$], sulfate [$SO_4{}^{2-}$], and chloride [Cl $^{-}$].

The ionic composition of a lake is of importance to both human use of the resource and ecosystem dynamics within the lake. High profile issues such as lake acidification, Zebra mussel infestation, and drinking water quality can all be influenced by the ionic composition of the lake.

In most freshwater aquatic systems the positive and negative charges associated with the various ionic species "approach" balance. However, analytical issues and the presence of un-quantified ions (e.g., organic ions) can result in minor differences in the calculated ion balance. For example, the average ratio of positive ions to negative ions for the USEPA 1991-95 Environmental Monitoring and Assessment Program (EMAP) data was 1.26 (USEPA, 1999a). A similar positive ion bias was apparent in most of the Finger Lakes during the 1990s.

Ion balances for each of the Finger Lakes during the later 1990s are presented in Figure 5.16. The ion balances presented here are intended to parallel those developed during the 1970s (Bloomfield, 1978), thus, for comparative purposes, they exclude some of the minor cation and anion species (e.g., ammonia and nitrate). Approximate comparisons between cation and anion totals from the 1970s and the 1990s are summarized in Table 5.9.

Figure 5.16: Finger Lakes cation/anion balance for the 1996-1999 period

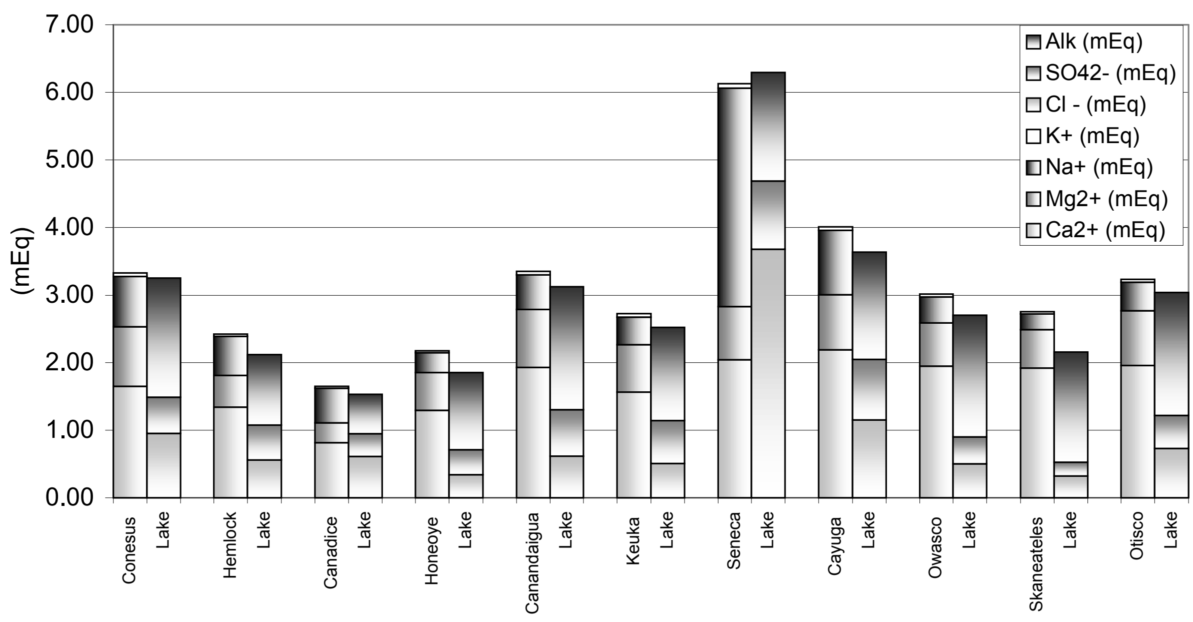


Figure 5.9: Temporal comparison of total cations and anions within the Finger Lakes

Lake	Total Cations (mEq)		Total Anions (mEq)	
	1970s	1990s	1970s	1990s
Conesus Lake	3.66	3.33	3.76	3.25
Hemlock Lake	2.18	2.42	2.23	2.12
Canadice Lake	1.44	1.65	1.40	1.53
Honeoye Lake	1.93	2.18	1.84	1.85
Canandaigua Lake	3.14	3.35	3.27	3.13
Keuka Lake	2.66	2.73	2.55	2.53
Seneca Lake	7.37	6.13	7.74	6.30
Cayuga Lake	5.24	4.01	5.03	3.64
Owasco Lake	3.13	3.01	2.98	2.70
Skaneateles Lake	2.73	2.75	2.71	2.16
Otisco Lake	3.61	3.23	3.38	3.04

Spatial comparisons of cation and anion levels within the Finger Lakes during the 1990s indicate the following patterns. *First*, and most apparent, is that Seneca Lake and Cayuga Lake exhibit significantly higher cation and anion levels than do the other 9 lakes. This is due, primarily, to the relatively high sodium and chloride levels found in these deeper lakes. As discussed earlier, Seneca and Cayuga Lakes are significantly deeper than the other 9 Finger Lakes (see Figure 2.2). This contrast is even more apparent when one factors in the depths of post-glacial sediments beneath the lakes (Mullins, 1996). This disparity in depth of scour, has led to the hypothesis that the marked elevation in sodium and chloride levels within Seneca and Cayuga Lakes is the result of intersection of the lake basins with naturally occurring salt deposits underlying the region (Wing, et. al., 1995). However, the apparent decline in the concentrations of these ions within these two lakes over a relatively short period of time would seem somewhat at odds with this hypothesis. The *second* discernable pattern is that three of the four western-most Finger Lakes (Hemlock, Canadice and Honeoye Lakes) show significantly lower ion levels than do the other 8 Finger Lakes. This is most pronounced for Canadice Lake which shows the lowest total cation and anion levels of any of the lakes. The relatively low ion levels are likely a result of several factors, including: (1) Surface elevation: these three lakes are situated at higher surface elevations than the other lakes (Canadice Lake is situated at the highest surface elevation of all the Finger Lakes). These differences in surface elevations are likely reflected in underlying geology and resultant ionic composition of tributary runoff; and (2) Watershed Controls: Hemlock and Canadice Lakes are in fairly protected watersheds with minimal development which likely limits anthropogenic inputs. Similar spatial patterns in total ion levels were also apparent in the 1970s data-set.

Temporal comparisons of total cation and anion levels between the 1970s and the 1990s indicate some significant changes. The most pronounced changes, in absolute terms, involved changes in sodium and chloride levels within Seneca and Cayuga Lakes - see further discussion below. Changes, on a percentage basis, were as follows: (1) The largest decline in total cation levels occurred in Seneca and Cayuga Lakes, with more modest reductions observed in Conesus and Otisco Lakes – the specific cation responsible for the majority of the change varied. For Cayuga and Seneca Lakes, the cation responsible for the majority of the change was sodium, whereas, the principal cations responsible for changes in Conesus and Otisco Lakes were magnesium and calcium. In fact, sodium levels in both Conesus and Otisco Lakes appear to have increased substantially on a percentage basis; (2) The largest increase in total cation levels occurred in Canadice and Honeoye Lakes, with the majority of the increase due to increases in sodium levels – once again, see further discussion to follow; (3) The largest decrease in total anion levels occurred in Cayuga, Seneca, and Skaneateles Lakes. In the case of Cayuga and Seneca Lakes the principal anion responsible for the change is chloride, whereas, in Skaneateles Lake the majority of the change is attributable to a marked decline in sulfate levels; and (4) The largest increase in total anion levels occurred in Canadice Lake and is due primarily to increases in chloride levels.

Specific Conductivity and pH

Specific conductivity is a measure of the total ionic activity in water, while pH indicates the relative acidity (or hydrogen ion content) in the water column. pH is measured on a logarithmic scale from 1 to 14 (see Figure 5.17), with lower numbers indicating increasing acidity. Representative vertical profiles for both parameters during mid to late summer are presented in Figures 5.18-5.19.

Figure 5.17: pH scale schematic

			ACIDIC				NEUTRAL					BASIC		
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
		Lemon Juice		Vinegar	NY Rain	Unpolluted Rain			Soap			Ammonia		

As one would expect given the link between specific conductivity and ionic concentration, Seneca Lake and Cayuga Lake (Figure 5.18) demonstrate higher specific conductivity levels than do the other 9 Finger Lakes. Similarly, Canadice Lake (Figure 5.18), which exhibits the lowest ionic levels, also shows the lowest specific conductivity levels of all the Finger lakes. The vertical profiles of specific conductivity indicate that each of the Finger Lakes show nearly uniform levels of specific conductance with depth. This was somewhat unexpected for Seneca and Cayuga Lakes given their relatively high conductivity levels and the suggestion that elevated ionic levels are the result of lake basin intersection with geologic salt deposits (Wing, 1995). It would seem that if the systems were being "fed" from salt deposits that this would result in a vertical gradient in conductivity levels. However, it is possible that such gradients are present in deeper waters – this investigation was limited by the length of the instrument cable (100 m) which precluded vertical measurements within the deepest portions of Seneca and Cayuga Lakes. It is also possible that mixing forces within the lakes dissipate any conductivity gradients.

The most discernable pattern from pH profiles is the elevation in pH levels within upper waters of each lake. This pattern is quite common for stratified lake systems and is the result of the following factors: (1) algal uptake of CO_2 from epilimnetic waters with an equivalent consumption of hydrogen ions – thus increasing pH; and (2) decomposition of senescing algae within the hypolimnion resulting in the release of CO_2 and hydrogen ions. Significant pH swings occur within the Finger lakes during the growing season. The water quality standard for pH is 6.5-8.5. All of the lakes on occasion exceed a pH of 8.5, and several of the lakes occasionally exceed a pH of 9.0. In addition, pH drops below 6.5 in several of the lakes, with a few (e.g., Canadice Lake) dropping below 6.0. The significance of these excursions beyond the ambient water quality standard for pH is not known.

Findings for individual cations and anions will be presented below. The discussion of ionic trends is premised upon the current investigation and information from the late 1960s and early 1970s. The reader is cautioned to take the temporal comparisons with a grain of salt (pun intended) for the following reasons: (1) The earlier data is derived from a number of different sources, and sample frequency varied significantly; (2) The methods used to derive the levels of certain ions involved visual interpretation from graphs of milli-equivalent levels - obviously, this approach is open to some error; and (3) Specific sample locations for the 1970s data are unavailable, which introduces spatial differences into the comparison.

Figure 5.18: Specific Conductivity and pH for 6 eastern Finger Lakes

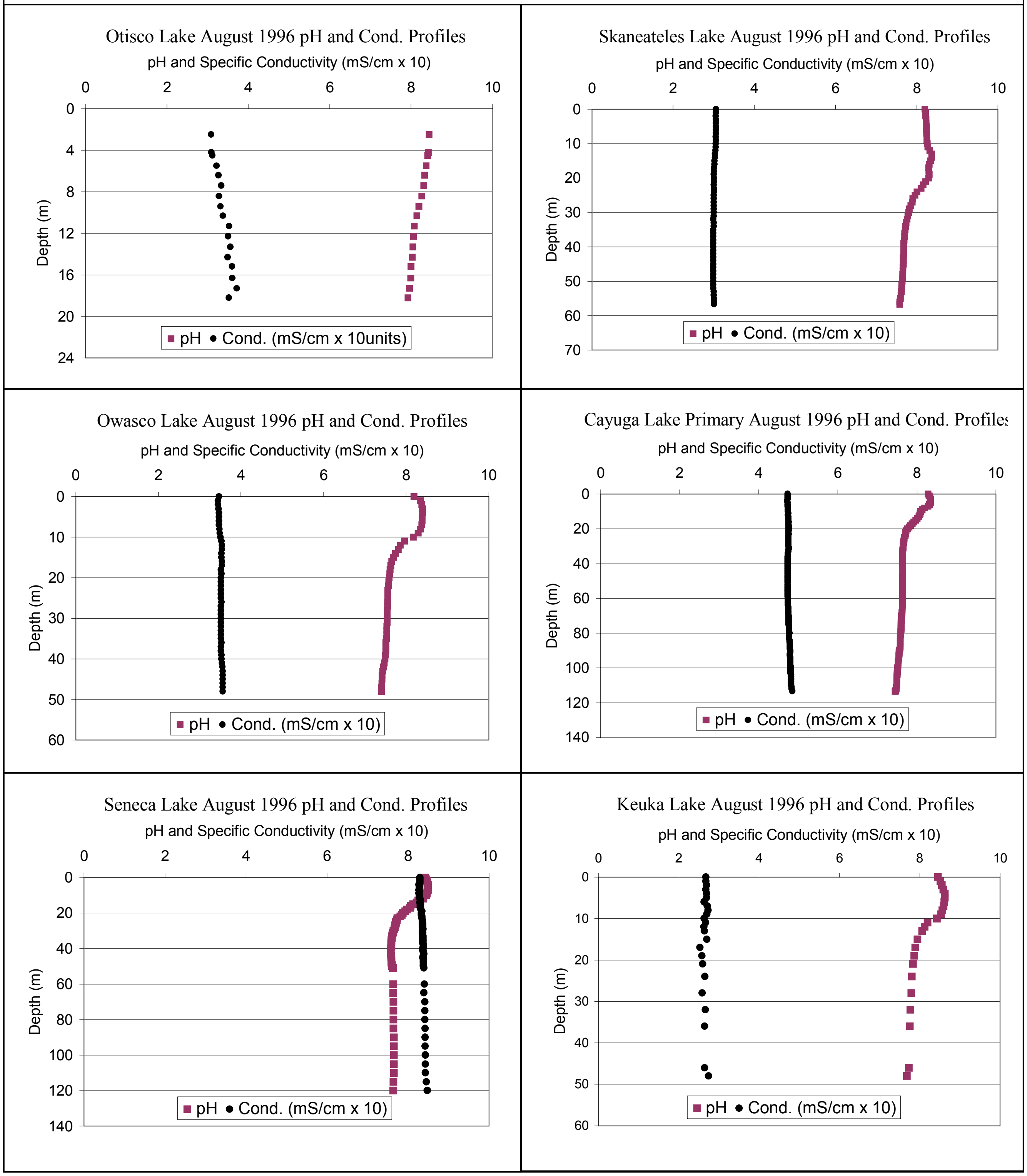
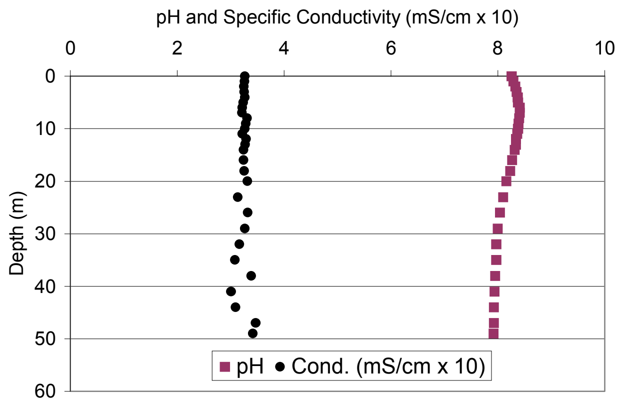
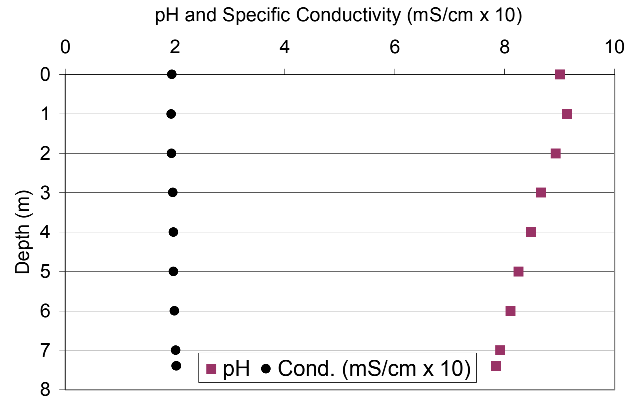


Figure 5.19: Specific Conductivity and pH for 5 western Finger Lakes

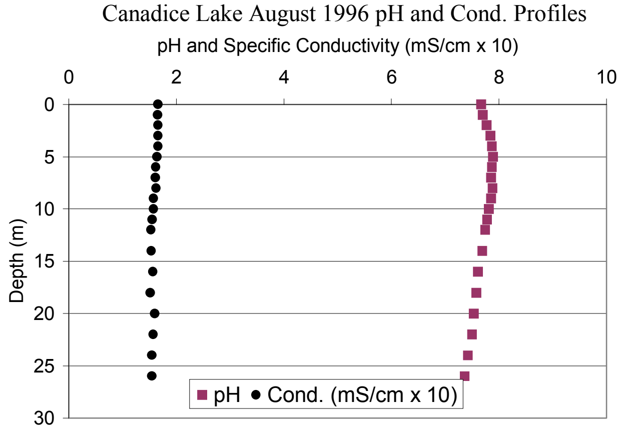
Canandaigua Lake August 1996 pH and Cond. profiles



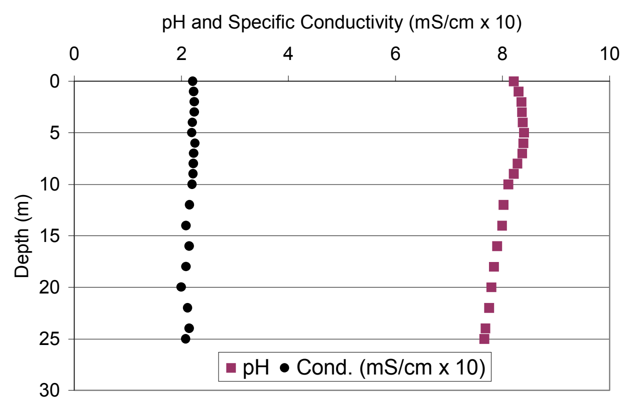
Honeoye Lake August 1996 pH and Cond. Profiles



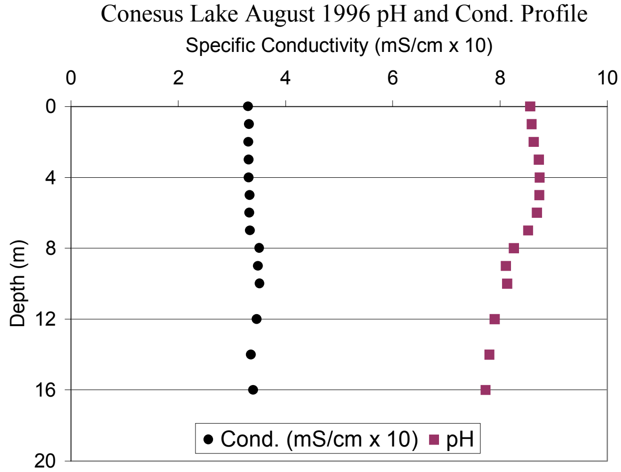
Canadice Lake August 1996 pH and Cond. Profiles



Hemlock Lake August 1996 pH and Cond. Profiles



Conesus Lake August 1996 pH and Cond. Profile



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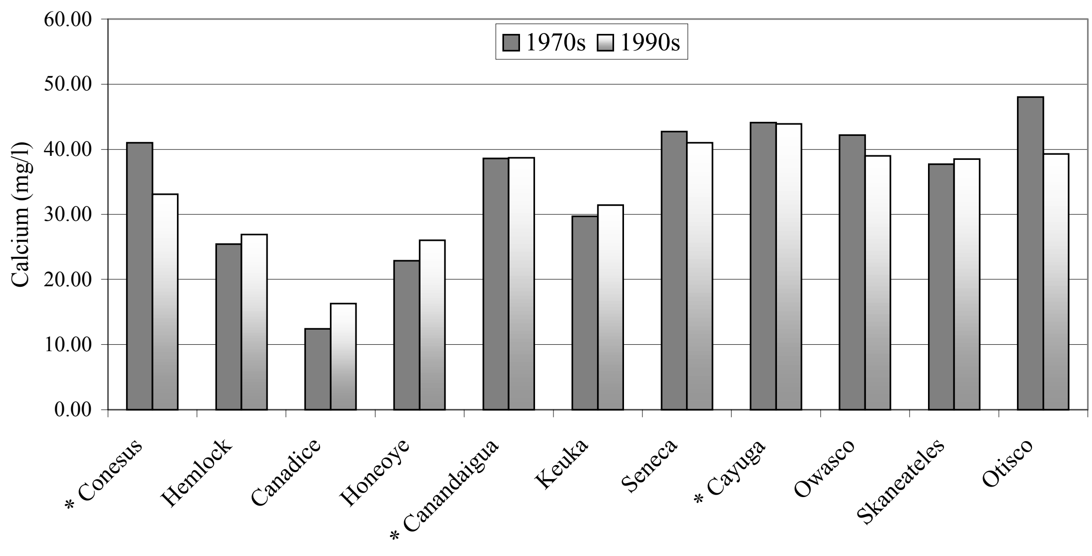
Calcium

Calcium is important to both the flora and fauna in fresh water aquatic systems, and is essential to the structure and functioning of cell membranes. Of particular concern to freshwater systems within the northeastern United States is the fact that calcium may play an important role in the establishment of Zebra mussel (Deissena polymorpha) populations within lake systems. The Zebra mussel is an exotic and invasive freshwater mussel which is native to the Black, Caspian, and Azov seas of southern Europe and Asia. Zebra mussels are capable of causing significant ecological changes within a lake by dramatically altering the food web structure. Furthermore, Zebra mussel infestations can result in significant economic impacts due to clogging of water supply intake pipes and other human structures. First introduced to the Great Lakes in the late 1980s, Zebra mussels have now been confirmed in all of the Finger lakes with the exception of Canadice Lake. The calcium concentration of a lake appears to be one of the primary limiting factors in Zebra mussel infestations (Ramcharan, et. al., 1992). It would appear that the calcium threshold for Zebra mussel development is in the range of 25-30 mg/l (Ramcharan, et al., 1992) – waters with calcium concentrations below this level do not appear to support the establishment of Zebra mussels while calcium concentrations above this level are conducive to the establishment of Zebra mussels. Furthermore, if calcium is a limiting factor to Zebra mussel proliferation within the Finger Lakes than it is possible that increasing calcium concentrations may exacerbate such infestations.

Epilimnetic calcium levels from the 1970s and the 1990s are presented in Figure 5.20. From a spatial perspective, 3 of the 4 western Finger Lakes exhibit significantly lower calcium levels than do the 7 eastern lakes. This is likely due to differences in geology and associated soil types within the lake watersheds – the result of differences in surface elevations. For example, Canadice Lake exhibits the lowest calcium levels and is located at the highest surface elevation of all the Finger Lakes – see Figure 2.4. Conesus Lake, the western-most Finger Lake, is the exception to this pattern.

From a temporal perspective, Conesus and Otisco Lakes show moderate declines in calcium levels over the past 2 decades. In contrast, Canadice and Honeoye Lakes show a moderate increase in calcium levels over the intervening time period. Owasco Lake exhibits a slight downward trend in calcium levels over the past couple of decades. Hemlock, Canandaigua, Keuka, Seneca, Cayuga, and Skaneateles Lakes have remained fairly static with respect to calcium levels.

Figure 5.20: Average epilimnetic calcium concentrations for the Finger lakes



Consistent with the hypothesis of calcium acting as a limiting nutrient for Zebra mussels, Canadice Lake, which is the only one of the Finger Lakes in which Zebra mussel colonization is not yet established, also showed the lowest calcium levels of the 11 lakes. Canadice Lake is the only Finger Lake with an average calcium level below 20 mg/l. It is possible that Canadice Lake has avoided Zebra mussel infestation due to watershed protection measures in place within the basin, however, Hemlock Lake, which has similar restrictions, has not escaped establishment of Zebra mussel populations. A more likely scenario is that the relatively low calcium levels observed within Canadice Lake have prevented the establishment of a viable Zebra mussel population. On a cautionary note, the calcium levels observed within Canadice Lake appear to have increased by approximately 30 percent over the past several decades and might approach threshold levels for support of Zebra mussel populations within the near future.

Figure 5.21: Zebra mussels on macrophytes.

Concerns about calcium levels and Zebra mussel proliferation may not be limited to Canadice Lake. The issue of concern in the other Finger Lakes is not a matter of establishing a Zebra mussel population within the lakes, as they are already known to be present, but rather whether population levels will increase due to increased availability of calcium. While water column trends suggest a moderate increase in calcium levels in only a few of the lakes, sediment core data indicate a more significant increase in calcium levels within the bottom sediments of the lakes (see later discussion of sediment core findings). This raises the question "*whether, or not, these calcium deposits within the sediments can be 'mined' by the benthic dwelling Zebra mussels?"*. While Zebra mussel monitoring has not been a formal part of the present investigation, informal observations have indicated a marked increase in Zebra mussels in certain parts of the Finger Lakes over the last couple of years. For instance, between 1998-99 a significant increase in Zebra mussel populations was observed at the south end of Cayuga Lake. This proliferation in Zebra mussel numbers within the southern end of Cayuga Lake appeared to be in association with certain types of aquatic macrophytes (see Figure 5.21).

Another phenomenon associated with the occurrence of calcium in lake systems is what is termed calcite precipitation (or whiting events) and is often characterized by a milky or cloudy appearance to the water. Calcite precipitation is controlled by several factors including water temperature, pH, and calcium concentration, and is believed to be biologically mediated. Calcite ($CaCO_3$) precipitation events can lead to significant fluctuations in calcium levels within lake systems. Researchers at the Upstate Freshwater Institute have documented whiting events in several of the Finger lakes.

Magnesium

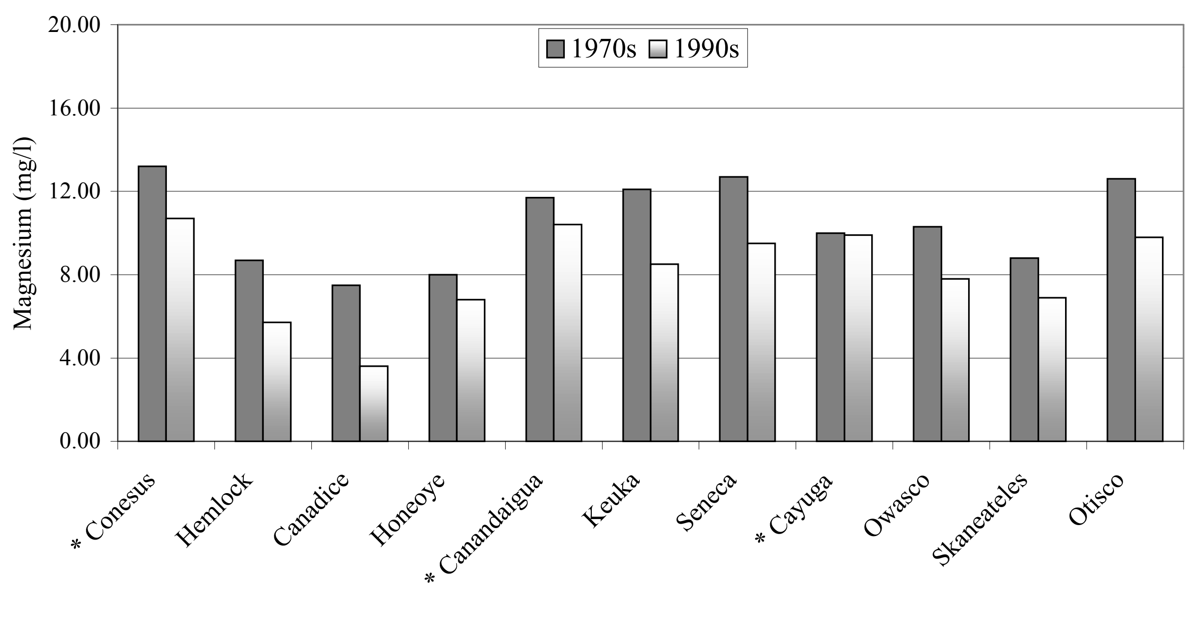
Magnesium is an important micronutrient in aquatic ecosystems. It is essential to the production of chlorophyll and is important in the functioning of certain enzymatic systems in algae, fungi, and bacteria.

Epilimnetic magnesium concentrations from the 1970s and the 1990s are shown in Figure 5.22. Spatial patterns for both periods are similar to those observed for calcium, in that magnesium levels are generally higher in the eastern lakes.

Temporal trends appear to indicate substantial declines in magnesium levels in each of the Finger Lakes, with the exception of Cayuga Lake, over the past several decades. The reduction is most pronounced (on a percentage basis) in the 3 western lakes. The magnitude of these apparent changes may indicate some anomaly in the data sets. It is conceivable that the analytical methods used during the two study periods were different. However, findings from Cayuga Lake suggest fairly static magnesium levels. Another issue may be the number of sample points available for several of these systems during the 1970s period. As indicated earlier, the number of data points available from the 1970s were quite limited for several of the lakes. For example, less than 5 data points were available for Otisco, Keuka, Seneca, Honeoye, and Canadice Lakes. However, a significant number of data points (> 10) were available for Conesus, Hemlock, Owasco and Skaneateles Lakes, each of which also showed marked declines in magnesium levels. It is also possible that 1973 (the year in which many of the earlier measurements were made) was somehow unusual, however, this would seem quite remarkable given the residence time of these waterbodies.

In summary, the magnesium findings would appear to warrant additional investigation. In particular, the analytical methods employed for the two study periods should be scrutinized. Should these apparent declines turn out to be real, the cause(s) and ecosystem consequences of such changes should be evaluated.

Figure 5.22: Average epilimnetic magnesium concentrations for the Finger Lakes



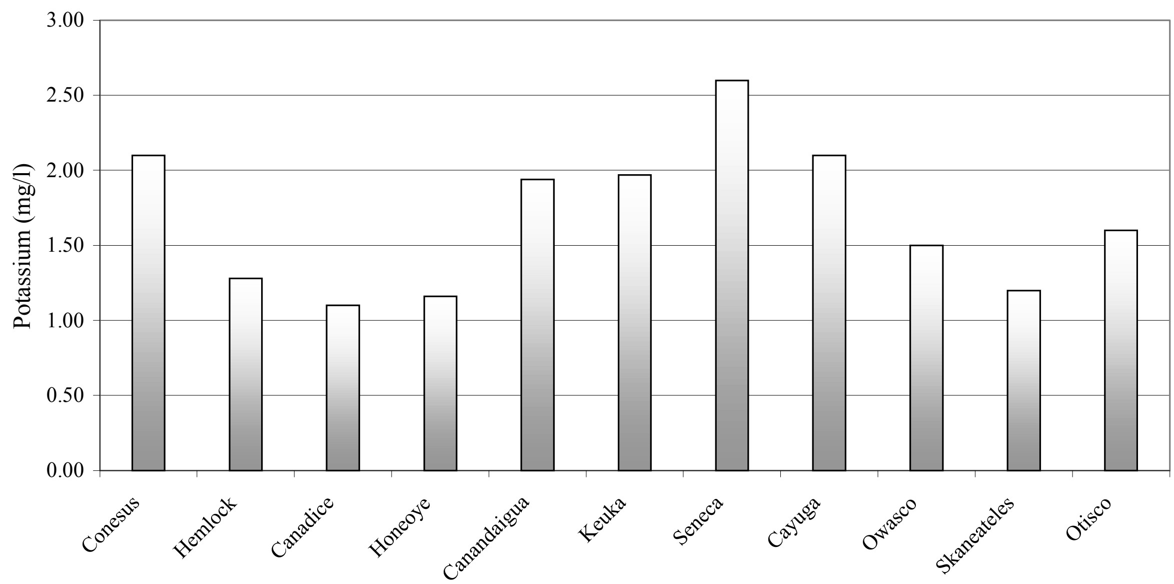
Potassium

Potassium is an essential nutrient for both plants and animals, and is involved in transport processes within living cells.

Potassium levels within the Finger Lakes vary by approximately two fold. Average epilimnetic potassium concentrations from the 1990s are shown in Figure 5.23 – potassium levels were not available from the 1970s. Potassium levels within the Finger Lakes range from a high of approximately 2.5 mg/l in Seneca Lake to a low of just over 1.0 mg/l in Canadice Lake. While the spatial patterns, once again, present something of an east-west trend, the differences are less pronounced than for some of the other ions discussed earlier. In this instance, the central lakes (and Conesus Lake) show the highest concentrations. The spatial patterns for potassium do not appear to parallel lake trophic status.

Temporal trends in potassium concentrations could not be evaluated given the lack of historical data. In addition, there are no applicable water quality standards for potassium.

Figure 5.23: Average epilimnetic potassium concentrations during the 1990s



Sodium

As with potassium, sodium is important in ion transport within living cells. However, elevated sodium intake has been implicated in hypertension and related heart problems in certain susceptible individuals. The New York State Department of Health has issued the following guidelines for drinking water (NYSDOH, 1998):

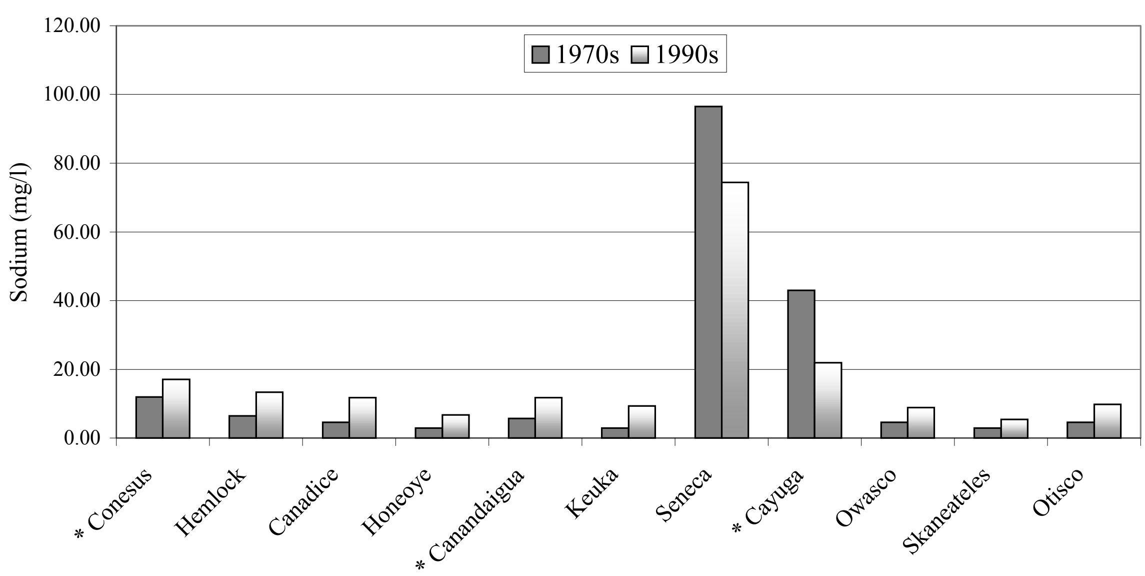
> "Water containing more than 20 mg/L of sodium should not be used for drinking by people on severely restricted sodium diets. Water containing more than 270 mg/L of sodium should not be used for drinking by people on moderately restricted sodium diets."

Other issues that can be of concern with respect to elevated sodium levels include: (1) increased corrosion in pipes; and (2) selective advantage to certain species of blue-green algae (Wetzel, 1983).

Mean epilimnetic sodium levels for the Finger Lakes are shown in Figure 5.24. Sodium levels presented for the 1970s are derived, largely, from a bar graph of milli-equivalents presented in Bloomfield (1978), as no compilation of sodium levels could be obtained elsewhere. Thus, the reader is cautioned that the 1970s values should be considered approximate. However, as one would expect, sodium patterns appear to parallel changes in chloride levels (see following discussion), the later of which are based on actual concentration measurements.

As has been known for some time, spatial patterns for sodium levels within the Finger Lakes indicate that the two larger lakes, Seneca Lake and Cayuga Lake, exhibit significantly higher levels (by nearly an order of magnitude) than do the other 9 lakes. The current findings continue to support this bifurcation, at least for Seneca Lake. Seneca Lake sodium levels continue to be at least 4 times higher than the other 9 Finger Lakes (excluding Cayuga Lake). In the case of Cayuga Lake, the most recent findings suggest that sodium levels are approaching the upper levels of the other 9 lakes. As discussed briefly above, the standing hypothesis for this divergence in sodium (and chloride) levels is that the deeper lakes intersect salt-laden strata which works its way into the water column (Wing, 1995). While this may account for some of the observed differences, there appear to be other factors at work – see discussion of temporal patterns below.

Figure 5.24: Mean epilimnetic sodium concentrations for the Finger Lakes.



Temporal changes in sodium levels within the Finger Lakes over the past several decades appear to follow one of two patterns. The two largest Finger Lakes, Seneca Lake and Cayuga Lake, exhibit a marked decline in sodium levels (in both absolute terms and on a percentage basis), while the other 9 lakes appear to show substantial increases in sodium levels (at least on a percentage basis) over the intervening period.

Sodium concentrations in Seneca Lake and Cayuga Lake have declined by approximately 20 percent and 50 percent, respectively, over the past 2 decades. This would seem to present something of a quandary for existing hypotheses regarding sodium variations within the Finger Lakes. The depth of scour hypothesis (Wing, et al., 1995) outlined earlier would seem a reasonable hypothesis to explain a static elevation in sodium levels within Seneca and Cayuga Lakes. However, such a hypothesis seems insufficient to explain the marked decline in sodium levels observed over the past several decades. The apparent dynamics in sodium levels over the relatively short time interval (from a geologic perspective) of the past several decades would suggest that some other factor(s), other than simply lake basin depth, is contributing to sodium levels within these two lake systems. A second, related factor, namely, the commercial mining of salt within the region might provide an explanation for the observed sodium changes in Seneca and Cayuga Lakes. It is conceivable that improvements in the operation of these mining facilities over the intervening period could be responsible for the observed changes.

In contrast to the 2 largest Finger Lakes, the remaining 9 lakes exhibited sizeable increases (on a percentage basis) in sodium levels over the same period. Increases in sodium levels for the other 9 lakes ranged from over 40 percent in Conesus Lake to over 200 percent in Keuka Lake. While the percentage change is quite high, absolute sodium levels remain relatively low. However, certain of the lakes (e.g., Conesus, Hemlock and Canadice Lakes) are approaching 20 mg/l - Department of Health criteria for people on severely restricted sodium diets. The reason(s) for the observed changes in sodium levels for these 9 lakes is not clear. One possible explanation for the observed increase in sodium levels within these lakes is increased use of deicing agents on roadways during the winter months. The combination of increased road building and, thus, increased demand for deicing agents, coupled with increased use of deicing agents per highway maintenance protocols, might account for the increases in observed sodium levels. Other possible explanations might include hydrologic variations (although these would have to be substantial given the retention times of these waterbodies), and/or changes in land use activities within these watersheds.

Chloride

Chloride is the anion most closely associated with the cation sodium. The coupling of these two ions produces the mineral sodium chloride which is better known as common table salt. The water quality standard for chloride is 250 mg/l.

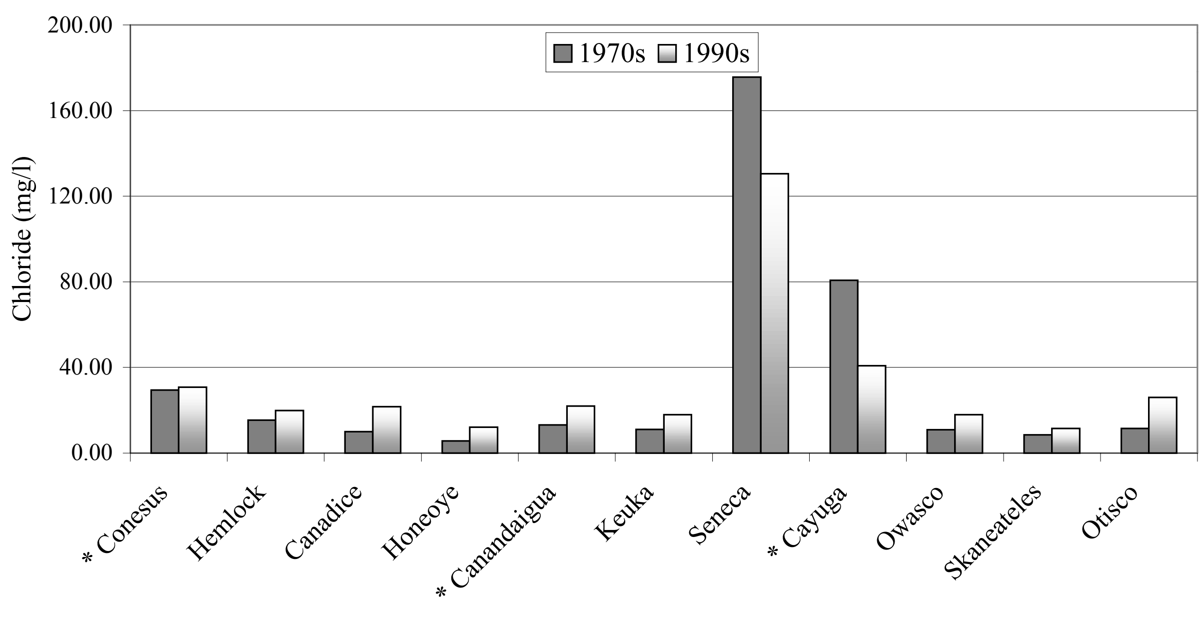
Mean epilimnetic chloride levels from the 1970s and the 1990s are presented in Figure 5.25. The 1970s values were obtained from either Mills (unpublished data, 1973) or Bloomfield (1978) .

As one might expect, given the close association between the anion chloride and the cation sodium, spatial patterns for chloride parallel those observed for sodium discussed above. Seneca Lake is clearly in a league of its own with respect to chloride levels. Chloride levels within Seneca Lake are more than 3 times greater than in any of the other Finger Lakes. Cayuga Lake also exhibits higher chloride levels than the other 9 Finger Lakes, however, the concentration differences have narrowed significantly over the past two decades.

Temporal patterns for chloride also parallel findings for sodium discussed above. For instance, the two largest Finger Lakes, Seneca Lake and Cayuga Lake, show significant declines in chloride concentrations - approximately 25 percent and 50 percent, respectively. The observed changes in chloride levels are probably of similar origins to those associated with changes in sodium concentrations (see previous discussion). Once again, this would appear to warrant some reevaluation of the hypotheses forwarded to account for chloride variations within the Finger Lakes. In contrast, the other 9 Finger Lakes show increases in chloride concentrations ranging from approximately 16 percent for Conesus Lake to 160 percent for Otisco Lake.

None of the Finger Lakes exceed the ambient water quality standard for chloride.

Figure 5.25: Mean epilimnetic chloride concentrations in the Finger Lakes.



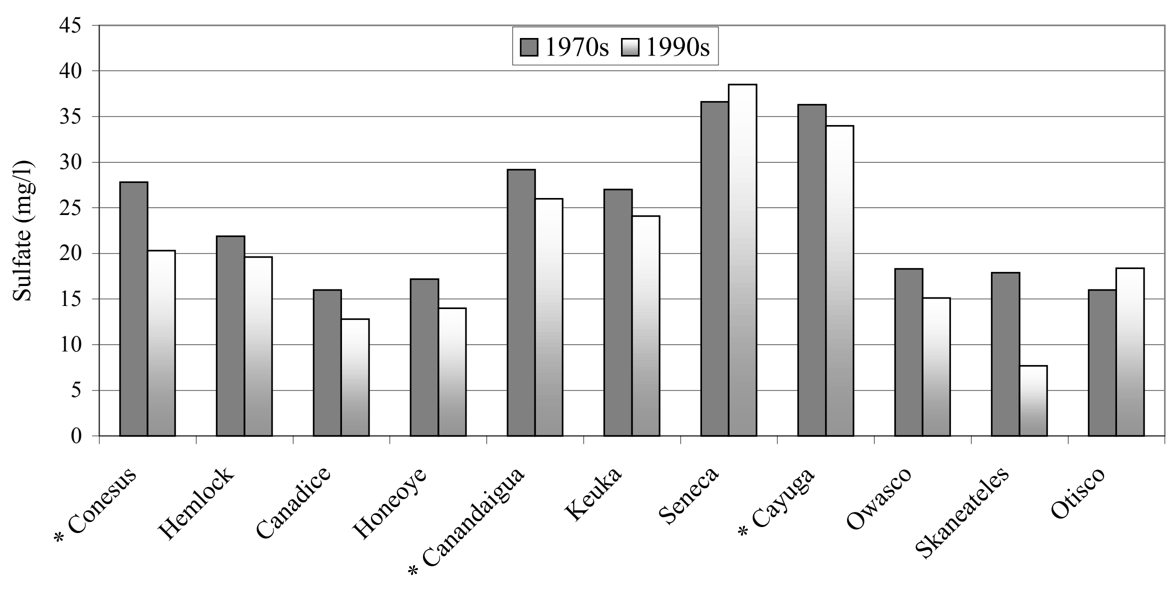
Sulfate

Sulfate (SO_4) is the predominant form of dissolved sulfur in most freshwater systems. Under conditions of low DO (reducing conditions) and low pH, sulfate can react to form hydrogen sulfide (H_2S) which imparts a "rotten egg" odor to a given water sample. We did not analyze for hydrogen sulfide, however, it is conceivable that the smaller eutrophic Finger Lakes may show some level of hydrogen sulfide during the mid to late summer months.

Mean epilimnetic sulfate levels within the Finger Lakes are presented in Figure 5.26. Spatial comparisons of sulfate levels indicate that Seneca Lake and Cayuga Lake exhibit the highest sulfate levels, and that Skaneateles Lake and Canadice Lake exhibit the lowest sulfate levels within the Finger Lakes. These findings are somewhat unexpected with respect to the conventional relationship between trophic state and/or DO levels, and sulfate production. Skaneateles Lake and Canadice Lake, which are on the less productive end of the productivity continuum, did show relatively low sulfate levels. However, Seneca Lake and Cayuga Lake exhibited higher sulfate levels than did Conesus and Otisco Lakes. This is inconsistent with the premise that increased productivity results is increasing sulfate levels. Findings also fail to show a correlation between DO levels and sulfate levels, in that epilimnetic and hypolimnetic sulfate levels within both Conesus Lake and Otisco Lake were largely the same.

Temporal findings appear to suggest that epilimnetic sulfate levels have increased slightly in Seneca Lake and Otisco Lake during the past several decades. In contrast, epilimnetic sulfate levels have declined significantly (20 percent or more) in Conesus Lake and Skaneateles Lake during the past several decades. Lesser declines are also apparent in many of the other Finger Lakes, including Hemlock, Canadice, Honeoye, Canandaigua, Keuka, Cayuga, and Owasco Lakes. The reason(s) for the observed changes in sulfate levels is not entirely clear. However, the downward trend in trophic conditions for many of the larger lakes is generally consistent with observed declines in sulfate levels.

Figure 5.26: Mean epilimnetic sulfate concentrations in the Finger Lakes.



Alkalinity

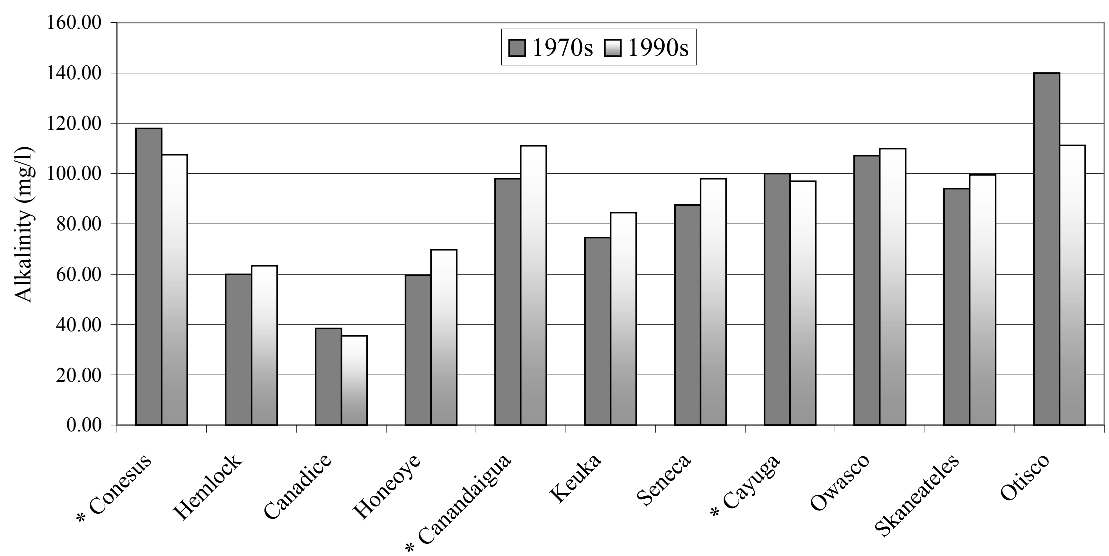
Alkalinity refers to the capacity of water to neutralize acid, and reflects the quantity of acid neutralizing constituents present within a water body. In most freshwater lakes in New York State, alkalinity is primarily a measure of bicarbonates (HCO_3^-) and carbonates (CO_3^{-2}).

The well publicized phenomenon of *lake acidification* is closely related to alkalinity. The principal determinants of whether a lake becomes acidified are: (1) the relative acidity of precipitation (e.g., rain) within the lake catchment – precipitation of pH < 5.6 is referred to as acid rain; and (2) the buffering, or neutralizing, capacity of the receiving water – largely controlled by the soils and underlying geology of the catchment. In general, alkalinity levels below 20 mg/l of $CaCO_3$ warrant concern.

Alkalinity levels for the Finger Lakes are presented in Figure 5.27. Alkalinity levels for the 1970s were obtained from Mills (unpublished, 1973) and Bloomfield (1978). Spatial patterns for alkalinity are similar to patterns observed for other ions in that Hemlock, Canadice, and Honeoye Lakes exhibit the lowest alkalinity levels. Alkalinity levels range from slightly greater than 100 mg/l for Conesus, Canandaigua and Otisco Lakes, to below 40 mg/l for Canadice Lake.

Temporal trends in alkalinity levels within the Finger Lakes vary somewhat. Conesus Lake and Otisco Lake show relatively large reductions in alkalinity levels over the past several decades. These changes may be the result of non-point source controls within these watersheds. The Otisco Lake watershed, in particular, has seen a significant investment in agricultural non-point control over the last decade, or so. Canadice Lake and Cayuga Lake show a smaller decline in alkalinity levels over the period, however, the numbers are clearly within the margin of error. In contrast, Honeoye, Canandaigua, Keuka, and Seneca Lakes show a moderate increase in alkalinity levels over the past couple of decades. Finally, Hemlock, Owasco, and Skaneateles Lakes show smaller increases in alkalinity levels, although, again, these are within the margin of error. In summary, all of the Finger Lakes, with the exception of Canadice Lake, exhibit alkalinity levels well above 20 mg/l. Thus, concerns about lake acidification and associated issues are not germane to most of the lakes. On the other hand, Canadice Lake probably warrants continued observation given its relatively low alkalinity levels and the slight downward trend.

Figure 5.27: Mean epilimnetic alkalinity levels within the Finger Lakes.



d. Other Parameters (nitrogen, silica, lead, arsenic, and pesticides)

Other parameters collected as part this investigation which did not logically fit under the previous topics include nitrogenous compounds, silica, the trace metals lead and arsenic, and current use pesticides.

Nitrogen, as any farmer or gardener is aware, is important for plant growth. However, as discussed above, primary productivity (algal growth) within the Finger Lakes is controlled largely by phosphorus availability (i.e., phosphorus-limiting systems). There are other issues which can be of concern with respect to certain nitrogenous species. This is reflected in ambient water quality standards (see Table 5.1) for both ammonia (NH_4) and nitrate/nitrite (NO_3/NO_2). Certain nitrogenous species can pose a threat to the health of both humans and aquatic biota.

There are two ambient water quality standards for total ammonia as follows: (a) human health standard related to drinking water supplies of 2 mg/l; and (b) aquatic toxicity standard, which is temperature and pH specific, ranging from 2.5 mg/l (at 0 °C and pH of 6.5) to 0.08 mg/l (Class "T" and "TS" waters at 30 °C and pH of 9.0). Total ammonia levels varied substantially within the Finger Lakes. While none of the lakes showed total ammonia levels above ambient water quality criteria, the relatively high pHs observed during the investigation and observed ammonia levels in certain of the lakes would seem to warrant continued observation. Three of the Finger Lakes (Conesus, Honeoye, and the southern shelf of Cayuga Lake), on occasion, exhibited total ammonia levels which could conceivably be of concern. Both Conesus Lake and Honeoye Lake exhibited several measurements of total ammonia above 0.1 mg/l. Conesus Lake showed a maximum total ammonia level of 0.21 mg/l and Honeoye Lake had a maximum total ammonia level of 0.17 mg/l. These measurements occurred at relatively low pHs and, thus, were below the ambient water quality standard. The southern Cayuga Lake site showed a total ammonia level of 0.46 mg/l on a single occasion. Once again, given the pH and the water temperature at the time, this would not constitute a violation of the ambient water quality standard. Furthermore, all other measurements of total ammonia at this site were less than 0.05 mg/l.

The ambient water quality standard for nitrate/nitrite is 10 mg/l and is designed to protect human health. In particular, this standard is intended to protect against a disease called methemoglobinemia (or blue baby syndrome) which can occur in infants under 6 months of age. The disease results from a reduction in the oxygen carrying capacity of the blood. Elevated nitrate/nitrite levels are most often a concern in ground waters underlying heavy agricultural areas. While quite infrequent, we did observe two instances when nitrate/nitrite levels approached or exceeded the 10 ug/l level. On June 6, 1996, a hypolimnetic (depth = 13 m) sample from Otisco Lake showed a nitrate/nitrite measurement of 9.6 mg/l. In addition, on August 5, 1996 a hypolimnetic (depth = 18 m) sample collected on Canadice Lake had a nitrate/nitrite concentration of 11.3 mg/l. The next highest nitrate/nitrite value observed on Canadice Lake during this investigation was 1.49 mg/l. In addition, discussions with Lenny Schantz of the Rochester Water Supply Bureau (personnel communication, 5-25-2000) indicated that this nitrate/nitrite value appeared unusually high.

Silica is a micronutrient which can be an important determinant of algal productivity in a lake. Specifically, silica is often the limiting nutrient for diatoms, an important group of freshwater algae. In many freshwater lakes the initial algal bloom of the season is composed of diatom species which require higher silica levels than do other algal species. Silica results during this investigation are consistent with the premise of algal uptake. In nearly all years and all lakes average silica levels were lower in the epilimnion than in the hypolimnion – in some instances there was a 10 fold difference between the upper waters and the lower waters. In addition, in many instances, the disparity in silica levels between the epilimnion and the hypolimnion often increased throughout the growing season – which is consistent with “scavenging” of silica from the epilimnion and subsequent transfer to the hypolimnion upon algal senescence. There are no ambient water quality criteria for silica.

Water samples were also analyzed for lead during this investigation. Lead, which is a neurotoxin, has been a contaminant of concern within the environment for many years. However, the ban on leaded gasoline in 1970 has resulted in significant declines in lead levels within the environment – see sediment core discussion to follow below. Sampling results showed no water column lead concentrations above 15 ug/l (ambient water quality standard is 50 ug/l), and nearly all samples were below the analytical detection limit of 5 ug/l.

Sediment cores collected in 1998 indicated elevated arsenic levels within the upper sediments of several of the Finger Lakes – see further discussion below. This prompted water column sampling for arsenic during 1999. Arsenic, which is a known carcinogen, can originate from both natural and anthropogenic sources. The USEPA is currently reevaluating the maximum contaminant level (MCL) for arsenic and is expected to lower the allowable level significantly. As with other parameters, water samples were collected from both the epilimnion and the hypolimnion. All results, with the exception of a single sample, were below analytical detection levels. The one sample in which arsenic was detected came from Owasco Lake in September 1999. While the overall results are encouraging, they are not conclusive for the following reasons: (a) spatial limitations – monitoring was limited to a single location within each lake and to only two discrete depths per lake, (b) temporal limitations – sampling was limited to the 1999 season, (c) analytical detection limits were 10 ug/l, which is at or above the proposed MCL.

The United States Geological Survey (USGS) in conjunction with the NYSDEC, conducted sampling for current use pesticides on the Finger Lakes during the late 1990s. While not officially part of the current investigation, summary results from the pesticide monitoring were deemed appropriate for inclusion within this report. Results of this effort are summarized in Table 5.10 (from USGS, 2000).

Table 5.10: Results of USGS pesticide monitoring on the Finger Lakes (USGS, in press)

Lake	Sample #	Pesticides Detected (#)	Max. Atrazine (ug/l)	Max. Metolachlor (ug/l)
Conesus	2	8	.273	.128
Hemlock	17	6	.040	.048
Canadice	7	5	.017	.011
Honeoye	2	4	.017	.005
Canandaigua	2	7	.149	.025
Keuka	2	6	.036	.007
Seneca	14	7	.143	.017
Cayuga	31	8	.314	.128
Owasco	2	6	.148	.101
Skaneateles	11	6	.086	.048
Otisco	2	5	.114	.123

Findings from the pesticide investigation indicate that pesticide levels within the Finger Lakes vary significantly between the lakes. Cayuga Lake and Conesus Lake exhibited the highest levels of atrazine and metolachlor. The in-lake concentrations observed are all below the current MCL for these compounds. However, the levels of pesticides observed in several of the lakes warrant additional investigation in the future.