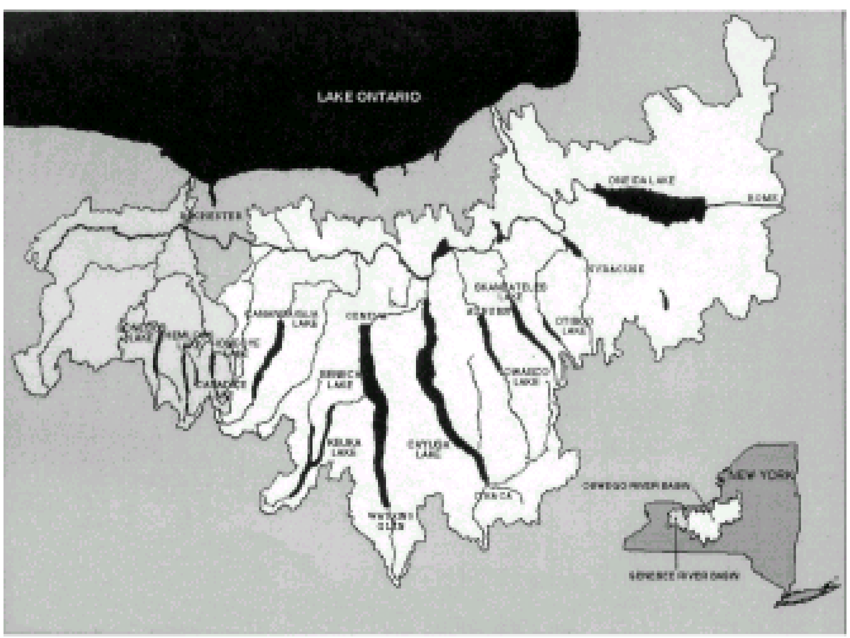
New York State

DEC

Division of Water

Water Quality Study of the Finger Lakes

July 2001



New York State Department of Environmental Conservation

George E. Pataki, *Governor*   Erin M. Crotty, *Commissioner*

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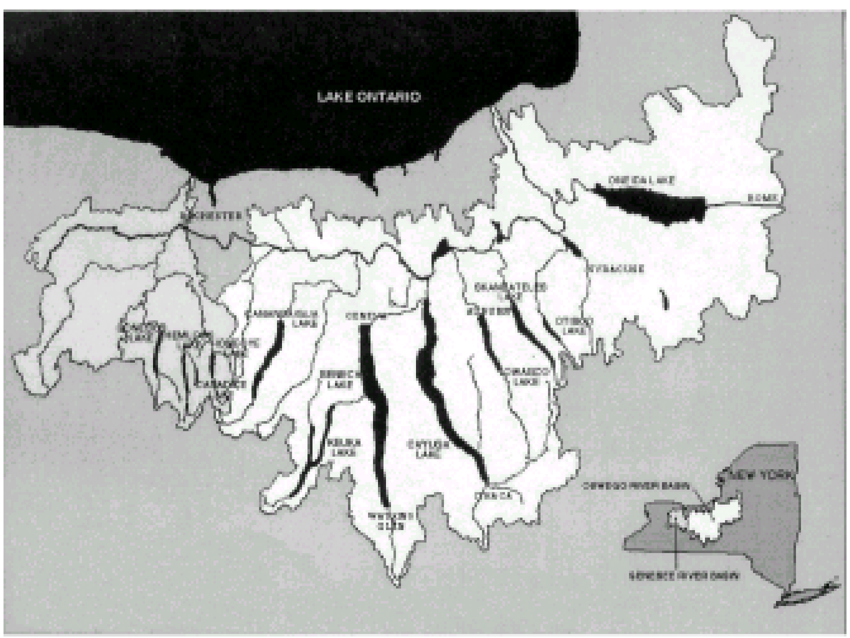

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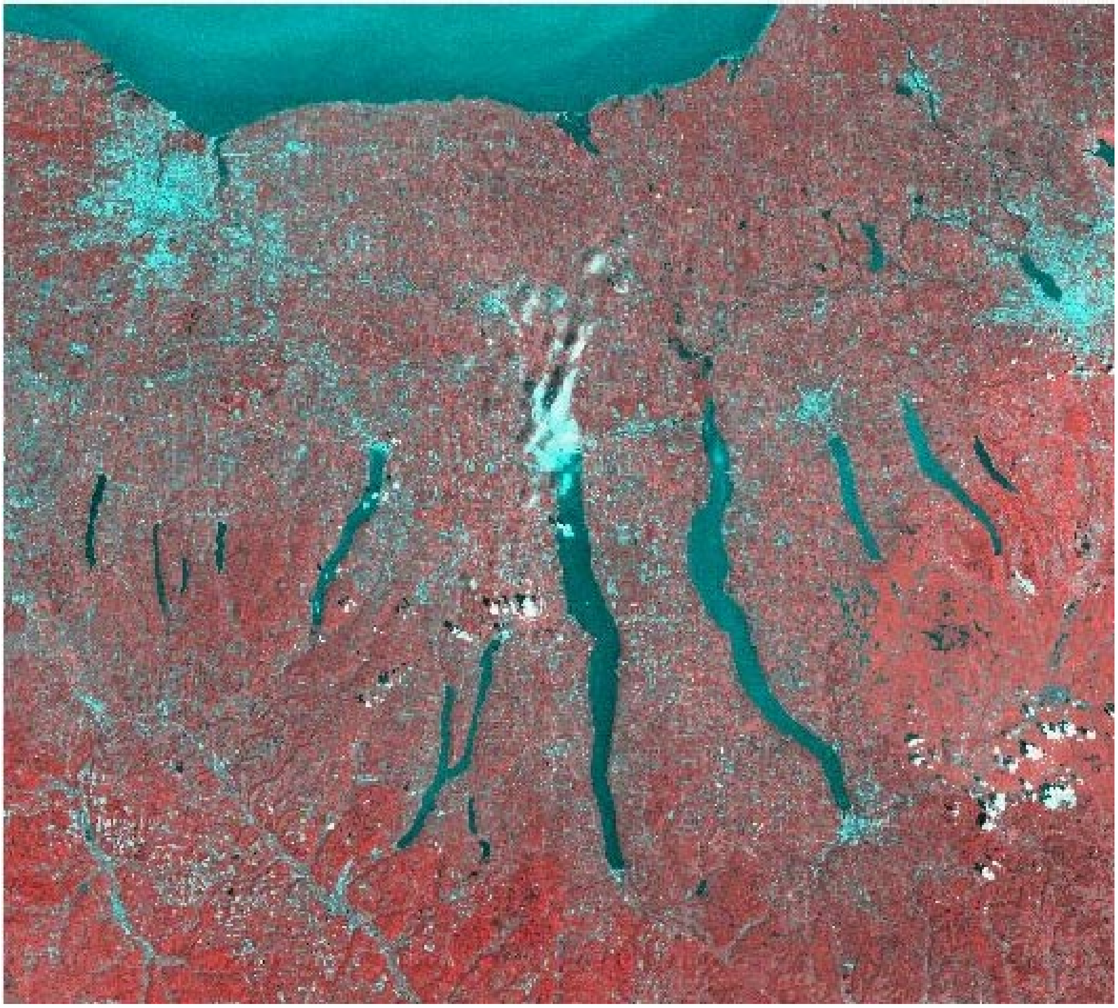
NASA 1991 Landsat Infrared Image

Water Quality Study of the Finger Lakes

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Date: July 2001
New York State Department of Environmental Conservation

Acknowledgements

As is often the case in a study such as this, certain hurdles must be overcome if the project is to be successful. This study was certainly no exception to the rule. Most notable of these hurdles was the coincidence of the later portion of the sediment core investigation with one of the largest tornado outbreaks in New York State history. On June 2, 1998 while sampling Canadice Lake the field crew came within a mere few miles of one of these storms. In fact, severe thunderstorm activity in the area resulted in the loss of our initial sediment core from Canadice Lake when a significant wind gust toppled the core as it rested on shore.

The Sediment Core Investigation would not have been possible without the significant efforts of Bruce Garabedian and Chandler Rowell of the NYSDEC; Hank Mullins and Chris Lajewski from Syracuse University; Ron Pause of the NYSDOH; and Mike Perry from Columbia Analytical Services. I would also like to extend my appreciation to Dick Draper, Frank Esterbrooks, Ron Sloan, and Karen Woodfield from the NYSDEC; as well as John Halfman from Hobart and William Smith College; Fred Luckey of the USEPA, and Dick Yager of the USGS for their assistance in this portion of the project.

The Synoptic Water Quality Investigation was also not immune to the erratic weather patterns in this picturesque part of New York State. While Skaneateles Lake is one of the most majestic waterbodies in the Empire State, it's weather patterns can be down right confounding. We were forced to seek safe harbor during several sampling excursions on Skaneateles Lake. Most notable of these episodes occurred on August 8, 1996, when an intense thunderstorm of approximately 3-4 hours duration stalled over the northern end of Skaneateles Lake and caused us to beat a hasty, and premature, retreat from the lake. My advice to all who venture onto this magnificent body of water is to always keep an eye to the sky.

The Synoptic Water Quality Investigation, which is continuing at present, is also a collaborative undertaking, and would not be possible without the considerable efforts of Scott Cook and Matt Romocki from NYSDEC Region 7 Water; Denise Richardson, Webster Pearsol, Gene Lane, and Dan Mulhul from NYSDEC Region 8 Fisheries; and Steve Effler, Carol Brooks, Bruce Wagner, and Nicholas Ohrazda of the Upstate Freshwater Institute – who provided significant assistance with the inception of this study. I would also like to thank Bill Abraham, Jay Bloomfield, Robert Bauer, Steve Eidt, Ricardo Lopez-Torrijos, Chris O'Connor, Tom Pearson, Howard Pike, and Les Wedge, of the NYSDEC; Ed Bugliosi, Dave Eckhardt, and Bill Kappel of the USGS; Ed Mills of the Cornell Biological Field Station; Larry Eichler from the Darrin Freshwater Institute; and Terry Faber of the USEPA for their assistance in this investigation.

Finally, I would like to thank my daughters, Nora and Caitlin, and my wife Amy for their insightful questions during the writing of this report. Their insistence on a recitation of the day's events, and a clear explanation of findings, prompted significant thought and revision of this report. For example, the glossary for this report is largely an outgrowth of their inquiries.

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Chapter 1: Executive Summary

The Finger Lakes are a series of 11 freshwater lakes located in the western part of New York State. The lakes were formed by glacial activity which ended approximately 10,000 years ago. The Finger Lakes include 3 of the largest 10 lakes in the New York State, and represent a significant asset to the Finger Lakes Region and the Empire State in general. All of the lakes, with the exception of Honeoye Lake, are used for public water supply. Permitted water withdrawals total approximately 180 million gallons per day. The Finger Lakes Region is also a well known tourist destination and generates an estimated $1.5 billion annually. The lakes and surrounding landscape of the region are a primary focus for tourism activity.

Water quality conditions within the Finger Lakes are generally good. However, there are water quality concerns as reflected by the fact that all 11 of the lakes are currently on the New York State Department of Environmental Conservation (NYSDEC) Priority Waterbodies List. Water quality issues of concern within the Finger Lakes are approximately equally split between water supply, swimming, and fish consumption issues. Pollutants of concern include nutrients, sediments, priority organics, pathogens, and salts.

Watershed management activities are underway in all 11 of the Finger Lakes watersheds. Management activities vary in level of complexity and stages of development. Canandaigua Lake and Keuka Lake are furthest along the watershed management continuum and have, to a degree, acted as a guide for management activities within several of the other Finger Lakes.

The Finger Lakes have been studied sporadically for nearly a century. The lakes were the focus of pioneering limnological studies by Birge and Juday during the early part of the 20th century. Following this initial foray, there would be a rather lengthy hiatus of nearly half a century before a comprehensive assessment of the lakes would occur. This later effort was conducted by a group of academicians, and culminated in publication of Lakes of New York State – Ecology of the Finger Lakes. Since the early 1970s, little systematic study of water quality conditions within the Finger Lakes has occurred, until the current investigation. There have been monitoring activities on a number of specific Finger Lakes over this time frame – these are largely locally-driven efforts focused on a single lake. However, comparative investigations of the Finger Lakes have been absent over the past several decades.

The purpose of the current study is to conduct such comparative investigations and to assess water quality conditions and trends within the Finger Lakes. The study is composed of two distinct components, *Synoptic Water Quality Investigation* and *Sediment Core Investigation*. The Synoptic Water Quality Investigation is designed to assess current limnological conditions, and to evaluate water quality trends within this important set of lakes. This portion of the Study was initiated in 1996 and is continuing at present. The Sediment Core Investigation is designed to assess chemical trends within the Finger Lakes over time. This portion of the Study is designed as a one-time effort, and sample collection occurred between 1997 and 1998.

The Synoptic Water Quality Investigation involves the collection of water samples and vertical water column profiles at a single deep water location within each lake – the only exception is for Cayuga Lake where there are 3 monitoring locations. Samples from both the epilimnion and hypolimnion are collected monthly during the growing season. In addition, vertical profiles of temperature, dissolved oxygen, pH, and conductivity are collected during each sampling run. The primary focus for this portion of the study is to assess the current trophic status of the lakes and evaluate trends in trophic indices. A secondary focus of the investigation is to assess the status and trends for major ions in the lakes.

Trophic conditions within the Finger Lakes, as reflected in conventional trophic indicators (total phosphorus, chlorophyll *a*, and Secchi Disk depth), have fluctuated significantly over the past century. Trophic conditions are thought to have increased significantly in most of the lakes between the early 1900s and the early 1970s, as evidenced by a marked decline in water clarity levels in most of the lakes. This increase in trophic state, generally considered undesirable, was likely the result of increased phosphorus loading to the lakes over this timeframe – phosphorus is the limiting nutrient within the Finger Lakes. The trend in trophic conditions from the early 1970s to present are somewhat less uniform. In general, the *larger* Finger Lakes have exhibited moderate to substantial declines in trophic state, while trophic conditions within the *smaller* lakes have remained static or increased moderately. The declines in trophic state observed in the larger lakes are believed the result of environmental management actions (e.g., phosphate detergent ban, construction of wastewater facilities, implementation of best management practices, etc.) implemented over the last several decades. Given that these management actions are not unique to the larger lake basins, raises the question "*why are the smaller lakes not responding accordingly*?". This apparent dichotomy in system response is thought to be the result of differences in hypolimnetic dissolved oxygen levels between the larger and smaller lakes, and resultant differences in phosphorus cycling within the respective lakes. It is believed that dissolved oxygen depletion in the smaller lakes trigger an internal release of phosphorus from lake bottom sediments, which, in effect, compensates for realized phosphorus load reductions from the watershed. This is consistent with dissolved oxygen observations in that the larger lakes exhibit little oxygen depletion with depth during the growing season, while the smaller lakes exhibit significant dissolved oxygen depletion during the summer months. The hypolimnion of a number of the Finger Lakes (Otisco, Honeoye, Canadice, Hemlock, and Conesus Lakes) drop below existing dissolved oxygen criteria. Furthermore, New York State's total phosphorus guidance value of 20 ug/l is exceeded in Conesus and Honeoye Lakes, as well as in the southern terminus of Cayuga Lake in certain years.

A secondary focus of the Synoptic Water Quality Investigation is to assess the status and trends for major ions within the Finger Lakes. Findings indicate that water column concentrations of certain ions within the Finger Lakes have changed somewhat over the past 3 decades. *First*, sodium and chloride levels have declined significantly in the two largest lakes (Seneca and Cayuga Lakes), while trends for these ions in the other Finger Lakes indicate increasing concentrations. Sodium and chloride levels have historically been much higher in Seneca and Cayuga Lakes than in the other Finger Lakes, likely due to the proximity of these deep lake basins to underlying salt strata and/or mining operations in the areas. This differential remains the case today, however the gap has narrowed somewhat. The increases in sodium and chloride levels observed in the other Finger Lakes are likely the result of increased use of deicing agents (e.g., sodium chloride) within the watersheds. With respect to water quality concerns, the sodium levels in both Seneca Lake and Cayuga Lake remain above water supply criteria (20 mg/l) for those on severely restricted sodium diets, and the levels within Conesus Lake are approaching this level. *Second*, calcium levels have increased within several of the Finger Lakes over the past few decades, which may raise concerns about Zebra mussel infestations. Zebra mussels, an exotic bivalve introduced into the US in the late 1980s, can cause substantial disruption to aquatic ecosystems, and result in significant impacts to human-made structures (e.g., clogging of water intake pipes). Calcium is often the limiting nutrient to Zebra mussel productivity and growth, thus increased calcium concentrations may lead to an exacerbation of Zebra mussel impacts. It is interesting to note that as of this time Zebra mussels have been found in all of the Finger Lakes with the exception of Canadice Lake. Furthermore, the lowest calcium levels observed in the Finger Lakes are in Canadice Lake, and occur at levels believed to inhibit establishment of Zebra mussel populations. However, given that calcium levels appear to be increasing in Canadice Lake, it is probable that Zebra mussels will eventually become established within the lake. *Third*, alkalinity levels within several of the Finger Lakes appear to have declined somewhat during the past several decades. While this is not of concern within most of the Finger Lakes due to their substantial buffering capacity, conditions within Canadice Lake bear watching due to its relatively low buffering capacity as compared to the other Finger Lakes.

The primary focus of the Sediment Core Investigation is to assess chemical trends within the Finger Lakes. A sediment core taken from the bottom of a lake can provide a chronological history of lake conditions. A single sediment core was collected from the deep water portion of each of the 11 Finger Lakes. Of the 11 sediment cores collected, 9 of the cores provide adequate radiometric profiles to support establishment of sediment dates (using cesium-137 and/or lead-210) – which provides the context for chemical chronologies within the given lake. Exceptions were Cayuga Lake and Hemlock Lake cores which failed to provide acceptable radiometric profiles. Computed sediment accumulation rates within the Finger Lakes ranged from approximately 0.2 cm/year for Canadice Lake and Skaneateles Lake to 0.7 cm/year for Otisco Lake, and were fairly consistent with findings of primary productivity for the lakes – lakes with higher levels of primary productivity show greater sediment accumulation rates. Chemical findings from the sediment core investigation are used as a means for assessing spatial differences between the 11 lakes, temporal trends within individual lakes, and comparisons to sediment quality guidance values – threshold effect level (TEL) and probable effect level (PEL).

The primary *organic* chemicals detected within the Finger Lakes sediment cores are *dichlorodiphenyl-trichloroethane (DDT)* and its metabolites, and *Polychlorinated biphenyl's (PCBs)*. These anthropogenic compounds are currently banned for use in the United States. In general, findings for DDT and its metabolites indicate that peak concentrations occurred several decades ago and that concentrations have declined markedly since that time. Although levels have declined, surficial sediment DDT concentrations remain above the TEL for total DDT in Keuka, Seneca, Conesus, and Canandaigua Lakes. As expected from the existing fish consumption advisory, Keuka Lake sediments show the highest DDT levels. However, indications from both sediments and fish flesh analyses suggest that DDT levels continue to decline in Keuka Lake. Findings for PCBs are somewhat less certain due to detection limitations associated with the analytical methods employed. PCB Aroclors, which were the primary focus of the PCB investigation, were detected in only a single core segment from Canadice Lake. PCB congener analyses (a more sensitive and also more expensive analysis) were also run on a single core segment from each of the lakes. PCB congeners were detected in all of the lakes in which testing was conducted (10 of 11 lakes). Total PCB results (summation of all measured congeners) indicate that sediment PCB levels within several of the lakes exceed upper sediment quality guidance values. Unfortunately, no trend analysis is possible from the data due to the fact that only a single core segment was evaluated from each lake. Furthermore, the core segment chosen for analysis on each of the lakes was taken from several centimeters below the top of the core, and thus may not represent current conditions. One intriguing finding concerning PCBs is that the total PCB concentrations detected in Conesus Lake and Seneca Lake are somewhat higher than the level detected in Canadice Lake, despite the fact that Canadice Lake has a fish consumption advisory currently in place.

A number of *inorganic* chemicals were also detected in the sediment cores extracted from the Finger Lakes. It is important to note that most of these substances can originate from natural, as well as, human sources. The most noteworthy findings are as follows. *First*, arsenic levels within upper sediments of several of the Finger Lakes are significantly enriched. The surficial sediments in several of the lakes exceed both lower and upper sediment quality values (TEL and PEL). There are several plausible explanations for this enrichment ranging from loading issues to geo-chemical processes, however, no definitive conclusions are possible at this juncture. Preliminary water column sampling was initiated in 1999 in response to the sediment core arsenic findings in an effort to assess possible drinking water implications. Preliminary findings are encouraging in that most samples were below the analytical detection level (10 ug/l). However, given the limited nature of the sampling (analytical, spatial, and temporal), and the fact that the USEPA is currently evaluating the existing maximum contaminant level (MCL) for arsenic, would suggest that additional study is warranted. *Second*, nickel levels while relatively homogeneous throughout each core, are above the TEL and PEL in many of the lakes. *Third*, several contaminants (chromium, copper, lead, and zinc) were found to exceed TEL values. In the case of copper, Otisco Lake was found to exceed the upper guidance values – likely due to copper sulfate treatments for algal growth. *Fourth*, while lead levels continue to exceed lower sediment quality values, the levels have declined markedly in many of the Finger Lakes. The declines observed in many of the lakes coincide very well with known restrictions on the use of leaded gasoline. *Fifth*, calcium levels within the sediments of many of the Finger Lakes show a marked increase over the past half century. Sediment calcium levels have increased by as much as 5-8 fold in some of the lakes. While the reason(s) for this increase are not certain, possibilities include the effects of acid rain, agriculture practices, among others. As discussed above, calcium increases might lead to an exacerbation of Zebra mussel related effects within the Finger Lakes.

Summary findings for each of the Finger Lakes are as follows. *Otisco Lake*, which is one of the smaller Finger Lakes, is a multi-purpose lake located in the Seneca-Oswego River Basin. The lake serves as a source of water supply for the City of Syracuse, and is best characterized as *eutrophic*. Trophic conditions within Otisco Lake have increased somewhat since the early 1970s, as evidenced by moderate increases in total phosphorus and chlorophyll *a* levels within the lake. The lake also undergoes sustained periods of hypolimnetic anoxia during the growing season. Major ion trends within Otisco Lake over the past several decades indicate *declines* in calcium, magnesium, and alkalinity levels, and *increases* in sodium, chloride, and sulfate levels. Sediment core findings from Otisco Lake indicate a *sediment accumulation rate* of 0.74 cm/year, which is one of the highest rates measured within the Finger Lakes. *Organic* chemical findings from the Otisco Lake sediment core indicate a total PCB concentration of 245 ppb at a sediment depth of 3-4 cm (~ 1990s) which is in the middle range of total PCB levels observed within the Finger Lakes, and is above the TEL for total PCBs. *Inorganic* chemical findings from the Otisco Lake sediment core indicate elevations in copper and nickel levels. Surficial sediments exceed the TEL for copper and the PEL for nickel. There is also a significant increase in sediment calcium levels over the past half century. Finally, sediment core findings indicate a substantial reduction in lead levels over the past several decades. *Recommendations* for Otisco Lake include: (1) Continue efforts to control nutrient inputs to the lake; (2) Evaluate the cause(s) and ecological effects of hypolimnetic anoxia within the lake; (3) Implement measures to minimize the input of salt to the watershed and the lake; (4) Continue to periodically monitor biota for chlorinated organic chemicals; (5) Evaluate the cause(s) and ecological effects of sediment nickel levels; and (6) Monitor Zebra mussel population dynamics within the lake and assess the ecological effects associated with this invasive exotic.

Skaneateles Lake, which is one of the six larger Finger Lakes, is a multi-purpose lake located in the Seneca-Oswego River Basin. The lake serves as a public water supply for the City of Syracuse, and is best characterized as *oligotrophic*. Trophic conditions within Skaneateles Lake have declined substantially over the past several decades, as evidenced by marked declines in total phosphorus and chlorophyll *a* levels, and a moderate increase in water clarity. The lake continues to be well oxygenated throughout the growing season. Major ion trends within Skaneateles Lake over the past several decades indicate *declines* in magnesium, and sulfate levels, and *increases* in sodium, and chloride levels. Sediment core findings for Skaneateles Lake indicate a *sediment accumulation rate* of approximately 0.2 cm/year, which is one of the lowest accumulation rates observed in the Finger Lakes. *Organic* chemical findings from the Skaneateles Lake sediment core indicate a total PCB concentration of 286 ppb (from 2-3 cm depth which represents the mid 1980s), which is in the middle range of total PCB levels observed within the Finger Lakes, and is above the TEL and slightly above the PEL. *Inorganic* chemical findings from Skaneateles Lake indicate a marked increase in arsenic and manganese levels within surficial sediments. Subsequent water column sampling, albeit limited, has not detected arsenic above 10 ug/l (detection level). There are also elevated levels of nickel within the sediments of Skaneateles Lake, with levels exceeding the TEL and PEL. Sediment core findings also indicate a moderate decline in lead levels over the past several decades. *Recommendations* for Skaneateles Lake include: (1) Efforts to control the input of nutrients to the lake have apparently been successful, and such efforts should continue; (2) Efforts to control inputs of salt to the watershed and the lake should be implemented and/or enhanced; (3) Continue periodic monitoring of biota for chlorinated organic chemicals; (4) Investigate the cause(s) of arsenic enrichment within surficial sediments and further assess possible environmental consequences of such increases; (5) Evaluate the cause(s) and ecological effects of elevated nickel levels; and (6) Monitor Zebra mussel population dynamics within the lake and assess the ecological effects associated with this invasive exotic.

Owasco Lake, which is one of the six larger Finger Lakes, is a multi-purpose lake located within the Seneca-Oswego River Basin. The lake serves as a drinking water supply for the City of Auburn, and is best characterized as mesotrophic. Trophic conditions within Owasco Lake have shown some limited change over the past several decades, with a moderate decline in chlorophyll *a* levels, but generally stable phosphorus concentrations and water clarity levels. As in the past, the lake remains well oxygenated throughout the growing season. Major ion trends within Owasco Lake over the past several decades indicate *declines* in calcium and sulfate levels, and *increases* in sodium and chloride levels. Sediment core findings for Owasco Lake indicate a *sediment accumulation rate* of 0.38 cm/year, which is in the middle range of accumulation rates observed in the Finger Lakes. *Organic* chemical findings from the Owasco Lake sediment core indicate a total PCB concentration of 374 ppb (from 3-4 cm depth representative of the late 1970s), which is in the upper range of total PCB levels observed within the Finger Lakes, and is above the TEL and PEL for PCBs. The PCB pattern was dominated by lower chlorinated congeners. *Inorganic* chemical findings from the Owasco Lake sediment core indicate a slight increase in arsenic levels within surficial sediment layers, and levels exceed the TEL but are slightly below the PEL. Subsequent water column sampling from Owasco Lake showed one measurement at 10 ug/l (which is below the current MCL). Nickel levels within lake sediments are consistently above the TEL and PEL. Sediment core findings also indicate a marked decline in lead levels with Owasco Lake over the last several decades. *Recommendations* for Owasco Lake include: (1) Continued efforts to control the release of nutrients within the Owasco Lake watershed are warranted; (2) Management efforts regarding the use and storage of salt within the watershed are suggested; (3) Continue periodic monitoring of aquatic biota for chlorinated organic chemicals; (4) Investigate the cause(s) of arsenic enrichment within surficial sediments and further assess the possible environmental consequences of such increases; (5) Evaluate the cause(s) and ecological effects of elevated nickel levels; and (6) Monitor Zebra mussel population dynamics within the lake and assess the ecological effects associated with this invasive exotic.

Cayuga Lake, which is one of the two largest Finger Lakes, is a multi-purpose lake located within the Seneca-Oswego River Basin. The lake serves as a public water supply for the City of Ithaca, and several other communities within the basin. The Synoptic Water Quality Investigation of Cayuga Lake is divided into an assessment of the main lake (deep basin) and the southern shelf of the lake. The reason for this bifurcation is that water quality conditions vary substantially between these two lake segments, and that a number of water quality concerns (water supply, swimming, etc.) have been raised specifically about the southern end of Cayuga Lake. The main portion of Cayuga Lake is best characterized as borderline between oligotrophic and mesotrophic. Trophic conditions within the main lake have declined over the past several decades, however, the level of decline has varied substantially between major trophic indicators. Findings from this study indicate a substantial decline in total phosphorus levels over the past several decades, with much smaller declines in chlorophyll *a*, and a moderate increase in water clarity since the early 1970s. These changes would indicate that nutrient control measures within the Cayuga lake watershed have been fairly effective with respect to the deep lake. As has been the case historically, Cayuga Lake appears to remain well oxygenated throughout the growing season. The trend for major ions within the main portion of Cayuga Lake over the past several decades indicate substantial *reductions* in sodium and chloride, and more modest *declines* in sulfate and alkalinity levels. Historically, there has been a marked longitudinal gradient in trophic conditions within Cayuga Lake moving from the southern shelf northward to the deep basin, with decreasing levels of total phosphorus and chlorophyll *a*, and increasing water clarity levels. The marked elevation in certain trophic indicators within the south lake continues at present, although there are indications of possible changes. Results from this investigation indicate that total phosphorus levels within the south shelf segment are substantially higher than in the main lake, and that the mean seasonal total phosphorus concentration exceeds the NYSDEC total phosphorus guidance value (20 ug/l) in certain years. Other recent studies confirm this finding (UFI, 2000, Sterns and Wheler, 1997). Findings for chlorophyll *a* and Secchi Disk depth are somewhat more equivocal with respect to longitudinal differences. While early findings from this investigation indicate marked longitudinal differences in chlorophyll *a* and water clarity levels, more recent findings suggest less apparent differences. It is believed that increases in Zebra mussel population numbers in the south lake may be causing a downward trend in chlorophyll *a* and an upward trend in water clarity within the south shelf area. Findings from the Cayuga Lake sediment core are limited due to the lack of an intact radiometric profile within the core, and anomalously low chemical findings. *Recommendations* for Cayuga Lake include: (1) Efforts to control nutrient (particularly phosphorus) and sediment loads within the Cayuga Lake watershed should be continued. This is particularly important within the south-lake catchment where use impairments are present. Additional study of water quality dynamics within the south lake should be pursued – this should include development of accurate estimates of nutrient and sediment loads to the southern catchment, and a coupled watershed/lake mass balance model for the south lake. Furthermore, a thorough assessment of use impairment issues (water supply, primary contact recreation, and aesthetic concerns) should be initiated, and should include evaluation of remedial measures; (2) Collection of an additional deep water sediment core(s) is also recommended; (3) Continue periodic monitoring of aquatic biota for chlorinated organic chemicals; and (4) Establish a Zebra mussel monitoring program within the lake to understand population dynamics and assess ecological effects associated with this invasive exotic.

Seneca Lake, which is one of the two largest Finger Lakes, is a multi-purpose lake located within the Seneca-Oswego River Basin. The lake serves as a source of public water supply for the City of Geneva and the Villages of Ovid, Waterloo, and Watkins Glen. Trophic conditions within Seneca Lake have declined substantially over the past several decades, as evidenced by marked declines in total phosphorus and chlorophyll *a* levels, and a substantial increase in water clarity. Furthermore, the lake continues to be well oxygenated throughout the growing season. Major ion trends within Seneca Lake indicate significant *declines* in chloride and sodium levels, and a smaller decline in calcium levels, as well as *increases* in sulfate and alkalinity levels. Sediment core findings for Skaneateles Lake indicate a *sediment accumulation rate* of 0.23 cm/year, which is one of the lowest accumulation rates observed in the Finger Lakes. *Organic* chemical findings from the Seneca Lake sediment core indicate a substantial decline in total DDT levels over the past several decades, but levels remain above the TEL. Sediment core findings indicate a total PCB concentration of 466 ppb (from 4-6 cm sediment depth representative of the late 1970s), which is in the upper range of total PCB levels observed within the Finger Lakes, and is above the TEL and PEL for PCBs. *Inorganic* chemical findings from the Seneca Lake sediment core indicate that arsenic levels are near or slightly above the PEL, although arsenic levels do not show the marked surficial enrichment seen in several of the other Finger Lakes. Subsequent water column sampling within Seneca Lake, albeit limited, has shown no detectable arsenic concentrations above 10 ug/l (analytical detection limit). Cadmium levels within the sediments were stable, and were above the TEL but below the PEL. As with many of the Finger Lakes, calcium concentrations within the sediments of Seneca Lake have increased substantially over the past several decades. Lead levels within Seneca Lake sediments have declined precipitously over the past several decades, and are below the PEL – however, they remain above the TEL. Mercury levels within Seneca Lake sediments have declined by approximately 50 percent over the past 40 years, and surficial concentrations are below the TEL and the PEL for total mercury. Nickel levels within the sediments of Seneca Lake are basically stable over the past half century, and concentrations are above the TEL but below the PEL. *Recommendations* for Seneca Lake include: (1) Efforts to control nutrient inputs to the lake have apparently been successful, and such efforts should continue; (2) Investigation of sodium and chloride dynamics within Seneca Lake should continue, and control measures for salt discharge within the watershed and the lake should be continued; (3) Continue periodic monitoring of aquatic biota for chlorinated organic chemicals; (4) Investigate the cause(s) of arsenic enrichment within lake sediments and further assess possible environmental consequences of such increases; (5) Evaluate the cause(s) and ecological effects of elevated nickel levels; and (6) Monitor Zebra mussel population dynamics within the lake and assess ecological effects associated with this invasive exotic.

Keuka Lake, which is one of the six larger Finger Lakes, is a multi-purpose water body located in the Seneca-Oswego River Basin. The lake is a source of public water supply for the Villages of Hammondsport and Penn Yan. Trophic conditions within Keuka Lake have declined markedly over the past several decades, as evidenced by substantial declines in total phosphorus and chlorophyll *a* levels, and a moderate increase in water clarity. The lake continues to be well oxygenated throughout the growing season. Major ion trends within Keuka Lake over the past several decades indicate *declines* in magnesium and sulfate levels, and *increases* in calcium, sodium, chloride, and alkalinity levels. Sediment core findings from Keuka Lake indicate a *sediment accumulation rate* of 0.37 cm/year, which is in the middle range of rates observed within the Finger Lakes. *Organic* chemical findings for Keuka Lake indicate that total DDT levels within the sediments of Keuka Lake have declined markedly, from a peak of nearly 400 ppb in the late 1970s to current levels of 72 ppb - this is consistent with recent fish flesh findings. While trends are encouraging, DDT levels remain above the TEL, but below the PEL. Sediment core findings also indicate a total PCB concentration of 449 ppb (289 ppb when adjusted for DDE) from a single sediment core segment (mid 1980s). The later value (289 ppb) is more appropriate given historical DDT levels in the lake, and is in the middle range of levels measured in Finger Lakes sediments – this is above the TEL and PEL for total PCBs. *Inorganic* chemical findings from the Keuka Lake sediment core indicate a marked increase in arsenic and manganese levels within surficial sediments. Subsequent water sampling, albeit limited, did not detect arsenic above 10 ug/l (analytical detection level). There are elevated levels of nickel within the sediments of Keuka Lake, and levels exceed the TEL and PEL. Findings also indicate a substantial decline in lead levels within Keuka Lake sediments over the past several decades. *Recommendations* for Keuka Lake include: (1) Efforts to control the input of nutrients to Keuka Lake have apparently been successful, and should be continued; (2) Management efforts to control the use salt within the watershed should be implemented and/or enhanced; (3) Continue periodic monitoring of biota for chlorinated organic chemicals; (4) Further investigation is warranted regarding the cause(s) of arsenic enrichment within lake sediments and possible consequences of this phenomenon; (5) Evaluate the cause(s) and ecological effects of elevated nickel levels; and (6) Monitor Zebra mussel population dynamics within the lake and assess ecological effects associated with this invasive exotic.

Canandaigua Lake, which is one of the six larger Finger Lakes, is a multi-purpose water body located in the Seneca-Oswego River Basin. The lake serves as a source of public water supply for the City of Canandaigua, and several other communities within the watershed. Trophic conditions within Canandaigua Lake have declined substantially over the past several decades, as evidenced by marked declines in total phosphorus and chlorophyll *a* levels, and a substantial increase in water clarity. The lake continues to be well oxygenated throughout the growing season. Trends for major ions within Canandaigua Lake over the past several decades indicate *declines* in magnesium and sulfate levels, and *increases* in sodium, chloride, and alkalinity concentrations. Sediment core findings within Canandaigua Lake indicate a *sediment accumulation rate* of approximately 0.2 cm/year, which is one of the lowest sediment accumulation rates within the Finger Lakes. *Organic* chemical findings from Canandaigua Lake indicate that total DDT levels within the sediments of Canandaigua Lake have declined markedly over the last several decades. However, DDT levels remain above the TEL within surficial sediments. *Inorganic* chemical findings from the Canandaigua Lake sediment core indicate a marked increase in arsenic and manganese levels within surficial sediments. Subsequent water column sampling, albeit limited, has not detected arsenic above 10 ug/l (detection level). There are elevated levels of nickel within the sediments of Canandaigua Lake, with levels exceeding the TEL and PEL. Findings also indicate a substantial decline in lead levels within Canandaigua Lake sediments over the past several decades. *Recommendations* for Canandaigua Lake include: (1) Efforts to control the input of nutrients to Canandaigua Lake have apparently been successful over the past several decades, and such control measures should continue; (2) Management efforts regarding the storage and use of salt within the watershed are suggested; (3) Continue periodic monitoring of aquatic biota for chlorinated organic chemicals; (4) Further investigation is warranted regarding the cause(s) of arsenic enrichment within lake sediments and assessment of possible environmental consequences; (5) Evaluate the cause(s) and ecological effects of elevated nickel levels; and (6) Monitor Zebra mussel population dynamics within the lake and assess ecological effects associated with this invasive exotic.

Honeoye Lake, which is one of the five smaller Finger Lakes, is a multi-purpose water body located in the Genesee River Basin. While the lake is classified "AA", it is not presently used as a public water supply. Trophic conditions within Honeoye Lake are best characterized as eutrophic, which is similar to the overall trophic status of the lake over the past several decades. However, current levels of major trophic indicators are somewhat different than in the past. Findings suggest an increase in total phosphorus levels, a decline in chlorophyll *a* levels, and a small increase in water clarity within the lake. Total phosphorus levels within the lake are above the NYSDEC total phosphorus guidance value of 20 ug/l, and there are sustained periods of hypolimnetic hypoxia during the growing season. Trends for major ions within Honeoye Lake over the past several decades indicate an *increase* in calcium, chloride, sodium, and alkalinity levels, and a *decrease* in sulfate and magnesium levels. Sediment core findings from Honeoye Lake indicate a *sediment accumulation rate* of approximately 0.5 cm/year, which is at the high end of accumulation rates observed within the Finger Lakes. *Organic* chemical findings from the Honeoye Lake sediment core indicate a total PCB concentration of 69 ppb from a single sediment core segment (3-6 cm sediment depth, which equates to approximately 1990). This is at the low end of total PCB levels observed in the Finger Lakes, however, it is above the TEL, but below the PEL. *Inorganic* chemical findings from the Honeoye Lake sediment core indicate that arsenic levels in the sediments increase in the 1970s and remain elevated thereafter. Surficial sediment arsenic concentrations are above the TEL and slightly above the PEL. Subsequent water column sampling, albeit limited, has not detected arsenic above 10 ug/l (detection level). Additional inorganic chemical findings from the Honeoye Lake sediment core indicate nickel levels above the TEL and PEL, and fluctuations in lead levels – initial decline followed by a recent increase. *Recommendations* for Honeoye Lake include: (1) Efforts to control the input of nutrients to Honeoye Lake should be continued and enhanced. Furthermore, efforts to understand nutrient loading to the lake, and to assess dissolved oxygen depletion within the lake are recommended. This should include the derivation of accurate tributary nutrient loads to the lake and review of permitted nutrient loads within the Honeoye Lake watershed; (2) Management efforts regarding the storage and use of salt within the watershed are indicated; (3) Continue periodic monitoring of aquatic biota for chlorinated organic chemicals; (4) Further investigation regarding the cause(s) of arsenic elevations within lake sediments and assessment of possible environmental consequences of such increases are warranted; (5) Evaluate the cause(s) and ecological effects of elevated sediment nickel levels; and (6) Implement a program to monitor Zebra mussel population dynamics within the lake and assess ecological effects associated with this invasive exotic.

Canadice Lake, which is one of the five smaller Finger Lakes, is located within the Genesee River Basin. The lake serves as a source of drinking water for the City of Rochester, and has fairly stringent watershed protection measures and lake use restrictions. The trophic status of Canadice Lake is best characterized as borderline between oligotrophic and mesotrophic, and trophic conditions are similar to those recorded several decades ago. Study findings also indicate sustained periods of hypolimnetic hypoxia within Canadice Lake during the later part of the growing season. Trends for major ions within Canadice Lake indicate an *increase* in the concentration of calcium, chloride, and sodium, and a *decrease* in sulfate and magnesium levels. Sediment core findings indicate a *sediment accumulation rate* of approximately 0.2 cm/year, which is one of the lowest accumulation rates measured within the Finger Lakes. *Organic* chemical findings from the Canadice Lake sediment core indicate a decline in DDT metabolites within lake sediments in recent decades. Sediment core findings also indicate a total PCB concentration of 352 ppb (4-6 cm sediment depth, representing the early 1970s), which is in the middle range of total PCB levels observed in other Finger Lakes cores, and is above the TEL and PEL for total PCBs. *Inorganic* chemical findings from the Canadice Lake sediment core indicate a significant increase in arsenic levels over the past several decades. This phenomenon of arsenic enrichment within upper sediment layers is also apparent in a number of the other Finger Lakes. The arsenic levels observed in the surficial sediments of Canadice Lake are above the TEL and PEL. Subsequent water column sampling, albeit limited, has not detected arsenic above 10 ug/l (detection level). Sediment core findings also indicate substantial increases in calcium levels within Canadice Lake over the past several decades – a pattern repeated in a number of other Finger Lakes. Manganese levels have also increased within Canadice Lake sediments in recent years, and roughly parallel arsenic changes. Nickel levels are fairly constant over the observed period, but are above the TEL and PEL. Sediment lead concentrations have declined substantially in recent decades, and are near the TEL for lead. *Recommendations* for Canadice Lake include: (1) Efforts to control the input of nutrients to Canadice Lake should be continued. Furthermore, efforts to understand nutrient loading to the lake, and to assess dissolved oxygen depletion dynamics within the lake are recommended; (2) Management efforts regarding the use and storage of salt within the watershed are suggested; (3) Continue periodic monitoring of aquatic biota for chlorinated organic chemicals; (4) Additional investigation is warranted regarding the cause(s) of arsenic/manganese elevations within lake sediments and possible environmental consequences of such increases; (5) Evaluate the cause(s) and ecological effects of elevated nickel levels; and (6) A program to monitor Zebra mussel population dynamics within the lake and assess ecological effects associated with this invasive exotic should be implemented – with particular attention on ambient calcium availability.

Hemlock Lake, which is one of the five smaller Finger Lakes, is located in the Genesee River Basin. Hemlock Lake is a source of public water supply for the City of Rochester, and has fairly stringent watershed protection measures and lake use restrictions. The trophic status of Canadice Lake is best characterized as borderline between oligotrophic and mesotrophic, as evidenced by current levels for major trophic indicators. Findings indicate a significant reduction in chlorophyll *a* levels and a significant increase in water clarity within Hemlock Lake over the past several decades. However, total phosphorus levels remain approximately equivalent to levels measured during the early 1970s. Furthermore, the hypolimnion of Hemlock Lake becomes hypoxic during the mid to late summer, with dissolved oxygen levels as low as 1 mg/l in certain deep water locations. Trends for major ions within Hemlock Lake indicate an *increase* in the concentration of calcium, chloride, and sodium, and a *decrease* in sulfate, and magnesium levels. Sediment core findings from Hemlock Lake are limited due to the lack of an intact radiometric profile. Thus, no sediment accumulation rate could be determined for the lake, and chemical findings must be viewed as composite values (no temporal, or trend information is discernable). *Organic* chemical findings from the Hemlock Lake sediment core indicate total DDT levels range from 25-49 ppb. Sediment core findings from Hemlock Lake also indicate a total PCB concentration of 67 ppb (4-6 cm sediment depth), which is at the low end of total PCB levels observed in other Finger Lakes cores, but is above the TEL for total PCBs. *Inorganic* chemical findings for Hemlock Lake indicate that sediment arsenic concentrations are above the TEL and PEL. Subsequent water column sampling, albeit limited, has not detected arsenic above 10 ug/l (detection level). Additional inorganic chemical findings for Hemlock Lake indicate nickel levels exceed the TEL and PEL. *Recommendations* for Hemlock Lake include: (1) Efforts to control the input of nutrients to Hemlock Lake should be continued. Furthermore, efforts to understand nutrient loading to the lake, and to assess dissolved oxygen depletion dynamics within the lake are recommended; (2) Management efforts regarding the use and storage of deicing agents within the watershed are indicated; (3) Continue periodic monitoring of aquatic biota for chlorinated organic chemicals; (4) Further investigation regarding the cause(s) of arsenic elevations within lake sediments and assessment of possible environmental consequences associated with such increases are warranted; (5) Evaluate the cause(s) and ecological effects of elevated nickel levels; (6) A program to monitor Zebra mussel population dynamics within the lake and assess ecological effects associated with this invasive exotic should be implemented; and (7) It would be beneficial to collect an additional deep water sediment core on Hemlock Lake for the purpose of assessing a sediment accumulation rate and chemical chronology within the lake.

Conesus Lake, which is one of the five smaller Finger Lakes, is a multi-purpose water body located in the Genesee River Basin. The lake serves as a source of public water supply for the Town of Livonia, and the Villages of Avon and Geneseo. The trophic status of Conesus Lake is best characterized as eutrophic, as evidenced by the levels of major trophic indicators. Findings indicate that trophic conditions within Conesus Lake have increased somewhat since the early 1970s. The mean annual total phosphorus level of the lake has increased slightly and is above the New York State total phosphorus guidance value of 20 ug/l, and water clarity has declined moderately. Furthermore, the hypolimnion of Conesus Lake becomes anoxic during mid to late summer, with dissolved oxygen levels dropping to near zero in a significant portion of the hypolimnion. Trends for major ions within Conesus Lake indicate an *increase* in the concentration of sodium, and a *decline* in calcium, magnesium, sulfate, and alkalinity levels. Sediment core findings from Conesus Lake indicate a *sediment accumulation rate* of approximately 0.4 cm/year, which is in the mid to upper range of accumulation rates observed in the Finger Lakes. *Organic* chemical findings from the Conesus Lake sediment core indicate that total DDT levels declined from the early 1960s to the early 1970s, and plateau thereafter. The total DDT levels observed are above the TEL but below the PEL. PCB findings from the Conesus Lake sediment core indicate a total PCB level of 490 ppb (at 4-6 cm sediment depth, which represents sediments deposited during the mid 1980s). This is the highest level of total PCBs observed within the Finger Lakes cores, and is above the TEL and PEL for total PCBs. *Inorganic* chemical findings for Conesus Lake indicate fairly high arsenic concentrations within benthic sediments. However, in contrast to some of the other lakes, there was not a marked increase in arsenic levels within surficial sediment layers. The arsenic levels observed were above the TEL and near or above the PEL for arsenic. Subsequent water column sampling, albeit limited, has not detected arsenic above 10 ug/l (detection level). Additional inorganic chemical findings from the Conesus Lake sediment core indicate fairly constant nickel concentrations that are above the TEL and PEL. Sediment core findings also indicate a substantial decline in lead levels within the sediments of Conesus Lake over the past several decades. *Recommendations* for Conesus Lake include: (1) Efforts to control the input of nutrients to Conesus Lake should be continued and enhanced. Furthermore, efforts to understand nutrient loading to the lake, and to assess dissolved oxygen depletion within the lake are recommended. This should include the derivation of accurate nutrient load estimates to the lake, and an assessment of existing nutrient load allocations within the watershed; (2) Management efforts regarding the storage and use of salt within the watershed are recommended; (3) Continue periodic monitoring of aquatic biota for chlorinated organic chemicals; (4) Further investigation regarding the cause(s) of arsenic elevations within lake sediments and assessment of possible environmental consequences of such levels are warranted; (5) Evaluate the cause(s) and ecological effects of elevated nickel levels; and (6) A program to monitor Zebra mussel population dynamics within the lake and assess ecological effects associated with this invasive exotic should be implemented.

Chapter 2: Introduction

The Finger Lakes are a series of 11 glacially formed lakes located in central New York State (see Figure 2.1). Native American legend suggests that *the lakes were formed when the creator paused in his work and placed his hands upon the Earth to rest*. On more pragmatic and scientific grounds, the Finger Lakes have garnered similar appreciation as illustrated by the words of E.A. Birge and C. Juday some 90 years ago "It is probable that there is no group of lakes in the world which offer the limnologist such opportunities for working out the problems of his science" (Birge and Juday, 1914). Individual lake names, also of Native American origin, are coarsely interpreted in Table 2.1.

Table 2.1: Finger Lake names and meanings

Lake	Native American Meaning
Conesus	"place where there are lots of berries"
Hemlock	not available
Canadice	"long lake"
Honeoye	"lying Finger"
Canandaigua	"the chosen place"
Keuka	"canoe landing"
Seneca	"place of the stone" or "stony place"
Cayuga	"boat landing"
Owasco	"the crossing" or "floating bridge"
Skaneateles	"long lake"
Otisco	"waters dried up or gone away"

The Finger Lakes and associated watersheds encompass a combined drainage area of nearly 12,000 square kilometers (approximately 4,600 square miles), and include all or portions of 12 New York State counties (see Table 2.2). While the million or so people of these 12 counties do not all reside within the Finger Lakes watershed, they are within commuting distance of the lake(s). Thus, the Finger Lakes represent a significant natural asset to the central New York region. It is important to understand, however, that the Finger Lakes Region is valued by even greater numbers of New Yorkers, as well as non-New Yorkers, as reflected in tourism activity within the region.

Figure 2.1: Finger Lakes Map

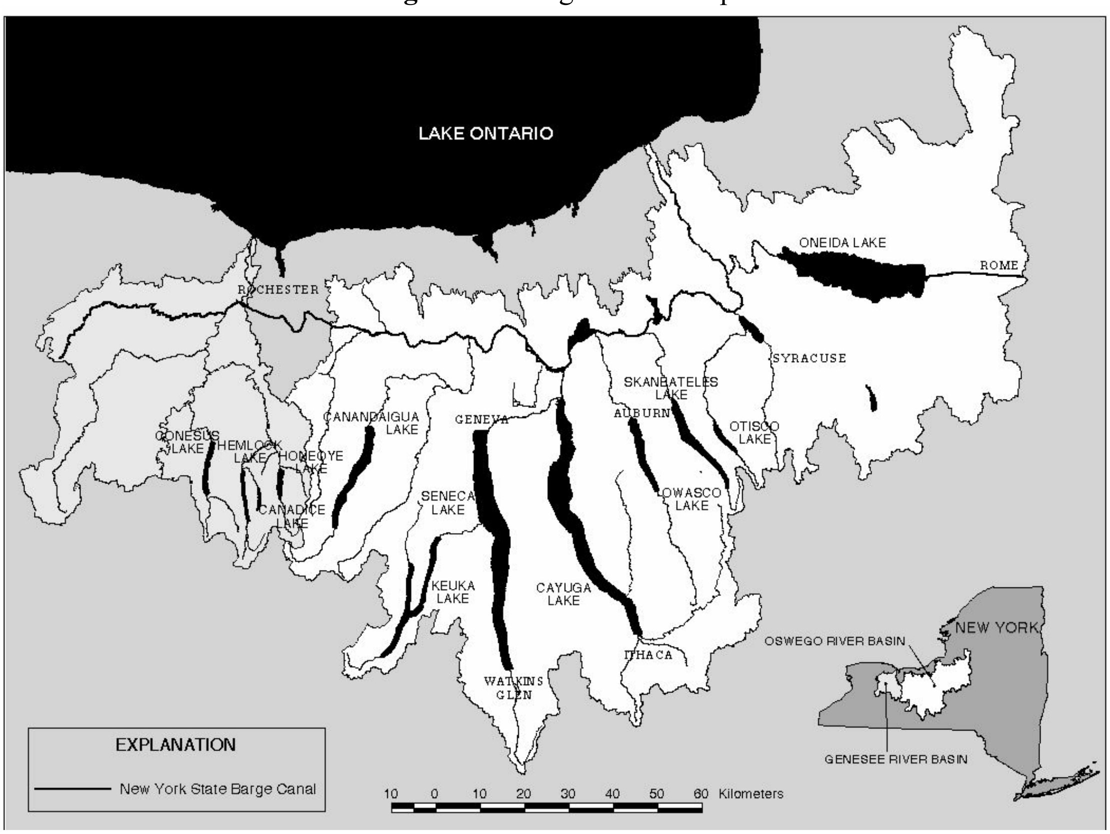


Table 2.2: Finger Lakes counties

County	*Population [1]*	*Lake and/or Watershed*
Cayuga	81, 703	**Cayuga, Owasco**, Skaneateles
Chemung	91,738	Seneca
Cortland	48,006	Cayuga, Otisco, Skaneateles
Livingston	65,851	Canadice, Canandaigua, **Conesus**, **Hemlock**, Honeoye
Onondaga	456,215	**Otisco**, Owasco, **Skaneateles**
Ontario	99,791	**Canadice**, **Canandaigua**, Hemlock, **Honeoye,** Seneca
Schuyler	19,229	**Seneca**
Seneca	31,925	**Cayuga**, **Seneca**
Steuben	97,699	Canandaigua, **Keuka**
Tioga	52,216	Cayuga
Tompkins	97,656	**Cayuga**, Owasco
Yates	24,556	**Canandaigua, Keuka, Seneca**

Bold: means that all or part of the lake proper is within the county.
[1]: from US Census, 1999 estimate

Attracted in large measure by the natural beauty of the area, tourism in the Finger Lakes Region generates roughly 1.5 billion dollars annually with approximately 22.2 million visitations per year (Finger Lakes Association, 2000). The region offers a remarkable mix of majestic lakes and spectacular gorges. In fact, the Finger Lakes include 3 of the 10 largest lakes in New York State, and 6 of the 20 largest lakes in the Empire State. Figure 2.2 provides an example of the many scenic gorges within the region – this is the author's personnel favorite.

Most of the Finger Lakes are multipurpose water bodies, albeit, to varying degrees. Human uses of these lakes range from public water supply to wastewater assimilation. With the exception of Honeoye Lake, all of the Finger Lakes are used for public water supply. Table 2.3 provides a summary of existing water supply usage for each of the lakes. Total permitted withdrawal from all of the Finger Lakes is approximately 180 million gallons per day (MGD).

Figure 2.2: Upper gorge at Robert H. Treman State Park

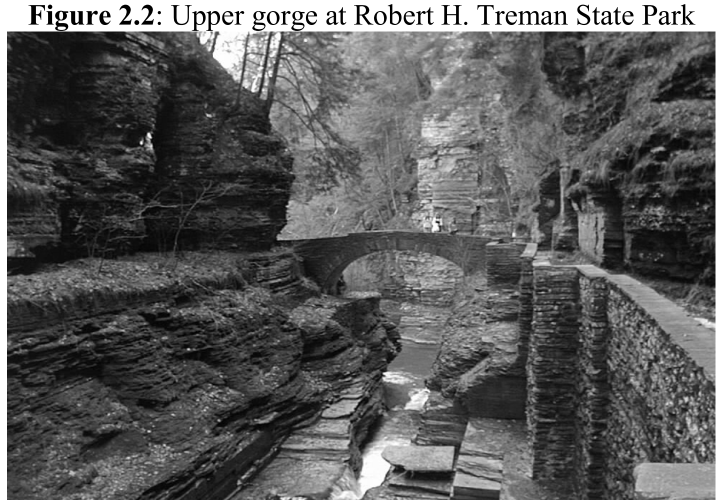


Table 2.3: Public water supply withdrawals

Lake	**# of Permitted Withdrawals**	**Total Permitted Withdrawals (MGD)**
Conesus	3	6.9
*Hemlock	1	37
*Canadice	see Hemlock	combined w/ Hemlock
Honeoye	0	0
Canandaigua	5	~ 16
Keuka	3	5.36
Seneca	4	~ 9
Cayuga	4	11.2
Owasco	2	16.0
Skaneateles	1	58.0
Otisco	1	20.0

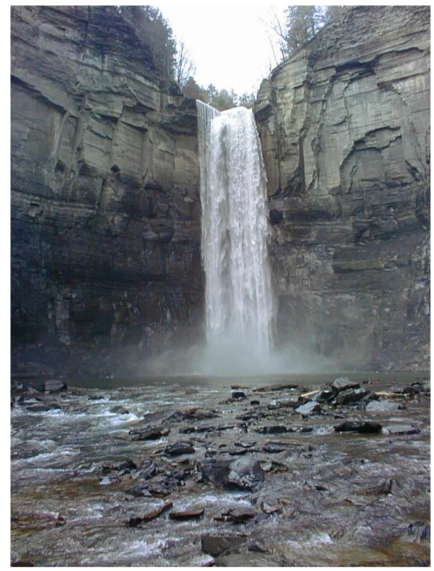
* The permit for Hemlock and Canadice is based on total from both lakes

Origin and Morphology

While the physical structure of the lake basins continue to evolve today, through processes such as sediment deposition and scour, the basic structure of the lake basins was largely complete some 10,000 years ago following "final" retreat of the Laurentide ice sheet.

Current theory suggests that the glaciers functioned as extensive earth moving operations by gouging out the lake basins and depositing vast quantities of glacial debris at the southern terminus of the present day Finger Lakes. These glacial forces, coupled with subsequent water runoff, are responsible for creating many of the spectacular natural features in the area (see Figure 2.3). These glacial forces were guided by pre-existing stream corridors and variations in underlying geology, preferentially removing the more erodible strata. The two largest lakes, namely, Seneca Lake and Cayuga Lake, were scoured to such an extent that the bottoms of these lakes are actually below sea level. For example, the water surface of Seneca Lake is at approximately 135 meters above sea level, while the maximum lake depth is approximately 200 meters. Thus, the lake bottom is approximately 65 meters below sea level. In fact, this is only the "tip of the proverbial iceberg" in that the sediments present at the bottom of Seneca Lake, much of which are the result of past glacial activity, account for more than 200 meters of additional scour. Thus, Seneca Lake, inclusive of both water column and sediments, is some 300 meters (nearly 1/5 of a mile) below sea level (Mullins, 1996).

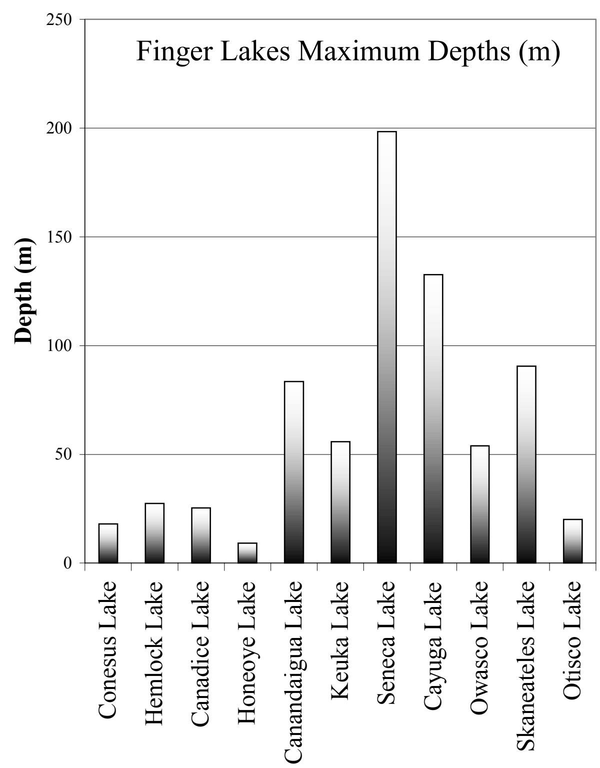
Figure 2.3: Taughannock Falls



While of similar origins, the lakes vary significantly in size. For example, the volume of Seneca Lake is more than 400 times that of Honeoye Lake. Similarly, the lakes vary markedly in maximum depths (see Figure 2.4). Seneca Lake is the largest in terms of both volume and surface area, while, Cayuga Lake is the longest of the 11 lakes. On the other extreme, Honeoye Lake is the smallest of the Finger Lakes with respect to volume, and Canadice Lake is smallest in terms of surface area.

As one might surmise from the size disparity between the Finger Lakes, some have partitioned the lakes into the six larger lakes (Canandaigua, Keuka, Seneca, Cayuga, Owasco, and Skaneateles), and the five smaller lakes (Conesus, Hemlock, Canadice, Honeoye, and Otisco). Volumes of the larger lakes are measured in *billions* of cubic meters, while volumes of the smaller lakes are measured in *millions* of cubic meters. As will be discussed below, this disparity in lake size likely plays a significant role in water quality conditions within the Finger Lakes. Comparative information regarding the physical characteristics of each of the Finger Lakes is shown in Table 2.4.

Figure 2.4: Comparison of maximum Finger Lakes depths (Bloomfield, 1978)



Lake	Mean;(Max) Depth (m)	Length (km)	Volume (10^6 m^3)	Surface Area (km^2)	Watershed (km^2)	Elevation (m above MSL)
Conesus	11.5 (18)	12.6	156.83	13.67	180.5	249
Hemlock	13.6 (27.5)	10.8	105.89	7.2	96.2	275.8
Canadice	16.4 (25.4)	5.1	42.6	2.6	31.8	334
Honeoye	4.9 (9.2)	6.6	34.81	7.05	95	245
Canandaigua	38.8 (83.5)	24.9	1640.1	42.3	476.6	209.7
Keuka	30.5 (55.8)	31.6	1433.7	47	404.6	217.9
* Seneca	88.6 (198.4)	56.6	15539.5	175.4	1180.6	135.6
** Cayuga	54.5 (132.6)	61.4	9379.4	172.1	1145.2	116.4
Owasco	29.3 (54)	17.9	780.7	26.7	470	216.7
Skaneateles	43.5 (90.5)	24.2	1562.8	35.9	154	263
Otisco	10.2 (20.1)	8.7	77.8	7.6	93.8	240.2

Table 2.4: Physical characteristics of the Finger Lakes (Bloomfield, 1978)

* Seneca: watershed includes inflow from Keuka Lake.

** Cavuga: watershed excludes inflow from Seneca Lake at the northern end of the Cavuga Lake.

The Finger Lakes constitute a fairly compact system of lakes. The distance separating western-most Conesus Lake from eastern-most Otisco Lake is only about 125 km (~ 80 miles). The span in longitude ranges from approximately 77° 43' 41"W for the western edge of Conesus Lake to 76° 14' 53"W for the eastern edge of Otisco Lake. Latitude ranges from approximately 42° 23' 02"N for the south end of Seneca Lake to 42° 56' 43"N for the north end of Skaneateles Lake.

All of the Finger Lakes share a predominantly north-south orientation due to their glacial origins. In addition, nearly all of the lakes are characterized by a single elongated basin. The lone exception is Keuka Lake, which exhibits a "forked" or "Y" shaped basin structure – see Figure 2.1. The lakes also show an intriguing symmetry or "lake pairing". The most remarkable of these pairings is that of Canandaigua and Skaneateles Lakes. These two lakes are, in a number of respects, mirror images of one another. Their depths (both mean and maximums) are within 10 percent of each other, their volumes are within 5 percent of each other, and their lengths are within 3 percent of each other. As will be discussed later, this similarity extends to a number of water quality indicators. The lakes do differ substantially, however, with respect to drainage area. Similar parallels can be made between Seneca Lake and Cayuga Lake, albeit to a lesser extent.

Hydrology

The Finger Lakes are also divisible based on their respective drainage basins. As discussed above, glacial activities had a profound effect on the region (e.g., formation of the lake basins). Another significant physical change attributable to glacial forces was a change in the prevailing flow patterns within the region. Prior to glacial activities, flow patterns of the major tributaries within the region were from north to south. The enormous rock and sediment deposits (termed valley head moraines) created by the advance of the glaciers now act as great earthen dams and resulted in a reversal of flow within the primary tributaries in the region. Consequently, all 11 Finger Lakes now flow south to north. The Finger Lakes are all located within the Lake Ontario drainage basin. However, the lakes fall within two distinct sub-basins. The four western-most lakes (Conesus, Hemlock, Canadice, and Honeoye) are within the Genesee River Basin, while the remaining seven lakes (Canandaigua, Keuka, Seneca, Cayuga, Owasco, Skaneateles, and Otisco) are within the Seneca-Oswego Basin.

Surface runoff estimates for the Finger Lakes, as derived by various researchers, are summarized in Table 2.5. These estimates were developed based upon existing inflow data coupled with extrapolation to ungaged drainage areas. The estimates range from 10.1 x 10^7 m^3/year for Canadice Lake to 6.5 x 10^8 m^3/year for Seneca Lake. Tributary inflow, coupled with lake volume and several other factors (e.g., evaporation rate) determine the water retention time (WRT) of a lake.

Table 2.5: Estimated annual surface runoff

Lake	Estimated Surface Runoff (10^6 m^3 yr^{-1})	Estimated Surface Runoff (10^6 gal yr^{-1})
Conesus [2]	42	11,000
Hemlock [1]	36.6	9,700
Canadice [1]	10.1	2,700
Honeoye [1]	27.8	7,300
Canandaigua [3]	114	30,000
Keuka [1]	148	39,000
Seneca [1]	652	172,000
Cayuga [4]	543	143,000
Owasco [1]	255	67,000
Skaneateles [1]	81.6	21,500
Otisco [1]	33.5	8,800

[1]: Knox & Nordenson (1955), [2]: Stewart & Markello (1974)
[3]: Eaton & Kardos (1978), [4]: Oglesby (1978)

WRT refers to the average length of time a molecule of water will remain in a given lake. This is not to suggest that every molecule of water entering a lake will remain in the lake for the specified time period. Some will have a shorter retention time due to factors such as evaporation or proximity to an outfall, and some will have a longer tenure due to avoidance of such factors. WRT can be derived in several ways. The most common approach, termed a water balance, is an accounting of the various inflows and outflows to the system - the general equation governing a water balance is as follows:

Table 2.6: Estimated Retention Times (units of years)

Lake	*Shaffner & Oglesby (1978)*	*Michel & Kraemer (1995)*	
		Tritium	*Runoff*
Conesus	1.4	2.5	2.0
Hemlock	2.0	2.5	2.5
Canadice	4.5	2.0	4.0
Honeoye	0.8	1.5	1.0
Canandaigua	7.4	8.5	10.0
Keuka	6.3	6.0	8.0
Seneca	18.1	12.0	23.0
Cayuga	9.5	8.5	10.0
Owasco	3.1	1.5	3.0
Skaneateles	17.7	8.5	14.0
Otisco	1.9	1.0	1.5

$$\mathbf{WRT = (V) / (I - O - E)},$$

where, V = lake volume, I = average inflow to the lake, O = average outflow from the lake, and E = average evaporation from the lake. Isotope data can also be used to estimate WRT. Tritium, a radio-isotope of hydrogen, has a known rate of radioactive decay with a half-life of 12.43 years. Tritium levels within the environment peaked in the early 1960s and have been decreasing since that time. By tracking tritium changes over time one can estimate the residence or retention time of a lake. Estimates of retention times based on both methods are shown in Table 2.6. The WRT of a lake can determine the length of time that an introduced substance will remain in a lake, and also the ultimate fate of such a substance. In theory, lakes with shorter WRTs are quicker to respond to environmental change and tend to retain less of the materials entering the basin, whereas, lakes with longer retention times are slower to respond to environmental change and retain a larger proportion of materials entering the basin.

Lake water quality is strongly influenced by the quality and quantity of tributary inflow. For example, the trophic state (algal productivity) of a lake is often determined by the nutrient load from its tributary system.

Water Quality Issues

New York State has established water classification designations for most water bodies within the state based upon the best usage of the water body or water body "segment". A detailed description of the classification system can be found in Water Quality Regulations – Part 700-705 (NYSDEC, 1991). Water classification(s) for each of the Finger Lakes are summarized in Table 2.7.

Table 2.7: Water classifications of the Finger Lakes

Lake	Description	Classification
Conesus	entire lake	AA
Hemlock	entire lake	AA(T)
Canadice	entire lake	AA(TS)
Honeoye	entire lake	AA
Canandaigua	entire lake	AA(TS)
Keuka	entire lake	AA(TS)
Seneca	from north end south 2.4 miles	B
	portion within 1-mile radius of mouth of Keuka Lake Outlet	B
	Pastime Park south for 32 miles, excluding previous segment	AA (TS)
	Quarter Mile Creek to south end	B
Cayuga	Mud Lock south 2.1 miles to Bridgeport-Seneca Falls Road	B
	Cooley Corners Road south to 0.8 mi. north of Hamlet of Levanna	A(T)
	from 0.8 miles north of Levanna to McKinney's Point	AA (T)
	from McKinney's Point south to end of lake	A
Owasco	entire lake	AA(T)
Skaneateles	entire lake	AA
Otisco	entire lake	AA

Water quality conditions in the Finger Lakes are generally good. However, there are issues of concern as evidenced by the fact that each of the 11 Finger Lakes are included of the NYSDEC Priority Water List (PWL) [NYSDEC, 1996]. Water quality issues of concern vary by lake, ranging from fish consumption advisories due to persistent toxic substances (e.g., PCBs and DDT) to impairment of recreational activities (swimming, boating, etc.) due to algal blooms and nuisance aquatic plants. For example, three of the Finger Lakes (Canadice, Canandaigua, and Keuka) are currently subject to fish consumption advisories, and while recent data suggest improvements in fish contaminant levels, the advisories are still deemed necessary. There are also concerns relating to trophic conditions within a number of the Finger Lakes. Summaries of use impairments and contaminant categories are provided in Figures 2.5 and 2.6 respectively, while a tabular summary is presented in Table 2.8.

Figure 2.5: Finger Lakes use impairment summary

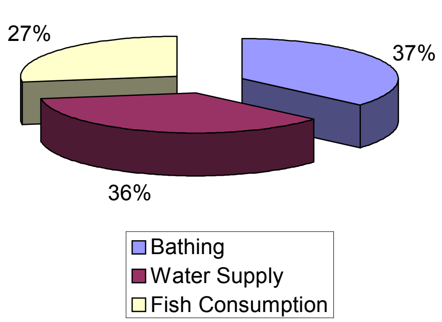


Figure 2.6: Finger Lakes contaminant summary

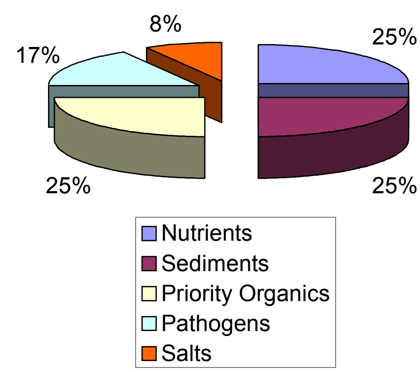


Table 2.8: Summary of 1996 Priority Waterbody List (NYSDEC, 1996).

Lake Name	County	Segment Description	Primary Impairment	Primary Pollutant
Canadice	Ontario	Entire Lake	Fish Consumption	PCBs
Canandaigua	Ontario	Entire Lake	Fish Consumption	PCBs
Cayuga	Cayuga	Northern end	Boating (macrophytes)	Nutrients
Cayuga	Seneca	Northern end	Bathing (macrophytes)	Nutrients
Cayuga	Tompkins	Southern end	Water Supply	Silt and Nutrients
Conesus	Livingston	Entire Lake in Conesus (T)	Bathing (macrophytes)	Nutrients
Hemlock	Ontario	Entire Lake in County	Water Supply	Hydro-modification
Honeoye	Ontario	Entire Lake	Water Supply	Nutrients
Keuka	Yates	Entire Lake	Fish Consumption	DDT
Otisco	Onondaga	Entire Lake	Bathing	Silt
Owasco	Cayuga	Entire Lake	Bathing	Pathogens
Seneca	Schuyler	Entire Lake w/in County	Water Supply	Salts
Seneca	Seneca	Entire Lake w/in County	Water Supply	Salts
Seneca	Yates	West side within County	Water Supply	Salts
Skaneateles	Onondaga	Northern 2/3 of Lake	Water Supply	Pathogens

The Finger Lakes and their surrounding watersheds vary markedly with respect to usage and watershed protection measures - ranging from largely single-use lakes with fairly stringent watershed protection measures to multi-use lakes with less restrictive watershed rules and regulations. Hemlock and Canadice Lakes, which serve as water supply reservoirs for the City of Rochester, have the most stringent watershed restrictions - a permit is required for public access to these lakes. Skaneateles Lake, a major source of drinking water for the City of Syracuse, is also governed by fairly stringent watershed protection measures, and is explicitly protected by New York State Environmental Conservation Law (ECL) - point source discharges to the lake and/or any of its tributaries are prohibited. The other Finger Lakes are subject to less stringent watershed regulations.

Past Water Quality Investigations

The first systematic limnological investigation of the Finger Lakes occurred nearly a century ago by two Wisconsin researchers (Birge and Juday 1914, 1921). While limited by the tools of their time, Birge and Juday established a valuable record of water quality conditions for this important series of lakes. They established the first record of water clarity levels and also recorded vertical profiles (temperature and dissolved gases) within the Finger Lakes. Following this initial foray, it would be nearly half a century before the next collective limnological investigation of the Finger Lakes took place.

In the early 1970s a group of researchers from the Finger Lakes Region initiated a comprehensive study of the Finger Lakes. Their efforts culminated in the publication “Lakes of New York State – Volume I: Ecology of the Finger Lakes” (Bloomfield, 1978). This study established baseline measurements of conventional trophic indicators as well as other physical, chemical, and biological characteristics of the Finger Lakes.

There are also a number of locally-driven monitoring activities occurring on several of the Finger Lakes. For example, both Canandaigua Lake and Keuka Lake have ongoing long-term monitoring programs involving both the lakes and selected tributaries. Local monitoring efforts are also occurring on several of the other Finger Lakes. However, comparative studies of water quality conditions within the entire system of lakes has not occurred since the early 1970s.

Current Investigation

The current investigation is designed to update the status and trends of water quality within the Finger Lakes. There are several approaches available for assessing the water quality of a lake. The most common approach involves periodic water column sampling within a given lake. Conventional water column monitoring is a valuable tool for assessing existing water quality conditions within a lake. The approach is generally used to assess the trophic status of a lake and/or to assess temporal trends in conventional limnological parameters related to lake water quality. However, unless sampling is conducted over an extended period of time - a diminishing likelihood given current resource constraints - and unless the monitoring effort includes chemicals of concern within the lake, the approach is seriously limited in its ability to characterize historical conditions and/or contaminant trends over time. Paleolimnology, or the study of past aquatic environments, offers an attractive addition to conventional water column monitoring, and can provide important insight into historical water quality conditions within a lake. Paleolimnological investigations generally involve the collection of a deep-water sediment core, followed by discrete segmentation of the core. Core segments can be analyzed individually for radiometric parameters, as well as for inorganic and organic chemical substances. The radiometric analyses are used to establish a timeline for the core, enabling one to assess historical chemical patterns within the lake. Sediment cores also offer the advantage of providing relatively high levels of chemical substances (relative to water column samples), which increases the likelihood of detecting particular chemical compounds. Thus, the collection of sediment cores can provide an important supplemental line of inquiry regarding historical lake trends.

The current investigation is designed to revisit the chemical limnology of the Finger Lakes, and to evaluate chemical trends in this system of lakes. Consistent with the previous discussion of available approaches, this Study is composed of two distinct, yet related, components:

(1) *Part A: Synoptic Water Quality Investigation* – ongoing investigation consisting of periodic water column sampling from one deep-water location within each of the 11 lakes, with a primary focus on conventional limnology and temporal trends over time; and

(2) *Part B: Sediment Core Investigation* – one-time effort consisting of the collection of a single sediment core from a deep-water location within each of the lakes, and focused upon sediment deposition rates, as well as organic and inorganic chemical trends over time.

While the efforts will be reported separately below, there are significant linkages between the two efforts. It is important to note that with the exception of chlorophyll *a*, this report will not evaluate the biological status of the Finger Lakes. As will be discussed in the recommendations, it is important that the biological status of the lakes be evaluated in the future. Unfortunately, the resources necessary to conduct such investigations were beyond those available to this study.

The remainder of the report is segmented into the two main components discussed above, and includes a discussion of study purpose, methods, findings and recommendations. Findings are presented based upon spatial comparisons between lakes, temporal trends within individual lakes, and comparison of study results to applicable regulatory criteria and/or possible issues of concern. The report concludes with summary remarks regarding each of the 11 Finger Lakes.

Part A: Synoptic Water Quality Investigation

Chapter 3: Purpose and Objectives

The purpose of Synoptic Water Quality Investigation is to systematically assess conventional limnological and water quality conditions in the 11 Finger Lakes. Specific objectives of this investigation include the following:

1. Assess current trophic status of the Finger Lakes and compare conditions between lakes;
2. Evaluate historical trends in trophic indicators for each of the Finger Lakes;
3. Assess current levels of major ions within the lakes and evaluate temporal trends;
4. Evaluate existing water quality conditions within the context of applicable regulatory criteria.

A second investigation, involving collection of sediment cores from each of the Finger Lakes to assess historical chemical patterns over time is presented in Part B.

Chapter 4: Design and Methods

This Investigation is composed of two components: (1) current synoptic investigation of the 11 lakes for conventional limnological parameters; and (2) review of findings from previous water quality studies within the Finger Lakes. The Synoptic Water Quality Investigation is designed to be conducted over a period of at least 5 years. It is felt that this is the minimum period of time necessary to accurately characterize this series of lakes, and to begin to assess water quality trends within this system of lakes.

The Synoptic Water Quality Investigation is composed of periodic sampling at a single deep water location on each of the 11 Finger Lakes during the growing season. The only exception to the single sample location per water body is for Cayuga Lake. Two additional sites have been established on the southern-shelf of Cayuga Lake to assess water quality concerns within this portion of the lake. Station locations and approximate water depths are provided in Table 4.1. Monitoring is conducted monthly during the growing season - in theory, May through October, however, in practice monitoring is frequently delayed until June. On these occasions, pre-stratification conditions may be missed for that particular year.

Table 4.1: Station locations and approximate water depths for Synoptic Water Quality Study

Lake	*Latitude*	*Longitude*	*Depth (m)*
Conesus	N 42° 45.645'	W 77° 42.839'	20
Hemlock	N 42° 44.102'	W 77° 36.873'	25
Canadice	N 42° 44.038'	W 77° 34.221'	25
Honeoye	N 42° 45.312'	W 77° 30.348'	8
Canandaigua	N 42° 45.973'	W 77° 19.058'	65
Keuka	N 42° 29.323	W 77° 09.297'	55
Seneca	N 42° 35.081'	W 76° 54.602'	70
Cayuga (deep)	N 42° 33.310'	W 76° 35.850'	50
Cayuga (shelf-W)	N 42° 28.070'	W 76° 31.120'	3
Cayuga (shelf-E)	N 42° 28.080'	W 76° 30.450'	5
Owasco	N 42° 50.670'	W 76° 30.960'	50
Skaneateles	N 42° 53.590'	W 76° 24.240'	60
Otisco	N 42° 52.040'	W 76° 17.570'	19

Field measurements include: (1) Secchi Disk depth; and (2) vertical water column profiles. Secchi Disk depth, a common measurement of water clarity, is measured using a 20 cm (~ 8 inch) diameter black and white disk. The Secchi disk is attached to a calibrated line and is slowly lowered into the water to the depth at which it disappears. The disk is then lifted until it reappears. An average of the two depths is then recorded. Vertical water column profiles are taken with a Hydrolab® Surveyor IV probe, and parameters include temperature, dissolved oxygen, pH, and conductivity.

Water samples are collected from both the epilimnion and hypolimnion at each site. Sample depths are determined as follows: (1) epilimnetic samples are collected at the measured Secchi Disk depth; and (2) hypolimnion samples are collected at 2/3rd station depth. Exceptions to this procedure are during non-stratified conditions and/or at monitoring locations with depths less than 10 meters. In these instances, a single water column sample is collected from the Secchi Disk depth.

Sample parameters have varied during the investigation due to funding constraints, etc. However, basic analytes include total phosphorus, ammonia nitrogen, nitrate+nitrite nitrogen, total Kjeldahl nitrogen, total organic carbon, major ions and trace metals, reactive silica, chlorophyll *a* and alkalinity. Table 4.2 provides a summary of analytical methods, and Table 4.3 describes processing and preservation methods.

Table 4.2: Analytical procedures for sample parameters and field measurements

PARAMETERS	METHOD
Phosphorus (all forms)	APHA 4500-PF
Ammonia nitrogen	USEPA 350.1
Nitrate (+ nitrite) nitrogen	USEPA 353.2
Total nitrogen	USEPA 351.2
Total organic carbon	USEPA 415.2
Dissolved organic carbon	USEPA 415.2
Dissolved inorganic carbon	APHA 4500-CO_2
Chloride	APHA 4500-Cl^- E
Reactive silica	USEPA 370.1
Metals (Fe, Ca, Mg, Na, K)	USEPA 200.7
Alkalinity	USEPA 310.1
pH	Hydrolab (1991)
Dissolved oxygen, in situ	Hydrolab (1991)
Temperature, in situ	Hydrolab (1991)
Specific conductance, in situ	Hydrolab (1991)

Table 4.3: Summary of processing, preservation, and sample containers

Parameter	Processing	Preservation	Hold Time (days)
Ortho-phosphorus	a	A	2
Total phosphorus	b	B	28
Ammonia nitrogen	b	A	28
Nitrate (+ nitrite) nitrogen	b	B	28
Total Kjeldahl nitrogen	b	A	28
Total organic carbon	b	B	28
Dissolved inorganic carbon	b	A	28
Dissolved organic carbon	b	A	28
Metals (Fe, Ca, Mg, Na, K, Pb)	b	C	182
Reactive silica	b	A	28
Total chlorides	b	A	28
SO_4	b	A	28
Chlorophyll a	a	D	30
Alkalinity	b	A	14

Processing: a - filtration through 0.45 µ cellulose nitrate filter
b - whole sample

Preservation: A - no addition, sample held at 4° C
B - 0.2 ml 5N H_2SO_4/20 ml of sample
C - 0.1 ml 1+1 HNO_3/20 ml of sample
D - $MgCO_3$, wrapped in aluminum foil, and frozen

In addition to the above measurements and analyses, intensive optics measurements were conducted at each of the primary sampling sites during the first two field seasons. The results of these investigations are available within a separate report (Effler, et al., 2000).

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

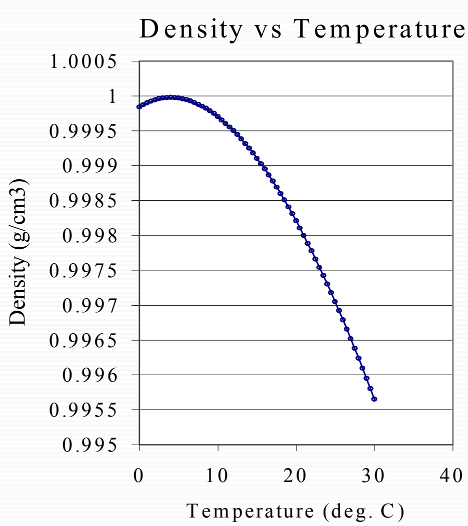
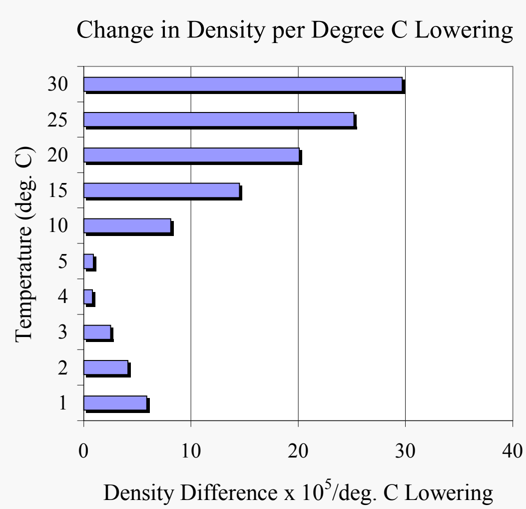


Figure 5.2: Change in density per degree C



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.

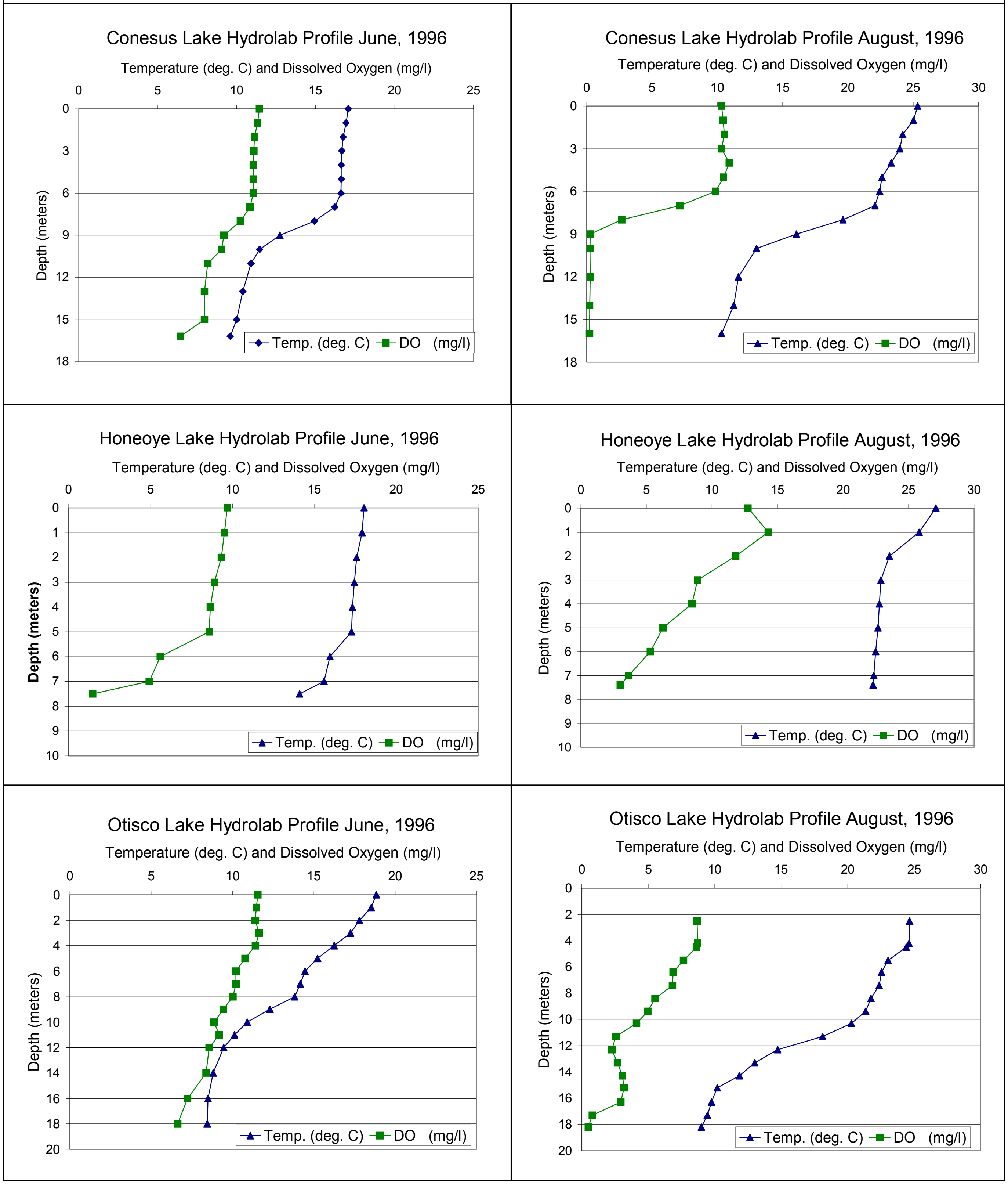


Figure 5.4: Vertical profiles (temperature and dissolved oxygen) for Owasco, Cayuga and Seneca Lakes

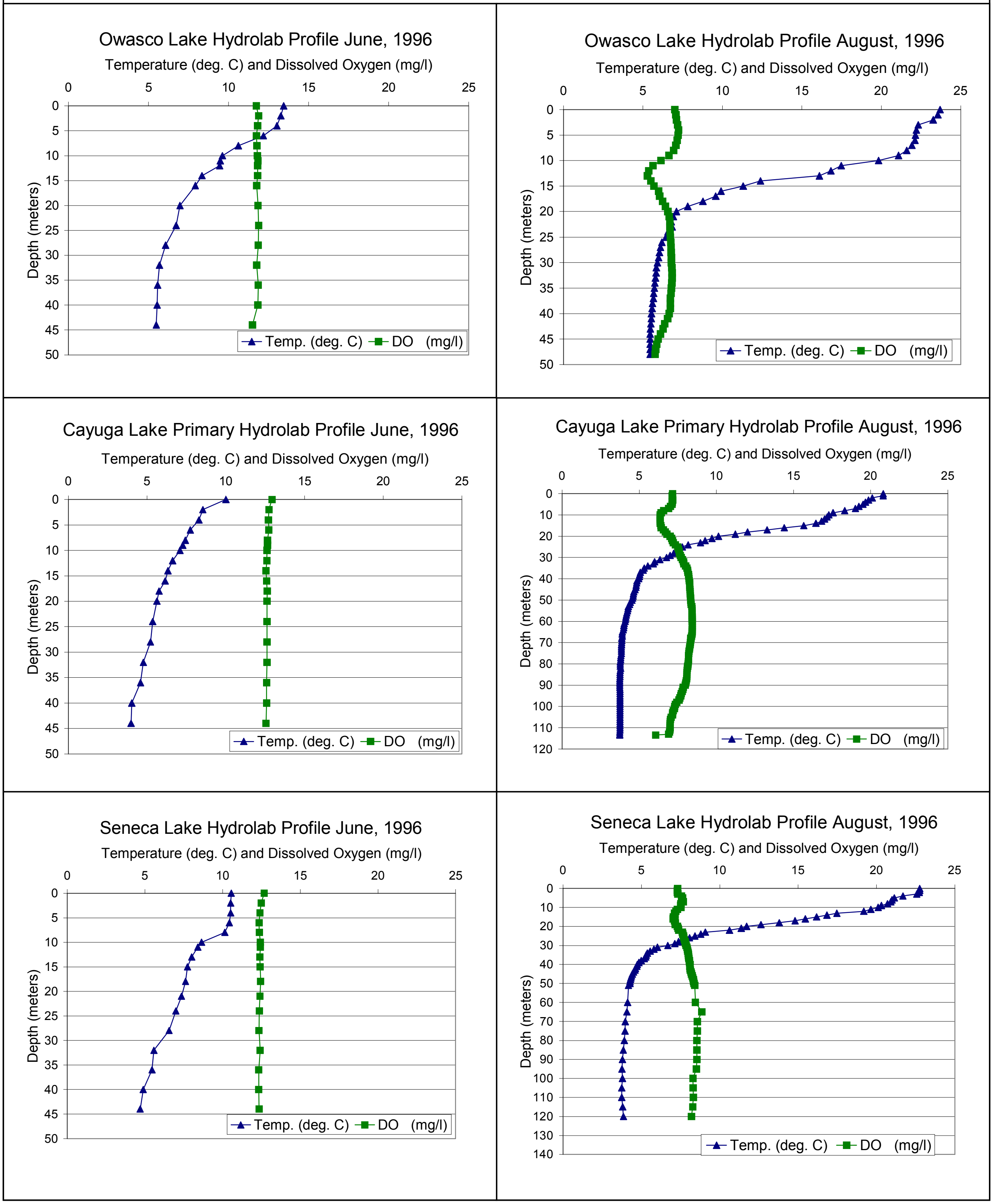
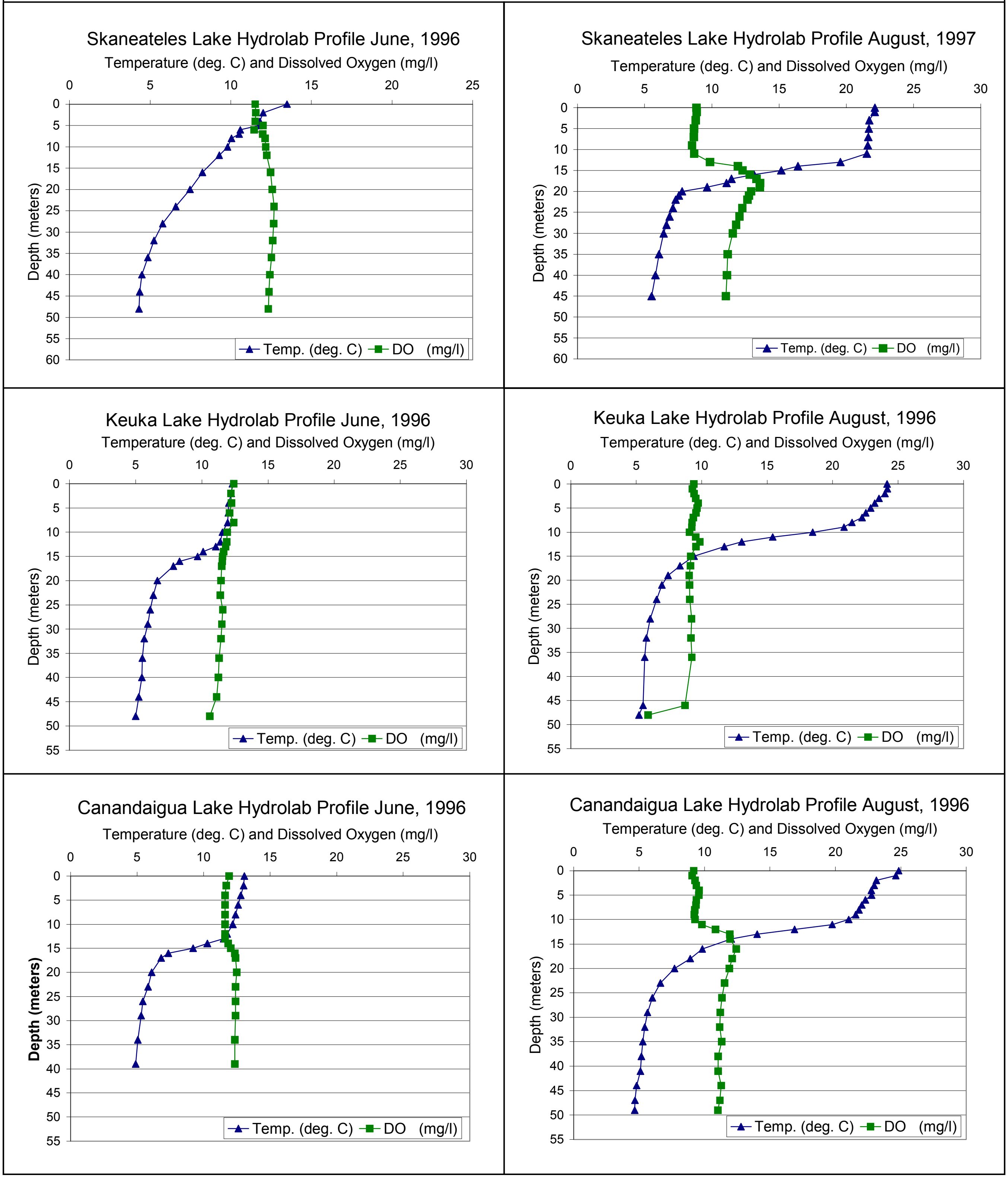


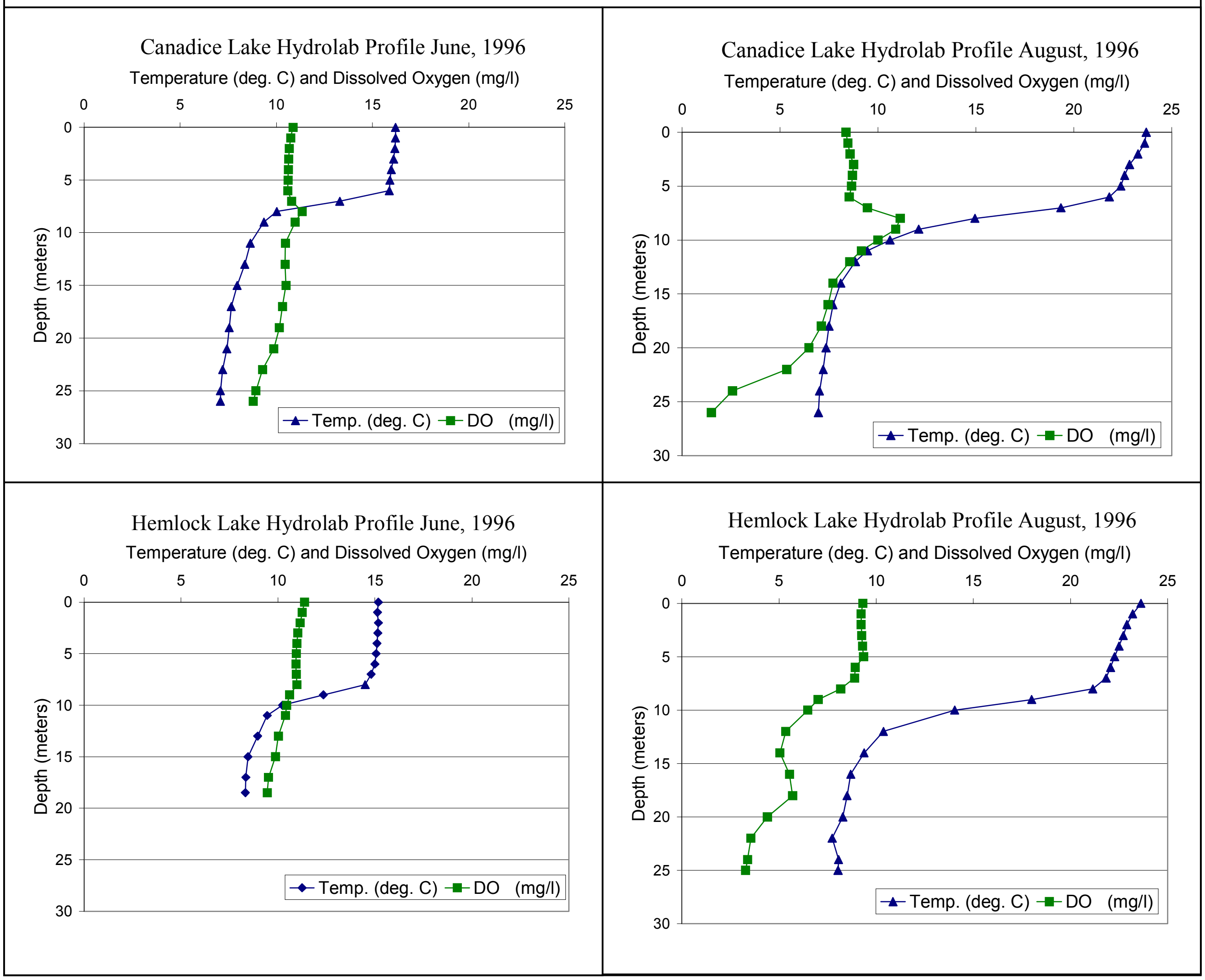
Figure 5.5: Vertical profiles (temperature and DO) for Skaneateles, Keuka and Canandaigua Lakes



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.				
	Nitrogen:Phosphorus		*Carbon:Phosphorus*	
Lake	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.

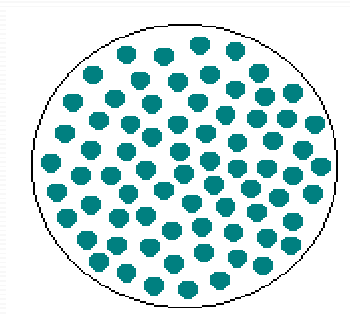
Trophic Indicators

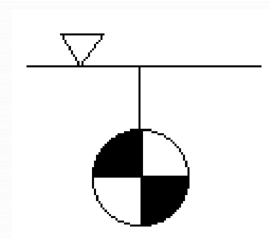
There are four common trophic indicators for freshwater lacustrine systems: (1) phosphorus; (2) chlorophyll a; (3) Secchi Disk depth; and (4) hypolimnetic dissolved oxygen. These four parameters are linked to varying degrees.

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.

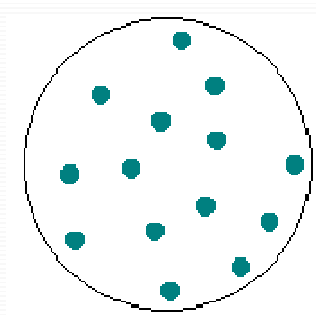
The validity of these linkages is dependant upon the strength of the underlying assumptions. Problems can arise when: (a) phosphorus is not the limiting factor for algal productivity – this would result in a higher TSI (TP) than TSI (chl a); (b) water clarity is controlled by other than algae (e.g., 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').

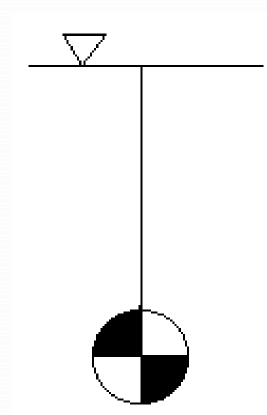
Case 1: P ↑ Chlorophyll a ↑ Secchi Disk ↓





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 in 6 western Finger Lakes – note scale differences

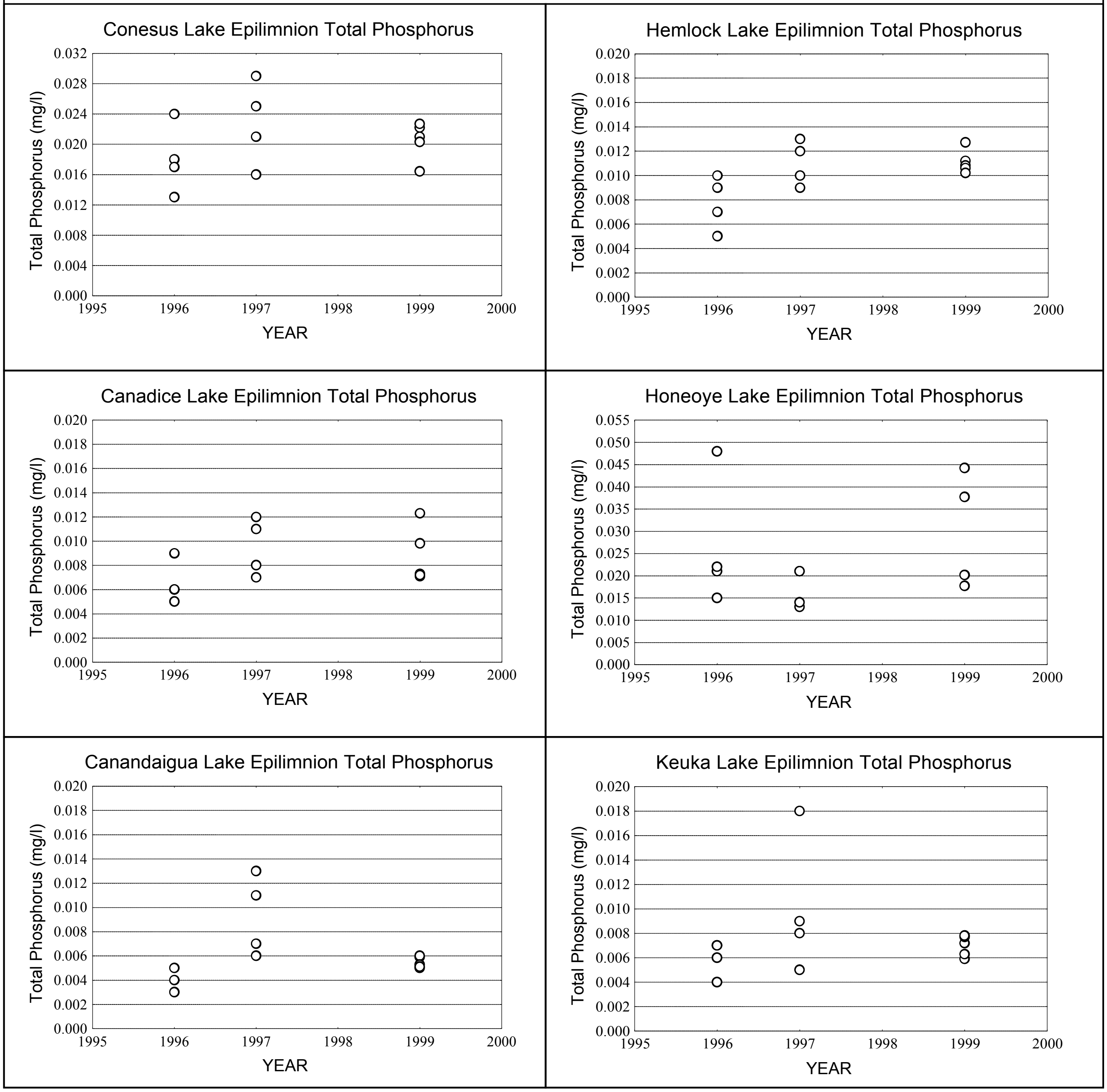
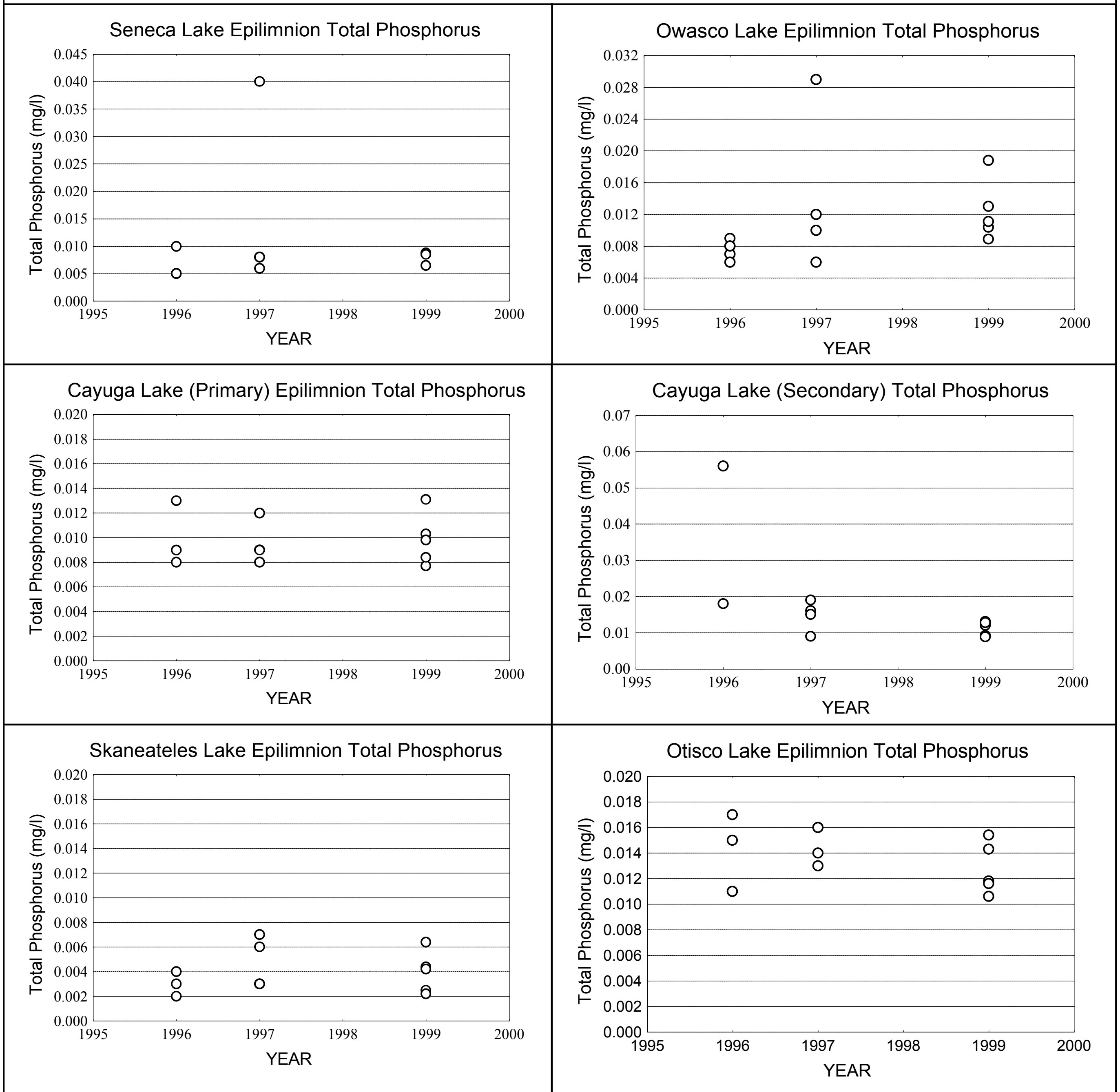


Figure 5.8: Epilimnetic total phosphorus levels in 5 eastern Finger Lakes – note scale differences



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* in 6 western Finger Lakes – note scale differences

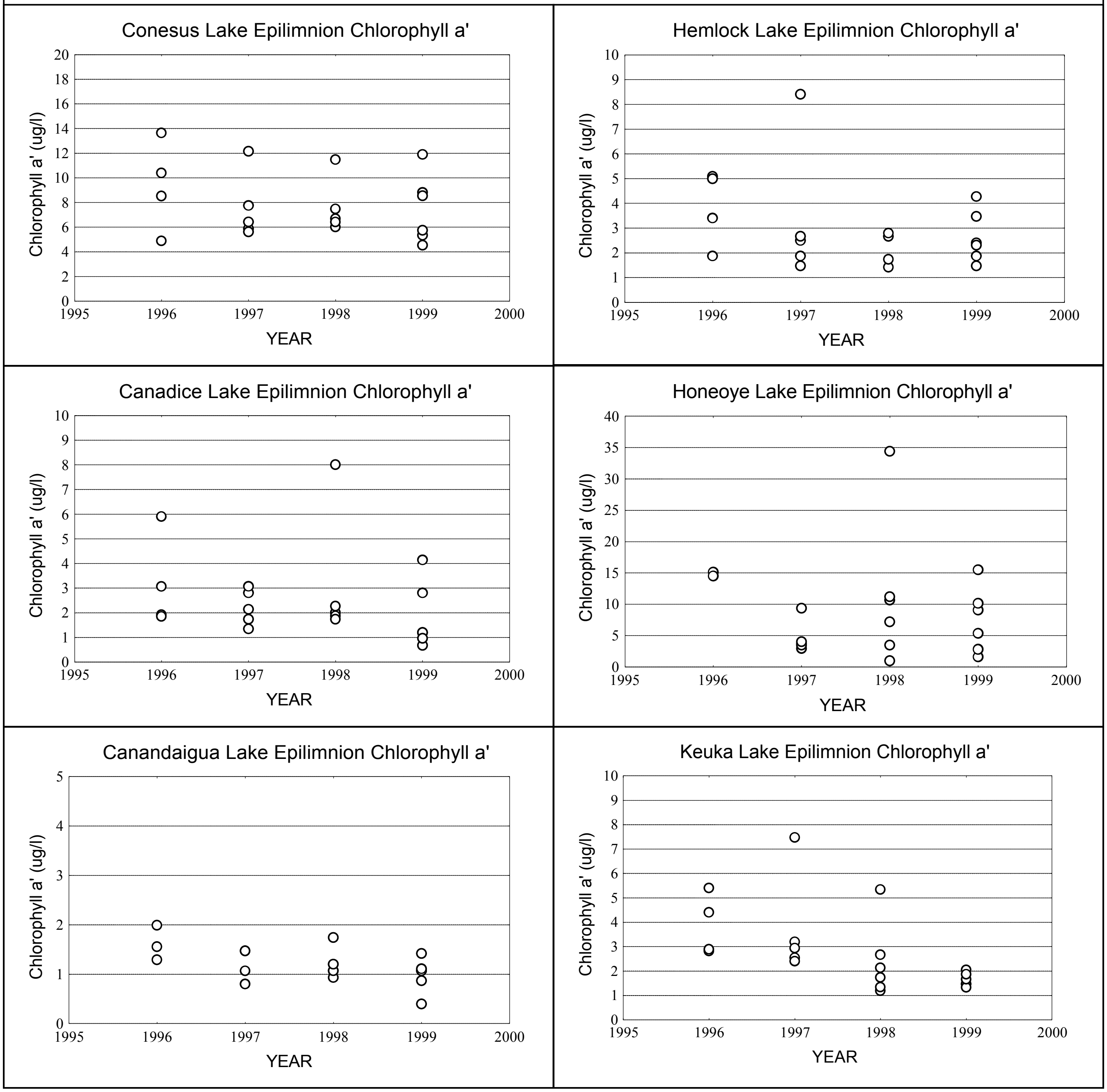
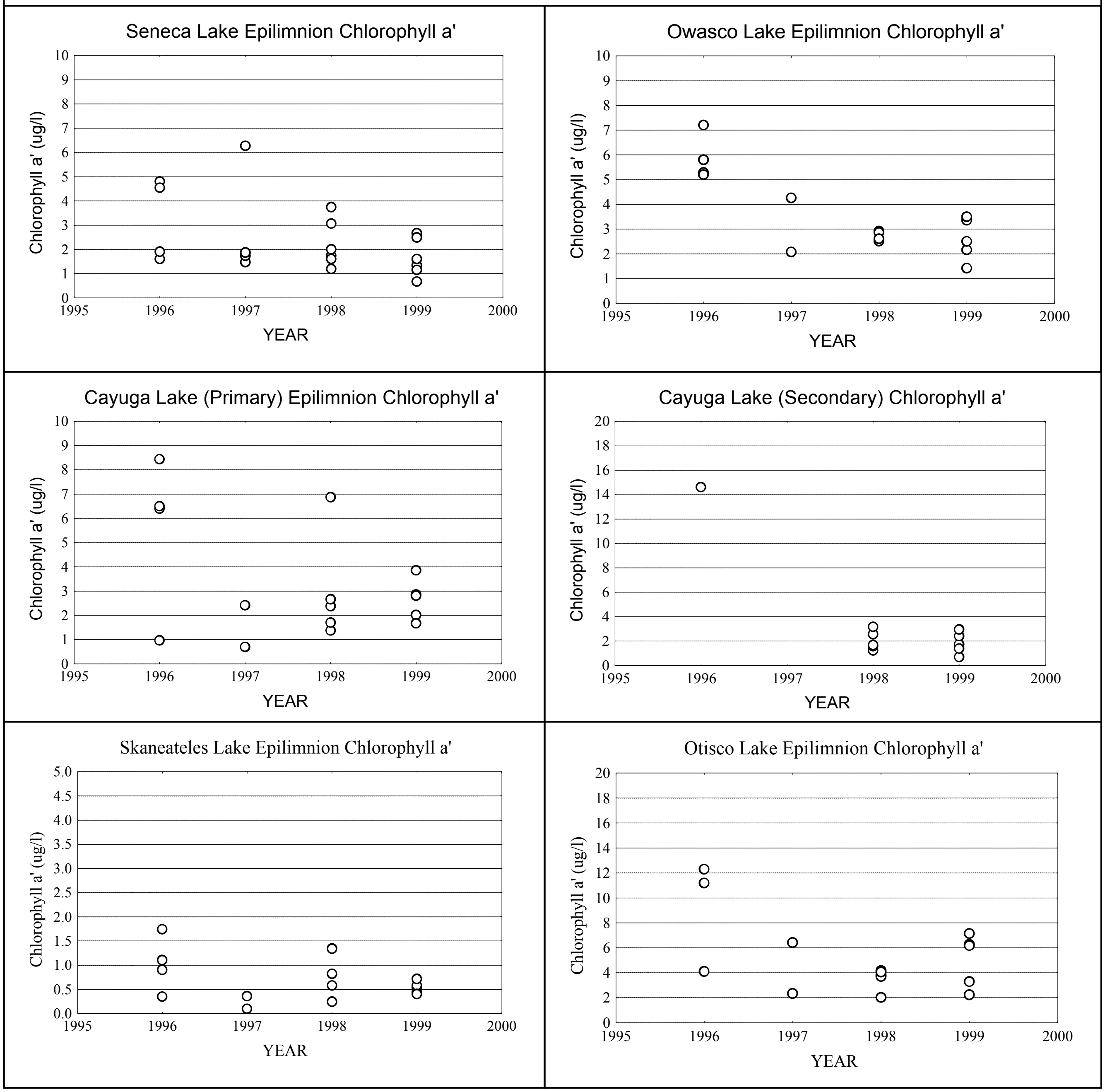


Figure 5.10: Epilimnetic chlorophyll *a* in 5 eastern Finger Lakes – note scale differences



Secchi Disk Depth

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)

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.

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 in 6 western Finger Lakes

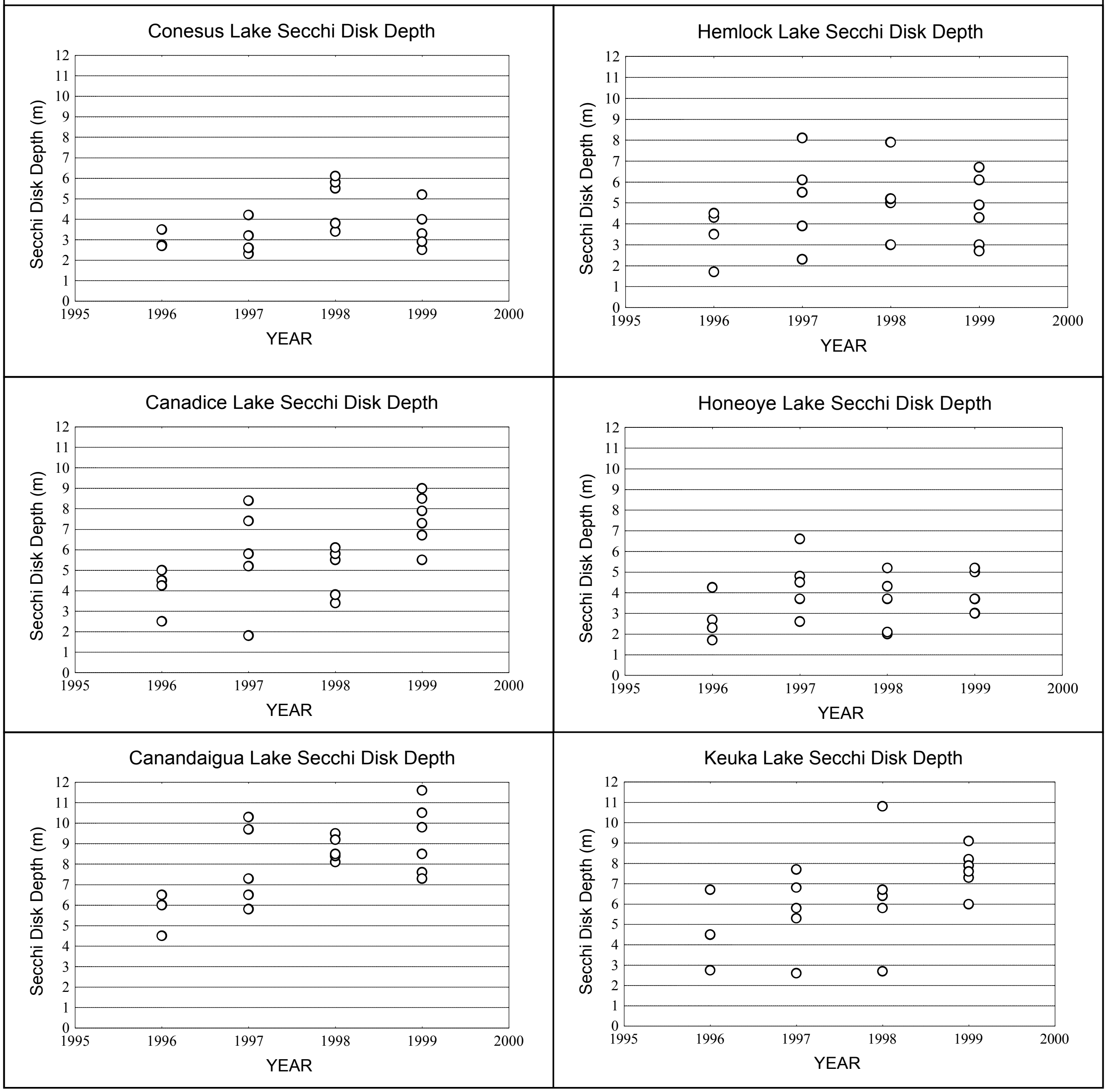
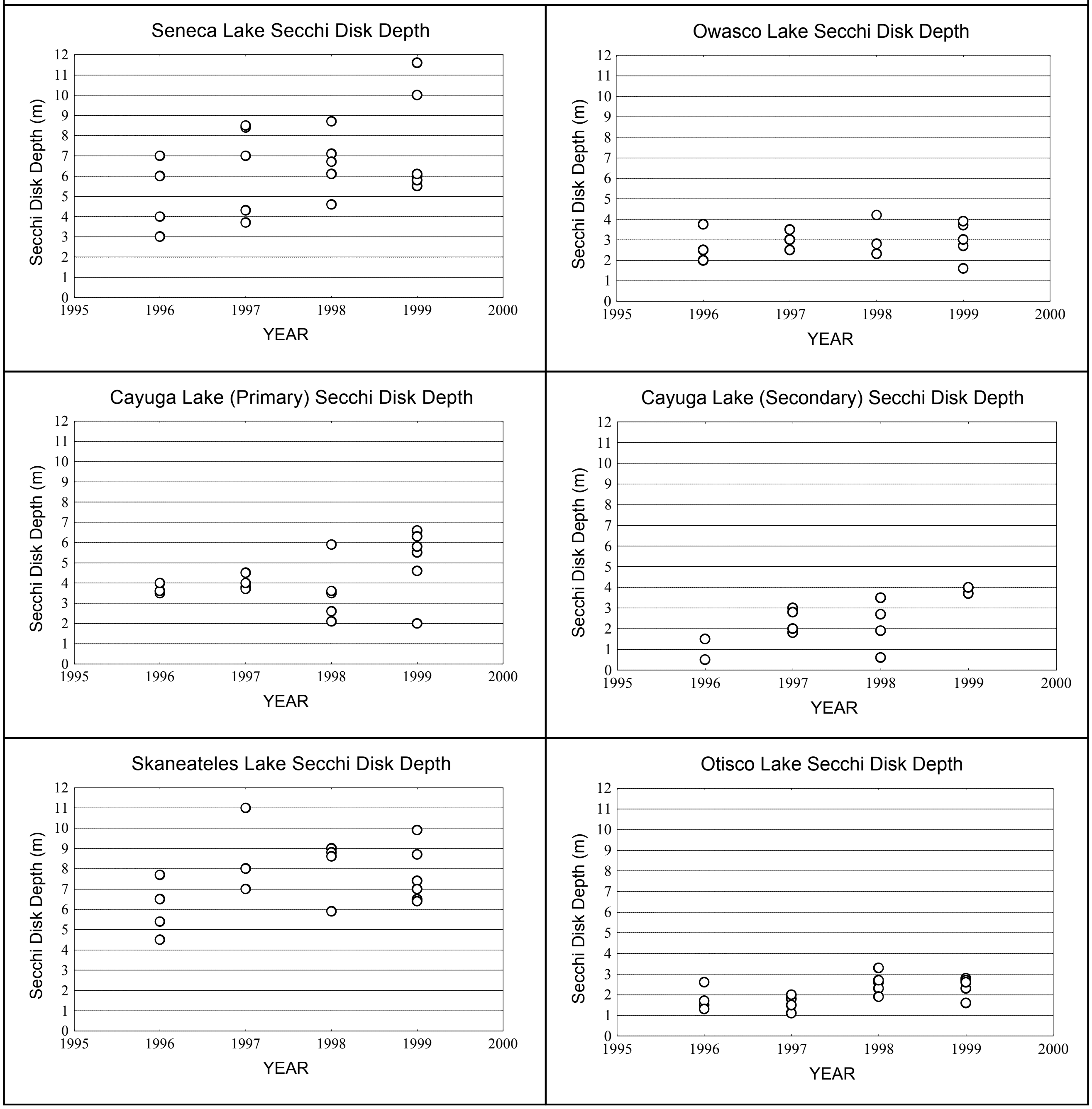


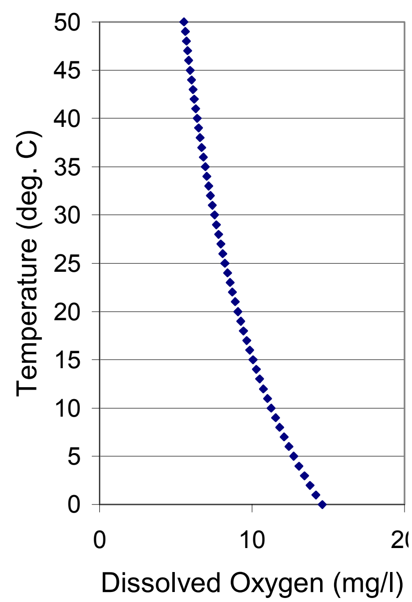
Figure 5.12: Secchi Disk Depths during the 1990s in 5 eastern Finger Lakes



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".

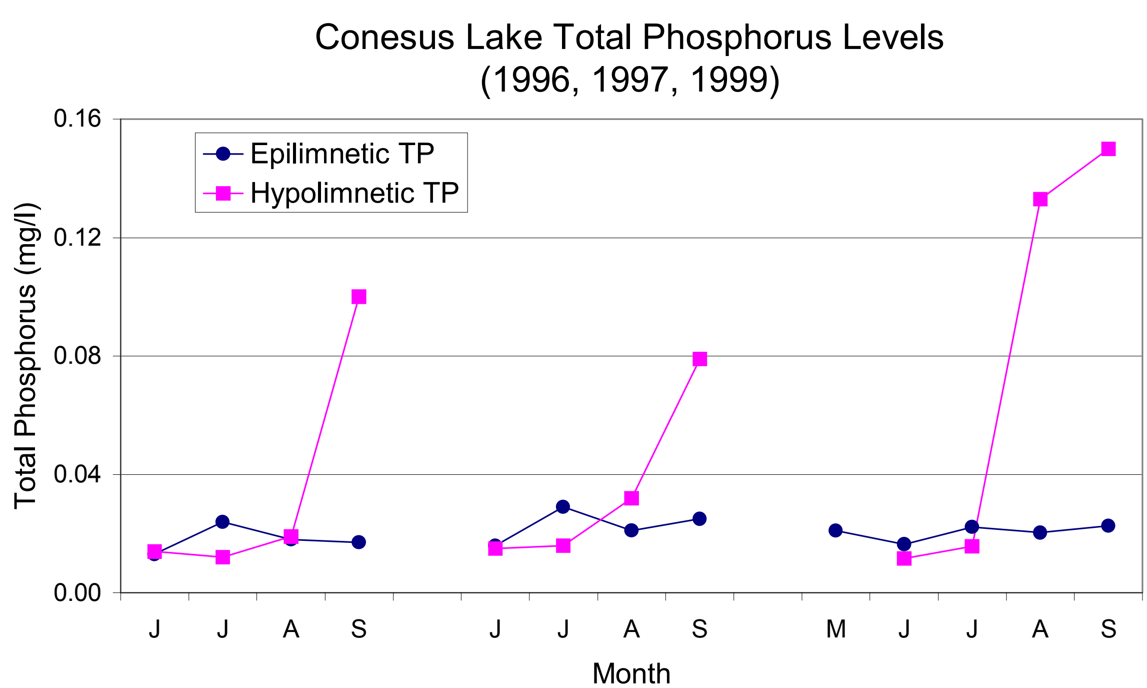
Third, the implementation of Best Management Practices (BMPs) in agricultural operations have also contributed to reductions in phosphorus loading from diffuse, or non-point sources. Other factors, such as land use changes also influence nutrient loading to the lakes, although the direction of change 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

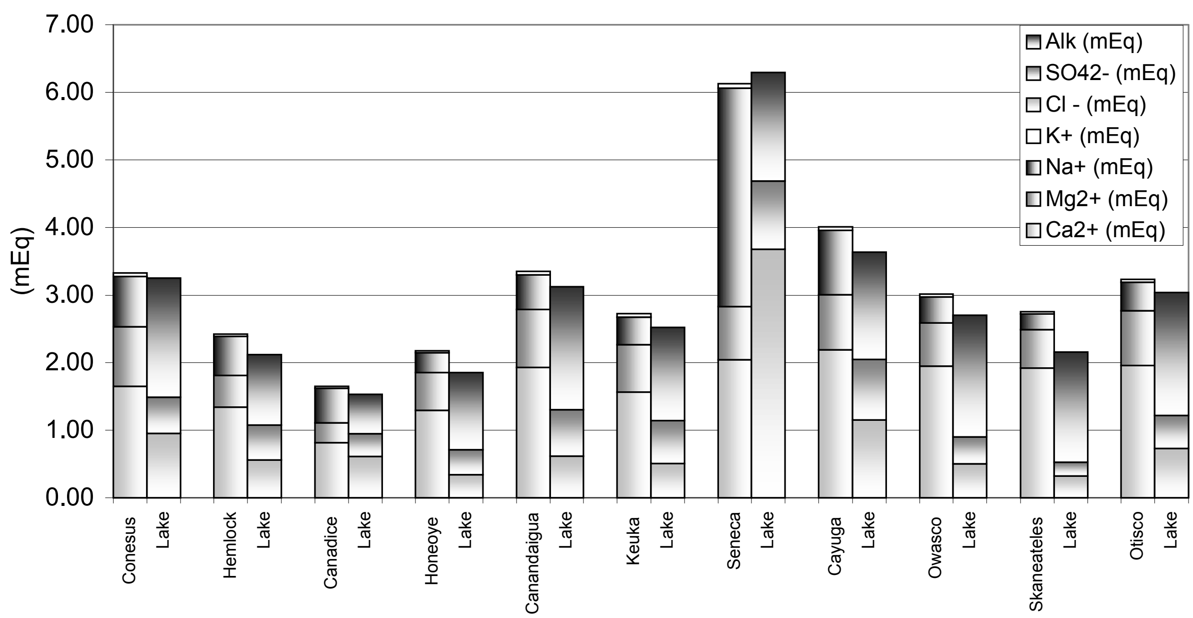


Figure 5.9: Temporal comparison of total cations and anions within the Finger Lakes

	Total Cations (mEq)		Total Anions (mEq)	
Lake	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 in 6 eastern Finger Lakes

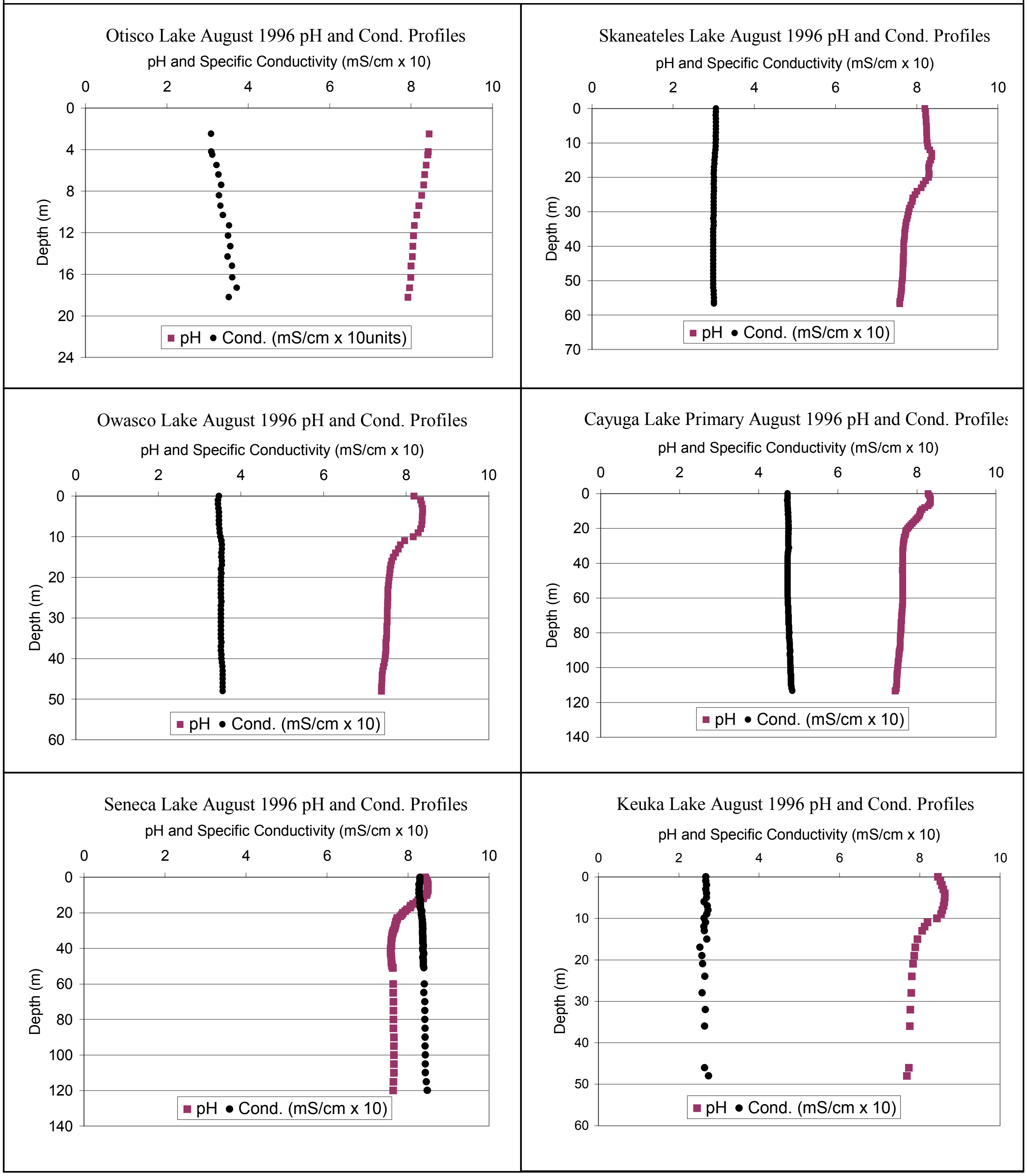
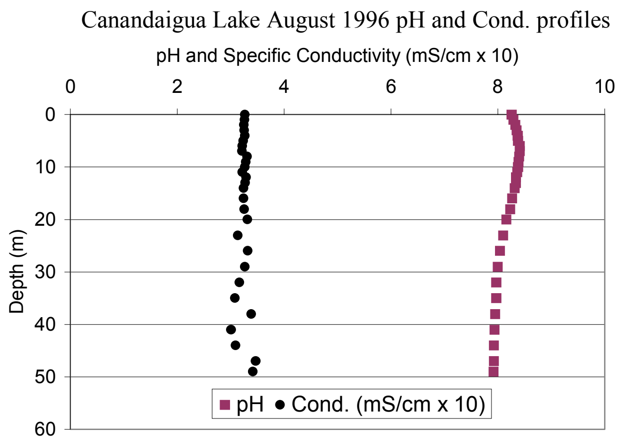
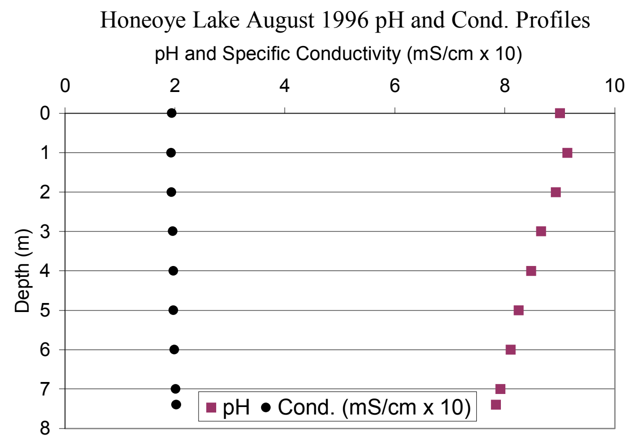
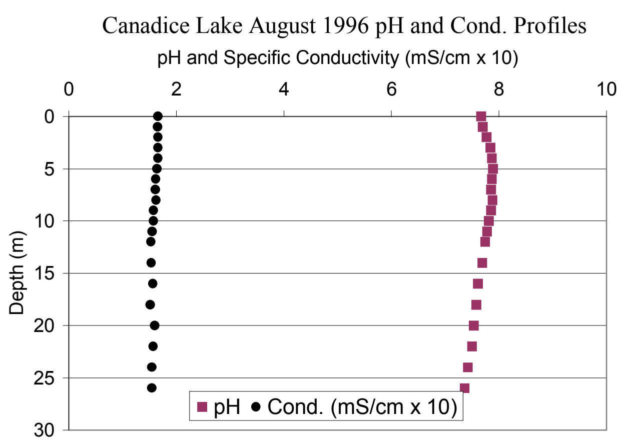
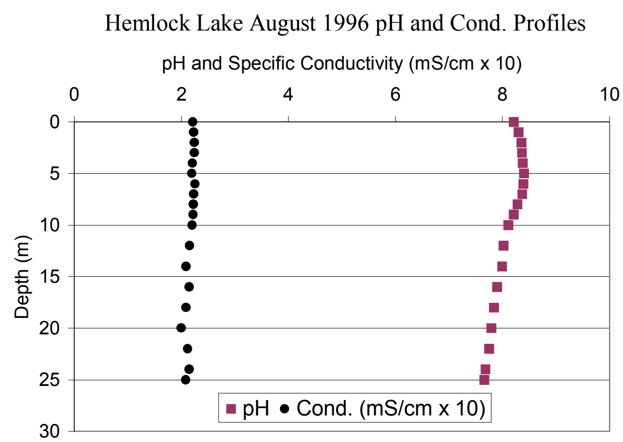


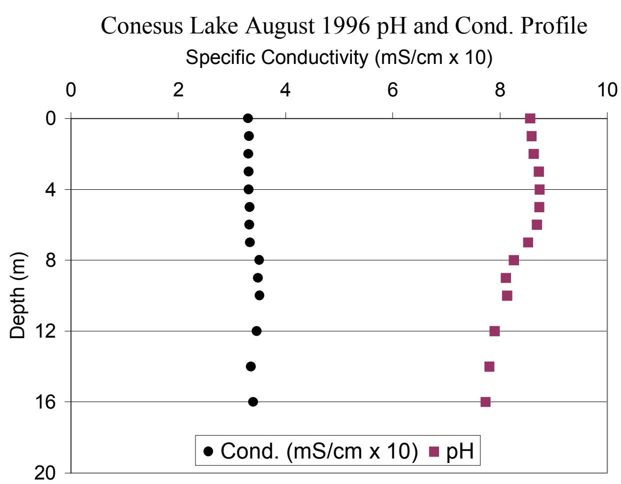
Figure 5.19: Specific Conductivity and pH in 5 western Finger Lakes











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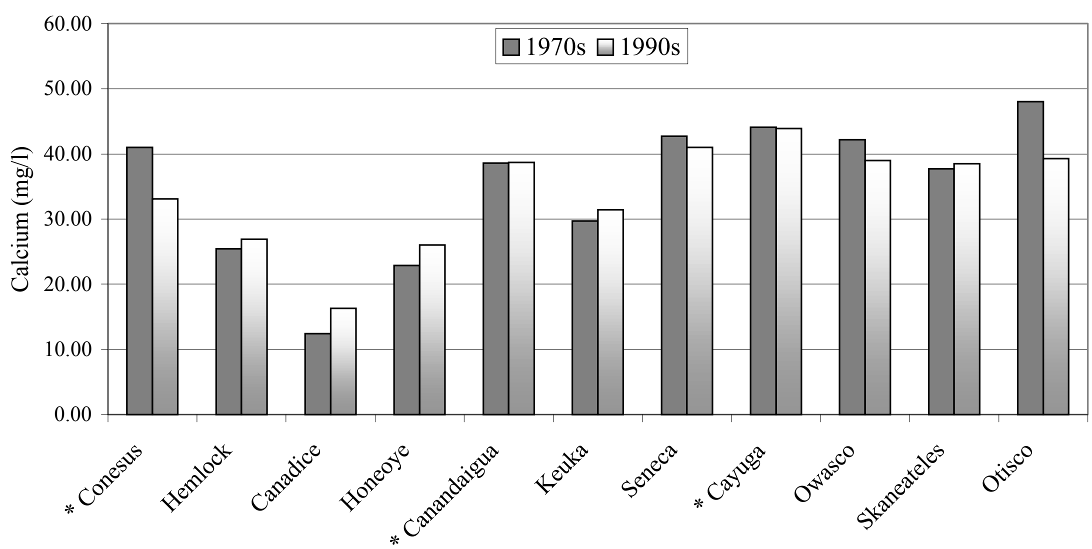
Calcium

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 in 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

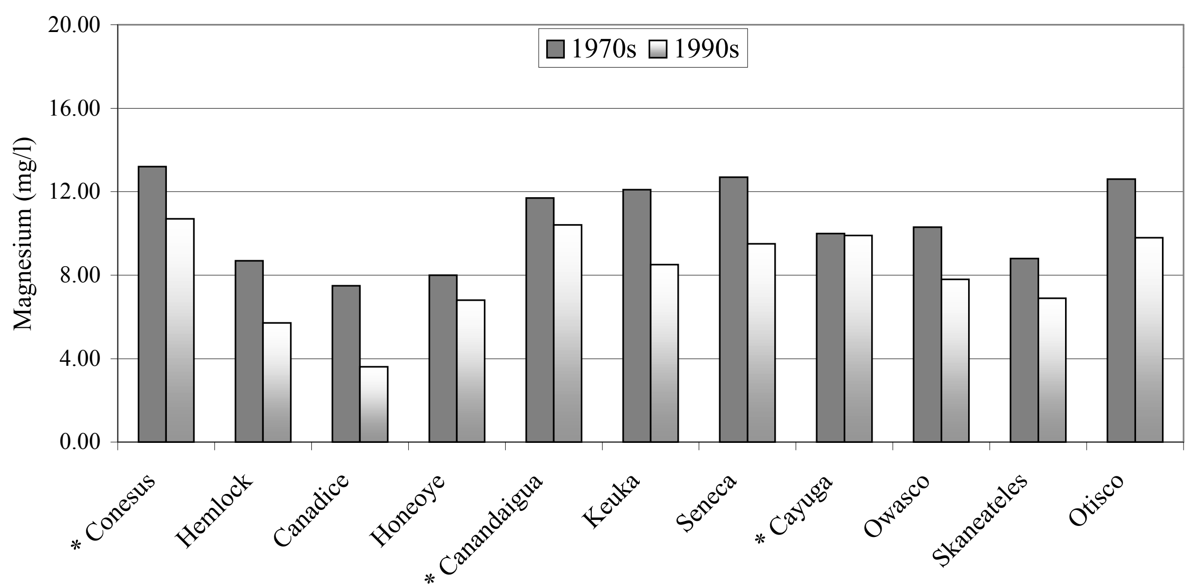
Magnesium is an important micronutrient in aquatic ecosystems. It is essential to the production of chlorophyll and is important in the functioning of certain enzymatic systems in algae, fungi, and bacteria.

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: Mean epilimnetic magnesium concentrations in the Finger Lakes



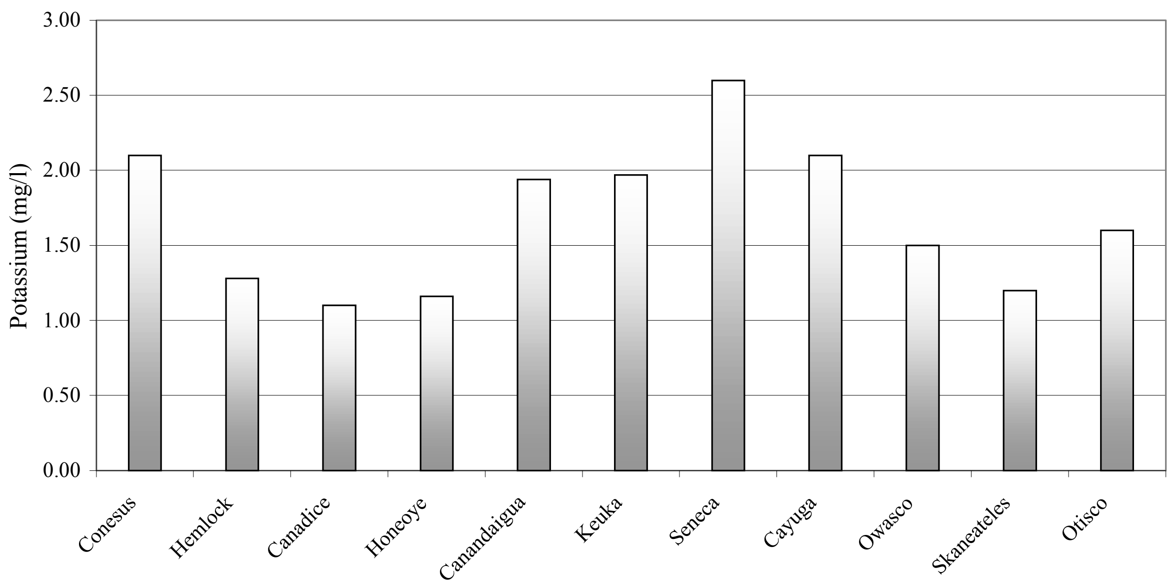
Potassium

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: Mean epilimnetic potassium concentrations in the Finger Lakes 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):

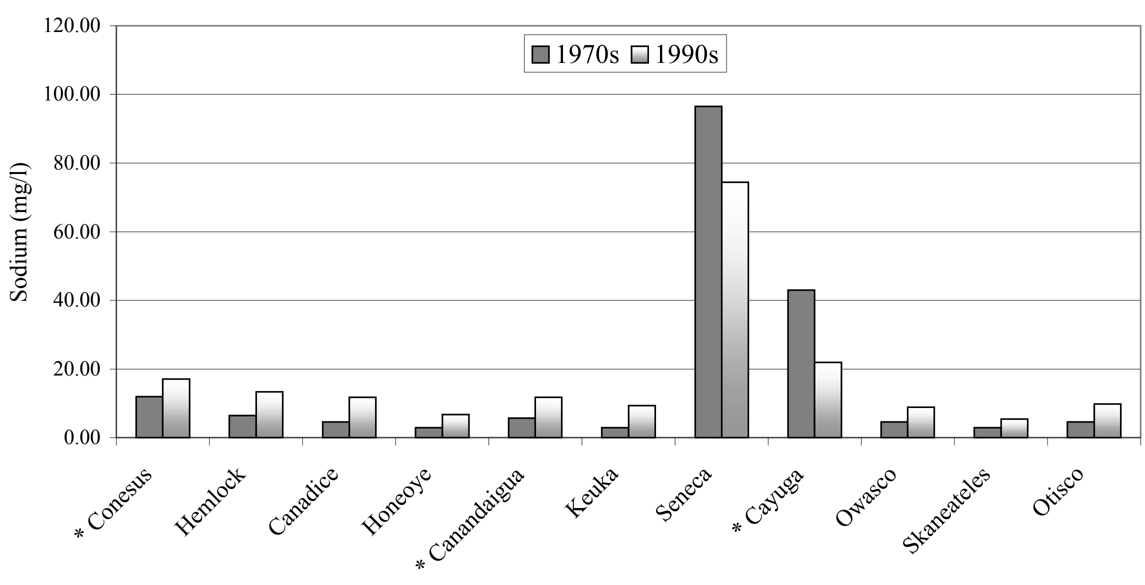
> "Water containing more than 20 mg/L of sodium should not be used for drinking by people on severely restricted sodium diets. Water containing more than 270 mg/L of sodium should not be used for drinking by people on moderately restricted sodium diets."

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 in 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.

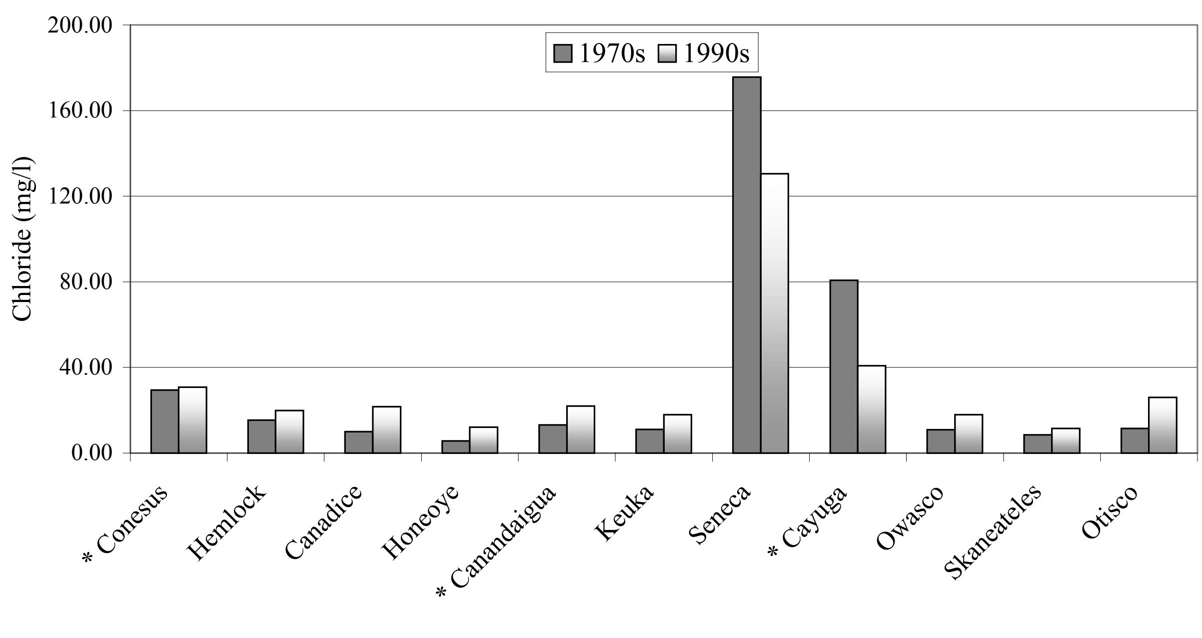
Mean epilimnetic chloride levels from the 1970s and the 1990s are presented in Figure 5.25. The 1970s values were obtained from either Mills (unpublished data, 1973) or Bloomfield (1978) .

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.



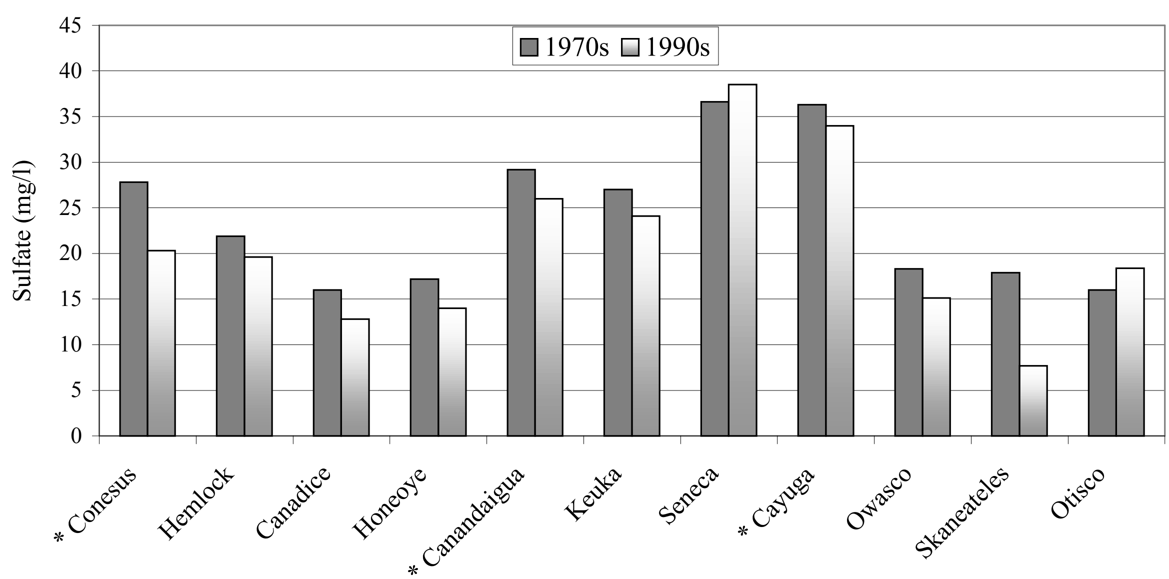
Sulfate

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

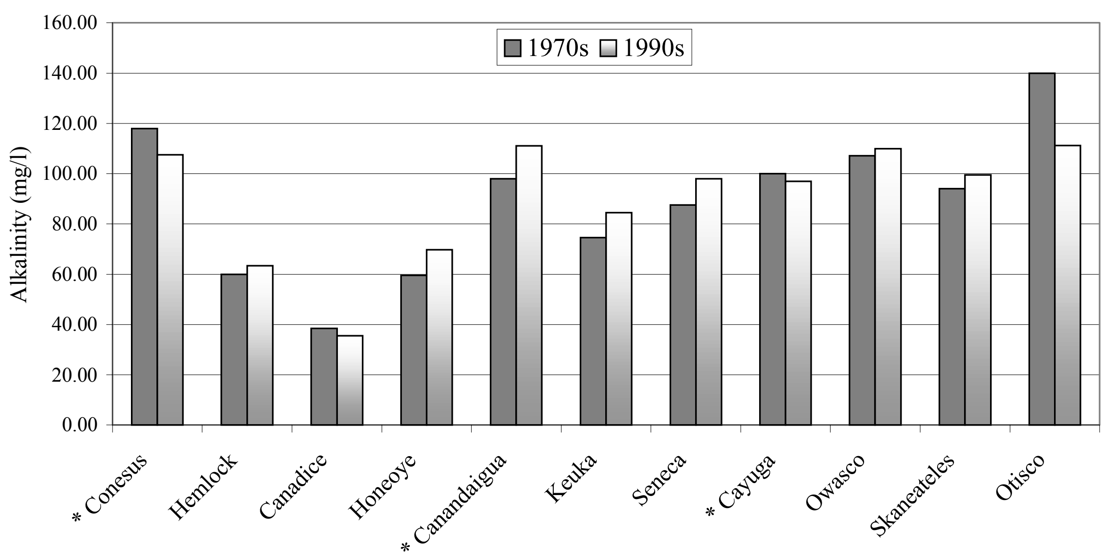
Alkalinity refers to the capacity of water to neutralize acid, and reflects the quantity of acid neutralizing constituents present within a water body. In most freshwater lakes in New York State, alkalinity is primarily a measure of bicarbonates (HCO_3^-) and carbonates (CO_3^{-2}).

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 in 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.

Chapter 6: Recommendations

The Synoptic Water Quality Investigation provides important information regarding current limnological conditions and limnological trends within the Finger Lakes. Findings from this investigation indicate substantial changes over the past several decades. However, important questions remain unanswered, and additional study is warranted as follows.

First, given the importance of these lakes to the Finger Lakes Region and New York State as a whole, and observed changes to date, it is recommended that the Long-term Synoptic Investigation continue for several more years. Continued study of the Finger Lakes should prove valuable in several regards, including: (a) evaluating the influence of anthropogenic activities within the Finger Lakes Region, (b) assessing the influence of exotic flora and fauna within the lakes (e.g., zebra mussels, spiny water flea, milfoil, etc.), (c) providing a sound statistical basis upon which to assess water quality trends within the Finger Lakes – natural inter-annual fluctuations necessitate long-term data sets, (d) assessing resultant water quality benefits derived from environmental management initiatives such as the 1996 Environmental Bond Act expenditures, lake/watershed management plans, best management practices, etc. and (e) providing valuable information in development of nutrient criteria for the state and/or ecoregion. Finally, as indicated by Birge and Juday nearly a century ago, this series of lakes provide an ideal laboratory for understanding limnological concepts.

Second, it is recommended that the Long-term Synoptic Investigation be expanded to encompass biotic indices for the Finger Lakes. By-in-large this investigation has focused upon chemical and/or physical parameters, with only a cursory look (e.g., chlorophyll *a*) at the biological components of the lakes. While there has been a parallel study ongoing within the western 7 Finger Lakes by the agency's Region 8 Fisheries unit which has involved additional biotic indices (e.g., zooplankton), it would clearly be beneficial to expand biotic monitoring to all 11 of the Finger Lakes and to add additional biotic indices. Additional biotic indices of interest include: (a) P*hytoplankton* – which represents the top of the food web for freshwater systems, and can provide valuable insight regarding the stability of the aquatic food web; (b) M*acrophytes* – several of the Finger Lakes are adversely effected by excessive growth of certain aquatic plant species which can interfere with certain uses of the lakes. Thus, a sound understanding of macrophyte coverage and dynamics within the lakes would be a valuable addition to the water quality investigation of these lakes; (c) *Bacteriological* – the Finger Lakes are used extensively as a source of drinking water and for primary contact recreation (e.g., swimming). Thus, it would be prudent to include systematic study of bacteriological and pathogen levels within the lakes. This should focus upon near shore areas and areas proximate to public water supplies and/or public beaches; (d) *Zebra mussels* – as discussed above, Zebra mussel infestation within the Finger Lakes may result in significant changes in both chemical cycling and ecosystem dynamics within the Finger Lakes. Therefore, it is suggested that a monitoring program be initiated within the Finger Lakes to track Zebra mussel infestation within the lakes. This should involve monitoring of both veligers and adult populations, and should parallel study of limnological conditions within the lakes; and (e) Other exotic flora and fauna – a number of other exotic species have become established within the Finger Lakes which should be monitored on a periodic basis.

Third, the apparent dichotomy in trophic response to nutrient load reductions between large and small lakes should be investigated more fully. It is recommended that efforts be made to assess nutrient loading reductions within the Finger Lakes watersheds (or a subset thereof) during the last several decades, and to assess whether those reductions have resulted in concomitant improvements in lake water quality. In addition, an assessment should be made of internal phosphorus dynamics within several of the smaller Finger Lakes, in an effort to understand the interplay between hypolimnetic dissolved oxygen levels and the release of phosphorus from benthic sediments.

Fourth, given that Conesus Lake, Honeoye Lake, and, on occasion, the southern end of Cayuga Lake exceed the New York State total phosphorus guidance value of 20 ug/l, efforts should be made to reduce phosphorus loading to these waters. Where best usage of the waters is impaired or precluded, a Total Maximum Daily Load (TMDL) should be developed to redress the water quality impairment condition(s).

Fifth, given the extensive use of the Finger Lakes for water supply, it would seem warranted to assess trihalomethane (THM) formation potential within these important water sources. THMs are a class of chlorinated organic contaminants which are under increasing scrutiny by public health agencies due to their potential cancinogenic properties and other possible health effects. THM production is a byproduct of the chlorine disinfection process. The production of THMs is also influenced by other factors such as the level of organic material present in the source water. Thus, cultural eutrophication can exacerbate THM related concerns.

Sixth, dissolved oxygen levels within several of the smaller Finger Lakes currently fall below existing water quality standards. Observed excursions include both hypoxia (DO < 4.0 mg/l) and anoxia (DO < 1.0 mg/l), and are limited to hypolimnetic waters. The cause(s) and possible impacts of these dissolved oxygen depletions should be investigated – see related recommendation #3 above. With respect to causality, efforts should be made to determine if observed dissolved oxygen depletions are primarily the result of natural conditions (e.g., lake morphometry) or are anthropogenically mediated (e.g., cultural eutrophication). Possible impacts of dissolved oxygen depletions should also be evaluated. These should include both ecosystem and human health related concerns relating to chemical availability.

Seventh, the causes and possible ramifications of increasing calcium levels should be assessed. In particular, Zebra mussel population dynamics should be evaluated in the context of existing food web structure and resource impairments (e.g., clogging of intake pipes, etc.).

Eighth, while continued study of the Finger Lakes is clearly warranted, it is critical that monitoring activities include sampling of tributary waters as well. Tributary monitoring efforts are, in fact, underway in several Finger Lakes watersheds (e.g., Canandaigua Lake, Keuka Lake, Seneca Lake, etc.). However, a coordinated approach to assessing event-based/nonpoint source loading within the Finger Lakes would be extremely valuable. It is suggested that the tributary sampling program be composed of two distinct components, as follows: (a) *Geographically Specific*: there are several locations within the Finger Lakes which should be specifically targeted for event-based tributary monitoring to support development of waste assimilative capacity estimates. These include Conesus and Honeoye Lakes, as well as the southern end of Cayuga Lake; and (b) *Reference Conditions*: a second component would involve the development of a tributary monitoring program designed to characterize generalized runoff coefficients within the Finger Lakes Region. These estimates could be used to calibrate basic water quality screening models which would be of value in watershed management activities. These local and regional efforts could best be carried out as collaborative efforts between local, state, and federal entities and with the possible involvement of academic and other institutions within the given locations.

Part B: Sediment Core Investigation

Chapter 7: Purpose

The purpose of the *Sediment Core Investigation* is to systematically assess chemical patterns within the Finger Lakes over time. Specific goals of the Study are as follows:

1. Assess spatial variations in chemical patterns between the Finger Lakes,
2. Assess temporal patterns of chemical inputs within each lake,
3. Evaluate chemical levels with respect to sediment quality assessment values,
4. Determine sediment accumulation rates.

A second, related study, termed the *Synoptic Water Quality Investigation*, involves long term synoptic water quality monitoring on each of the lakes and is discussed above (see Part A)
.

Chapter 8: Design and Methods

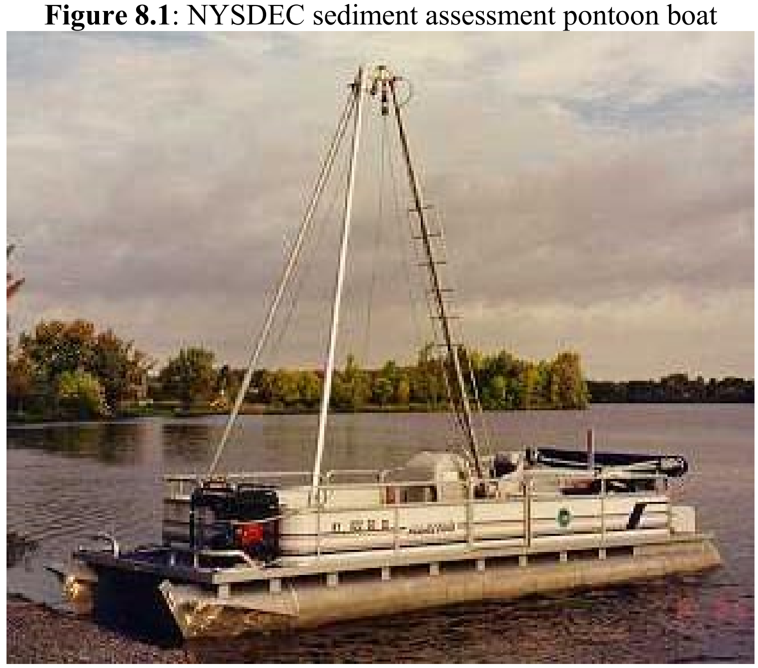
The Finger Lakes Sediment Core Investigation involved the collection of a deep water sediment core from each of the 11 Finger Lakes, vertical segmentation of the core, radiometric dating of core segments, and chemical (organic and inorganic) analysis of core segments. The Sediment Core Investigation was designed as a one-time effort and was conducted between 1997-98.

Sample Collection

All sediment cores, with the exception of the Seneca Lake core, were collected from the New York State Department of Environmental Conservation (NYSDEC), Division of Water (DOW) sediment assessment vessel (Figure 8.1). The vessel, a 23 feet long aluminum pontoon boat, is equipped with a 19 feet tall tripod and electric winch. The deck of the vessel has a 4 x 3 foot opening to allow deployment of the sediment coring device.

The Seneca Lake core was collected in cooperation with Professor John Halfman of Hobart and William Smith College (Geneva, NY) using their research vessel, which is stationed on Seneca Lake.

Figure 8.1: NYSDEC sediment assessment pontoon boat



Sediment cores were collected with a modified Wildco Box Corer [model # 191-A15; dimensions 15.2 x 15.2 x 100 cm] – see Figure 8.2, and associated acrylic core liner. Factory modification involved lengthening the corer to accommodate collection of 1-meter cores. The corner seams of the liner(s) proved of insufficient strength (often splitting upon removal and/or core extrusion) and had to be reinforced with duct tape. Otherwise, the box corer worked well.

Figure 8.2: Wildco Box Corer

The core collection procedure is as follows: (a) the box corer is lowered to within approximately 2 meters of the lake bottom using an electric winch; (b) sufficient winch cable is spooled out to allow free-fall of the corer to the lake bottom; (c) the sample crew secures the spooled cable, and when in position they release the cable in unison; (d) immediately after core penetration, tension is reestablished on the cable to establish vertical stability of the corer; (e) the corer is retrieved using an electronic winch; (f) once on board the sampling vessel, the box corer is placed within a wash basin and the corer is lifted off the core liner; (g) water overlying the core is siphoned off to minimize disturbance of the upper core layers during transport to shore; (h) core length is measured; and (i) core is secured for transport to shore.

The core extrusion and segmentation procedure is as follows: (a) core liner is hoisted atop an extrusion apparatus (this consists of a wooden frame with an extruding surface area slightly smaller than the surface area of the core liner); (b) meter stick is affixed to the side of the liner to enable measurement of individual sediment segments; (c) sediment core is pushed upward by prescribed increment; (d) core segment is inspected and visually described; (e) core segment is sliced off and sub-sectioned for laboratory submission; and (f) steps c through e are repeated as necessary. Sediment cores are sectioned into 1–4 cm increments and analyzed for the following parameters: (1) radioisotopes, (2) organic compounds, (3) inorganic compounds, and (4) ancillary parameters.

All sediment cores were collected from deep water locations – either maximum lake depth or greater than 25 meters. Deep water locations are more likely to contain undisturbed sediment deposits than are shallower areas. Thus, in theory, deep water cores insure an intact sediment chronology – as will be discussed below, this proved only partially true. Sample locations and approximate water depths for each of the sediment cores are shown in Table 8.1.

Table 8.1: Sediment core sample locations

Lake	**Latitude**	**Longitude**	**Water Depth (m)**	**Landmarks (**latitudinal**)**
Otisco	42 51 24	76 16 37	20	South of Bay Shores
Skaneateles	42 53 33	76 24 08	35	Thornton Grove
Owasco	42 51 48	76 31 21	35	Burtis Point
Cayuga	42 32 50	76 34 01	65	Between Myers & Taughannock Points
Seneca	42 43 07	76 56 14	130	Sampson State Park
Keuka	42 25 58	77 11 00	45	Silvernail Road
Canandaigua	42 41 50	77 21 11	60	Just south of Long Point
Honeoye	42 45 05	77 30 42	8	California Point
Canadice	42 43 01	77 34 01	27	Mid-point of lake
Hemlock	42 42 26	77 35 37	27	3.8 km from south end of lake
Conesus	42 45 00	77 43 05	16	Cotton Wood Point

Analyses

Radioisotopes

Selected core segments were analyzed for radioisotopes (including ^{137}Cs, ^{210}Pb, ^{214}Bi, and ^{226}Ra) in an effort to establish time chronologies within the given core.

Samples were dried in a hood under a heat lamp and ground in a mortar with a pestle. Sub-samples were transferred to plastic vials and sealed for at least twenty days to allow the short-lived daughters of ^{226}Ra to grow into equilibrium. The sub-samples were analyzed for ^{137}Cs, total ^{210}Pb ($^{210}Pb_{tot}$), ^{214}Pb, and ^{214}Bi via gamma counting. ^{214}Pb and ^{214}Bi are short-lived daughters of ^{226}Ra (which is also the parent of ^{210}Pb). The mean equilibrium activity of ^{214}Pb and ^{214}Bi is equal to the supported ^{210}Pb ($^{210}Pb_{sup}$), the portion of $^{210}Pb_{tot}$ "supported" by the decay of ^{226}Ra in the sediments. Subtraction of $^{210}Pb_{sup}$ from $^{210}Pb_{tot}$ yields excess ^{210}Pb ($^{210}Pb_{xs}$) which was derived from the atmosphere and decays away in the sediments with a half life of 22 years. ^{137}Cs activities are reported in units of picocuries per kilogram (pCi/kg) while ^{210}Pb activities are given in decays per minute per gram (dpm/g). Dividing dpm/g by .00222 yields pCi/kg.

Radionuclide measurements were carried out using a gamma counter with an intrinsic germanium detector. Blank corrections were applied to each sample based on the analysis of empty sample containers. Background corrections were applied to each radionuclide based on the sample count rate at energies just above and just below each peak of interest. For ^{137}Cs, detector efficiency was calibrated using an NBS sediment standard (River sediment NBS 4350B), a liquid NBS standard (NBS 4953-C) that was used to prepare spiked sediments (G-standards), and secondary standards (D-standards) prepared at the Lamont-Doherty Earth Observatory and calibrated to NBS standards.

No major problems were encountered with the gamma counter: it remained stable during the entire period of counting.

Organic Chemicals

The suit of organic analytes measured during this study is shown in Table 8.2. These substances are termed organochlorines due to their composition (carbon and chloride molecules). All of these substances are currently either banned or restricted for usage within the United States. Thus, occurrence of these substances in the environment is likely the result of historical use and/or improper disposal. Unfortunately, from an environmental perspective, many of these substances are quite stable in aquatic environments and susceptible to biotic uptake and bioaccumulation. Thus, a number of these substances can remain in the environment for long periods of time and can increase in concentration within biota.

The analytical method used for organic analyses was EPA method 608/8080 [Organochloride Pesticides/PCB's (Dual column GC/ECD)]. Sediment samples were homogenized and a 5-10 gram aliquot was used for analysis. The aliquots were Soxhlet extracted for 16 hours using acetone/hexane (1:1). After extraction, the extracts were treated with anhydrous sodium sulfate and given further cleanup with gel permeation chromatography and Florisil. The analyses were performed using a 5890 Hewlett Packard gas chromatograph with a 60 meter DB-5 capillary column (J&W scientific), I.D. - 0.25 mm with a film thickness of 0.1 micron, using a Nickel 63 electron capture detector. The carrier gas was helium (0.8 mL/min) with nitrogen as the auxiliary gas (60 mL/min). The initial temperature of 90 degrees C was held for one minute, programmed to 150 degrees C at 25 degrees C per minute and held for 4 minutes, then programmed to 290 degrees C at 1.5 degrees C per minute. The final temperature was held for 40 minutes. Samples were also analyzed for total organic carbon using the Walkley-Black titration procedure.

Table 8.2: Organic analytes and usage (mostly historical).

Analyte	**Description**
HCH, alpha	Breakdown product of HCH, gamma
HCH, gamma	Hexachloro Cyclo Hexane; Insecticide - common name is lindane.
HCH, Beta	Breakdown product of HCH, gamma
HCH, Delta	Breakdown product of HCH, gamma
Heptachlor	Insecticide, restricted to underground termite control.
Heptachlor Epoxide	Formed by chemical and biological transformation of heptachlor.
Endosulfan I	Insecticide
Endosulfan II	Insecticide
Endosulfan Sulfate	Breakdown product of endosulfan
Aldrin	Insecticide
Dieldrin	Insecticide
Endrin	Insecticide
Endrin Aldehyde	Metabolite of endrin.
* 4,4'-DDT	Dichloro Diphenyl Trichloro Ethane; Insecticide
* 4,4'-DDE	Dichloro Diphenyl Dichloro Ethylene; breakdown product of DDT.
* 4,4'-DDD	Dichloro Diphenyl Dichloro Ethane; Insecticide
Methoxychlor	Insecticide
Toxaphene	Insecticide
Chlordane	Insecticide
Mirex	Insecticide and fire retardant.
* Total PCBs	
PCB Aroclor 1221	Hydraulics, plasticizers, adhesives, and electrical capacitors.
PCB Aroclor 1016/1242	Electrical capacitors and transformers, vacuum pumps, and gas-transmission turbines, heat transfer fluid, hydraulic fluids, rubber plasticizer, carbonless paper, adhesives and wax extenders.
PCB Aroclor 1248	Hydraulic fluids, vacuum pumps, plasticizers, synthetic resins, & adhesives.
PCB Aroclor 1254	Hydraulic fluid, rubber plasticizers, synthetic resins, adhesives, wax extenders, de-dusting agents, inks, cutting oils, pesticide extenders, sealants and caulking compounds.
PCB Aroclor 1260	Electrical transformers, hydraulic fluids, plasticizer, synthetic resins and de-dusting agents.

* Findings are presented below for these compounds

Inorganic Chemicals

Inorganic analytes are shown in Table 8.3. Analytical methods for inorganic analysis are: (1) SW-846 ICP method 6010 for total metals; (2) method 7740 for selenium; and (3) method 7470 for mercury.

The sediments are initially digested using SW-846 method 3050B. A representative aliquot of sample is weighed into a beaker and digested using nitric acid and hydrogen peroxide on a standard hot plate. Hydrochloric acid is used as a final reflux acid for ICP analyses. Nitric Acid is used as the final reflux acid for Graphite Furnace analyses. The samples are then analyzed by ICP-AES or Graphite Furnace Atomic Absorption (GFAA). The metals are analyzed on a Perkin Elmer Optima 3000XL Axial ICP using the internal standard, Yttrium, to help stabilize the "plasma environment". This axial ICP allows for much lower detection limits than the standard radial ICP, but the Linear Range is sacrificed to obtain lower level detection limits. Metals that do not need low detection limits and are known to have high concentrations, such as the Alkaline Earth metals (Ca, K, Na, and K) are analyzed on a Leeman PS3000 radial ICP. Any low level metals such as As, Se, Pb and Tl that do not fall within SW-846 6010B criteria, can also be analyzed by GFAA - performed on a Perkin Elmer 4100ZL. This furnace has a Zeeman Background Correction that is used to help overcome difficult matrix interference. The sediments are also digested and analyzed for Mercury using Cold Vapor Atomic Absorption (CVAA) using method 7471. A Perkin Elmer FIMS analyzer was used to determine Hg concentrations in the sediment samples.

Table 8.3: Inorganic analytes and potential sources

Analyte	Symbol	Comments and Possible Sources
Aluminum	Al	Possible sources include geology and mining
Antimony	Sb	
*Arsenic	As	Possible sources include geology and pesticides
Barium	Ba	
Beryllium	Be	
*Cadmium	Cd	Possible sources include metal plating, etc.
*Calcium	Ca	Possible sources include geology and agriculture
*Chromium	Cr	Possible sources include metals plating, wood preservation, etc.
Cobalt	Co	
*Copper	Cu	Possible sources include geology and plumbing
Iron	Fe	Possible sources include geology, mining, and plumbing
*Lead	Pb	Possible sources include leaded gasoline and paint
Magnesium	Mg	
*Manganese	Mn	Possible sources include geology and the production of steel and batteries
*Mercury	Hg	Possible sources include fossil fuels and incinerators
Molybdenum	Mo	
*Nickel	Ni	Possible sources include metal plating, etc.
Potassium	K	
Selenium	Se	
Silver	Ag	
Sodium	Na	Possible sources include geology and mining
Strontium	Sr	
Thallium	Ti	
Tin	Sn	
Titanium	Ti	
Vanadium	V	
*Zinc	Zn	Possible sources include metal plating, etc.

* Findings presented below for these elements

Chapter 9: Results and Findings

Results of the Sediment Core Study are divided into the following four sections: (1) Conventional and Descriptive Findings; (2) Radiometric Dating and Sediment Accumulation Rates; (3) Organic Chemical Findings; and (4) Inorganic Chemical Findings.

Interpretation of study results will consist of the following: (a) spatial comparison between the 11 Finger Lakes; (b) temporal comparisons of chemical patterns within 9 of the 11 lakes – unfortunately, sediment chronologies could not be constructed for Cayuga Lake and Hemlock Lake due to inadequate radioisotope profiles; and (c) comparison of sediment core findings to pertinent sediment quality guidance values and discussion of issues of concern.

As was mentioned earlier, the Finger Lakes offer an excellent opportunity for *spatial* comparisons between similar lake systems. The discussion of results will focus on similarities and dissimilarities in chemical patterns between the various lakes. In certain instances, spatial comparisons between adjacent lake systems can provide important clues regarding the origin(s) of chemical constituents. Such a study can help to delineate whether a contaminant problem is originating within a lake watershed (e.g., local hazardous waste site) or from outside the watershed (e.g., atmospheric deposition). For example, if two adjacent lakes indicate a similar chemical profile it is likely that the source is regional, whereas, if only one of the lakes exhibit the pattern the source is more likely local in nature. Other factors that should be considered in such spatial comparisons include physical (morphology, runoff patterns, etc.) chemical (chemical dynamics), and biological (trophic state, food web, etc.) characteristics of the lake systems.

Temporal comparisons of chemical patterns will be based upon chemical chronologies as recorded in the vertical sediment cores. An intact sediment profile can serve a number of purposes in this regard. *First*, the core profile can provide a historical perspective on chemical trends within the lake. Several scenarios are possible, including: (a) chemical levels could decrease with depth (higher concentrations in upper sediments), indicating an increase in chemical inputs to the system over time, or, alternatively, a reduction in sediment loading and static levels of chemical input; (b) chemical levels could increase with depth (higher concentrations in the deeper sediments), indicating a decrease in chemical input to the system over time, or, alternatively, increases in sediment loading and static chemical input; or (c) chemical levels could remain constant with depth, indicating stable chemical input to the system over time. *Second*, while the entire core is of interest with respect to determining chemical trends over time, the upper segments of the core are of particular interest for the following reasons: (a) *chemical availability*: the upper sediment layers are more readily available to resident biota, and available for exchange with the overlying water column; and (b*) current load*: the upper sediment layers provide a picture of current chemical input to the lake and/or watershed. *Third*, sediment core chemical profiles also provide a comparison to chemical uptake information as recorded in biotic indices (e.g., fish flesh date). Thus, the temporal history of chemical inputs as recorded in the sediment profiles can be compared to temporal trends in fish flesh data for those chemicals routinely monitored in sport fish.

The final task to be addressed in the discussion will be to compare observed chemical levels to applicable sediment quality assessment values. At the present time, there are several sets of sediment quality assessment values available for use in freshwater systems. Selection of appropriate assessment values depends upon the intended purpose (e.g., protection of benthic organisms, bioaccumulation and protection of human health, etc.). Once again, greater scrutiny will be placed on upper sediment layers due to their availability to resident biota and possible exchange with overlying water column, as well as their reflection of recent contaminant patterns within the lake and watershed. Specific assessment values will be presented and discussed within the discussion of organic and inorganic findings below.

a. Conventional and Descriptive Findings

The Finger Lakes sediment cores ranged in length from 45 - 77 cm in length (see Table 9.1), indicating good penetration of bottom sediments. There were no instances of core over-penetration (core being pushed beyond the top of the coring devise).

In general, the upper layers of the sediment cores were brown in color and had relatively high water content, while the lower layers of the cores appeared dark gray to black and exhibited lower water content. The color differences could be due to differences in reduction/oxygenation (redox) conditions between the upper and lower sediment layers. At the time of core collection it is likely that the hypolimnion of all of the lakes, with the exception of Otisco Lake, were oxygenated. Thus, pore water within the upper layers of most of the cores would likely be oxygenated, at least to some degree, due to oxygen exchange with the overlying water. In contrast, the lower sediment layers are uniformly deprived of oxygen due to isolation from an available source of oxygen.

Table 9.1: General characteristics of individual cores

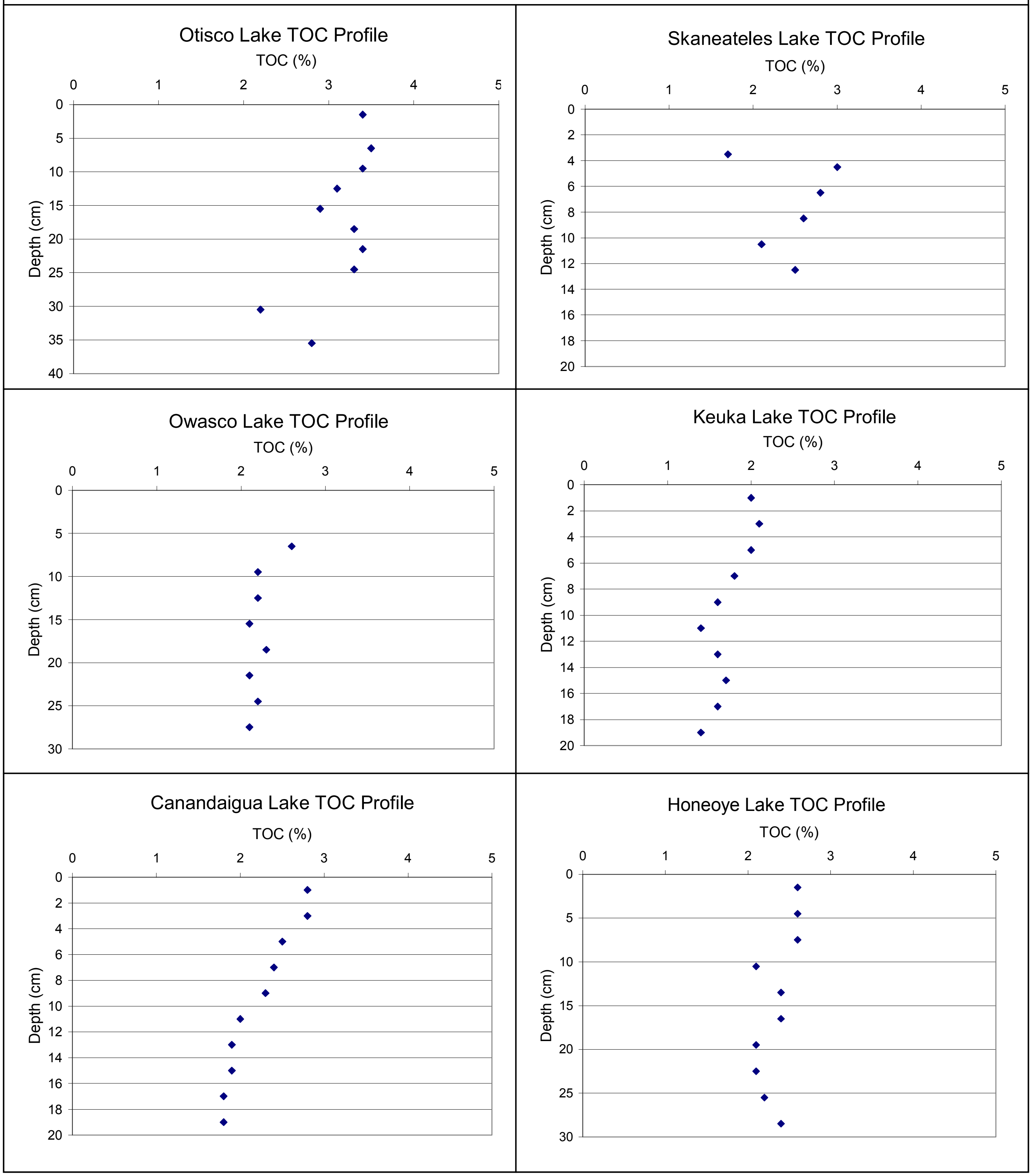
Lake	Length (cm)	Physical Description
Conesus	77	*surface* layers - brown & watery, *deep* layers - black & less water
Hemlock	60	*surface* layers - brown & gray, *deep* layers - black & gray
Canadice	45	*surface* layers - brown, *deep* layers - dark gray to black
Honeoye	62	*surface* layers - brown and gray, *deep* layers - dark gray
Canandaigua	66	*surface* layers - brown, *deep* layers - dark gray to black
Keuka	na	*surface* layers - brown to gray, *deep* layers - dark gray to black
Seneca	69	*surface* layers - brown, *deep* layers - dark gray to black
Cayuga	51	*surface* layers - gray, *deep* layers - dark gray to black
Owasco	61	*surface* layers – brown, *deep* layers - gray
Skaneateles	73	*surface* layers – brown, *deep* layers - gray
Otisco	68	*surface* layers – brown, *deep* layers - gray

Lake sediments are composed of both organic and inorganic materials. The relative percentage of these constituents is indicative of conditions within the lake and it's surrounding watershed. Total organic carbon (TOC) is a common measure used to characterize the benthic sediments of a lake. Organic carbon is composed of plant and animal materials either generated within the lake (autochthonous) or brought to the lake via it's tributary system (allochthonous). In general, sediment TOC levels are expected to parallel the productivity level of the lake – more productive lakes show higher TOC levels while less productive lakes exhibit lower TOC levels.

TOC profiles for 8 of the 11 Finger Lakes are presented in Figures 9.1 and 9.2. As discussed, sediment cores collected from Cayuga and Hemlock Lakes were insufficient for establishing sediment chronologies and are not included. In addition, the Seneca Lake core was not analysed for TOC due to a study oversight.

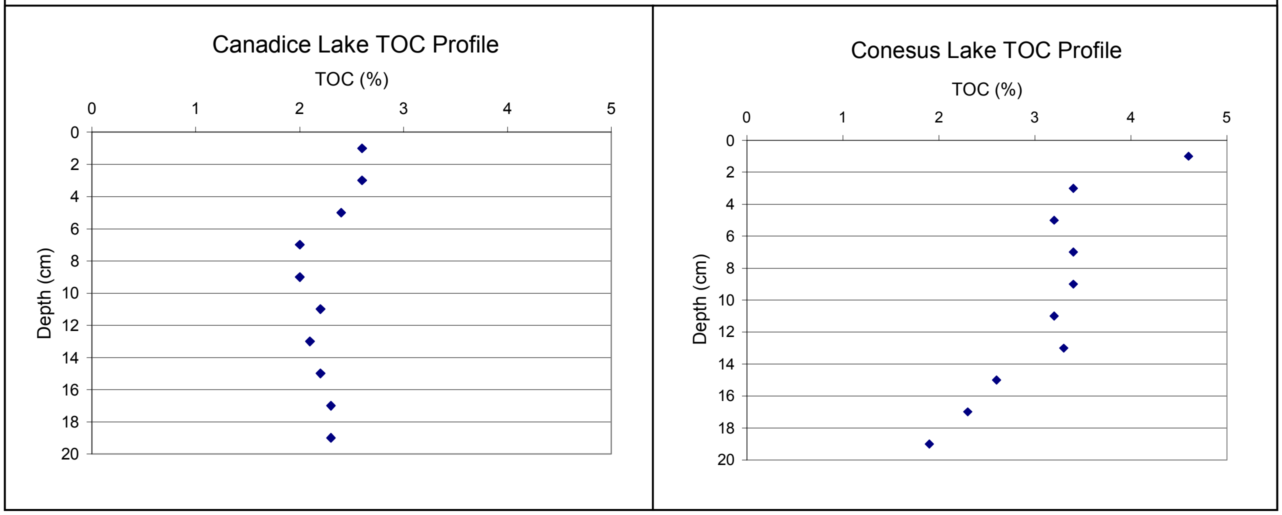
In general, results are reasonably consistent with the premise that benthic TOC levels parallel lake productivity. For example, TOC levels are higher in the Otisco Lake than in Owasco Lake (see Figure 9.1), which is consistent with findings presented above concerning the relative productivity of the two systems. Similarly, TOC levels in upper sediment layers of Conesus Lake are higher than in Canadice Lake (see Figure 9.2), which is again consistent with water quality findings presented above. However, there are some apparent exceptions. For instance, upper layers of Canandaigua and Canadice Lakes show higher TOC levels than would be expected given their productivity levels.

Figure 9.1: Sediment core TOC profiles for 6 of the Finger Lakes (note scale differences)



By contrast, Honeoye Lake, which is relatively productive, showed somewhat lower TOC levels than might have been expected. Findings for Honeoye Lake might be the result of: (a) relatively short retension time of Honeoye Lake, which may limit accumulation of organic matter; and (b) relatively shallow depths and limited stratification – which may keep finer materials in suspension for longer periods.

Figure 9.2: Sediment core TOC profiles for 2 additional Finger Lakes



Temporal trends in TOC levels, as reflected in vertical sediment profiles, can offer some indication of changes in organic loading to a lake over time. However, it is also possible that "apparent" changes are the result of analytical variability. Several of the lake cores indicate an increase in TOC levels beginning in the late 1930s or early 1940s. For example, Canandaigua Lake (Figure 9.1) shows an initial increase in TOC levels beginning at 13.5 cm (circa 1933), and Skaneateles Lake (Figure 9.1) shows an initial increase beginning at 10.5 cm (circa 1944). These observations are consistent with increases in population and development within the watersheds during this time period. In the case of Conesus Lake, TOC levels increase between 19 cm (circa 1950) and 13 cm (circa 1965). However, because we have no record below 19 cm the increase may have begun prior to this point in time. Sediment cores from two of the lakes, Owasco and Keuka Lakes, indicate a more recent increase in TOC levels. The Owasco Lake core shows an increase in TOC at 9 cm (circa 1972), while the Keuka Lake core shows an increase at 11 cm (circa 1971). These more recent TOC increases seem counterintuitive given the observed changes in productivity occuring over the intervening period – stable for Owasco Lake and decreasing for Keuka Lake. TOC trends at the top of the cores suggest fairly stable conditions for most of the lakes. Exceptions include a significant decrease in the case of Skaneateles Lake and a significant increase in the case of Conesus Lake. The direction of these findings are consistent with limnolological findings discussed above in that productrivity levels in Skaneateles Lake have declined markedly over the past several decades while productivity levels within Conesus Lake have increased substantially over the same period. Once again, however, the TOC findings may be analytical anomalies, and would require confirmation from additional cores.

There are no sediment quality assessment values for total organic carbon, however, organic content can play a role in the derivation of organic contaminant assessment values.

b. Radiometric Dating and Sedimentation Accumulation Rates

Radiometric dating is a method of ascribing dates to discreet segments of a vertical sediment core. The process involves analyzing vertical core segments for specific radioisotopes.

Two of the more common radioisotopes used for dating of relatively recent sediments (100 years of age, or less) are cesium 137 (^{137}Cs) and lead 210 (^{210}Pb). The two isotopes are often used in concert for sediment dating purposes, with date estimates of one isotope acting as confirmation of dates established using the other isotope. For this study, cesium 137 (^{137}Cs) is used as the primary isotope, and lead 210(^{210}Pb) is used as the secondary, or confirmatory radioisotope – see further discussion in box below.

Vertical profiles of ^{137}Cs for each of the Finger Lakes sediment cores are presented in Figure 9.3 (eastern 6 lakes) and Figure 9.4 (western 5 lakes). The ^{137}Cs profiles from all but 2 of the lakes (Cayuga and Hemlock Lakes) were deemed acceptable for dating purposes in that they exhibited ^{137}Cs profiles consistent with known fallout trends resulting from nuclear weapons testing.

For example, the Skaneateles Lake plot (Figure 9.3) shows an increase in ^{137}Cs levels from the surface of the core down to approximately 7 cm (cesium peak). This is followed by a decrease in ^{137}Cs levels thereafter down to virtually zero at a sediment depth of approximately 12.5 cm (cesium horizon). This indicates that Skaneateles Lake sediments located at a depth of 7 cm were deposited at or around the peak in above-ground nuclear weapons testing in 1963, and that sediments at a depth of 12.5 cm were deposited at or around the onset of large-scale nuclear weapons testing in the early 1950s. Similar trends of increasing ^{137}Cs levels to a given depth, followed by decreasing levels thereafter were observed for 7 of the other Finger Lakes (Conesus, Canadice, Canandaigua, Keuka, Seneca, Owasco, and Otisco Lakes), and an acceptable ^{137}Cs horizon was available for an additional lake (Honeoye Lake). Table 9.2 provides a summary of ^{137}Cs markers for the Finger Lakes.

Table 9.2: Depth of ^{137}Cs markers

	^{137}Cesium	
Lake	Peak (cm)	Horizon (cm)
Conesus	13	19.5
Hemlock	na	na
Canadice	5	9
Honeoye	na	19.5
Canandaigua	7	13
Keuka	13	21
Seneca	7	15
Cayuga	na	na
Owasco	12.5	24.5
Skaneateles	6.5	12.5
Otisco	24.5	na

^{137}Cs profiles for Cayuga Lake and Hemlock Lake sediment cores were not sufficient for determination of time chronologies.

In contrast to the "well behaved" cores discussed above, the ^{137}Cs trends in Cayuga Lake (Figure 9.3) and Hemlock Lake (Figure 9.4) do not show a pattern of ^{137}Cs deposition consistent with known fallout patterns. It is possible, that the ^{137}Cs profile for Cayuga Lake is intact but incomplete (^{137}Cs peak is present, but horizon is not present). However, if this is so, than the sedimentation rate within Cayuga Lake is extremely high (approaching 1 cm/year). Fortunately, in the case of Cayuga Lake, previous coring efforts conducted by the United State Geological Society (Yager, 1999) provided acceptable estimates of sedimentation rates and sediment chronology. Unfortunately, no alternative source of data is available for Hemlock Lake.

In summary, reasonable temporal chronologies and sediment accumulation rates (SAR) are available for 10 of the 11 Finger Lakes, and acceptable sediment chronologies are available for 9 of the 11 lakes.

Radiometric Dating (^{137}Cs and ^{210}Pb)

Rainfall and erosion activities within a lake watershed result in the transport of sediments and associated chemicals to a lake. These suspended sediments, or a portion thereof, eventually “rain” down from the water column and reach the lake bottom. If these sediments come to rest in so-called depositional areas of a lake they record the temporal history of chemical inputs to the lake. By extracting and vertically segmenting these sediments (sediment cores) one can document historical chemical patterns within a lake. However, in order to ascribe specific dates to individual core segments one must identify temporal markers that can be used to date the given segment. Temporal markers can include either chemical (e.g., radioisotopes) or biological (e.g., pollen) constituents of the sediments. In this study we used two radioisotopes (^{137}Cs and ^{210}Pb) to date sediment core segments. The methods used to derive sediment dates vary for the two radioisotope markers. Dates associated with ^{137}Cs are premised on temporal markers associated specific historical events, while dates derived from ^{210}Pb are based upon the natural decay of the isotope.

^{137}Cs is a byproduct of nuclear weapons testing. Atmospheric testing of nuclear weapons began in the 1940s, accelerated through the 1950s and early 1960s, and declined thereafter (replaced by below-ground weapons testing). This historical chronology provides two distinct temporal markers associated with ^{137}Cs deposition as follows: (1) ^{137}Cs *horizon*: which refers to the first appearance of ^{137}Cs in the environment – generally considered to represent the early 1950s (e.g., 1952) – resulting from large-scale nuclear weapons testing; and (2) ^{137}Cs *peak*: which refers to the period of maximum above-ground nuclear testing and subsequent ^{137}Cs fallout – generally considered to have occurred in the early 1960s (e.g., 1963) – resulting from “unloading” of weapons stockpiles in advance of a world-wide atmospheric test ban treaty in 1964. Figures 9.5 and 9.6 depict world-wide above-ground nuclear weapons testing and ^{137}Cs fallout in Finland, respectively.

^{210}Pb is a naturally occurring uranium (U) isotope. Major intermediate isotopes in the decay of 238Ur, and their approximate half-lives (years), are as follows:

^{238}U ($4.5\text{x}10^9$) → ^{234}U ($2.5\text{x}10^5$) → ^{230}Th ($7.5\text{x}10^4$) → ^{226}Ra ($1.6\text{x}10^3$) → **^{210}Pb** (22.3) → ^{206}Pb (stable)

The half-life of ^{210}Pb (22.26 years) provides a reference by which to estimate sediment dates within lake sediments. The process involves the following steps: (1) plot $^{210}Pb_{ex}$ concentrations within the vertical sediment core against sediment depth, (2) determine the depth of sediment accumulation which results in a halving of excess ^{210}Pb levels; and (3) divide this value by the half-life of ^{210}Pb.

Figure 9.5: Above ground nuclear weapons testing estimated yield

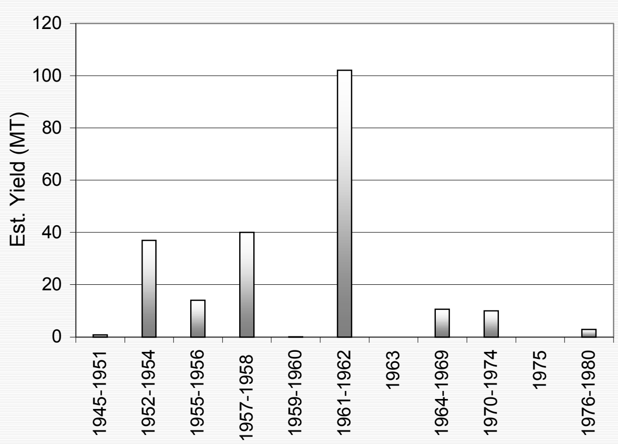


Figure 9.6: Record 137Cs fallout – Finland

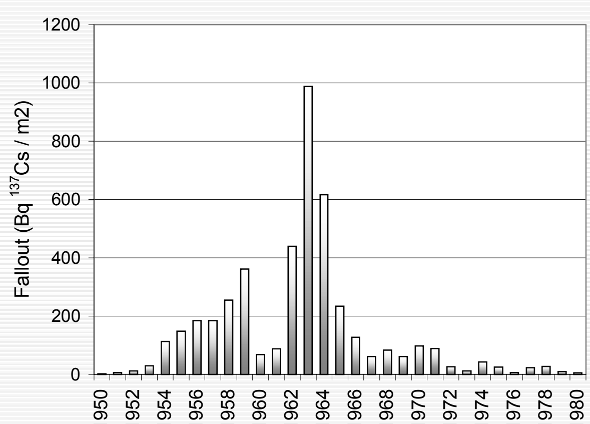


Figure 9.3: Sediment core ^{137}Cesium profiles for 6 eastern lakes (note scale differences)

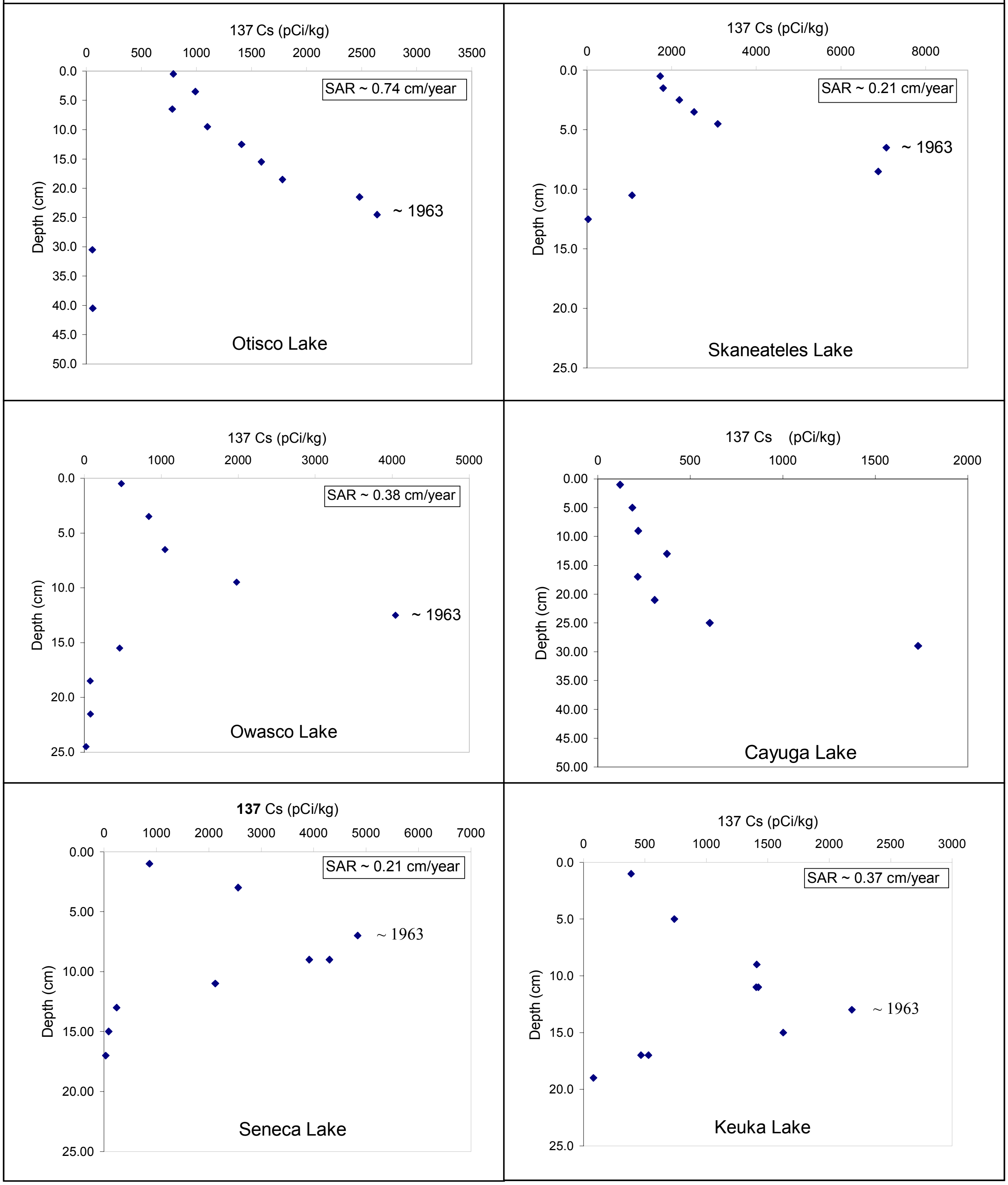
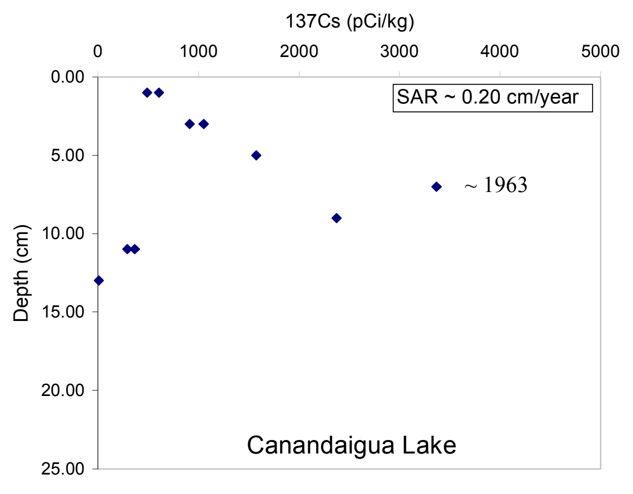
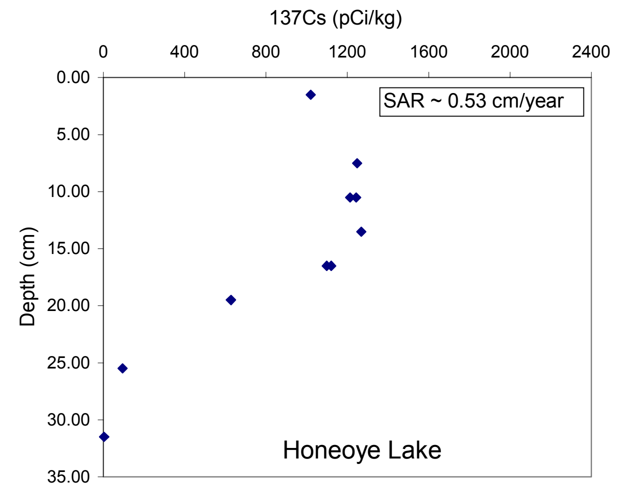
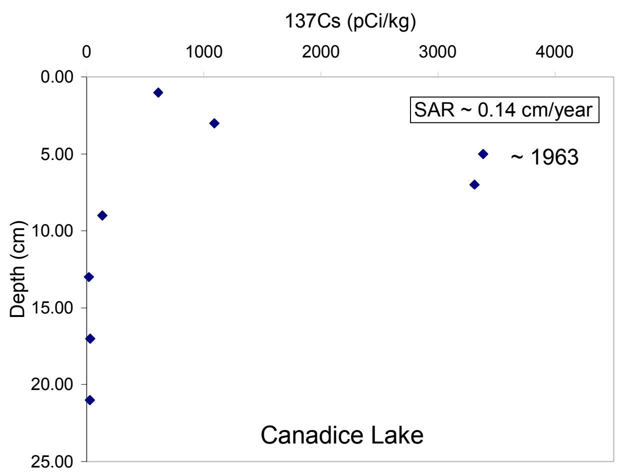
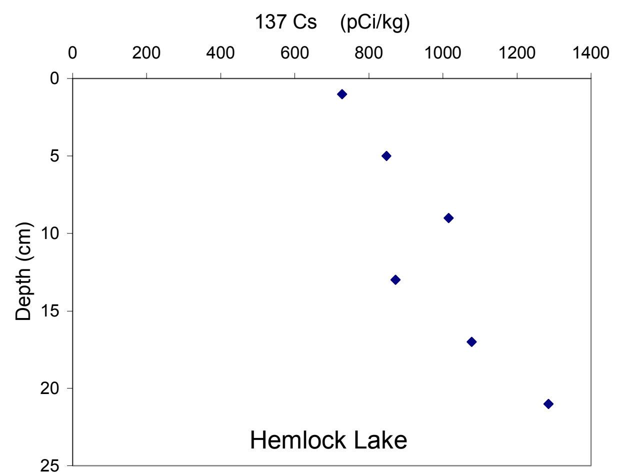


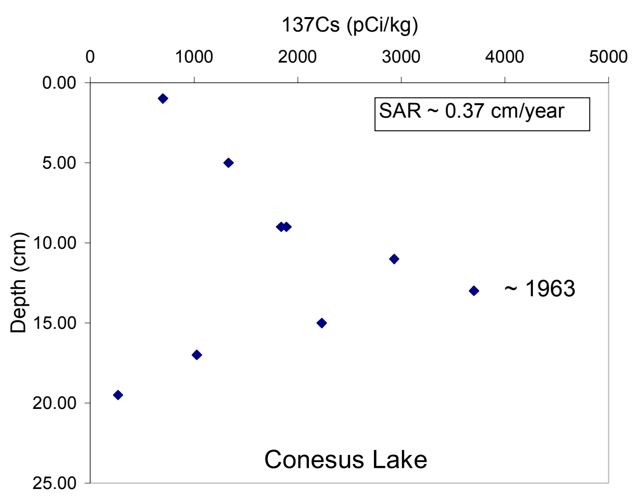
Figure 9.4: Sediment core ^{137}Cesium profiles for 5 western lakes (note scale differences)











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Sediment accumulation rates (SARs) for each of the Finger Lakes, as derived from both ^{137}Cs profiles (both peak and horizon) and ^{210}Pb profiles, are shown in Table 9.3. It is important to keep in mind that the reported SARs are for a single location within each lake, and that some longitudinal variation would be expected – particularly, for the larger (longer) lakes. The SAR shown for Cayuga Lake is based on an average of 6 cores collected by the USGS (Yager, 2001) during the early to mid 1990s. SARs, based upon ^{137}Cs, range from 0.17 cm/year for Canadice Lake to 0.74 cm/year for Otisco Lake. The rates derived by both ^{137}Cs markers (peak and horizon) and ^{210}Pb are reasonably consistent for each lake. The only major exception to this finding was for Otisco Lake, which shows a higher SAR based upon ^{137}Cs than that based on ^{210}Pb. The reason for this disparity is not clear.

Table 9.3: Sediment accumulation rates (cm/year)

Lake	^{137}Cesium		^{210}Lead	Comments
	Peak	Horizon		
Conesus	0.37	0.42	0.41	
Hemlock	na	na	na	No useable data
Canadice	0.17	0.23	0.23	
Honeoye	na	0.53	na	No discernible ^{137}Cs peak
Canandaigua	0.20	0.25	0.3	
Keuka	0.37	0.40	0.45	
Seneca	0.23	0.33	0.32	
Cayuga	0.42	na	na	Based on USGS data (Yager, unpublished)
Owasco	0.38	0.5	0.45	
Skaneateles	0.21	0.28	0.26	
Otisco	0.74	na	0.54	^{137}Cs rate ~ 40 percent higher than ^{210}Pb rate

The sediments within a lake can originate in two principle ways: (1) externally: sediments can be eroded from the lake catchment and delivered via the tributary system to the lake – this typically includes both organic and inorganic sediments; and/or (2) internally: sediments can originate internally via the growth and senescence of plant (phytoplankton and macrophytes) and animal communities – these are strictly organic sediments.

If the sediments of a lake are primarily of internal origin (algal growth and senescence) then the SAR is likely to reflect the long-term trophic state of the lake. The SARs derived for the Finger Lakes are reasonably consistent with trophic state findings presented earlier in that the eutrophic Finger Lakes (e.g., Otisco and Honeoye Lakes) generally exhibit higher SARs than do the oligotrophic Finger Lakes (e.g., Skaneateles and Canandaigua Lakes). These findings are consistent with expectations, in that higher trophic status reflects greater productivity which results in greater particulate material available for deposition. There are, however, some apparent anomalies to this general finding.

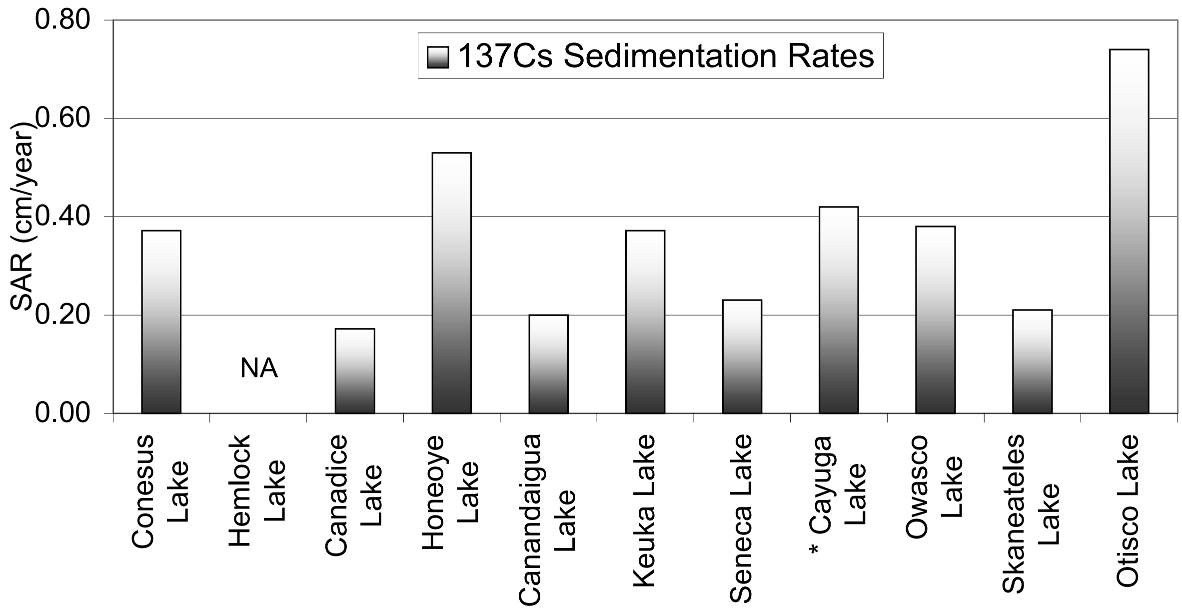
For example, the SAR for Cayuga Lake is slightly greater than that for Conesus Lake, whereas, the current trophic state of Conesus Lake is greater than that of Cayuga Lake. There are several possible explanations for this apparent disparity. First, SARs, by definition, represent an integration of conditions over time, whereas, trophic status is a snapshot in time. You may recall from the earlier discussion of trophic state that the trophic status of Cayuga Lake (main lake) has dropped significantly since the 1970s as reflected in total phosphorus and chlorophyll a levels (see Tables 5.3 and 5.4). Thus, the SAR for Cayuga Lake, or any waterbody, is indicative of long-term conditions, and may be somewhat inconsistent with conditions at any one instant in time. Second, the Cayuga Lake cores used for derivation of SAR were all collected in the southern third of the lake and may be somewhat biased due to conditions in the south end of the lake (e.g., tributary inflow, sewage discharge, etc.) which is considerably more productive than the deeper basin of the lake.

Figure 9.7 provides a graphical comparison of SARs within the Finger Lakes based upon ^{137}Cs findings. The rates presented are best estimates of sediment accumulation rates based on radiometric measures and selected chemical markers.

The SARs presented for Conesus, Canadice, Keuka, Owasco, Skaneateles, and Otisco Lakes are based upon the ^{137}Cs peak observed in each of the cores. The rates presented for both Seneca Lake and Canandaigua Lake are based upon the ^{137}Cs horizon observed in the respective cores. The reason for use of this modified approach for these particular cores stems from observations of specific chemical markers (see discussion of DDT and metabolites below). As with ^{137}Cs, these organic substances have a fairly well defined temporal history that can be used to "fine-tune" the radiometrically derived chronology. Thus, when this sort of additional information is available, one generally takes a "weight of the evidence" approach in interpreting sediment chronology and assessing accumulation rates.

Finally, as discussed earlier, the SAR reported for Cayuga Lake represents an average SAR based upon the ^{137}Cs peaks observed in 6 cores taken by USGS in the early 1990s (Yager, 2001).

Figure 9.7: Estimate of sediment accumulation rates



c. Organic Chemical Findings

The suite of organic chemicals analyzed during this investigation are shown in Table 8.2. Of the approximately 25 substances investigated, only a few were present at detectable levels within the Finger Lakes sediment cores. The substances detected most often include: (1) dichlorodiphenyl-trichloroethane (DDT) and related compounds dichlorodiphenyl-dichloroethylene (DDE) and dichlorodiphenyl-dichloroethane (DDD); and (2) Polychlorinated biphenyl's (PCBs). Both groups of substances are termed organochlorines, and have largely been banned for use in the United States. However, these substances continue to cycle through many aquatic environments due to their persistence and ability to bioaccumulate. As discussed earlier, these are the chemicals responsible for the current fish consumption advisories in Canadice Lake (PCBs), Canandaigua Lake (PCBs), and Keuka Lake (DDT).

As alluded to earlier, several sets of sediment quality assessment values are available for use in freshwater systems. Representative values for organic chemicals at issue within the Finger Lakes are presented in Table 9.4. The values are taken from a compilation of sediment criteria compiled by Smith et al. (1996). The threshold effect level (TEL) implies occasional adverse effects on resident biota, whereas, the probable effect level (PEL) implies frequent adverse effects on biota.

Table 9.4: Sediment guidance criteria for selected organic chemicals

Substance	TEL (ppb)	PEL (ppb)
Total DDT	7	4,450
Total PCBs	34.1	277

TEL: threshold effect level (Smith, et al., 1996)
PEL: probable effect level (Smith, et al., 1996)

DDT and Related Compounds

DDT is a synthetic (human-made) insecticide composed of carbon, hydrogen and chlorine atoms (see further discussion in box below). DDT gained widespread use in the 1940s following World War II. Once heralded as the "savior of mankind" due to its ability to control the insect vectors responsible for the spread of many human diseases, DDT began to fall out of favor in the 1960s as concerns over its efficacy and safety (environmental and human health) came into question. DDT was banned for use in the United States in 1972, however, the compound is still in use in several developing countries (e.g., Mexico).

Findings for DDT and its metabolites are only available for 7 of the 8 western Finger Lakes, as cores from the 3 eastern lakes and Honeoye Lake were not analyzed for these compounds.

Spatial comparisons of the lakes indicate that DDT was detectable in certain segments of all 7 of the lakes evaluated, however, levels varied significantly between lakes (see Table 9.5). From a historical context, Keuka Lake had the highest ΣDDT (DDT + DDD + DDE) level, which occurred in the 12-14 cm sediment increment. The fact that Keuka Lake exhibited the highest DDT levels is not surprising given the standing fish consumption advisory on Keuka Lake. Two of the other Finger Lakes, Seneca and Canandaigua Lakes, also showed relatively high historical ΣDDT levels – note the peak levels of 153 ppb and 219 ppb, respectively. With respect to DDT levels in surface sediments, Keuka Lake again shows the highest ΣDDT levels (72 ppb), followed by Seneca Lake (40 ppb) and Conesus Lake (30 ppb). As noted earlier, it is not possible to discern temporal trends in the Cayuga and Hemlock cores do to apparent mixing within the core sediments, however, both cores exhibited detectable ΣDDT levels – somewhat higher in Hemlock Lake than in Cayuga Lake. It is important to view these findings as composite or aggregate values.

DDT and Related Compounds

DDT was initially synthesized by a German graduate student in 1874. However, more than half a century would pass before the commercial utility of the compound became known. In 1939, a Swiss entomologist named Dr. Paul Muller found that DDT was a potent insecticide. The importance of Muller's discovery is underscored by the fact that he was awarded the Nobel Prize in Medicine in 1948 due to the importance of DDT in the control of several human diseases. Following its initial use to control insect vectors of human diseases (e.g., malaria, typhus, yellow fever, etc.), DDT was eventually used to control a broad array of insect pests (both agricultural and non-agricultural pests). The list of target insects included codling moths (important pest in fruit orchards), spruce bud worms (important pest in silvaculture), and elm bark beetles (vector for Dutch Elm disease).

While of significant importance in the control of both human disease vectors and insect pests in general, environmental and human health concerns relating to DDT began to arise in the late 1940s and 1950s. These concerns would reach a worldwide audience with the release of Silent Spring (Carson, 1962). Use of DDT in the United States peaked in the early 1960s, and declined thereafter for the following reasons: (1) development of resistance in certain target species; (2) concerns regarding its effects on the environment and human health; and (3) introduction of alternative insecticides. DDT use was banned in the United Sates in 1972, however, several countries continue to use the compound.

DDT consists of two phenyl (six carbon hexagon) rings - thus diphenyl - with 2 chlorines attached to the ring structures and 3 additional chlorine molecules attached to the central carbon molecule. The chemical structure of DDT is shown in Figure 9.8. The two principal metabolites (or breakdown products) of DDT are DDE and DDD (Figures 9.9 and 9.10, respectively). DDD was actually marketed separately as an insecticide, while DDE has never been marketed commercially and is only found as a by-product of DDT breakdown. While DDT and its metabolites can be degraded within the environment, the rate of degradation is quite slow.

As with other organochlorine compounds, DDT has a strong affinity for organic material and will accumulate within lipid (fat) deposits of living organisms. This propensity for DDT and related compounds to concentrate within biota is termed bioaccumulation. This process, coupled with the compound's persistence within the environment, has led to significant environmental problems. The most widely heralded being the precipitous decline in predatory bird populations (e.g., Bald eagles) in North America due to eggshell thinning and embryo deaths.

DDT and its metabolites have been shown to cause chronic adverse health effects on the liver, kidneys, nervous system, immune system, and reproductive system in experimental animals. In addition, the USEPA considers these compounds to be suspected human carcinogens. Fish consumption advisories (e.g., Keuka Lake) are based upon a United States Food and Drug Administration (FDA) limit of 5 ppm.

Figure 9.8: Structure of DDT
Chlorine molecule (green)

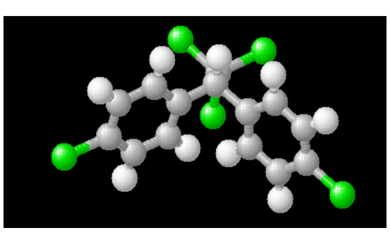


Figure 9.9: Structure of DDE
Carbon molecule (gray)

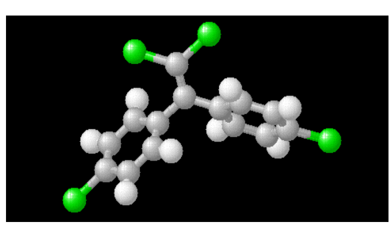
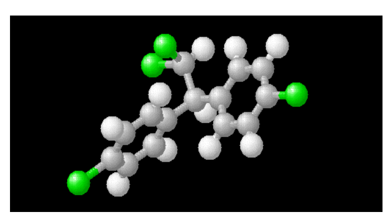


Figure 9.10: Structure of DDD
Hydrogen molecule (white)

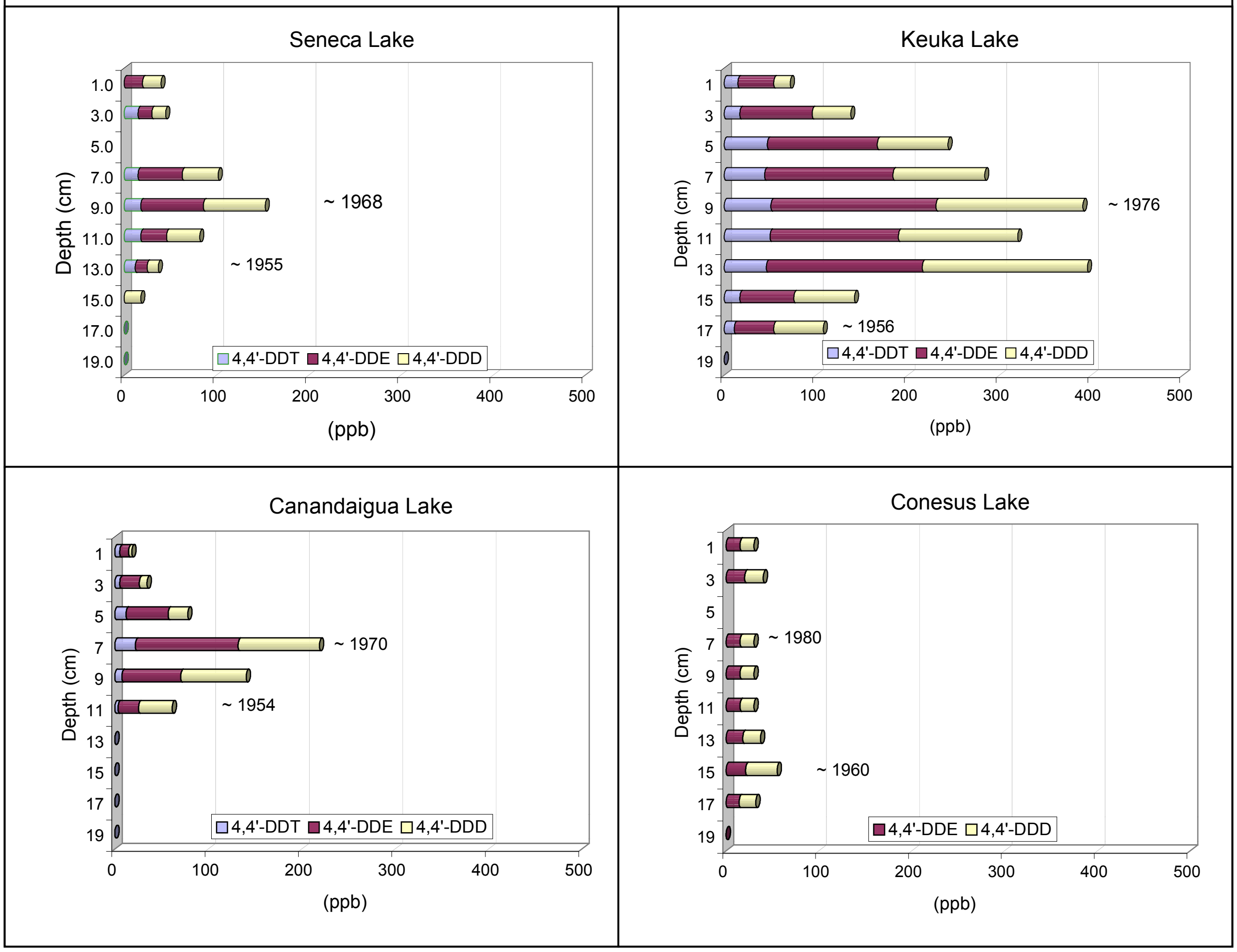


Figures from: http:www.atsdr.cdc.gov

Table 9.5: Finger Lakes sediment cores Σ DDT summary			
Lake	*Peak Σ DDT (ppb)*	*Surface Σ DDT (ppb)*	*Comments*
Cayuga	30 – depth na	na	no temporal significance
Seneca	153 @ 8-10 cm	40	second highest surface level
Keuka	396 @ 12-14 cm	72	DDT-based fish consumption advisory
Canandaigua	219 @ 6-8 cm	18.2	Second highest peak level
Honeoye	na	na	
Canadice	65 @ 6-8 cm	5.6	
Hemlock	54 – depth na	na	no temporal significance
Conesus	55 @ 14-16 cm	30	
TEL: 7 ppb PEL: 4,450 ppb			

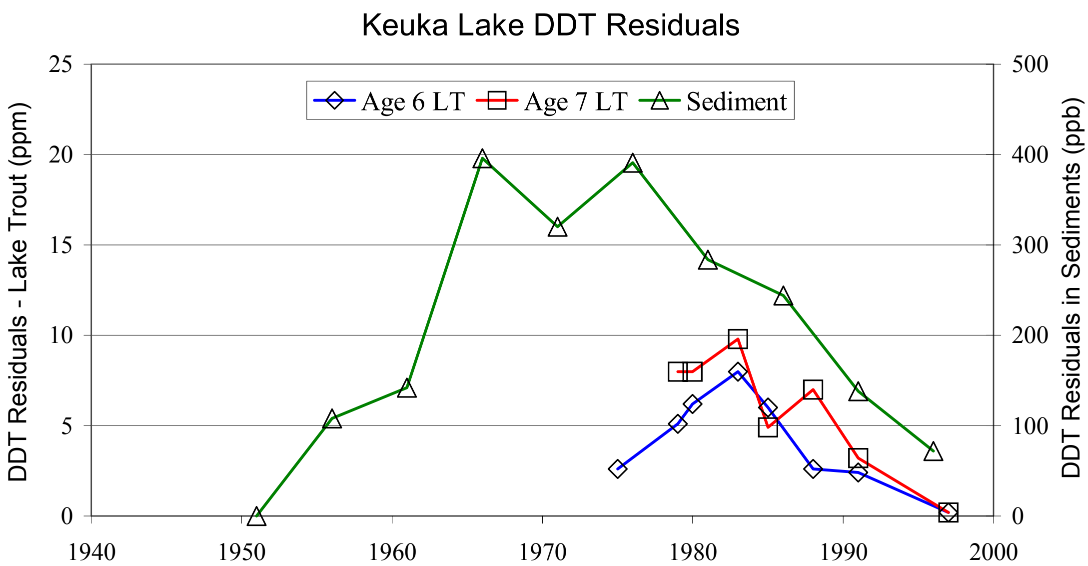
In general, DDT levels within the western 7 lakes are declining in both the sediments and biota. Temporal profiles of DDT, DDE, and DDD from sediment cores taken in 4 of the Finger Lakes are presented in Figure 9.11. Trends indicate that DDT and its metabolites have been declining over the past several decades within the study lakes. For example, ΣDDT levels in Keuka Lake sediments have declined by more than 5 fold from nearly 400 ppb in the mid 1970s to approximately 70 ppb in the mid 1990s. Steep declines are also apparent in both Seneca Lake (~ 4 fold decline over 30 years) and Canandaigua Lake (~ 12 fold decline over 30 years). The temporal pattern observed in Conesus Lake is somewhat different than the other three lakes. For instance, Conesus Lake does not show the marked decline in ΣDDT levels exhibited by the other 3 lakes. On the other hand, historical ΣDDT levels in the sediments of Conesus Lake are considerably less than in the other 3 lakes. Another temporal difference relates to the date of the observed peak in ΣDDT levels. For the 3 larger lakes, the peak in ΣDDT levels coincides with the late 1960s and early 1970s, whereas the peak for Conesus Lake is somewhat earlier (~ 1960). One additional difference relates to the relative proportions of DDT and it principal metabolites DDE and DDD. The 3 larger lakes exhibited detectable levels of the parent compound in most of the core segments, while Conesus Lake only contained detectable levels of the metabolites. While this pattern difference might be explained by the relatively low concentrations of ΣDDT found in Conesus Lake, an alternative explanation is that it might reflect the relative age of the DDT signal. A common approach used to estimate the “age” of a DDT source is to compare the relative ratios of the parent compound (DDT) to its metabolites (DDE and DDD). Obviously, the absence of a detectable DDT signal in the Conesus Lake core, would indicate an enrichment of the metabolites relative to the parent compound. Thus, it is conceivable that the original source of DDT contamination within Conesus Lake is somewhat older than in the other lakes. This is consistent with the observation that the peak in ΣDDT within Conesus Lake is approximately 10 years earlier than in the other 3 lakes. However, this raises the question of why the levels of ΣDDT in Conesus Lake sediments have not declined significantly within recent years. Plausible explanations for the observed plateau in ΣDDT levels within Conesus Lake include: (1) possible use of DDD within the watershed - DDD was used independently as an insecticide in the US for several years following the ban on DDT; (2) more effective ecosystem recycling of DDT and it’s metabolites – Conesus Lake is substantially shallower than the other three Finger Lakes and may be more susceptible to resuspension events; (3) ongoing release of metabolites within the watershed.

Figure 9.11: Sediment core profiles of DDT, DDE, and DDD for selected Finger Lakes



Fish flesh analyses have been conducted on sport fish taken from the Finger Lakes for several decades. This data is the basis for the fish consumption advisories currently in place for several of the Finger Lakes and other water bodies within New York State. As with the sediment profiles, DDT trends in fish within the Finger Lakes have also been decreasing (see Figure 9.12). For example, lake trout (ages 6 & 8 years) from Keuka Lake have shown a 30-40 fold reduction in ΣDDT level over the past decade and a half. The US Food and Drug action level for DDT in fish flesh is 5 ppm, and the most recent data indicate that Lake trout from all age ranges are below this level. It is also interesting to compare the pattern of reduction between the sediments and the fish. There is a noticeable delay between the peak in sediment concentrations and the peak in fish concentrations (see Figure 9.12). This is consistent with expectations in that fish accumulate these compounds over time and reflect environmental conditions in aggregate, while specific sediment core segments represent conditions at a discreet instance in time. Fish flesh data for the other Finger Lakes are less extensive than for Keuka Lake, however, the general trend is toward decreasing levels of DDT contamination.

Figure 9.12: Comparison of ΣDDT levels in fish flesh and sediments from Keuka Lake.



Beginning in 1996, the NYSDEC Division of Fish, Wildlife and Marine Resources initiated an investigation within the Keuka Lake watershed in an effort to track down the source(s) of DDT (and related compounds) to the lake (Spodaryk, et al., 2000). The investigation involved the deployment of passive in-situ chemical extraction samplers (PISCES) on various tributaries within the watershed. Findings indicated elevated ΣDDT levels in Tributary 64, which enters Keuka Lake near Bluff Point. The probable source of the DDT to Tributary 64 was determined to be an old disposal area just upstream from Central Avenue in Keuka Park. Track down efforts were concluded in 1999, due to the continuing decline in ΣDDT levels recorded in Keuka Lake biota.

Sediment quality assessment values for ΣDDT are listed in Table 9.4. Once again, the primary focus of this discussion will be on surficial sediments due to biological availability considerations. Surficial sediment ΣDDT levels in 4 of the 5 Finger Lakes with available DDT data are above the TEL guidance level of 7 ppb. Canadice Lake was the only one of these lakes that had surficial sediment levels below the TEL. It is not possible to determine the surficial ΣDDT levels in Cayuga and Hemlock Lakes – due to apparent disturbance of these sediments. None of the Finger Lakes sediment cores showed ΣDDT levels above the PEL of 4,450 ppb. It should be noted, however, that the PEL was not even exceeded within the Keuka Lake sediment core (at any depth), which has had a fish consumption advisory for a number of years due to DDT levels within certain fish species. Thus, failure to exceed the existing PEL should not be interpreted as precluding fish tainting. Peak historical ΣDDT levels observed in Keuka, Canandaigua, and Seneca Lakes warrant consideration should dredging activities within near shore areas be considered in the future, or if unusually large hydrologic events occur. Such activities could conceivably disturb and remobilize these DDT-laden sediments.

PCBs – Arochlors and Congeners

As with DDT and its metabolites, PCBs are a class of man-made organic compounds composed of carbon, hydrogen and chlorine atoms (see further discussion in box below). Originally introduced for industrial use in 1929, US production of PCBs reached a peak of 85 million pounds in 1970 (HHS, 1993). PCBs were used for a wide variety of industrial applications ranging from electrical transformers to carbon-less copy paper. The use of PCBs within the United States has been greatly curtailed over the past several decades.

PCBs tend to bioaccumulate due to their environmental persistence and lipophilic/hydrophobic nature. The property of persistence allows PCBs to circulate for extended periods within the environment, while the properties of lipophilicity and hydrophobicity facilitate the molecule's association with organic and particulate matter, respectively.

PCB analyses can involve quantification of either Aroclors (commercial product composed of specific congeners) or individual congeners. Figure 9.13 provides a visual illustration of a number of the major Aroclor formulations. Given the analytical costs associated with the two methods (congener method is significantly more expensive than Aroclor method), most of the analyses from this study focused upon Aroclors. Aroclor analyses were conducted on approximately 8-10 core segments from each sediment core from the western eight lakes, while congener analyses were run on only one segment from each of the Finger Lakes cores.

As it turns out, most of the Aroclor analyses conducted during this investigation were below detection. Only one sediment core segment, Canadice Lake (2-4 cm), showed reportable Aroclor levels (Aroclor 1260 at 67 ppb). On the other hand, all sediment cores for which congener analyses were conducted showed reportable levels of congeners. Total congener values for these sediment cores are included in Table 9.6. The table includes both actual totals and adjusted totals (total congeners minus p,p'DDE + IUPAC-85, which co-elute on the chromatogram). As can be seen in Table 9.6, this adjustment is important for several of the Finger Lakes (Keuka and Seneca Lakes). This is consistent with findings discussed above concerning past DDT contamination in these lakes. PCB levels were highest in Conesus, Canadice, Seneca, and Owasco Lakes. Keuka, Otisco, and Skaneateles Lakes fall into an intermediate category, and Honeoye Lake showed the lowest PCB levels. It is important to note that the reference timeframes differ among the lakes, ranging from the early 1970s to the early 1990s. Total congener levels found in the Cayuga Lake core segment were also quite low, however, the Cayuga core segment must be viewed as a composite, rather than a discrete moment in time, due to the failure to establish an intact cesium profile.

Table 9.6: Total congeners for Finger Lakes core segments

Lake	*Approximate Date*	*Σ Congeners (ppb)*	**Adjusted Congeners (ppb)*
Conesus Lake	1985	490	481
Hemlock Lake	na**	67	62
Canadice Lake	1973	352	342
Honeoye Lake	1990	69	65
Canandaigua Lake	na	na	na
Keuka Lake	1986	449	289
Seneca Lake	1978	466	408
Cayuga Lake	na**	76	74
Owasco Lake	1987	374	370
Skaneateles Lake	1984	286	278
Otisco Lake	1991	245	243

*: Total congeners minus IUPAC-85 and DDE
**: not appropriate due to failure of radiometric dating

PCBs

PCBs (see Figure 9.14) were originally synthesized in the late 1800s, but were not used commercially until the late 1920s. The Monsanto Company was the sole manufacturer of PCBs in the US (CEC, 1996). From an industrial perspective, PCBs offer a number of attractive properties. The properties of greatest value to industry include low conductivity (good insulator), flame retardant, and chemical stability. PCBs were used in products ranging from electrical transformers to carbon-less copy paper. The total quantity of PCBs produced in the US between 1929 and 1977 is estimated at 1.4 billion pounds (635 million kilograms) (CEC, 1996) – see Figure 9.15. Electrical transformers and capacitors accounted for 61 percent of PCB use prior to 1971, and 100 percent of PCB use from 1971-1979 (NAS, 1979).

PCBs are composed of two benzene rings and from 1-12 chlorine atoms (see Figure 9.14). Such a structure affords up to 209 possible permutations, which are termed *congeners*. Commercial PCB formulations have specific mixtures of congeners. The commercial mixtures used within the US have the trade name of *Aroclors*. Seven Aroclor formulations (1016, 1221, 1232, 1242, 1248, 1254, and 1260) account for 98 percent of the PCBs sold in the US since 1970. Aroclor numbers (except 1016) can be interpreted as follows: first 2 digits refer to the number of carbon atoms present (two benzene rings contain 12 carbon atoms), while the later 2 digits is the approximate weight percentage of chlorine (i.e., Aroclor 1242 is approximately 42 percent chlorine). The three Aroclor formulations most often associated with contamination sites are Aroclors 1242, 1254, and 1260 (see Figure 9.13).

PCBs were first recognized as potential environmental contaminants by a Swedish researcher in the mid-1960s. Studies indicated PCB accumulation in several hundred pike collected throughout Sweden, and in one eagle (Jensen, 1966). Since that time, many studies have documented bioaccumulation of PCBs in fish and wildlife throughout the environment. PCBs are known to cause cancer in laboratory animals, and are suspected to cause cancer in humans (USDOH, 1993). Oral exposure, through consumption of contaminated food, is believed to be the major route of PCB exposure in the general population (USDOH, 1993).

PCB regulation began in the US in the mid to late 1970's under the Toxic Substances Control Act. Under current regulation, PCBs are banned from manufacture, import, export, and use except under limited circumstances. PCB-containing products or equipment are regulated based on concentration. The most stringent regulation applies to products with PCB concentrations greater than or equal to 500 ppm - regulations include limited disposal options, and storage, marking, location, and record keeping requirements (CEC, 1996). PCB releases are also regulated by the Clean Air Act, Clean Water Act, Resource Conservation and Recovery Act (RCRA), and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

Figure 9.14: PCB Structure

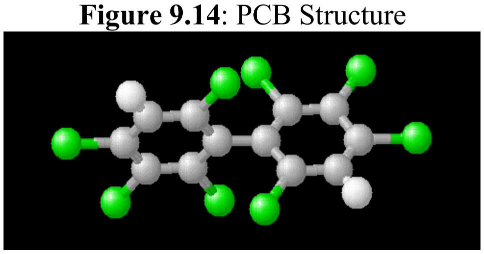


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Figure 9.15: US Domestic PCB Sales (NIOSH, 1975)

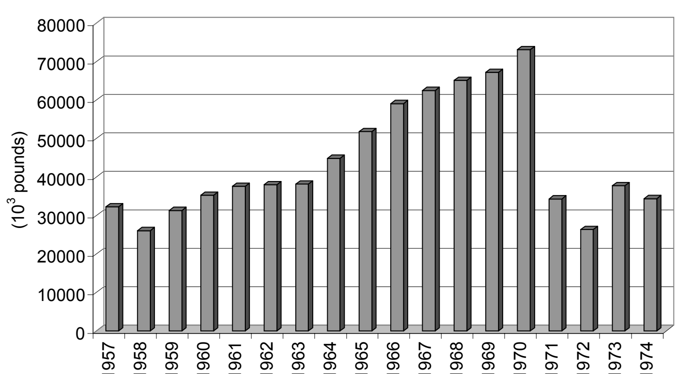
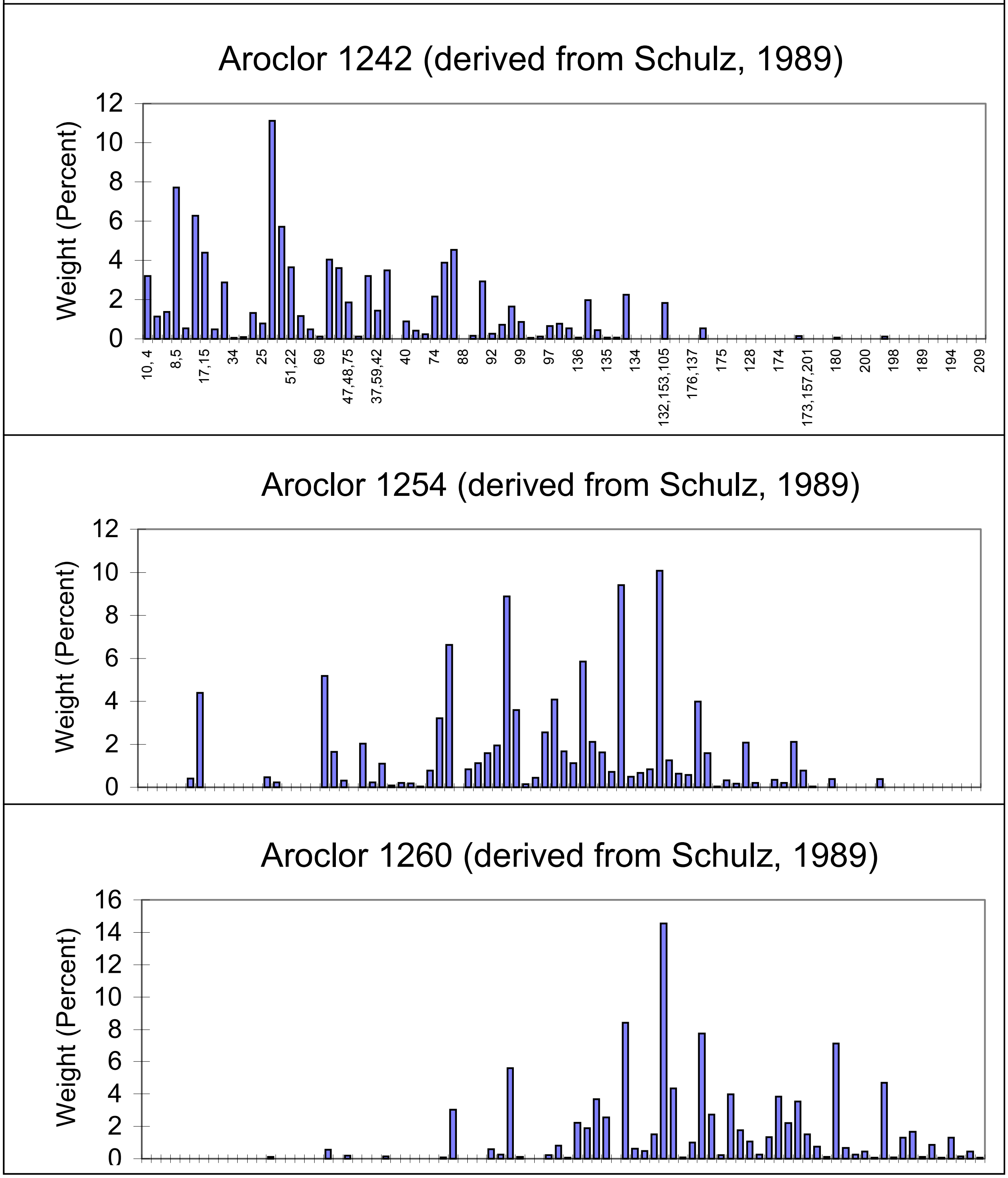


Figure 9.13: Congener pattern for various PCB Aroclor formulations (from Schulz, 1989)



PCB results do not indicate any spatial patterns within the Finger Lakes. However, the congener patterns in several of the Finger Lakes cores (Figure 9.16) suggest differences in contaminant patterns. Once again, while all three core segments were collected from a similar sediment depth (4-6 cm), the time periods represented by the segments vary due to differences in sediment deposition rates within each lake. The Conesus Lake core segment represents sediments deposited during the mid 1980s, while the core segments from Canadice and Seneca Lakes, represent sediments deposited during the early 1970s and the late 1970s, respectively. While as mentioned above, laboratory assessment of Aroclors were all below detection levels with the exception of a single core segment from Canadice Lake, the congener data does appear to provide some clues as to possible parent compounds. Thus, comparison of congener patterns observed within the lakes (Figure 9.16) to those of commercial products in most common use within the United States (Figure 9.13), provides some perspective with respect to possible contaminant sources. The congener profiles from Conesus Lake and Canadice Lake (Figure 9.16) most closely resemble Aroclor 1242 (Figure 9.13) – note the preponderance of lower chlorinated congeners. It is important to note that an exact pattern match between environmental samples and commercial products is very unlikely due to environmental weathering of the chemical signal, and that the best that can be expected is a general resemblance. One unexpected finding worth noting in the Canadice Lake core is that the congener pattern observed in the 4-6 cm section (Aroclor 1242) is different from both the fish flesh pattern observed during the past decade, or so, and from the pattern observed in the core segment immediately above (2-4 cm) which were considered consistent with higher chlorinated Aroclor compounds (Aroclor 1254 and/or 1260). The congener pattern in the Seneca Lake core segment (Figure 9.16) is somewhat more complex than that from the other two lake cores discussed above. The pattern would suggest the presence of two Aroclors – note the peaks on both the left and middle portions of the plot. The left-most pattern is again indicative of Aroclor 1242 (see Figure 9.13), historically the most widely used Aroclor product within the United States. The middle portion of the plot most closely resembles Aroclor 1254 (see Figure 9.13). For example, the largest peak in this portion of the plot (IUPAC-118) represents approximately 8 percent of the total congener mass of the sample while it represents approximately 7 percent of Aroclor 1254. Thus, the Seneca Lake findings indicate that PCB inputs to the lake may originate from more than one source.

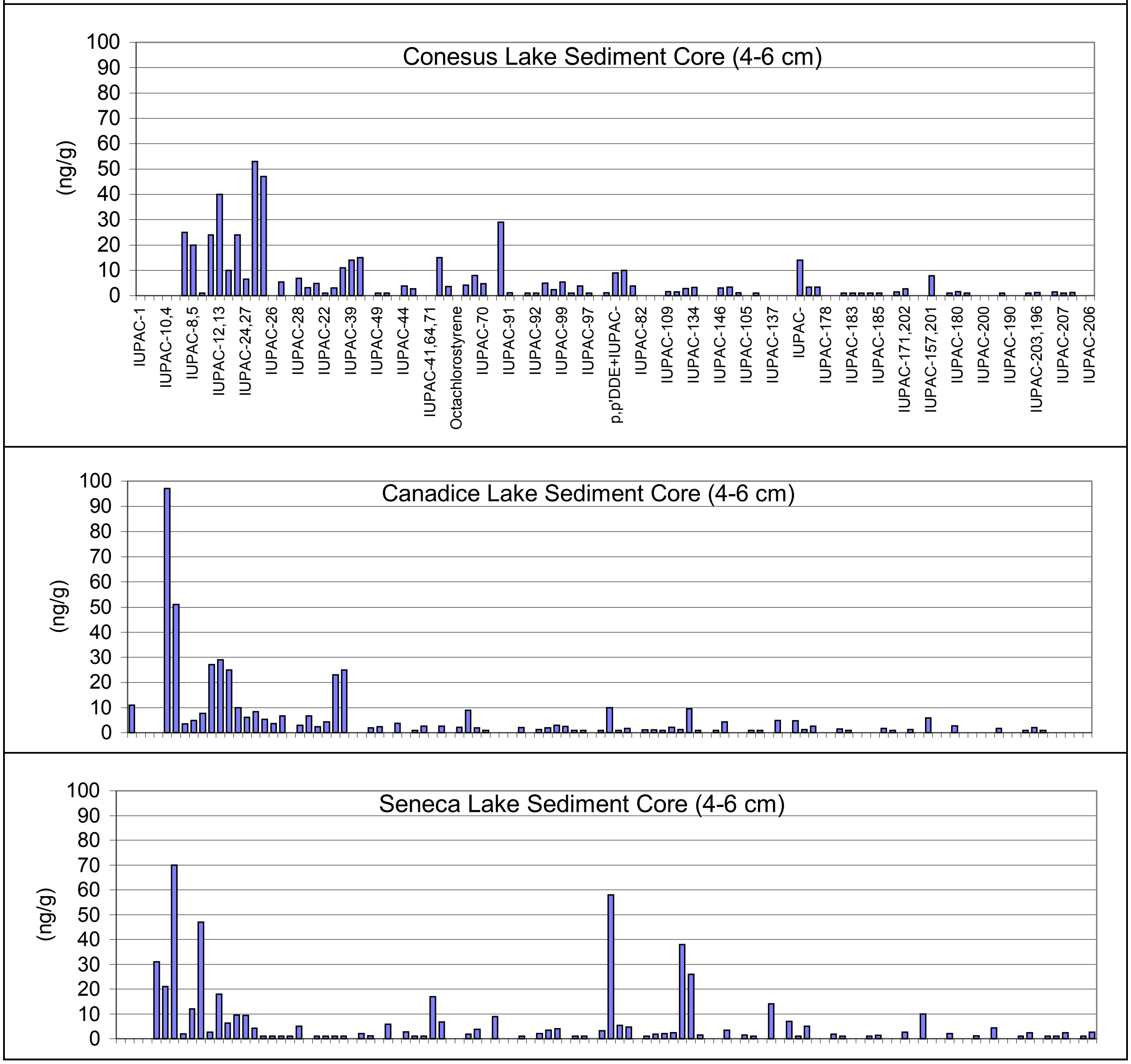
The lack of detectable Aroclors precludes evaluation of temporal PCB trends within the Finger Lakes. In retrospect, it would have been advisable to analyze several sediment core segments using the congener method.

With respect to sediment quality assessment values, the PCB congener totals indicate that all of the Finger Lakes, for which PCB congener data is available, exceed the TEL (34.1 ppb) for PCBs and that a number of the lakes (Skaneateles, Owasco, Seneca, Keuka, Canadice, and Conesus Lakes) exceed the PEL (270 ppb) for total PCBs. Furthermore, while no congener information was available for Canandaigua Lake, it is likely that it would also exceed the TEL and possibly the PEL, given the existing fish consumption advisory. The fact that the sediments in many of the Finger Lakes show elevated levels of PCBs is probably indicative of a diffuse source (e.g., atmospheric) of PCBs to the basins. However, the pattern differences observed in Seneca Lake may indicate some local influence. Furthermore, the relatively low productivity in many of these lakes probably contributes to the observed elevations in that concentrations are reported on a weight per weight basis.

Other Organic Chemicals

The only other organic contaminant found in any of the Finger Lakes cores was Dieldrin. Dieldrin, also an organochlorine pesticide, was historically used for termite control, corn pests, and control of moths (clothing and carpets). Dieldren was banned in the United States in 1974 except for termite control. Dieldrin was found in only a single sediment core segment taken from Canadice Lake. Judging from the level observed (6 ppb) and the depth of occurrence (6-8 cm, ~ 1963), it is likely that Dieldren is of little environmental concern within the Finger Lakes.

Figure 9.16: PCB congener pattern for selected Finger Lakes



d. Inorganic Chemical Findings

Inorganic substances analyzed during this investigation are shown in Table 8.3. In contrast to the organic substances discussed previously, the inorganic substances discussed below can originate from either natural or human processes and/or activities. A listing of the relative quantities (in parts per million) of certain of these elements in the earth's lithosphere (earth's crust) is presented in Table 9.7. Obviously, the concentration of these elements within the earth's crust varies spatially, however, these values provide some perspective regarding the relative abundance of these elements within nature.

Table 9.7: Concentration of selected elements in Earth's Lithosphere (Gammel, 1998)

Element	*Symbol*	*Atomic Number*	*Atomic Weight*	*Concentration (ppm)*	*Percentage*
Arsenic	As	33	74.92	1.5	1.5×10^{-4}
Cadmium	Cd	48	112.40	0.11	1.1×10^{-5}
Calcium	Ca	20	40.08	41,000	4.1
Chromium	Cr	24	52.00	100	1.0×10^{-2}
Copper	Cu	29	63.54	50	0.5×10^{-2}
Lead	Pb	82	207.2	14	1.4×10^{-3}
Manganese	Mn	25	54.94	950	9.5×10^{-2}
Mercury	Hg	80	200.6	0.05	5.0×10^{-6}
Nickel	Ni	28	58.71	80	8.0×10^{-3}
Zinc	Zn	30	65.37	75	7.5×10^{-3}

More than two dozen inorganic chemicals were investigated during this study. However, sediment quality assessment values are available for only a subset of them (see Table 9.8). The relevant assessment values for these compounds are listed in Table 9.8. As with the organic compounds discussed earlier, two assessment values (TEL and PEL) are presented. The reference values are taken from Smith, et al. (1996). These assessment values are believed to be appropriate for evaluating the chemical findings from the Finger Lakes sediment cores. Historical (deep sediment) levels of these chemicals from other parts of New York State are presented in Table 9.9.

Given the large number of analytes assessed during this investigation, the limited availability of assessment values, and space constraints, discussion of results is limited to: (a) those chemicals for which sediment quality assessment values are available; and (b) two additional chemicals (calcium and manganese) which provide additional insight regarding lake chemistry within the Finger Lakes.

Table 9.8: Inorganic sediment assessment values

Substance	TEL (ppm)	PEL (ppm)
Arsenic	5.9	17
Cadmium	0.6	3.53
Chromium	37.3	90
Copper	35.7	197
Lead	35	91.3
Mercury	0.17	0.49
Nickel	18	36
Zinc	123	315

TEL: threshold effect level (Smith, et al., 1996)
PEL: probable effect level (Smith, et al., 1996)

Table 9.9: Historical inorganic chemical levels in NY State sediments (Estabrooks, unpublished data)

Element/Information	NY Harbor (fine grained)	Oswego River (coarse grained)
Arsenic (ppm)	na	0.95
Cadmium (ppm)	0.5	0.6
Chromium (ppm)	60	3.8
Copper (ppm)	25	7.9
Lead (ppm)	20	1.7
Mercury (ppm)	0.3	0.09
Nickel (ppm)	35	3.7
Zinc (ppm)	80	8.8
Carbon (percent)	5	na
Est. Age (years)	500	300

Arsenic

Arsenic (As) is a naturally occurring element in the Earth's crust and is also generated by certain human activities (both current and historical). Arsenic can enter aquatic environments as a result of naturally induced weathering of arsenic containing rock formations. Anthropogenic activities which can result in the release of arsenic to the environment range from arsenic-based insecticides to the burning of fossil fuels – see box below for additional information.

Arsenic was detected in all 11 of the Finger Lakes sediment cores. However, arsenic concentratios varied markedly (more than 4 fold) between the lakes. Table 9.10 provides a summary of arsenic findings for each of the lakes – the table provides a listing of peak arsenic levels and associated sediment depths, as well as surficial sediment concentrations for each of the Finger Lakes. There was no discernable spatial pattern for arsenic levels within the Finger Lakes. The highest sediment arsenic concentrations were observed in surficial sediments from Keuka Lake and Canandaigua Lake. Somewhat lower arsenic levels were observed in surficial sediments from Skaneateles Lake and Canadice Lake. Hemlock Lake also showed substantial sediment arsenic concentrations, however, temporal patterns were not available due to poor radiometric profiles. Sediment core arsenic results for a number of the Finger Lakes are presented in Figures 9.19 and 9.20 - the figures show sediment core arsenic concentrations versus sediment depth.

Table 9.10: Arsenic summary for Finger Lakes sediment cores

Lake	*Peak Arsenic (ppm)*	*Surface Arsenic (ppm)*	*Comments*
Otisco	11 @ 3-4 cm	< 10	surface sediment below detection
Skaneateles	34 @ surface	34	
Owasco	14 @ 3-4 cm	10	
Cayuga	12.5 @ surface	12.5	no temporal significance due to disturbance
Seneca	19 @ surface	19	
Keuka	47.1 @ surface	47.1	highest peak and surface As levels
Canandaigua	45 @ surface	45	2nd highest peak and surface As levels
Honeoye	19.4 @ 6-9 cm	17.1	
Canadice	29.3 @ surface	29.3	
Hemlock	21.4 @ surface	21.4	no temporal significance due to disturbance
Conesus	20.2 @ 4-6 cm	16.9	
TEL	5.9		
PEL	17.0		

In general, temporal trends in sediment arsenic levels within the Finger Lakes indicate increasing concentrations over the past several decades. As shown in Table 9.5 above, 5 of the 9 Finger Lakes with intact sediment chronologies (Skaneateles, Seneca, Keuka, Canandaigua, and Canadice Lakes) show arsenic peaks within surficial sediment layers. Furthermore, 3 additional lakes (Otisco, Owasco, and Conesus Lakes) demonstrate higher arsenic levels in the upper half of the sediment cores. Similar trends in arsenic levels have been observed in Lake Champlain (Lassel, 1996). While the reason(s) for the upward trend in arsenic levels in upper sediment layers is not certain, there are several plausible hypotheses.

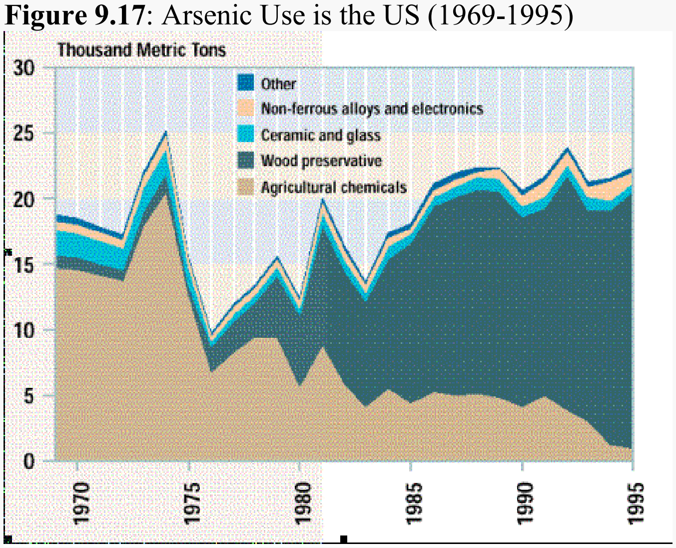
Arsenic

Arsenic (As) has been used as an insecticide for centuries. Some evidence suggests that the Chinese used arsenic as an insecticide as early as 200 BC (US Army, 2000). More recent use figures for the United States are included in Figure 9.17. In general, prior to 1975, agricultural use was the predominant anthropogenic source of arsenic to the environment, however, from 1975 to the present agricultural use of arsenic has declined while wood preservative applications have increased markedly. Arsenic compounds used in wood preservation include chromated copper arsenate (CCA) and ammoniacal copper arsenate (ACA). The burning of fossil fuel is also a significant source of arsenic to the environment. Arsenic may also reach aquatic systems via natural processes such as the dissolution of mineral and/or rock deposits containing arsenic.

Arsenic is a naturally-occurring mineral, and is considered a transitional metal, or metaloid, with respect to its position in the Periodic Table. This suggests that arsenic can behave as either a metal or a non-metal. The primary arsenic species found in natural waters are arsenate ions (oxidation state +V) which are most prevalent in aerobic waters and arsenite ions (oxidation state +III) which are most common in anaerobic waters. The two species show significantly different chemical behavior. One particularly important difference is that arsenate behaves similar to phosphate in aquatic systems, which can have significant implications for biotic uptake and availability. Arsenic can occur in both inorganic and organic forms. The principal forms of arsenic and their cycling through the aquatic environment are depicted in Figure 9.18. Arsenic toxicity varies, in general the trivalent (+III) compounds are considered more toxic than the pentavalent (+V) compounds.

As with DDT, arsenic is featured prominently in Rachel Carson's Silent Spring (Carson, 1962). Arsenic exhibits both acute toxicity (neuro-toxin) and chronic toxicity (carcinogenicity). Arsenic has long been known to be a neurotoxin. This is the principal mechanism by which arsenic acts as a pesticide. With respect to chronic toxicity, arsenic has been linked to cancers of the skin, liver, bladder and lung. The United States Environmental Protection Agency (EPA) is currently in the process of evaluating the maximum contaminant level (MCL) for arsenic in drinking water supplies. EPA is reviewing the MCL for arsenic because of concerns that it may not be sufficiently protective of human health. The proposed MCL is 10 ug/l, which would be a 5-fold reduction from the existing MCL of 50 ug/l.

Figure 9.17: Arsenic Use is the US (1969-1995)



Source: Interagency Working Group on Industrial Ecology, 1998

Figure 9.18: Arsenic Cycle (from Sohrin, 1997)

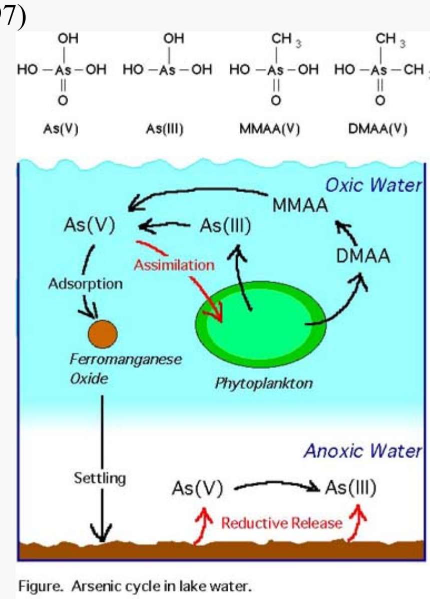
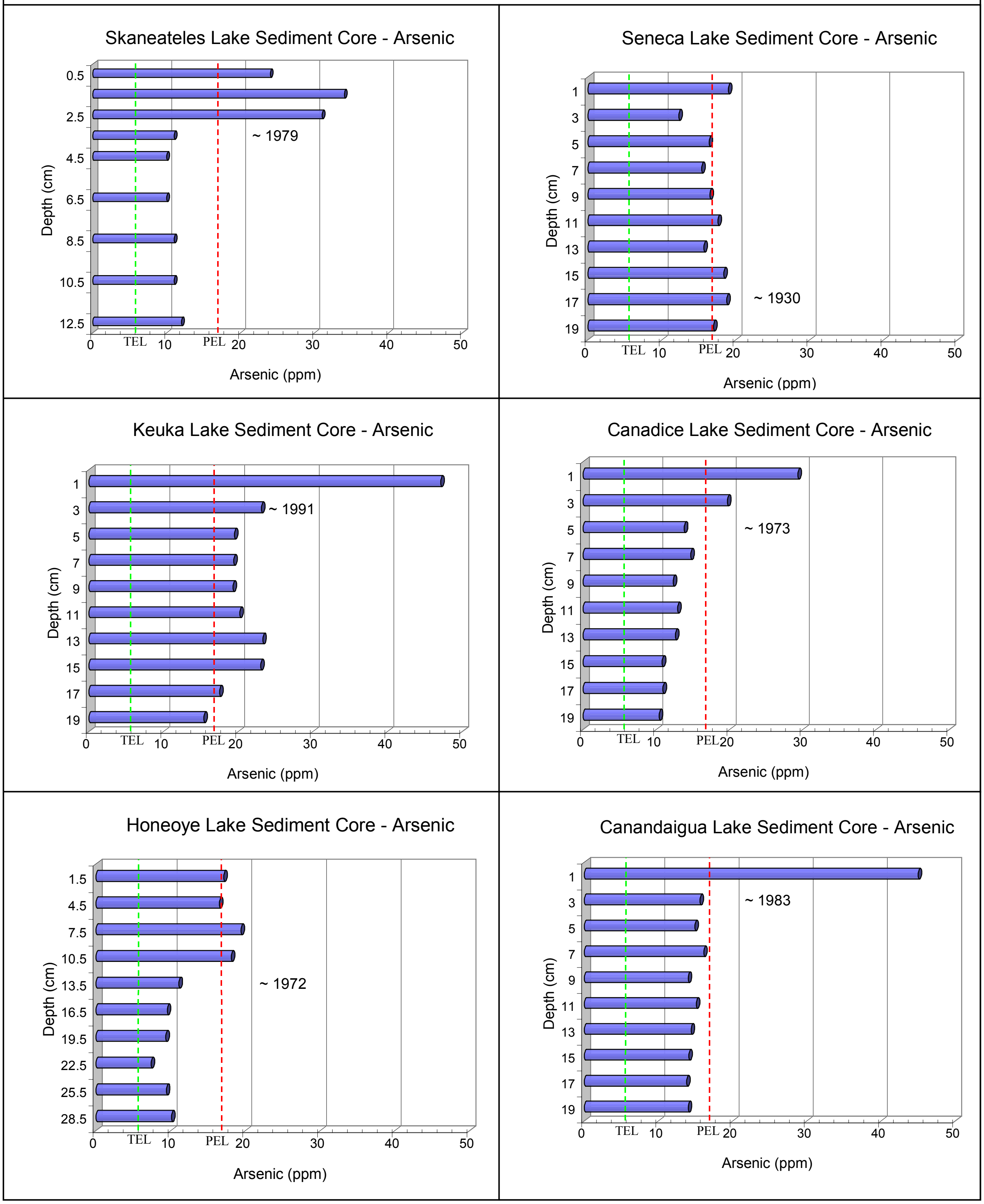
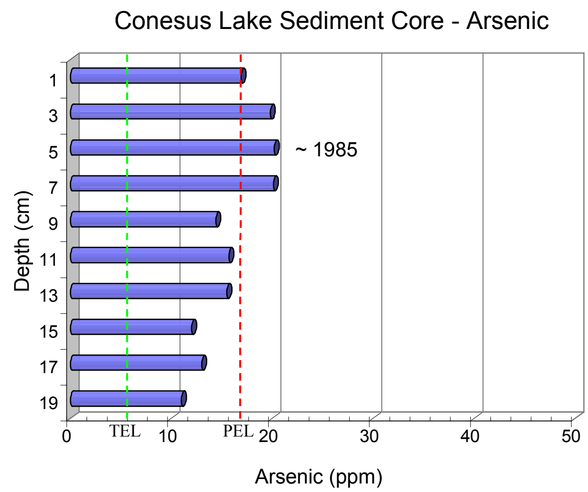


Figure 9.19: Sediment core arsenic profiles for selected Finger Lakes



First, it is conceivable that the increase in arsenic concentration in the upper sediments of these lakes is the result of decreased primary productivity within these systems. Arsenic concentrations within the sediments are recorded on a weight per weight basis (ug/kg). If one assumes a constant input of arsenic to a lake, then, as the mass of other material being contributed to the bottom sediments is reduced (due to decreased algal productivity, etc.), the concentration of arsenic within the sediments, on a weight per weight basis, would tend to increase. Thus, one would expect an inverse relationship between sediment arsenic concentration and primary productivity for a given lake. There are several lines of evidence that lend support to this hypothesis. For instance, the increases in arsenic levels coincide temporally, to a degree, with reductions in lake trophic indicators. The arsenic increases appear within the past 2-3 decades and are thus consistent (temporally) with reductions in phosphorus loadings as discussed earlier. Furthermore, those lakes (Otisco, Honeoye, and Conesus Lakes) that have shown little or no reduction in trophic conditions, also exhibit less pronounced increases in arsenic levels, or no recent spike in arsenic levels. Furthermore, the magnitude of change in both sediment arsenic concentration (~ 2-3 fold increase) and primary productivity (~ 2-3 fold decrease as measured by chlorophyll *a*) are approximately equivalent in those lakes exhibiting arsenic enrichment. One line of evidence that would appear to work against such a hypothesis is that one would expect other compounds (with a constant rate of supply over time) to mimic the arsenic patterns. The only inorganic chemical to show a similar chronological pattern as arsenic is manganese, and this parallel might have an alternative explanation – see below.

Figure 9.20: Conesus sediment core arsenic profile



S*econd*, it is possible that there is an upward migration of arsenic within the sediments due to reduction/oxidation conditions within the benthos. The solubility of arsenic in water is influenced by dissolved oxygen levels – in general, as dissolved oxygen levels increase arsenic solubility decreases, and visa versa. A similar relationship exists for several other elements (e.g., phosphorus, manganese, etc.). Thus, in well-oxygenated lakes, the upper sediment layer of the benthos remains oxygenated, thereby restricting the solubility of arsenic in the pore waters of these sediments. In contrast, lower sediment layers, being largely devoid of oxygen (due to oxygen consumption and lack of replenishment), show increased arsenic solubility in pore waters. This disparity in pore water solubility would theoretically establish a vertical *concentration gradient* within the benthic sediments - with lower pore water arsenic concentrations within surface sediments and higher pore water arsenic concentrations within the deeper sediments – resulting in an upward migration of arsenic within the sediments. However, once the arsenic reaches the surficial sediment layer (which remains oxygenated in many of the study lakes) it precipitates out of solution and is incorporated within the benthic sediments. There are several lines of support for this hypothesis. First, other researchers have observed a similar upward migration for manganese within the bottom sediments of aquatic systems (Williams, et al., 1978), and, as will be discussed below, manganese was found to show very similar patterns to arsenic within the Finger Lakes. In addition, USGS research conducted on Cayuga Lake cores found differences in pore water arsenic concentrations with depth – with maximum pore water arsenic concentrations at between 35-50 cm depth (Kraemer, unpublished data).

Third, it is the possible that arsenic loading to the Finger Lakes has increased over the past several decades due to either anthropogenic activities or natural processes. For example, it is conceivable that acid rain within the watersheds may be accelerating the leaching of arsenic from underlying rock strata. Alternatively, either current arsenic use or historical (buried) sources may be contributing to arsenic loading within the watersheds.

Fourth, in some of the lakes, observed arsenic increases coincide temporally with the invasion of Zebra mussels. It is conceivable that Zebra mussel populations are altering the processing of arsenic within the lake ecosystem. As alluded to earlier, Zebra mussels are extremely efficient at scavenging particulate material from the water column. In effect, Zebra mussels behave like filters within a water body, and short circuit the normal processing of particulate material.

Regardless of cause(s), the arsenic spikes at the top of these sediment cores raise several environmental concerns. The arsenic levels observed within the sediments of certain Finger Lakes cores exceed current sediment quality assessment values. The surficial sediments from Canadice, Canandaigua, Keuka, Seneca, and Skaneateles Lakes exceed the PEL (17 ppm), while the surficial sediments from most of the other Finger Lakes exceed the TEL (5.9 ppm). The presence of arsenic in surficial sediments raises the following concerns: (a) possible availability of arsenic to the overlying water column through diffusion; and (b) availability of arsenic to the benthic biotic community. As discussed in the box above, there is currently a heightened concern about arsenic toxicity, and the USEPA is currently in the process of revising the MCL for arsenic.

Given these findings, and the fact that 10 of the 11 Finger Lakes serve as public water supply sources, water column sampling for arsenic was initiated in 1999 as part of the Synoptic Investigation. Findings were generally encouraging - only one sample showed detectable levels of arsenic (Owasco Lake epilimnetic sample from September 1999 at 10 ug/l). However, several caveats are in order regarding these findings: (a) analytical detection limits for the water samples were 10 ug/l, which is at the currently proposed MCL; (b) sampling was conducted at our prescribed sampling locations which included both epilimnetic and hypolimnetic samples, however, the hypolimnetic sample depth is, by definition, 2/3rds the station depth – thus, it is conceivable that arsenic concentrations could be higher nearer the lake bottom due to diffusion from the benthos; and (3) sample collection was quite limited (spatially and temporally) due to resource limitations.

Cadmium

Cadmium is found in relatively low concentrations in the earth's crust. Anthropogenic sources of cadmium include metal-plating operations, battery manufacture, pigment production, and plastics manufacturing. It can also be found in fairly high concentrations in sewage sludge. Cadmium is considered a potential human carcinogen, and has also been shown to cause other adverse health effects including kidney damage, bone defects, high blood pressure, and reproductive problems.

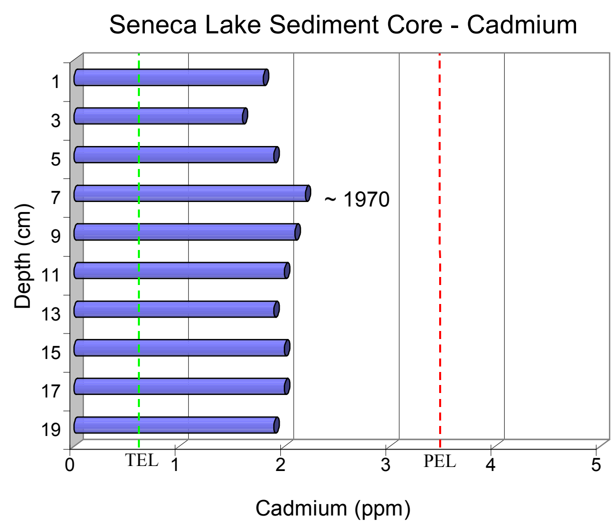
Detectable levels of cadmium were found in Conesus, Canadice, Seneca, and Cayuga Lakes (see Table 9.11). Cadmium levels in these cores ranged from below detection to 3.43 ppm. The highest observed cadmium concentration (3.43 ppm) was from Conesus Lake in the 2-4 cm core segment. Other core segments from Conesus Lake were below detectable levels. Unfortunately, analytical detection levels for core samples collected from the 3 eastern lakes (Otisco, Skaneateles, and Owasco Lakes) were relatively high (in certain instances above the PEL) and all samples came back as below detection. Thus, conclusions regarding cadmium levels for these lakes, or comparisons including these lakes, are not appropriate.

Table 9.11: Cadmium in Finger Lakes sediment cores

Lake	*Peak Cd (ppm)*	*Depth(cm)/Age*
Otisco	below detection	na
Skaneateles	below detection	na
Owasco	below detection	na
Cayuga	0.8	na
Seneca	2.2	6-8 cm (1970)
Keuka	below detection	na
Canandaigua	below detection	na
Honeoye	na	na
Canadice	1.4	6-8 cm (1963)
Hemlock	below detection	na
Conesus	3.4	2-4 cm (1990)
TEL	0.6	na
PEL	3.53	na

Due to the large number of analytical non-detects, temporal trends in cadmium levels are only discernable from the Seneca Lake core. The vertical profile for cadmium in the Seneca Lake sediment core is depicted in Figure 9.21. The trend indicates a slight decline in cadmium levels over time, beginning with a cadmium peak in approximately 1970.

Figure 9.21: Seneca Lake sediment core cadmium profile



Certain sediment core segments from each of the 4 lakes in which cadmium was detected (Cayuga, Seneca, Canadice, and Conesus Lakes) were above the TEL (0.6 ppm), but all were below the PEL (3.53 ppm) with the exception of a single core segment from Conesus Lake.

These findings appear to indicate that cadmium is not a significant environmental concern within the Finger Lakes. Furthermore, the relatively uniform cadmium concentrations observed within the Finger Lakes sediments, would suggest that the source of cadmium to these lakes is diffuse in nature (e.g., atmospheric deposition).

Calcium

Calcium (Ca) is relatively abundant in the earth's crust, and is generally not considered a toxic contaminant. The reasons for including calcium in this discussion are as follows: (1) temporal changes observed during this study may be indicative of ecosystem changes occurring within the Finger Lakes; and (2) findings indicate the potential to exacerbate problems associated with Zebra mussel populations.

The sediment core findings are largely consistent with water column findings presented above, in that sediment calcium levels exhibit significant spatial differences between lakes (see Table 9.12). Sediment calcium peak values varied by nearly an order of magnitude, with a minimum in Canadice Lake and a maximum in Otisco Lake. As with water column findings for major ion species, there is an apparent east/west trend in the calcium levels within the Finger Lakes, probably reflecting watershed soil conditions and underlying geology. In general, calcium levels are higher in the eastern Finger Lakes than in the western lakes. The lake sediments can be grouped into low (< 10,000 ppm), medium (> 10,000 ppm but < 50,000 ppm), and high (> 50,000 ppm) calcium levels based upon maximum calcium levels observed. Otisco and Owasco Lakes fall into the high calcium category, Skaneateles, Cayuga, Seneca, Canandaigua, and Conesus Lakes fit within the medium calcium category, and the remainder of the lakes (Keuka, Honeoye, Canadice, and Hemlock Lakes) fall into the low calcium category. These finding are consistent with water column findings presented above (See Figure 5.19).

Table 9.12: Calcium levels in Finger Lakes sediment cores

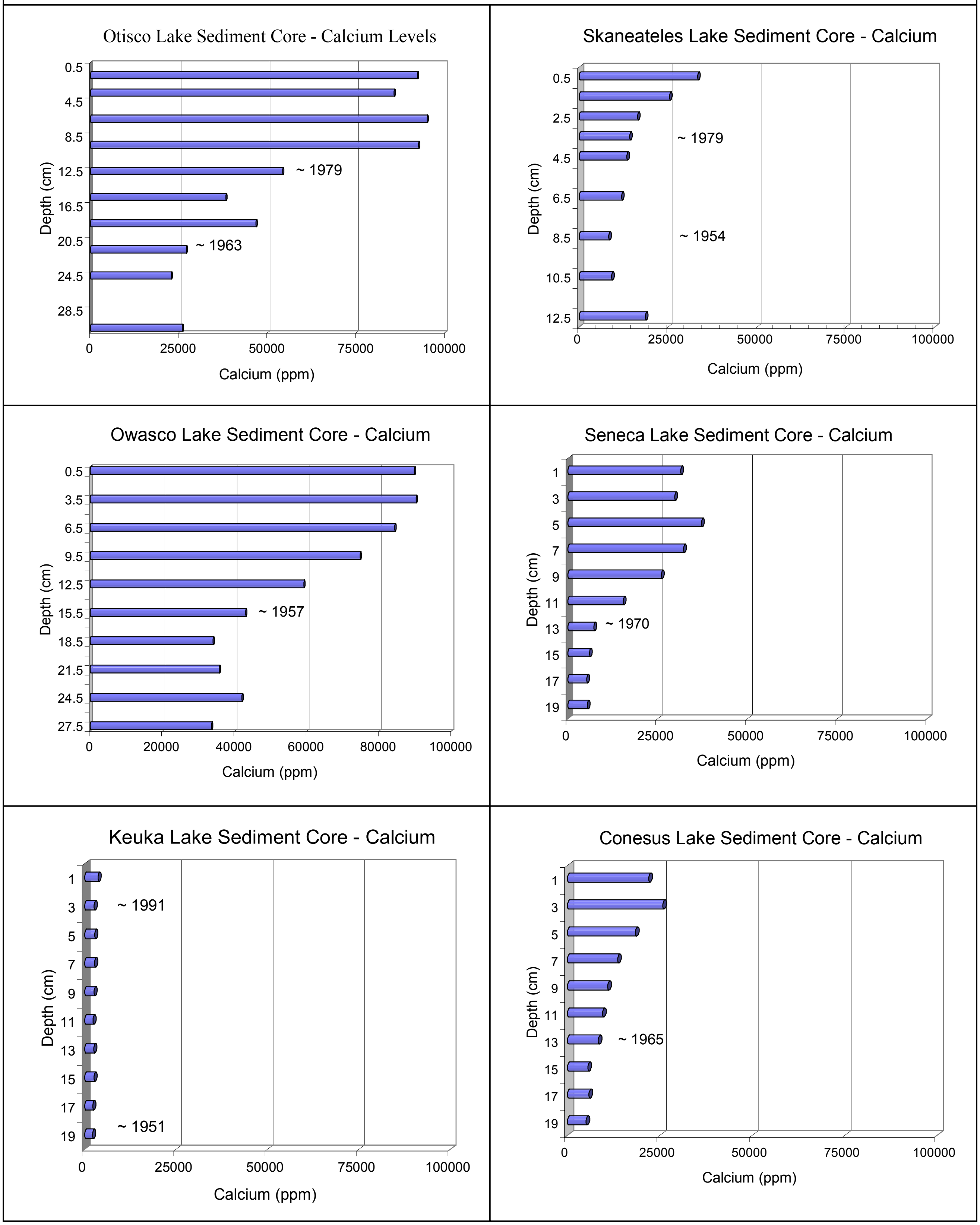
Lake	*Peak Ca (ppm)*	*Depth (cm)/~ Age*
Otisco	94,900	6-7 (1987)
Skaneateles	25,400	1-2 (1989)
Owasco	90,200	3-4 (1987)
* Cayuga	46,100	na
Seneca	37,200	4-6 (1978)
Keuka	3,680	0-2 (1996)
Canandaigua	18,900	14-16 (1923)
Honeoye	4,550	0-3 (1996)
Canadice	2,540	2-4 (1983)
* Hemlock	3,470	na
Conesus	25,800	2-4 (1990)

* Cayuga Lake and Hemlock Lake cores showed disturbed sediment chronologies.

The sediment cores offer some intriguing temporal insights with respect to changes in calcium levels within the Finger Lakes. Sediment core findings for nearly every one of the Finger Lakes (in which intact chronologies were available) show a significant increase in calcium levels over the past half-century. These findings are illustrated in Figure 9.22. Our results suggest significant increases in calcium levels beginning between the mid-1950s to the late-1970s, with peak concentrations occurring within the last two decades. However, our analyses were generally limited to the upper 30 cm of the sediment cores. Researchers from Syracuse University, which participated in this investigation, analyzed calcite concentrations from deeper portions of the cores. Their results indicate that calcite concentrations began to increase in the 1920s and 1930s (Mullins, et al., 2000). Their working hypothesis is that the calcium increases observed over the past half-century or more may be due to the effects of acid rain. It is hypothesized that acid rain accelerates the leaching of minerals (e.g., calcium) within the watershed, and the minerals are then transported to the lake basin. This hypothesis is consistent with other researchers (Lawrence, et al., 1997) who have documented accelerated calcium depletion rates from forest soils.

The implications of the observed calcium changes are not yet clear. However, as discussed earlier, increasing calcium levels within the lake water column could lead to an increase in Zebra mussel populations, which could in turn exacerbate problems associated with these exotic invaders. It is also possible that accelerated leaching of calcium (and other cations) from watershed soils might eventually lead to diminished buffering capacity within certain Finger Lakes (e.g., Canadice Lake). Effects might also extend beyond the lake itself. There are some indications in other areas of the world that acid rain has adversely affected certain forest ecosystems and degraded forest productivity.

Figure 9.22: Calcium profiles for selected Finger Lakes (notice scale differences for Depth)



Chromium

Chromium (Cr) is found at relatively low levels within the earth's crust. Anthropogenic sources of chromium include chrome plating, the manufacture of pigments, leather tanning, and treatment of wood products (recall the discussion of arsenic and the use of CCA). Chromium occurs in the environment in three principal states –chromium (0), chromium (III), and chromium (VI). Chromium (III) occurs naturally in the environment, while chromium (VI) and chromium (0) result primarily from industrial processes. Chromium toxicity varies significantly depending upon the species present. Chromium (III) is the least toxic of the three species, and is actually considered an essential nutrient.

Sediment core findings indicate moderate levels of chromium within the Finger Lakes – see Table 9.13. Results are for total chromium levels and do not differentiate between chromium species. The results suggest some spatial patterns across the lakes. The three eastern lakes exhibit the highest chromium levels. However, it should be noted that analyses for the three eastern lakes sediment cores were conducted at a different laboratory than were the western lake cores. Unfortunately, sample collection for the two sets of lakes occurred in different years and no sample splits were conducted.

Temporal trends in chromium levels, as interpreted through sediment core profiles, suggest that chromium levels within the Finger Lakes generally peaked between the 1950s and the 1970s. Exceptions to this general trend are Canandaigua Lake (peak about 1913), Skaneateles Lake (peak about 1989) and Honeoye Lake (peak about 1996). In the latter two instances, while the peaks occurred relatively recently, the data do not show a consistent trend. This can be seen in the chromium profile for Skaneateles Lake (see Figure 9.23). While chromium levels peaked in 1989, the level was only slightly higher than in some earlier years.

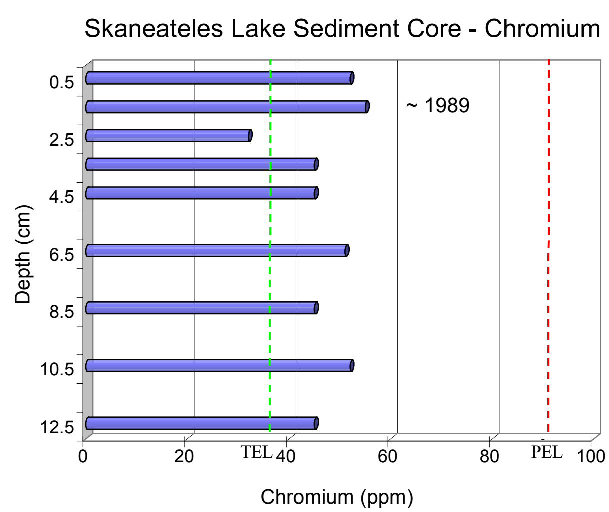
Chromium levels observed in certain Finger Lakes sediment cores segments (primarily, the three eastern lakes) exceed the TEL for chromium. However, none of the core segments exceeded the PEL for chromium.

Table 9.13: Chromium in Finger Lakes sediment cores

Lake	*Peak Cr (ppm)*	*Depth (cm)/~ Age*
Otisco	58	25-26 (1962)
Skaneateles	55	1-2 (1989)
Owasco	52	12-13 (1964)
* Cayuga	18.3	na
Seneca	30.1	6-8 (1970)
Keuka	30.2	14-16 (1961)
Canandaigua	27.6	16-18 (1913)
Honeoye	32.5	0-3 (1996)
Canadice	28.6	2-4 (1983)
* Hemlock	30.5	na
Conesus	29.3	16-18 (1955)
TEL	37.3	na
PEL	90	na

* Cayuga Lake and Hemlock Lake cores show disturbed sediment chronologies.

Figure 9.23: Skaneateles Lake sediment chromium profile



The significance of the chromium finding is not clear. In general, the results would suggest diffuse loading of chromium to the Finger Lakes, as evidenced by the relatively uniform levels of chromium observed.

Copper

Copper (Cu) is found at relatively low levels within the earth's crust. However, copper is used widely in human activities. This is due to the fact that copper offers a number of attractive industrial properties (e.g., corrosion resistance, malleability, and conductivity). Copper is used extensively in the electrical, plumbing, and automotive industries. Copper, in the form of copper sulfate, has been used historically to control the growth of algae in aquatic systems. Copper is toxic to many freshwater invertebrates and fish. Copper toxicity is influenced by several factors, including water hardness, pH, and the level of organic matter present.

Sediment core findings indicate fairly uniform levels of copper within the Finger Lakes with the exception of Otisco Lake (see Table 9.14). Seven of the Finger Lakes (Owasco, Keuka, Canandaigua, Honeoye, Canadice, Hemlock, and Conesus Lakes) show remarkably similar peak copper levels. Skaneateles and Seneca Lakes show somewhat higher peaks with respect to sediment copper levels. However, Otisco Lake sediments exhibit far higher copper levels than the other Finger Lakes. The copper profile for Otisco Lake is shown in Figure 9.24. The elevations in copper levels are likely the result of copper sulfate treatments for the control algal growth, which have taken place on Otisco Lake for many years. In fact, if one looks at the lower sediments (~ 1955 back) the copper levels are quite consistent with the historical levels observed in most of the other Finger Lakes.

Table 9.14: Copper levels in Finger Lakes sediment cores

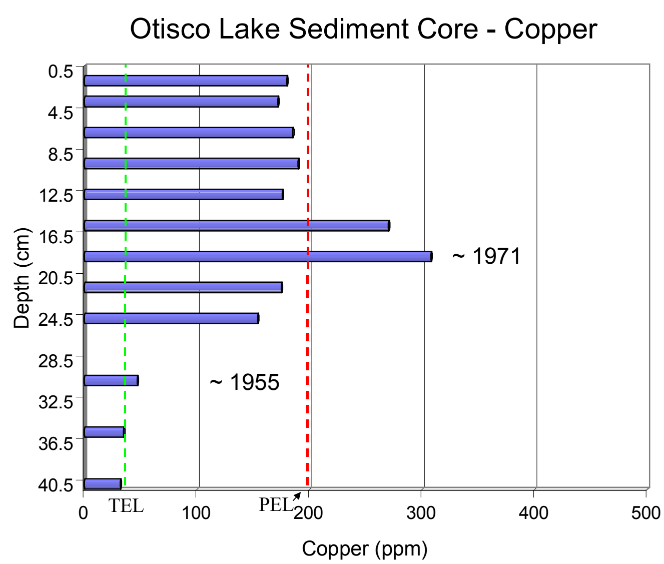
Lake	*Peak Cu (ppm)*	*Depth (cm)/~ Age*
Otisco	308	18-19 (1971)
Skaneateles	78	8-9 (1954)
Owasco	44	0-1 (1995)
* Cayuga	31.4	na
Seneca	61.8	6-8 (1970)
Keuka	45.1	4-6 (1986)
Canandaigua	42.2	2-4 (1983)
Honeoye	44.8	24-27 (1948)
Canadice	45.9	2-4 (1983)
* Hemlock	49.8	na
Conesus	44	10-12 (1970)
TEL	35.7	na
PEL	197	na

* Cayuga Lake and Hemlock Lake cores showed disturbed sediment chronologies.

The temporal trends in copper, as captured in sediment core profiles, are sporadic for most of the Finger Lakes. The only exception to this pattern is Otisco Lake. Otisco Lake shows a marked increase in sediment copper levels in the late 1950s, and a peak in copper levels during the early 1970s. The levels decline somewhat thereafter, but plateau at about four times background levels. Once again, these temporal trends in sediment copper concentrations likely reflect copper sulfate treatments within Otisco Lake.

Most of the Finger Lakes exceed the TEL for copper. Otisco Lake was the only one of the lakes to exceed the PEL for copper, and that was several decades ago.

Figure 9.24: Otisco Lake sediment core copper profile



Lead

Lead (Pb) is relatively rare in the earth's crust. However, lead has been used in human activities for thousands of years. In fact, some theorize that lead poisoning played a role in the demise of the Roman Empire - due to leaching of lead from Roman aqueducts. Lead offers a number of attractive properties for industrial applications including, softness, high density, low melting point, and corrosion resistance.

While lead can reach aqueous environments from natural processes (e.g., erosion of rock, forest fires, etc.), elevated levels are most often associated with human activities. Anthropogenic sources of lead range from lead-based house paint to industrial mining operations. Other sources of lead contamination include lead-based pipes and solder, lead-acid batteries, and lead-based sinkers and shot. However, the most pervasive source of lead to the environment during the past century has been leaded gasoline. Lead was first used as a gasoline additive during the 1920s. The additives tetraethyl and tetramethyl lead were used to prevent engine knock, enhance octane levels, and lubricate engine valves. By the late 1960s and early 1970s, it was apparent that lead had become a widespread contaminant in the environment, and efforts were begun to address the situation. Lead exposure can cause damage to the brain, nervous system, red blood cells, and the kidneys. By the mid 1980s, regulations were in place that curtailed the use of leaded gasoline. As a comparison, in 1979 automobiles released 94.6 million kilograms of lead into the air in the United States, while by 1989 that number had declined to 2.2 million kg – over a 40 fold reduction (USPHS, 1993).

Table 9.15: Lead in Finger Lakes sediment cores

Lake	*Peak Pb (mg/kg)*	*Depth (cm)/~ Age*
Otisco	55	24-25 (1963)
Skaneateles	102	6-7 (1964)
Owasco	73	12-13 (1965)
* Cayuga	26.3	na
Seneca	84.6	6-8 (1970)
Keuka	69.4	12-14 (1966)
Canandaigua	78	6-8 (1963)
Honeoye	62.9	12-15 (1972)
Canadice	64.2	4-6 (1973)
* Hemlock	52.5	na
Conesus	108	10-12 (1970)
TEL	35	-
PEL	91.3	-

* Cayuga Lake and Hemlock Lake cores showed disturbed sediment chronologies.

Comparisons of sediment lead levels within the Finger Lakes indicate some spatial differences between lakes (see Table 9.15). Peak lead levels, for those lakes in which intact sediment chronologies were available, ranged from 55 mg/kg in Otisco Lake to 108 mg/kg in Conesus Lake. The highest lead levels observed occurred in Conesus and Skaneateles Lakes, which represent the productivity extremes within the Finger Lakes. In both instances, peak levels occurred approximately 3-4 decades ago. The lowest lead levels observed overall were in the Cayuga Lake sediment core. Recall, however, that the Cayuga Lake core was not considered appropriate for dating purposes due to its poor cesium profile. Thus, the peak lead level in Cayuga Lake should be viewed as a composite value. Furthermore, there are indications that lead may be a concern in the southern end of Cayuga Lake. For example, there is an ongoing investigation of a contamination site in Ithaca, adjacent to Fall Creek, which is believed to contain significant levels of lead. Furthermore, sediment investigations within the southern end of Cayuga Lake showed elevated lead levels (123 ppm) on the east side of the lake (Sterns and Wheler, 1997).

Sediment core lead profiles for a number of the Finger Lakes are shown in Figures 9.25 and 9.26.

Figure 9.25: Lead profiles in sediment cores from selected Finger Lakes - 1 (note scale differences)

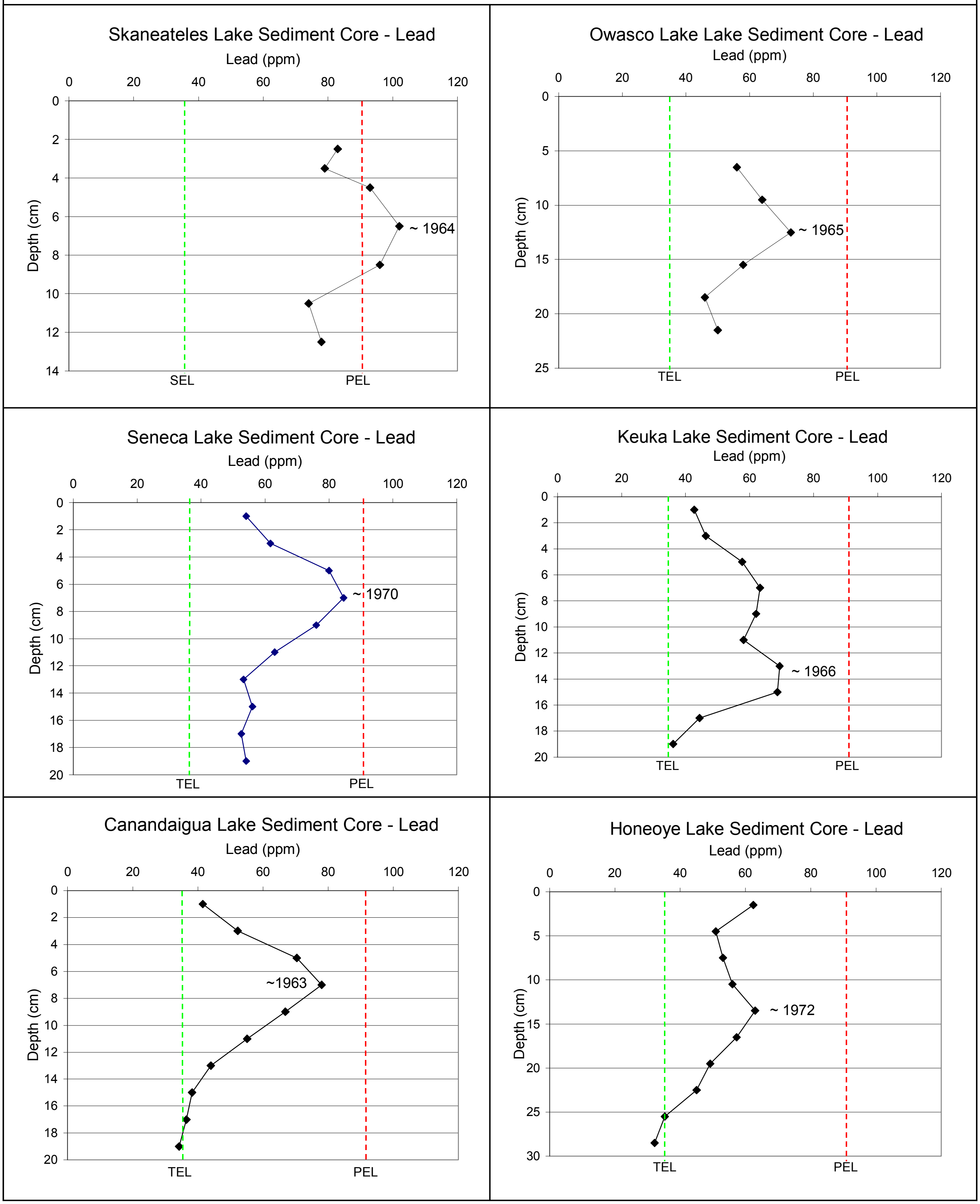
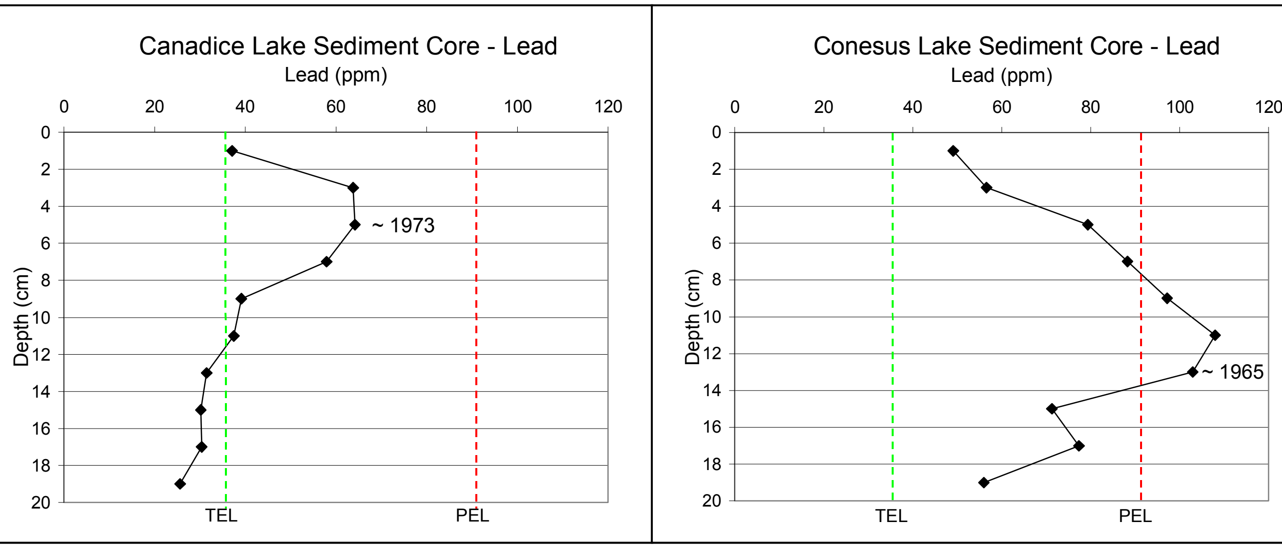


Figure 9.26: Lead profiles in sediment cores from selected Finger Lakes - 2



Temporal trends for lead within the Finger Lakes sediment cores indicate a predominantly downward trend. Findings from all of the lakes, in which intact sediment cores were obtained, indicate that maximum lead levels occurred between the mid-1960s and the mid-1970s. Furthermore, with the exception of Honeoye Lake, all of the lakes exhibit a pronounced decline in lead levels over the past 3-4 decades. It is interesting to note the rather narrow range in peak lead levels observed (~ 70-110 mg/kg), which would appear to support the notion of a widespread loading source (e.g., leaded gasoline). This is also consistent with the phasing-out of leaded gasoline within the United States during the past several decades. As noted above, the only exception to the downward trend in lead levels is Honeoye Lake. While Honeoye Lake does show a significant decline in lead levels between the mid-1970s and the late 1980s, there is a recent up-tick in lead levels (as shown in the most recent core segment). The lead level observed in the most recent core segment is close to the peak value observed in the early 1970s. The cause and/or validity of this recent upturn in lead levels within Honeoye Lake are not certain.

While lead levels have declined markedly within the Finger Lakes over the past several decades they remain, for the most part, above the TEL. However, none of the Finger Lakes surficial core segments exceed the PEL for lead – although deeper sediments within Conesus and Skaneateles Lakes do exceed the PEL.

It is unclear from our findings whether lead levels will continue to decline or whether they have reached a plateau. The question of "background" lead concentrations within the Finger Lakes is not entirely answerable. For example, note that observed "background" levels (background is in quotations because it is unclear if the deepest core segments represent true background conditions) range from approximately 30 ppm on Canadice Lake (ca. 1903) to approximately 80 ppm on Skaneateles Lake (ca. 1934). Obviously, the Canadice Lake core segment is from an earlier date than is the Skaneateles Lake core segment. Thus, the lead levels observed within the deep sediments of Canadice Lake are probably a better representation of actual background concentrations within the Finger Lakes, given their earlier vintage and lower concentration. This may indicate that lead levels within several of the Finger Lakes remain elevated above historical background levels.

Manganese

Manganese (Mn) is moderately abundant in the earth's crust. It is used in the production of steel, batteries, and ceramics. In addition, manganese, in the form of methylcyclopentadienyl manganese tricarbonyl (MMT), is used to enhance octane levels in gasoline. MMT is one of the substances used to replace lead compounds in gasoline. Manganese is an essential nutrient, however, it can have toxic effects at elevated concentrations. It can have adverse effects on the nervous system, lung, and reproductive system.

The Finger Lakes sediment cores collected for this study show substantial spatial variation in manganese levels (see Table 9.16). Peak levels vary by nearly 5 fold, ranging from 1,800 ppm in Canadice Lake to 8,810 ppm in Skaneateles Lake – this excludes Cayuga and Hemlock Lakes due to disturbed sediment chronologies discussed above. There was no apparent east-west trend in the data, nor were manganese levels significantly correlated to lake size or lake productivity level.

Table 9.16: Manganese in Finger Lakes sediment cores

Lake	*Peak Mn (ppm)*	*Depth (cm)/~ Age*
Otisco	1710	9-10 (1983)
Skaneateles	8810	0-1 (1994)
Owasco	3630	0-1 (1995)
* Cayuga	940	na
Seneca	2450	0-2 (1994)
Keuka	5650	0-2 (1996)
Canandaigua	4960	0-2 (1993)
Honeoye	2410	0-3 (1996)
Canadice	1800	0-2 (1993)
* Hemlock	2550	na
Conesus	3490	10-12 (1970)
TEL (LEL)	na	-
SEL	na	-

* Cayuga Lake and Hemlock Lake cores showed disturbed sediment chronologies.

Temporal trends indicate a significant increase in sediment manganese levels within many of the Finger Lakes over the recent past. Sediment core profiles for manganese are shown in Figures 9.27 and 9.28. With the exception of Conesus Lake, peak manganese levels in each of the Finger Lakes sediment cores are found in the surficial sediment layer. This pattern is quite similar to the arsenic findings discussed above.

At the present time there are no established sediment quality assessment values for manganese in benthic sediments.

Figure 9.27: Manganese profiles in sediment cores from Skaneateles and Owasco Lakes.

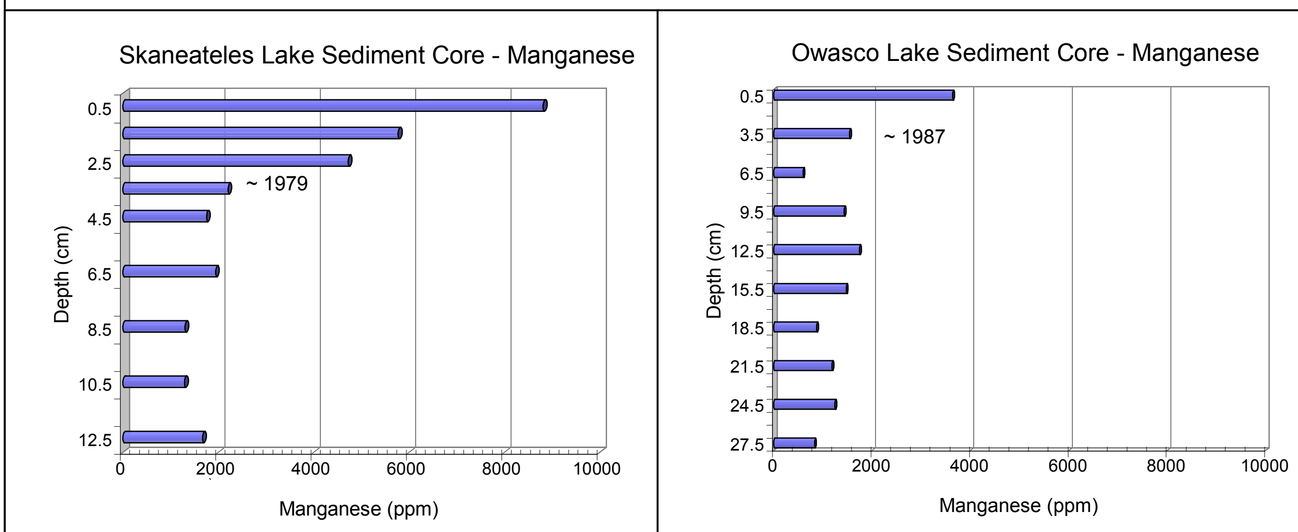
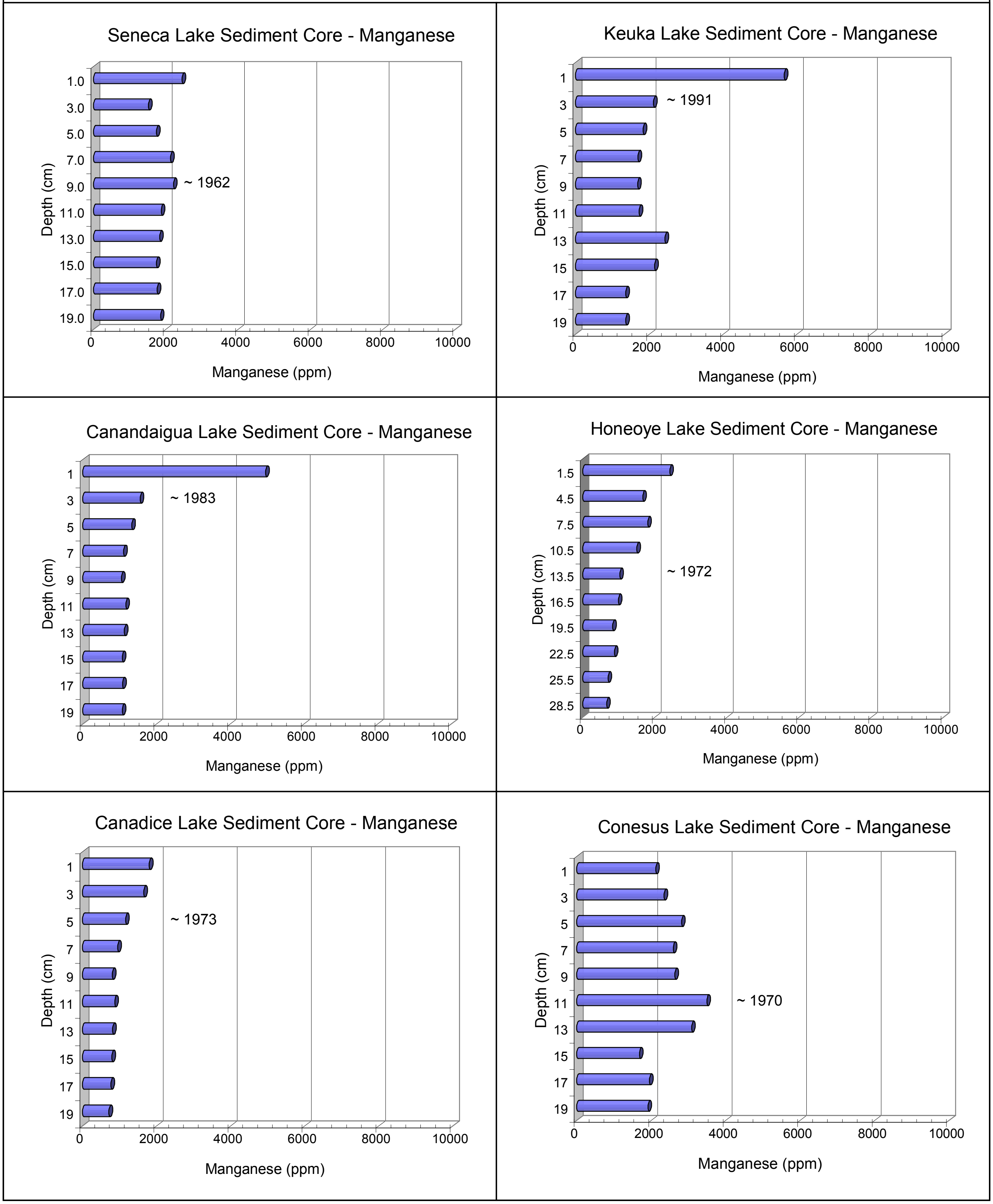


Figure 9.28: Manganese profiles in sediment cores for selected Finger Lakes



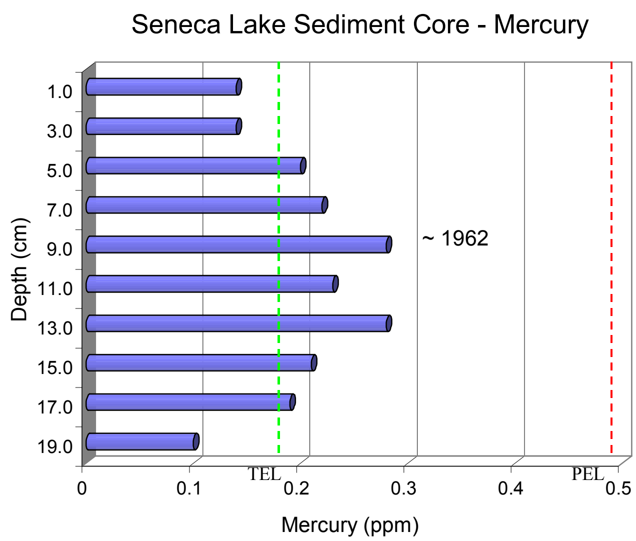
Mercury

Mercury (Hg) is quite rare in the Earth's crust, and, although mercury can be released by natural processes, anthropogenic sources are the primary concern. Major human sources of mercury to the environment include the burning of fossil fuels and municipal waste incineration. The later route of release underscores the fact that a significant number of consumer products contain, or at one time contained, this metal. This list includes batteries, fluorescent lights, thermometers, and dental amalgams. While several of these products no longer contain mercury, the waste stream has a long "environmental memory".

As with the organochlorine compounds discussed above, concerns over mercury in the environment stem from: (a) its persistence within the environment – mercury tends to cycle rather efficiently through aquatic ecosystems; (b) the ability to bioaccumulate within aquatic food chains; and (c) its toxicity. Mercury is a neurotoxin that can adversely affect the central nervous system.

Unfortunately, results from this study are somewhat inconclusive with respect to mercury levels within the Finger Lakes due to the analytical detection limits of the laboratory methods used. In most instances, the analytical detection levels exceeded the TEL and/or PEL for mercury. Furthermore, analytical detection levels varied approximately 5 fold due to factors such as available sample mass and/or interferences. Thus, attempts to assess spatial variability in sediment mercury levels across the Finger Lakes is not possible with the data set available from this investigation.

Figure 9.29: Seneca Lake sediment core mercury profile



With respect to temporal patterns of mercury contamination within the Finger Lakes, only one of the lake cores (Seneca Lake) showed sufficient levels of detection to establish a reasonable temporal profile for mercury (see Figure 9.29). Mercury levels observed within Seneca Lake sediments varied approximately 3 fold. Mercury levels peak at 0.28 mg/kg in approximately 1946 and 1962, and decline thereafter – although the final two sampling periods (1986 and 1994) may indicate that mercury levels have stabilized. The most recent mercury levels are somewhat elevated as compared to the oldest period available (ca. ~ 1922).

Sediment quality assessment values for mercury are 0.174 and 0.49 for the TEL and PEL, respectively. Once again, analytical detection limits proved problematic when it came to evaluating sediment mercury levels in that the detection levels were frequently above the TEL and PEL. As can be seen from the Seneca Lake profile (Figure 9.29), the deeper sediments exceed the TEL, however, more recent sediments (including surficial sediments) are below the TEL and PEL.

Mercury levels within fish tissue (Lake trout) from the Finger Lakes are generally between 0.1 and 0.9 ppm. This is below the Food and Drug Administration's (FDA) actionable level of 1.0 ppm.

Nickel

Nickel (Ni) is found at relatively low levels within the earth's crust. Anthropogenic uses of nickel include the manufacture of stainless steel and other corrosion-resistant alloys, armor plates and vaults, and plating to provide a protective coating for other metals. Occupational exposure to nickel has been linked to increased risk of nasal and lung cancers. In addition, repeated exposures may lead to asthma and other respiratory ailments. The health and/or environmental effects of lower nickel exposure are not known.

Spatial comparisons of nickel levels within Finger Lakes sediments (Table 9.17) indicate a narrow range of concentrations. For example, in those lakes with intact sediment cores, peak nickel levels ranged from 46.1 ppm in Seneca Lake to 72 ppm within Skaneateles Lake. There was no apparent east-west trend in nickel levels, nor was there significant correlation with lake productivity levels. Once again, as with several other metals, nickel levels within the Cayuga Lake sediments appeared inordinately low – approximately half the level found in the other Finger Lakes. Nickel levels for Hemlock Lake are consistent with the other Finger Lakes.

Table 9.17: Nickel in Finger Lakes sediment cores

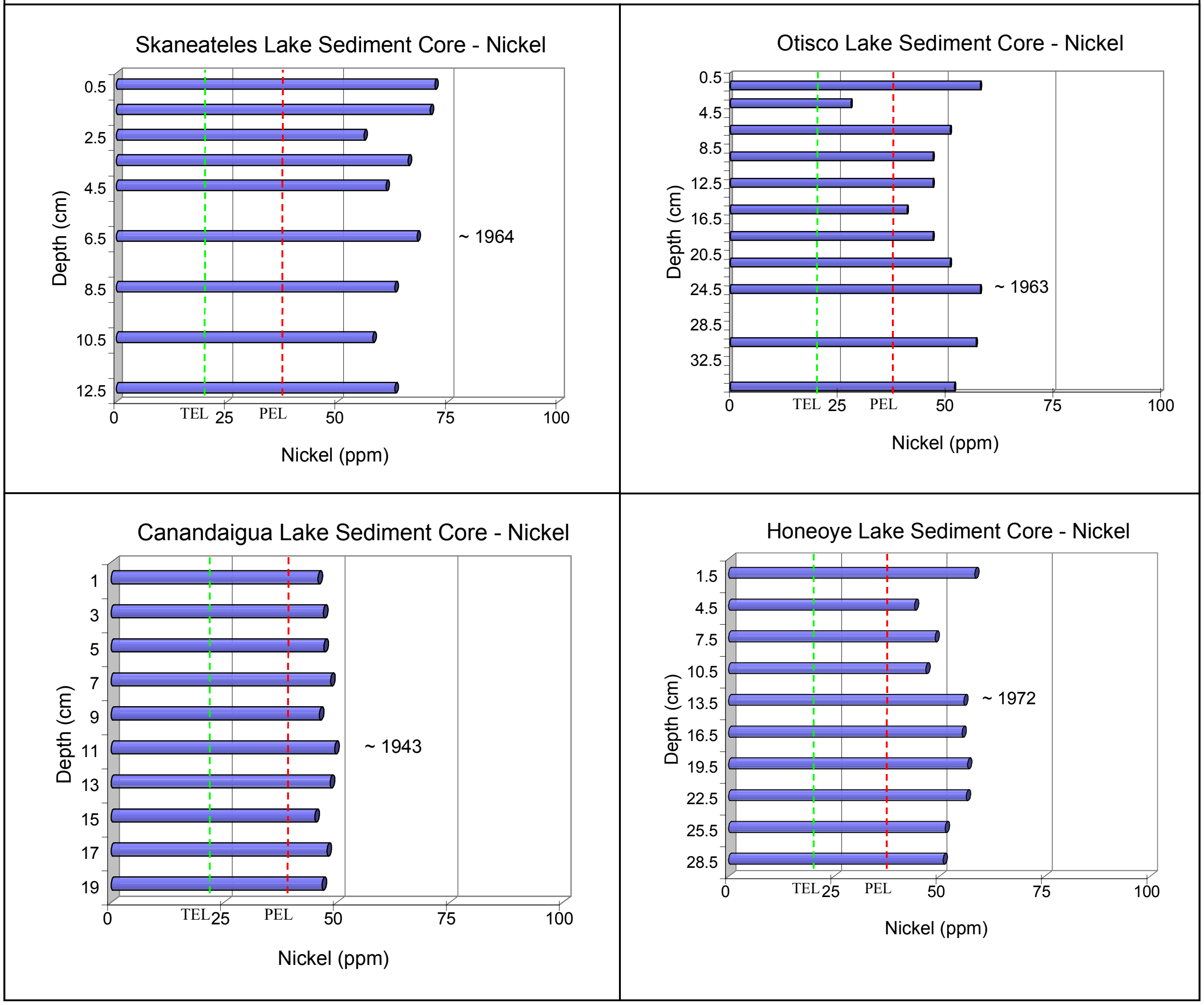
Lake	*Peak Ni (ppm)*	*Depth of Peak (cm)/~ Age*
Otisco	58	1-2 & 24-25 (1994 & 1963)
Skaneateles	72	0-1 (1994)
Owasco	66	12-13 (1965)
* Cayuga	29.9	na
Seneca	46.1	6-8 (1970)
Keuka	50.3	14-16 (1961)
Canandaigua	49.5	10-12 (1943)
Honeoye	58.4	0-3 (1996)
Canadice	53.4	2-4 (1983)
* Hemlock	57.6	na
Conesus	49.2	16-18 (1955)
TEL	18	-
PEL	36	-

* Cayuga Lake and Hemlock Lake cores showed disturbed sediment chronologies.

Temporal trends in sediment nickel levels vary somewhat within the Finger Lakes. For example, peak nickel levels occur between the early 1940s for Canandaigua Lake and the mid-1990s for Honeoye, Skaneateles, and Otisco Lakes. Sediment nickel profiles for several of the Finger Lakes cores are shown in Figure 9.30. While peak nickel levels within several of the lakes occur within surficial sediment layers, the levels do not vary greatly over time. For example, Skaneateles Lake sediments range from 56 – 72 mg/kg, while Honeoye Lake sediments range from 44.1 – 58.4 mg/kg.

The surficial sediments from all of the Finger Lakes cores, with the exception of Cayuga and Conesus Lakes, exceed both the TEL and PEL for nickel. Historical nickel levels (deep sediments) also consistently exceed these assessment values within each of the lakes. The uniform pattern observed for nickel levels, both spatially across lakes and temporally within given lakes, would suggest that nickel inputs are diffuse in nature and likely originating from either atmospheric transport or geological weathering. The environmental significance of the observed nickel levels in not clear.

Figure 9.30: Sediment nickel profiles from selected Finger Lakes



Zinc

Zinc (Zn) is found at relatively low levels within the earth's crust. Industrial uses of zinc include the manufacture of steel, dry cell batteries, pharmaceuticals, paint, rubber, dyes, wood preservatives, and the production of alloys (brass and bronze). Although zinc is an essential element in the human diet, ingestion or inhalation of elevated amounts of zinc can cause anemia and pancreatic damage.

Zinc levels within the Finger Lakes sediment cores were fairly uniform (see Table 9.18). For example, in those lakes for which intact sediment cores were available, peak zinc levels varied by approximately 40 percent. The lowest sediment zinc levels were observed in Keuka Lake, while the highest zinc levels observed are in Skaneateles Lake. The peak zinc level observed in Hemlock Lake sediments was 156 mg/kg, which is relatively consistent with the levels observed in most of the other Finger Lakes. However, as found with other metals, the peak zinc level observed within Cayuga Lake is unusually low.

Temporal trends for zinc within the Finger Lakes are inconsistent. For example, the trend within Conesus Lake is that of moderately declining zinc levels. On the other hand, the trend in Skaneateles Lake is toward moderately increasing levels of zinc. Vertical sediment profiles of zinc for these two lakes are presented in Figure 9.31.

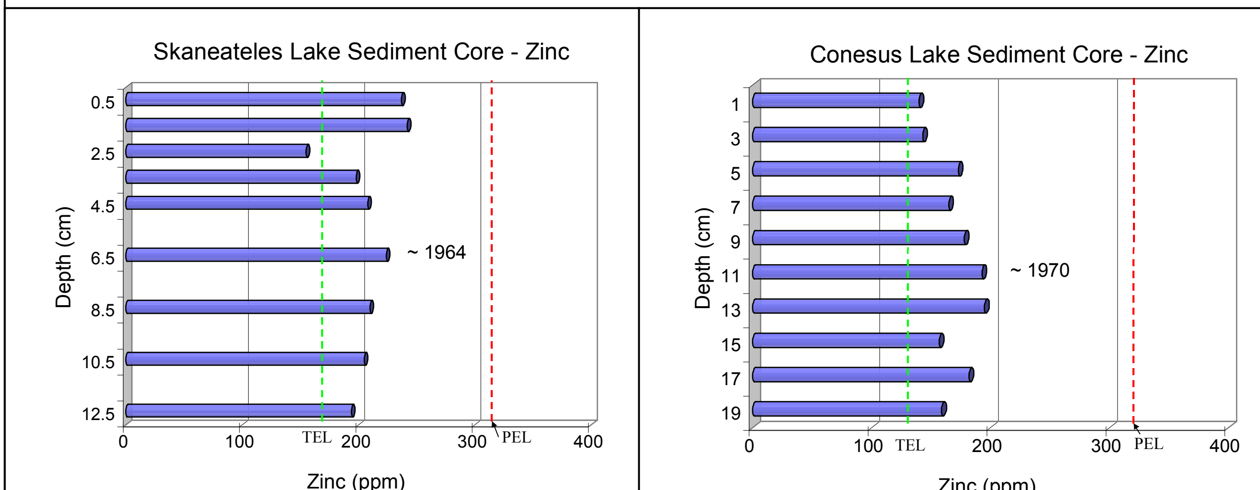
Table 9.18: Zinc in Finger Lakes sediment cores

Lake	*Peak Zn (mg/kg)*	*Depth (cm)/~ Age*
Otisco	194	24-25 (1963)
Skaneateles	242	1-2 (1989)
Owasco	180	15-16 (1957)
* Cayuga	96.5	na
Seneca	176	6-8 (1970)
Keuka	168	14-16 (1961)
Canandaigua	173	6-8 (1963)
Honeoye	170	0-3 (1996)
Canadice	180	2-4 (1983)
* Hemlock	156	na
Conesus	195	12-14 (1965)
TEL	123	-
SEL	315	-

* Cayuga Lake and Hemlock Lake cores showed disturbed sediment chronologies.

Zinc levels within the sediments of nearly all of the Finger Lakes (Cayuga Lake being the only exception) are above the TEL, however, all were below the PEL. As discussed with nickel levels above, the findings would suggest that zinc inputs to the lake are diffuse in nature, and likely stem from either atmospheric transport and/or geological weathering.

Figure 9.31: Vertical profiles of zinc in selected Finger Lakes cores



Chapter 10: Recommendations

As discussed above, the *Sediment Core Investigation* provides some important insight regarding water quality conditions within the Finger Lakes. However, the results of this investigation could be substantially enhanced by a number of additional activities as follows.

First, while the current study was successful in defining the chronology of chemical inputs within 9 of the 11 Finger Lakes, results were not sufficient for 2 of the lakes, namely, Cayuga Lake and Hemlock Lake. In both instances, radiometric findings were insufficient to define an accurate chronology of chemical patterns. It is suspected that the sediment cores from these two lakes were disturbed in some manner over time. Thus, it would be advantageous to revisit these 2 water bodies in an effort to complete our understanding of sediment chemical patterns within this important series of lakes. Equipment limitations with respect to maximum water depth for core collection was the likely reason for failure on Cayuga Lake, and future efforts should focus on deeper waters. The reason(s) for failure on Hemlock lake are not clear, however, it is recommended that follow-up sediment core investigations involve the collection of multiple cores and preliminary evaluation of radiometric markers in order to select the best candidate core for full assessment. A second rationale for revisiting Cayuga Lake relates to the fact that many of the inorganic results from the sediment core were well below levels observed within the other Finger Lakes, including Hemlock Lake. The reason(s) for this disparity are not clear at this point. Landuse patterns within the Cayuga Lake Watershed are not significantly different from those in certain other Finger Lakes watersheds, and, thus, the results are somewhat puzzling.

Second, *arsenic* findings within several of the Finger Lakes warrant additional study to assess both possible causes for observed increases within the upper sediments and possible environmental implications (human health and ecosystem). While limited water column sampling would appear to allay immediate concerns, follow-up investigation is certainly in order. For example, follow-up water column monitoring is warranted and should include: (a) lower analytical detection levels in the range of 1 ppb or better, given EPA's proposed revision in the MCL for arsenic, (b) better spatial resolution (both horizontal and vertical) to assess potential exposure, particularly in proximity to existing water intake locations, (c) better temporal resolution – particularly including measurements under differing dissolved oxygen conditions, and (d) arsenic speciation to determine the various forms of arsenic which are present. In addition, investigation of possible arsenic sources and its ecosystem processing within the Finger Lakes and surrounding watersheds is advisable. Finally, comparisons of the Finger Lakes arsenic findings with other lake sediment cores (particularly within the Lake Ontario Basin) would be of value.

Third, as with arsenic, *manganese* findings indicate significant enrichment of upper sediments within several of the Finger Lakes. While there are currently no established sediment quality assessment values for manganese, the levels observed, coupled with their coincidence with arsenic elevations, would warrant additional investigation. It is likely that the source(s) and/or mechanism(s) responsible for the observed arsenic enrichment are also responsible for the observed enrichment in manganese levels. Thus, it is recommended that any follow-up study of arsenic include investigation of manganese as well.

Fourth, *DDT* levels within the *biota* of several of the Finger Lakes (e.g., Conesus, Keuka, and Seneca Lakes) should continue to be monitored. It is important to determine future trends in DDT levels (e.g., decline, plateau, or increase) within predatory fish. An effort should be made to systematize this effort across each of the Finger Lakes to allow comparisons between lake systems.

Fifth, *PCB* results from this study were not definitive due to analytical detection limitations. Findings with respect to PCB congeners in several of the lakes (Conesus and Seneca Lakes) may warrant additional investigation. Core samples from each of the Finger Lakes for which PCB congener analyses were performed indicate that PCB congener levels exceed the TEL for total PCBs, and levels within several of the lakes (Otisco, Skaneateles, Owasco, Seneca, Keuka, Canadice, and Conesus Lakes) also exceeded the PEL for total PCBs. The fact that several of the lakes exhibited higher total PCB levels than did Canadice Lake (which currently has a fish consumption advisory) was somewhat surprising. It is recommended that other available information (e.g., fish flesh data, hazardous waste site information, etc.) be evaluated to determine if the observed PCB levels justify further investigation. Any future investigations should emphasize PCB congeners rather than Aroclors.

Sixth, the sediments from a number of the Finger Lakes were found to exceed the upper sediment assessment value for *nickel*. The significance of these findings should be assessed with respect to effects on resident biota and/or human health concerns, and the levels should be compared to levels in other parts of New York State.

Seventh, our investigation of *mercury* trends within the Finger Lakes was significantly hampered by analytical detection issues. The only acceptable, or reasonably complete, profile came from Seneca Lake and showed a moderate decline in mercury levels over the past several decades. It would be instructive to assess mercury trends in the other Finger Lakes. However, future sediment coring efforts will need to critically assess analytical detection issues if those efforts are to be fruitful. In particular, should Cayuga Lake and Hemlock Lake be revisited as discussed in recommendation 1 above, an effort should be made to utilize analytical methods capable of detecting mercury within those cores.

Eighth, observed *calcium* increases over the past half-century warrant additional investigation. The possible causes for the observed increases should be evaluated, and the ramifications of these increases should be assessed. In particular, the implications of increasing calcium levels as they relate to Zebra mussel population dynamics should be investigated.

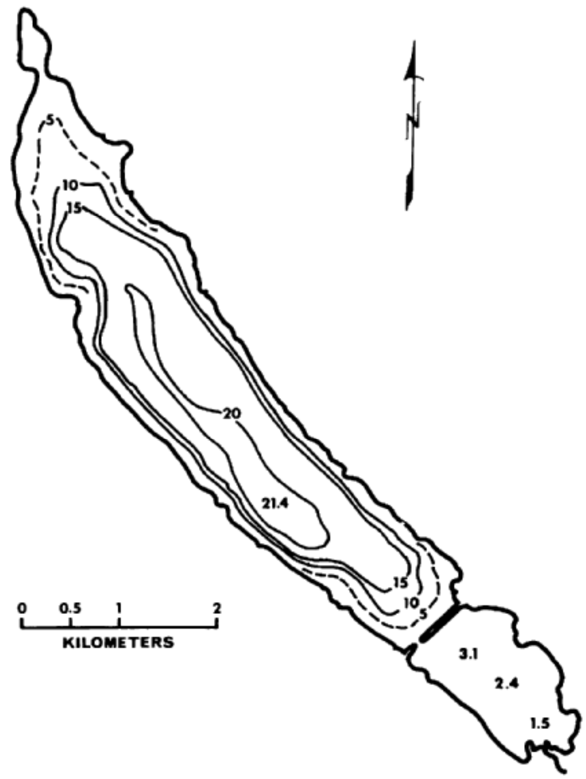
Chapter 11: Individual Lake Summaries

Previous discussions focused upon overall conditions within the 11 Finger Lakes and comparisons between the lakes. The purpose of this chapter is to provide a synopsis for each individual lake with respect to current conditions, chemical trends, and issues of concern. The lakes are discussed moving from east to west, beginning with Otisco Lake and finishing with Conesus Lake.

Otisco Lake

Otisco Lake (see Figure 11.1) is one of the smaller Finger Lakes. The lake and entire watershed are located in Onondaga County. The lake is a multi-purpose water body, and is a source of public water supply for the City of Syracuse. Otisco Lake has a water use classification of "AA", and is currently listed on the NY State PWL due to bathing impairments related to silt. The lake is somewhat unusual in that it is segmented by a causeway. The two segments are joined by a rather narrow opening on the southwest side of the structure. The southern (or southeast) portion of the lake is quite shallow and receives a large percentage of the inflow to the lake. This situation, coupled with the limited mixing between the two segments, results in significant differences in water quality conditions in the adjoining segments. The southeast portion of the lake tends to show significantly higher concentrations of phosphorus and chlorophyll a, and lower water clarity. The primary focus of this investigation is on the north-west, or main, portion of the lake.

Figure 11.1: Otisco Lake



Not intended for navigation purposes.

Otisco Lake is best characterized as eutrophic due to its chlorophyll *a*, water clarity, and hypolimnetic dissolved oxygen levels. Findings suggest that trophic conditions within the lake have increased moderately over the past several decades. This is reflected by the fact that total phosphorus and chlorophyll *a* levels have increased somewhat since the early 1970s. The hypolimnion of Otisco Lake becomes anoxic during the summer and early fall. It is unclear whether anoxic conditions within the hypolimnion of Otisco Lake are human-induced or natural in origin. Major ion trends within Otisco Lake over the past several decades indicate *declines* in calcium, magnesium, and alkalinity levels, and *increases* in sodium, chloride, and sulfate levels.

Sediment core findings from Otisco Lake show a sediment accumulation rate of 0.74 cm/year. This is the highest sediment accumulation rate of all the Finger Lakes. *Organic* chemical findings from the Otisco Lake sediment core are limited to PCB congeners (organochlorine pesticides were not run on these core samples) from a single core segment. The total PCB congener concentration found in this core segment is 245 ppb, which is in the middle range of levels found in the other Finger Lakes, and is above the TEL and slightly below the PEL for total PCBs. No clear Aroclor pattern was present in the sample. DDT levels were not assessed for Otisco Lake. *Inorganic* chemical findings from the Otisco Lake sediment core indicate that copper levels exceed the TEL within the surficial sediments. Furthermore, historical copper levels exceed the PEL for copper. Copper levels within Otisco Lake sediments raged from 35–308 ppm. Copper levels began to rise markedly in the early 1960s and reached a maximum concentration in the early 1970s. The trend in copper levels is likely the result of copper sulfate treatments for the control of algae that have occurred periodically within the lake since the early 1960s. Additional inorganic findings indicate: (a) Arsenic levels within Otisco Lake range from below detection to 11 ppm, and two of the mid-depth core segments exceed the TEL; (b) Calcium levels within Otisco Lake *sediments* have increased significantly during the past half-century, which is in contrast to *water column* trends over the past three decades. Calcium levels range from 17,600-94,900 ppm; (c) Chromium levels range from 28-58 ppm, and show no clear temporal trend - levels are above the TEL; (d) Manganese levels range from 890-1,660 ppm, and have increased modestly over the past several decades; (e) Nickel levels range from 28-58 ppm, with no apparent temporal trend, and are above the PEL; and (f) Zinc levels range from 120-194 ppm with no apparent temporal trend, and are above the TEL.

Recommendations for Otisco Lake are as follows. *First*, management actions to control cultural eutrophication within the watershed are advisable. There are currently several efforts underway to implement Best Management Practices (BMPs) within the watershed. Addition efforts should be directed at understanding the internal cycling of phosphorus within the lake and the impacts of anoxia within hypolimnetic waters. *Second*, water quality trends indicate an increase in the concentration of chloride and sodium levels within the lake. Thus, measures to control inputs of chloride and sodium to the lake should be implemented. *Third*, sediment core PCB findings would suggest that periodic monitoring of PCB levels in aquatic biota should be continued in Otisco Lake. *Fourth*, calcium increases observed within the sediments of Otisco Lake over the past several decades may lead to an exacerbation of Zebra mussel related issues within the lake in coming years. Thus, as with the other Finger Lakes, it is suggested that Zebra mussel population dynamics be studied within the lake. The study should include examination of population dynamics, investigation of the cause(s) of calcium increases within lake sediments, and the availability of pore water calcium to Zebra mussel populations. *Fifth*, as with a number of the Finger Lakes, nickel levels within Otisco Lake sediments exceed the TEL and PEL. Thus, efforts to understand the origin(s) and implications of these nickel levels are advisable.

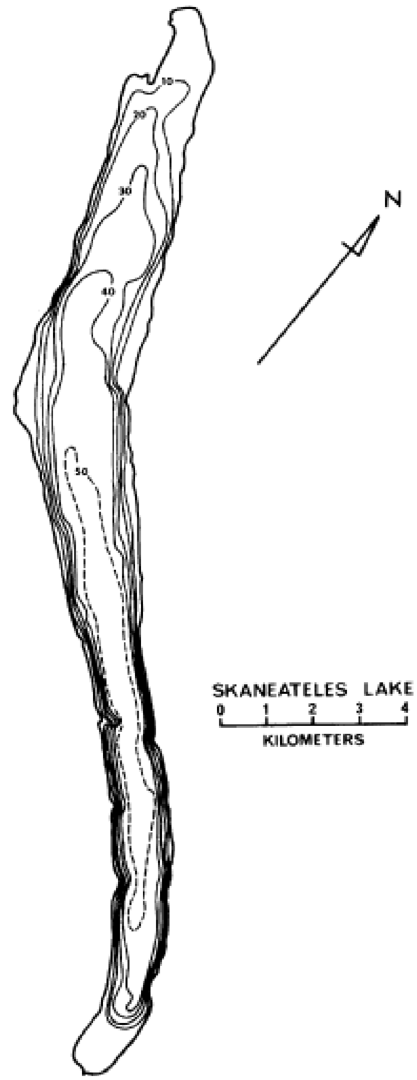
Skaneateles Lake

Skaneateles Lake (see Figure 11.2) is one of the six larger Finger Lakes. The lake itself is located in Onondaga County, with the watershed extending into Cayuga County and a small portion of Cortland County. The lake is a multi-use water body, and is a major source of public water supply for the City of Syracuse. Skaneateles Lake has a water use classification of "AA", and there are significant watershed protection measures in place within the watershed. In fact, Skaneateles Lake is one of only eight lakes within New York State with explicit statutory restrictions with respect to sewage discharge within the lake and watershed. Article 17, Title 17, section 17-1709 of New York State Environmental Conservation Law (ECL) states:

> "*No person or corporation shall cause or permit the fall, flow or discharge into Lake George or Skaneateles lake or any of their tributaries, of any sewage matter, or other foul, noxious or deleterious, solid or liquid matter or effluent from any sewage disposal plant, or any matter that may be declared such by the board of health of any municipality adjacent to such lakes where any such fall, flow or discharge shall occur.*" (NY State ECL, 2000).

Despite this protection, Skaneateles Lake is currently listed on the NY State PWL due to water supply concerns related to pathogens.

Figure 11.2: Skaneateles Lake



Not intended for navigation purposes.

Skaneateles Lake is an oligotrophic lake, as evidenced by total phosphorus, chlorophyll *a*, water clarity, and hypolimnetic dissolved oxygen levels. Findings suggest a marked reduction in trophic conditions over the past several decades. For example, the mean total phosphorus concentration observed during the present study is 4.0 ug/l, as compared to approximately 6.0 ug/l in the early 1970s. Similar reductions are apparent for chlorophyll *a*. The mean chlorophyll *a* concentrations measured in the early 1970s and the late 1990s, are approximately 2.0 ug/l and 0.7 ug/l, respectively. While water clarity levels have not changed by a similar degree, they have increased. Mean Secchi Disk depth measurements for the two periods were 6.6 m (1970s) and 7.7 m (1990s). These changes in trophic indicator levels are likely the result of management actions (e.g., phosphate detergent ban, on-site system controls, etc.) that have taken place over the past quarter century. The hypolimnetic waters of Skaneateles Lake remain well oxygenated throughout the growing season. Major ion trends within Skaneateles Lake over the past several decades indicate *declines* in magnesium, and sulfate levels, and *increases* in sodium, and chloride levels.

Sediment core findings from Skaneateles Lake indicate a sediment accumulation rate of approximately 0.2 cm/year. This is one of the lowest accumulation rates recorded within the Finger Lakes and reflects the relatively low productivity within the lake. *Organic* chemical findings from the Skaneateles Lake sediment core are limited to PCB congener levels from a single core segment. The total PCB congener concentration observed (286 ppb) is in the middle range of levels observed in the other Finger Lakes, and is above the TEL and slightly above the PEL for total PCBs. The pattern is not consistent with any specific Aroclor formulation, however, there were elevations in both lower chlorinated congeners and higher chlorinated congeners. DDT levels were not assessed in Skaneateles Lake. *Inorganic* chemical findings for Skaneateles Lake indicate a marked elevation in arsenic and manganese concentrations within the upper sediment layers of the lake. This pattern is also apparent in several other Finger Lakes cores. Arsenic and manganese levels within Skaneateles Lake sediments range from 10-34 ppm and 1,290-8,810 ppm, respectively. The cause(s) of the surficial sediment enrichment in arsenic and manganese is not certain – see discussion in Chapter 9. The arsenic levels detected in the upper sediment layers of Skaneateles Lake exceed both the TEL and PEL. As indicated earlier, follow-up water column monitoring conducted during 1999, albeit limited, did not detect arsenic within the water column. Additional inorganic chemical findings from the Skaneateles Lake sediment core analysis include the following: (a) Calcium levels range from 8,320-33,300 ppm, and have increased markedly over the past two decades; (b) Chromium levels range from 32-55 ppm, with no apparent temporal trends, and exceed the TEL but are below the PEL; (c) Copper levels range from 44-78 ppm and are generally static over time – levels exceed the TEL but are below the PEL, (d) Lead levels range from below detection to 102 ppm and have declined modestly over time, but remain above the TEL; (e) Nickel levels range from 56-72 ppm and remain largely constant over time, however, levels exceed both the TEL and PEL; (f) Zinc levels range from 155-242 ppm and have increased somewhat in the last decade, or so. Zinc levels exceed the TEL.

Recommendations for Skaneateles Lake and its surrounding watershed are as follows. *First*, efforts to control nutrient loading to Skaneateles Lake over the past several decades appear to have been effective, as evidenced by reductions in primary productivity (algal growth) over the intervening time period. Therefore, it is recommended that these measures continue in the future. *Second*, chloride and sodium levels have increased within Skaneateles Lake over the past several decades. Thus, measures to control the input of salt to the lake should be implemented and/or enhanced. *Third*, sediment core PCB findings would suggest that continued monitoring of PCB levels in aquatic biota is warranted within Skaneateles Lake. *Fourth*, calcium increases observed within the sediments of Skaneateles Lake over the past several decades may lead to an exacerbation of Zebra mussel related issues within the lake in coming years. Thus, as with the other Finger Lakes, it is suggested that Zebra mussel population dynamics be studied within the lake. The study should include examination of population dynamics, investigation of the cause(s) of calcium increases within lake sediments, and the availability of pore water calcium to Zebra mussel populations. *Fourth*, as discussed above, sediment core findings indicate an enrichment of arsenic and manganese within the upper sediment layers of Skaneateles Lake, as well as several other Finger Lakes. It is recommended that additional investigation of this phenomenon be undertaken. Future study should focus upon the following: (a) implications for public exposure to arsenic, particularly via drinking water supplies – while preliminary investigations proved encouraging, additional study is warranted, and (b) the cause(s) for the observed enrichment in arsenic and manganese levels within upper sediments – is the underlying cause(s) of the observed enrichment related to increased arsenic loading within the watershed, physio-chemical processing of the compounds, reductions in primary productivity within the lake, etc. *Fifth*, as with a number of the other Finger Lakes, nickel levels within the sediments of Skaneateles Lake are above the TEL and PEL. Thus, additional study regarding: (a) the source(s) of nickel to the Skaneateles Lake watershed, and (b) possible adverse environmental effects is warranted.

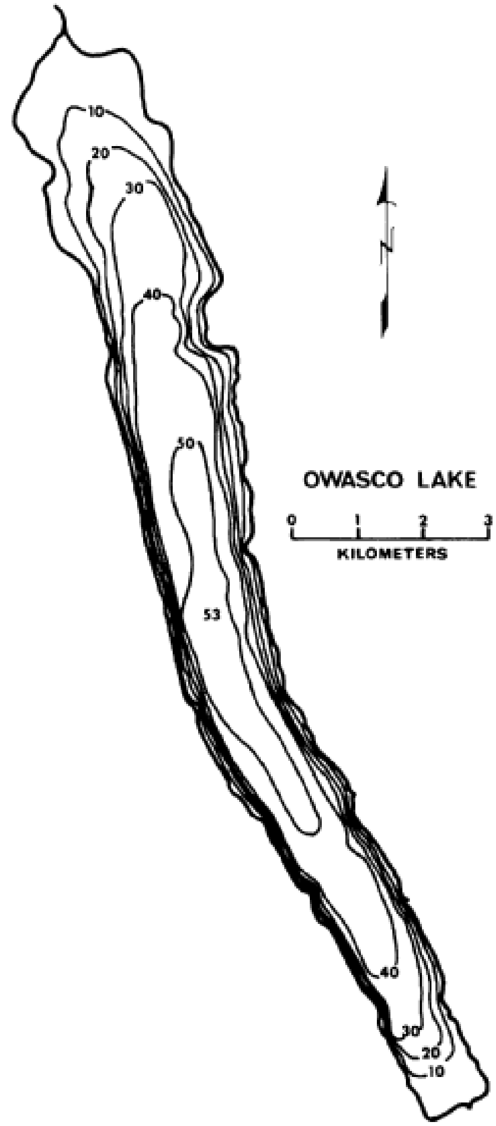
Owasco Lake

Owasco Lake (see Figure 11.3) is one of the six larger Finger Lakes. The lake itself is entirely within Cayuga County, while the watershed includes parts of Cayuga County and Tompkins County. Owasco Lake is a multi-use water body. The lake has a water use classification of "AA(T)", and serves as a source of water supply for the City of Auburn and the Town of Owasco. As with Skaneateles Lake, Owasco Lake is explicitly protected by NY State ECL. Article 17, Title 17, section 17-1704 of New York State Environmental Conservation Law (ECL) states:

> "*No person or corporation shall cause or permit the fall, flow or discharge into the surface waters of the Owasco Lake watershed extending from the city dam on the outlet to the existing Moravia village outfall sewer on the inlet, of any sewage matter, or other foul, noxious or deleterious, solid or liquid matter or effluent from any wastewater disposal system located therein except for those operating under a duly authorized permit from the state or county health departments and except for run-off from accepted agricultural practices*." (NY State ECL, 2000).

Despite this protection, Owasco Lake is currently listed on the NYSDEC PWL due to bathing impairments related to pathogens.

Figure 11.3: Owasco Lake



Not intended for navigation purposes.

Owasco Lake is best characterized as mesotrophic with respect to all three trophic indicators. The lake has shown a moderate decline in primary productivity over the past 2-3 decades as demonstrated by the reduction in chlorophyll *a* levels from 5.5 ug/l in the early 1970s to 3.8 ug/l in the late 1990s. The other two trophic indicators have shown less significant changes, with water clarity levels declining only marginally, and total phosphorus levels remaining, essentially, constant. As in earlier years, the hypolimnion of Owasco Lake remains fairly well oxygenated throughout the growing season. Major ion trends within Owasco Lake over the past several decades indicate *declines* in calcium and sulfate levels, and *increases* in sodium and chloride levels. Owasco Lake was the only one of the Finger Lakes not to show a marked decline in magnesium concentration over the past several decades. The reason for this exception is not clear. Sediment core findings from 1998 regarding arsenic enrichment (see further discussion below) prompted follow-up water column sampling of all the Finger Lakes during 1999. This monitoring recorded only one sample with a detectable level of arsenic – this was an epilimnetic sample taken from Owasco Lake in September 1999 at a depth of approximately 4 m. The arsenic concentration of this sample was 10 ug/l, which is just above the detection level. Interestingly, Owasco Lake did not exhibit the marked arsenic enrichment within surficial sediments that was apparent in several of the other Finger Lakes.

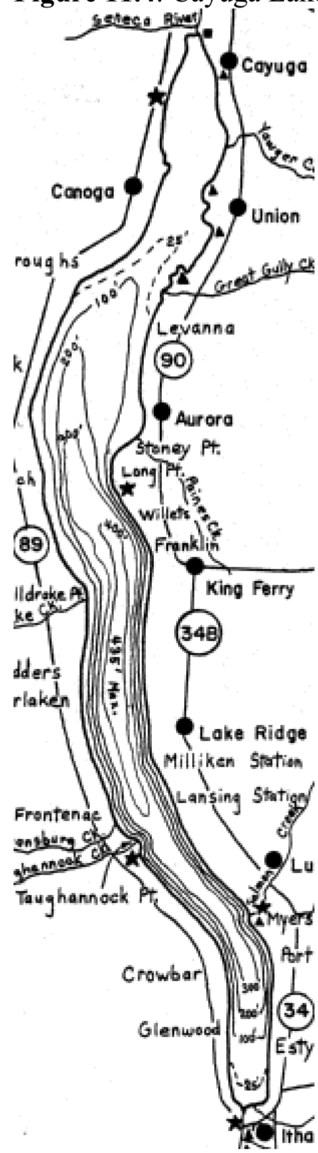
Sediment core findings from Owasco Lake indicate a sediment accumulation rate of 0.38 cm/year. This is in the middle range of sediment accumulation rates observed within the Finger Lakes. *Organic* chemical findings from the Owasco Lake sediment core are limited to PCB congeners from a single core segment. The sediment PCB congener level was 374 ppb, which is in the upper range of levels observed within the Finger Lakes, and exceeds the PEL for total PCBs. The congener pattern was dominated by lower chlorinated congeners, indicative of Aroclor 1242 or 1016. DDT levels were not assessed in Owasco Lake. *Inorganic* chemical findings from the Owasco Lake sediment core are as follows: (a) Arsenic levels range from 4-14 ppm and demonstrate a slight increase over the past several decades. Arsenic levels are above the TEL but below the PEL; (b) Calcium levels range from 33,600-90,200 ppm, and show a marked increase beginning in the early 1960s, with a nearly three fold increase since the 1940s; (c) Chromium levels range from 27-52 ppm and show significant fluctuation over time. Chromium levels are above the TEL, but below the PEL; (d) Copper levels range from 29-44 ppm and are moderately elevated within surficial sediments - levels are above the TEL; (e) Lead levels range from below detection to 73 ppm. Lead levels reach a maximum in the mid-1960s and show a marked decline over the past 3-4 decades. Lead levels are above the TEL, but below the PEL; (f) Manganese levels range from 596-3,630 ppm and show significant enrichment within surficial sediment layers; (g) Nickel concentrations range from 39-66 ppm and fluctuate somewhat over time, but show no consistent trend. Nickel levels are above the TEL and PEL; and (h) Zinc levels range from 115-176 ppm and also fluctuate somewhat over time. Zinc levels are above the TEL but below the PEL.

Recommendations for Owasco Lake are as follows. *First*, unlike most of the other large Finger Lakes, Owasco Lake showed little reduction in ambient total phosphorus levels between the 1970s and 1990s. This would suggest that Owasco Lake has not had a significant reduction in external phosphorus loading over the past several decades. Therefore, efforts to reduce external nutrient loading to Owasco Lake should continue. *Second*, chloride and sodium levels within Owasco Lake have increased over the past several decades. Thus, measures to control the input of salt to the lake should be implemented. *Third*, sediment core PCB findings from Owasco Lake would suggest that monitoring of PCB levels in aquatic biota should be continued. *Fourth*, sediment core findings indicate a moderate degree of arsenic enrichment, and a more pronounced, manganese enrichment in Owasco Lake surficial sediments. While sediment arsenic enrichment is less pronounced in Owasco Lake than in some of the other Finger Lakes, the fact that a water column sample did show a detectable level of arsenic, would suggest the need to include Owasco Lake in future arsenic investigations within the Finger Lakes – see Sediment Core recommendations. *Fifth*, calcium increases observed within the sediments of Skaneateles Lake over the past several decades may lead to an exacerbation of Zebra mussel related issues within the lake in coming years. Thus, as with the other Finger Lakes, a Zebra mussel monitoring program is recommended for Owasco Lake. The study should include examination of Zebra mussel population dynamics, investigation of the cause(s) of calcium increases within lake sediments, and an assessment of the availability of calcium in sediment pore water to Zebra mussel populations. *Sixth*, as with a number of the Finger Lakes, nickel concentrations within Owasco Lake sediments are elevated. Thus, additional study of the origin(s) and possible environmental effects of nickel levels may be warranted.

It is important to reiterate that this study did not assess bacteriological conditions within the lakes. Given past issues regarding beach closures and coliform contamination within the lake, it would seem prudent to continue efforts to identify and control bacteriological contaminant sources to the lake.

Cayuga Lake

Figure 11.4: Cayuga Lake



Not intended for navigation purposes.

Cayuga Lake (Figure 11.4) is the longest of the Finger Lakes, and second only to Seneca Lake with respect to lake volume. The lake basin itself is within Cayuga, Seneca, and Tompkins Counties, while the watershed extends slightly into three additional counties, namely, Cortland, Schuyler, and Tioga Counties. Cayuga Lake is a multi-use water body, and supports uses ranging from water supply to wastewater assimilation. Cayuga Lake serves as a source of water supply for a number of municipalities within the watershed, including the City of Ithaca, the Towns of Dryden and Lansing, and the Villages of Aurora, Cayuga, Cayuga Heights, and Seneca Falls. The City of Ithaca, which is the largest municipality within the Finger Lakes Region, is situated at the southern end of the lake. Cayuga Lake carries several water use classifications ranging from "AA(T)"for most of the deep basin to "B" at the northern end of the lake.

Several segments of Cayuga Lake are listed on the NYSDEC PWL. The northern end of the lake is listed on the PWL due to swimming and boating impairments related to aquatic plant growth. The primary pollutant of concern in this portion of the lake is nutrients. The southern end of the lake is listed on the PWL due to water supply issues and swimming impairments. The primary pollutants in this portion of the lake are sediments and nutrients. The southern end of Cayuga Lake is also listed on the 303(d) list.

Given the variation in water quality conditions present in Cayuga Lake, monitoring sites were established in both the main lake (proximate to Taughannock Falls State Park) and within the shallow southern delta (see Table 4.1 for approximate coordinates of monitoring sites). For the purposes of this report, the southern delta or "shelf" of the lake is defined as extending from the south-eastern terminus of the lake north for approximately 2.0 km to McKinney's Point and on the west side of the lake from the confluence with Indian Creek to the south-west end of the lake – this is approximately the area carrying a water use class of "A" (NYSDOS, 1999). The main, or deep portion of the lake is defined as extending from the northern edge of the south shelf north to Cooneys Corners Road (Lat. 42 47 51, Long. 76 40 47.9). The northern shelf is defined to be from Cooney's Corners Road north to the end of the lake. The remainder of this discussion will focus upon the main portion of the lake and the southern shelf. Unfortunately, resource limitations and logistical considerations precluded sampling of the northern portion of Cayuga Lake.

Main Lake

Water quality conditions in the main portion (deep basin) of Cayuga Lake are generally good. From a trophic perspective, the main lake is best characterized as borderline between oligotrophic and mesotrophic. Results from this investigation indicate seasonal means for total phosphorus, chlorophyll *a*, and Secchi Disk depth of approximately 10 ug/l, 3.5 ug/l, 4.0 m, respectively. Other studies [Sterns and Wheler, 1997, and Upstate Freshwater Institute (UFI), 2000)] show somewhat different trophic conditions for the deep lake – see Table 11.1. These differences are likely due to variations in site selection, sampling methodology, etc. Trends from this study indicate a decline in the major trophic indices over the last several decades. Total phosphorus levels exhibit the most pronounced decline - from approximately 18 ug/l during the late 1960s to approximately 10 ug/l in the later 1990s. Less pronounced changes are apparent for chlorophyll *a* (4.2 ug/l to 3.5 ug/l) and Secchi Disk depth (3.6 m to 4.0 m). The disparity in the level of change for the various trophic indicators is somewhat puzzling. The reduction in productivity levels within the main lake is generally viewed as a positive development. The marked declines in total phosphorus levels are likely the result, at least in part, of the nutrient control measures discussed earlier. However, it is possible that the introduction of Zebra mussels to the lake have also contributed to observed nutrient reductions. As in the past, the hypolimnetic waters of the Cayuga Lake appear to remain fairly well oxygenated throughout the growing season. The trend for major ions within the main portion of Cayuga Lake over the past several decades indicate substantial reductions in sodium and chloride, and more modest declines in sulfate and alkalinity levels. The trend observed in sodium and chloride levels within Cayuga Lake continues a trend observed during previous studies (Effler, et al. 1989). Effler, et al. modeled chloride concentrations within the lake and concluded that concentrations would continue to decline to a steady-state concentration of approximately 30 mg/l by approximately circa 2000.

Sediment core findings from Cayuga Lake are limited due to several issues. *First*, radiometric findings were not sufficient to establish sediment chronologies from the sediment core (see earlier discussion). Previous studies (Yager, 2001) indicate an average sediment accumulation rate of approximately 0.4 cm/year in Cayuga Lake, which is in the middle range of sediment accumulation rates observed within the Finger Lakes. Given that radiometric dating proved unsuccessful, chemical findings from the Cayuga Lake sediment core can only be interpreted as composite values. *Second*, chemical findings from the Cayuga Lake sediment core indicate remarkably low levels for a number of chemical compounds. *Organic* chemical findings indicate total PCB levels are the lowest observed within the Finger Lakes cores, and total DDT levels were the second lowest for the Finger Lakes. *Inorganic* chemical findings for Cayuga Lake also suggest unusually low levels of many of the trace elements investigated during this study. For example, the concentrations of arsenic, chromium, copper, lead, nickel, and zinc in the Cayuga Lake sediment core are the lowest of all of the Finger Lakes. In some instances, chemical levels observed within the Cayuga Lake sediment core are *less than half* the levels observed in the other Finger Lakes (including Hemlock Lake – which also exhibited a radiometric profile indicative of disturbed sediments). Thus, it is believed that the chemical levels observed within the Cayuga Lake core are not indicative of levels for Cayuga Lake sediments in general.

There are several possible explanations for these observations. *First*, it is conceivable that the Cayuga Lake sediment core is substantially lower in organic material than are cores from the other Finger Lakes. Organic material is particularly effective in sorbing many chemicals. Thus, if the Cayuga Lake sediment core contained less organic material relative to the sediment cores from the other Finger Lakes, it would have a diminished capacity to sorb chemical substances. It is possible that the Cayuga Lake core could have been from a "sand bar" or shelf area – and may have contained a disproportionate amount of large grained or sand particles. Unfortunately, organic carbon levels (and particle sizes) were not assessed in the Cayuga Lake core, so evaluation of this hypothesis cannot be accurately assessed. As indicated earlier, the sample location for the Cayuga Lake sediment core had to be adjusted (moved to shallower water) due to equipment limitations (winch cable length). By comparison, the Cayuga Lake sediment core was collected in approximately 65 m of water, whereas, the Seneca Lake core was collected in approximately 130 m of water. *Second*, it is possible that the sample location for the Cayuga Lake sediment core was subject to elevated depositional rates due to productivity levels within the south lake. If this were the case, the large influx of organic material could have a dilutional effect on other chemical substances in the core and result in lower chemical concentrations – recall that chemical levels are reported on a weight per weight basis. As will be discussed below, productivity levels within the southern end of Cayuga Lake are markedly higher than in the main lake. Furthermore, it is possible to interpret the radiometric data (see Figure 9.3) as indicating a much higher depositional rate than discussed previously. For example, if one assumes this to be an intact sediment core, then the cesium peak occurs at 30 cm, which would indicate a sediment accumulation rate of greater than 1 cm/year. However, the lack of a cesium horizon, as well as past sediment core investigations would suggest that such a high accumulation rate is unlikely.

Recommendations for the main portion of Cayuga Lake are as follows. *First*, comparison of recent findings to those of several decades ago, indicate that trophic conditions within the main portion of Cayuga Lake have declined somewhat over the past several decades. This trend is generally viewed as a positive development, and nutrient control efforts should be continued within the watershed - particularly within the south lake (see following discussion). *Second*, the sediment core findings from Cayuga Lake are not particularly informative, and given recent concerns regarding hazardous waste site(s) in the southern catchment, it would be prudent to collect at least one additional sediment core from the lake. Given the difficulties encountered during the present study several recommendations are suggested regarding future coring efforts. Sediment core(s) should be collected from deep-water locations (> 100 m) to maximize the likelihood of obtaining intact radiometric profiles (undisturbed sediments). In addition, future sediment core investigations should consider extracting multiple sediment cores. The entire set of cores would not need to be fully analyzed, but preliminary analyses (radiometric dating) could be conducted on several of the cores to determine which of the cores would be most suitable for more extensive chemical evaluation. It might also be informative to consider collecting several sediment cores along the north-south axis of the lake to evaluate longitudinal gradients within the lake. Should an additional sediment core(s) be collected from the lake, it is recommended that PCB analyses focus upon congener analyses as opposed to Aroclor analyses. In addition, methods for mercury analyses should be chosen to achieve acceptable detection levels (at least one order of magnitude below existing sediment quality guidance levels).

South Lake

Water quality conditions within the southern end of Cayuga Lake have been of concern to area residents for several decades. Issues of concern include: (1) permanent closure (in the early 1960s) of a public swimming beach due to water clarity and bacteriological issues, (2) drinking water concerns related to sediments and trihalomethane (THM) precursors, and (3) aesthetic concerns related to algal blooms, macrophyte growth, odors, etc.

As was highlighted in the July 4, 1998 issue of the Ithaca Journal (1998), concerns about the absence of a public beach at the southern end of Cayuga Lake have existed for several decades. Up until the early 1960s, a public bathing beach was operational at the southern end of Cayuga Lake (Stewart Park). However, public records indicate that water quality concerns about the Stewart Park beach increased during the early 1960s. The beach went through a series of temporary closures during the early 1960s due to a combination of limited water clarity and bacteriological concerns. There was also at least one drowning at the beach during this time frame that was, at least in part, attributed to lack of water clarity in the area. The beach was closed permanently after the 1964 swimming season. The viability of reopening a public beach in this area is not known at this time due to a lack of understanding regarding water quality dynamics within this portion of the lake.

There are also concerns regarding THM levels in the regional public water supply (PWS) taken from Cayuga Lake. THMs are a class of organic chemicals formed as a by-product of certain disinfection processes (e.g., chlorination). It is important to note that the disinfection of public water supplies has been an extremely successful public health effort and has greatly reduced the threat of waterborne diseases such as typhoid, cholera, and dysentery. However, chlorination of potable water supplies, which is the primary method of disinfection in use today, also results in the production of undesirable chemical compounds such as THMs. This class of organic compounds has been linked to certain forms of cancers and other adverse health effects. THMs are formed as a result of a chemical reaction(s) between chlorine and natural organic matter (NOM). Several factors play a role in the formation of THMs including the concentration of NOM, the chlorine dosage, and the length of chlorine contact time. The USEPA has issued a *Stage 1 Disinfectant and Disinfection Byproducts Rule* which calls for all public water supply (PWS) systems serving greater than 10,000 people to meet certain criteria related to THMs. The current rule requires that total THMs not exceed 100 ug/l based on a running annual average (EPA, 1999). More stringent requirements are also scheduled for implementation in several years under the Stage 2 rule. The Bolton Point Municipal Water System (BP-MWS), which draws water from Cayuga Lake, is located approximately 4 km (2.5 miles) from the southern end of the lake. Total THM levels in finished water from the BP-MWS ranged from 44-116 ug/l during 1999 (Bolton Point Municipal Water System, 2000). Thus, THM levels are a concern within the BP-MWS. The plant has been investigating methods to reduce THM levels over the past few years (BP-MWS, 2000). However, it is likely that reductions in NOM – via reductions in loadings of sediments and nutrients to the south lake would assist plant managers in controlling THM levels within the water supply system.

Finally, there are also concerns within the southern end of Cayuga Lake relating to aesthetics. Citizen complaints include noxious odors, nuisance algal blooms, and extensive growth of rooted aquatic plants, among other complaints. Levels of concern tend to vary over time due to the natural variations in water quality conditions within the lake. The concerns are believed to stem primarily from issues of cultural eutrophication and sediment dynamics.

Findings from this investigation indicate a substantial gradient in total phosphorus levels from the southern terminus of Cayuga Lake to the main lake site. Mean total phosphorus levels within the south lake were 17.2 ug/l, versus approximately 10 ug/l at the main lake site. Other trophic parameters (chlorophyll *a* and Secchi Disk depth) did not show a similar longitudinal gradient during this study. However, other investigations [Sterns and Wheler, 1997, and UFI, 2000)] have documented such gradients for other trophic parameters - see Table 11.1. These studies also indicate that total phosphorus levels within the south lake regularly exceed the New York State total phosphorus guidance value of 20 ug/l. The UFI study, sponsored by Cornell University as part of its Lake Source Cooling (LSC) permit conditions, provides the best spatial resolution in water quality conditions within the south lake. The UFI study indicates that water quality conditions vary substantially within the south shelf area. In general, findings suggest that trophic indicators tend to be higher (elevated total phosphorus and chlorophyll *a*, and lower water clarity) on the eastern side of the southern shelf than on the western side. This is consistent with predominant circulation patterns that exist in the south-lake which tend to move in a counter-clockwise direction, and thus, carry tributary loads to the eastern side of the lake. Unfortunately, historical records (prior to the mid to late 1990s) for trophic parameters in the south lake are not available, and thus, long-term temporal changes could not be assessed. There is also some indication that Zebra mussels may be influencing water quality conditions within the south-lake and may account for the general trend toward lower levels of phosphorus and chlorophyll a, and increases in water clarity. As discussed earlier, the presence of Zebra mussels can significantly modify aquatic ecosystems due to their efficient filtration of suspended particulate material. While a formal investigation has not been a part of this study, visual observations during the latter half of this investigation indicate significant numbers of young Zebra mussels affixed to aquatic macrophytes within the south-lake (see Figure 5.20).

Table 11.1: Trophic indicator findings from past water quality investigations of Cayuga Lake

	Total P (ug/l)		*Chlorophyll a (ug/l)*		*Secchi Disk (m)*		
Year	*Main Lake*	*S. Lake*	*Main Lake*	*S. Lake*	*Main Lake*	*S. Lake*	*Reference*
1994	22.4	30.8	4.1	8.9	2.1	1.5	Sterns and Wheler, 1997
1995	16.3	23.7	4.8	6.8	2.2	1.7	Sterns and Wheler, 1997
1996	13.2	25.7	3.4	7.6	2.5	1.9	Sterns and Wheler, 1997
1998	14.7	26.5	4.8	5.7	-	-	UFI, 2000
1999	10.6	15.9	4.7	4.4	-	-	UFI, 2000

Note: Station(s) varied between studies

Current use impairments within the south end of Cayuga Lake, coupled with water quality findings from this and other studies, indicate that conditions within the south lake are degraded. However, while it is clear that water quality conditions within the south lake are degraded, current understanding as to the causes of the degradation and water quality dynamics within the south lake are limited. There are significant data gaps within both the south lake and the contributory watershed that need to be more fully defined and understood.

There are several studies underway within the Cayuga Lake watershed that should contribute to a better understanding of water quality issues within the south lake. These efforts include both in-lake activities and watershed activities. In-lake activities include: (1) water column sampling by the Upstate Freshwater Institute (UFI) in association with the Cornell LSC discharge permit and by NYSDEC as part of the Long-term Synoptic Study, and installation of a Robotic Underwater Sampling Station (RUSS) unit and associated hydrodynamic study being conducted by Cornell University. Watershed activities currently underway include event-based monitoring efforts on Six Mile creek being conducted by USGS and the City of Ithaca, planned event-based monitoring of Fall Creek and the Cayuga Inlet by the NYSDEC, and watershed modeling efforts being conducted within the Fall Creek watershed by Cornell.

Beyond the ongoing and planned studies discussed above, several additional measures are recommended for the southern end of Cayuga Lake to more fully characterize water quality dynamics within the south lake. *First*, given the reality of limited resources, it is important that the activities already underway be coordinated to maximize the efficiency and minimize the redundancy of existing studies. This should include regular meetings to discuss study plans, findings, and related topics. *Second*, an effort should be initiated to develop detailed material loading estimates for all three major tributaries to the south lake. This effort will require the collection of water samples in conjunction with flow measurements proximate to the mouths of the three major tributaries to the south-lake. Fortunately, the USGS currently maintains flow gages on all three tributaries. In addition to flow measurements, water samples will need to be collected from the tributaries. At a minimum, sample parameters should include total phosphorus, soluble reactive phosphorus, total suspended solids, and chlorides. Tributary material loads are often dominated by high flow events. Thus, it is essential that water samples be collected across a broad spectrum of hydrologic conditions, and that every effort be made to capture significant *storm events*. Given the importance of capturing storm-events, the study should be conducted over a several year period so as to increase the likelihood of capturing as many high-flow events as possible. *Third*, a deterministic, coupled, watershed/lake mass balance model should be developed for the southern catchment to determine the relative importance of the various forcing conditions within the south lake segment. *Fourth*, a total maximum daily load (TMDL) should be developed to address the various issues of concern within the south lake. This effort should focus on current use impairment issues within this lake segment including preclusion of public swimming beach, THM issues, and aesthetic concerns.

Seneca Lake

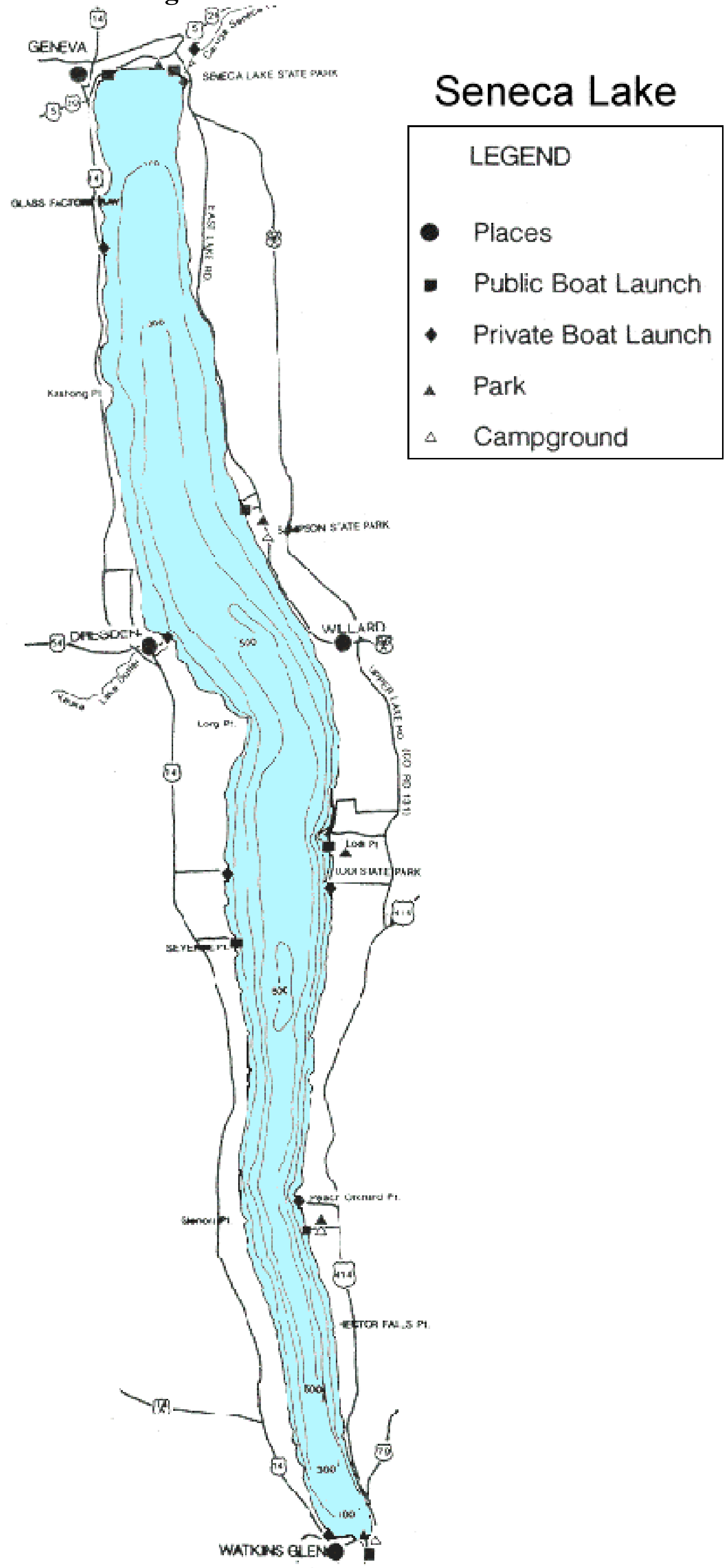
Seneca Lake (see Figure 11.5) is the largest of the Finger Lakes with respect to lake volume, and is the second longest of the 11 lakes. The lake itself is situated in Schuyler, Seneca, and Yates County, while the watershed also extends into Chemung and Ontario Counties. Seneca Lake is a multi-use water body and serves as a source of water supply for the City of Geneva and the Villages of Ovid, Waterloo, and Watkins Glen. As with Cayuga Lake, Seneca Lake has several water use classifications ranging from "AA(TS)" within much of the deep basin to "B" at the northern and southern ends of the lake. Seneca Lake is listed on the NYSDEC PWL due to water supply concerns relating to salt levels within the lake.

The current trophic state of Seneca Lake is best characterized as borderline between oligotrophic and mesotrophic. The mean total phosphorus concentration, chlorophyll *a* concentration, and Secchi Disk depth recorded during the later 1990s are 9.8 ug/l, 2.4 ug/l, and 6.0 m, respectively. These findings suggest that Seneca Lake has exhibited a significant decline in primary productivity over the past several decades. A comparison of the present findings to those from the early 1970s indicate that total phosphorus levels have declined by approximately 30 percent, while chlorophyll *a* levels have declined by more than three fold. In addition, water clarity levels have approximately doubled during the same time period. The findings for total phosphorus and water clarity are similar in magnitude to those observed in a number of the other large Finger Lakes, however, the decline in chlorophyll *a* levels was significantly larger (on a percentage basis) than that observed in most of the other lakes. While it is likely that nutrient control measures instituted in the intervening time frame could account for the observed changes in total phosphorus levels within the lake, the magnitude of changes observed in water clarity and, particularly, chlorophyll *a* seem unusually large. Other researchers have suggested that the introduction and proliferation of Zebra mussel populations within Seneca Lake has had a dramatic effect on these trophic parameters. This would seem a reasonable hypothesis given the magnitude of change and local observations regarding Zebra mussel increases. As with previous studies, hypolimnetic waters within Seneca Lake appear to remain well oxygenated throughout the growing season. It should be noted, however, that due equipment limitations of this study, vertical profiles from this study were limited to 100 m. Thus, given the significant depths of Seneca Lake, it is not possible to draw conclusions regarding deeper portions of the lake. Major ion trends within Seneca Lake indicate significant *declines* in chloride and sodium levels, and a smaller decline in calcium levels, as well as *increases* in sulfate and alkalinity levels. The marked decline in chloride and sodium levels would appear to call into question the premise that concentrations observed during the 1960s and 1970s were the result of natural conditions associated with the depth of the lake basin – see earlier discussion.

Sediment core findings from Seneca Lake indicate a sediment accumulation rate of 0.23 cm/year. This is in the lower range of sediment accumulation rates observed within the Finger Lakes. *Organic* chemical findings from the Seneca Lake sediment core are limited to DDT and its metabolites, and PCB congeners. Total DDT levels within Seneca Lake appear to have declined significantly over the past several decades (see Figure 9.6). Levels peaked at 153 ppb in approximately 1968. Surficial sediment concentrations of total DDT are 40 ppb, which is above the TEL but substantially below the PEL. Total PCB congener levels observed in the Seneca Lake sediment core are 466 ppb (408 ppb after adjustment for DDE), which is in the upper range of PCB levels observed within the Finger Lakes, and exceed the PEL for total PCBs. These values are from a single core segment taken from 4-6 cm in depth, which is estimated to represent sediments deposited in the late 1970s. The levels of PCBs within the surficial sediments were not evaluated. *Inorganic* chemical findings from the Seneca Lake sediment core are as follows: (a) Arsenic levels within the Seneca Lake sediment core range from 12.3-19.0 ppm, and are either slightly below or slightly above the PEL. The upper sediment layer was above the PEL for arsenic. This tendency toward higher arsenic levels within surficial sediments is apparent in several of the Finger Lakes. As discussed earlier, subsequent water column sampling, albeit limited, failed to detect arsenic (> 10 ug/l) in either the epilimnion or the hypolimnion – see further discussion above; (b) Cadmium levels range from 1.6-2.2 ppm and are largely constant over the recorded time period. Sediment cadmium levels are above the TEL but below the PEL; (c) Calcium concentrations range from 5,250-37,200 ppm and have increased substantially over the past several decades – there are no guidance values for calcium; (d) Chromium levels range from 26.2-30.1 ppm, and reach a peak in approximately 1970. Surficial sediment concentrations are below the TEL and PEL; (e) Copper levels range from 44.2-61.8 ppm and reach a maximum in about 1970. Surficial sediment concentrations are above the TEL but below the PEL for copper; (f) Lead levels range from 52.6-80.0 ppm and have declined over the past several decades. Lead levels within surficial sediments are above the TEL, but below the PEL; (g) Mercury levels range from 0.1-0.28 ppm and have declined by approximately 50 percent over the past 4 decades. Surficial concentrations are below the TEL and PEL for total mercury; (h) Nickel levels range from 39.9-46.1 ppm and are largely constant over the past half century. Nickel levels are above the TEL but below the PEL; and (i) Zinc levels range from 139-176 ppm and are largely constant over the past half century. Concentrations are above the TEL but below the PEL for zinc.

Recommendations for Seneca Lake are as follows. *First*, study results indicate that nutrient control measures within the Seneca Lake watershed have been quite successful over the past several decades as evidenced by the decline in total phosphorus levels over the intervening time frame. Thus, continued efforts with respect to the control of nutrient inputs to the lake are warranted. *Second*, while trophic conditions within Seneca Lake have “improved” somewhat over the past several decades, the trophic status of the lake is somewhat complicated by the presence of Zebra mussels (and possibly Quagga mussels) within the lake. Thus, it is recommended that a program to quantify Zebra mussel dynamics within Seneca Lake be initiated. *Third*, findings indicate that sodium and chloride levels within Seneca Lake are in decline, however, these observations would suggest that ambient concentrations are originating from other than natural conditions. Previous investigations have concluded that the elevated levels of sodium and chloride within Seneca Lake are the result of the intersection of the lake basin with salt strata. However, if this were the case one would expect the level of these ions to remain relatively static. The observation that levels are changing would seem to warrant additional study as to the cause(s) of the observed changes. *Fourth*, PCB findings from the Seneca Lake sediment core indicate that total PCB levels exceed the PEL. There have also been indications that PCB levels in certain sport fish are elevated (although, not above current FDA action levels). These findings warrant continued monitoring of biota for PCB levels in the future. *Fifth*, although surficial sediments in Seneca Lake do not exhibit a significant up-tick in arsenic levels as observed in several of the other Finger Lakes, arsenic levels within the sediments of Seneca Lake are fairly high – surficial concentrations exceed the PEL. Thus, additional investigation is warranted regarding: (a) source(s) of arsenic within the Seneca Lake benthic sediments, and (b) environmental cycling and availability of arsenic. *Sixth*, as with a number of the Finger Lakes, nickel concentrations within Seneca Lake sediments are elevated. Thus, additional study of the origin(s) and possible environmental effects of nickel levels may be warranted.

Figure 11.5: Seneca Lake



Not intended for navigation purposes.

Keuka Lake

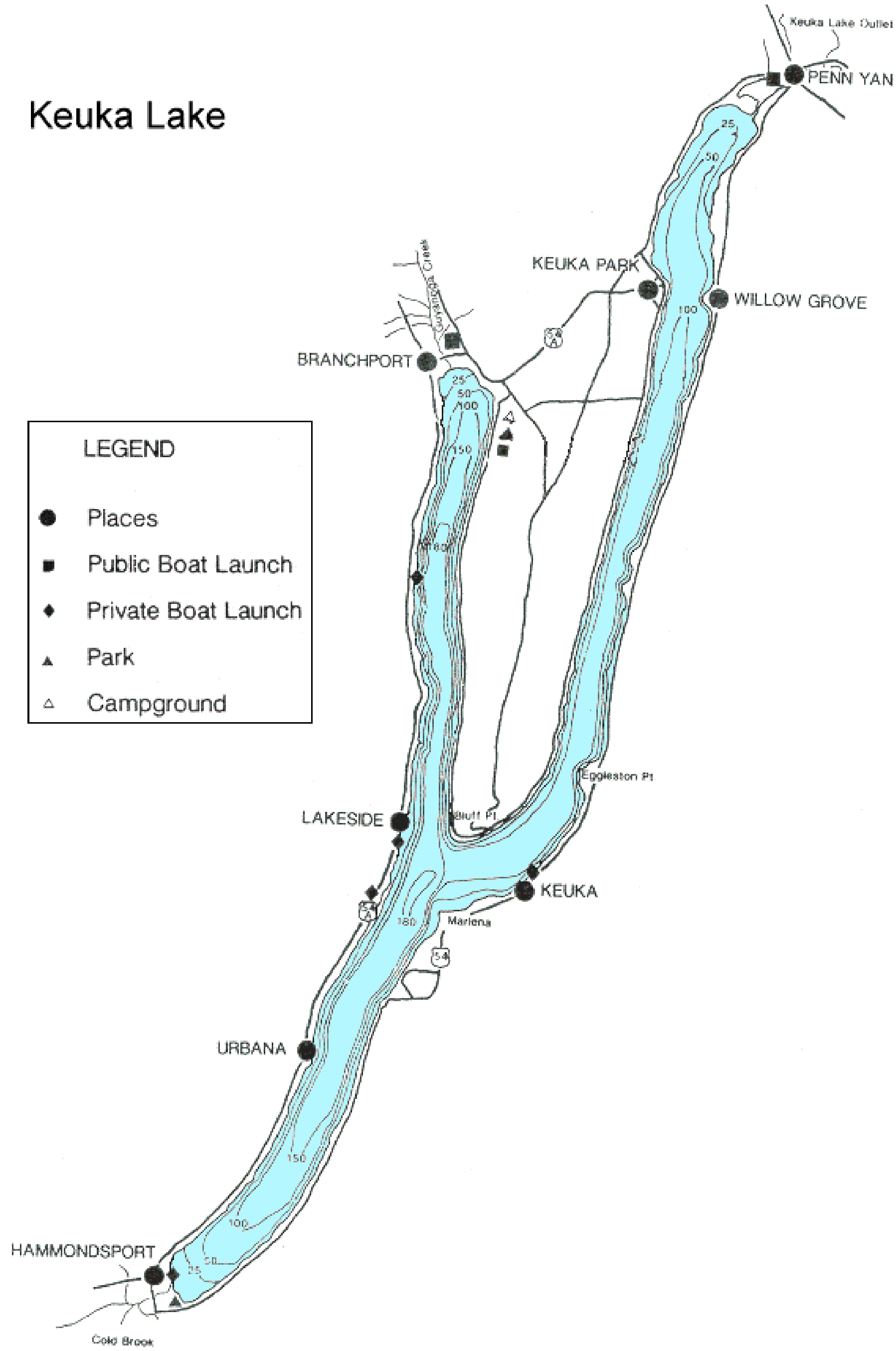
Keuka Lake (see Figure 11.6) is readily distinguishable from the other 11 Finger Lakes due to the characteristic "Y" shaped of the lake basin. The lake and watershed are situated in Steuben and Yates Counties. The lake is a multi-purpose waterbody, and serves as a source of water supply for the Villages of Hammondsport and Penn Yan. Keuka Lake has a water use classification of "AA(TS)", and is listed on the NYSDEC PWL list due to a fish consumption advisory relating to DDT and its metabolites.

The current trophic state of Keuka Lake is best characterized as borderline between oligotrophic and mesotrophic. The mean total phosphorus concentration, chlorophyll *a* concentration, and Secchi Disk depth measured during the later 1990s are 8.0 ug/l, 2.8 ug/l, and 5.6 m, respectively. These finding indicate that trophic conditions within Keuka Lake have declined substantially over the last several decades. A comparison of the present findings to those from the early 1970s indicate that total phosphorus levels and chlorophyll *a* levels have declined by approximately 40 percent. In addition, water clarity levels increased by approximately 15 percent. Furthermore, as has been the case historically, the water column of Keuka Lake remains well oxygenated during the growing season. Major ion trends within Keuka Lake over the past several decades indicate *declines* in magnesium and sulfate levels, and *increases* in calcium, sodium, chloride, and alkalinity levels.

Sediment core findings from Keuka Lake indicate a sediment accumulation rate of 0.37 cm/year, which is in the middle range of sediment accumulation rates within the Finger Lakes. *Organic* chemical findings for Keuka Lake are limited to DDT and its metabolites, and total PCBs. Total DDT levels within the sediments of Keuka Lake have decline markedly over the last several decades, from a peak of nearly 400 ppb in the late 1970s to current levels of 72 ppb (as measured in surficial sediments). This decline is consistent with findings for fish flesh analyses from the lake. While the DDT trends are encouraging, DDT levels remain above the TEL, however, they are below the PEL. Total PCBs were measured from a single sediment core segment taken from Keuka Lake. The core segment represents sediments deposited in the mid 1980s, and measured 449 ppb or 289 ppb when adjusted for DDE levels. The later value is probably more accurate given historical DDT levels within the lake. Thus, total PCB levels within Keuka Lake are in the middle range of PCB concentrations measured in Finger Lakes sediments, and are above the TEL and PEL for total PCBs. Fish flesh data from the mid 1980s showed limited elevation in Aroclors 1254 and 1260 (from below detection to 0.288 ppm) – the current FDA action level for PCBs is 5 ppm. *Inorganic* chemical findings for Keuka Lake indicate a marked increase in arsenic and manganese concentrations in the upper sediments of the lake. This pattern is also apparent in several other Finger Lakes cores. Arsenic and manganese levels within Keuka Lake sediments range from 15.4-47.1 ppm and 1,360-5,650 ppm, respectively. The cause(s) of the surficial sediment enrichment in arsenic and manganese is not certain – see discussion in Chapter 9. The arsenic levels detected in the upper sediment layers of Keuka Lake exceed both the TEL and PEL. As indicated earlier, subsequent water column monitoring conducted during 1999, albeit limited, did not detect arsenic (at > 10 ppb) within the water column (epilimnion or hypolimnion) – see further discussion above. Additional inorganic findings from the Keuka Lake sediment core investigation are as follows: (a) Calcium levels range from 2,160-3,680 ppm and are fairly constant over time, which stands in contrast to many of the other Finger Lakes, which have shown marked increases in calcium concentrations over the past several decades; (b) Chromium levels range from 26.7-30.2 ppm and reach maximum levels in approximately 1960. Surficial sediment chromium levels are below both the TEL and PEL; (c) Copper levels range from 37.3-45.1 ppm and peak in the mid-1980s. Copper concentrations in surficial sediments exceed the TEL but are below the PEL; (d) Lead levels range from 36.1-69.4 ppm and have declined substantially since a peak in the mid 1960s. However, lead concentrations in surficial sediments remain above the TEL, but below the PEL; (e) Nickel levels range from 42.5-50.3 ppm and remain fairly constant over time, however, levels exceed both the TEL and PEL for nickel; (f) Zinc levels range from 128-168 ppm and are fairly constant over the documented time interval, with surficial sediments exceeding the TEL but below the PEL.

Recommendations for Keuka Lake are as follows. *First*, Keuka Lake has exhibited a substantial reduction in productivity levels over the past several decades as evidenced by changes in the levels of trophic indicators. These changes, which are generally viewed as a positive development, are most likely the result of nutrient control measures implemented over the last several decades. Thus, it is recommended that efforts to control nutrient releases within the watershed be continued. *Second*, DDT findings indicate a substantial decline in total DDT levels within the sediments of Keuka Lake over the past several decades. However, DDT levels remain relatively high within surficial sediment layers. Thus, continued monitoring of DDT levels in biota (e.g., fish) within the lake is advisable. *Third*, PCB findings from the Keuka Lake sediment core indicate some elevation in PCB levels within the Lake. However, past analyses of fish tissue do not indicate significant PCB levels within sport fish. Given these somewhat conflicting findings, it is advisable to continue PCB analyses within sport fish in conjunction with DDT analyses discussed above. *Fourth*, as with several of the Finger Lakes, sediment core findings from Keuka Lake show a marked enrichment in arsenic and manganese within surficial sediments. Water column sampling within Keuka Lake, subsequent to the core findings, failed to show detectable levels of arsenic in the water column of Keuka Lake. However, these water column findings should be considered preliminary due to the limited scope of sampling (both spacially and temporally) and the analytical detection levels of the methods employed. Thus, additional study of arsenic and manganese within the watershed is warranted – the focus of future study should include efforts to determine the cause(s) of the observed arsenic and manganese enrichment, and further evaluation of possible human exposure and/or environmental effects of the arsenic levels observed. *Fifth*, elevated nickel levels were also observed within the sediments of Keuka Lake. Assessment of possible sources of nickel to the watershed and the environmental implications of the levels observed is warranted. *Sixth*, as with the other Finger Lakes, it is recommended that a Zebra mussel monitoring program be initiated on Keuka Lake. The study should include an examination of Zebra mussel population dynamics within the lake, and an assessment of possible ecological effects resulting from their presence.

Figure 11.6: Keuka Lake



Not intended for navigation purposes.

Canandaigua Lake

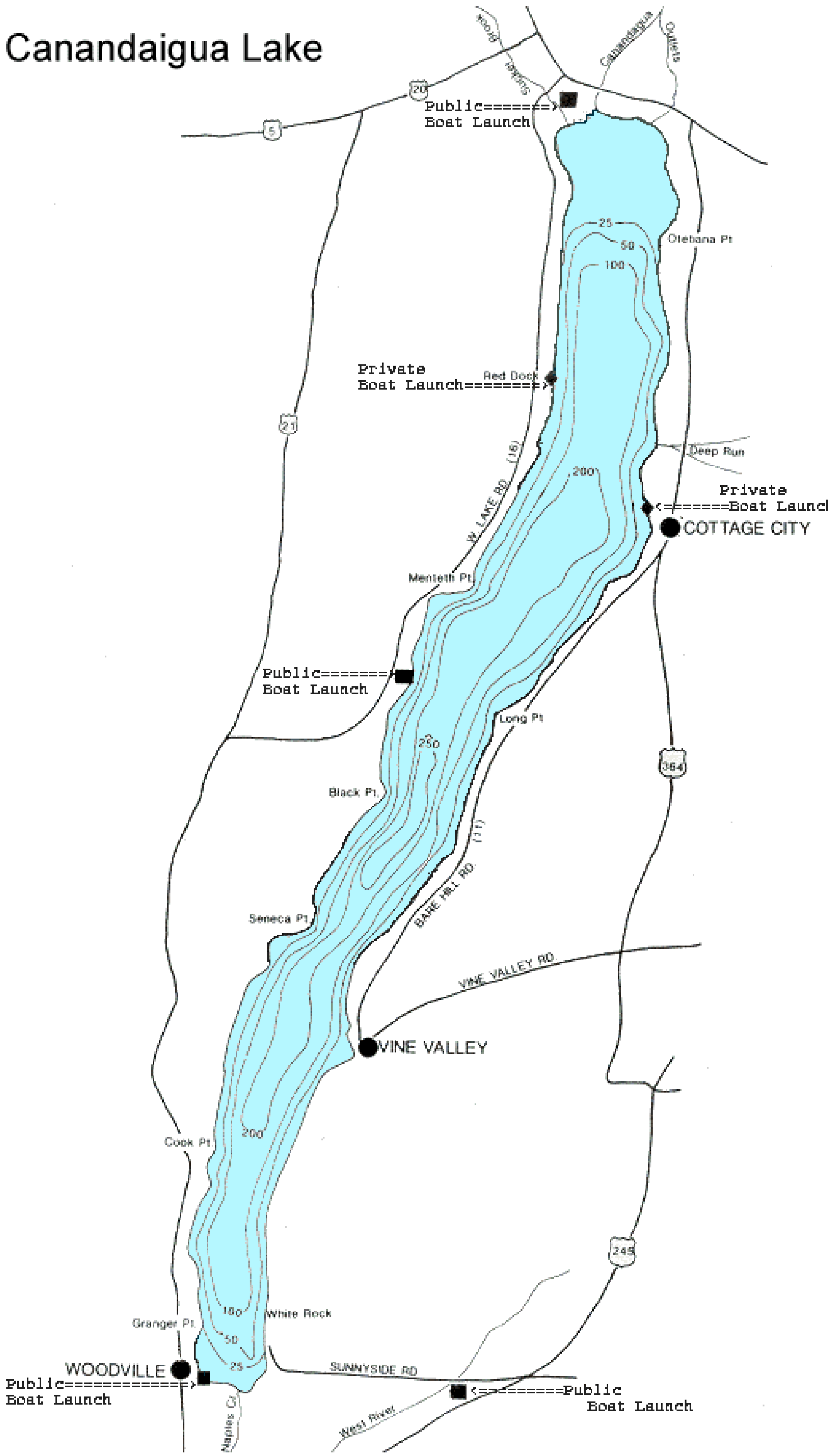
Canandiagua Lake (see Figure 11.7) is one of the six larger Finger Lakes. The lake is within Ontario and Yates Counties, while the watershed also extends into Livingston and Steuben Counties. Canandaigua Lake is a multi-purpose lake and serves as a source of water supply for the City of Canandaigua, and the Villages of Bristol Harbor, Gorham, Newark, Palmyra, and Rushville. The lake has a water use classification of "AA(TS)", and is listed on the NYSDEC PWL due to a fish consumption advisory relating to PCBs.

The current trophic level of Canandaigua Lake is best characterized as oligotrophic, as evidenced by the current level of trophic indicators. The mean total phosphorus concentration, chlorophyll *a* concentration, and Secchi Disk depth measured during the later 1990s are 8.0 ug/l, 2.8 ug/l, and 5.6 m, respectively. These finding indicate that trophic conditions within Canandaigua Lake have declined substantially over the last several decades. A comparison of the present findings to those from the early 1970s indicate that total phosphorus levels and chlorophyll *a* levels have declined by approximately 40-50 percent. In addition, water clarity levels increased by approximately 50 percent. Furthermore, as has been the case historically, the water column of Canandaigua Lake remains well oxygenated during the growing season. Trends for major ions within Canandaigua Lake over the past several decades indicate *declines* in magnesium and sulfate levels, and *increases* in sodium, chloride, and alkalinity concentrations.

Sediment core findings from Canandaigua Lake indicate a sediment accumulation rate of approximately 0.2 cm/year, which is in the lower range of depositional rates observed within the Finger Lakes. *Organic* chemical findings for Canandaigua Lake are limited to DDT and its metabolites. Total DDT levels within the sediments of Canandaigua Lake have declined markedly over the last several decades, from a peak of slightly more than 200 ppb in the early 1960s to current levels of less than 20 ppb (as measured in surficial sediments). The total DDT levels measured in the upper sediments are below the PEL and only slightly above the TEL for total DDT. Unfortunately, total PCB levels for the Canandaigua Lake core were not analyzed due to a study oversight. *Inorganic* chemical findings for Canandaigua Lake indicate a marked increase in arsenic and manganese concentrations in the upper sediment layer of the lake. As discussed above, this pattern is also apparent in several other Finger Lakes cores. Arsenic and manganese levels range from 13.8-45.0 ppm and 1,050-4,960 ppm in Canandaigua Lake sediments, respectively. The cause(s) of the surficial sediment enrichment in arsenic and manganese is not certain – see discussion in Chapter 9. The arsenic levels detected in the upper sediment layers of Canandaigua Lake exceed both the TEL and PEL. Subsequent water column monitoring conducted during 1999, albeit limited, did not detect arsenic (at > 10 ppb) within the water column of Canandaigua Lake – see further discussion above. Additional inorganic findings from the Canandaigua Lake sediment core investigation are as follows: (a) Calcium levels range from 6,660-18,900 ppm within the sediments of Canandaigua Lake and are somewhat atypical, in that while the core exhibits a substantial increase in calcium levels from the 1960s to the 1970s, it also exhibits higher calcium levels prior to the 1940s. This "U" shaped pattern in sediment calcium levels is unique within the Finger Lakes; (b) Chromium levels range from 24.1-27.6 ppm and remain fairly constant over time. The surficial sediment chromium concentration is below both the TEL and PEL; (c) Copper levels range from 33.1-42.2 ppm and are fairly uniform over the recorded time period. The surficial sediment copper concentration is below both the TEL and PEL for copper; (d) Lead levels range from 34.2-70.4 ppm and have declined substantially since the early to mid-1960s. However, lead concentrations in surficial sediments remain above the TEL, although they are below the PEL; (e) Nickel levels range from 45.1-49.5 ppm and are fairly constant over time, however, levels exceed both the TEL and PEL for nickel; (f) Zinc levels range from 133-173 ppm and appear fairly constant over the documented time interval, with surficial sediments exceeding the TEL but below the PEL.

Recommendations for Canandaigua Lake are as follows. *First*, it is likely that nutrient control measures over the past several decades have contributed to a significant reduction in trophic conditions within the lake – this is generally interpreted as a positive development. Thus, efforts to control the input of nutrients (particularly phosphorus) to the lake should be continued in the future. *Second*, while it is probable that nutrient control measures are responsible for a significant portion of the reduction in primary productivity, there are also indications that Zebra mussels may be influencing trophic conditions within Canandaigua Lake. The presence of Zebra mussels within the lake could have significant ecological consequences for the lake. Thus, as with the other Finger Lakes, it is recommended that a Zebra mussel monitoring program be initiated on Canandaigua Lake. The study should include an examination of Zebra mussel population dynamics within the lake, and an assessment of possible ecological effects resulting from their presence. *Third*, as with many of the Finger Lakes, chloride and sodium levels within Canandaigua Lake have increased over the past several decades. Thus, efforts to control the use and release of salt within the watershed should be implemented. *Fourth*, while sediment core PCB results are not available for Canandiagua Lake due to a study oversight, it would be prudent to continue monitoring biota for chlorinated organic compounds, given past findings. *Fifth*, as with several of the Finger Lakes, arsenic enrichment was evident in the surficial sediments of Canandaigua Lake. Additional investigation concerning the cause(s) of the observed enrichment, and possible environmental consequences of these findings is warranted. *Sixth*, as with several of the Finger Lakes, nickel levels within the sediments of Canandaigua Lake are above the TEL and PEL. Additional investigation as to the origins and possible ecological consequences of these nickel levels is warranted.

Figure 11.7: Canandaigua Lake

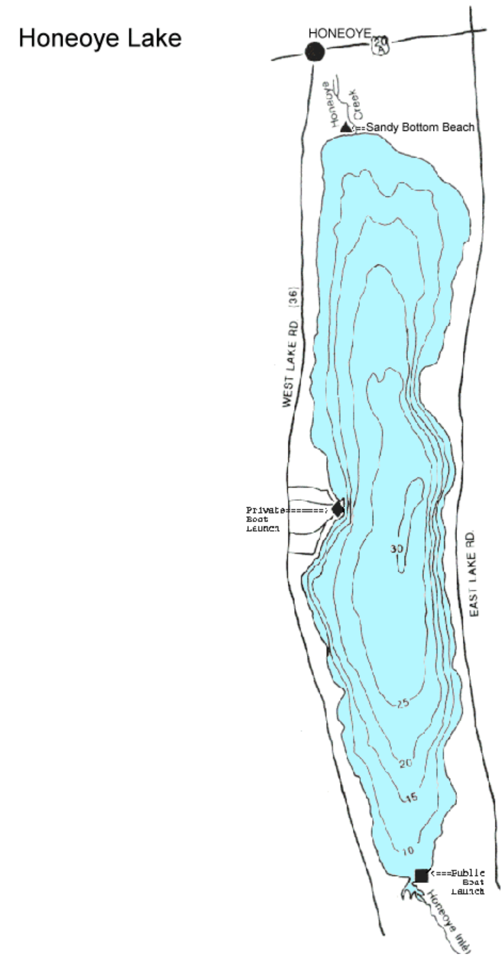


Not intended for navigation purposes.

Honeoye Lake

Honeoye Lake (see Figure 11.8) is one of the smaller Finger Lakes, and has the smallest volume and average depth of any of the lakes. The lake and watershed are located in Ontario County. Honeoye Lake is a multi-purpose lake, and is the only one of the Finger Lakes not currently used as a source of public water supply. However, the lake has a water use classification of "AA", and likely serves as a water supply for individual home owners around the lake. Honeoye Lake is currently listed on the NYSDEC PWL due to water supply concerns relating to nutrients.

Figure 11.8: Honeoye Lake



Not intended for navigation purposes.

The current trophic level of Honeoye Lake is best characterized as eutrophic, as evidenced by existing levels of major trophic indicators. The mean epilimnetic total phosphorus concentration, chlorophyll *a* concentration, and Secchi Disk depth measured during the later 1990s are 24.2 ug/l, 8.4 ug/l, and 3.7 m, respectively. While the trophic level of Honeoye Lake remains similar to that of the early 1970s, the levels of major trophic indicators are considerably different from those observed in the early 1070s. Findings from the early 1970s show mean levels of total phosphorus, chlorophyll *a*, and Secchi Disk depth of 19 ug/l, 25.7 ug/l, and 3.0 m, respectively. Thus, total phosphorus levels have increased, chlorophyll *a* levels have declined, and Secchi Disk depth has apparently increased. The hypolimnion of Honeoye Lake frequently becomes hypoxic during the growing season. The cause(s) and/or consequences of this dissolved oxygen depletion are uncertain. For example, while dissolved oxygen depletion is, no doubt, a consequence of both natural and human-related processes, the relative importance of the two factors is unclear. Trends for major ions within Honeoye Lake indicate an *increase* in calcium, chloride, sodium, and alkalinity levels, and a *decrease* in sulfate and magnesium levels.

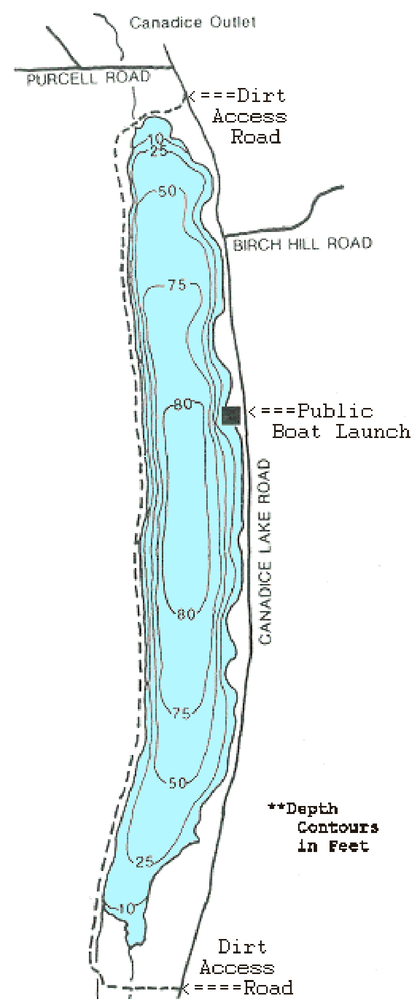
Sediment core findings from Honeoye Lake indicate a sediment accumulation rate of approximately 0.5 cm/year, which is on the high end of accumulation rates observed within the Finger Lakes. *Organic* chemical findings from the Honeoye Lake sediment core are limited to PCB congeners from a single sediment core segment (3-6 cm – approximately 1990). The total PCB concentration from this core segment is 69 ppb, which is on the low end of total PCB levels observed in the Finger Lakes. This is above the TEL for total PCBs, but below the PEL. *Inorganic* chemical findings from the Honeoye Lake sediment core are as follows: (a) Arsenic levels range from 7.4-19.4 ppm, and exhibit an increase in concentration during the 1970s, with a plateau thereafter. Surficial sediment arsenic concentrations are above the TEL and slightly above the PEL. Sediment arsenic enrichment is apparent in a number of the Finger Lakes cores, and the cause(s) of the arsenic enrichment is not certain at this juncture – see discussion in Chapter 9. Subsequent water column monitoring conducted during 1999, albeit limited, did not detect arsenic (at > 10 ppb) within the water column of Honeoye Lake – see further discussion above. (b) Chromium levels range from 25.4-32.5 ppm and remain fairly constant over time. Chromium levels are below both TEL and PEL; (c) Copper levels range from 24.6-44.8 ppm and remain fairly constant over time. Copper levels are below TEL and PEL levels; (d) Lead levels range from 32.2-62.9 ppm and show a decline from the early 1970s until approximately 1990, but appear to have increased of late. This apparent increase is based on a single core segment. However, the observed rate of decline in lead levels in Honeoye Lake from the 1970s to the 1990s (see Figure 9.17) is somewhat less pronounced than observed in several other Finger Lakes. Thus, it is possible that there is a relatively "new" source of lead within the watershed. The lead level within the surficial sediment layer is above the TEL, but below the PEL; (e) Manganese levels range from 661-2,410 ppm and exhibit a significant increase in concentration over time; (f) Nickel levels range from 44.1-58.4 ppm and remain fairly constant over the recorded time interval. Nickel levels are above the TEL and PEL; (g) Zinc levels range from 121-170 ppm and also remain fairly constant over much of the recorded time interval, however, a moderate increase in concentrations is apparent in the surficial sediment layer. Zinc concentrations are above the TEL, but below the PEL.

Recommendations for Honeoye Lake are as follows. *First*, total phosphorus levels observed within Honeoye Lake are above the current New York State guidance value for total phosphorus. In addition, hypoxic conditions occur within the hypolimnion of the lake on a seasonal basis. Thus, it is important that nutrient control measures within the watershed be enhanced. This should include an assessment of nutrient loading to the lake and an evaluation of permitted loads. Furthermore, as with several of the smaller Finger Lakes, nutrient dynamics within Honeoye Lake are not fully understood. Therefore, it is suggested that additional study of nutrient dynamics within Honeoye Lake be conducted. The focus of such a study should be to more fully define both external and internal inputs of nutrients to the lake. *Second*, the presence of Zebra mussels has been documented within Honeoye Lake. Zebra mussels are believed to be having significant ecological effects on several of the Finger Lakes. Thus, a Zebra mussel monitoring program is recommended for Honeoye Lake. *Third*, as with many of the Finger Lakes, chloride and sodium levels have increased over the past several decades. Thus, efforts to control the use and release of salt within the watershed should be encouraged. *Fourth*, as with several of the Finger Lakes, arsenic levels within the sediments of Honeoye Lake have increased of late. Thus, efforts to understand the cause(s) and possible environmental consequences of the observed increases in arsenic is suggested. *Fifth*, as with several of the Finger Lakes, nickel levels within the sediments of Honeoye Lake are above the TEL and PEL. Additional investigation as to the origins and possible ecological consequences of these nickel levels is warranted.

Canadice Lake

Canadice Lake (see Figure 11.9) is one of the five smaller Finger Lakes, and has the smallest surface area and drainage area of any of the lakes. The lake is located in Ontario County, while its watershed also extends into Livingston County. Canadice Lake is primarily used for water supply by the City of Rochester. The lake has a water use classification of "AA", and has fairly stringent watershed protection measures in place. Canadice Lake is listed on the NYSDEC PWL due to a fish consumption advisory related to PCBs.

Figure 11.9: Canadice Lake



Not intended for navigation purposes.

The trophic state of Canadice Lake is best characterized as borderline between oligotrophic and mesotrophic. The mean epilimnetic levels for major trophic indicators during the late 1990s are 8.3 ug/l, 2.5 ug/l, and 5.0 m, for total phosphorus, chlorophyll *a*, and Secchi Disk depth, respectively. These findings indicate a slight reduction in trophic conditions within Canadice Lake over the past several decades. The hypolimnion of Canadice Lake becomes hypoxic/anoxic during the mid to late summer. Dissolved oxygen levels drop below 1 mg/l within portions of the hypolimnion for sustained periods of time. The cause(s) and/or consequences of this dissolved oxygen depletion are uncertain. For example, while dissolved oxygen depletion is obviously a consequence of both natural and human-related processes, the relative importance of the two factors is unclear. Trends for major ions within Canadice Lake indicate an *increase* in the concentration of calcium, chloride, and sodium, and a *decrease* in sulfate and magnesium levels. In addition, there appears to be a slight decline in alkalinity levels.

Sediment core findings from Canadice Lake indicate a sediment accumulation rate of approximately 0.2 cm/year. This is one of the lowest accumulation rates observed within the Finger Lakes. *Organic* chemical findings for Canadice Lake are limited to DDT and its metabolites, and PCBs. DDT results from the Canadice Lake sediment core are fairly limited – most core segments were below detectable levels for DDT and its metabolites. However, two core segments did show detectable levels of the metabolites DDE and DDD. These findings indicate that levels of these chemicals have declined over the past several decades within Canadice Lake. PCB findings from the Canadice Lake sediment core are also quite limited. Study results did show discernable levels of Aroclor 1254 within the 2-4 cm sediment segment (mid 1980s). PCB congeners, analyzed from the 4-6 cm sediment segment (early 1970s), indicated a total PCB concentration of 352 ppb. This is in the middle range of levels observed in other Finger Lakes cores. One unexpected finding worth noting in the Canadice Lake core is that the congener pattern observed in the 4-6 cm section (Aroclor 1242) is different from both the fish flesh pattern observed during the past decade, or so, and from the pattern observed in the core segment immediately above (2-4 cm) which was considered consistent with higher chlorinated Aroclor compounds (Aroclor 1254 and/or 1260). *Inorganic* chemical findings from the Canadice Lake sediment core indicate a significant increase in arsenic and manganese levels over the past several decades. This phenomenon of arsenic and manganese enrichment within upper sediment layers is also apparent in a number of the other Finger Lakes. Arsenic and manganese levels within Canadice Lake sediments range from 10.4-29.3 ppm and 712-1,800 ppm, respectively. The cause(s) of the arsenic and manganese enrichment in surficial sediments is not certain – see discussion in Chapter 9. The arsenic levels observed in the surficial sediments of Canadice Lake are above the TEL and PEL. Subsequent water column monitoring conducted during 1999, albeit limited, did not detect arsenic (at > 10 ppb) within the water column (epilimnion or hypolimnion) of Canadice Lake – see further discussion above. Additional inorganic chemical findings for the Canadice Lake core are as follows: (a) Calcium levels range from 1,500-2,540 ppm and have increased substantially over the past several decades. This pattern is present in many of the Finger Lakes; (b) Chromium levels range from 21.4-28.6 ppm and appear fairly stable over time. Chromium levels are below the TEL and PEL; (c) Copper levels range from 31.1-45.9 ppm and are fairly stable over time, however, levels show a spike in the early 1980s and a subsequent drop in the early 1990s. Copper levels are near the TEL but below the PEL; (d) Lead levels range from 25.6-64.2 ppm and exhibit a marked decline following a peak in the mid-1970s. Lead levels within surficial sediments are very close to the TEL; (e) Nickel levels range from 38.4-48.4 ppm and are fairly constant over time, however, there would appear to be a downward trend in the last decade. Nickel levels within the surficial sediments are above the TEL and slightly above the PEL; (f) Zinc levels range from 123-180 ppm and parallel the patterns observed for nickel, with fairly uniform levels until the last decade and then a slight decline. Zinc levels are above the TEL but below the PEL.

Recommendations for Canadice Lake are as follows. *First*, trophic conditions within Canadice Lake appear to have declined slightly over the past several decades – this is generally considered a positive development. It is recommended that nutrient control measures be continued within the watershed. *Second*, dissolved oxygen levels within the hypolimnion of the lake are reduced to fairly low levels during much of the growing season. The reasons for this dissolved oxygen depletion are not certain, and additional study of this phenomenon is recommended. The focus of future study should be directed at investigation of the cause(s) of the observed depletion, and possible ecological implications of these hypoxic conditions. *Third*, it is unclear, at this time, whether or not Zebra mussels are established in Canadice Lake. However, the presence of Zebra mussels has been confirmed in all of the other Finger Lakes. Thus, a Zebra mussel monitoring program should be initiated for Canadice Lake. This study should attempt to determine if Zebra mussels are present in the lake, and what ecological effects are occurring, or likely to occur, given colonization. The issue of water column calcium levels should be a component of the Canadice Lake study given the apparent increase in calcium levels within the lake and the importance of calcium levels in Zebra mussel ecology. *Fourth*, as with many of the other Finger Lakes, chloride and sodium levels have increased within Canadice Lake over the past several decades. Thus, it is recommended that measures to control the use and storage of salt within the watershed be implemented. *Fifth*, while PCB levels have declined in certain species of fish over the past several years, monitoring of biota for PCB levels is still warranted. *Sixth*, as with several of the Finger Lakes, arsenic levels within Canadice Lake have increased over the past several decades. Thus, additional study of the cause(s) and possible environmental effects of these increases is recommended. *Seventh*, as with many of the Finger Lakes, nickel levels within the sediments of Canadice Lake appear fairly high. Investigation of the cause(s) and possible environmental consequences of these nickel levels is recommended.

Hemlock Lake

Hemlock Lake (see Figure 11.10) is one of the five smaller Finger Lakes. The lake is located in Livingston County, while the watershed also extends into Ontario County. Hemlock Lake is used primarily as a water supply by the City of Rochester. The lake has a water use classification of "AA(T)", and has fairly stringent watershed protection measures in place. Hemlock Lake is listed on the NYSDEC PWL due to water supply concerns relating to hydrologic modification.

The trophic state of Hemlock Lake is best characterized as between oligotrophic and mesotrophic. The mean epilimnetic levels for major trophic indicators during the late 1990s are 10.0 ug/l, 3.0 ug/l, and 4.7 m, for total phosphorus, chlorophyll *a*, and Secchi Disk depth, respectively. These findings indicate a significant reduction in chlorophyll *a* levels and a significant increase in water clarity within Hemlock Lake over the past several decades. However, total phosphorus levels remain approximately the same as was found in the early 1970s. The hypolimnion of Hemlock Lake becomes hypoxic during the mid to late summer, with dissolved oxygen levels as low as 1 mg/l in certain deep-water locations. The cause(s) and/or consequences of this dissolved oxygen depletion are uncertain. While hypolimnetic dissolved oxygen depletion is obviously a consequence of both natural and human-related processes, the relative importance of the two factors is unclear. Trends for major ions within Hemlock Lake indicate an *increase* in the concentration of calcium, chloride, and sodium, and a *decrease* in sulfate, and magnesium levels.

Sediment core findings from Hemlock Lake were not particularly informative, due to the lack of an intact radiometric profile. Thus, no sediment accumulation rate could be determined for the lake, and chemical results can only be viewed as composite values (no temporal or trend information is available). *Organic* chemical findings for Hemlock Lake are limited to DDT and its metabolites, and PCBs. Total DDT levels within the Hemlock Lake sediment core ranged from 25-49 ppb. As discussed previously, the sediment core from Hemlock Lake appears to have been disturbed, therefore, temporal trends for DDT are not possible. However, ratios of DDT to its metabolites (DDD & DDE) indicate that the signal in Hemlock Lake is fairly weathered – in fact, DDT itself is below detection within the sediment core, and there are only detectable levels of DDD and DDE. This would appear to indicate that the source(s) of these chemicals within the watershed stem from historical releases within the basin. PCB findings from the Hemlock Lake sediment core are also quite limited. PCB congeners, analyzed from the 4-6 cm sediment segment (early 1970s), indicate a total PCB concentration of 67 ppb. This is in the low range of levels observed in other Finger Lakes cores, and is above the TEL, but below the PEL for total PCBs. *Inorganic* chemical findings for Hemlock Lake indicate that sediment arsenic levels are above the TEL and PEL. Arsenic levels range from 13.5-21.4 ppm, with a concentration of 21.4 within the surficial sediment layer. Sediment arsenic enrichment is apparent in a number of the Finger Lakes, and the cause(s) of the arsenic enrichment is not certain – see discussion in Chapter 9. Subsequent water column monitoring conducted during 1999, albeit limited, did not detect arsenic (at > 10 ppb) within the water column of Hemlock Lake – see further discussion above. Additional inorganic chemical findings from the Hemlock Lake sediment core are as follows: (a) Chromium levels range from 27-30.5 ppm – these levels are below the TEL and PEL; (b) Copper levels within the sediments of Hemlock Lake range from 39.6-49.8 ppm, which is above the TEL but below the PEL; (c) Lead levels range from 40.7-52.5 ppm, and show little variation within the core. The lack of a pronounced decline in lead levels within the Hemlock Lake sediment core, which stands in contrast to observations in a number of the other Finger Lakes cores, reinforces the idea that the Hemlock Lake sediments had been disturbed. The observed levels of lead are above the TEL but below the PEL; (d) Nickel levels range from 48.0-57.6 ppm, which is above the TEL and PEL for nickel; and (e) Zinc levels range from 136-155 ppm, which is above the TEL but below the PEL for zinc.

Recommendations for Hemlock Lake are as follows. *First*, trophic conditions within Hemlock Lake have declined significantly over the past several decades with respect to chlorophyll *a* and water clarity – this is generally considered a positive development. However, similar declines in total phosphorus levels are not apparent. In spite of this apparent disconnect in trophic indicators, continued efforts to control the release of nutrients within the watershed are recommended. *Second*, dissolved oxygen levels within the hypolimnion of the lake declined significantly during much of the growing season. The reasons for this dissolved oxygen depletion are not certain, and additional study of this phenomenon is recommended. The focus of future study should be directed at investigation of cause(s) of the observed depletion, and possible ecological implications of these hypoxic conditions. *Third*, the presence of Zebra mussels has been confirmed within Hemlock Lake. Zebra mussels can have profound effects on the ecosystem of a lake, and can result in significant problems for water intake systems. Thus, a Zebra mussel monitoring program should be initiated for Hemlock Lake. This study should focus upon Zebra mussel population trends, and possible ecological effects. *Fourth*, as with many of the Finger Lakes, chloride and sodium levels have increased within Hemlock Lake over the past several decades. Thus, it is recommended that measures to control the use and storage of salt within the watershed be implemented. *Fifth*, as with several of the Finger Lakes, sediment arsenic levels within Hemlock Lake have increased in recent decades. Thus, additional study of the cause(s) and possible environmental effects of these increases is recommended. *Sixth*, as with many of the Finger Lakes, nickel levels within the sediments of Hemlock Lake appear fairly high. Investigation of the cause(s) and possible environmental consequences of these nickel levels is recommended. *Seventh*, it would be informative to collect an additional sediment core from Hemlock Lake for the purposes of establishing a sediment accumulation rate and chemical chronology for the lake.

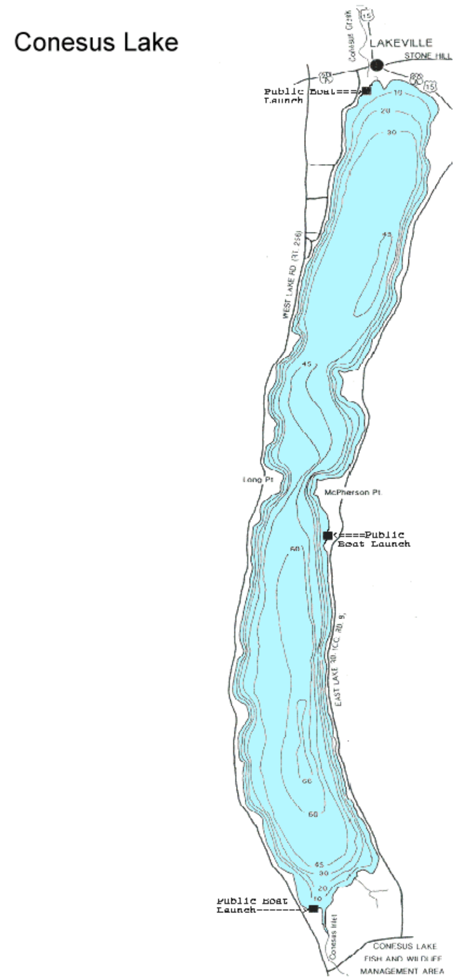
Figure 11.10: Hemlock Lake

Not intended for navigation purposes.

Conesus Lake

Conesus Lake (see Figure 11.11) is one of the five smaller Finger Lakes. The lake and watershed are located in Livingston County. Conesus Lake is a multi-purpose water body, and is used as a source of water supply by the Town of Livonia, and the Villages of Avon and Geneseo. The lake has a water use classification of "AA", and is listed on the NYSDEC PWL due to swimming concerns relating to macrophytes and nutrients.

Figure 11.11: Conesus Lake



Not intended for navigation purposes.

The current trophic state of Conesus Lake is best characterized as eutrophic. The mean epilimnetic levels for major trophic indicators during the late 1990s are 22.2 ug/l, 7.9 ug/l, and 3.7 m, for total phosphorus, chlorophyll *a*, and Secchi Disk depth, respectively. These findings indicate that trophic conditions within Conesus Lake have increased somewhat since the early 1970s – this is generally considered undesirable. The annual mean total phosphorus level has increased slightly and is above the New York State total phosphorus guidance level of 20 ug/l, and water clarity has declined moderately. Furthermore, the hypolimnion of Hemlock Lake becomes anoxic during mid to late summer, with dissolved oxygen levels dropping to near zero in a significant portion of the hypolimnion. The cause(s) and/or consequences of this dissolved oxygen depletion are uncertain. While hypolimnetic dissolved oxygen depletion is obviously a consequence of both natural and human-related processes, the relative importance of the two factors is unclear. Trends for major ions within Conesus Lake indicate an *increase* in the concentration of sodium, and a *decline* in calcium, magnesium, sulfate, and alkalinity levels.

Sediment core findings from Conesus Lake indicate a sediment accumulation rate of approximately 0.4 cm/year, which is in the mid to upper range of accumulation rates observed in the Finger Lakes. *Organic* chemical findings for Conesus Lake are limited to DDT and its metabolites, and PCB congeners. Total DDT (sum of DDT and its metabolites) findings for Conesus Lake are somewhat puzzling. Total DDT levels within the sediments of Conesus Lake show that peak levels occurred in the early 1960s and then decline somewhat by the early 1970s. Since the 1970s, levels appear to have reached a plateau. This might indicate a continuing influx of DDT and/or its metabolites to the lake. However, the chemical signal is composed of only DDD and DDE, which is generally an indication of historical inputs, as opposed to recent inputs, of the parent product (DDT) to the basin. The total DDT levels observed are above the TEL but below the PEL. PCB findings for Conesus Lake are limited to a single sediment core segment representing sediments from approximately the mid 1980s (4-6 cm core segment). Total PCB levels within these sediments are 490 ppb, which is the highest level of PCBs observed within the Finger Lakes. The PCB signal (see Figure 9.13) from Conesus Lake appears generally consistent with lower chlorinated Aroclors (e.g., Aroclor 1242). The total PCB level observed is above the TEL and PEL. *Inorganic* chemical findings for Conesus Lake indicate fairly high arsenic concentrations within benthic sediments. However, in contrast to some of the other Finger Lakes, there was not a marked increase in arsenic levels within surficial sediment layers. Arsenic levels range from 11.0-20.2 ppm, and the arsenic levels observed are above the TEL and close to or above the PEL for arsenic. The cause(s) of the arsenic enrichment within benthic sediments is not certain – see discussion in Chapter 9. Subsequent water column monitoring conducted during 1999, albeit limited, did not detect arsenic (at > 10 ppb) within the water column of Conesus Lake – see further discussion above. Additional inorganic chemical findings for Conesus Lake are as follows: (a) Cadmium was detected in a single sediment segment (~ 1990), which is above the TEL and slightly below the PEL. However, the cadmium level within all other core segments was below detection; (b) Chromium levels range from 20.0-29.3 ppm, and show a moderate decline over time. These levels are below the TEL and PEL for chromium; (c) Copper levels range from 27.1-44.0 ppm and are fairly stable throughout the core. The copper levels observed are generally below the TEL and PEL; (d) Lead levels range from 49.1-108 ppm. Lead levels reach a maximum in the mid-1960s to early-1970s, and exhibit a marked decline thereafter. However, lead levels within surficial sediments remain above the TEL, but below the PEL; (e) Nickel levels range from 33.3-49.2 ppm and are generally stable throughout the core, with perhaps a slight decline in the upper sediments. Nickel levels are above the TEL and near or above the PEL for nickel; and (f) Zinc levels range from 140-195 ppm. Zinc levels reach a maximum in the late-1960s, and exhibit a moderate decline thereafter. Zinc levels are above the TEL but below the PEL.

Recommendations for Conesus Lake are as follows. *First*, total phosphorus levels observed within Conesus Lake are above the current New York State guidance value for total phosphorus (20 ug/l). Furthermore, anoxic conditions occur within the hypolimnion of the lake for sustained periods during the growing season. Thus, it is important that nutrient control measures within the watershed be enhanced. A nutrient loading study is also recommended for the watershed. Furthermore, as with several of the smaller Finger Lakes, nutrient dynamics within Conesus Lake are not fully understood. Therefore, it is suggested that additional study of nutrient dynamics within Conesus Lake be conducted. The focus of such a study should be to more fully define both external and internal inputs of nutrients to the lake, and to assess the ecological consequences of dissolved oxygen depletion within the hypolimnion. *Second*, the presence of Zebra mussels has been documented within Conesus Lake. Zebra mussels are believed to be having significant ecological effects on several of the Finger Lakes. Thus, a Zebra mussel monitoring program is recommended for Conesus Lake. *Third*, as with many of the Finger Lakes, chloride and sodium levels have increased over the past several decades. Thus, efforts to control the use and storage of salt within the watershed should be encouraged. *Fourth*, total PCB levels within Conesus Lake are above sediment quality guidance values. Therefore, it is recommended that fish tissue analyses be conducted in Conesus Lake. *Fifth*, as with several of the Finger Lakes, arsenic levels within the sediments of Conesus Lake are above certain sediment quality guidance values. Thus, efforts to understand the cause(s) and possible environmental consequences of the observed elevations in arsenic levels are recommended. *Sixth,* as with many of the Finger Lakes, nickel levels are elevated in the sediments of Conesus Lake. Investigation of the cause(s) and possible environmental consequences of these nickel levels is recommended.

Glossary

Aerobic: in the presence of oxygen.

Allochthonous: originating or growing away from the place of origin; not native.

Anaerobic: absence of oxygen.

Anion: a negatively charged ion.

Anoxia: the absence of oxygen – operationally defined as dissolved oxygen levels below 1 mg/l.

Autochthonous: originating or produced within a given habitat or system; native.

Bioaccumulation: the tendency for certain chemicals to increase in concentration in living organisms.

Biomagnification: the process in which certain chemical compounds (e.g., PCBs, DDT, mercury, etc.) move up the food chain, and increase in concentration within organisms at higher trophic levels.

Cations: a positively charged ion.

Clinograde: dissolved oxygen concentrations decreasing with depth – characteristic of eutrophic lakes.

Congener: a chemical substance that is related to other chemical substances in some manner.

Epilimnion: the upper waters of a thermally stratified lake.

Eutrophic: a lake or other body of water, containing an abundant supply of plant nutrients and characterized by high levels of primary productivity.

Hydrophobic: having a strong aversion for water.

Hypolimnion: bottom waters of a thermally stratified lake.

Hypoxia: waters with dissolved oxygen concentrations of less than 2 ppm, the level generally accepted as the minimum required for most marine life to survive and reproduce.

Limnology: the study of the physical, chemical, biological, and hydrological aspects of fresh water.

Lipophilic: having a strong affinity for lipid (fat) and organic material.

Lithosphere: uppermost shell of the earth, broken into a number of tectonic plates.

Maximum Contaminant Level (MCL): the MCL is the amount of a chemical substance which must be reported to state authorities if discovered by a local water treatment plant.

Macrophyte: a large plant.

Mesotrophic: a lake or other water body having intermediate amounts of plant nutrients and levels of primary productivity.

Metalimnion: the water column layer of a thermally stratified water body characterized by a rapid change in temperature – also see thermocline.

Oligotrophic: a lake or other water body having low amounts of plant nutrients and levels of primary productivity.

Organochlorine: a class of manmade chemicals composed of carbon and chlorine.

Orthograde: dissolved oxygen concentrations increasing with depth – characteristic of oligotrophic lakes.

Paleolimnology: the study of the conditions and processes of lakes in the geologic past.

pH: a symbol representing the logarithm of the reciprocal of the hydrogen-ion concentration of an aqueous solution - used to express the relative acidity or alkalinity of an aqueous solution.

Phytoplankton: a type of free floating plant plankton, such as algae, that is the basic food source in many aquatic and marine ecosystems.

Probable Effect Level (PEL): The concentration level of a particular chemical, above which, it is believed to be frequently associated with adverse biological effects on resident biota.

Radiometric Dating: a method of determining the approximate age of certain objects based upon the ratio of a radioisotope concentration to that of a stable isotope.

Secchi Disk: a black and white disk used to measure water clarity.

Seiche: the pendulum-like movement of a body of water that continues after cessation of the originating force - usually wind but may be other atmospheric phenomena or seismic disturbances; a tide is a special case of a seiche.

Stoichiometric: the branch of chemistry that applies the laws of definite proportions and conservation of matter and energy to chemical processes.

Synoptic: obtained simultaneously over a wide area in order to afford a simultaneous overall view.

Thermal Stratification: The formation of distinct layers of different temperatures in a lake or reservoir.

Thermocline: The depth at which there is a rapid decrease in temperature in a thermally stratified lake or reservoir - usually defined as >= 1°C per meter.

Threshold Effect Level (TEL): The concentration level of a particular chemical, above which, it is believed to be occasionally associated with adverse biological effects on resident biota.

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