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

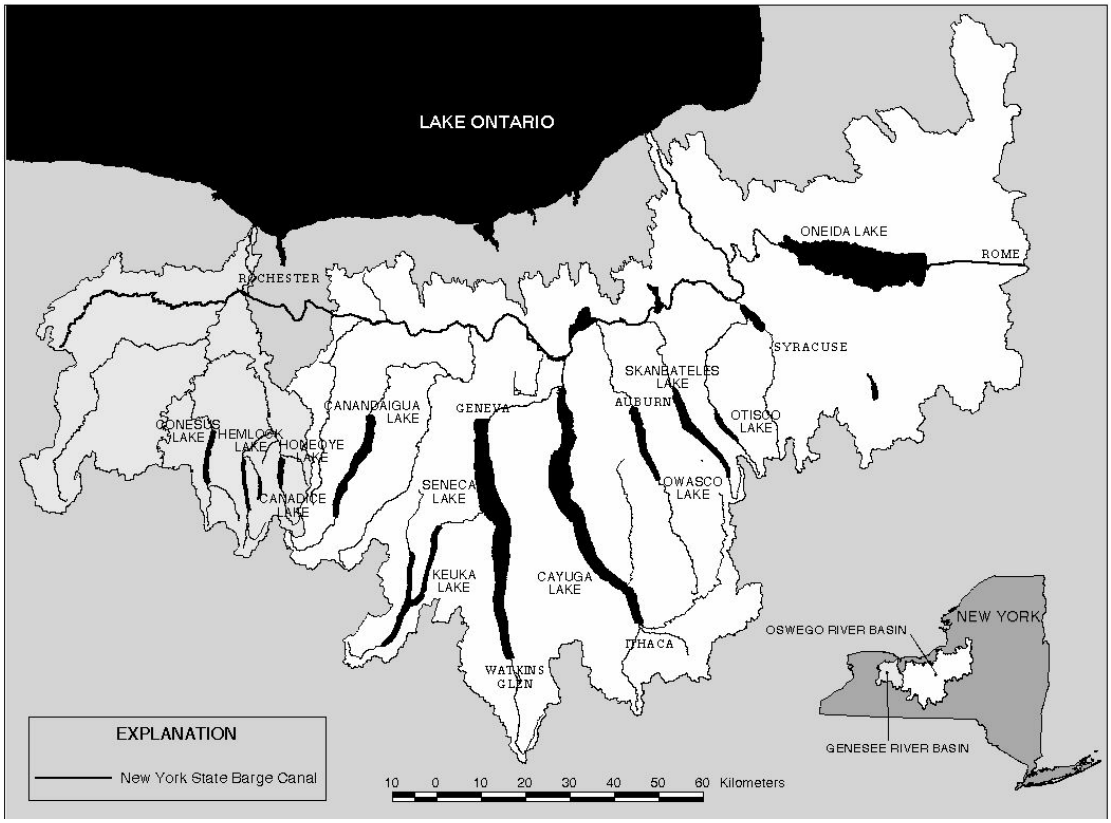


Table 2.2: Finger Lakes counties

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

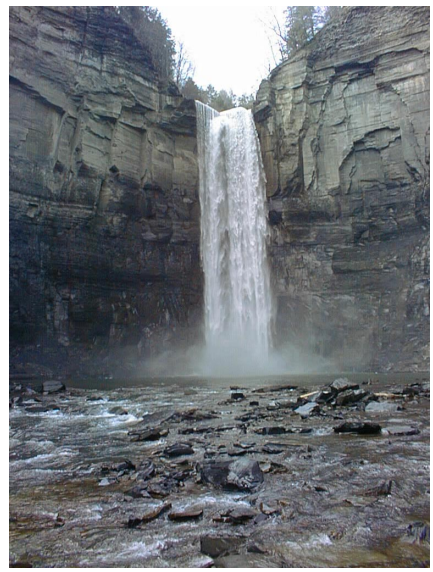
* The permit for Hemlock and Canadice is based on total from both lakes

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.

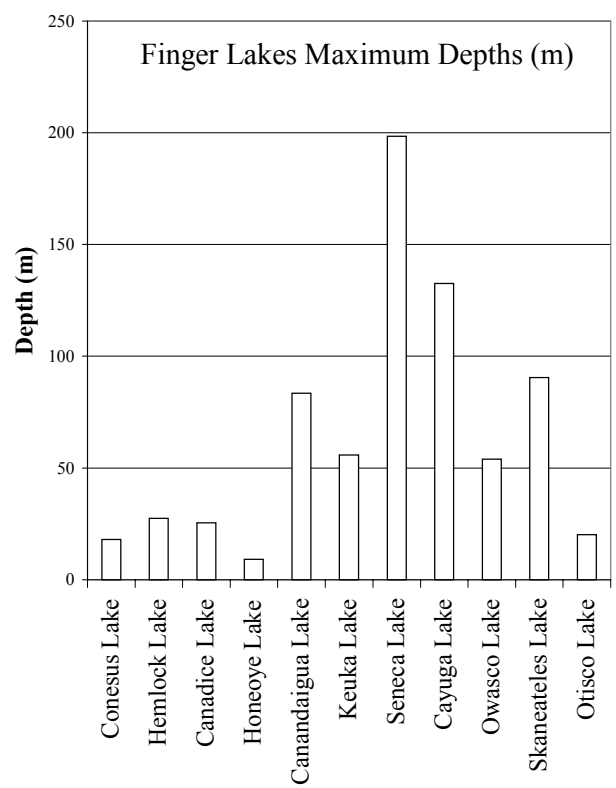
Current theory suggests that the glaciers functioned as extensive earth moving operations by gouging out the lake basins and depositing vast quantities of glacial debris at the southern terminus of the present day Finger Lakes. These glacial forces, coupled with subsequent water runoff, are responsible 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 the volume of Honeoye Lake. Similarly, as one can see in Figure 2.4 there is a large variation in maximum lake depths. Seneca Lake is the largest of the Finger Lakes on both a volumetric and surface area basis, 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 the smallest with respect to surface area.

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



As one can understand from inspection of 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). The volumes for the larger lakes are measured in *billions* of cubic meters, whereas the volumes of the smaller lakes are measured in *millions* of cubic meters. As will be discussed later, 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.

Table 2.4: Physical characteristics of the Finger Lakes (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

* Seneca: watershed includes inflow from Keuka Lake.
** Cayuga: watershed excludes inflow from Seneca Lake at the northern end of the Cayuga 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.

Estimated surface runoff estimates for the various 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 for the Finger Lakes

Lake	Estimated Surface Runoff	
	(10^6 m^3 yr^{-1})	(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 (years)

Lake	**Shaffner & Oglesby (1978)**	**Michel & Kraemer (1995)**	
		Tritium	**USGS Runoff**
Conesus	1.4	2.5	2
Hemlock	2.0	2.5	2.5
Canadice	4.5	2	4
Honeoye	0.8	1.5	1
Canandaigua	7.4	8.5	10
Keuka	6.3	6	8
Seneca	18.1	12	23
Cayuga	9.5	8.5	10
Owasco	3.1	1.5	3
Skaneateles	17.7	8.5	14
Otisco	1.9	1	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 designations for the 11 Finger Lakes range from AA(TS) to B. The classifications 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 which warrant 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. Graphical 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

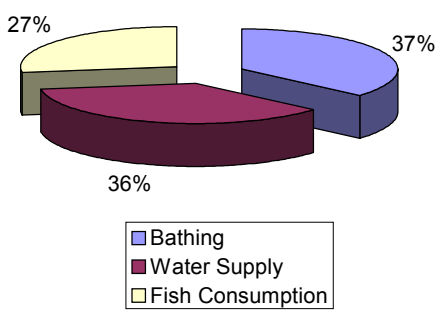


Figure 2.6: Finger Lakes contaminant summary

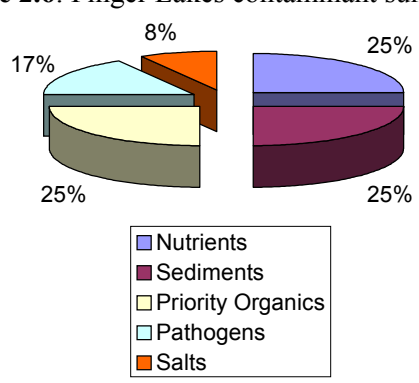


Table 2.8: Summary of 1996 Priority Waterbody List (NYSDEC, 1996).

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.