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great lakes program

GREAT LAKES RESEARCH CONSORTIUM

Sea Grant New York

Working together for Great Lakes research and education

Lake Ontario-St. Lawrence River Ecosystem

Great Lakes Research Review

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ABOUT THIS PUBLICATION:

Several years ago, staff from the Great Lakes Program, the Great Lakes Research Consortium, and New York Sea Grant realized an information gap existed between peer reviewed journal articles and newsletter type information related to Great Lakes research. The *Great Lakes Research Review* was created to fill that gap by offering a substantive overview of research being conducted throughout the basin.

This publication is designed to inform researchers, policy-makers, educators, managers, and stakeholders about Great Lakes research efforts.

This fourth volume focuses on the Lake Ontario-St.Lawrence River ecosystem. The first two-issue volume focused on the fate and transport of toxic substances and the effects of toxics, while the second two-issue volume examined Great Lakes Fisheries issues. The third two-issue volume focused on exotic species and their impact on the Great Lakes. All the previous issues highlighted the work of researchers associated with the sponsoring organizations and others who are involved in these specified research areas.

The Great Lakes Program at the University at Buffalo gratefully acknowledges all of the contributing authors who willingly shared their research efforts for this publication. Our appreciation is also extended to Barbara Spinweber of the USEPA – Region 2 and the Lake Ontario LaMP Workgroup, for writing the introduction.

Questions concerning this issue may be addressed to the editor, Helen M. Domske, Associate Director, Great Lakes Program. Those who are interested in obtaining copies of the first four issues may contact the Great Lakes Program.

THE UPCOMING ISSUE:

The second issue of *Volume Four* will also address the topic of Lake Ontario-St.Lawrence River ecosystem. Those who may have questions concerning the next issue, or authors interested in contributing material, should contact Jack Manno, Executive Director of the Great Lakes Research Consortium.

Introduction

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The Great Lakes Research Review serves an important role in facilitating the communication of ongoing research being conducted on the Great Lakes. Given that this issue will focus on Lake Ontario, this serves as an excellent opportunity to convey the goals of the Lake Ontario Lakewide Management Plan (or "LaMP"). Research specific to Lake Ontario is essential for gaining a better understanding of the Lake Ontario ecosystem in order to effectively restore, protect, and manage this system.

The U.S. Environmental Protection Agency, Environment Canada, The New York State Department of Environmental Conservation, and the Ontario Ministry of the Environment (together known as the "Four Parties") are working together to restore the beneficial uses of Lake Ontario through the development of the Lake Ontario LaMP.

The Lake Ontario LaMP builds upon an earlier initiative known as the Lake Ontario Toxics Management Plan (LOTMP), in which the Four Parties defined the Lake's toxics problem and identified agency actions to reduce the amounts of toxic chemicals entering Lake Ontario. The Lake Ontario LaMP is broader in scope than the LOTMP, in that it embodies an ecosystem approach, considering all media causes of lakewide problems, in addition to toxics.

The Great Lakes Water Quality Agreement specifies that LaMPs will be developed for each Lake, and in 4 stages:

Stage 1 – defining the problem
Stage 2 – setting strategies for pollutant reductions
Stage 3 – selecting remedial measures
Stage 4 – documenting / monitoring successes

In May of 1998, after consultation with other natural resource agencies and the public, the Four Parties submitted the Lake Ontario Stage I LaMP to the International Joint Commission and the public. This document lays out the problems that exist in Lake Ontario on a lakewide basis, and identifies the activities that the Four Parties plan to undertake to resolve these problems. The Four Parties will depend heavily on existing and future partnerships forged at the federal, state, and local level in order to address these problems.

BENEFICIAL USE IMPAIRMENTS OF LAKE ONTARIO

The Great Lakes Water Quality Agreement describes environmental problems in terms of beneficial use impairments, and sets out fourteen indicators of impairment. The Four Parties worked together to identify the beneficial use impairments that exist in Lake Ontario on a lakewide basis, and identify the causes or likely causes of these impairments.

The chart provided below summarizes the beneficial use impairments which exist on a lakewide basis in Lake Ontario, and indicates their chemical, physical, and biological causes:

SUMMARY OF LAKE ONTARIO LAKEWIDE BENEFICIAL USE IMPAIRMENTS AND RELATED CRITICAL POLLUTANTS AND OTHER FACTORS:

Lakewide Impairments	***Impacted Species***	***Lakewide Critical Pollutants & Other Factors***
Restrictions on Fish and Wildlife Consumption	Trout, Salmon, Channel catfish, American eel, Carp, White sucker	PCBs, Dioxins, Mirex
	Walleye, Smallmouth Bass[a]	PCBs, Dioxins, Mirex
	All waterfowl[b]	PCBs, DDT, Mirex[b]
	Snapping Turtles[b]	PCBs[b]
Degradation of Wildlife Populations	PCBs, DDT, Mirex[b]	PCBs, Dioxin, DDT
	Mink & Otter[c]	PCBs
Bird or Animal Deformities or Reproductive Problems	Bald Eagle[b]	PCBs, Dioxin, DDT
	Mink & Otter[c]	PCBs
Loss of Fish and Wildlife Habitat	A wide range of native fish and wildlife species	Lake Level Management
		Exotic Species
		Physical Loss, Modification, and Destruction of Habitat

[a] Canadian advisories only.

[b] U.S. advisories only.

[c] Indirect evidence only (based on fish tissue levels).

Notes: Dieldrin, although listed as a LaMP critical pollutant, is not associated with an impairment of beneficial use. “DDT” includes all DDT metabolites; “Dioxin” refers to all dioxins / furans.

Through the LaMP, the Four Parties seek to restore the lakewide beneficial uses of Lake Ontario by reducing the amount of “Critical Pollutants” (PCBs, DDT and its metabolites, mirex, dioxins / furans, mercury, and dieldrin) and other persistent, bioaccumulative toxics entering the lake, and also addressing the physical / biological factors causing loss of fish and wildlife habitat.

FUTURE ACTIVITIES

The Stage I Lake Ontario LaMP includes a Binational Workplan, which identifies the activities that the Four Parties have committed to undertake over the next several years to restore the beneficial uses of Lake Ontario. This binational workplan lays out our three-year objectives, and identifies the priority activities which will be undertaken to achieve these objectives, towards the goal of developing a draft Stage 2 LaMP (a schedule for load reduction activities) in the fall of the year 2000.

- We will seek to reduce inputs of critical and other pollutants into Lake Ontario. We will evaluate the effectiveness and estimated reductions of existing source reduction programs, including the binational Virtual Elimination Strategy, update data on current point and nonpoint sources entering Lake Ontario directly or through it's tributaries, undertake source track-down to identify sources, and facilitate cooperative lakewide monitoring. The enhancement of our mass balance models is an important step in this process (see Dr. Joseph DePinto's article on page 15). The enhanced models will help us gain an understanding of the relative significance of the source categories to Lake Ontario and its tributaries. The model will help us to understand the environmental significance of our load reduction activities and to prioritize additional load reduction activities that may be necessary to achieve a desired endpoint (*i.e.*, the chemical body burden in sportfish). The model will also help us estimate the amount of time it will take to achieve our desired endpoint, and help us to select the most cost effective toxics load reduction activities.

- With public input, we will be finalizing draft ecosystem objectives for Lake Ontario, and developing ecosystem indicators that will provide a way for us to measure our success in achieving our ecosystem goals.

- We will further assess the status of lakewide beneficial uses, focusing on the chemical impacts on benthos, phytoplankton, and zooplankton populations; as well as assessing the status of colonial waterbirds, bald eagle, mink, and otter populations.

- We will be working with other agencies involved in habitat issues (such as the U.S. Fish and Wildlife Service and entities involved in local Remedial Action Plans) to determine how we can cooperatively address these issues without duplicating efforts.

- We will implement our three-tiered public involvement strategy, aimed to more fully support efforts to create and strengthen partnerships with citizens, groups, and organizations (business, industry, etc.) taking action in the Lake Ontario Basin. We are in the process of establishing Basin Teams and Partnerships, and will hold public forums at significant stages in the LaMP process.

As can be seen by the activities summarized above, research is essential for gaining a baseline understanding of the Lake Ontario ecosystem and prioritizing the activities which would have the most significant impact towards restoring this system. We need a better understanding of the sources and loads of critical pollutants entering Lake Ontario and the respective contributions from the different source categories, in order to successfully reduce their inputs. Similarly, we need to better understand the biological and physical factors contributing to the loss of fish and wildlife habitat and how best to restore these habitats. We also need to develop ecosystem objectives and indicators for Lake Ontario that will be effective in monitoring progress towards restoration of these impaired uses. Research relevant to these management issues, and communication of the results of that research, will play an important role in determining the pace at which these beneficial uses are restored.

I invite those who are conducting research on Lake Ontario to become more familiar with and involved in the development and implementation of the Lake Ontario LaMP, so that we can work closely together to restore the beneficial uses of Lake Ontario.

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Lake Ontario Zooplankton: Their Response to Management Initiatives

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The importance of zooplankton lies in their direct link to fish both as food and as a monitor of the balance between piscivores and planktivores in the system. Our work has focused on two broad areas where zooplankton are key components: the response of the lake ecosystem to new stresses and management actions, and the transfer of production through the lower trophic levels to fish. Needless to say, tackling these questions has involved the expertise of many people and benefited from multi-disciplinary, multi-trophic level studies.

Rehabilitation of Lake Ontario started in the early 1970s with the implementation of the Great Lakes Water Quality Agreement of 1972, which limited phosphorus loading to the lake. On the heels of these efforts, came programs to reduce contaminant loadings, and to re-establish top predator populations through

LAKE ONTARIO BIOINDEX SITES

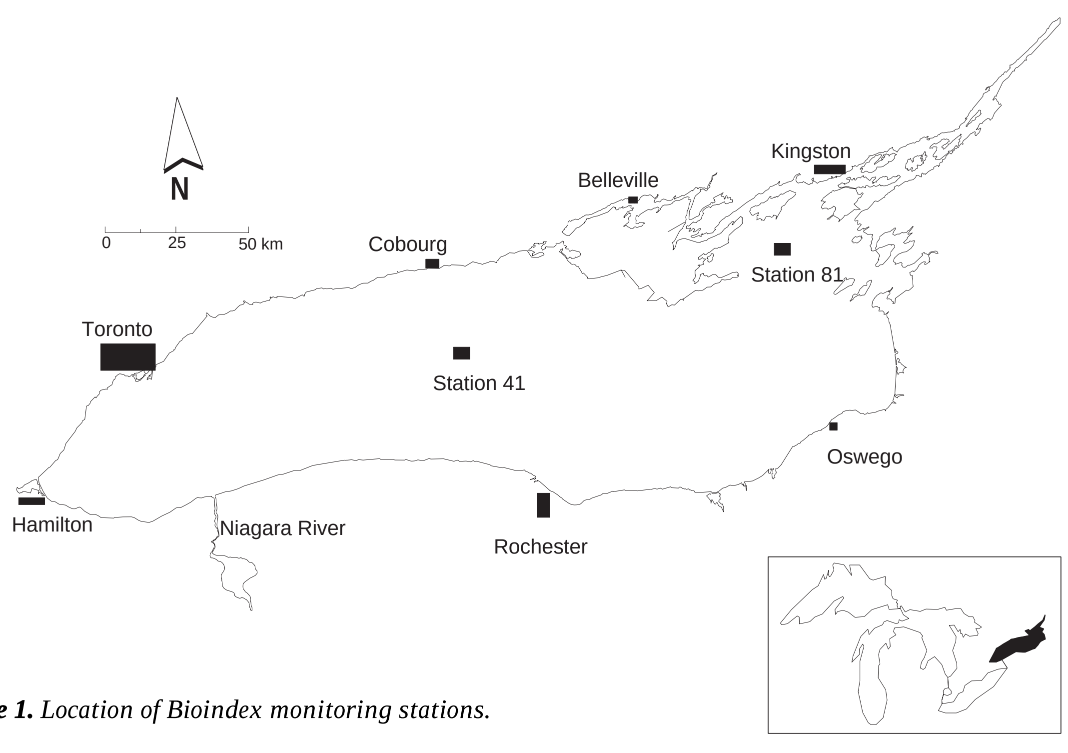

Figure 1. *Location of Bioindex monitoring stations.*

salmonid stocking, rehabilitation of streams and control of lamprey populations. Introduction of new exotic species, such as *Bythotrephes* and *Dreissena* were coincidental with these management actions and had the potential to reinforce or mimic some impacts.

We are very fortunate in Lake Ontario to have had the benefit of long-term biomonitoring programs. The Department of Fisheries and Oceans, Canada, initiated the Bioindex Program in 1981 and most of the information presented in this article comes from this program. Originally, four index stations were sampled on a weekly basis between April and October; however, two sites were dropped in 1985, leaving only a mid-lake and an eastern basins station (Fig.1). Most pelagic production occurs in the surface waters of a lake; therefore, we studied principally this layer. Zooplankton were sampled with a 64-mm, 50-cm diameter net; the data were corrected for net efficiency.

IMPACT OF BOTTOM-UP FORCES: LESS PHOSPHORUS AND MORE GRAZERS

Density and Production

In spite of reductions in phosphorus loads to the lake during the 1970s, no significant change was detected in zooplankton composition or biomass between the pre-rehabilitation period and the early 1980s (Johannsson 1987; Taylor *et al.* 1987; Neilson *et al.* 1995). The response occurred during the 1980s (Johannsson *et al.* 1998). In the mid-lake, zooplankton production and density declined and stabilized again as of 1986-1987, in synchrony with the stabilization of total phosphorus (TP) concentrations at their target level of 10 mg.L^{-1}. Epilimnetic June 15 – October 31 production fell from approximately 20 g. dry wt.m^{-2} to 10 g dry wt.m^{-2} (Fig. 2). In contrast, mysid production at the mid-lake site increased (Fig. 2). In the eastern basin, zooplankton production declined through the 1981-1987 period and did so again between 1991 and 1995, the last years of data (Fig. 2). Epilimnetic zooplankton production during the early 1980s ranged between 30 and 50 g. dry wt.m^{-2}. By 1995, it was 7.3 g dry wt.m^{-2} (Fig. 2). The decrease through the 1980s is thought to be related to the general decrease in productivity of the system with reductions in phosphorus loading. The declines coincided with declines in particulate organic carbon (POC) and nitrogen (PON), total algal biomass and / or cryptophyte biomass (Johannsson *et al.* 1998). Cryptophytes are an edible group of algae. The decrease through the 1990s in the eastern basin is thought to be a dreissenid-mediated effect.

The changes wrought by dreissenids on a system are similar to those of oligotrophication because the mussels remove particles from the overlying water and route that material and energy to the benthic food web. Thus, in the eastern basin we see increases in water clarity, and further decreases in TP, POC, PON, and total algal biomass, namely cryptophytes (Johannsson *et al.* 1998). There are several reasons we attribute the changes in the 1990s to dreissenids. The response of the mid-lake and eastern basin biota to decreases in phosphorus loadings were fairly synchronous. In the 1990s, the mid-lake showed no change in productivity. Dreissenid veliger larvae were first reported from Port Weller in Lake Ontario in the autumn of 1989 (Schaner 1991) and colonized the south shore of the lake. Mussel populations were well established in the eastern basin by 1993 (Stewart *et al.* 1994). Thus, the establishment of the mussels coincides with the observed changes in the eastern basin. In addition, impacts of dreissenids have been documented along the south shore (Mills *et al.* 1998). Mills *et al.* found that the chlorophyll *a* to TP ratio was not aligned with the Dillon-Rigler relationship and was more characteristic of a grazer-dominated system. In addition, zooplankton densities in the nearshore were similar to those offshore based on whole water column samples. Johannsson *et al.* (1991) had shown that zooplankton densities declined along the nearshore-offshore gradient in these types of samples. This suggests that zooplankton densities have also been depressed in the nearshore in the presence of dreissenids. Similar findings were reported by Dahl *et al.* (1995) and Graham *et al.* (1996) for a nearshore, dreissenid-infested region in Lake Erie.

In spite of the declines in algal biomass and TP in the eastern basin, no corresponding decrease had occurred in primary production which had been measured at the Bioindex sites since 1987 (Millard *et al.* 1996; Johannsson *et al.* 1998). Algal species composition had changed during this period. One explanation for the decline in summer zooplankton density and production during the 1990s could be the decline in cryptophyte algal biomass.

Species Composition

Patalas (1969) and Watson and Carpenter (1974) described the zooplankton community in the late 1960s – early 1970s, prior to rehabilitation, as dominated by small species: *Diacyclops thomasi*, *Tropocyclops extensus* (formerly *T. prasinus mexicanus*), *Bosmina longirostris*, *Eubosmina coregoni*, *Daphnia retrocurva* and *Ceriodaphnia lacustris*. *Limnocalanus macrurus* and *Mysis relicta*, the opossum shrimp, were abundant in the hypolimnion. Although the dominant zooplankton species did not change during the 1967-1995 period, subtle changes have been observed in the presence or abundance of some of the sub-dominant species (Johannsson *et al.* 1998). *Polyphemus pediculus* and *Chydorus sphaericus* were observed regularly in the mid-lake until 1991 and in the east-

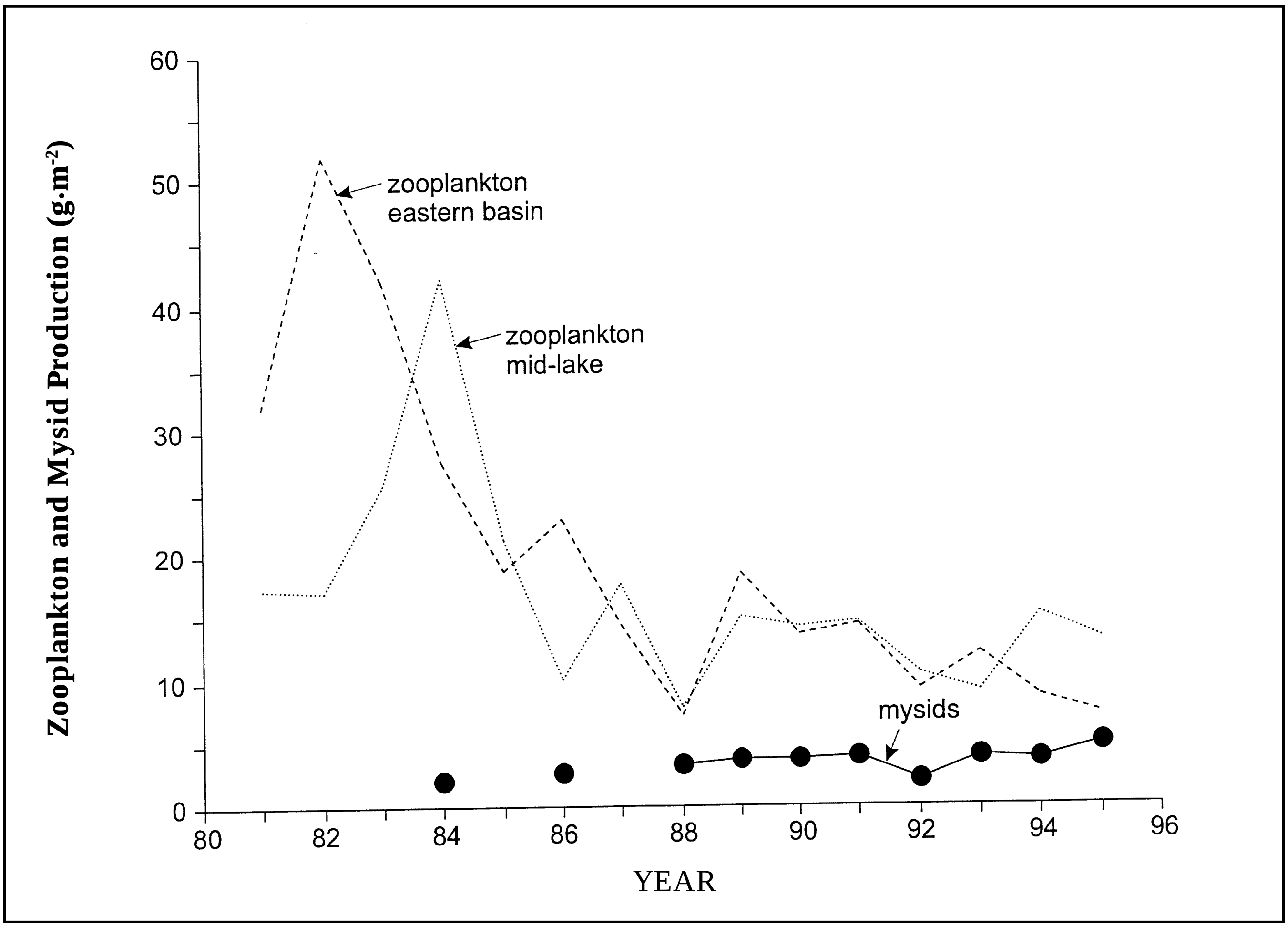

Figure 2. *Taken from Johannsson et al. (1998). Seasonal (June 15 - October 31) epilimnetic zooplankton production at stations 41 (mid-lake) and 81 (eastern basin) in Lake Ontario. Annual mysid production at station 41.*

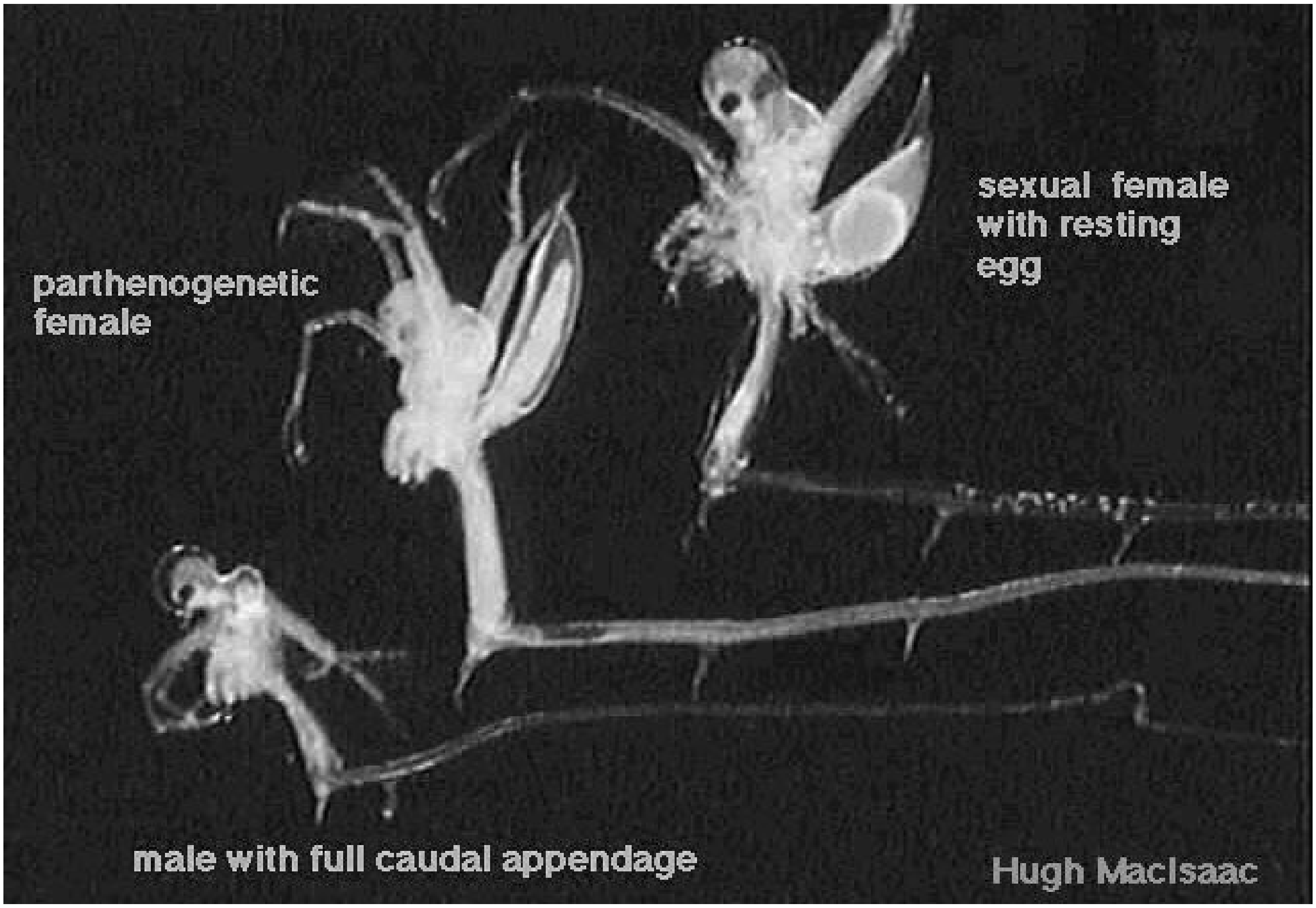

Figure 3. *Pictures of Cercopagis pengoi from Lake Ontario, courtesy of Dr. Hugh MacIsaac, Great Lakes Research Centre, University of Windsor. Caudal appendages of females are not complete.*

ern basin until 1992, then they disappeared. Other species present predominantly during the 1980s were *Ceriodaphnia quadrangula, Daphnia longiremis*, *Mesocyclops edax* and *Cyclops vernalis*. On the plus side, *Epischura lacustris*, a large predatory calanoid native to the Great Lakes, has been observed in the mid-lake since 1993 and in the eastern basin since 1994. *Bythotrephes cederströemi*, an exotic predatory cladoceran, was first observed in Bioindex samples in 1987, two years after it was found along the south shore of the lake by Lange and Cap (1986). It has rarely been observed in the lake, reaching noticeable numbers only in 1987 and 1994. *Bythotrephes* is found predominantly in deeper waters and is not detected in epilimnetic samples unless the population is well established**.** Alewife are thought to keep its abundance at low levels (Makarewicz *et al.* 1990; Johannsson *et al.* 1991). During the summer of 1998, *Cercopagus pengoi*, another predatory cladoceran, a relative of *Bythotrephes*, fouled fishing lines throughout the lake (Fig. 3). This was the first recorded appearance of this species in the Great Lakes.

The overall trends in zooplankton species composition across the years are best portrayed graphically using multi-dimensional scaling (MDS) (Johannsson *et al.* 1998) (Fig. 4). In the eastern basin, 1992 stood out from the other years and 1993 to 1995 were distinct from the cluster of remaining years. The last three years (1993 to 1995) to the far left on dimension 1, were characterized by relatively lower densities of *Bosmina* and *Ceriodaphnia*, a loss of *Chydorus sphaericus*, and higher than average abundances of the larger, rarer species, namely, *Leptodora kindtii*, *Limnocalanus macrurus*, *Leptodiaptomus sicilis* and *Holopedium gibberum*.

In the mid-lake, 1987 stood out as an unusual year in the MDS configuration (Fig. 4). The other years form an arc around it with the data from the 1980s tending to be to the upper right and the data from the 1990s tending to be to the left. 1987 was characterized by low levels of *Ceriodaphnia* and *Bosmina* and higher levels of *Polyphemus*, *Daphnia galeata mendotae*, *Eurytemora affinis* and *Eubosmina*. This was also the first year that *Bythotrephes cederströemi* appeared at the Bioindex sites (Johannsson *et al.* 1991). 1990, 1994 and 1995, to the far left of the first MDS dimension, were characterized by relatively higher *Bosmina* and *Leptodora* densities and low *Ceriodaphnia* and total zooplankton densities.

Therefore, through the 1990s we have had a loss of a species characteristic of more productive nearshore environments, namely *Chydorus*, and an increase in larger species such as *Leptodora* and *Epischura* both in the mid-lake and eastern basin, and *Limnocalanus*, *Holopedium* and *Leptodiaptomus sicilis* in the eastern basin only.

IMPACT OF TOP-DOWN FORCES: MORE PISCIVORES

By the late 1960s the piscivore populations in Lake Ontario had been decimated. Salmonid stocking started in 1968 in an attempt to re-establish the top trophic level. Stocking reached a peak in 1984 and was not reduced until 1993 (Orsati *et al.* 1994). The consequent decline in planktivore populations, mainly alewife, *Alosa pseudoharengus*, through the late 1980s and early 1990s (O'Gorman *et al.* 1994) should have reduced predation pressure on zooplankton. However, the evidence for release from predation is not dramatic. In the mid-lake, cyclopoid

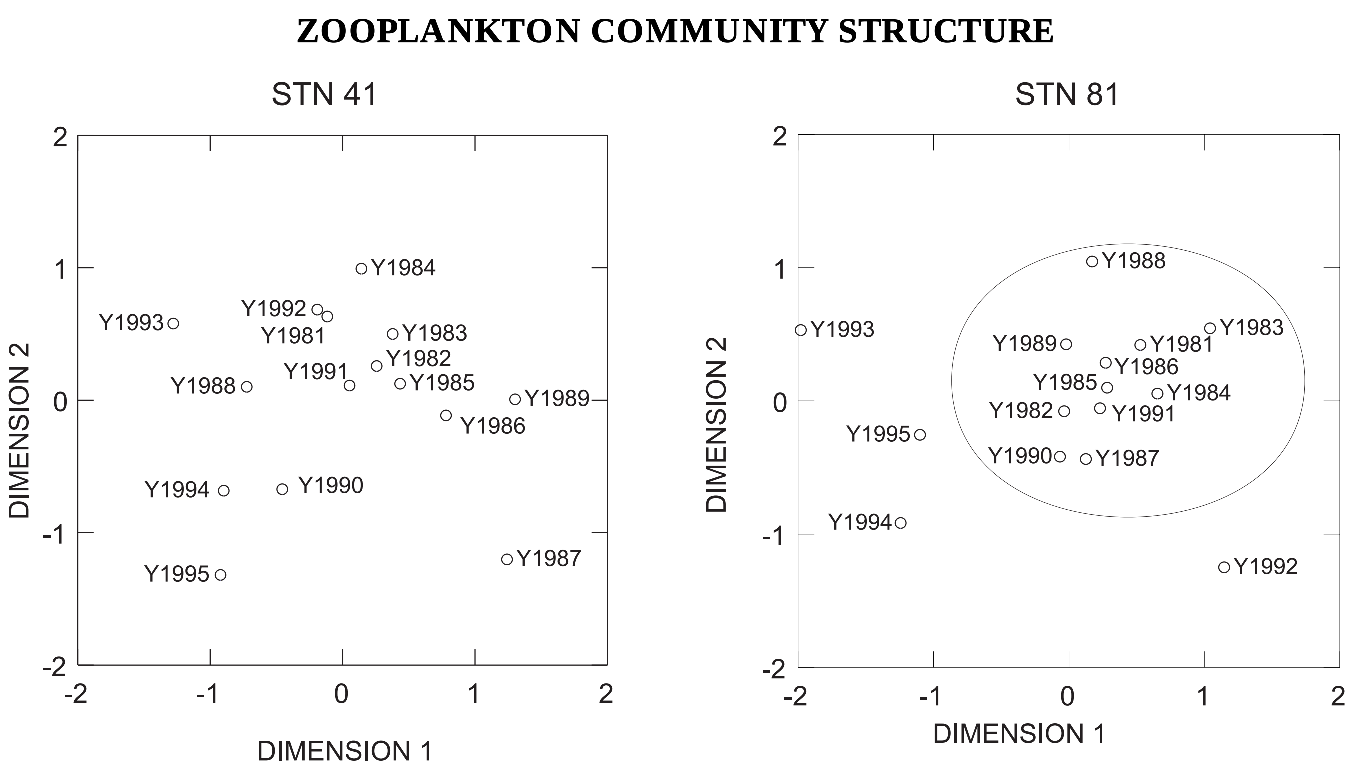

Figure 4. *Taken from Johannsson et al. (1998). Zooplankton community relationships through the 1981-1995 period as determined from multidimensional scaling of the Euclidean distance-based dissimilarity matrices of the log transformed, seasonally weighted mean densities based on species data (no veligers or juvenile copepods included).*

densities increased during the summer over the 1987-1995 period and *Leptodora* and *Epischura*, large predatory species, were more abundant in the mid-1990s. The increasing trend in mysid production may also reflect some release from predation; however, not enough is known about possible changes in their food supply or diet to draw a firm conclusion. In the eastern basin, total zooplankton density, mainly cyclopoids, increased in the prestratified period between 1987 and 1995 and the abundance of larger zooplankton was higher in the 1993-1995 period. It would appear that any decrease in predation during the summer period was nearly balanced by the continuing decrease in zooplankton production. Other indications of the continuing importance of alewife in structuring the zooplankton community, were the lack of persistent *Bythotrephes* populations in the lake and the persistence of a community dominated by small-bodied species.

BIOMONITORING

The present discussion of changes in the plankton community in the offshore of Lake Ontario and our ability to detect and interpret the trends indicates to a small degree the value of long-term monitoring programs. The Bioindex Program has also supported a number of research initiatives on Lake Ontario by providing a platform, associated data and expertise. In return, the information gleaned from these initiatives has helped to increase our understanding of pelagic interactions and to interpret changes, or lack of changes, in the system. These associated programs have studied (1) phosphorus and light limitation of algal growth, (2) interactions of zooplankton and planktivorous fish, (3) predation rates and diet of *Diacyclops*, (4) *Limnocalanus* life history and production, (5) *Mysis relicta* diet, feeding rates and whole-lake production, (6) estimation of zooplankton production from size-based production / biomass ratios, and (7) food-web models to examine energy and contaminant flow in the lake. This combination of long-term databases and research projects is very powerful. Long-term biomonitoring should form the backbone of much of the ecological research on the Great Lakes.

Long-term biomonitoring programs are not easy to undertake or maintain. Implementing biomonitoring programs on the Great Lakes requires the cooperation and coordination of people from many different agencies and institutions. The Lake Committees of the Great Lakes Fishery Commission would be the most effective umbrella for such work, due to their long-term stability of their mandate and need for much of the information.

REFERENCES

Dahl, J. A., D. M. Graham, R. Dermott, O. E. Johannsson, E. S. Millard and D. M. Myles. 1995. Lake Erie 1993, western, west central and eastern basins: Change in trophic status, and assessment of the abundance, biomass and production of the lower trophic levels. *Can. Tech. Rep. Fish. Aquat. Sci.* No. 2070: 118.

Graham, D. M., J. A. Dahl, E. S. Millard, O. E. Johannsson and L. L. White. 1996. Assessment of abundance, biomass and production of the lower trophic levels in the eastern basin of Lake Erie, 1994. *Can. Tech. Rep. Fish. Aquat. Sci.* No. 2110: x+104.

Johannsson, O. E. 1987. Comparison of Lake Ontario zooplankton communities between 1967 and 1985: before and after implementation of salmonid stocking and phosphorus control. *J. Great Lakes Res.* 13: 328-339.

Johannsson, O. E., E. S. Millard, K. M. Ralph, D. D. Myles, D. D. Graham, W. D. Taylor, B. Giles and R. A. Allen. 1998. Trends in nutrient conditions and measures of phytoplankton and zooplankton abundance, composition and productivity in the surface waters of Lake Ontario (1981-1995): A report of the DFO Lake Ontario

Biomonitoring Program (The Bioindex Program) *Can. Tech. Rep. Fish. Aquat. Sci.* No. (in press).

Johannsson, O. E., E. L. Mills and R. O'Gorman. 1991. Changes in the nearshore and offshore zooplankton communities in Lake Ontario. *Can. J. Fish. Aquat. Sci.* 48: 1546-1557.

Lange, C. and R. Cap. 1986. *Bythotrephes cederstroemi* (Schodler) (Cercopagidae: Cladocera): A new record for Lake Ontario. *J. Great Lakes Res.* 12: 142-143.

Makarewicz, J. C. and D. Jones. 1990. The establishment of *Bythotrephes cederstroemi* in the offshore of Lake Ontario. *J. Great Lakes Res.* 16: 143-147.

Millard, E. S., D. M. Myles, O. E. Johannsson and K. M. Ralph. 1996. Phytoplankton photosynthesis at two index stations in Lake Ontario 1987-92: assessment of the long-term response to phosphorus control. *Can. J. Fish. Aquat. Sci.* 53: 1092-1111.

Mills, E. L., L. G. Rudstam, N. K. Pauliukonis, S. K. Hall, C. P. Schneider, B. C. Weidel, S. Lary, D. Busch, R. McCullough, D. Bishop and G. Lane. 1998. Status of the Lake Ontario Ecosystem: A biomonitoring Approach (1997 Progress Report) *New York State Department of Environmental Conservation 1997 Annual Report:* 1-44.

Neilson, M., S. L'Italien, V. Glumac and D. Williams. 1995. *Nutrients: Trends and system response.* State of the Lakes Ecosystem Conference, Chicago, Illinois.

O'Gorman, R., R. W. Owens, S. P. Schneider and T. H. Eckert (1994). *Status of the Major Fish Stocks in the U.S. Waters of Lake Ontario.* Niagara Falls, Ontario, Great Lakes Fishery Commission: 93-99.

Orsati, S. D. and G. C. LeTendre. 1994. *Lake Ontario Stocking and Marketing Program.* Lake Ontario Committee 1994 Annual Meeting, Niagara Falls, Ontario, Great Lakes Fishery Commission.

Patalas, K. 1969. Composition and horizontal distribution of crustacean plankton in Lake Ontario. *J. Fish. Res. Board Can.* 26: 2135-2164.

Schaner, T. (1991). OMNR's zebra mussel monitoring program on Lake Ontario, 1990. *Lake Ontario Fisheries Unit 1990 Annual Report*. Picton, Ontario, Ontario Ministry of Natural Resources. 5: 1-5.

Stewart, T., J. Hoyle and T. Schaner (1994). Zebra mussel studies. *Lake Ontario Fisheries Unit 1993 Annual Report.* Picton, Ontario, Ontario Ministry of Natural Resources. 6: 1-3.

Taylor, W. D., H.-J. Fricker and D. R. S. Lean. 1987. Zooplankton Seasonal Succession in Lake Ontario at northshore, midlake and southshore stations in 1982, and a comparison with 1970. *Can. J. Fish. Aquat. Sci.* 44: 2178-2184.

Watson, N. H. F. 1974. Zooplankton of the St. Lawrence Great Lakes-Species composition, distribution and abundance *J. Fish. Res. Board Can.* 31: 783-794.

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Towards an Ecosystem-Wide Model of Contaminant Fate in the Great Lakes – St. Lawrence Regions

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ABSTRACT

This review gives an account of past and present research activities at the Environmental Modelling Centre at Trent University and it outlines our modelling philosophy as it guides future plans. Abiotic water quality models have been developed for Lake Ontario, the Otonabee River – Rice Lake system in southern Ontario and in Lac Saint Louis and the Saguenay Fjord in Quebec. Complementary to these are biotic or food web models. Efforts have also been devoted to analyses of monitoring data and development of a synoptic indicator of ecosystem contamination. We are convinced that ultimately, successful environmental management of the Great Lakes – St. Lawrence system will require comprehensive atmosphere, terrestrial, aquatic, biota, ecosystem-wide mass balance models. We view our work as contributing to this long-term goal.

At the Environmental Modelling Centre we have underway a program of mass balance modelling applied to the Great Lakes – St. Lawrence Region. This brief review describes past, present and planned future activities with the ultimate objective of compiling a comprehensive model of the entire region.

LAKE MODELS

In 1989, Mackay published a dynamic / QWASI fugacity model of PCB fate in Lake Ontario which traced contamination levels in air, water, sediment and fish from 1940 to the present (Mackay 1989). Assumptions were made regarding concentrations in air and the Niagara River and about point source emissions which resulted in concentration histories which were in general agreement with monitoring data. This topic was revisited in 1994 when the model was modified to describe the processes in terms of rate constants and concentrations rather than fugacities (Mackay *et al.* 1994). The analytical solution to a declining emissions / restoration scenario was presented as a contribution to 'virtual elimination' efforts. The use of a rate constant format consolidates all environmental process parameters into seven rate constants, thus enhancing interpretation and facilitating uncertainty analyses.

In 1992, Thompson compiled a first comprehensive set of current loading data for selected contaminants of concern in Lake Ontario (Thompson 1992). She also applied these loadings to the rate constant model and sought to reconcile observed concentrations with monitoring data. This work was published in her Master's thesis (Thompson 1995), but not in the refereed literature because it lacked adequate treatment of uncertainty. The topic has since been revisited by MacLeod as a component of his Master's thesis on mass balance modelling in the Great Lakes basin and a series of reports on this topic is being produced. A paper suggesting a role for the rate constant model in development of a strategy for virtual elimination of persistent toxic contaminants from Lake Ontario has been prepared (Thompson *et al.* 1998). The model predicts the response time of the lake to reductions in contaminant loadings, and estimates the time required to reach benchmarks on the path to virtual elimination (Figure 1). In a related study Vlahos *et al.* (1995) have examined the issue of air-water exchange of organic contaminants in lakes in general and in the Great Lakes in particular.

Lun *et al.* (1998) compiled a steady-state model of PAH fate in the Saguenay Fjord which flows into the St. Lawrence River east of Quebec City. This work is being extended to treat PAH behaviour in food webs in this general region with collaboration from Dr. K. Lee of the Canadian Department of Fisheries and Oceans. There has also been collaboration with Dr. J. Hellou of the same agency in the general area of modelling the fate and bioaccumulation of hydrophobic organic contaminants in marine environments, especially harbours (Hellou *et al.* 1995, 1998).

Mackay and Hickie (1998) have compiled a mass balance for PAHs in Lac Saint Louis, adjacent to Montreal, with collaboration and support from Alcan Ltd. which operates an aluminum smelter at Beauharnois, on the south shore of Lac Saint Louis. One aim of this study was to estimate the contribution of smelter emissions to PAH concentrations in sediments.

AQUATIC – TERRESTRIAL – ATMOSPHERIC SYSTEMS

As part of the general program of addressing the entire aquatic-terrestrial-atmospheric ecosystem MacLeod has completed a study of the sources, fate and concentrations of benzene and the chlorobenzenes in Southern Ontario using the ChemCAN model. This work has also yielded a comparison of current measured and calculated contaminant levels with "acceptable" levels and has shown that the contaminant of most concern within this group is benzene (MacLeod and Mackay 1998). It is noteworthy that Koprivnjak and Poissant (1997) have also applied the ChemCAN model to the St. Lawrence Valley. As well, Booty *et al.* (1994) have applied the model to a number of contaminants in this region.

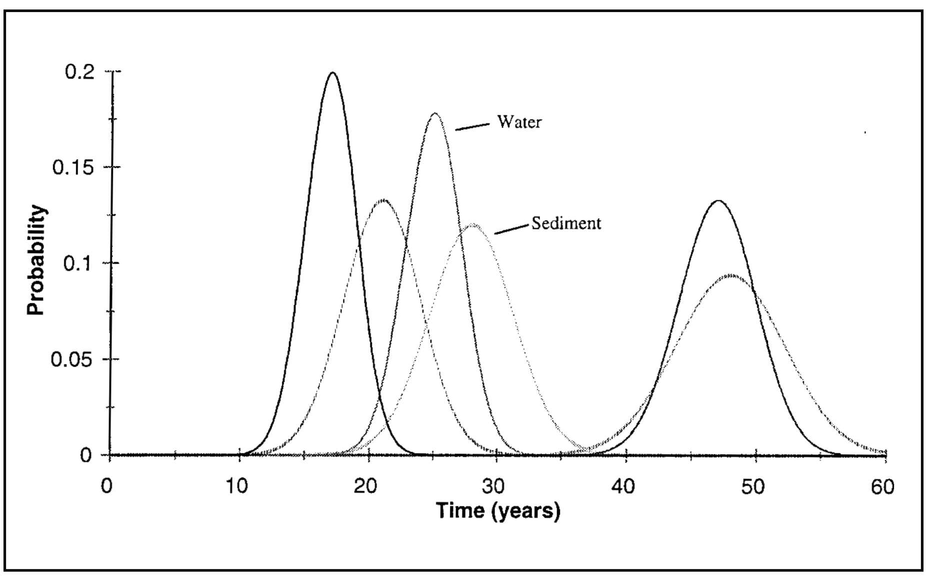

Figure 1. *Probable time for total PCB concentrations in Lake Ontario to reach 1/10 current levels under loading reductions of 15, 10 and 5% per year.*

There is thus growing confidence in the ability of the ChemCAN model to simulate the multimedia fate of chemicals. It is clearly important to work towards a coupled and carefully segmented aquatic-terrestrial-atmospheric model if we are to fully describe the key contaminant sources, pathways and sinks.

ANALYSIS OF MONITORING DATA

Mackay and Bentzen (1997) have analysed some of the IADN data reported by Hoff *et al.* (1996, 1997) and have shown that Lakes Ontario and Superior are approaching a state of near equilibrium with the atmosphere. This has profound implications for virtual elimination strategies because the contaminant levels in the lakes and their biota are becoming increasingly controlled by exchange with the atmosphere, which in turn is presumably controlled by exchange with the adjacent terrestrial environment. Plans are underway to address the formidable task of modelling this large and complex system.

Bentzen is also currently completing a comprehensive review of PCB fish monitoring data from Lake Ontario (Bentzen *et al.* 1998). This review highlights the importance of changes in food web structure and lipid content, and shows that proper trend-data interpretation requires careful assessment of the analytical methods, type of tissue analysed and sample location. Simple plots of concentration in a species versus time can produce misleading results, especially over relatively short time periods. Fish are invaluable biomonitors of hydrophobic contaminant levels, however, the raw data must be interpreted with care.

In a related attempt to describe the level and trends of ecosystem-wide contamination Webster *et al.* (1998) have devised a novel synoptic indicator of contamination status which is termed the Equilibrium Lipid Partitioning (ELP) concentration. In this approach contaminant concentration in all media ranging from air to biota, water and sediments are converted to the common, and comparable units of g / m^3, or 'part per million', in lipid at equilibrium with the medium. This approach clearly demonstrates the trend of reduced contamination levels in Lakes Ontario (Figure 2) and Superior as a result of cessation of discharges and reduced atmospheric concentrations. We believe that it can be applied to assess contaminant trends in other ecosystems.

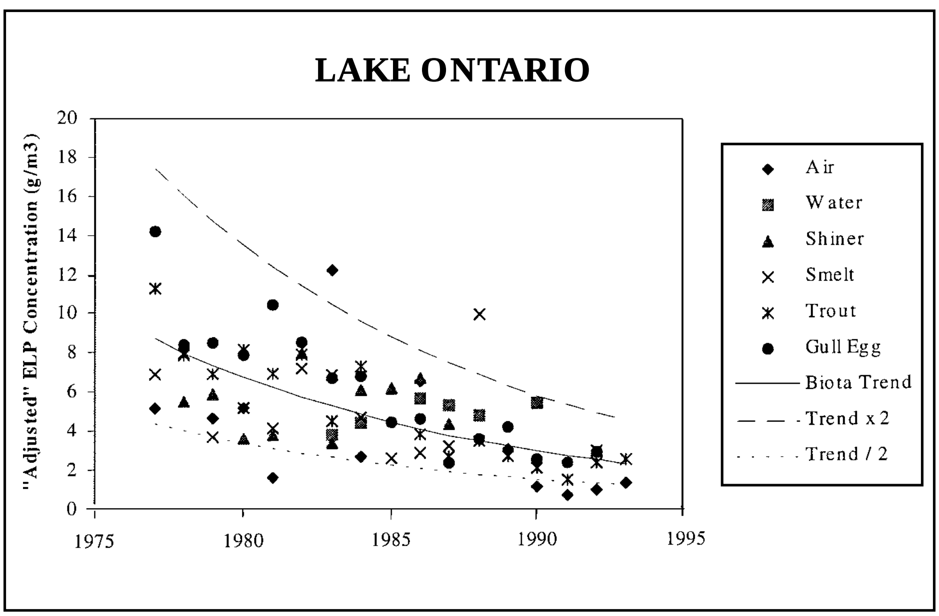

Figure 2. *Adjusted "ELP" concentration for various media in Lake Ontario.*

FOOD WEB MODELS

Campfens addressed the issue of describing the Lake Ontario food web using a novel fugacity-matrix approach (Campfens and Mackay 1997). The model treats the migration of contaminant from both pelagic and benthic sources. Recently, Sharpe has extended this food web model to treat terrestrial animals, birds and vegetation; thus potentially giving a comprehensive account of all key aquatic and terrestrial components of Great Lakes food webs, especially as they change under the influence of factors such as exotic species.

Hickie *et al.* (1998) have recently completed a pharmacokinetic model of PCB uptake by beluga whales extending over the lifetime of both males and females. This model has been applied to the St. Lawrence beluga population and clearly shows the influences of pregnancy, birth and lactation for modulation of contaminant burdens. The model supports the hypothesis that eels migrating from Lake Ontario are a significant source of contamination for the population.

RIVER MODELS

Most of the Centre's modelling work has been devoted to lakes, but in recognition of the importance of rivers, Milford (1998) has undertaken a mass balance study of total PCB in the Otonabee River-Rice Lake system as part of her Master's thesis. The model treats the river system as a series of six individual segments which are connected by advective flow downstream as shown in Figure 3. The predicted concentrations for water, sediment and fish clearly show downstream transport of PCBs from an historic point source and are in agreement with observed concentrations. This work has sharpened the Centre's skills in river modelling, now enabling us to apply the same techniques to larger riverine systems. Currently, Milford is developing a mass balance model of PCB fate in the St. Lawrence Area of Concern, from the Moses-Suanders power dam in Cornwall, to the Beauharnois power dam in Quebec. This project has been undertaken in collaboration with the University of Ottawa (Professor D. Lean), the St. Lawrence River Institute of Environmental Science (Dr. J. Ridal), the Canada Centre for Inland Waters (H. Biberhofer) and Centre Saint-Laurent (Y. De Lafontaine, T. Pham and S. Lepage).

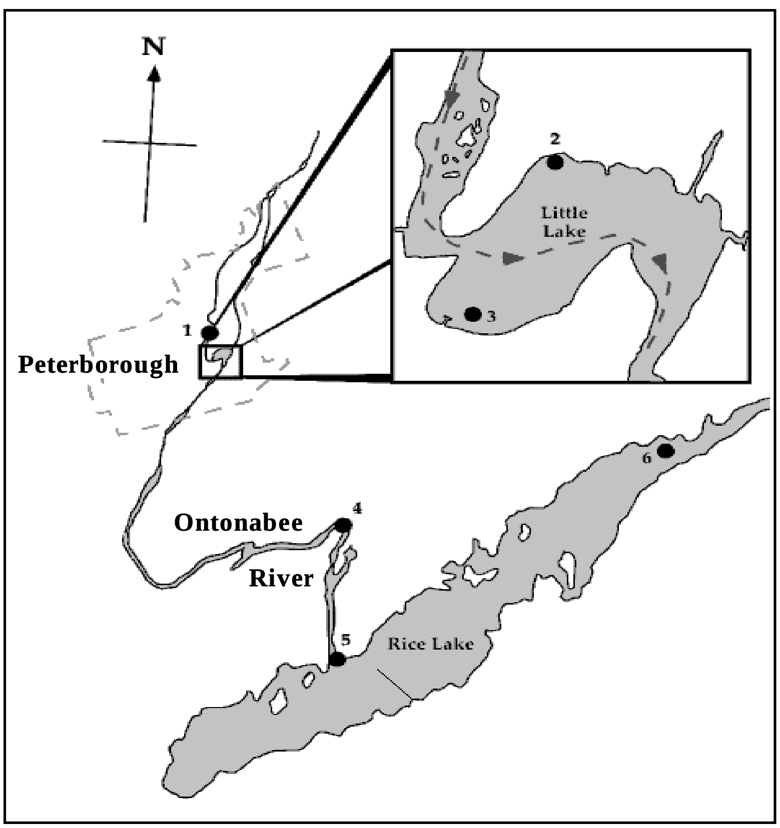

Figure 3. *The Otonabee River-Rice Lake system. The system was divided into six segments based on physical characteristics.*

A key initiative which is planned for the near future is to link the LOTOX I model of PCB fate in Lake Ontario, developed by DePinto and colleagues at SUNY Buffalo, to the St. Lawrence River model. This will represent the first major integrating step in the overall goal to compile a comprehensive model of contaminant fate in the Great Lakes – St. Lawrence system project, involving groups from Canada and the United States working in tandem. Parallel tasks are to apply the models to other contaminants including other hydrophobic organics, endocrine modulating substances and metals, especially mercury.

CONCLUSIONS: THE FUTURE

We believe that ultimately there will be a comprehensive contaminant mass balance effort extending over all the Great Lakes, their terrestrial drainage

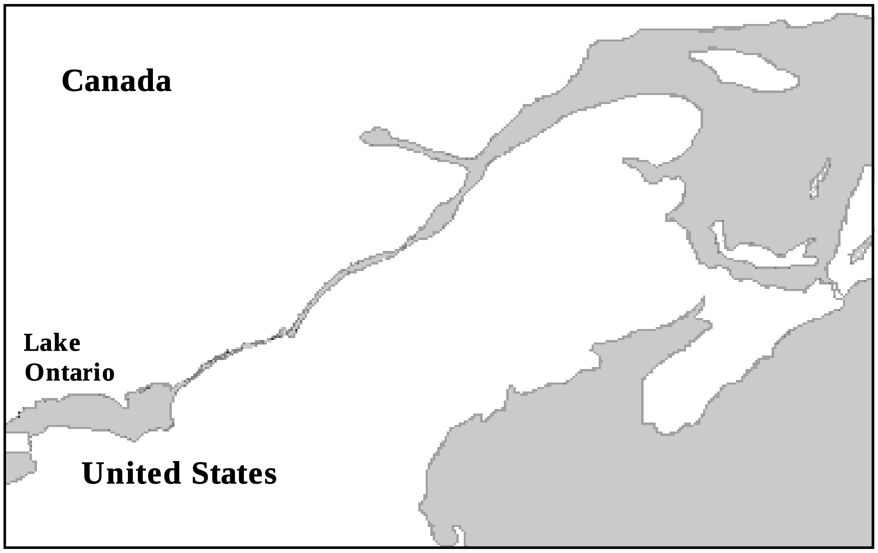

Figure 4. *The geographical location for many of the modelling efforts at the Environmental Modelling Centre starting at Lake Ontario and ending at the Saguenay Fjord.*

basins and the atmosphere, including the St. Lawrence River and Estuary. Mass balance modelling of fragments of this system as is presently done will eventually prove inadequate because it is a connected system of outputs and inputs with strong local urban influences and several regions of particular concern due to urban inputs and past contamination. A unified, binational effort is required to quantitatively describe contaminant fate within the entire geographic region depicted in Figure 4. In many respects, the merits of this approach are supported by the success of other comprehensive mass balance projects applied, for example, to the Hudson River, Lake Michigan and Chesapeake Bay (Thomann 1998).

We are convinced that the existence of a quantitative mass balance model of the entire Great Lakes Basin – St. Lawrence River system, applicable to a variety of contaminants, will provide a sound foundation for environmental management of this key region of North America. The rather fragmented studies which have been described here are viewed as ultimately contributing to this overall model and management system.

ACKNOWLEDGEMENTS

The authors are grateful for financial support from the Natural Science and Engineering Research Council of Canada (NSERC) and the Trent University – Chemical Industry Consortium. We also are grateful for support from the Toxic Chemical Research Program of the Department of Fisheries and Oceans.

REFERENCES

Bentzen, E., D. Mackay, D.R.S. Lean and B.E. Hickie. 1998. Temporal trends in persistent organic pollutants in Lake Ontario compared between species and between data sources. (Paper in Preparation).

Booty, W.G. and I.W.S. Wong. 1994. Application of a fugacity model for assessing chemical fate in ecodistricts of southern Ontario. *Ecological Modelling.* 84:245-263.

Campfens, J. and D. Mackay. 1997. Fugacity-Based Model of PCB Bioaccumulation in Complex Aquatic Food Webs. *Environ. Sci. Tech.* 31:557-583.

Hellou, J., D. Mackay, and B. Fowler. 1995. Bioconcentration of Polycyclic Aromatic Compounds from Sediments to Muscle of Finfish. *Environ. Sci. Technol.* 29:2555-2560.

Hellou, J., D. Mackay, and J.H. Banoub. 1998. Dietary and Aqueous Exposure of Finfish to Organochlorine Compounds: A Case Study. *Environ. Contam. Toxicol.* 34:280-288.

Hickie, B., M.C.S. Kingsley, P.V. Hodson, D.C.G. Muir, P. Beland and D. Mackay. 1998. A modelling perspective of PCB contamination of the St. Lawrence Beluga whale population: past, present and future. (Paper in Preparation).

Hoff, R.M., W.M.J. Strachan, C.W. Sweet, C.H. Chan, M.Shackleton, T.F. Bidleman, K.A. Brice, D.A. Burniston, S. Cussion, D.F. Gatz, K. Harlin, and W.H. Schroeder. 1996. Atmospheric Deposition of Toxic Chemicals to the Great Lakes: A Review of Data Through 1994. *Atmos. Environ.* 30:3505-3527. Errata: 1997. *Atmos. Environ.* 31:1585.

Koprivnjak, J.F. and L. Poissant. 1997. Evaluation and application of a fugacity model to explain the partitioning of contaminants in the St. Lawrence River Valley. *Water, Air, and Soil Pollution.* 97:379-395.

Lun, R., K. Lee, L. De Marco, C. Nalewajko, and D. Mackay. 1998. A Model of the Fate of Polycyclic Aromatic Hydrocarbons in the Saguenay Fjord, Canada. *Environ. Toxicol. Chem.* 17:333-341.

Mackay, D. 1989. Modelling the Long Term Behaviour of an Organic Contaminant in a Large Lake: Application to PCBs in Lake Ontario. *J. Great Lakes Res.* 15:283-297.

Mackay, D., S. Sang, P. Vlahos, M. Diamond, F. Gobas, and D. Dolan. 1994. A Rate Constant Model of Chemical Dynamics in a Lake Ecosystem: PCBs in Lake Ontario. *J. Great Lakes Res.* 20:625-642.

Mackay, D., and E. Bentzen. 1997. The Role of the Atmosphere in Great Lakes Contamination. *Atmos. Environ.* 31:4043-4047.

Mackay, D. and B. Hickie. 1998. *Mass Balance Model of the Sources, Transport and Fate of PAHs in the Sediments and Water of Lac Saint Louis, Quebec.* Report for Alcan Ltd.

MacLeod M., and D. Mackay. 1998. *An Assessment of the Environmental Fate and Exposure of Benzene and the Chlorobenzenes in Canada.* Chemosphere (In Press).

Milford, L., D. Mackay, and C.D. Metcalfe. 1998. A Model of the Fate of Polychlorinated Biphenyls in the Otonabee River-River Lake Ecosystem, Peterborough Ontario. (Paper in Preparation).

Thomann, R.V. 1998. The Future "Golden Age" of Predictive Models for Surface Water Quality and Ecosystem Management. *Journal of Environmental Engineering.* 124:94-103.

Thompson, S. 1992. *Estimating Loadings of Eighteen Persistent Toxics to Lake Ontario.* Report for Environmental Protection-Ontario Region Conservation and Protection, Environment Canada.

Thompson, S. 1995. A Practical Approach to Reduce Persistent Toxic Chemicals in Lake Ontario. M.Sc Thesis, University of Toronto.

Thompson, S., D. Mackay, and M.MacLeod. 1998. A Modelling Strategy for Virtual Elimination of Persistent toxic Chemicals from the Great Lakes: An Illustration of Four Contaminants in Lake Ontario. (Submitted to the *Journal of Great Lakes Research*).

Vlahos, P., D. Mackay, S.J. Eisenreich, and K.C. Hornbuckle. 1995. "Exchange of Chemicals Between the Atmosphere and Lakes", *In Physics and Chemistry of Lakes,* Lerman, A., Imboden, D.M. and Gat, J.R., (eds), Springer-Verlag, Berlin Heidelberg, pp. 167-184.

Webster, E., D. Mackay, and K. Qiang. 1998. Equilibrium lipid partitioning concentrations as a multi-media synoptic indicator of contaminant levels and trends in aquatic ecosystems. (Submitted to *Journal of Great Lakes Research*).

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Development of LOTOX2: Solids and PCB Calibration, Management Applications

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INTRODUCTION

A group of researchers, operating under the auspices of the New York Great Lakes Research Consortium and supported by U.S. EPA - Region II, have undertaken a multi-year project to develop and implement a long-term plan for improving our capability to predict the transport, fate and bioaccumulation of toxic chemicals in the Niagara River / Lake Ontario system. The first year of the project was spent in acquiring data, developing a baseline (state-of-the-art) model (LOTOX1) for Lake Ontario, and analyzing the data and model to develop the long-term plan. Among the most immediate priorities of the plan was to update and improve the spatial and temporal resolution of the solids (*i.e.*, sorbent) and chemical dynamics in the model. Implementation of this recommendation during the past year has led to the development of a second version of the model, which we call LOTOX2.

LOTOX2 has an increased spatial resolution and an increased temporal resolution of process parameterization relative to LOTOX1. We have also conducted a long-term ^{137}Cs / solids mass balance calibration to insure accurate simulation of solids sedimentation and deposition-resuspension dynamics. With a calibrated solids model, we were then able to implement a long-term PCB hindcast that allowed refinement of our PCB dynamics parameterization and reduction of uncertainty in making long-term predictions of the response of Lake Ontario to load controls. Finally, we applied LOTOX2 in a predictive mode to illustrate the expected trajectories of PCBs in Lake Ontario, in response to varying loading scenarios.

LOTOX2 SPATIAL SEGMENTATION

Our first task was to develop a three-dimensional water column and sediment segmentation scheme for LOTOX2 that would allow us to describe the circulation, vertical mixing, and sediment resuspension behavior of Lake Ontario in a more representative way. This required us to include an epilimnion and hypolimnion in the lake, to distinguish between nearshore and offshore regions, to account for a general counter-clockwise circulation pattern, and to capture the sediment depositional zones as distinct from predominantly non-depositional zones. The resulting model segmentation scheme is depicted in Figure 1.

SOLIDS DYNAMICS CALIBRATION

Because ^{137}Cs has a strong affinity for solids ($K_p = 10^5$) and because it had a well-known atmospheric loading rate to large lakes like Lake Ontario as a result of above-ground thermonuclear testing in the 1950s and early 1960s, it serves as an excellent tracer of the solids dynamics in these lakes. We used this radionuclide to develop a long-term solids dynamics mass balance for Lake Ontario by adjusting solids deposition, resuspension and burial in five zones (four depositional basins – Niagara, Mississauga, Rochester, and Kingston – and a non-depositional zone) of the lake, on a seasonal basis (stratified and unstratified periods), until our model predictions of sediment profiles in the various depositional zones matched data collected by Howdeshell and Hites (1996).

The ^{137}Cs tracer approach produced a solids calibration that does an excellent job of reproducing the observed ^{137}Cs profiles and is also consistent with the trend of decreasing primary production of solids in Lake Ontario from the mid-1970s to the mid-1980s as a result of phosphorus controls. An example of the results of the Cs sediment profile calibration is shown in Figure 2. This figure illustrates the model prediction for the Rochester and Kingston basins in comparison to the depth profiles for Howdeshell and Hites (1996) cores collected within those basins. It is important to note that the model is able to capture both the timing and magnitude of the peak as well as the general shape (especially the slope of the decline in recent times after virtual elimination of ^{137}Cs loading to the lake). It should also be noted in comparing the two profiles that the Rochester basin peak occurs deeper in the core than the Kingston peak. This demonstrates, because both peaks occur at virtually the same point in time, that the net sedimentation rate of solids is higher in the deep Rochester basin than in the shallower Kingston basin. Although not shown, the calibration results for the other two depositional basins produced similarly good model comparisons.

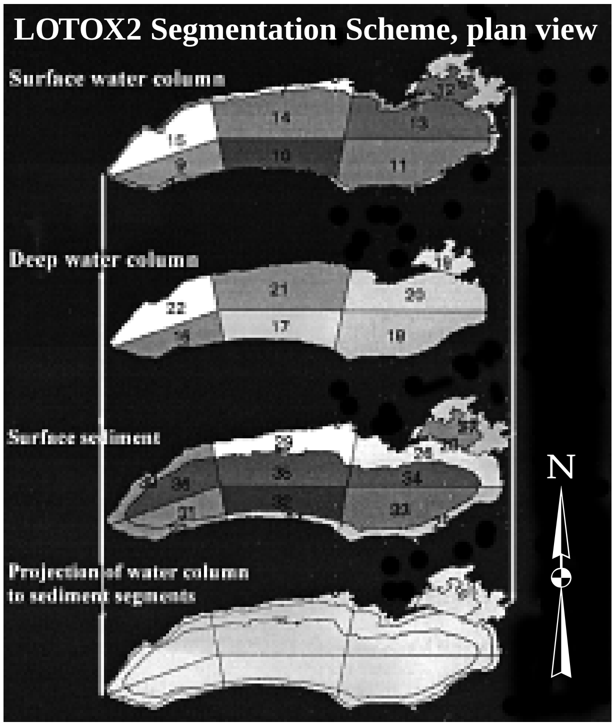

***Figure 1**. Three dimensions segmentation scheme for LOTOX2. Sediment segments have multiple layers – up to 20 cm depth.*

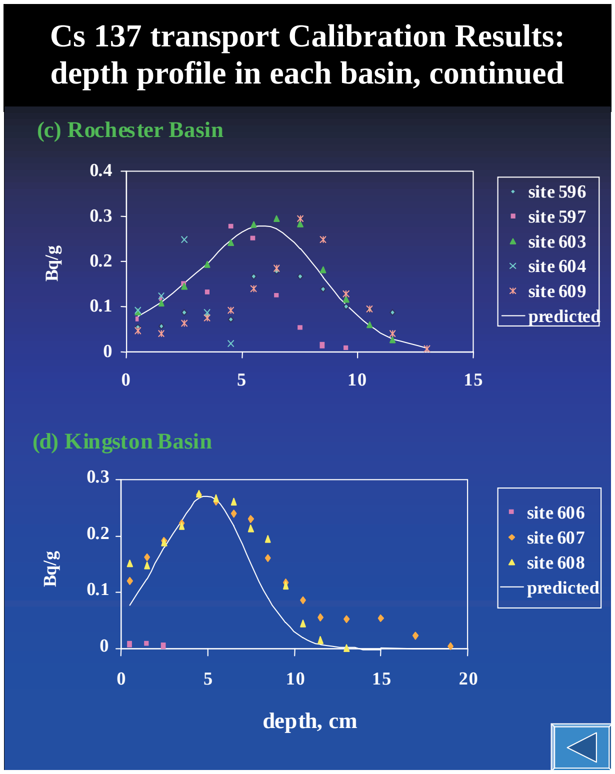

***Figure 2.** Comparison of ^{137}Cs sediment profiles in Rochester and Kingston basins with long-term model predictions.*

LONG-TERM PCB CALIBRATION

Once the solids dynamics of the system are calibrated, the strategy for calibrating LOTOX2 to any hydrophobic chemical is to keep the solids parameters constant, begin with chemical parameters obtained from theory and / or empirical results from the literature, and then adjust those chemical transport and transformation parameters for a site-specific calibration data set. We have completed this strategy for total PCBs by constructing a long-term hindcast from a number of sources, all of which are listed in the reference list below.

The results of our long-term hindcast calibration for PCBs in the water column and in lake trout are shown in Figures 3 and 4. These plots show a very good agreement with observed whole-lake data. They give us confidence in our solids dynamics and in our predictions of the trajectory of PCBs in response to washout and burial of historic inputs and to recent declines in external PCB loading to the lake.

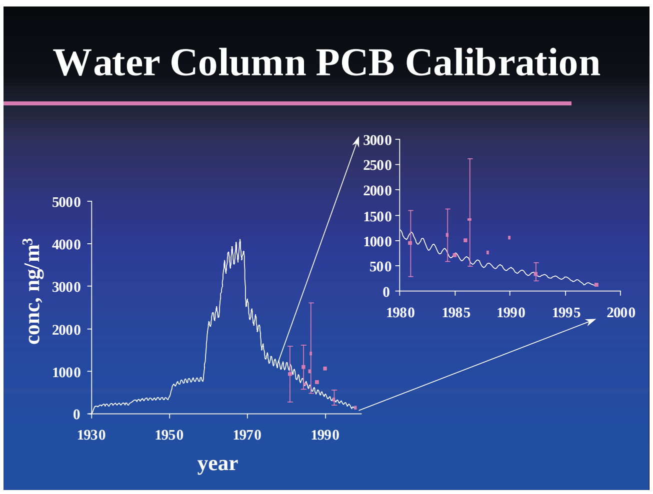

Figure 3. *Results of historical simulation of PCB concentration in Lake Ontario water column in comparison to available data.*

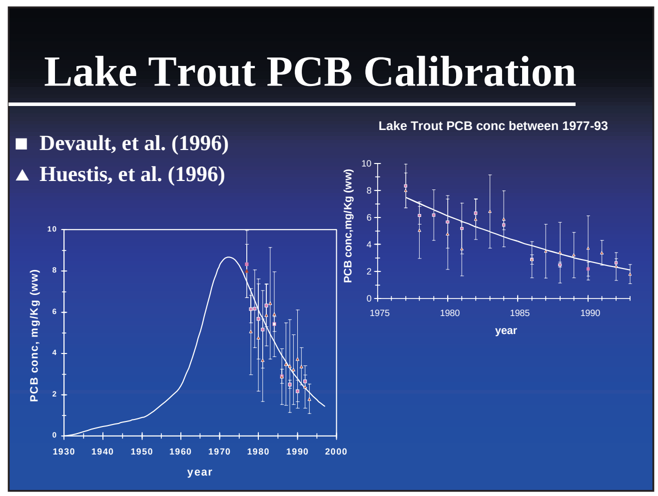

Figure 4. *Results of historical simulation of PCB concentration in Lake Ontario lake trout in comparison to available data.*

of PCBs for Lake Ontario beginning in 1930 and running through 1995. There is insufficient time to relate all the details of this calibration; but like any model calibration process it required us to construct a loading and boundary condition data set for input into the model and to compile a data set of field observations for comparison with the model output. The historic load and atmospheric gas phase boundary condition reconstructions were a combination of the analyses described in the presentation of Tom Young and the report of Rodgers, *et al.* (1988). Observational time trends for PCB concentrations in the water column, sediments and top predator fish (lake trout) were compiled

LOTOX2 PROJECTIONS

Having gained some confidence in LOTOX2 through the above long-term hindcast, we feel somewhat comfortable in making model projections under different loading scenarios. This type of analysis can provide insight regarding how the lake will respond (both extent and time frame) to management actions that might be implemented under the various Lake Ontario programs. As a demonstration of this use of the model, two sets of forecasting runs were made. In Figure 5 we show the model prediction of the concentration of total PCBs in lake trout under three different loading scenarios implemented in 1995. In our hindcast we calculated the lake trout PCB concentration in 1995 to be just below 2 ppm (wet weight basis). In this analysis we applied three different loading scenarios in the post-1995 period:

1. Hold the loading and atmospheric gas phase boundary condition constant from 1996 forward at the values that were used in 1995 (850 Kg / yr);
2. Allow the loading and atmospheric gas phase boundary condition to exponentially decline at the same rate that has been observed over the past 15 years (0.125 yr^{-1});
3. Immediately decrease the loading and atmospheric gas phase boundary condition to 20% of the 1995 value and hold them constant at those values from 1996 forward.

It is apparent from these simulations that the lake is not at steady-state with the 1995 loads and that it will take on the order of 20 years to approach that steady-state condition. It is also clear – because of the similarity among the trajectories for about the first ten years after 1995 – that *in-lake* processes (particularly, sediment feedback) acting on historical inputs of PCBs are important in governing the rate of decline. Because of this 10-20 year response time, it will be difficult to distinguish among these three loading scenarios until about 2005-2010. However, at that time, as the lake begins to approach steady-state with respect to its external loads – because scenario 2 calls for a continued exponential decline in loading to zero, the fish concentrations will also exponentially approach zero – the predicted fish levels deviate measurably. The steady-state values then will become proportional to the loading, which is why the steady-state value for scenario 3 is 20% of the steady-state value (0.4 ppm).

Based on the results presented in Figure 5, one might get the impression that there is very little to be gained from further load reductions. But it should be emphasized that PCBs are an example of a major historical contaminant that has been banned for some time but is still circulating in the environment. It should also be noted that at this point in time we have progressed quite a distance along the exponential decline of loading of PCBs that was to be expected subsequent to its production ban; and we would **not** be where we are today if the PCB ban had not been instituted in the 1970s. Therefore, to demonstrate the significance in PCB loading reduction to the state of Lake Ontario today and in the future, we have conducted another set of loading scenario runs (Figure 6). In the runs for Figure 6, we used the conditions in Lake Ontario (based on our hindcast modeling) in 1980 as our initial conditions for water,

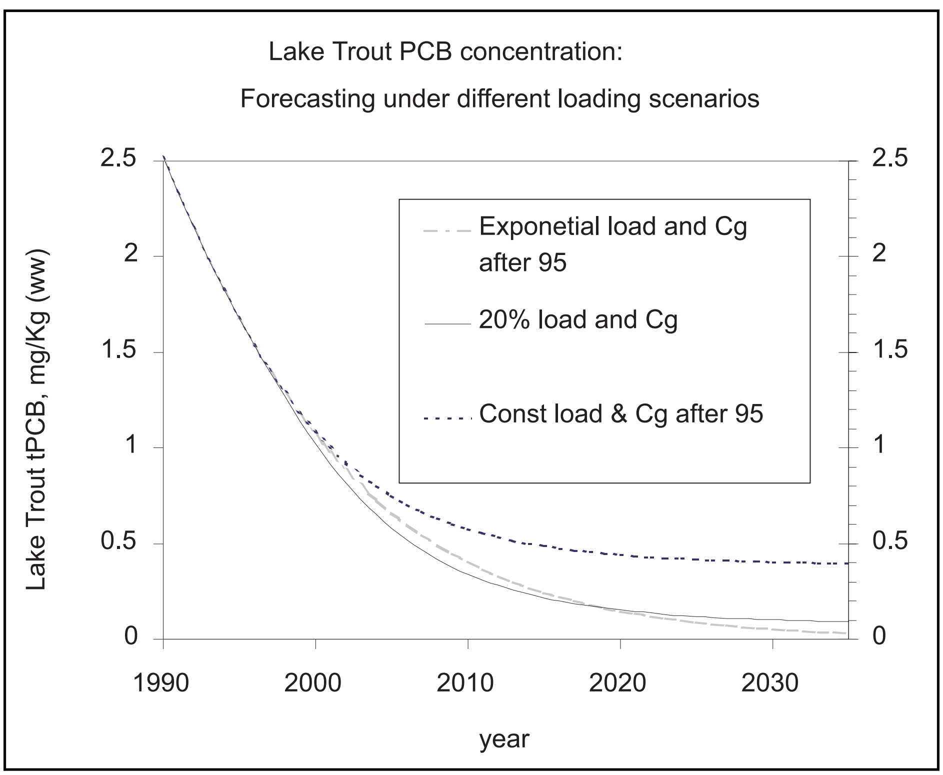

Figure 5. *LOTOX2 prediction of lake trout total PCB concentration in Lake Ontario after 1995 under different loading scenarios.*

sediments, and biota concentrations. Then we ran three different loading scenarios from 1980 forward:

1. Hold the loading and atmospheric gas phase boundary condition constant from 1980 forward at the values that were used in 1980 (3700 Kg / yr);
2. Allow the loading and atmospheric gas phase boundary condition to exponentially decline at a rate of 0.125 yr^{-1} from 1980 forward (this scenario is close to a simulation of actual history of the lake from 1980-1995); and
3. Immediately decrease the loading and atmospheric gas phase boundary condition to 20% of the 1980 value and hold them constant at those values from 1980 forward.

These scenarios are relatively similar to those in Figure 5, except for the initial conditions for their application. These results indicate the even in 1980 the lake was still responding to historical PCB inputs and that the response time to a new steady-state – seen in the scenario 1 in which loads are held constant – is still approximately 15-20 years. What this set of runs does illustrate, that was not as graphic in the previous set of runs (in Figure 5), is how important the continued decline in loading has been and will continue to be in governing the response trajectory of the lake. As shown in Figure 6 (scenario 1), if the loading did not continue to decline after 1980, the lake trout levels would still continue to decline for 10-15 years but not nearly at the same rate that was observed. Today, lake trout PCB levels would still be approximately 3 ppm if it had not been for the decline in PCB inputs, and they would remain at those levels as long as the loading did not change.

In summary, our modeling analysis for PCBs in Lake Ontario suggests that the lake is still responding to historical inputs, but that it is significantly better than it would have been had we not seen the exponential reduction in PCB loading over the past 10-15 years. We would also conclude that further PCB loading reductions will indeed produce in-lake benefits, but those benefits will not be evident for about ten years.

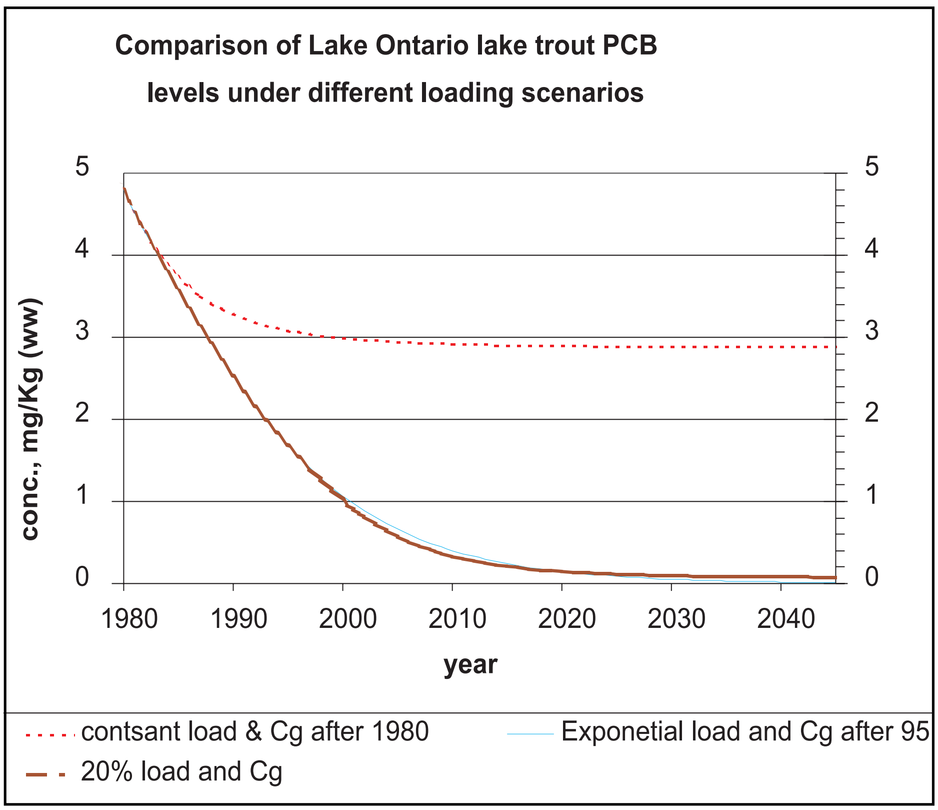

Figure 6. *LOTOX2 prediction of lake trout PCB concentration in Lake Ontario after 1980 under different loading scenarios.*

REFERENCES

Bicksler, J. L. 1996. Polychlorinated biphenyls in the spring-time water column of the Great Lakes, thesis, University of Minnesota.

DeVault, D.S., Hesselberg, R., Rodgers, P.W., and Feist, T.J. 1996. Contaminant Trends in Lake

Trout and Walleye from the Laurentian Great Lakes, *J. Great Lakes Res.* 22(4):884-895.

Filkins, J. C., J. M. Towsend, and Rood, S. G. 1983. Organochlorines in offshore waters of the Great Lakes, 1981. Cranbrook Institute of Science. Bloomfield Hills, Michigan, Unpublished report.

Howdeshell, M. J. and Hites, R. A. 1996. Historical input and degradation of toxaphene in Lake Ontario sediment, *Environ. Sci. Technol.*, 30(1), 220-224.

Howdeshell, M. J. and Hites, R. A. 1996. Is the Hyde Park Dump, near the Niagara River, still affecting the sediment of Lake Ontario?, *Environ. Sci. Technol.,* 30, 969-974.

Huestis, S. Y., Servos, M. R., Whittle, D. M., and Dixon, D. G. 1996. Temporal and age-related trends in levels of polychlorinated biphenyl congeners and organochlorine contaminants in Lake Ontario lake trout, *J. Great Lakes Res.*, 22(2):310-330.

L'Italien, S. 1992. Organic contaminants in the Great Lakes 1986-1990, *mf94042,* Environment Canada, Environmental Conservation Branch, Ecosystem Health Division / Ontario Region.

Mudroch, A., K. L. E., Kaiser, M. E., Comba and Neilson, M. A. 1994 Particle associated PCBs in Lake Ontario, *The Science of the Total Environment*, 158, 113-125.

NYDEC Report, Enhanced Toxics Sampling for Trace organic chemicals in Lake Ontario, April, 1998.

Oliver, B. G., Charlton, M. N., and Durham, R. W. 1989. Distribution, redistribution, and geochronology of polychlorinated biphenyl congeners and other chlorinated hydrocarbons in Lake Ontario sediments, *Environ. Sci. Technol.,* 23, 200-208.

Oliver, B.G. and Niimi, A.J. 1988. Trophodynamic analysis of polychlorinated biphenyl cogeners and other chlorinated hydrocarbons in the Lake Ontario ecosystem, *Environ. Sci. Technol.*, 22:388-397.

Rodgers, P.W., DePinto,J.V., Booty,W., and Slawecki, T. 1988. "LTI Toxics Model Application: PCBs in Lake Ontario." Report contained in *Report on Modeling the Loading-Concentration Relationship for Critical Pollutants in the Great Lakes*. IJC Great Lakes Water Quality Board, Toxic Substances Committee, Task Force on Toxic Chemical Loadings, 49 pp.

Stevens, R. J. J. and Neilson, M. A. 1989. Inter- and intralake distributions of trace organic contaminants in surface waters of the Great Lakes, *J. Great Lakes Res.*, 15(3):377-393.

Strachan, W. M. J., and Eisenreich, S. J. 1988. *Mass balancing of toxic chemicals in the Great Lakes: the role of atmospheric deposition,* International Joint Commission, Windsor, Ontario.

Wong, C., Sanders, G., Engstrom, D. R., Long, D. T., Swackhamer, D. L. and Eisenreich, S. J. 1995. Accumulation, inventory, and diagenesis of chlorinated hydrocarbons in Lake Ontario sediments, *Environ. Sci. Technol.*, 29, 2661-2672.

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Surveillance and Monitoring of Lake Ontario and the Niagara and St. Lawrence Rivers

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ABSTRACT

Since the mid-1970s, Environment Canada has conducted open lake surveillance cruises on Lake Ontario, and operated water quality monitoring stations in the Niagara and St. Lawrence rivers. A wide variety of physical, biological and chemical parameters, including organic contaminants, are measured. These programs provide information on the loads to and from Lake Ontario, as well as in-lake conditions. Together, they provide corroborative evidence of the observed changes. The programs are designed to fulfill the requirements of the Canada-U.S. Great Lakes Water Quality Agreement as outlined below.

INTRODUCTION

Intent on preventing further pollution of the Great Lakes System resulting from continuing population growth, resource development, and increasing use of water, Canada and the United States signed the Canada-United States Agreement on Great Lakes Water Quality in 1972. The 1972 Agreement established specific water quality objectives, defined programs and other measures to attain these objectives and identified the need for surveillance and monitoring programs to determine the effectiveness of implemented programs. The focus of the 1972 Agreement was the reduction of phosphorus inputs to the Great Lakes.

A revised Agreement was signed in 1978. While the 1978 Agreement incorporated updated phosphorus loading targets for the lakes, it also marked a shift in focus from eutrophication to toxic substances. Annex 11 specified that surveillance and monitoring be undertaken for the following purposes:

- to measure compliance with jurisdictional control requirements
- to measure achievement of General and Specific Objectives of the Agreement
- to evaluate water quality trends
- to identify emerging problems

The 1978 Agreement also committed the Parties to develop a joint surveillance and monitoring program which included, among other components, assessment of inputs from, and outputs to, the connecting channels.

The 1978 Agreement was amended by the 1987 Protocol. Annex 2 of the Protocol requires the Parties, in cooperation with state and provincial governments, to develop Lakewide Management Plans (LaMPs) for "critical pollutants" for each of the Great Lakes. The purpose of these Plans is to restore and protect the fourteen beneficial uses outlined in the same Annex.

In 1974, scientists at CCIW designed a Lake Ontario Open Lake Surveillance Program to address the 1972 Agreement requirements (Watson and Williams 1975). This initial Open Lake Surveillance Program was focused on determining the response of the lake to phosphorus control management actions. The station pattern was designed to give a comprehensive view of the open waters of the lake. Most of the sampling stations were located between 2 and 10 km from shore which historically had exhibited the greatest variability. To better define temporal variability, 15 surveillance cruises were conducted on the lake in 1974. While the cruise frequency was reduced in subsequent years, the station pattern was maintained so that meaningful spatial variability analyses could be done. Surveillance cruise dates and sampling details, including station locations and parameters, have been documented elsewhere (Kwiatkowski and Neilson, 1983; L'Italien 1992).

In response to the 1978 Great Lakes Water Quality Agreement requirements, sampling for trace organic contaminants was eventually added to the Open Lake Surveillance Program. In addition, Environment Canada had already initiated water quality sampling in the Niagara and St. Lawrence rivers, at Niagara-on-the-Lake (NOTL) and Wolfe Island (WI), respectively, to measure the concentrations and loads of nutrients, major ions and trace metals. Trace organic contaminants were subsequently added in the mid-1980s.

The Lake Ontario Open Lake Surveillance Program, and the Niagara River and St. Lawrence River monitoring programs, among other Agreement requirements, also provide support to the Lake Ontario LaMP.

METHODS

Lake Ontario Open Lake Surveillance Program

Large research vessels with laboratory space and 24-hour sampling capability have been used for all Surveillance cruises conducted on Lake Ontario. Approximately 100 stations are sampled during each cruise (Figure 1) for a

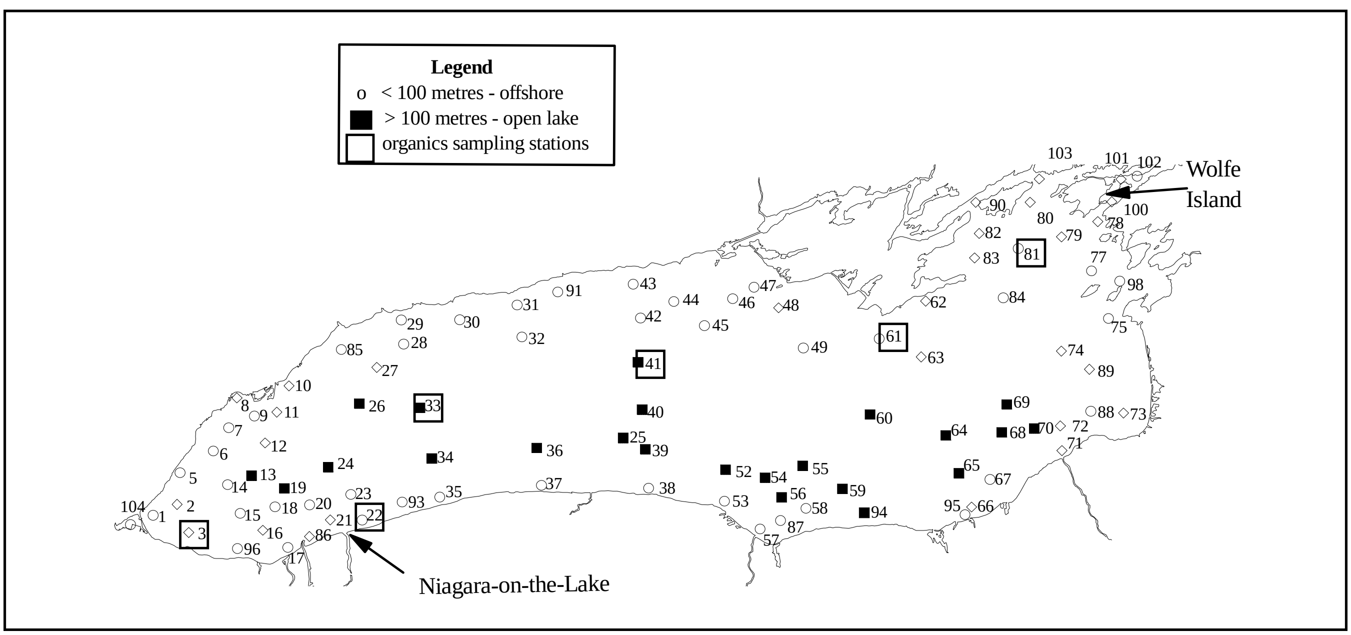

Figure 1. *Location of Sampling Stations in Lake Ontario, 1992 and 1993.*

variety of physical, chemical and biological parameters. In general, during spring isothermal conditions, samples are collected from the surface of the lake (1m). During summer and fall thermal stratification, samples are collected at multiple depths in both the epilimnion and hypolimnion. Biological samples (eg., chlorophyll a) are collected using a 0-20 metre depth integrating sampler. All parameters are not necessarily measured at every station and depth on each cruise.

Sampling methodology and analytical methods have been documented (L'Italien and Fay 1993: Environment Canada 1997). Surveillance data are stored in the STAR (STorage And Retrieval) database, maintained by Environment Canada in Burlington, Ontario. Spatial and temporal trend information has been summarized in earlier reports (Neilson and Stevens 1987; Stevens and Neilson 1987; Stevens 1988; Stevens and Neilson 1989; Neilson *et al* 1995; Williams *et al* 1998).

Niagara River Monitoring Program

Due to the importance of Niagara River input to Lake Ontario, a monitoring station was established at the mouth of the Niagara River, at Niagara-on-the-Lake (NOTL), in 1975. The cross-river chemical homogeneity at this site (Green / Seastar 1988) makes it suitable for determining the chemical loads from the river to Lake Ontario. An automated sampling system collects water samples on a twice-weekly basis for physical parameters, major ions, and nutrients. From 1986-1997, weekly, large-volume water and suspended sediment samples have been collected over a 24-hour period for trace organic contaminants and trace metals; *post*-1997, sample collection was changed to biweekly. Station set-up details and sampling and analytical protocols have been documented (NRSP 1988; NRAP 1992). Data are stored in the ENVIRODAT database maintained at CCIW. Previous reports include those by Kuntz and Tsanis (1990; 1993), and the annual (1986-1997) publications of the Data Interpretation Group of the Niagara River Monitoring Committee (NRDIG 1997).

St. Lawrence River Monitoring Program

Wolfe Island, in the St. Lawrence River, divides the flow leaving Lake Ontario with approximately 60% of the flow in the south channel, and the remaining 40% in the north channel (Casey and Salbach 1974). In 1979, a sampling site was established at Banford Point along the south shore of Wolfe Island, to measure the concentrations and exit loads of chemicals from Lake Ontario. An automated sampling system collects weekly water samples for physical parameters, major ions, nutrients and trace metals. Large-volume water and suspended sediment samples are collected monthly over a 24-hour period for trace organic contaminants. Station set-up details and sampling and analytical protocols have been documented (Sylvestre *et al* 1987: Kuntz 1996: Environment Canada 1997). Data are stored in ENVIRODAT. Results have been previously summarized (Sylvestre *et al* 1987); Biberhofer 1995; Merriman 1997; Merriman 1998).

RESULTS AND DISCUSSION

The Niagara River significantly impacts Lake Ontario by supplying more than 83% of the total tributary input flow (Eadie and Robertson 1976), 50% of the total input of suspended solids (Kemp and Harper 1976), and significant loads of many chemicals to the lake. As such, a decline in chemical loads from the Niagara River to Lake Ontario should result in a decline in both the concentrations in the lake and the exit loads from the lake. Indeed, this has, generally, been the case over the longer term. More recently, however, there has been a departure from this generality for some chemicals (eg., phosphorus) as noted briefly below. In-lake concentrations do not directly reflect changes in Niagara River loads. Chemical trends at Wolfe Island, however, still remain similar to those observed in Lake Ontario.

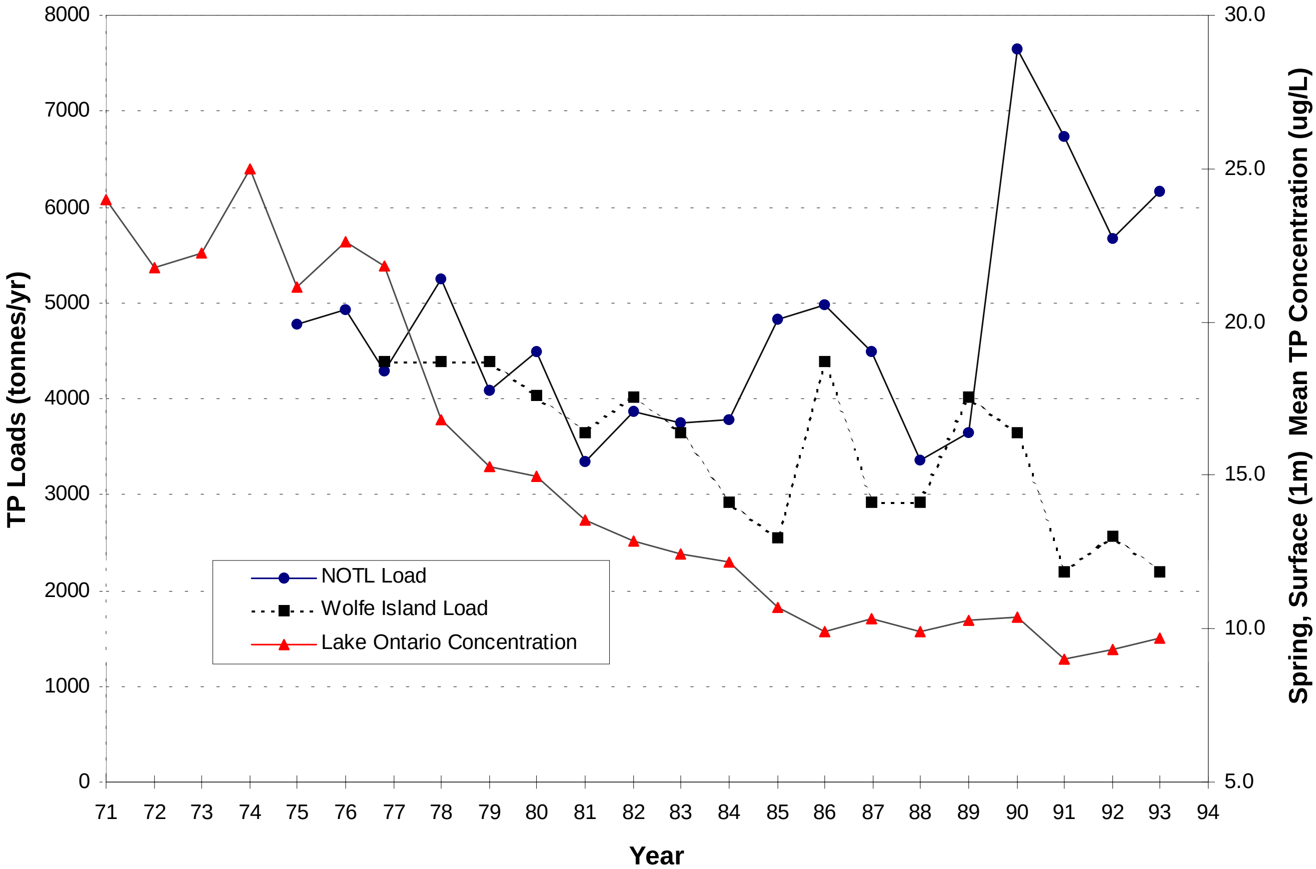

Figure 2. *Trends in Spring, Surface (1m) Total Phosphorus Concentrations in Lake Ontario and the Loads at NOTL and Wolfe Island.*

Nutrients

Nutrient concentrations are greatest in early spring, before algal production begins. Concentrations at this time determine the limits to algal growth during the summer. For this reason, the target phosphorus load for Lake Ontario is based on achieving a spring mean total phosphorus (TP) concentration of 10 ug/L. Based on the open lake data (stations >100m depth), this concentration has been achieved for the past several years (Figure 2). Elevated concentrations, however, are still observed in localized nearshore areas. For example, spring, surface (1m) TP concentrations in 1993 ranged from 8.0 to 26.3 ug/L with the highest concentrations occurring off the mouths of the Niagara and Oswego rivers.

While the trends in Lake Ontario TP concentrations have generally followed the trends in loads from the Niagara River, this has not been the case since about 1985. Figure 2 shows that Niagara River TP loads generally declined over the period 1975-1984. Similarly, in-lake TP concentrations also declined. Subsequent to 1984, however, Niagara River TP loads have oscillated considerably with a peak in both 1986 and in 1990. In contrast, Lake Ontario TP concentrations plateaued at about 10 ug/L. Comparing NOTL TP concentration and flow data (not shown) to the calculated loads shows that the 1986 high is flow related while that in 1990 is concentration related. The fact that there is little change in in-lake TP concentrations suggests that these oscillations do not significantly impact the whole lake.

Notwithstanding the lack of correlation between Niagara River loads and Lake Ontario TP concentrations, the exit loads from Lake

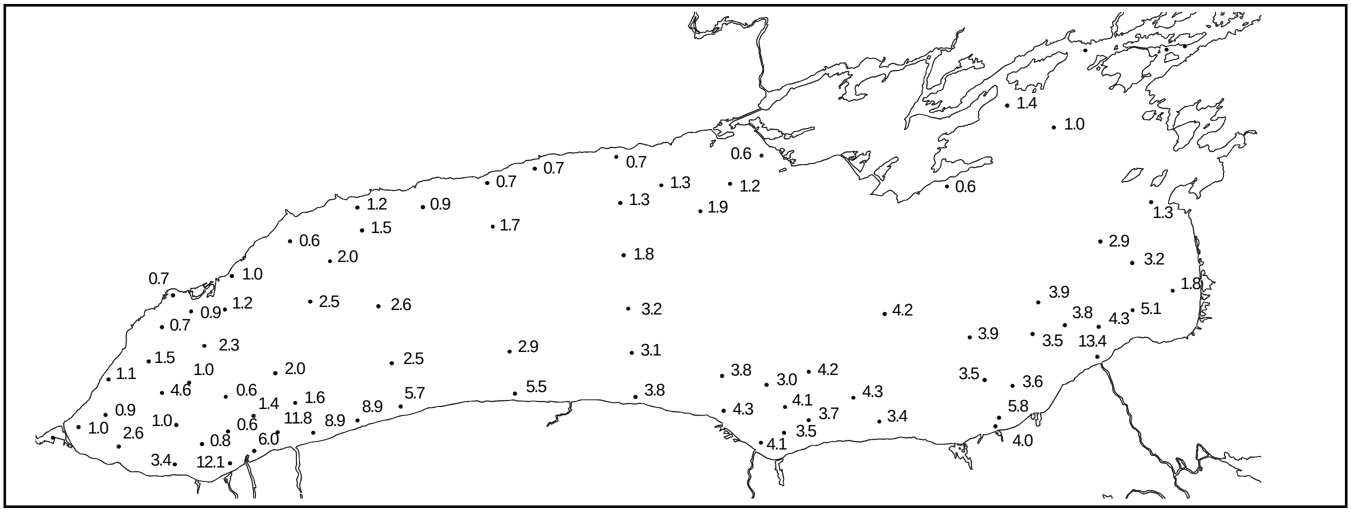

Figure 3. *Spring, Surface (1m) Distribution of SRP in Lake Ontario, 1993.*

Ontario measured at Wolfe Island continue to mirror the trend observed in Lake Ontario. Merriman (1997) attributed the changes at Wolfe Island, in part, to reduced phosphorus loads from sewage treatment plants and the steadily decreasing use of phosphate fertilizers in the Great Lakes Basin since the late 1970s.

Soluble reactive phosphorus (SRP) represents the biologically available fraction of total phosphorus. The decrease in in-lake SRP concentrations tends to parallel the decreasing trend observed for total phosphorus. Spring, surface (1m) concentrations in 1993 ranged from 0.6 to 13.4 ug/L with the highest concentrations again occurring off the mouths of the Niagara River (Welland Canal) and Oswego River similar to total phosphorus (Figure 3). Jackson and Hamdy (1982) found that SRP concentrations greater than 2.0 ug/L were adequate to promote the growth of *Cladophora*, a filamentous algae that grows on rocks and other substrates, that was responsible for the bad odour problems occurring along the Lake Ontario shoreline in the 1960s and 1970s. SRP concentrations measured at many of the stations along the south shore of the lake in 1993 exceeded this value.

The decline in SRP concentrations has resulted in noticeable changes in algal biomass. Open lake, summer concentrations of chlorophyll a (an indirect measure of algal biomass) are less than 2 ug/L indicative of oligotrophic conditions (Thomas *et al* 1980). In 1993, summer concentrations ranged from a low of 1.1 ug/L in the open lake to a maximum of 15.0 ug/L off the mouth of the Black River in the eastern end of the lake.

Nitrogen is also an important nutrient for algal growth. Major sources of nitrogen to the lake include agricultural runoff, atmospheric deposition, and municipal sewage treatment plants. Concentrations of nitrate-plus-nitrite (NO_3+NO_2) have increased steadily in all the Great Lakes including Lake Ontario (Williams 1992; Neilson *et al* 1995). Figure 4 shows the concentration trends for NO_3+NO_2 at Niagara-on-the-Lake and Wolfe Island and the trend in the spring, surface (1m) concentrations in the lake. Generally, the trends mirror each other very closely. Furthermore, NO_3+NO_2 concentrations at all three sites continue to increase (*post*-1990) despite the decrease in use of nitrogen fertilizer from a peak of about 240,000 tonnes in 1985 to 175,000 tonnes in 1995. Current spring concentrations in Lake Ontario range between 0.37 and 0.55 mg/L, with an open lake mean of 0.394 mg/L. This is a substantial increase from the 1974 mean of 0.286 mg/L. The concentrations are still well below the drinking water guideline for the protection of human health (10.0 mg/L).

Major Ions

The mean annual concentrations of major ions (eg., Cl, SO_4, Na, K, Ca, Mg) at NOTL are always lower than those in Lake Ontario and at Wolfe Island. Trends in the NOTL, Wolfe Island, and spring, surface (1m) concentrations in Lake Ontario, all tend to mirror each other. The concentrations of chloride, sodium and potassium all declined between 1977 and 1993.

The most significant features in the trends for sulphate, calcium and magnesium at all three locations over this same time period were the substantial concentration changes which occurred between 1989 and 1991. Sulphate concentrations exhibited a major decrease, with the minimum occurring in 1991. Similarly, calcium concentrations declined substantially *post*-1989, with the 1992 Lake Ontario mean concentration being the lowest over the period of record. In contrast, magnesium concentrations *post*-1989 were elevated compared to earlier data. Figures 5 shows the data for magnesium.

The post-1989 changes in calcium and magnesium, coincide with the first observation of zebra mussels (*Dreissena polymorpha*) in Lake Ontario and the eastern basin of Lake Erie (Griffiths *et al.* 1991). We speculate that this may be at least one of the reasons contributing to the observed changes. Increases in *Dreissena* densities would deplete the water column of calcium which is used for shell development. Magnesium is the central metal ion in the por-

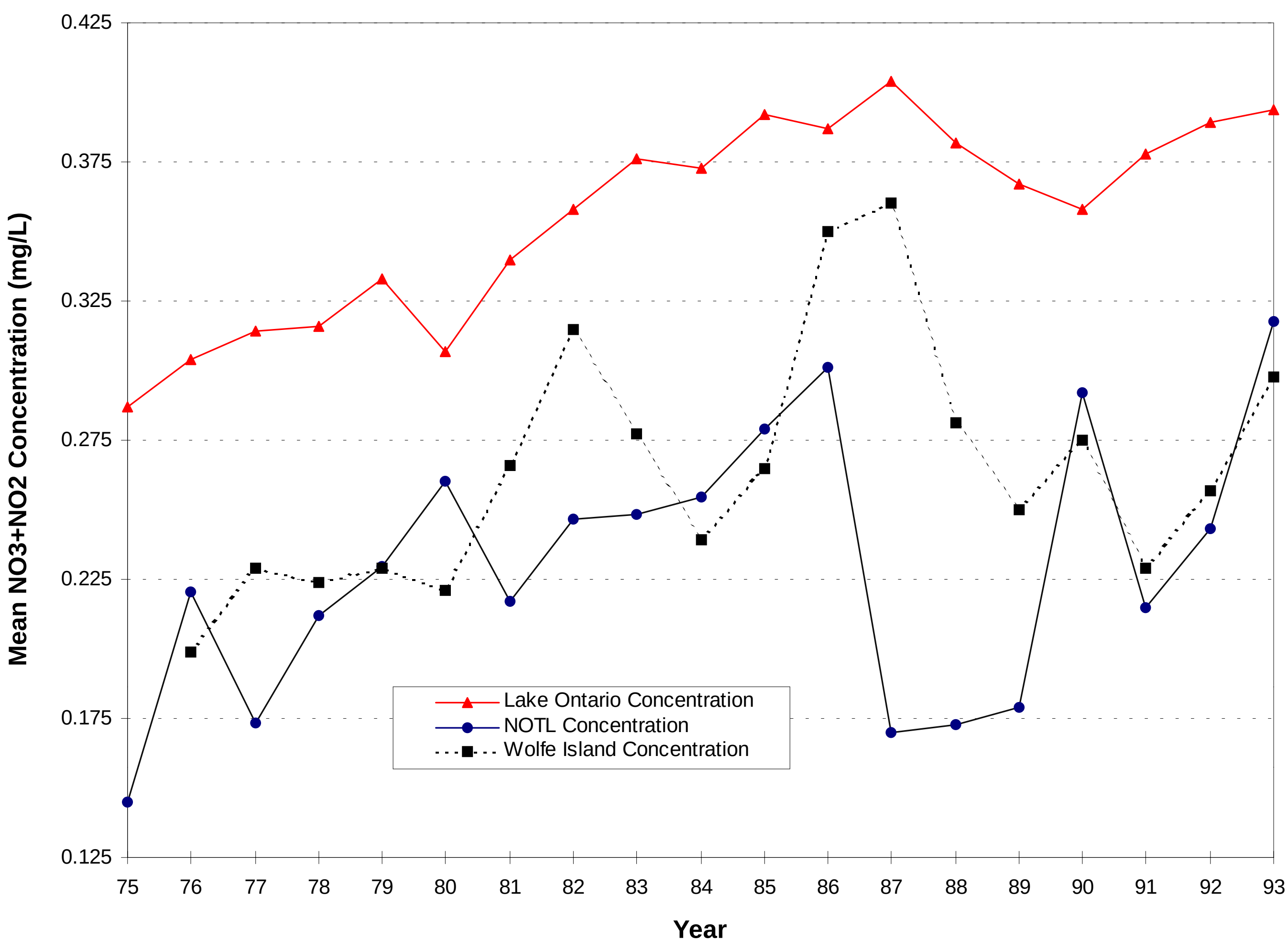

Figure 4. *Trends in Spring, Surface (1m) NO_3+NO_2 Concentrations in Lake Ontario and Loads at NOTL and Wolfe Island.*

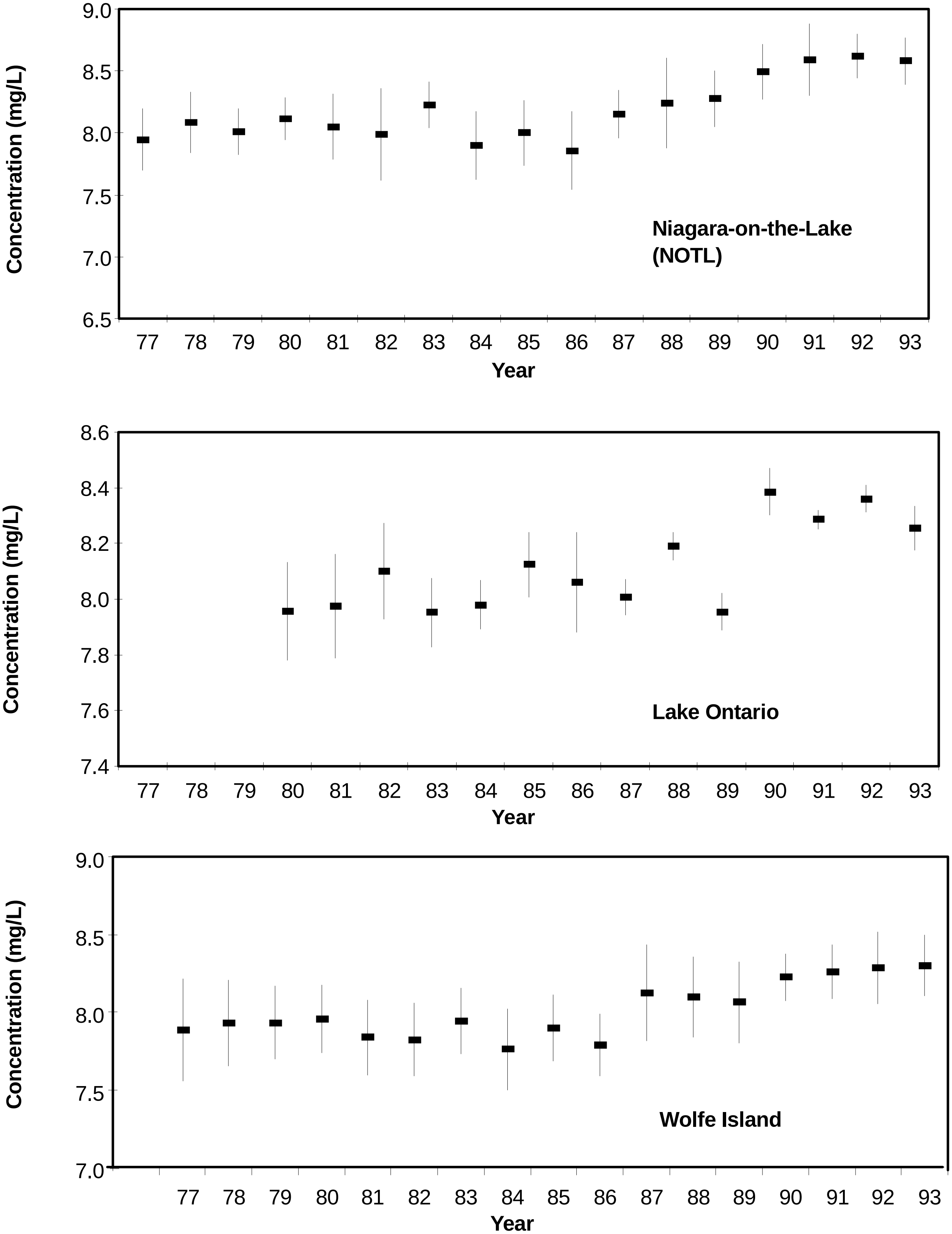

Figure 5. *Trends in Magnesium Concentrations in Lake Ontario, and at NOTL and Wolfe Island.*

phyrin structure of chlorophyll. Removal of large quantities of phytoplankton from the water column by *Dreissena* filtration would mean fewer phytoplankton using magnesium to manufacture chlorophyll. Furthermore, *Dreissena* filtration would directly remove phytoplankton from the water column, thus, short circuiting the normal process of decomposition during settling to the bottom and increasing the rate at which unbound magnesium is returned to the water column. Both mechanisms would tend to act additively to increase the water concentrations of magnesium. Summer (April-October) calcium and magnesium concentrations in the Niagara River showed a statistically significant decrease and increase, respectively, just after the invasion of the eastern basin of Lake Erie by *Dreissena* (Williams, unpublished data). These changes, probably resulting from colonization of eastern Lake Erie and the Niagara River (eg., the power reservoirs) by *Dreissena*, could also impact the concentrations of these two major ions in Lake Ontario and at Wolfe Island.

Organic Contaminants

The low concentration of water column particulate matter in Lake Ontario (mean = 0.59 mg/L, 1992-1993) precluded obtaining sufficient sample (~10g) for reliable, routine quantitative analysis of particulate phase contaminant concentrations. This has also become an issue at Wolfe Island with the recent concentrations of suspended particulate matter having

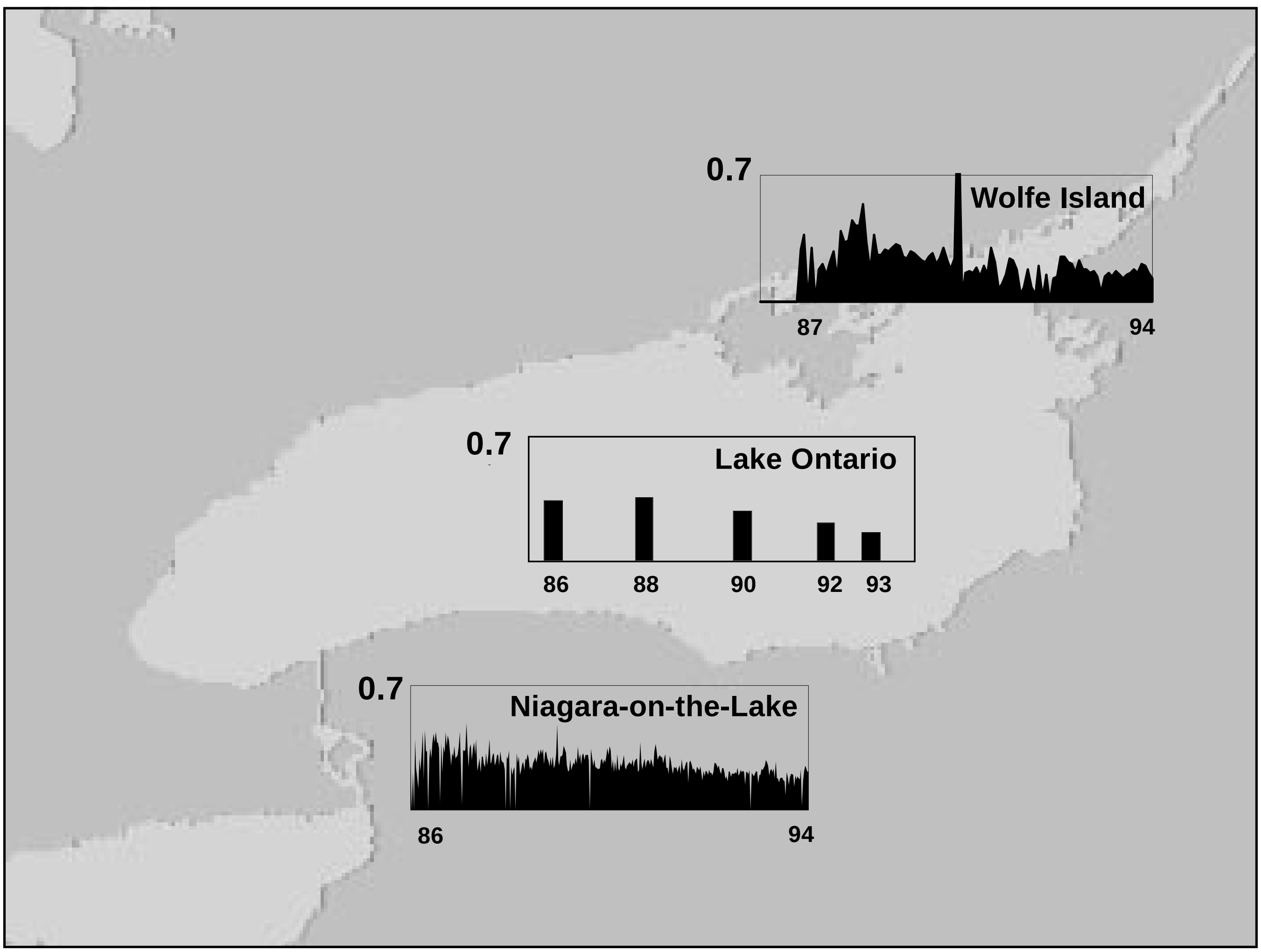

Figure 6. *Trends in Dieldrin Concentration (ng/L) in Lake Ontario and at Wolfe Island and Niagara-on-the-Lake.*

declined from 1.4 mg / L in 1991 to less than 0.2 mg / L in 1995. Consequently, the following discussion focuses only on the dissolved phase concentrations of organic contaminants.

Several studies suggest that, with few exceptions, the dissolved phase is the most significant contributor to the whole water contaminant concentrations. McCrea *et al.* (1985) found that in terms of water column total concentrations, virtually all of the organochlorine chemicals present in Lake Ontario occurred in the aqueous (i.e., dissolved) phase. Similarly, Stevens and Neilson (1989) found that, with the exception of two chemicals (cis-chlordane and total PCBs), there was no significant difference between Lake Ontario whole water and dissolved phase concentrations.

There has been a substantial decrease in the water column concentrations of most organic contaminants in the lake since 1986 (Table 1). The ranges of the dissolved phase concentrations for many of the contaminants measured in Lake Ontario in 1992 and 1993 agree well with annual mean concentrations at Niagara-on-the-Lake and at Wolfe Island (Williams *et al.* 1998). Concentrations at Wolfe Island are generally the lowest. The high concentrations of many of the chemicals (eg., chlorobenzenes) at Niagara-on-the-Lake point to the Niagara River as a major source to Lake Ontario. Figures 6 and 7 show the dieldrin and α-BHC concentrations, respectively, in Lake Ontario and at Wolfe Island and Niagara-on-the-Lake. The more robust (i.e., higher frequency sampling, annual estimates) data sets for Wolfe Island and

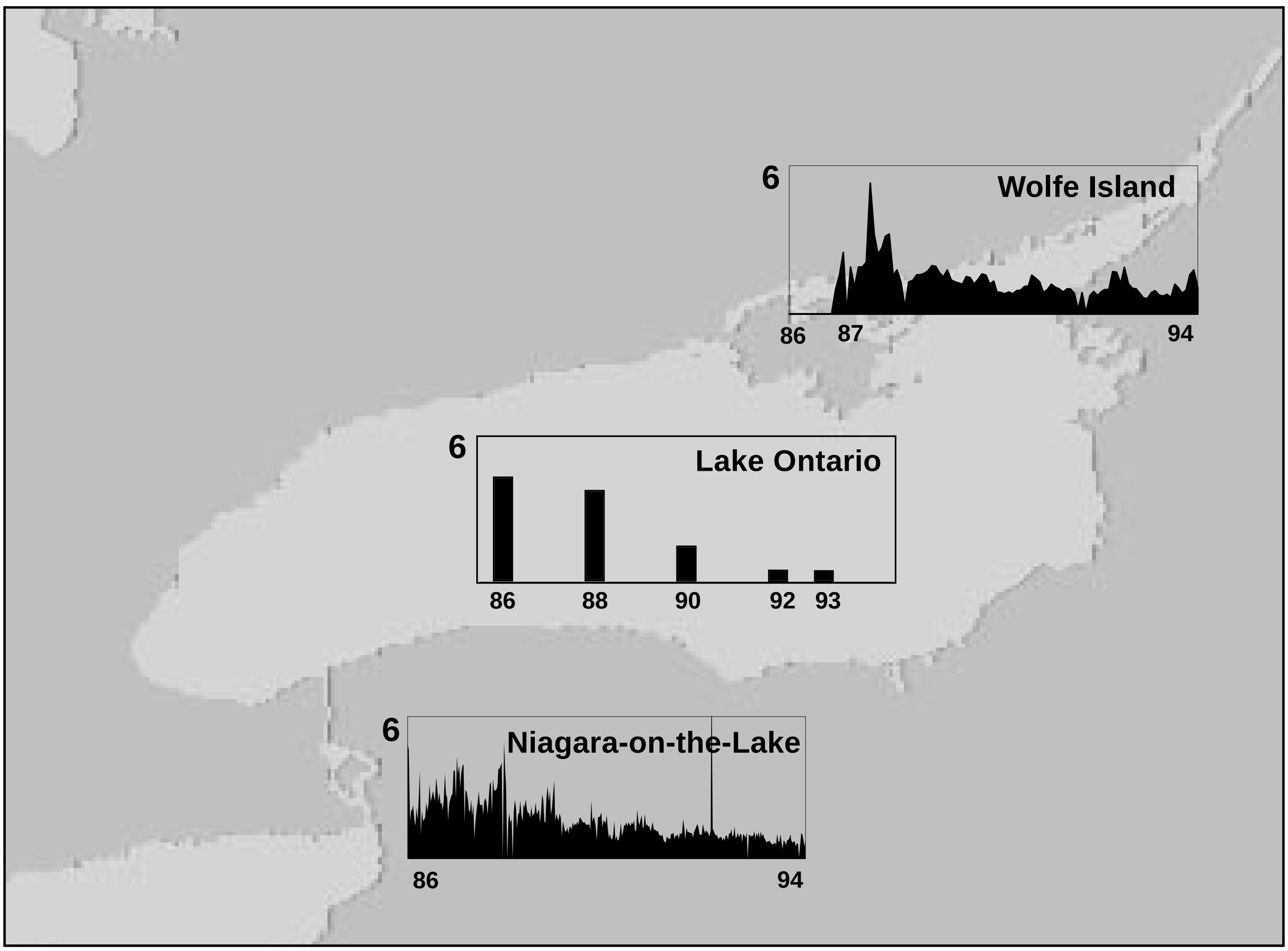

Figure 7. *Trends in a-BHC Concentration (ng/L) in Lake Ontario and at Wolfe Island and Niagara-on-the-Lake*

Table 1. Lake Ontario <u>Spring</u>, Surface (1m) Concentrations (ng/L) of Organics in 1986, 1988, 1990, 1992 and 1993.

COMPOUNDS	1986[1]	1988[1]	1990[1]	1992[2]	1993[2]
Organochlorines					
α-BHC	4.27	3.82	1.53	0.98 - 1.24	0.15 - 1.16
γ-BHC	1.38	0.87	0.55	0.32 - 0.53	0.07 - 0.41
Dieldrin	0.34	0.36	0.29	0.12 - 0.26	<DL - 0.31
Aldrin	ND	ND	ND	<DL	<DL
Endrin	0.05	0.06	ND	<DL	<DL
Endrin aldehyde	NA	NA	NA	<DL	NA
Heptachlor	ND	ND	ND	<DL	<DL
Heptachlor-epoxide	0.12	0.25	0.10	<DL - 0.11	<DL - 0.13
p,p'-DDT	ND	ND	ND	<DL - 6.05	<DL
o,p'-DDT	ND	ND	ND	<DL - 1.94	<DL
p,p'-DDE	ND	0.06	ND	<DL	<DL - 0.09
p,p'-TDE	ND	ND	ND	<DL - 0.74	<DL
α-chlordane	0.05	0.05	ND	<DL	<DL
γ-chlordane	ND	0.01	ND	<DL - 0.09	<DL
α-endosulfan	ND	ND	ND	<DL - 0.08	<DL - 0.05
β-endosulfan	ND	ND	ND	0.27 - 0.58	<DL
Methoxychlor	ND	ND	ND	<DL	<DL
Mirex	ND	ND	ND	<DL	<DL
Photomirex	NA	NA	NA	<DL	NA
Octachlorostyrene	NA	NA	NA	<DL	NA
Hexachlorobutadiene	NA	NA	NA	<DL - 0.06	NA
HCCPD	NA	NA	NA	<DL - 0.61	NA
Total PCBs	1.14	0.91	1.20	NA	NA
Chlorobenzenes					
1,3-DCB	0.34	0.19	ND	<DL	<DL - 0.24
1,4-DCB	1.70	0.96	1.20	<DL - 2.05	0.94 - 1.65
1,2-DCB	0.97	0.80	ND	<DL - 2.42	<DL - 0.59
Total DCBs	3.03	1.68	1.31		
1,3,5-TCB	0.03	0.02	ND	<DL - 0.10	<DL
1,2,4-TCB	0.52	0.35	0.14	0.04 - 0.56	0.07 - 0.29
1,2,3-TCB	0.10	0.08	0.04	<DL - 0.14	<DL - 0.09
1,2,3,4-TeCB	0.14	0.38	0.06	0.06 - 0.44	0.04 - 0.18
PentaCB	0.06	0.04	ND	0.10 - 0.39	<DL - 0.08
HexaCB	0.06	0.07	0.04	<DL - 0.08	<DL - 0.04

Table 1. cont'd. Lake Ontario Spring, Surface (1m) Concentrations (ng/L) of Organics in 1986, 1988, 1990, 1992 and 1993.

COMPOUNDS	1986[1]	1988[1]	1990[1]	1992[2]	1993[2]
Polynuclear Aromatic Hydrocarbons (PAHs)					
1,2,3,4-THNP	NA	0.92	0.34	<DL	<DL
Indene	NA	ND	0.32	<DL	<DL - 0.97
Naphthalene	NA	NA	NA	NA	NA
2-Methylnaphthalene	NA	2.33	1.43	<DL - 5.63	0.81 - 2.64
1-Methylnaphthalene	NA	1.11	1.07	<DL - 3.42	0.37 - 1.70
2-Chloronaphthalene	NA	ND	ND	<DL	<DL
Acenaphthylene	NA	ND	0.21	<DL	<DL
Acenaphthene	NA	0.45	0.16	<DL	<DL - 0.56
Fluorene	NA	1.96	0.41	<DL	<DL - 0.58
Phenanthrene	NA	25.70	8.64	6.82 - 8.64	0.51 - 2.02
Pyrene	NA	10.01	0.45	<DL	<DL - 1.10
Fluoranthene	NA	11.61	0.87	<DL	0.70 - 1.98
Benzo(b/k)fluoranthene	NA	ND	0.28	<DL - 1.09	<DL
Benzo(a)pyrene	NA	ND	ND	<DL	<DL
Benzo(a)anthracene	NA	NA	NA	NA	NA
Dibenzo(a,h)anthracene	NA	NA	NA	NA	NA
Chrysene/Terphenylene	NA	NA	NA	NA	NA
Indeno(1,2,3-cd)pyrene	NA	ND	ND	<DL	<DL
Benzo(g,h,i)perylene	NA	ND	ND	<DL	<DL

[1] Mean of whole water concentrations (MLE) [from L'Italien and Williams 1997]

[2] Range of dissolved phase concentrations based on sampling six stations (L'Italien 1996a)

ND = Less than three values above the detection limit – means (MLE) not calculated

NA = Not Analyzed

DL = detection limit (<DL means concentrations below the method detection limit)

MLE = Maximum Likelihood Estimation

HCCPD = Hexachlorocyclopentadiene

THNP = Tetrahydronaphthalene

NOTE: Duplicate samples are not considered in this table.

Niagara-on-the Lake corroborate the decreasing trends in the concentrations of these chemicals in Lake Ontario.

CONCLUSIONS

The surveillance program data show that the programs to control phosphorus have been largely successful in achieving the target phosphorus concentration in Lake Ontario. The data also show, however, that localized problems, particularly in nearshore areas, still exist or have the potential to (re)occur. For example, the concentration of SRP in some of these areas is high enough, potentially, to initiate *Cladophora* growth. In addition, the human population around the lakes continues to increase. This could result in the loads of phosphorus to the lake increasing once again. Both these points need to be considered carefully in light of recent suggestions from some quarters to add phosphorus to the lower lakes. Continued monitoring will be required to ensure that gains made to date are not jeopardized.

The dissolved phase water column concentrations of most contaminants in Lake Ontario have decreased between 1986 and 1993. Comparison of the Lake Ontario results with the more robust data from Niagara-on-the-Lake and Wolfe Island corroborate the observed in-lake decreases in concentrations.

The focus of the open lake surveillance and connecting channels monitoring programs has shifted from eutrophication-related issues to toxic chemicals, including those that are persistent, bioaccumulative and can biomagnify in the Great Lakes ecosystem. The 1978 Agreement called for virtual elimination of "persistent toxic chemicals." The 1987 Protocol to the Agreement calls for the development of Lakewide Management Plans (LaMPs) to rid the lakes of "critical pollutants." Continued monitoring will be required to support the LaMPs and to ensure that management actions designed to control and eliminate these chemicals are having the desired effect of reducing their concentrations and ultimately, eliminating their presence in the lake.

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REFERENCES

Biberhofer, J. 1995. Concentrations and Loadings of Trace Organic Compounds Measured in the St. Lawrence River Headwaters at Wolfe Island: 1989 - 1993. Report No. EHD / ECB-OR / 95-03 / I. Environment Canada.

Casey, O.J., and S.E. Salbach. 1974. IFYGL stream materials balance study (IFYGL). In Proc.17th Conf. Great Lakes Res., pp. 668-681.

Eadie, B.J., and A.J. Robertson. 1976. An IFYGL carbon budget for Lake Ontario. *J. Great Lakes Res.* 2:307-323.

Environment Canada. 1997. Manual of Analytical Methods. Volumes I, II and III.

Green / Seastar. 1988. Determination of Contaminant Concentrations Across the Niagara River Using Automatic *in situ* Water Samplers. Final Report, April 1988. Unsolicited Proposal DSS Contract No. 02SE-KW405-7-9195. David

Green, Seastar Instruments Ltd., Dartmouth, N.S.

Griffiths, R.W., D.W. Schloesser, J.H. Leach, and W.P. Kovalak. 1991. Distribution and dispersal of the zebra mussel (*Dreissena polymorpha*) in the Great Lakes region. *Can. J. Fish. Aquat. Sci.* 48:1381-1388.

Jackson, M.B., and Y.S. Hamdy. 1982. Projected *Cladophora* growth in southern Georgian Bay in response to proposed municipal sewage treatment plant discharges to the Mary Ward shoals. *J. Great Lakes Res.* 8:153-163.

Kemp, A.L.W., and N.S. Harper. 1976. Sedimentation rates and a sedimentation budget for Lake Ontario. *J. Great Lakes Res*. 2: 324-340.

Kuntz, K.W. 1996. Wolfe Island Sampling Protocol. Ecosystem Health Division, Environmental Conservation Branch / Ontario Region, Environment Canada, Burlington, Ontario. (Unpublished Report).

Kuntz, K.W., and I.K. Tsanis. 1990. Trends in nutrients, major ions and physical water quality parameters in the Niagara River during the 1977-87 period. *Water Poll. Res. J. Canada* 25(1):15-32.

Kuntz, K.W., and I.K. Tsanis. 1993. Trends in nutrients, major ions, physical water quality parameters and trace metals in the Niagara River from 1975 to 1989. *Water Poll. Res. J. Canada*. 28(2): 473-493.

Kwiatkowski, R.E. and M.A.T. Neilson. 1983. Lake Ontario Surveillance Data, 1968-1980. Technical Bulletin No. 126. Inland Waters Directorate, Water Quality Branch, Ottawa, Ontario. 69pp.

L'Italien, S. 1992. Lake Ontario Surveillance Activities Including Sampling Strategies, 1981-1991. Department of Environment, Inland Waters Directorate, Ontario Region, Water Quality Branch, Burlington, Ontario, Report No. WQB / IWD-OR-92-01 / I.

L'Italien, S. and L. Fay. 1993. Great Lakes Surveillance Program - Field Methods Manual. Water Quality Branch, Inland Waters Directorate, Ontario Region, Burlington, Ontario, Report No. WQB / IWD-OR / 93-01 / I.

McCrea, R.C., J.D. Fischer, and K.W. Kuntz. 1985. Distribution of organochlorine pesticides and PCB's between aqueous and suspended sediment phases in the lower Great Lakes region. *Water Poll. Res. J. Canada*. 20(1):67-78.

Merriman, J. 1997. Water quality in the St. Lawrence River at Wolfe Island. Report No. EHD / ECB-OR / 97-01 / I. Environment Canada.

Merriman, J. 1998. Trace organic contaminants in the St. Lawrence River at Wolfe Island. Report No. EHD / ECB-OR / 98-02 / I. Environment Canada.

Neilson, M.A., and R.J.J. Stevens. 1987. Spatial heterogeneity of nutrients and organic matter in Lake Ontario. *Can. J. Fish. Aquat. Sci*. 44: 2192-2203.

Neilson, M.A. S. L'Italien, V. Glumac, D. Williams, and P. Bertram. 1995. Nutrients: trends and system response. State of the Lakes Ecosystem Conference Background Paper, Environment Canada and the United States Environmental Protection Agency. EPA 905-R-95-015.

NRAP. 1992. Analytical Protocol for Monitoring Ambient Water Quality at the Niagara-on-the-Lake and Fort Erie Stations. Joint Report of EC, USEPA, MOEE and NYSDEC.

NRSP. 1988. Niagara River Sampling Protocol. Joint Report of EC, USEPA, MOEE and NYSDEC.

NRDIG. 1997. Joint Evaluation of Upstream/ Downstream Niagara River Monitoring Data: 1995-1996. Report to the River Monitoring Committee. Environment Canada, Ecosytem Health Division - Ontario Region.

Stevens, R. J. J. 1988. *A Review of Lake Ontario Water Quality with Emphasis on the 1981-1982 Intensive Years.* Report to the Surveillance Subcommittee of the Great Lakes Water Quality Board. International Joint Commission.

Stevens, R. J. J., and M. A. Neilson. 1987. Response of Lake Ontario to reductions in phosphorus load, 1967-1982. *Can. J. Fish. Aquat. Sci.* 44(12):2059-2068.

Stevens, R.J.J., and M.A. Neilson. 1989. Inter- and intralake distributions of trace organic contaminants in surface waters of the Great Lakes. *J. Great Lakes Res.* 15(3):377-393.

Sylvestre, A., K.W. Kuntz, and N.D. Warry. 1987. *Water quality at the inlet to the St. Lawrence River, 1977 to 1983.* Technical Bulletin No. 142. Inland Waters Directorate. Water Quality Branch, Ottawa, Ontario.

Thomas, N.A., A. Robertson, and W.C. Sonzogni. 1980. Review of Control Objectives: New Target Loads and Input Controls. In Loehr, Martin, and Rast [Eds.] *Phosphorus Management Strategies for Lakes,* Ann Arbor Science Publishers Inc., Ann Arbor, Michigan. pp 61-90.

Watson and D.J. Williams. 1975. Design and Operation of a Pilot Surveillance Programme for Lake Ontario. Abstracts l8th Conference on Great Lakes Research, International Association for Great Lakes Research, Albany, New York, 1975.

Williams, D.J. 1992. Great Lakes Water Quality: A Case Study. In Dunnette and O'Brien [Eds.] *The Science of Global Change: The Impact of Human Activities on the Environment.* American Chemical Society Symposium Series 483, Washington. pp. 207-223.

Williams, D.J., K.W. Kuntz, S. L'Italien and V. Richardson. 1998. Lake Ontario Surveillance Program: Spatial and Temporal Trends of Selected Parameters, with Emphasis on 1992-1993 Results. Report No. EHD/ECB-OR/98-04/I. Environment Canada.

Bi-national St. Lawrence River-Lake Ontario (SLRLO) Research Initiative

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THE SLRLO INITIATIVE

While we are interested in advancing the state of the science, our focus is on the key management needs of the Parties responsible for managing the Niagara River-Lake Ontario-St. Lawrence River ecosystem. Thus, our research program grows out of a set of management issues/questions associated with such activities as the Niagara River Toxic Management Plan and RAP, the Lake Ontario LaMP, the Lake Ontario Fish Community Objectives, St. Lawrence River management issues, and RAPs within the Lake Ontario and St. Lawrence River systems. The Lake Ontario – St. Lawrence River ecosystem has not been the subject of a comprehensive, multi-disciplinary research study since the International Field Year of the Great Lakes (IFYGL). Excellent lake-wide programs (e.g., LONAS, LOTT) have been undertaken subsequent to IFYGL and we draw on these efforts and build on them, but we are also pushing for an ecosystem level of effort that truly addresses the interactions among multiple management issues. The Great Lakes community needs to demonstrate what it means by the "Ecosystem Approach" to managing the lakes, and the Lake Ontario – St. Lawrence River ecosystem is a perfect place to do it.

Risk Assessment and Risk Management of Toxic Chemicals

The Lake Ontario LAMP (Stage 1) identifies activities that the Four Parties will undertake to move towards completion of Stage 2. Identifying likely point- and non-point sources of critical pollutants, and forecasting the effectiveness of reductions in loadings of these pollutants are among the activities proposed. The SLRLO Group is conducting research and monitoring in support of achieving the objectives of the Lake Ontario LAMP and seeks to work in conjunction with and in addition to existing programs of the Parties.

The Research Questions:

- What is the relative contribution of source categories (Niagara River, Hamilton Harbor, other tributaries, point sources, atmospheric deposition, etc.) to the concentration of toxic chemicals of concern (PCBs, dioxins/furans, mirex, DDT and its metabolites, dieldrin, and Hg) in water, sediments, and biota of the system.
- What is the quantitative spatial and temporal relationship between these loadings and the concentrations in water, sediments and biota? Can we quantify the relationship between remedial actions in the AOCs and the system-wide response?

The Great Lakes are plagued by problems associated with persistent organic pollutants and other chemicals which exist in our environment and are known to have toxic effects in living organisms alone or in synergy with other chemicals. There is direct or indirect evidence that PCBs, DDT and its metabolites, mirex, and dioxins/furans are degrading fish and wildlife populations and their habitat, causing animal deformities or reproductive problems, and prompting restrictions on consumption of fish and wildlife by humans.

The Research Questions:

- Are the fish and wildlife (fish-eating mammals and birds) in Lake Ontario subject to effects of exposure to toxic contaminants that are impairing their normal functioning within the ecosystem, and how much source reduction of these contaminants is necessary to eliminate those effects?
- Can we eat the fish? When can we eat the fish? and What can we do to hasten the progress toward that end?

Solids Dynamics

Lake Ontario has undergone a considerable decrease in primary productivity over the past 15- 20 years. We hypothesize that this decrease in the base of the food chain has had two significant impacts on other parts of the ecosystem: Because algal production is such an important contributor to suspended sorbents in the system, the system's solids (HOC sorbents) dynamics have changed considerably since it was last quantified in the early 80's. Solids dynamics, in turn, play a very important role in the transport and fate of HOCs. We hypothesize that mirex and mirex/photomirex ratios in various segments of Lake Ontario be used as a unique and independent "tracer" of the solids (sorbent) dynamics in the system, much as one would use a mass balance of a radionuclide like 137Cs. A new sorbent dynamics budget for the system needs to be determined using this approach along with other more conventional methods.

Sportfisheries Management

The carrying capacity of Lake Ontario for top predator fish is determined by nutrient loading and processing efficiency, and the maximum level of salmonid stocking that the lake can sustain.

- Is there an antagonism between nutrient control and fish management in Lake Ontario and can we develop a quantitative understanding (i.e., a model) that will aid decision-making that will satisfy the objectives of both management areas?
- How many and of what species of sport fish should we stock to maximize the carrying capacity of the lake and river without endangering the sustainability of the sport fishery?
- Is there a possibility to manage the fishery so that there is a balance between the off-shore salmonid fishery and the near-shore water fishery?
- Are bird populations (especially cormorants in the eastern basin) having a significant detrimental impact on the sport fishery and how can this problem be best managed?
- What is the current economic value of the sport fishery? How important are fish consumption advisories and a reduced abundance of large (chinook) salmon to the attractiveness and economic viability of the sport fishery?

Understanding and Managing Lake Levels

- Can we predict water level fluctuations in Lake Ontario and the river from antecedent weather?
- How can this capability be used to help manage the detrimental impacts of extremely high or low water levels?
- What water level risk management options are there and which would produce the most benefits?
- Can we control water levels to avoid flooding and erosion and to maximize power generation without losing the beneficial effects of periodic flooding and draining on wetland integrity and diversity?

Landuse Impacts and Sustainable Development

- How will future development in the watershed impact the physical, chemical and biological integrity of the lake and river?
- What is our vision for the system and can it be sustained in the face of economic development in the region?

Nearshore Productivity

In Lake Ontario, significant differences exist between the nearshore and offshore (open-water) biotic communities, although these differences and interrelationships are neither well understood or quantified. We need to determine the spatial extent of the nearshore community and develop an understanding of the physical (i.e., hydrodynamics, temperature gradients, light, etc.), chemical (nutrients, dissolved oxygen, etc.) and biological (predation, habitat, etc.) factors which tend to establish and maintain the nearshore-offshore gradients as opposed to those factors which tend to destroy those gradients.

- Does the productivity in the nearshore of Lake Ontario make an important and significant contribution to the overall lake productivity?
- Do significant differences exist in biotic communities and productivity exist between the north and south nearshore areas of Lake Ontario, again due to temperature and hydrodynamic factors?

Aquatic Nuisance Species

- How serious is the zebra mussel (and other aquatic nuisance species) invasion of Lake Ontario and the St. Lawrence River?
- How is it impacting sport fish production? How is it impacting BCC cycling and bioaccumulation in the food chain?
- Is there an economic loss resulting from ANS invasions and can we quantify it?
- What impacts are zebra mussels in Lake Ontario having on energy, organic carbon, and particle flow through the ecosystem and how are these impacts affecting food chain bioaccumulation of BCCs?

Hypothesis: Zebra mussels are the cause of a shift in the energy flow through this ecosystem toward a benthic food chain and away from a pelagic food chain.

Indicators of Progress

- If we set certain goals (IJC refers to them as "Desired Outcomes") for the Niagara River-Lake Ontario-St. Lawrence River ecosystem, what are the best indicators of progress toward those goals and can we design and implement a monitoring program that will allow us to effectively measure progress and communicate it to our stakeholders?

Drinking Water Quality

- What is the risk of off-taste and odor, disinfection by-products, pathogenic contamination (Cryptosporidium, Giardia, etc.) of drinking water sources in the system? For sources at risk, what risk management measures can and should be taken?
- What is the economic value of this system for supplying drinking water and what will be the cost of meeting new safe drinking water standards relative to the above and other contaminants?

Hypothesis: The presence of off-flavor compounds and pathogenic contamination of drinking water intakes is the result of localized watershed inputs and environmental conditions in the vicinity of the intakes as opposed to factors that are endemic to the whole system.

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