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# Council of Great Lakes Research Managers. Report to the International Joint Commission. 1993

Council of Great Lakes Research Managers

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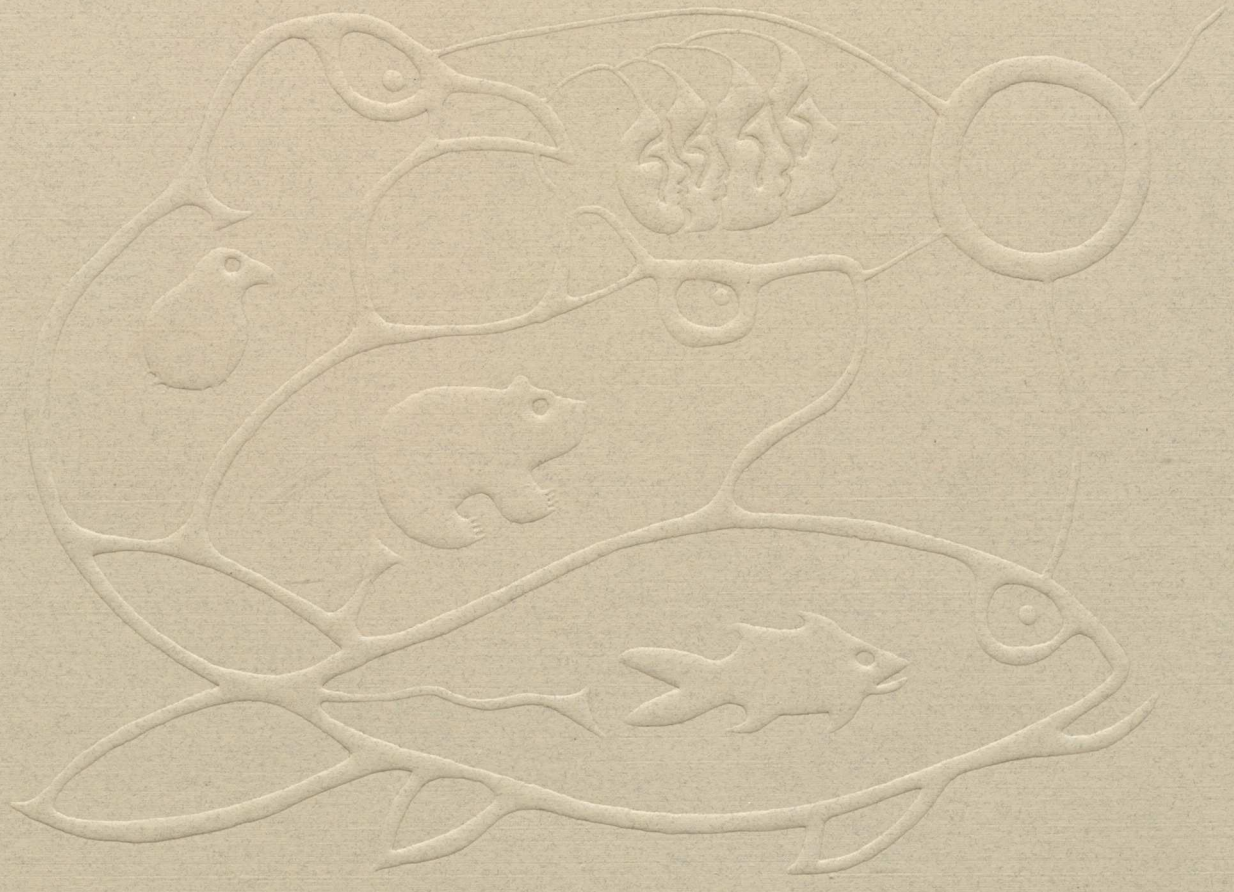
# 1993 REPORT TO THE INTERNATIONAL JOINT COMMISSION



International Joint Commission
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# Council of Great Lakes Research Managers

# 1993 Report to the International Joint Commission

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International Joint Commission
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## *New Year*

The color painting reproduced in this report is *New Year*, by Roy Thomas. The artist comments on this work:

"The New Year is the time all people celebrate the beginning of nature's life cycle. The circle on the right hand side is the place of our maker, the Creator; it also represents the sun which is the life giver, the fire. This is when the birds are born. (You will see a little bird inside the big one). Also, the animals give birth and the fish spawn. This is nature's own life cycle and we celebrate that also. These also represent the life givers. The bird represents the air; the animals represent the land; the fish represent the water.

All the multi-colours are going all over the place to show the new life cycle being blessed to us by our Creator. Also, the birds and the animals and the fish have always served our purposes by providing humans with food."

Mr. Thomas is a member of the Ojibwa tribe, born in 1949 at Longlac, Ontario. His Ojibwa name, *Gahgahgeh,* means "crow". He was given this name by his grandmother, because as a child he cared for an orphaned crow which came back to him every spring for a number of years.

International Joint Commission
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June 1, 1993 Windsor, Ontario

International Joint Commission
United States and Canada

Commissioners:

It is with great pleasure that the Council of Great Lakes Research Managers submits its 1993 Biennial report to the International Joint Commission. The report explains how we have carried out our primary objective to enhance the ability of the Commission, to provide effective leadership, guidance, support and evaluation of Great Lakes research programs. We also report on how the research community addressed the priorities you established for this biennial period.

We wish to call your attention to a short list of recommendations at the end of the report. Four of these recommendations call for Commission action, which we believe would enable the Council to better serve your information needs during the next biennial period. The other nine recommendations are intended to assist the parties in setting research priorities. The Council members recognize that these are important issues and will seek to implement them themselves as funding permits.

The Council is looking forward to presenting this report in person to you and the public at the 1993 Biennial Meeting on Great Lakes Water Quality.

Respectfully submitted,

Jon G. Stanley
U.S. Cochair

J. Roy Hickman
Canadian Cochair

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# *Preface*

This 1993 Biennial Report is the first opportunity for the Council of Great Lakes Research Managers to report independently to the International Joint Commission. Previously the Council reported to the Commission through the Cochairs of the Science Advisory Board because the Council was established to enhance the ability of that Board to provide leadership, guidance and evaluation of Great Lakes research programs. The new terms of reference issued in 1991 direct the Council to compile a research inventory identifying research needs and to coordinate research projects. In addition to reporting on progress toward achieving our goals, we have expanded our geographical area of interest and membership to include the St. Lawrence River and thus now use the term Great Lakes-St. Lawrence River basin ecosystem.

The report moves from present to future and is organized in three main sections dealing with current research, a strategy for future research and a framework for setting research directions and priorities. Accordingly, we first report on the completion of an inventory of research that addresses the Commission's priorities, other research topic areas and Annex 17 of the Great Lakes Water Quality Agreement. The results of the inventory indicate that the research community has indeed tackled many difficult problems, including research on the priorities identified by the Commission. Secondly, we describe our views of where research is headed in the 1990s and how we, as the executives of research organizations, intend to address both pressing and chronic problems of the Great Lakes and St. Lawrence River. Finally, we report on the development of a framework, or decisionmaking process for setting priorities on research to be conducted in support of the Great Lakes Water Quality Agreement.

One feature of this report is that research findings of our member organizations are highlighted in boxes throughout the text. As space does not allow reporting of all relevant research results, readers seeking a more comprehensive overview should consult the research inventories.

All funds identified in this report are expressed in U.S. dollars.

# *Acknowledgements*

Preparation of this report was initiated by the Council of Great Lakes Research Managers, cochaired by Roy Hickman (Canadian Section) and Jon Stanley (U.S. Section). We would like to recognize the contribution provided by all Council members in the development of this document, in particular the Council Biennial Report Committee, chaired by Rod Allan and supported by John Cooley, Nelson Thomas, Bob Werner and Doug Haffner. Recognition is also accorded to the International Joint Commission staff and contractors who assisted with production: Zsolt Kovats, Ed Mazak and Sandra Parker for preparing the 1990-1991 and 1991-1992 Research Inventories and thus the foundation for Chapter 3.0, Karen Jeffrey for processing the text of this document, Michael Gilbertson for providing technical review and Frank Bevacqua for editing the manuscript. The Council's Liaison Officers at the International Joint Commission, Andy Hamilton and Bruce Bandurski provided insight into the Commission process. Peter Seidl, Secretary of the Council for the past three years, has been instrumental in supporting the collective efforts of the Council and developing this first biennial report to the Commission.

Credits for photos used in highlights are: (page 6) Ohio Sea Grant College Program; (page 7-top) Wastewater Technology Centre; (page 8) Joan Elias, U. of Wisconsin; (page 9) Health and Welfare Canada; (page 10) Great Lakes Institute; (page 17) North Shore of Lake Superior RAP; (page 18) Health and Welfare Canada; (page 20) Frank Bevacqua; (page 22) John Laflen, U.S. Dept. of Agriculture; (page 25) S. Jerrine Nichols, USFWS; (page 29) Wastewater Technology Centre; (page 31) Ohio Sea Grant College Program; (page 36) Bob Werner, SUNY.

# 1.0 Challenges of Great Lakes-St. Lawrence River Research in the 1990s

## 1.1 Historical Context

The Great Lakes research community has played a central role in alerting governments and the public to the need for action addressing the human impacts on the Great Lakes-St. Lawrence River system. In the 1950s and 1960s, scientists working individually and collectively focussed public attention on problems such as eutrophication; one direct result was a reference from the Governments of the United States and Canada to the International Joint Commission in 1964 to examine and report on the pollution of Lake Erie, Lake Ontario and the International Section of the St. Lawrence River. The Commission's recommendations under this reference formed the basis for the Great Lakes Water Quality Agreement signed by the two governments in 1972.

In the 1970s research undertaken pursuant to the Agreement, as well as other study efforts, advanced the work under two other major references to the Commission. Both the Upper Great Lakes Reference Group and the Pollution from Land Use Activities Reference Group, the latter commonly known as PLUARG, highlighted the issue of toxic substances in the Great Lakes-St. Lawrence River system and focused attention on the dangers posed by toxic substances. These studies, along with reports of the Commission's Great Lakes Research Advisory Board (subsequently reconstituted as the Great Lakes Science Advisory Board), drew attention to the need for an ecosystem approach to restoring the integrity of the Great Lakes Basin Ecosystem. In 1978, a new Great Lakes Water Quality Agreement incorporating these principles replaced the earlier agreement and the ecosystem approach has since been gaining wide acceptance throughout North America and the rest of the world.

The Commission delegated responsibility to the Council of Great Lakes Research Managers to report on the effects of severe environmental exposures in Eastern Europe. Recent information clearly shows that observed human health effects in Eastern Europe are associated with problems of chemical contamination of the environment (Appendix I) and that there is much to be learned from this association.

## 1.2 An Ecosystem Approach

***The Council of Great Lakes Research Managers recommends that the Great Lakes-St. Lawrence River basin research community place greater emphasis on a holistic approach to defining future research priorities for the Great Lakes-St. Lawrence River basin by implementing binational integrated multidisciplinary studies, as defined in the overall Council strategy for the protection of ecosystem integrity.***

Great Lakes-St. Lawrence River basin research managers must work to promote, develop and practice the ecosystem approach of the Great Lakes Water Quality Agreement. The challenge of implementing the ecosystem approach is to recognize the degree of uncertainty inherent in the biophysical and social systems and to make influencing human actions a tenet guiding new concepts for research. Research managers should develop the concept of lakewide ecosystem management plans to reflect concern for whole systems and not just the most degraded parts. Such efforts could be patterned on the development of Remedial Action Plans. The 1990s will be a time to consolidate society's visions for the future of the precious and unique resources of the Great Lakes-St. Lawrence River basin. Sound, secure research programs, guided by the information needs of ecosystem management, must emerge from these visions and be directed toward the desired solutions.

Research managers need to place a greater emphasis on transdisciplinary and interdisciplinary work to investigate linkages between areas of research that have proceeded largely in isolation. Developing interdisciplinary research programs is essential to support the holistic policy analyses necessary for responding effectively to the growth in human activities affecting the Great Lakes-St. Lawrence River basin ecosystem. All those with a stake in using and protecting the resources of the basin must be involved in defining such research needs.

Research is needed into new and better ways to evaluate and describe the condition of Great Lakes and St. Lawrence River ecosystems. Traditional water quality criteria based on chemical concentrations, productivity and biological oxygen demand fail to provide a complete picture of

ecosystem quality. Efforts to develop criteria for judging the state of Great Lakes and St. Lawrence River ecosystems are underway and include measures of such things as suitability and availability of habitat for native and desired species, subtle degradation of the quality of biological health from chronic toxicity, species diversity and richness, and the ability of ecosystems to rebound from stresses.

Ecology and economics need to be linked before we can thoroughly understand the Great Lakes-St. Lawrence River basin ecosystem. Ecology has incorporated the human economy, and energy and material transformations as integral parts of the ecosystem. By contrast, the mainstream economic model treats the economy as independent and separate from nature. Research managers argue that human survival depends on the integrity of the ecosystem, which is affected by economic activity but not measured in economic analyses. There is a need to develop ecologically-based economic indicators that sensitize economic processes to the dynamics of the ecosystem.

Modeling is an activity likely to gain prominence during the 1990s. Numerical models are an excellent way to synthesize data and gain understanding that allows predictions for management purposes. Models are also useful in communicating strategies, explaining results to the public and linking science to policy and management. The Council's recent initiative to develop a Great Lakes-St. Lawrence River basin ecosystem framework shows how data can be synthesized and applied to a useful purpose. Interdisciplinary research must take a holistic view when addressing issues such as human health and consider questions such as the possible impact on the Canadian and U.S. health care systems resulting from the degradation of the health of the Great Lakes-St. Lawrence River basin ecosystem.

## 1.3 Better Communication and Cooperation

As research managers, we have a responsibility to ensure that the information derived from our efforts is presented and interpreted in the best possible way for use in decisionmaking. Our commitment to taking an ecosystem approach to understanding and resolving Great Lakes-St. Lawrence River problems means that we are not content to exchange data among scientists; we accept the challenge to place data in the context of the interacting social, economic and ecological systems that constitute the Great Lakes-St. Lawrence River basin ecosystem.

In response to this challenge, we are experimenting in our laboratories and institutions with new tools for analyzing and displaying complex interactions, improved methods for defining and quantifying ecosystem vitality, resilience, integrity and health, improved means of presenting alternative scenarios based on models of uncertain system dynamics, and new forms of environmental gaming and decision process simulations. In order for these tools to be regularly applied toward improving Great Lakes decisionmaking, we need ongoing support for their further development and use.

***We recommend that the Commission recognize the importance of developments in communication and decisionmaking by continuing and expanding its support for the Council of Great Lakes Research Managers' efforts to develop an ecosystem-based decision support framework.***

Ecosystem representations should be easy to use and designed to improve understanding of the economic and ecological values of the Great Lakes. They should be designed to empower users and provide expanded opportunities to participate in defining problems, identifying targets and setting priorities on an informed basis. Examples of efforts by the research community include the integration of fate and transport models of toxic substances with geographic information systems, the integration of health effects models with mass balance models, and other ways of integrating and displaying interrelated ecosystem processes.

***We recommend that the research community develop communication and educational tools for describing and displaying ecosystem information in cooperation with end users, including resource managers, political leaders, citizen groups, and leaders of business and industry.***

The research community could increase involvement by the interested public in selecting targets and priorities for work under the Agreement and build broader ownership and support for the needed research efforts. Such planning processes involving the public will be demanding and time consuming, but under the ecosystem approach, all remediation strategies are considered as part of the relationship between humans and the natural environment. For the research manager, this implies that greater emphasis be placed on assessing the integrity of natural and societal systems, conducting interdisciplinary science, holistic planning, and adaptive or anticipatory management. Adaptive experimental management is a powerful research approach that is particularly well suited for increased use during the 1990s. Remedial Action Plans offer

ideal platforms for the application of concepts and ideas developed by researchers over the past twenty years. This approach of linking action to research provides unique, large scale opportunities for researchers to show that their work is useful and build public support.

The research community should strive collectively to use improved communication tools and link action to research. The Great Lakes-St. Lawrence River community has been a leader in cooperative interagency planning, beginning with the first Great Lakes Water Quality Agreement in 1972. The Council, itself an auditor of research activities, represents a continuing commitment to improved cooperation, efficiency and partnerships among institutions. An example of improved communications and cooperation is the development by the Council of a comprehensive research inventory.

***We recommend that the research inventory be maintained and updated periodically.***

Maintaining and updating of the research inventory would facilitate the process of synthesizing and re-evaluating existing research data and results, and further the establishment of research priorities in support of a binational management strategy.

Significant reductions in the levels of specific contaminants found in the environment and biota have been achieved through the elimination, substitution or reuse of these substances in industrial processes and commercial products. Research and development of alternate process technologies and product materials is needed to decrease the use, transportation and disposal of contaminants of concern throughout the Great Lakes-St. Lawrence River basin. Our experience has shown that cooperative research between government and industry can be an effective means of advancing technologies and products that are both economically viable and environmentally responsible.

***We urge the Commission to recommend that the Parties give continued emphasis to researching, developing and implementing pollution prevention initiatives, including point source and process optimization initiatives.***

Activities to be encouraged include the development of alternate process technologies through co-operative research efforts between government and industry, and research into education tools to promote pollution prevention by consumers, business and government.

## 1.4 Long Term Commitment

The unpredictable nature of research funding by the two nations impacts the consistency and performance of Great Lakes-St. Lawrence River programs. The present binational resource allocations for ecosystemic research is practically nonexistent.

***We recommend that the Commission continue to fully utilize good science in its policy evaluation and urge the Commission to recommend that the Parties sustain long term research programs to ensure scientific efforts remain strong.***

This approach to research coordination will enhance the consistency and selection of sound policy options that are beneficial to the Great Lakes-St. Lawrence River community.

Research managers must continually strike an effective balance between the extremes of excessive fragmentation of staff and resources and the project diversification that seems necessary to support laboratories and scientists when funding sources and priorities are fluid. The manager has to balance the allocation of staff time spent on research and assisting operational programs. During the 1980s, budgets and staff declined as inflation and competition for government tax dollars increased. While this trend is likely to continue in the 1990s, researchers and managers have realized that programs cannot continue to do more with less *ad infinitum*. We need to continue to explore and expand partnerships in research with academic institutions in both Canada and the United States, comparable to educational networks such as the U.S. National Sea Grant College Program, Environment Canada's Great Lakes University Research Fund and the Research Council of Canada's Tri-Council Initiative.

During the early years of the Agreement, researchers were often seen as the bearers of bad news and an impediment to progress. They were constantly finding new problems, but rarely the solutions or remedies. Whether these criticisms are valid or not, there is little public support for increasing, or perhaps even maintaining research budgets. Cutting research budgets seems painless -- if the approximate $100 million annual Great Lakes research budget were cut tomorrow, the public would see no immediate effect other than savings. However, the long term effects of reducing research budgets could be disastrous for sustainable development in the Great Lakes-St. Lawrence River basin and will impact the recruitment, training and development of a new generation of scientists needed for the next century.

***We recommend that the research community provide support to general science education in order to encourage the recruitment, training and development of a new generation of scientists, and to increase science literacy and promote an ethic of conservation and pollution prevention within the general public.***

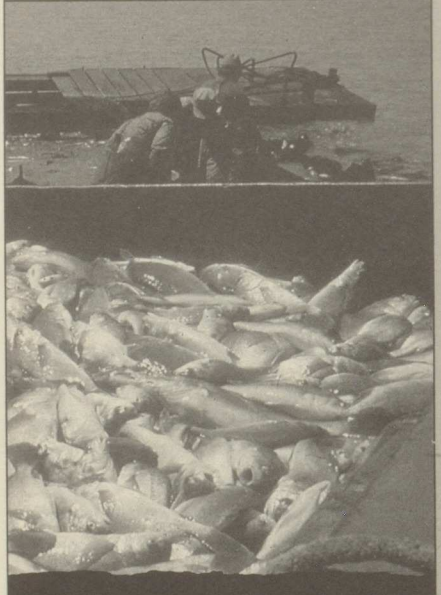
***We recommend that the Commission provide support to the Council of Great Lakes Research Managers to evaluate the requirements for recruiting, training and developing a new generation of scientists.***

The research community in the 1990s will continue to face the challenge of valuable core programs of long term research being displaced by "crisis research" where the funding is soft and short term and the objectives are narrowly focused. What may not be immediately obvious is that the success of such short term ventures will depend, in large measure, on the accumulated strengths of core research. Indeed, long term research is needed to provide a sound understanding of ecosystems, including natural and technological systems, and thus enable research institutions to respond quickly and effectively to crisis needs.

mechanism for tracking Great Lakes-St. Lawrence River research and providing data for the assessment of trends and the responsiveness of government-funded research to emerging issues. They also allow one to assess the development of collaborative efforts that are multi-disciplinary and take the ecosystem approach. When considering the complexity and importance of the Great Lakes-St. Lawrence River basin ecosystem and the community it supports, the research effort identified in the inventories is moving towards a multidisciplinary approach, but is still inadequate and entirely too narrow in scope. Only approximately 18 percent of the research projects encompass multiple objectives of two or more. The Great Lakes-St. Lawrence River community has lost significant ground in facing the challenge of managing its most important resource.

Another area where the Research Inventory has demonstrated its utility is in assessing the number of projects addressing priority areas, including virtual elimination of persistent toxic substances, human health, remedial action plans and the connecting channels, groundwater, air quality, climate change, nonindigenous species, wetlands, and the topics in Annex 17 of the 1987 Protocol to the Great Lakes Water Quality Agreement.

These examples illustrate the many uses for the database in the research inventory, which is readily available to the Great Lakes-St. Lawrence River basin community and others. As stated, the Council recommends that the research inventory be maintained and updated periodically. This would facilitate the process of synthesizing and re-evaluating existing research data and results, as well as establishing research priorities in support of a binational management strategy.



### PCB'S in Great Lakes Biota

**After polychlorinated biphenyls (PCBs) were banned during the mid 1970s, PCBs declined in lake trout, but the rate of decline has been slower since 1982. Two of the more toxic PCBs followed the trend for total PCBs, whereas a third congener declined only slightly in all the Great Lakes except Ontario, where it has declined steadily since 1980. This information has contributed to the understanding of PCB levels and fate in the environment. Past successes at banning PCBs give hope that future efforts will also be effective for virtual elimination of all toxic chemicals.**

**PCB contaminant levels in lake trout in small Ontario lakes were four times higher if alewife, rainbow smelt, or cisco were present. Lake trout were even more contaminated in lakes with the freshwater shrimp (Mysis relicta), that feeds on plankton. The latitude of the lakes and their degree of eutrophication also influenced PCB levels in lake trout. Fat fish had proportionally more PCB contamination than lean ones. These findings account for the relatively high PCB concentrations in the lake trout in the Great Lakes and explain the lag time between contaminant control and when declines were seen in PCB levels in lake trout.**

## 2.2 Strategy for Future Research Directions

The Council's overall research strategy incorporates four topic areas in order to meet the goals of environmental and economic sustainability in the Great Lakes-St. Lawrence River basin. They address toxic substances, protecting and restoring habitat, protecting human health and the health of the ecosystem's other species, and socioeconomic activity as it relates to ecosystem integrity.

### 2.2.1 Toxic Substances

Ecosystem quality in the Great Lakes and St. Lawrence River today is improved from conditions 20 years ago, in part because of the construction of municipal and industrial waste treatment systems, and remedial efforts to clean up contaminants already in the ecosystem.

The most significant improvements in the reduction of persistent toxic substances have only been realized through restrictions or bans on the manufacture or use of persistent toxic substances such as PCBs and DDT. Beyond this, no clear strategy has been established to achieve further reductions and zero discharge (International Joint Commission 1991b).

Toxic substances pose a serious challenge to the way that natural resources, health and pollution control agencies are structured and function. Toxic substances enter the environment from aqueous discharges at pipes and landfill sites, smoke stack emissions and direct volatilization. Once in the environment they move between water, air and land and contaminate plankton, fish, birds, reptiles and mammals, including humans. Traditionally, institutions have been structured

around these separate phenomena. However, persistent toxic substances such as PCBs have challenged the isolated disciplines of these traditional institutions and necessitated an interdisciplinary and transdisciplinary approach to research, monitoring and regulation. Our strategy for toxic substances outlines an approach that measures the risk of exposure, ranks sources, assesses impacts, models cause and effect relationships, analyzes costs and benefits of risk reduction, develops technologies and implements pollution prevention strategies.

## 2.2.2 Protecting and Restoring Habitat

The main thrust of this topic area is to restore and maintain ecosystem integrity, with a focus on the preservation and rehabilitation of Great Lakes-St. Lawrence River wetlands.

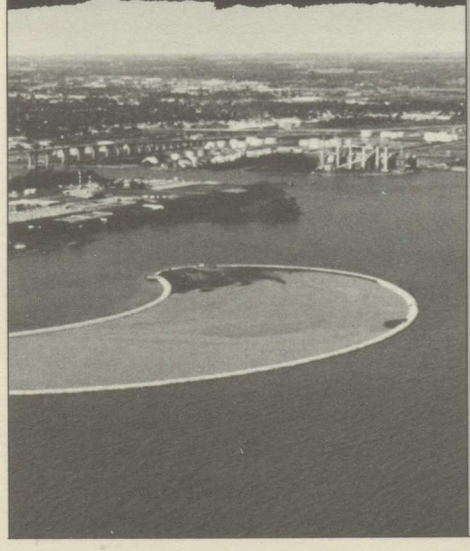
The issue of habitat protection and restoration has been at the forefront of environmental debates for many years. As development and resource use expand in the Great Lakes-St. Lawrence River basin, many aquatic habitat and wetland areas are degraded or eliminated. Research studies show that about two-thirds of the original wetlands in the basin have been lost and about 20,000 acres per year continue to be lost (International Joint Commission 1989). Some areas have suffered more extensive wetlands destruction than others (Table 2.1).

Wetlands play a significant role in the life cycle of many fish and wildlife species in the Great Lakes-St. Lawrence River basin. They provide spawning habitat for several fish species, and also nesting sites for migratory birds. Wetlands continue to be threatened by agricultural, urban and industrial development. Other factors also contribute to wetland degradation, such as recreational development, lake level


### Pollution Control Systems Optimization

**Provision of wastewater collection and treatment facilities is one of the prime responsibilities of municipal governments and one of their largest budget expenditures. Increasingly, municipal governments are finding financial resources inadequate to meet growing demands. As we move toward a cleaner environment and as effluent standards become more stringent, a more systematic approach to the planning of sewage collection and treatment facilities and maximizing their efficiency is vital. Research has shown that in many cases the capacity of existing wastewater treatment infrastructure can be extended dramatically using sensor-based monitoring, automated process control and sophisticated software systems as operational tools. In addition, strategies and technologies for the alleviation of problems caused by combined sewer overflow and stormwater discharges are being developed. Specific projects have been initiated to demonstrate combined sewer overflow and stormwater treatment and control options and, in some cases, develop pollution control plans. Research is also being done to introduce a measure of control to industrial discharges to municipal sewers and utilize the capability of treatment plant facilities to reduce toxic contaminant loadings to receiving waters.**

### Mass Balance



**A mass balance study of Green Bay and the Fox River was undertaken by state and federal agencies and academia during 1987-1991 as a pilot project to test the usefulness of this approach for assessing the sources and fates of toxic substances affecting the Great Lakes ecosystem. It was intended to validate and refine monitoring and analytical assumptions made by the agencies as well as to test models. Polychlorinated biphenyls (PCBs) were chosen as the surrogate pollutant. Successful application of the methodologies used in the study provide a means for cost-effective pollution control and a foundation for setting objectives for Lakewide Management Plans and Remedial Actions Plans.**

**Table 2.1:**

**Wetlands Losses in the Great Lakes Region[1]**

| *Location/Area* | *Wetland Assessment* |
|---|---|
| Minnesota | 76% loss since 1953 |
| Wisconsin | 50% loss since presettlement |
| Illinois | 90% loss since presettlement |
| Indiana | 86% loss in areas studied |
| | 71% loss in northern Indiana |
| Michigan | 71% loss since presettlement |
| Ohio | Loss of almost the entire 1,500 square miles of the Black Swamp |
| Lake St. Clair wetlands | 85% loss since presettlement |
| Ontario | 68% loss in Southern Ontario[2] |

[1] The Conservation Foundation and the Institute for Research on Public Policy, 1990. *Great Lakes, Great Legacy?* p. 144. The source cited did not present an overall assessment for Pennsylvania or New York.

[2] Environment Canada. 1991. The Federal Policy on Wetland Conservation. p. 4

## Water Level Regulation May Affect Wetland Habitat for Fish and Wildlife

**Wetlands provide important spawning, nesting, rearing, and feeding habitats for fish and wildlife. Changes in water level regulation on Lakes Ontario and Superior and introduction of regulation to other Great Lakes could alter wetlands and affect fish and wildlife. Under IJC's Levels Reference Study, the relationships between plant communities at different elevations and their water level histories were studied at 17 Lake Ontario and 18 Lake Superior wetlands. The data were used to assess the potential impact of the proposed water level regulation schemes. Results showed the greatest diversity of wetland plant communities occurred at elevations subject to flooding once every ten to 20 years and to dewatering for two successive years between floods. Proposed level regulation schemes would keep interannual fluctuations within one foot of the long-term mean level. Over a 90-year horizon, this regulation scheme was predicted to reduce the most diverse wetland areas by about 55 percent in Lake Ontario and 40 percent in Lake Superior. Following these predictions, alternate water level regulation schemes have been devised to produce temporal patterns of water level change needed to maintain diverse wetland communities.**

management and drainage for forestry. There are approximately 500,000 acres of wetlands remaining throughout the basin and they are of extreme value to the Great Lakes-St. Lawrence River basin ecosystem. The Council proposes to identify the research needs required to appropriately classify habitats in the basin, define goals for habitat protection, develop ecosystem indicators to monitor progress, and support research to restore and maintain the integrity of these remaining wetlands.

### 2.2.3 Protecting Human Health and the Health of the Ecosystem's Other Species

Our research has shown that the major route of human exposure to critical pollutants is through the consumption of food, and in particular fish and wildlife from the Great Lakes-St. Lawrence River basin. Exposure to the critical pollutants from breathing the air and drinking the water, and water-based recreation is not likely to exceed 10-15 percent of the total exposure.

Research findings show that toxic chemicals affect growth and reproduction, and ultimately the survival of some fish species in the Great Lakes and St. Lawrence River, and cause reproductive and other problems in 11 wildlife species (two mammals, eight birds and one reptile). The populations of cormorant and ring-billed gull are now 20-40 fold greater than any recorded historically, indicating that some fundamental alterations in the Great Lakes-St. Lawrence River basin ecosystem have occurred; bald eagle pairs nesting along the shores of Lakes Michigan and Huron continue to reproduce poorly and no nesting has occurred on Lake Ontario since 1951. Birth defects in young fish-eating birds have been recorded in ten species in the Great Lakes-St.

Lawrence River basin; a higher percentage of snapping turtles from the shorelines of Lakes Ontario and Erie have considerably higher numbers of unhatched eggs and deformed embryos than those from inland populations.

Research has shown that subtle developmental and reproductive effects also occur in a wide range of species including birds, reptiles, fish and mammals exposed to mixtures of contaminants in the Great Lakes-St. Lawrence River basin. While differences exist in behaviour and exposure patterns of humans and wildlife, research findings suggest that studies of human populations should focus on these subtle effects.

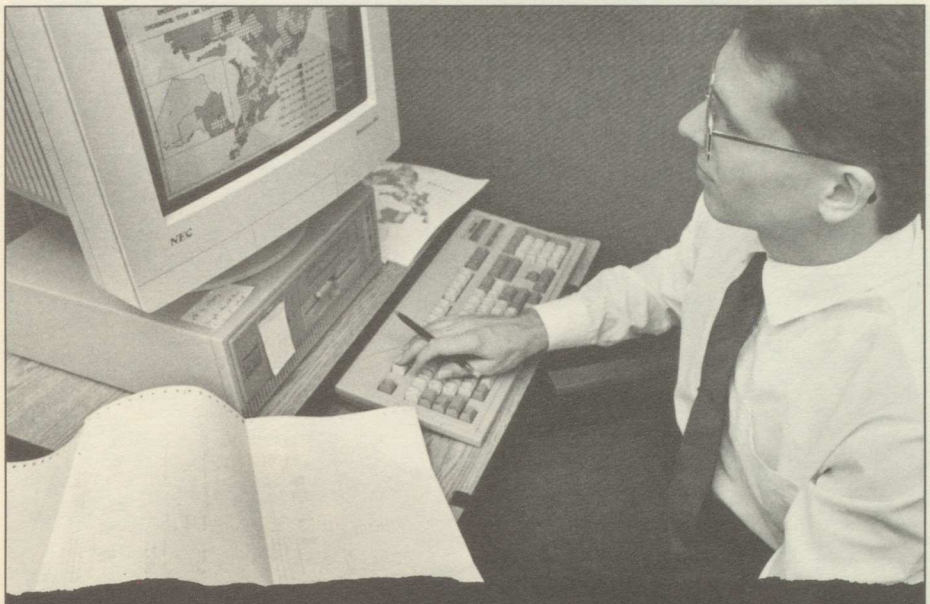
The limited human tissue residue data available indicate that the general population residing in the Great Lakes-St. Lawrence River basin is probably not exposed to higher levels of the most persistent pollutants than people residing elsewhere in North America. However, individuals consuming large amounts of contaminated fish and wildlife, especially native peoples and sportsmen, do have greater exposure to several persistent pollutants. Since elevated levels of contaminants in the Great Lakes-St. Lawrence River basin and elsewhere do pose a threat to human health, it is up to the research community to determine the precise nature and extent of this threat. The Council's research strategy uses an ecosystem approach in an attempt to protect human health and biological integrity.

## 2.2.4 Socioeconomic Activity and Ecosystem Integrity

The Great Lakes-St. Lawrence River research community has a special responsibility to provide easily understood and accurate information to the people who live in the basin and to decisionmakers in the public and private sectors. Given the seriousness of the issues, the Council recognizes there is a need to develop a proactive education and communication strategy that involves all stakeholders in the identification of research needs and priorities on an informed basis.

The ecosystem approach involves all aspects of the environment as part of a dynamic process integrating input and regulating output. The approach is intended to link socioeconomic and environmental factors in decisionmaking, but because of the difficulties in carrying this out, has been used more often to characterize an approach to the management of integrated environmental processes, and only sometimes to their further integration with socioeconomic factors. Ecologists study the dynamics of energy and material flows among species in ecosystems; economists study the efficient allocation of resources among competing interests in human society. However, the economy is generally considered independent and removed from nature. We have witnessed technological progress sufficient to overcome emerging resource scarcities, but such progress has not included the maintenance and restoration of the integrity of the ecosystem. This technological substitution to augment resource use creates the basic belief that growth is not constrained by the biological and physical factors of the ecosystem.

Population expansion, and the resultant resource extraction and consumption, dictates imminent carrying capacity limitations and compromises the ecosystem health



## Study of Water Use Patterns and Cancer in Ontario

**The Canadian public is concerned that environmental contaminants in the Great Lakes basin could cause cancer. A study is now under way of cancer cases in Ontario and their relationship to environmental exposures. In addition, the incidence of various kinds of cancer in Ontario has been mapped for the first time so that spatial variations can be examined at the county level and compared to the provincial averages. These efforts will help researchers and public health experts develop hypotheses about the relative risks of cancer in relation to the environment and lifestyle.**

## Promoting Careers in Environmental Toxicology

**As part of a veterinary training program, a Great Lakes university designed a pilot summer workshop to promote careers in environmental toxicology for aquatic animal biologists, veterinarians and veterinary students from the Great Lakes basin. The curriculum focused on freshwater aquatic ecology and the health effects of toxic substances on wildlife. An overwhelmingly positive response to this pilot summer program resulted in a multiyear commitment by the university to conduct intensive aquatic toxicology courses. As a result of this program, veterinarians, veterinary students and other wildlife specialists participating in the summer workshops will be highly trained in understanding how toxic substances in the ecosystem affect aquatic wildlife.**

of the basin. While great strides have been made to raise public awareness of waste reduction and recycling within the basin, additional research is needed to identify and refine methods and educational tools to influence societal behaviour and consumer expectations in order to promote pollution prevention.

## 2.3 Framework to Determine Research Priorities and Cooperation

The third component of the Council's approach to the management of Great Lakes-St. Lawrence River research is the development of an ecosystem framework and process for decisionmaking and research coordination based on the ecosystem approach.

A key mission of the Council is to identify the research priorities in a binational and collaborative manner that encourages inter-disciplinary science and supports adaptive management and policy considerations. This is often difficult to achieve in fields where research institutions have traditionally rewarded reductionist and theoretical contributions along disciplinary lines. Furthermore, it is difficult to take into account the totality of that which is implied by the ecosystem approach when making decisions about research priorities. A conscientious effort to adopt an ecosystem perspective requires that one comprehend both the natural and societal systems as an integrated whole -- no small task on its own. Then, within a concept of the entire system, decisionmakers must access a tremendous diversity of information relevant to the issues and apply the concept as a basis for organizing and using the information as an aid for setting research priorities.

The problem is that the ecosystem perspective is such a radical departure from scientific tradition that there are few, if any, conventional tools that support construction and use of such a framework. Without a framework and a procedure, the ecosystem approach is at best a well-intentioned and unfocused ideal. At worst, it is a shroud for traditional research practices that continue under the guise of an ecosystem approach.

The ecosystem approach can only be implemented if we are willing to expand the boundaries of problem solving. The evaluations of issues are often too narrowly defined at the outset, preventing a full assessment of solutions. Many of the models that have been produced, and much of the available historical information, have not been fully utilized in past analyses of issues. Any attempts to oversimplify the analysis of options can lead to inadequate decisionmaking. Also, scientists are often reluctant to venture beyond the narrow

bounds of their research. What is needed is to promote "second order" sciences capable of linking knowledge to decision-making.

Existing laws and policies are not able to adequately address emerging environmental problems and issues. It is also clear that public opinion has renewed enthusiasm for environmental protection coupled with disenchantment of current institutional regulatory efforts. Therefore, other options need to be investigated to ensure that ideas and linkages, including institutional changes, result in sound scientific advice on the environmental issues confronting the Great Lakes-St. Lawrence River basin.

The Council has identified a need to address the problems of the Great Lakes-St. Lawrence River basin in a more effective and efficient manner (International Joint Commision 1991a). The establishment of key linkages between major areas of research is identified as essential for holistic policy analyses in order to respond effectively to growing demands on the resources of Great Lakes-St. Lawrence River basin ecosystem.

Recognizing this need, the solution is to provide research managers with a framework and process for assessing the relative merit of research issues that reflect the interconnectedness of issues, attributes and indicators in the Great Lakes-St. Lawrence River basin ecosystem, and the policy relevance of the research being considered.

The framework will serve as a mechanism for synthesizing current knowledge about the ecosystem, portraying areas of knowledge as well as areas of ignorance, and providing some indication of which research approaches would be most productive. Ideally, the framework and process will embed human activities in natural systems (e.g., the ecosphere) at various time and spatial scales.

Supporting the framework will be a process for using the information it provides. The procedure would serve the research management community in its efforts to plan and coordinate interdisciplinary research and to establish research needs and priorities related to ecosystem integrity. Most importantly, the process will guide research managers in their consideration of the complexities of the Great Lakes-St. Lawrence River basin ecosystem and how various research options might lead to more effective water quality management in the basin.

The Council recognizes the importance of developing the framework and has undertaken a number of supporting initiatives that help guide and promote research in the Great Lakes-St. Lawrence River basin. The Great Lakes-St. Lawrence Research Inventories provide an assessment of the status quo of research in the basin and its relevance to the Agreement objectives. The Council plans to make this inventory database more interactive and incorporate the research activities into geographic information systems, as well as linking these activities to the Great Lakes Water Quality Agreement objectives. In this way, the integration of research activities addressing specific issues can be assessed and recommended to the research community.

The overall Council research strategy, including the topic areas of toxic substances, protecting and restoring habitat, protecting human health and the health of the ecosystem's other species, and socioeconomic activity and ecosystem integrity will be incorporated into the framework and integrated to link relevant Great Lakes-St. Lawrence River basin research to policy options. These activities are further elaborated in subsequent chapters of this report.

# 3.0 *Status and Evaluation of the Great Lakes-St.Lawrence Research Inventory*

The information provided in this chapter is summarized from the *Great Lakes-St. Lawrence Research Inventory* for 1990-1991 and 1991-1992 (International Joint Commission 1992a and 1993). Identification of principle investigators, funding sources, research objectives, and networks of researchers and institutions is provided in the inventories, which are available in hard copy or on diskette from the International Joint Commission, Great Lakes Regional Office, through the secretary of the Council of Great Lakes Research Managers.

The inventory lists government and university research, as well as some funded by the private sector. Projects are categorized according to the goals of the Great Lakes Water Quality Agreement and specific issues concerning the Great Lakes-St. Lawrence River basin. The total number of projects in 1990-1991 and 1991-1992 was 697 and 1,015, respectively, with associated funding totaling approximately $77 million in 1990-1991 and $107 million in 1991-1992. The inventory classification system and information continue to evolve and the expansion of the database will occur to accommodate emerging issues and new clients. The 1991-1992 inventory included socioeconomic and private sector research projects, but no information on legal research was available at the time of publication.

The inventory is intended to provide opportunities to the Great Lakes research managers, research community, private sector and public for creating partnerships, assessing unmet research needs and determining the emerging issues in the Great Lakes-St. Lawrence River basin.

## 3.1 Relevant Research in the Great Lakes-St. Lawrence River Basin

Research centres with significant Great Lakes programs were identified in the Great Lakes Research Review (International Joint Commission 1982) and by the Council in greater detail in *Great Lakes 2000: Building a Vision* (International Joint Commission 1991a).

In Canada, government-funded research programs relevant to Great Lakes-St. Lawrence River basin are clearly identified, and information concerning these programs is relatively easy to obtain. Recent major additions include the Great Lakes Action Plan and the St. Lawrence Action Plan, representing large-scale coordinated federal research programs, and the Great Lakes University Research Fund, which provides grants to academic researchers on a competitive basis. The Great Lakes Health Effects Program of the Great Lakes Action Plan was the only program in the Great Lakes region during 1991-1992 specifically established to address human health effects caused by pollution. Provincial ministries in Ontario and Quebec also contribute significantly to research activities in the basin through internal programs and grants to university-based researchers. Basic research in the basin is also funded by the Natural Sciences and Engineering Research Council.

A large proportion of the Canadian institutions conducting Great Lakes research is located at the Canada Centre for Inland Waters, operated by the federal government (Environment Canada, and Fisheries and Oceans Canada). Of the large federal institutions, the St. Lawrence Centre, established in 1988 under the St. Lawrence Action Plan, is the most significant recent addition. Projects from the St. Lawrence Centre's four major departments, Technological Development, Ecotoxicology and Ecosystem, Interior Waters, and State of the Environment, are represented in the research inventories.

Coordination of Great Lakes-St. Lawrence River research in Canada is shared by Environment Canada and the provincial ministries. Research programs funded under the Great Lakes Action Plan are developed and coordinated by Environment Canada. The 1986 Canada-Ontario Agreement Respecting Great Lakes Water Quality, required formal cooperation between the federal and provincial governments. Under this agreement, the Board of Review was designated as the body responsible for recommending new research in conjunction with recommendations made by the Commission. Currently the Ontario Ministry of the Environment and the Ontario Ministry of Natural Resources develop their own research priorities and programs, but consult regularly with Environment Canada. Provincial agencies participate in collaborative federal-provincial projects, and government scientists frequently interact with university-based researchers.

In the United States, the federal government also funds the majority of relevant research. Great Lakes states conduct internal research, contribute to the Great Lakes Protection Fund, provide partial funding to cooperative federal-state research

programs and support academic research. At both the federal and state levels, however, the relevant research frequently occurs under programs that do not focus specifically on Great Lakes issues. In addition, projects are more geographically diffuse and funded by a greater number of agencies than in Canada, making it more difficult to gather information and select relevant projects.

Significant federally funded research is conducted at large laboratories operated by the Environmental Protection Agency (U.S. EPA), the U.S. Fish and Wildlife Service of the Department of the Interior (USFWS), and the National Oceanic and Atmospheric Administration of the Department of Commerce (NOAA). These agencies also fund university-based research, including joint funding by NOAA and the states for Sea Grant College programs, Cooperative Research Units (USFWS), and various grants to universities by the U.S. EPA. The Great Lakes Human Health Effects Research Program of the Agency for Toxic Substances and Disease Registry of the U.S. Department of Health and Human Services, is the only U.S. program that will specifically assess the adverse human health effects of water pollutants in the Great Lakes system.

Relevant research is also funded by other federal departments (Agriculture, Defense and Transportation), Department of the Interior agencies (U.S. Geological Survey and National Park Service) and independent federal agencies such as the National Science Foundation. One example is the research program, headed by the U.S. Department of Agriculture under the President's Water Quality Initiative. While the initiative is nationwide in scope, a number of research projects conducted in the Great Lakes basin are specific to the Great Lakes, and are therefore included in the inventory. However, none of these agencies have identifiable Great Lakes research programs.

Historically, coordination of U.S. Great Lakes research programs at the federal and state levels has been highly decentralized, with programs supporting the mandates of the sponsoring departments and agencies at the various levels of government. Interagency formal collaboration among scientists has been infrequent, and large scale, coordinated multi-agency Great Lakes research programs do not exist. The U.S. Great Lakes Research Strategy, developed and approved by the U.S. Policy Committee, is designed to coordinate the Great Lakes research efforts of U.S. federal and state agencies, and may provide the necessary framework for directing U.S. Great Lakes research in the future (U.S. Policy Committee 1992). The Council's 1990-1991 research inventory provided a basis for the evaluation of unmet research needs identified by the Committee and included in its strategy.

Relevant projects funded by industry in both countries deal with reducing pollution through remedial and preventative technology. More industrial projects will be included as the scope of relevant research in the inventory increases.

## 3.2 Evaluation of Great Lakes-St. Lawrence River Research

To evaluate the adequacy and relevance of research programs to Agreement objectives, a comprehensive compilation of Great Lakes-St. Lawrence River research needs is essential. Past research needs have been documented (International Joint Commission 1976 and 1988) and current research activities are listed in the Council's research inventory for 1991-1992 (International Joint Commission 1993). Since research needs change as new concerns emerge and the issues change in relative importance, the evaluations must be based on a current compilation of research needs. While, for example, the most important current issue is the presence and effects of persistent toxic substances, no framework or comprehensive system is presently in place to develop research needs.

Although an overall evaluation of Great Lakes research is not feasible, three approaches were used to examine how research addressed Great Lakes-St. Lawrence River issues. First, research projects and funding were identified that related to the Commission's priorities for its biennial cycle, including virtual elimination, human health, atmospheric deposition to Lake Superior, groundwater contamination, and remedial action plans and the connecting channels. Second, research projects were classified according to the topic areas used in the Council's research inventory project classification code (see Appendix V). Third, research projects were examined to determine their relevance to the topics in Annex 17 of the Agreement. Assessing the relevance of projects to the Commission priorities and Annex 17 topics was somewhat subjective in nature, and under all three approaches, projects with multiple objectives were listed more than once if they related to more than one priority or topic area.

## 3.3 Priorities of the International Joint Commission

A number of priorities were selected by the Commission as the focus for work during the biennial cycle, which ran from October 1991 through September 1993. The Council has attempted to assess the progress of research initiatives associated with those priorities. Elements used to evaluate these priorities were developed by the workgroups delegated to address them (i.e., Virtual Elimination Task Force).

### 3.3.1 Virtual Elimination of Persistent Toxic Substances

Consistent with the provisions of the Agreement, it is the policy of the governments of the United States and Canada that

**" ... the discharge of any or all persistent toxic substances be virtually eliminated"**

(Great Lakes Water Quality Agreement, Article II).

Virtual elimination of persistent toxic substances from the Great Lakes-St. Lawrence River basin ecosystem was selected as the top priority by the Commission for the 1991-1993 biennial cycle. Development of the strategy to attain this goal has included five elements defined by the Virtual Elimination Task Force of the Commission (Table 3.1).

Most of these elements are based on scientific research, and clearly, coordinated scientific research is an essential component of implementing the virtual elimination policy. To explore the degree to which research in the basin is addressing issues identified by the Task Force, the research inventory was screened for projects relating to elements of its virtual elimination strategy. Research projects were grouped by priority categories and subcategories of virtual elimination, and projects with multiple objectives were listed under each relevant topic. Since a number of projects were not described in adequate detail, subjective decisions were necessary regarding relevance of these projects. Results are summarized in Table 3.1.

Criteria employed in preparing the research inventory databases may influence the completeness of the surveys considerably. The 1990-1991 research inventory includes government funded research in natural science disciplines. It does not include source monitoring studies for regulatory purposes, unless they have a research component (e.g., developing methods for monitoring). Based on these limitations, the 1990-1991 listing may be incomplete with respect to the following in element (2) source investigation: source monitoring; element (4) evaluation of tools: socioeconomic considerations, and privately funded technology development; and element (5) indicators: socioeconomic indicators. The 1991-1992 research inventory was expanded to include the socioeconomic and legal fields to improve on the information base related to these elements, but the solicited information on legal research was not received.

The St. Lawrence Action Plan project descriptions have been added to the 1991-1992 inventory increasing the project and fund totals. As more research agencies and institutions submit information about their activities, the database will continue to expand.

***Summary of Research on Virtual Elimination***

Projects addressing virtual elimination make up a significant proportion of the total government-funded research effort in the basin, amounting to 32 percent of the total number of projects and 29 percent of funding. Considering the limitations of the database outlined above, the actual amount of research is probably greater. The following summarizes research addressing the five virtual elimination strategy elements based on information in Table 3.1.

***(1) Criteria:***
Few research projects focus on the development of selection criteria of toxic substances for virtual elimination. Although scientific research may contribute to this process, this element is more closely related to regulatory activities.

***(2) Source Investigation:***
Investigation of persistent toxic substance sources is an important element of virtual elimination. The variety of potential sources necessitates a large amount of research, as is reflected in the resources allocated to this element, which amount to approximately 37 percent of the total virtual elimination research effort. Studies of loadings from secondary sources (e.g., atmospheric deposition and inputs from tributaries) dominate the source investigation category. The majority of these projects investigate transport and fate of persistent toxic substances, and source investigation is in some cases not explicitly stated as a project objective. Relatively few studies were aimed at developing procedures for estimating loadings of persistent toxic substances. As indicated above, the present compilation of projects investigating primary contaminant sources is probably incomplete since it excludes monitoring activities and privately funded research and monitoring.

**Table 3.1**
**Research during 1990-1991 and 1991-1992 in Support of Virtual Elimination of Persistent Toxic Substances**
(Breakdown according to elements of virtual elimination)

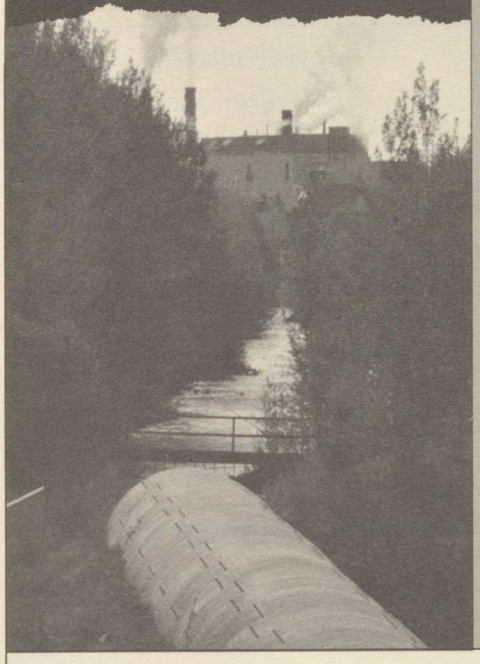
| ELEMENT | NO. OF PROJECTS* 1990-1991 | FUNDING ($1000**) 1990-1991 | NO. OF PROJECTS* 1991-1992 | FUNDING ($1000**) 1991-1992 |
|---|---|---|---|---|
| **1.Criteria for selecting substances** These research projects develop criteria for determining which substances are subject to virtual elimination. | 1 | 45 | 6 | 204 |
| **2. Source Investigation** These research projects investigate procedures to determine and assess loadings of persistent toxic substances to the Great Lakes Basin Ecosystem. | 48 | 9,872 | 97 | 11,834 |
| **3. Contaminant Remediation** These research projects assess persistent toxic substance use, and remediation procedures and practices to eliminate or control their entry into the Great Lakes Basin Ecosystem. | 65 | 8,648 | 89 | 9,598 |
| **4. Evaluation of Tools** These research projects evaluate tools that are developed to reduce or eliminate toxic substance inputs to the Great Lakes Basin Ecosystem. | 22 | 1,974 | 23 | 2,221 |
| **5. Indicators** These research projects investigate the status of persistent toxic substance trends in the Great Lakes Basin Ecosystem. | 31 | 2,078 | 113 | 7,310 |
| TOTALS | 167 | 22,617 | 328 | 31,167 |

* Some projects address a number of elements.
** $ U.S. (Approximate funding, adjusted for projects without funding information).

***(3) Contaminant Remediation:***
Development of contaminant remediation techniques is an active area of research in the Great Lakes-St. Lawrence River basin accounting for approximately 31 percent of virtual elimination research. Few projects investigate current storage and disposal practices and procedures, and the contribution of contaminants from existing storage and disposal facilities. By contrast, sediment remediation techniques receive the greatest proportion of funding, corresponding to the magnitude of sediment contamination problems in the Great Lakes-St. Lawrence River region. The remainder of projects dealing with contaminant remediation (soil/groundwater and nonspecific environmental media) may also have applicability to sediments and were considered to be relevant. Research efforts outside the Great Lakes-St. Lawrence River basin may also contribute significantly to the development of this element of virtual elimination.

***(4) Evaluation of Virtual Elimination Tools:***
Technology development aimed at preventing the generation and release of persistent toxic substances receives a moderate amount of research effort (seven percent of the total funds allocated to virtual elimination). The majority of funding is provided by the Canadian federal government under the Great Lakes Action Plan and the St. Lawrence Action Plan. Although a large amount of research addressing technology development is being carried out in the United States, few projects were specifically aimed at Great Lakes-St. Lawrence River contamination problems. Consequently, studies of technology development outside the basin, and similar efforts by private industry may add significantly to those listed in the research inventory.

## Pulp and Paper Sector Pollution Prevention Technology



**Research efforts have concentrated on technology development and demonstration programs directed towards the enhanced removal of contaminants, including chlorinated organic contaminants from pulp and paper mill effluents, particularly those from bleached kraft mills -- a significant problem at many Areas of Concern. This program focuses on two critical areas. First, the development and demonstration of optimized wastewater treatment plant designs and modes of operation that can be implemented relatively inexpensively by all bleached kraft mills with existing treatment facilities or as part of new installations; and secondly, the development of membrane and advanced bio-reactor technologies for in-plant application to high strength segregated bleach plant effluents.**

***(5) Indicators:*** The research inventory lists a significant number of projects investigating the use of indicators to track levels and effects of persistent toxic substances in the ecosystem. It accounts for 23 percent of the funding directed towards virtual elimination of persistent toxic substances. Research activities relevant to this element were dominated by studies investigating health effects indicators and biomarkers, at the expense of traditional contaminant indicators such as tissue concentrations and community structure.

### 3.3.2 Human Health Effects of Great Lakes Contaminants

The Agreement calls upon the Parties to

**" ... establish monitoring and research programs at a level sufficient to identify the impact of persistent toxic substances on the health of humans"** (Great Lakes Water Quality Agreement, Annex 12).

Ecosystem health, including human health, is one of the Commission's priorities for the 1991-1993 biennial cycle. The following summary is based on projects in the 1990-1991 and 1991-1992 research inventories investigating element one of the human health priority, "Applicability of investigative/integrative approaches to human health."

Research focusing on human health effects makes up a relatively small proportion of the research inventory, accounting for approximately six percent of the binational Great Lakes-St. Lawrence River research effort in 1990-1991. Canadian environmental health research in the basin is represented by the Great Lakes Health Effects Program, Health and Welfare Canada, a coordinated federal research program aimed at investigating human health effects arising from contamination of the Great Lakes-St. Lawrence River basin. The approximate total budget for this program for 1990-1991 and 1991-1992 was $3.4 million. In contrast, no specific Great Lakes-St. Lawrence health research programs were in place in FY 1991 under the auspices of the U.S. Government. In 1992, the U.S. Congress appropriated $2 million in support of a research grants program, coordinated by the Agency for Toxic Substances and Disease Registry, that emphasizes identifying human populations at health risk, improving exposure assessment methods and data, and evaluating select health effects in presumed at-risk populations in the Great Lakes-St. Lawrence River basin. Nine research projects were awarded in September 1992 and reported in the 1991-1992 research inventory. Several projects funded by the Great Lakes Protection Fund were clearly identifiable as relevant, as well as projects funded by Wisconsin Sea Grant College Program, the Michigan Great Lakes Protection Fund and several state agencies. Information regarding the remainder of U.S. studies listed in the research inventory was gathered by means of a search of the National Institutes of Health's current research database.

The 1991-1992 research inventory includes 72 projects examining human health issues in the Great Lakes-St. Lawrence River basin, with a total funding of approximately $9 million (Table 3.2). Overall, analysis of the research inventory suggests that Great Lakes-St. Lawrence River human health research is dominated by studies of exposure to toxic substances and associated health effects from consumption of contaminated Great Lakes-St. Lawrence River fish. There is a small number of projects investigating health risk advisories and human awareness and perception of health risks associated with the consumption of Great Lakes fish.

In addition to projects listed in the research inventory, significant amount of environmental (human) health research is being conducted

**Table 3.2**
**Research Addressing Great Lakes Human Health Issues, 1990-92.**
Column totals were adjusted for projects with multiple objectives, and for projects without funding information.

| SUBJECT | NO. OF PROJECTS* (1990-1991) | FUNDING ($1000**) (1990-1991) | NO. OF PROJECTS* (1991-1992) | FUNDING ($1000**) (1991-1992) |
|---|---|---|---|---|
| 1. **Exposure Assessment** Covers fish consumption and other exposure or nonspecific research. | 21 | 2,329 | 43 | 5,406 |
| 2. **Human Health Effects*** ** Covers reproductive, behavioural, developmental, cancer and other effects research. | | | 23 | 3,303 |
| 3. **Health Risk/Advisory** | | | 6 | 292 |
| **TOTALS:** | 21 | 2,329 | 72 | 9,001 |

* Some projects address multiple subjects (i.e. only 62 distinct projects in 1991-1992).
** U.S. Funds.
*** 57 percent of studies are health effects due to consumption of Great Lakes-St. Lawrence River fish.

in the Great Lakes-St. Lawrence River basin at five environmental health sciences centers (estimated total funding: $15-20 million), partially funded by the National Institute of Environmental Health Sciences, and at U.S. EPA laboratories. However, as research programs at these institutions address environmentally induced diseases in general rather than Great Lakes-St. Lawrence River health issues, they were not designated as Great Lakes-St. Lawrence River research. Similarly, although most laboratory studies of contaminant effects on animals are generally not specific to the Great Lakes, they are valuable in understanding and predicting human health effects in the basin.

The Human Health issue is addressed primarily by the objectives of Annex 12 in the GLWQA, and to a lesser extent Annex 17. The majority of the research which is conducted focuses upon determining the impact of, and exposure to, persistent toxic substances through various exposure media, as well as the development of appropriate reproductive, physiological, and biochemical measures as health effects indicators. A significant quantity of research is also

## Studies on the Toxicity of Selected PCB Congeners and their Metabolites

**There is little information on the toxicity of some kinds of PCB molecules (congeners) found in human tissues and in some food sources. A series of studies with selected PCB congeners and some of their metabolites has been carried out in laboratory animals to determine which are the most toxic ones, and which tissues are being affected by them. This knowledge will permit better priority setting in coping with PCB contamination and more relevant advisories for the public on means to reduce their exposure to the most troublesome congeners.**

directed towards the objectives of Annex 17 of the Agreement, such as, "the use of population-based studies to determine the long term, low level effects of toxic substances on human health."

### 3.3.3 Groundwater Contamination

Consistent with the provisions of the Agreement, it is the policy of the Governments of the United States and Canada, in cooperation with state and provincial governments

**"to coordinate existing programs to control contaminated groundwater affecting the boundary waters of the Great Lakes System"**
(Great Lakes Water Quality Agreement, Annex 16).

Groundwater related research received approximately $8.3 million during the 1991-1992 period. Of the total 71 groundwater projects, 59 addressed specificiations of one or more individual Agreement annexes and represented 86 percent of the total funds allocated in the groundwater category (table 3.3). Due to the large number of projects focusing on contaminated groundwater and the contaminant sources, Annex 16 received over half of the research funds related to Agreement annexes. Numerous projects also addressed multiple annexes, and although the major focus of research was on contamination and remediation, additional topics investigated included the effect of land use practices on water quality and the development of indicator species as health effect indicators for groundwater quality. Projects not related to the annexes were primarily descriptive, taking a qualitative look at various aspects of groundwater and the physical processes surrounding its role in the watershed.

### 3.3.4 Atmospheric Deposition

The Agreement calls upon the Parties to

**" ... conduct research surveillance and monitoring and implement pollution control measures for the purpose of reducing atmospheric deposition of toxic substances, particularly persistent toxic substances, to the Great Lakes Basin Ecosystem"**
(Great Lakes Water Quality Agreement, Annex 15).

Tracking the Parties' work to estimate and identify sources of atmospheric deposition to Lake Superior was also one of the Commission's priorities for the 1991-1993 biennial cycle. The total number of atmospheric projects is 47, of which ten projects ($879,000) specifically address contaminant

**Table 3.3**
**Groundwater Research Related to Great Lakes Water Quality Agreement Annexes in 1991-1992**

| ANNEX | RESEARCH OBJECTIVES | RESEARCH EFFORT | |
|---|---|---|---|
| | | No. of Projects | Funding ($1000**) |
| 2 | Remediation recommendations and further identification of environmental problems sources and pathways of critical pollutants and use of modelling for loading estimation. | 11 | 471 |
| 7 | Investigation of the fate and pathways of contaminants in dredged material and those resulting from disposal activities. | 2 | 121 |
| 11 | Evaluation and monitoring of water quality trends; evaluation of indicator species. | 3 | 771 |
| 12 | Identification of temporal and spatial trends in concentrations of persistent toxic substances; use of reproductive and physiological measures in fish and wildlife as health effect indicators; establishment of joint programs for the disposal of pesticides; identification of the sources of input of persistent toxic substances. | 11 | 663 |
| 13 | Determination of nonpoint source pollutants; loading estimates; evaluation of changes in land-use and land management practices and the effect on water quality. | 9 | 346 |
| 16 | Identification of groundwater contaminant sources; hydrogeological mapping of contaminant sources; sampling and analysis; loading estimates. | 61 | 3737 |
| 17 | Evaluation of mass transfer of pollutants between groundwater and other ecosystem components; development of control technologies for industrial and municipal effluents; assessment of transfer of groundwater contaminants to other areas in the Great Lakes basin. | 21 | 1058 |
| | **TOTAL** | 118* | 7167 |

* some projects address more than one Annex (i.e. only 19 distinct projects)

** Funding in $U.S., median funding assumed for projects without funding information.

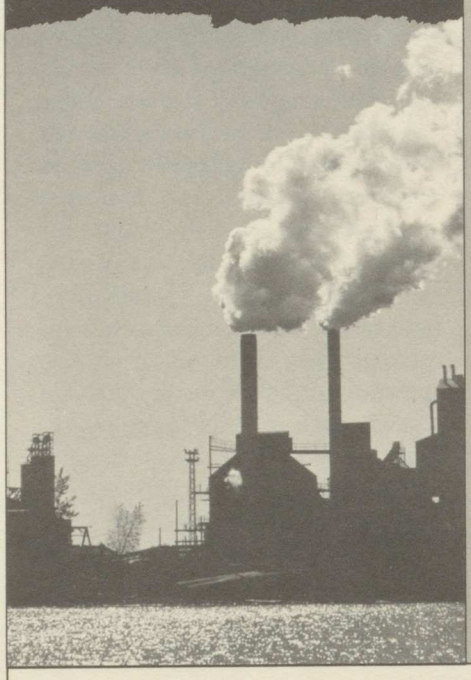
deposition in Lake Superior. In Table 3.4, the research topic "dynamics and fate" deals with toxic substances after they have been deposited in the Great Lakes basin from the atmosphere. All other subject areas in this priority deal with toxic substances while in the atmospheric medium; studies on the regulation of atmospheric emissions are lacking.

## 3.3.5 Remedial Action Plans and Connecting Channels

The Agreement states the general principle that **"Remedial Action Plans shall embody a systematic and comprehensive ecosystem approach to restoring and protecting beneficial uses in Areas of Concern"** (Great Lakes Water Quality Agreement, Annex 2). The Council conducted a search for research projects related to Remedial Action Plans.

While project descriptions were limited in scope and not always identified geographically, 19 projects addressing Remedial Action Plans were found. Descriptions of 12 research projects were directed towards socioeconomic aspects and development of Remedial Action Plan programs in general, involving studies on mass balance; levels, transport, fate and effects of pollutants; pollution prevention; and treatment methods (Table 3.5). The other eight research projects covered the same categories, but were directed at the following specific Remedial Action Plan sites: Nipigon Bay, St. Marys River, Green Bay, Muskegon Lake, Severn Sound, Hamilton Harbour, Bay of Quinte and St. Lawrence River including Cornwall and Massena. The research carried out in Severn Sound and Nipigon Bay supported reme-

### Volatilization of PCBs from the Great Lakes



**Polychlorinated biphenyls (PCBs) and other semivolatile organic chemicals have the potential to volatilize from the surface of the Great Lakes or enter the lakes from the atmosphere. The fluxes of 70 PCB congeners were studied in Green Bay of Lake Michigan and in Lake Superior under various wind conditions. Summertime volatilization fluxes were higher in more contaminated areas. Volatilization increased with wind. Volatilization of PCBs is an important loss transport process in Lake Superior and Green Bay. This research has contributed to a better understanding of the fate and transport of PCBs in the ecosystem.**

**Table 3.4**
**Research Addressing Atmospheric Deposition of Toxic Substances, 1990-92**

| SUBJECT | NO. OF PROJECTS* (1990-1991) | FUNDING ($1000**) (1990-1991) | NO. OF PROJECTS* (1991-1992) | FUNDING ($1000**) (1991-1992) |
|---|---|---|---|---|
| **Atmosphere (Lake Superior only)** | **(8)** | **(817)** | **47 (10)** | **8,566 (879)** |
| Covers sampling/analytical methods, sources of pollution, transport/deposition loading, dynamics/fate, modeling, and regulation. | | | | |
| | **(8)** | **(817)** | **47** | **8,566** |

* Some projects address a number subjects (i.e. 38 distinct projects having 47 counts in 91/92).

** $ U.S. (Approximate funding, adjusted for projects without funding information, funds divided equally for multiple listings).

dial fish stocking programs. The majority of funding for Canada Remedial Action Plans originated from the Great Lakes Action Plan preservation and pollution prevention funds.

A search for research projects linked to the Great Lakes connecting channels found that research conducted in the St. Lawrence River dominated this category. Most funding originated from the St. Lawrence River Action Plan and St. Lawrence River Centre in Canada, and the National Institute of Health in the United States. The St. Marys and Niagara Rivers received about $1 million and $2 million in funding, respectively.

Overall, 46 areas of the project classification system (see appendices to the Great Lakes-St. Lawrence Research Inventories) were addressed by 81 projects, indicating a broad range of research activities within the connecting channels. There are limitations to the evaluation of the research database in the inventory, however, due to incomplete project descriptions. In 1992-1993, the database will be linked to a geographic information system to allow for a more comprehensive assessment of the research in the Areas of Concern.

## 3.4 Other Research Inventory Topic Areas

In addition to the Commission's priorities, the Council has attempted to address the research activities focused on emerging issues and other impacts prevalent in the Great Lakes-St. Lawrence basin. These topic areas include climate change, nonindigenous species, wetlands and other impacts and issues, such as water levels, bacteria and radionuclides.

**Table 3.5**
**Research Addressing Remedial Action Plans/Connecting Channels in the Great Lakes-St. Lawrence River Basin, 1991-92.**
Numbers in bold are subtotals or totals.

| SUBJECT | NO. OF PROJECTS* (1991-1992) | FUNDING ($1000)** (1991-1992) |
|---|---|---|
| **1. Remediation** | **20** | **4,616** |
| General | 12 | 2,086 |
| Specific | 8 | 2,530 |
| **2. Connecting Channels** | **81** | **9,859** |
| St. Lawrence River | 53 | 5,597 |
| St. Marys River | 5 | 1,066 |
| Niagara River | 11 | 1,706 |
| St. Clair River | 8 | 294 |
| Detroit River | 1 | 48 |
| Not Specified | 3 | 1,148 |
| **TOTALS** | **101** | **14,475** |

* Some projects address both subject areas (i.e. 97 distinct projects).
** U.S. Funds.

### 3.4.1 Climate Change

Previously a subcategory under emerging issues in the 1990-1991 research inventory, climate change is now treated as a separate topic with most research focusing on the effects on the physical environment and biological communities (Table 3.6). Studies of physical environmental effects examine impacts on large lake ice cycles, snowfall characteristics, lake hydrology and regional water resources. Fish communities are the primary topic of studies of effects on biological communities, though one project examined the effects on plants of higher levels of ultraviolet light. Numbers of projects and funding decrease somewhat for the categories of "basic research," "forcing functions" and "socioeconomic effects." Basic research involves obtaining climatological data for the models used to understand climate change scenarios. The forcing function subcategory deals with the effects of carbon dioxide and ozone on global climate change. More should be invested in developing strategies to reduce impacts of climate change as no effort at all is being made in this subcategory at present.

### 3.4.2 Other Impacts and Issues

Other impacts and issues is a research inventory category that includes topic areas currently funded under $1 million (Table 3.7). Only three of the eight categories -- pathogens and bacterial pollution; erosion and sedimentation; and agricultural practices -- are funded over $500,000. Projects in the pathogens and bacterial pollution category focus on detecting and modeling bacterial pollution caused by rainfall, runoff and manure application. Modeling of dynamics related to waves and storms along shorelines is the major theme for projects in the erosion and sedimentation category. There are many agricultural practices resulting in the loss of nutrients, sediments and pesticides to surface and subsurface waters of the Great Lakes-St. Lawrence River

**Table 3.6**
**Research addressing Climate Change in the Great Lakes, 1990-92**

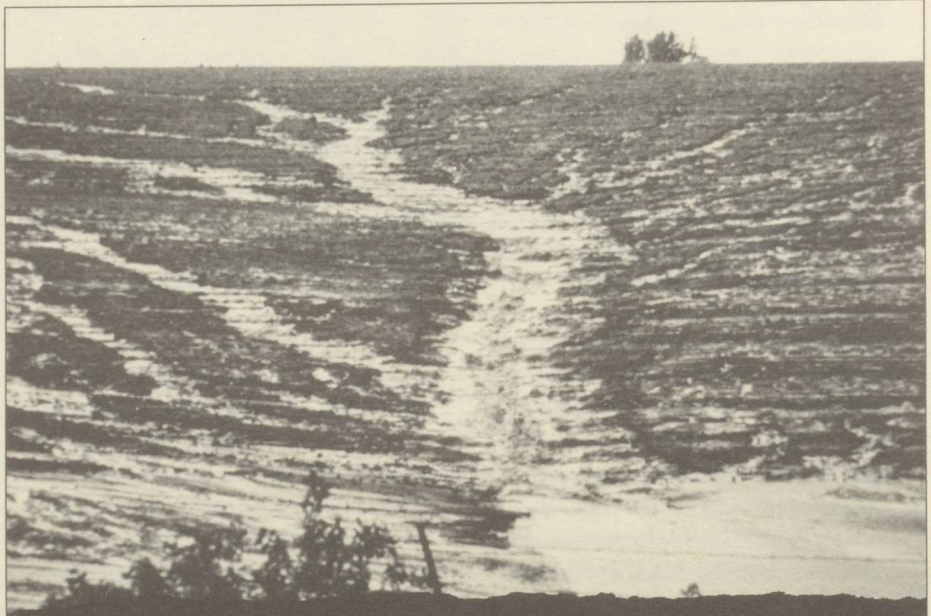
| SUBJECT | NO. OF PROJECTS* (1990-1991) | FUNDING ($1000**) (1990-1991) | NO. OF PROJECTS* (1991-1992) | FUNDING ($1000**) (1991-1992) |
|---|---|---|---|---|
| **Climate** Covers basic research, forcing functions effects on physical environment, effects on biological communities, socioeconomic implications, and strategies to reduce impacts. | **8** | **919** | **29** | **2,347** |

* Some projects address a number of topic areas (i.e. 28 distinct projects addressing 29 counts in 1991-1992).

** $ U.S. (Approximate funding, adjusted for projects without funding information, funds divided equally for multiple listings).

basin. The agricultural practices research topic evaluates impacts of different agricultural practices in order to minimize detrimental effects.

It is not clear whether research directions are set in the Great Lakes-St. Lawrence River basin based on the importance of current issues to the ecosystem as required by the Agreement, or based on economic interests. Due to the scarcity of historical data on trends in research in the Great Lakes-St. Lawrence River basin, it is difficult to evaluate how responsive the research community has been to emerging issues. The recent invasion of the Great Lakes-St. Lawrence River basin ecosystem by the zebra mussel is the only example we know of where an immediate increase in research effort was applied to an emerging issue. The response by funding agencies and researchers appears to be adequate. However, zebra mussel effects are of considerable economic significance compared with other issues (e.g., wetlands and endangered species) that receive much lower levels of research attention.



## Development of Soil Erosion Prediction Technology

**Soil erosion on agricultural lands continues to be a major contaminant of surface waters. Erosion prediction technology has been used to select conservation and management practices for agricultural lands over the last several decades. As erosion prediction technology requires empirical data, it is difficult to use in evaluating new practices. Additionally, it is not designed to predict the movement of materials from agricultural land to receiving water bodies.**

**A Water Erosion Prediction Project has been established to develop fundamental processed based erosion prediction technology. This project was initiated in 1987, and it has produced a model which after verification and validation will be used on most of the basin. It is a set of daily simulator models that will predict erosion deposition on the landscape, as well as erosion and sediment transport through channel systems. The technology will be useful at the field level by local conservationists and the model is currently scheduled to be delivered to action agencies in 1995.**

Table 3.7
**Research addressing Other Impacts and Issues in the Great Lakes, 1990-92**

| SUBJECT | NO. OF PROJECTS (1990-1991) | FUNDING ($1000*) (1990-1991) | NO. OF PROJECTS (1991-1992) | FUNDING ($1000*) (1991-1992) |
|---|---|---|---|---|
| Water Levels | 8 | 465 | 5 | 225 |
| Bacterial Pollution | 8 | 371 | 10 | 800 |
| Erosion/Sedimentation | 7 | 225 | 10 | 754 |
| Agricultural Practices** | | | 9 | 504 |
| Brine Inputs** | | | 1 | 73 |
| Radionuclides** | | | 2 | 112 |
| Land Use** | | | 4 | 273 |
| Other | 9 | 335 | 2 | 174 |
| **TOTALS** | **22** | **1,396** | **43** | **2,915** |

* U.S. Funds.

** Not surveyed in 1990-1991.

## 3.4.3 Nonindigenous Species

Under the revised Agreement, the U.S. and Canadian Coast Guards responsible for reviewing

**" ... practices and procedures regarding waste water and their deleterious effect on water quality, including, as required, studies to determine if live fish or invertebrates in ballast water discharges into the Great Lakes System constitute a threat to the System"**
(Great Lakes Water Quality Agreement, Annex 6).

To support evaluation of such activities, the research inventory includes a compilation of research projects investigating nonindigenous species in the Great Lakes-St. Lawrence River system.

The Council's research inventories include a relatively large number of projects dealing with nonindigenous species. With the exception of six Canadian projects funded by the Province of Ontario and some U.S. state funded research, the majority of projects in 1990-1991 were funded by federal agencies. The total government funding expended on nonindigenous species research in 1990-1991 amounts to approximately $6.1 million: $5.4 million spent by the United States and $0.7 million by Canada. Approximately two-thirds of this research in the United States was conducted at academic institutions, while most research in Canada was conducted at government-operated institutions. It should be noted that the 1990-1991 research inventory did not include industrial and municipal government funding for nonindigenous species research.

The 1991-1992 inventory database was expanded to include research in the socioeconomic field, and by industry and private organizations. The total funding expended on nonindigenous species research in 1991-1992 is estimated at $11.6 million, of which $1.5 million was contributed by the private sector, and $8.0 million and $2.1 million by U.S. and Canadian government agencies respectively (Table 3.8). While there was some U.S. state funded research and five projects funded internally by Canadian Universities, the majority of projects continued to be funded by federal agencies in 1991-1992. In Canada, however, the level of effort by the federal and provincial governments was similar.

Table 3.8 shows a breakdown of projects by organism in the 1990-1991 and 1991-1992 research inventories. The majority of projects investigated zebra mussels and the sea lamprey. Only a small proportion deal with other invaders and the majority of these are Sea Grant research projects in the United States. The effects of zebra mussels and sea lampreys have considerable economic significance, in contrast to other recent invaders, which may cause significant ecological damage, but incur less evident economic costs (i.e., *Bythotrephes* and purple loosestrife). As the latter invaders receive considerably lower research effort, it appears that research on nonindigenous species is to some extent motivated by economic considerations.

Table 3.9 lists research needs adopted by the Great Lakes Panel on Aquatic Nuisance Species, an entity of U.S. federal and state agencies created under the Nonindigenous Aquatic Nuisance Species Prevention and Control Act of 1990. The majority of research projects deal with the control, effects, biology and spread of invading organisms. Marked increases in projects and funding in 1991-1992 demonstrates there is increased concern over the

**Table 3.8**

**Nonindigenous Species Research, 1990-92.**

Projects listed by invading organism. Column totals were adjusted for projects with multiple objectives and for projects without funding information.

| ORGANISM | NO. OF PROJECTS (1990-1991) | FUNDING ($1000*) (1990-1991) | NO. OF PROJECTS (1991-1992) | FUNDING ($1000*) (1991-1992) |
|---|---|---|---|---|
| Zebra mussel | 45 | 4,434 | 148 | 10,050 |
| Sea lamprey | 11 | 541 | 8 | 360 |
| *Bythotrephes* | 5 | 440 | 5 | 552 |
| Purple loosestrife | 1 | 98 | 4 | 175 |
| Alewife | 2 | 59 | 2 | 57 |
| Eurasian watermilfoil | 1 | 45 | 2 | 87 |
| Smelt | 0 | 0 | 2 | 138 |
| European ruffe | 2 | 77 | 2 | 78 |
| Quagga mussel | 0 | 0 | 1 | 56 |
| Goby | 0 | 0 | 1 | 3 |
| Not specified | 3 | 431 | 6 | 478 |
| **TOTALS:** **70** | | **6,125** | **181** | **12,034** |

*U.S. Funds.

spread and distribution of nonindigenous species. In the "effects" category, the majority of population-level studies examine the impacts of nonindigenous species on fish, a finding that reflects concern over potential damage to economically important fisheries resources. Few studies address preventing future invasions of nonindigenous species, suggesting that research on nonindigenous species is largely reactive. Research in the social sciences is still minimal.

The Great Lakes Panel on Aquatic Nuisance Species has also proposed a preliminary list of three primary management goals with respect to nonindigenous species in the Great Lakes-St. Lawrence region: (1) preventing introduction (intercontinental), (2) containing potentially damaging species (intracontinental), and (3) controlling recognized invaders (sea lamprey, alewife, ruffe, zebra mussels, new invaders and disease-causing invading organisms). The 1990-1991 and 1991-1992 research inventories include 22 and 63 projects respectively that address these issues, indicating that nonindigenous species management-related topics comprise an active area of research in the Great Lakes-St. Lawrence River basin.

**Table 3.9**

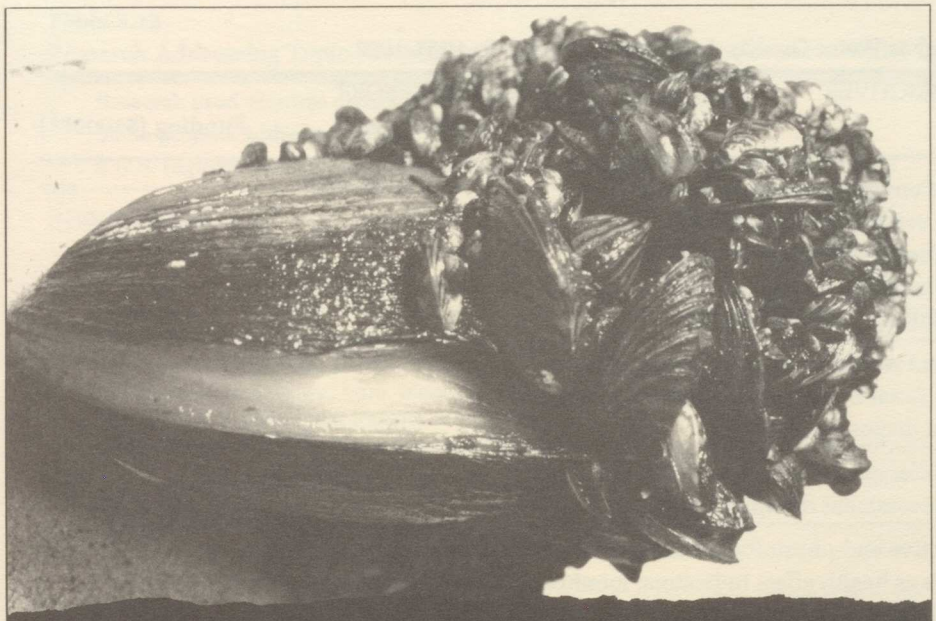
**Nonindigenous species research, 1990-92.**

Project listed according to research needs. Column totals were adjusted for projects with multiple objectives and for projects without funding information. Note that 1991-1992 figures include projects by private industry.

| RESEARCH NEED | NO. OF PROJECTS* (1990-1991) | FUNDING ($1000**) (1990-1991) | NO. OF PROJECTS* (1991-1992) | FUNDING ($1000**) (1991-1992) |
|---|---|---|---|---|
| Spread | 9 | 315 | 28 | 1,319 |
| Biology/Life History | 25 | 1,162 | 55 | 2,534 |
| Ecosystem Effects | 38 | 2,892 | 59 | 3,575 |
| Control/Mitigation | 18 | 1,407 | 60 | 3,715 |
| Prevention of Introduction | 4 | 487 | 3 | 206 |
| Socioeconomic Costs and Benefits | 1 | 38 | 4 | 274 |
| **TOTALS:** | **95** | **6,301** | **209** | **11,623** |

* Some projects address a number of research needs (i.e. 181 distinct projects in 91/92).

** $U.S. (Approximate funding, adjusted for projects without funding information).



## Zebra Mussels

**Hot water has been shown to be an effective control treatment for zebra mussels in closed systems. Chlorine is most widely used as a control treatment in part because it is relatively inexpensive. Its continued use, however, is contrary to the IJC recommended policy of reducing chlorine discharges to the Great Lakes ecosystem. Research has shown potassium, bromine, ozone and ultra-violet light as possible alternatives to chlorine, and more than 30 other compounds are also being evaluated.**

**In the laboratory, researchers have been able to induce zebra mussels to spawn by providing an artificial stimulus. This promising technique might be used to control zebra mussel populations by causing them to spawn at the wrong time of the year.**

**Table 3.10**
**Nonindigenous Species Research in Lake Erie (including Lake St. Clair), 1991-92.** Numbers in bold are totals.

| SUBJECT | NO. OF PROJECTS* (1991-1992) | FUNDING ($1000)** (1991-1992) |
|---|---|---|
| **1. Nonindigenous species** | **67** | **3,410** |
| Spread/Distribution | 7 | 79 |
| Biology/Life History | 12 | 505 |
| Ecosystem Effects | 34 | 1,767 |
| Control Mitigation | 11 | 854 |
| Prevention of Introduction | 0 | 0 |
| Socioeconomic | 3 | 205 |
| **2. Other research *** ** | **47** | **5,156** |
| **TOTALS** | **115** | **8,566** |

* Some projects address more than one subject area (i.e. 96 distinct projects).

** U.S. Funds.

*** Other research implies other than nonindigenous species investigation.

Lake Erie is a dynamic ecosystem as the issue of eutrophication in the 1970s amply demonstrated. This sensitivity has drawn the Council to caution that the recent invasion of Lake Erie by nonindigenous zebra mussels is impacting the lake's ecological integrity. Table 3.10 lists projects that were carried out within Lake Erie and Lake St. Clair focusing on zebra mussels. Physical conditions favouring the zebra mussel, including optimal substrate, water depth and nutrient levels, make Lake Erie particularly susceptible to ecological impacts. Presently, zebra mussel research in Lakes Erie and St. Clair accounts for 67 projects and 3.4 million dollars, with projects on ecosystem effects accounting for approximately half of these amounts. The "ecosystem effects" studies concentrated on, in descending order of effort, effects on fish, food web dynamics, plankton, contaminant dynamics, unionid clams, waterfowl, zooplankton and water quality (clarity). Major funding sources included Ontario Ministry of Natural Resources, Ohio Sea Grant and the U.S. Environmental Protection Agency. A second prominent category of Lake Erie research was the control and mitigation of zebra mussels. For purposes of comparison, any project in the research inventory unrelated to nonindigenous species that contained "Lake Erie" in its title or objective was included under "other research." Projects in this area dealt with 25 categories and subcategories, indicating a wide range of research.

### 3.4.4 Wetlands

Wetlands provide natural water treatment and nutrient cycling, and much needed habitat for a host of species. A total of 33 research projects were found pertaining to either wetland marshes or deltas and accounting for approximately $2.0

**Table 3.11**
**Wetlands Research Related to Great Lakes Water Quality Agreement Annexes in 1991-1992.**

| ANNEX | RESEARCH OBJECTIVES | RESEARCH EFFORT No. of Projects | Funding ($1000**) |
|---|---|---|---|
| 2 RAP LaMP | Identification of environmental problems in Areas of Concern and use impairments such as bird or animal deformities or reproductive problems, and loss of wildlife habitats. Also includes an evaluation of current and future remedial measures. | 7 | 107 |
| 7 Dredging | Identification and remedial action to preserve those wetlands in the Great Lakes basin which are threatened by dredging and disposal activities. | 2 | 23 |
| 11 Surveillance Monitoring | Evaluation of water quality trends and baseline data collections for assessment of inputs and effects. | 2 | 23 |
| 12 Persistent Toxic Substances | Use of reproductive and physiological measures in wildlife and fish as health effect indicators; monitoring and research programs to identify temporal and spatial trends in the concentration of persistent toxic substances; rehabilitation of portions of the Great Lakes system adversely affected by persistent toxic substances. | 8 | 123 |
| 13 Pollution from non-point sources | Preservation of wetlands in the Great Lakes systems which are threatened by urban and agricultural development and waste disposal activities. | 3 | 31 |
| 14 Contaminated sediments | Areas affected by contaminated sediment caused by agricultural or industrial sources. | 1 | 7 |
| 15 Airborne Toxics | Areas affected by the deposition of Airborne Toxic Substances. | 1 | 28 |
| 16 Contaminated Groundwater | Areas affected by contaminated groundwater due to a confined waste disposal site. | 1 | 17 |
| 17 Research and Development | Evaluation of wetlands as a control technology for the retention of contaminants; determination of the input of non-indigenous species and the development of control options within wetlands. | 8 | 319 |
| **TOTAL** | | 33* | 678 |

* some projects address more than one Annex (i.e. only 19 distinct projects)

** Funding in $U.S., median funding assumed for projects without funding information.

million in funding. These projects were classified according to the Agreement annexes most related to the research. Of the 33 projects, 19 were directly applicable to particular annexes, with several applying to more than one annex (Table 3.11). The remaining 14 projects did not specifically relate to the Agreement, but applied to topics such as wetlands ecology, contaminant and nutrient dynamics, descriptive analysis of various aspects of the wetland areas (use of multispectral imagery, description of aquifers) and unspecified wetland research.

Of the total funding for wetland research, 65 percent was applied to projects not directly related to the objectives of the Agreement. Almost 50 percent of the funding related to annexes was directed to Annex 17 projects, and dominated by research involving nonindigenous species within wetlands, the feasibility of wetland construction and maintenance as a means of control of contaminated effluent, and waste disposal.

## 3.5 Annex 17 — Research and Development

The Council is responsible for the review and evaluation of research and development under Annex 17 of the Agreement, the purpose of which is:

**"This Annex delineates research needs to support the achievement of the goals of this Agreement"**
(Great Lakes Water Quality Agreement, Annex 17).

**Table 3.12**
**Research Addressing Topic Areas Listed in Annex 17 of the Great Lakes Water Quality Agreement**

* Research need requires clarification; critical sections are in italics.

** Some projects address a number of topic areas.

*** $ U.S. (Approximate funding, adjusted for projects without funding information)

| RESEARCH NEED * (Annex 17, Great Lakes Water Quality Agreement) | No. of Projects ** | Funding ($1000) *** | Research Inventory Categories and Project Numbers |
|---|---|---|---|
| (a) Mass transfer of pollutants between the Great Lakes Basin Ecosystem components of water, sediments, air, land, biota and the processes controlling the transfer of pollutants across the interfaces between these components | 220 | 22,764 | Most in category 1.03 (Levels Transport, and Fate - Toxic Subst.) Few projects from category 5.01 (Physical Environment) and Category 1.04 (Exposure) |
| (b) Load reduction models for pollutants in the Great Lakes System | 8 | 1,039 | #70, 133, 580, 791, 796, 954, 969, 990 |
| (c) Physical and transformational processes affecting the delivery of pollutants by tributaries to the Great Lakes | 7 | 781 | #4, 368, 573, 580, 767, 947, 969 |
| (d)* Cause-effect inter-relationships of *productivity* and ecotoxicology | 4 | 485 | #49, 183, 804, 920 |
| (e) The relationship of contaminated sediments on ecosystem health | 20 | 2,867 | Studies from Category 1.05 (Effects - Toxic Substances): #29, 34, 71, 74, 202, 224, 226, 250, 252, 260, 379, 382, 450, 586, 600, 741-744, 750 |
| (f)* Pollutant exchanges between the Areas of Concern and the open lakes including *cause-effect inter-relationships among nutrients, productivity, sediments,* and development of in-situ chemical, physical and biological remedial options | 36 | 4,902 | Pollutant exchange between AOCs and open waters: #8, 34, 40, 392, 397, 461, 573, 580, 865<br>Cause-effect inter-relationships: #49, 54, 260, 183, 804, 920<br>In-situ remediation: #34, 74, 115, 117, 118, 119, 120, 121, 122, 281, 370, 556, 568, 569, 735, 786, 799, 913, 916, 961, 998 |
| (g) The aquatic effects of varying lake levels in relation to pollution sources, particularly respecting the conservation of wetlands and the fate and effect of pollutants in the Great Lakes Basin Ecosystem | 0 | 0 | No applicable studies in inventory |
| (h)* *The ecotoxicity and toxicity effects of pollutants in the development of water quality objectives* | 5 | 372 | Studies aimed at developing water quality objectives: #343, 381, 641, 738, 801 |
| (i)* The impact of *water quality* and the introduction of non-native species on fish and wildlife populations and habitats in order to develop feasible options for their recovery, restoration or enhancement | 191 | 16,757 | Category 1.05 (Effects - Toxic Substances Cat. 2.03 (Effects - Eutrophication), Part of category 3.01, and 3.03 (Nonindigenous Species) |
| (j) Development of control strategies for treatment of municipal and industrial effluents, atmospheric emissions and the disposal of wastes, including wastes deposited in landfills | 64 | 6,663 | Category 1.06 (Remediation/Management) and applicable projects |
| (k) Develop action levels for contamination that incorporate multi-media exposures and the interactive effects of chemicals | 6 | 455 | Studies from category 1.05 (Effects of Toxic Substances) #255, 421, 752, 962, 968, 1018 |
| (l) Approaches to population-based studies to determine the long-term, low-level effects of toxic substances on human health | 16 | 2,535 | All human and mammal health-related studies of Toxic Substances Categories 1.04 (Exposure) and 1.05 (Effects) |
| **TOTALS** | **577** | **59,620** | |

The research inventory database was evaluated on the basis of the implementation of 12 objectives listed in Annex 17 (Table 3.12). The majority of research effort falls under: (a) mass transfer of pollutants and (i) the impact of water quality and the introduction of nonindigenous species. Other objectives with moderate activity by the Governments of Canada and the United States are in: (j) the development of control strategies for treatment of municipal and industrial effluents, atmospheric emissions and the disposal of wastes, (e) the relationship of contaminated sediments on ecosystem health, (f) pollutant exchanges between the Areas of Concern and the open lake, and (l) approaches to population based studies to determine chronic health effects in humans.

Few studies by the United States and Canadian governments were found that investigated six of the 12 objectives (Table 3.12). The total number of projects and funds identified relevant to Annex 17 in 1991-1992 makes up approximately 57 percent of the total inventory project listings (1,015 projects) and 56 percent of the total inventory funds ($107 million).

The integrative nature of the Annex 17 objectives requires, in most cases, a multidisciplinary approach. Evaluation of the objectives, such as (a) mass transfer of pollutants, (i) impact of water quality and (j) development of control strategies, shows that the Parties have dedicated substantial effort and funding to address them. The institutional collaboration and relevant research needed to achieve the ecosystem oriented objectives of Annex 17 will require implementing a framework for research coordination and prioritization. The Council of Great Lakes Research Managers is undertaking such an initiative for the Commission (see Chapter 5.0).

# 4.0 *Great Lakes-St. Lawrence River Strategy for Future Research Directions*

The Council of Great Lakes Research Managers research strategy describes the future research program needed to meet the overall vision of sustainable development as it is linked to the restoration and maintenance of the chemical, physical and biological integrity of the Great Lakes-St. Lawrence River basin ecosystem.

The strategies to achieve the vision will require decisive action through ecosystem science management and a concentrated effort to influence human action by involving stakeholders in deciding on targets and priority setting.

The two principle goals of the strategy are:

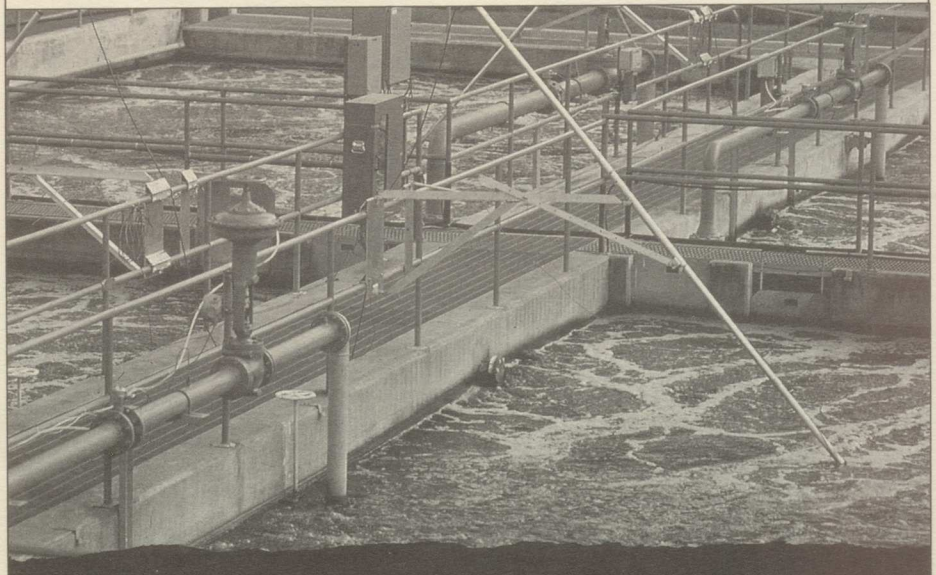
- Cleaning up past mistakes; and
- Preventing future ecosystem degradation.

To achieve these goals, the following broad objectives should be pursued:

- correcting past environmental mistakes particularly in the Areas of Concern, including remediation of contaminated sediments, groundwater, waste sites and confined disposal facilities, as well as restoration of natural habitats;
- preventing future ecosystem degradation, involving research to prevent and control pollution impacts, and to conserve human and ecosystem health; and
- influencing human action by encouraging ecologic and economic integration and informing stakeholders of research findings.

Cleaning up past mistakes is a multifaceted effort that includes the reclamation of Areas of Concern by restoring the beneficial uses listed in Annex 2 of the Great Lakes Water Quality Agreement, remediating contaminated substrates and groundwater, as well as restorating and protecting habitats and other ecologically significant environments. All remediation strategies to accomplish these goals must be considered as part of the relationship between humans and the natural environment. For the Council, this implies greater emphasis on interdisciplinary and transdisciplinary science, integration of natural and societal systems, holistic planning and adaptive or anticipatory management. What emerges from this approach is a multidisciplinary research strategy incorporating short and long term objectives, and directing relevant research towards the cleanup of past mistakes and prevention of future ones.

Preventing and controlling pollutant impacts requires research to develop scientifically sound policy options on the virtual elimination of toxic substances and regulations for point sources, drinking water, sewage effluents, waste disposal and spills. It also involves the quantification, control and prevention of nonpoint source pollution such as airborne toxics and nitrification, as well as a better understanding of the environmental consequences of human activities. Conserving human health and the health of the ecosystem's other species, incorporates research to protect and promote fish and



## Pulp and Paper Sector Effluent Treatment Research

**Research is underway to assess the performance capabilities of biological treatment processes such as aerated lagoons and activated sludge systems. Work is also being done to develop and demonstrate advanced anaerobic and aerobic biotechnologies for removing toxic compounds such as chlorinated organic chemicals found in bleached pulp mill effluents or the highly concentrated wood extractives found in chemi-thermomechanical pulping wastewaters.**

wildlife populations and human health, enhance protected areas and ensure sustainable land use, and prevent and mitigate climate change impacts, among other objectives.

Nonpoint source inputs of toxic substances and conventional pollutants is a serious problem that requires an expanded research emphasis. Nonpoint source research should focus on source elimination and the control of contaminated sediments, urban runoff and atmospheric deposition, particularly from outside the Great Lakes-St. Lawrence River basin, as well as the development of new technologies, product substitutions and alternative practices, including practices to reduce dependency on agricultural chemicals.

***We urge the Commission to recommend that the Parties encourage collaboration and interdisciplinary partnerships within the research community to investigate the impact, control and elimination of nonpoint source inputs affecting the integrity of the Great Lakes-St. Lawrence River ecosystem.***

***We urge the Commission to recommend that the Parties give continued emphasis to researching, developing and implementing pollution prevention initiatives, including point source and process optimization initiatives.***

Recovery and recycling technologies to contain by-products at the source are required immediately. In addition, pollution control systems must be optimized to ensure their operational integrity. Over the long term, new manufacturing techniques and processes will be required to insure pollutants are not generated in the first place.

Influencing the attitudes and behaviour of peoples can be achieved through effective communication and education. Socioeconomic levers, including pricing, taxation and instruments such as resource accounting can also be used to restore and maintain the integrity of the ecosystem, and to regulate commodity flows based on ecologically sustainable rates of supply rather than global market demand.

The Council recognizes the importance of addressing these goals and objectives through decisive action supported by ecosystem science management, particularly in the following four areas:

- Reducing and virtually eliminating persistent toxic substances;
- Restoring and protecting habitats vital to healthy and diverse communities of plants, fish and wildlife;
- Protecting human health, and restoring and maintaining stable, diverse and self-restoring populations of plants, fish and wildlife; and
- Promoting ecosystem integrity through effective communication and education.

## 4.1 Toxic Substances Research Strategy

The Council endorses the following objective relating to toxic substances:

***To restore the chemical integrity of the waters of the Great Lakes-St. Lawrence River basin ecosystem, we will reduce the level of toxic substances in the waters and surrounding habitat, with an emphasis on the virtual elimination of persistent toxic substances from the ecosystem, so that all organisms are adequately protected.***

Considerable progress has been made over the past 20 years to reduce concentrations and inputs of toxic substances in the Great Lakes-St. Lawrence River basin ecosystem. The most significant improvements have been realized through imposing restrictions on the manufacture and use of substances such as DDT and PCBs. Despite these improvements, concentrations of many toxic substances currently found in fish tissue, as well as other indicators of ecosystem health, remain at unacceptable levels.

A coordinated research strategy for toxic substances is required to meet short-term management goals and remediate past mistakes, as well as address the long term need to prevent future ecosystem degradation. Toxic substances include organic chemicals, metals, metalloids, radionuclides, nutrients and oxygen consuming substances. The following approach builds upon the existing risk assessment and risk reduction framework:

- Rank principal contaminant sources and map contaminated sites;
- Conduct problem diagnoses;
- Assess present and significant past risks to human health and ecosystems;
- Analyze costs and benefits of risk reduction;
- Develop in-situ and ex-situ technologies for source and site cleanup;
- Propose regulatory and remedial action scenarios, guidelines and regulations specific for chemicals and mixed effluents;
- Implement regulatory and remedial actions;
- Conduct options analysis and implement demonstration projects;
- Develop and run predictive cause-effect models of pollutants;
- Conduct cumulative impact assessments; and
- Conduct post-action environmental effects monitoring and audit previous model predictions.

Research is required to support the implementation of this strategy, including research on sources, transport, fate, exposure, effects and remediation of toxic substances pollution. Models must be developed that relate loadings of toxic substances to their concentrations and effects in air, water, sediment, ground water and the food chain, and include impacts on ecosystem components, including population, community and habitat. Inherent in the concept of an ecosystem approach is the treatment of humans as an integral part of the Great Lakes-St. Lawrence River basin ecosystem, as well as its major perturber.

## 4.2 Research Strategy for Protecting and Restoring Habitat

The Council endorses the following objective for protecting and restoring Great Lakes-St. Lawrence River basin habitats:

***To restore the ecological integrity of the Great Lakes-St. Lawrence River basin, we will protect and restore habitats, especially wetlands, vital for the support of healthy and diverse communities of plants, fish and wildlife, with an emphasis on those habitats needed by threatened and endangered species, and interjurisdictional fish and wildlife.***

This will be accomplished through the development and implementation of a binational habitat rehabilitation plan, including a binational Great Lakes wetland conservation action plan. The present effort by the Parties to develop a scientific basis for habitat management decisions is inadequate.

***We urge the Commission to recommend that the Parties provide the resources necessary to initiate research in support of the Council of Great Lakes Research Managers' habitat strategy and the implementation of a binational Great Lakes-St. Lawrence River basin wetlands conservation action plan.***

In the broadest sense, habitat includes the physical, chemical, biological and socioeconomic components of a species' environment. From the standpoint of ecological integrity, this broad definition includes the total life support system for an individual organism. From a resource management viewpoint, however, a narrower definition of habitat, focusing on physical substrates and the biological communities they support, is more operational. Specific research initiatives to support management goals can be applied to physical habitat, including rocky reefs used by spawning fishes, islands used by nesting birds, and wetlands supporting a variety of plants and animals. The narrower definition focusing on physical habitat integrity will be used here because other sections in this strategy address biological and chemical integrity.

### Organochlorines in Birds' Eggs from Great Lakes Wetlands

**Organochlorine (OC) levels in eggs of red-winged blackbirds and tree swallows varied among Great Lakes wetlands. PCB levels were highest in the Massena-Cornwall Area of Concern. DDE levels were highest at Four Mile Creek near the Niagara River and are thought to be due to intensive DDT spraying on orchards within the watershed from past stored supplies. Other monitoring sites included Severn Sound, Cootes Paradise, Long Point and Holland Marsh.**

**OC levels measured in tree swallow chicks and eggs varied considerably among sites and might be useful biomonitors for wetland contamination. Chick OC levels are likely indicative of local contamination.**

A generic strategy for conducting research on physical habitat at a selected site follows:

- Select habitats requiring attention using ranking criteria to identify sensitive habitats vital to the restoration or maintenance of ecosystem integrity;

- Establish a common binational habitat database for the Great Lakes-St. Lawrence River basin using geographic information systems to include ecosystem functions, values and existing stresses. One product would be the geographic extent of vital habitats;

- Develop and implement a uniform habitat classification and evaluation system, including indicators for the Great Lakes-St. Lawrence River basin;

- Define goals, based on scientific assessment of biological and socioeconomic values, for habitat protection and remediation (creation, enhancement, restoration and rehabilitation);

- Develop and field test wetland habitat rehabilitation and creation techniques suitable for the Great Lakes-St. Lawrence River basin, and assess their effectiveness, and environmental impacts and benefits;

- Define specific functional needs of Great Lakes-St. Lawrence River habitats, including undertaking long term research on the ecology of Great Lakes-St. Lawrence River coastal wetlands with respect to the influence of fluctuating lake levels;

- Select key shoreline habitats that should be secured and kept in, or converted to a natural state to minimize the economic impact of water level fluctuations; and

- Develop and implement an evaluation plan that includes the use of ecosystem indicators to assess whether habitat goals have been met, and use the results to modify strategies where necessary.

This generic strategy is designed to be applied to management goals and recognizes the necessity to combine technical, socioeconomic and policy perspectives.

Examples of possible sites for implementing this strategy are as follows:

**United States**
- The remaining coastal wetlands in Black Marsh in Maumee Bay, Ohio on Lake Erie;
- Pickerel Creek, Sandusky, Ohio on Lake Erie;
- Mentor Marsh, Mentor on the Lake, Ohio on Lake Erie.

**Canada**
- Oshawa's second marsh, Ontario on Lake Ontario;
- Hamilton Harbour, Ontario on Lake Ontario.
- Grand River mouth marshes, Ontario on Lake Erie.

## 4.3 Research Strategy to Protect Human Health and the Health of the Ecosystem's Other Species

Given the presence of persistent toxic chemicals and demonstrated adverse health effects, the Council endorses the following objective for protecting human health and restoring and preserving populations of other Great Lakes-St. Lawrence River basin species:

***To protect biological integrity, we will protect human health and restore and maintain stable, diverse and self-sustaining populations of fish, other aquatic life, wildlife and plants within the Great Lakes-St. Lawrence River basin ecosystem.***

The ecosystems of the Great Lakes-St. Lawrence River basin, which have suffered numerous environmental insults over the past two centuries, now support a substantially altered flora and fauna, and show signs of seriously compromised ecosystem integrity. For many federal, state and local agencies, the goal of restoring and preserving the original high-quality nature of the ecosystem is seldom explicit.

Affecting the health of the Great Lakes-St. Lawrence River basin ecosystem's species are a wide range of persistent toxic substances, including PCBs, DDT and its metabolites, dieldrin, toxaphene, mirex, methylmercury, benzo(a)-pyrene, hexachlorobenzene, furans, dioxins and alkylated lead. These persistent toxic substances bioaccumulate in the food chain, with species at the top of the chain being among the ultimate recipients. It is known from studies of many wild species that their health has been compromised by toxic substances and some populations have declined as a result. Additional research is required to understand the impact of these declines on the integrity of the Great Lakes-St. Lawrence River basin ecosystem and what they may portend for human health.

Research has also shown that developmental and reproductive effects can occur in a wide range of species including birds, reptiles, fish and mammals exposed to mixtures of contaminants in the Great Lakes basin. While differences exist in behavior and exposure patterns between humans and wildlife, research findings suggest that studies of human populations should focus on these subtle effects, rather than on gross, clinical end points, such as cancer. Certain populations -- Native Americans, sport anglers, the elderly, as well as fetuses and nursing infants of mothers who con-

# Effects of Pulp and Paper Mill Effluents on Fish

**Pulp mill discharges in Areas of Concern have long been a source of problems to receiving water in the Great Lakes. Notwithstanding the ultimate goal of "zero discharge," there are questions as to what should be regulated on a priority basis in pulp and paper effluent to protect the ecosystem. Research has shown that even after some effluents have had secondary treatment, evidence remains of biological effects in fish in the receiving area. Specifically, fish in the vicinity of pulp mill effluent can be found to have elevated mixed function oxidase (enzyme) induction, reductions in steroids and changes in gonad and liver size. Studies have shown some of these changes were evident in mills without chlorine bleaching. Research is ongoing to determine exactly what is causing the effects and what needs to be done to eliminate the problem.**

sume contaminated fish -- may have a potentially higher risk of long-term adverse effects resulting from exposure to these contaminants.

In order to meet the objective of protecting biological integrity, the primary strategy will be based on the model of prevention of adverse health effects in the ecosystem's species, including human populations. The prevention model consists of five interconnected elements: identifying patterns of adverse health effects, evaluating the causes of the identified adverse effects, controlling the causes, disseminating information about the effects, their causes and control, and developing infrastructure to support all the elements of prevention. These five elements are made up of the following steps:

**Identification**

- Define the problem: What populations are at greatest risk? Are endangered species being affected?
- Conduct assessments of human health exposure to and impacts of airborne and waterborne chemicals, including food chain accumulations;
- Identify data needed to develp an analytical model for management scenarios, and monitoring and surveillance programs;
- Identify patterns of morbidity and mortality;
- Assemble relevant and necessary data through registries and tissue banks; and
- Collect new data if necessary.

**Evaluation**

- Formulate an analytical model to characterize exposure;
- Develop and implement an evaluation plan to monitor and assess whether the health of humans and the ecosystem has been protected;
- Build a conceptual model that identifies variables important for human health or species integrity;
- Identify end points and biomarkers;
- Evaluate causal factors that account for the observed pattern of morbidity or mortality; and
- Formulate an analytical model that characterizes exposure.

**Control**

- Control causal factors that account for the observed pattern of morbidity or mortality.

**Dissemination**

- Disseminate information about controlling the observed pattern of morbidity/mortality.

**Development of infrastructure**

- Implement management actions associated with urbanization/development, and
- Establish infrastructure to support the identification, evaluation, control and dissemination elements of disease prevention.

The ecosystem approach, coupled with the strategy of prevention of adverse health effects, dictates that all important variables must be considered as essential for a complete

understanding of the healthy survival of any species in the Great Lakes-St. Lawrence River basin. While this approach does not differ substantially from concepts invoked in the past, it emphasizes incorporating a much broader suite of variables. The physical and chemical environment thus is equally important to species integrity as species-to-species interactions.

In order to obtain maximum protection of the integrity of human health and the ecosystem's species, it is vital to understand the complete suite of variables that may be critical for any species or group of species. A modeling framework is advocated that would include conceptual models as well as analytical models. The purpose of conceptual models is to reveal those variables that are important for species integrity, which in turn will reveal the nature of the database required to move from a conceptual modeling approach to an analytical modeling approach. The latter type of model can serve as the tool for developing management scenarios and enable the prevention of adverse effects in species at health risk.

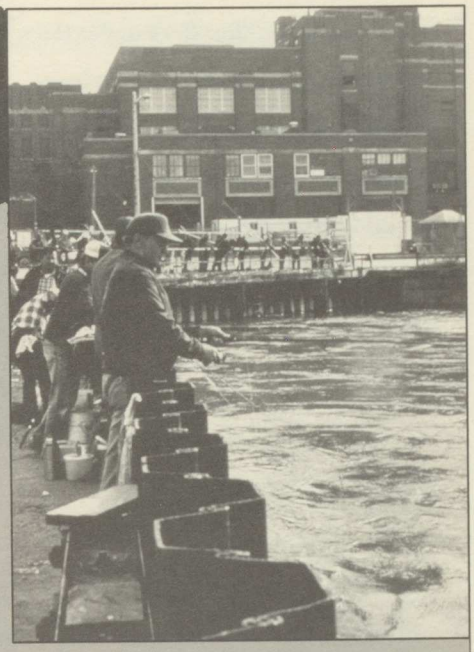
Subtending the overall ecological goal of preventing adverse health effects in the Great Lakes-St. Lawrence River basin ecosystem are four subgoals specific to maintaining species integrity: achieve desired population levels and diversity of aquatic flora and fauna; reduce exposure of organisms and humans to harmful pollutants and disease vectors; prevent the introduction of new, and lessen the impact of existing undesirable nonindigenous species; and improve the status of endangered and threatened species to the point where they can be "delisted" from these categories.

## Effects of Pulp and Paper Effluents on Herring Gulls

**Related studies on herring gulls have shown similar results to the fish studies. Research on the reproductive performance of herring gulls exposed to pulp and paper effluent is currently being undertaken. All 38 nests of herring gulls monitored on three islands in Jackfish Bay, Lake Superior during May and June of 1991 failed to fledge any young. The herring gull pairs at a control site produced approximately one young per nest. Levels of dioxins and furans in eggs from Jackfish Bay were relatively low; levels of other organochlorines were not significantly different from other Great Lakes herring gull colonies. Bioassays of egg extracts revealed no significant levels of any EROD-inducing and porphyrinogenic compounds. But, of the 99 nests monitored in 1992, no young were fledged. All hatched young died prior to day four. With the eggs from Jackfish Bay that were artificially incubated in the lab, there was no significant difference in hatching between the Jackfish Bay eggs and controls. Analytical results are forthcoming and the investigation of cause and effect relationships continues.**

***We urge the Commission to recommend that the Parties implement the goal of protecting the biological integrity of the ecosystem by furthering research to elaborate the nature and extent of adverse health effects of toxic substances in the Great Lakes-St. Lawrence River basin ecosystem on sensitive wildlife, fish and human populations. The results of this research can be used as the basis for intervention strategies to protect human health and the health of the ecosystem's other species.***

## Impact on Human Health of Fish Consumption in the Great Lakes



**A two year research program has been initiated in the United States to identify human populations residing in the Great Lakes basin who may be at risk due to contact with chemical contaminants in one or more of the Great Lakes and to prevent any adverse health effects. In support of this goal, a strategy built upon the five traditional elements of disease prevention: Identification, Evaluation, Control, Dissemination and Infrastructure has been implemented.**

**The objectives of this program are to: (1) build upon and amplify the results from past and ongoing research, (2) develop information, databases and research methodologies that will provide long term benefit to the Great Lakes human health research effort, (3) develop directions and methodology for future research on human health effects, (4) provide health information to the subjects of the research and their medical professionals, and (5) increase public awareness of the health implications of the toxic pollution problems in the Great Lakes.**

**The focus of the research is on populations identified as having a higher risk of long-term adverse health effects from exposure to contaminants in Great Lakes fish including Native Americans, sport anglers, urban poor, and fetuses and nursing infants of mothers who consume contaminated Great Lakes fish. Collectively, these studies will extend our knowledge of the effects of Great Lakes contaminants on human reproductive/developmental, behavioural, neurological, endocrinological and immunological health effects.**

# 4.4 Research Strategy for Socioeconomic Activity and Ecosystem Integrity

The Council endorses the following objective for socioeconomic activity and ecosystem integrity:

***To protect the integrity of the Great Lakes-St. Lawrence River ecosystem, we will support linking the understanding of environmental quality and economic activity.***

Protecting the integrity of the Great Lakes-St. Lawrence River basin ecosystem involves a change in attitude and behaviour of the peoples inhabiting the basin. The Council, in its report to the Commission, has repeatedly noted the importance of establishing the linkages between the quality of the environment and economic activity.

To initiate the development of these linkages, the Council sees the following activities as necessary steps towards the formulation of a strategy integrating economic activity and ecosystem health:

**Policy**

- Establish a dialogue between the research community and the public to assess research needs and priorities;
- Bring science and research findings into the public education system at all levels; and
- Evaluate institutional policy focusing on issues to accelerate management of human action affecting ecosystem integrity.

**Education**

- Develop a mechanism for recruiting and training graduate students in the area of ecosystem management.

**Information**

- Encourage the development of useful issue-specific ecological/economic indicators and models (i.e., wetland area losses and housing developments, or the amount of paved land and natural productivity);
- Develop a framework and process for natural resource accounting which is adaptable to needs at various geographic scales;
- Assess current data collection systems and modify them to provide relevant information to decision-makers regarding sustainable developments; and
- Determine a framework and process for sustainable development linked to the maintenance and restoration of the biological, chemical and physical integrity of the Great Lakes-St. Lawrence River ecosystem.

***We recommend that the Parties develop linkages between environmental management, ecosystem health and economic development as an important step towards attaining the goal of sustainable development.***

## 4.5 Research Strategy Linkages

Research resulting from the four strategic elements outlined in this chapter needs to be linked to provide informed guidance for the management and protection of ecosystem integrity. This can be accomplished through the development of conceptual and analytical models. The purpose of the conceptual model is to reveal those variables that are important for species integrity, which in turn will assist in identifying the nature of the database required for the analytical models. The framework described in chapter five is one approach to developing conceptual models.

### Education/Socioeconomic

**An important aspect of the Council's mandate is to assist in the preparation of the next generation of scientists working on the Great Lakes. One approach is already underway in a summer practicum for college teachers. It consists of a three week undergraduate faculty training program that demonstrates environmental problem solving techniques using the Great Lakes as a laboratory. Participants learn state of the art environmental analysis techniques, modeling and problem solving procedures. They are expected to integrate what they have learned into their courses and curricula at their home institution generating increased interest in the Great Lakes which will awaken in students the excitement of doing research in the Great Lakes in the future. In an earlier practicum, 16 out of 18 participants had developed new, or revised existing teacher materials based on their summer experience.**

### Education/Socioeconomic

**A concern of the Council is the integration of economic and environmental activities in such a way as to insure minimal economic impact but maximal environmental benefit. The legislative mandate for virtual elimination of persistent toxic substances has the potential to impose substantial costs to Great Lakes-St. Lawrence River basin industries, while generating environmental benefits. Exactly how virtual elimination is achieved -- what kinds of regulatory and/or incentive-based instruments are used and how they are applied -- will have major influence on the competitive position of industries, communities and ultimately, the Great Lakes-St. Lawrence River region. Research is underway to: (1) complete a conceptual analysis of the efficiency and cost incidence properties of alternative policy and regulatory instruments, particularly economic incentives; (2) complete an empirical case study of the benefits, costs, and economic impacts of incentive-based policy instruments to control selected persistent toxic substances in a selected industry; and (3) communicate research findings in the ongoing policy process in the Great Lakes via established agencies and interagency organizations.**

# 5.0 *Development of a Framework for Determining Research Priorities*

## 5.1 Ecosystem Framework and Process for Decisionmaking and Research Coordination

This chapter provides a perspective on how the Council of Great Lakes Research Managers is attempting to implement a framework and process for establishing research priorities.

Research managers must evaluate existing information to better understand the Great Lakes-St. Lawrence River basin ecosystem, to integrate scientific information with economic information and to establish better mechanisms for getting that information to decisionmakers in an understandable format. A systematic approach is needed to using interdisciplinary knowledge as the basis for International Joint Commission recommendations to the Parties to the Great Lakes Water Quality Agreement, the Governments of the United States and Canada. Crucial information gaps, where they exist, need to be identified for the Commission to establish research priorities to achieve an ecosystem approach in managing Great Lakes-St. Lawrence River basin environmental quality.

The cumulative results of human activities continue to have profound and often adverse impacts on the Great Lakes-St. Lawrence River basin ecosystem. It is increasingly important for all decisionmakers to view the basin as an ecosystem where all human and ecological activity is connected. These connections form a complex web of interactions that make problems difficult to bound and manage. For the research manager who is supplying decision support, this requires that greater emphasis be placed on planning and conducting ecosystemic and anticipatory interdisciplinary science. The methods of such inquiry include policy exercises, modeling and other interactive methods.

The Council of Great Lakes Research Managers organized two workshops and a roundtable discussion (International Joint Commission 1991 and 1992) to further the establishment of a framework for coordinating future natural and social science research in the Great Lakes-St. Lawrence River basin. What emerged were recommendations addressing the need to develop linkages among major areas of research, that is among the economic, social and ecological components of the Great Lakes-St. Lawrence River basin ecosystem. These sessions identified a framework or process for addressing critical issues as the major need, rather than a single large model. By coordinating research efforts on selected resource or societal questions, the process of delivering scientifically sound policy options to the Commission, and in turn to the Parties, can be significantly improved.

While an ecosystem perspective requires a diverse and often substantial information base, there are new methods of inquiry germane to furthering an ecosystem approach. The Great Lakes research managers recognize the need for bringing new and traditional methods of inquiry together in a comprehensive method for systematic assessment of research alternatives.

## 5.2 The Framework Exercise

One approach to address the needs described above, and provide a mechanism for developing and assessing research priorities within an ecosystem context, is referred to as a "framework exercise." The framework exercise is a management support system that integrates information tools (i.e., models, geographic information systems, databases, etc.), into a process for decisionmaking and research coordination.

The objective of the "framework exercise" is to establish a framework and process that can be used to coordinate research and develop research priorities based on an ecosystem approach. It involves developing a schematic representation of how a question will be examined that integrates various perspectives and explicitly designates the substantive areas that the exercise will address. This framework is then broken down into components, and a subset is identified for representation in the exercise. Scoping of the issue is undertaken and the most appropriate process for proceeding under the framework is selected and represented (e.g., flowchart).

The framework exercise is essentially a scenario development procedure that focuses on possible policies and courses of action, and identifies the research necessary to develop and assess the alternatives. In the exercise stakeholders, decisionmakers and experts are brought together to explore alternatives for setting research priorities. The core of the procedure is a workshop where participants develop gamed scenarios and "future histories" as a means of

exploration and synthesis. Such scenarios integrate different technical and institutional perspectives on alternative courses of action.

Through this process of scenario development and interpretation, the participants learn about possible trends, events and impacts of policies over time. They also learn about the linkages between institutional, natural, and technical systems as they relate to the questions at hand. The exercise helps participants clarify shared goals, areas of special interest, possible conflicts and the value of selected courses of action in light of these interests. Finally, the participants discover deficiencies in their collective knowledge and areas where further investigation could improve policy.

The objectives of the priority setting exercise are realized in its products. In addition to focused information sharing and integrative model building, several concrete products emerge from the exercise: the gamed scenarios and future histories, the strategy assessment and the division of responsibilities, based on the framework and process, among the institutions in the Great Lakes-St. Lawrence River basin research community. In addition, two reports will be produced; one identifies priorities for select research topics and another documents the utility of the framework exercise in addressing a complex topic.

To illustrate the framework exercise proposed by the Council, a specific topic will be selected that can serve as an example for future topics. We propose to study the Lake Erie ecosystem as a case study. Other possible topics that could be considered for this exercise are:

- human health;
- contaminated sediments;
- climate change;
- water levels;
- wetlands;
- virtual elimination;
- groundwater contamination;
- nonindigenous species; and
- air quality.

## 5.3 Lake Erie Ecosystem — A Case Study

At its 19th meeting in Atlanta, Georgia, the Council proposed the selection of aquatic nonindigenous species and the attendant ecosystem interactions as a case study for applying the framework exercise at the Great Lakes-St. Lawrence River basin scale. The Lake Erie ecosystem is considered a subset of this initiative.

Immense changes have occurred in the Lake Erie ecosystem as a result of the invasion of zebra mussels. First observed in the mid-1980s in Lake St. Clair, zebra mussels are no longer just a Great Lakes problem. Carried mainly by the normal flow of water and boat traffic, zebra mussels have already colonized the Hudson, Ohio, Illinois, Tennessee, Susquehanna, Mississippi and Arkansas Rivers. Zebra mussels now inhabit 12 states and the Province of Ontario.

While the zebra mussel invasion and its immense impact on the Great Lakes ecosystem has focused attention on the issue, the introduction of nonindigenous (exotic) species is not a new problem. An estimated 130 nonindigenous species have been introduced to the Great Lakes, most of them arriving since the St. Lawrence Seaway opened in 1959. Several of these species -- including the sea lamprey, alewife, smelt, carp and milfoil -- have contributed to massive changes in Great Lakes fish and plant communities.

The overwhelming colonization of Lake Erie by zebra mussels has altered the pathways of nutrient and energy flow. Effects are particularly evident in the shallow western basin (average depth 7.5 metres) because of an abundant supply of food and suitable substrate. First observed in the lake in 1988, the mussels reached densities of 30,000/metre$^2$ in 1989, 70,000 metre$^2$ in 1990 and over 700,000/metre$^2$ in 1992 at water intakes in the western basin. At these densities, the mussels filter a volume of water 26 times as large as that in the western basin each day. This massive turnover of the water mass and the plankton has the potential to seriously disrupt energy flow from the plankton to small fish. Dramatic impacts on the ecosystem have been observed, including an 80 percent decrease in diatoms in the western basin, drastic decline in chlorophyll concentrations to 1 microgram/litre or less and a 400-600 percent increase in transparency. Microzooplankton are disappearing such as rotifers (90 percent decrease) and copepod nauplii (60 percent decrease) due to the combined effects of reduced food supply and direct mortality. Cladocerans and other larger crustaceans have also declined drastically.

Food chain effects have been demonstrated in fish. Young-of-the-year yellow perch showed a decline in growth rates over the four year period from 1988 to 1992. Although walleye stocks appeared to be unaffected through 1991, yellow perch declined and the reasons are not well understood. Zebra mussels do not appear to be affecting adult fish stocks at present, but there is likely to be a delayed response to the drastic changes in energy flow as zebra mussels reroute energy from the pelagic zone to the benthos.

The effects are most severe in the western basin of Lake Erie where mussel densities are highest. Lower densities in the central and eastern basin combined with a greater volume of water have lessened the impact. The shift in dominance of another invading nonindigenous species, the *quagga* mussel over the zebra mussel from west to east may have equally devastating effects in the deeper parts of the lake. The larger *quagga* mussels are found in deeper water than the zebra mussels and do not require hard substrate.

As a result, they can survive throughout much of the deeper eastern basin on the soft bottom.

The Lake Erie ecosystem is complex and has been influenced by other rapidly changing factors over the last decade in addition to zebra mussels and phosphorous controls. There has been increased demand on the forage fish base due to the resurgence of the top predator walleye, and other stocks such as yellow perch, white perch and smelt have undergone significant fluctuations in recent years.

Research has shown that zebra mussels are beginning to alter contaminant cycling in the Great Lakes. Their prodigious filtration capacity and high lipid content allow them to accumulate contaminants at approximately ten times the level of native clams. They pass this contaminant burden on to fish when eaten and on to small shrimp-like organisms called gammarids, which eat zebra mussel feces, pseudofeces and dead zebra mussels. These gammarids are also eaten by many fish and their populations have increased greatly since the invasion of zebra mussels.

Lake Erie is the largest freshwater fishery in the world and this unique and valuable resource is presently in jeopardy due to changes in the ecosystem caused by zebra mussels. Lake St. Clair, which due to its smaller size may presage changes in Lake Erie, is in danger of losing its walleye fishery. In Ohio alone, the Lake Erie walleye fishery has an economic value in excess of $500 million per year and supports a marina industry with annual gross receipts in excess of $500 million. In addition, the Lake Erie commercial fishery is valued at $90 million per year. Consequently, it is easy to see that damage to this fishery will have very significant binational impacts.

***We urge the International Joint Commission to recommend on an emergency basis that the Parties bring the appropriate groups together to formulate a reference, pursuant to Article VII of the Great Lakes Water Quality Agreement, on the impact of aquatic nonindigenous nuisance species in the Great Lakes-St. Lawrence River basin, initially examining the impact of zebra mussels on the Lake Erie ecosystem. (In response to such a Reference the International Joint Commission would preferably work with the Great Lakes Fishery Commission and its collaborators).***

It may be desirable for the studies and subsequent report to the Governments resulting from a "Lake Erie Ecosystem Reference" to be jointly undertaken by the International Joint Commission and Great Lakes Fishery Commission. Consideration should be given to cooperation by the two Commissions, as an initial activity, on a review of Lake Erie Research is being undertaken by the Lake Erie Committee of the Great Lakes Fishery Commission.

The focus of the reference would be to identify ecological changes and their impacts attributed to the invasions of nonindigenous species. Changes at the population and community levels would be documented and used in predicting future impacts. Attention would be directed toward understanding shifts in energy and contaminant transfer as entire functioning segments of the ecosystems are replaced.

There is an immediate need to proceed with the development of strategies to cope with the expected dramatic ecosystem changes. It is suggested that such a reference proceed in three phases with the first focusing on the impact of the zebra mussel on the Lake Erie ecosystem and the subsequent economic impacts.

If the appropriate agencies were given immediate direction to proceed, it would be possible to prepare an impact report and coping strategies by December, 1994. This first phase could be complemented by a study on Saginaw Bay where ecological data have also been collected before and during the invasion by the zebra mussel. These data could provide additional valuable insight into the diversion of energy from the pelagic system to the benthic system.

Involvement by the fisheries agencies could be facilitated by the Great Lakes Fishery Commission and its collaborators, and involvement by the many agencies collecting data on the lower trophic levels through the International Joint Commission.

The efforts in the first phase focusing on Lake Erie and Saginaw Bay would provide the scientific basis for a second phase emphasizing ecosystems in the other lakes and rivers where zebra mussels are currently expanding their numbers and range.

A third phase could focus on other nonindigenous species, such as the small fish called the ruffe. The ruffe was first observed in 1986 in the St. Louis River harbor on Lake Superior at Duluth, Minnesota. Research between 1988 and 1991 showed the population of ruffe to increase from about 100,000 to more than two million. During this three-year period, the forage fish population decreased two- to three-fold, and yellow perch and walleye populations also declined dramatically. This fish is well established in the St. Louis River and is spreading to other rivers in Wisconsin that empty into Lake Superior. If the ruffe were to expand to

the lakes where yellow perch is the main fishery, the results could be disastrous.

The recommended reference should:

- Document the impacts on the Great Lakes-St. Lawrence River basin ecosystem of invading nonindigenous species and the changes resulting from the invasions;

- Document the changes in the major fisheries of the Great Lakes resulting from the changes in energy flow; and

- Develop strategies to cope with the changes.

# 6.0 Recommendations

1. *The Council of Great Lakes Research Managers recommends that the Great Lakes-St. Lawrence River basin research community place greater emphasis on a holistic approach to defining future research priorities for the Great Lakes-St. Lawrence River basin by implementing binational integrated multidisciplinary studies, as defined in the overall Council strategy for the protection of ecosystem integrity.* page 1

2. *We recommend that the Commission recognize the importance of developments in communication and decision-making by continuing and expanding its support for the Council of Great Lakes Research Managers' efforts to develop an ecosystem-based decision support framework.* page 2

3. *We recommend that the research community develop communication and educational tools for describing and displaying ecosystem information in cooperation with end users, including resource managers, political leaders, citizen groups, and leaders of business and industry.* page 2

4. *We recommend that the research inventory be maintained and updated periodically.* page 3

5. *We urge the Commission to recommend that the Parties give continued emphasis to researching, developing and implementing pollution prevention initiatives, including point source and process optimization initiatives.* page 3 & 30

6. *We recommend that the Commission continue to fully utilize good science in its policy evaluation and urge the Commission to recommend that the Parties sustain long-term research programs to ensure scientific efforts remain strong.* page 3

7. *We recommend that the research community provide support to general science education in order to encourage the recruitment, training and development of a new generation of scientists, and to increase science literacy and promote an ethic of conservation and pollution prevention within the general public.* page 4

8. *We recommend that the Commission provide support to the Council of Great Lakes Research Managers to evaluate the requirements for recruiting, training and developing a new generation of scientists.* page 4

9. *We urge the Commission to recommend that the Parties encourage collaboration and interdisciplinary partnerships within the research community to investigate the impact, control and elimination of nonpoint source inputs affecting the integrity of the Great Lakes-St. Lawrence River ecosystem.* page 30

10. *We urge the Commission to recommend that the Parties provide the resources necessary to initiate research in support of the Council of Great Lakes Research Managers' habitat strategy and the implementation of a binational Great Lakes-St. Lawrence River basin wetlands conservation action plan.* page 31

11. *We urge the Commission to recommend that the Parties implement the goal of protecting the biological integrity of the ecosystem by furthering research to elaborate the nature and extent of adverse health effects of toxic substances in the Great Lakes-St. Lawrence River basin ecosystem on sensitive wildlife, fish and human populations. The results of this research can be used as the basis for intervention strategies to protect human health and the health of the ecosystem's other species.* page 34

12. *We recommend that the Parties develop linkages between environmental management, ecosystem health and economic development as an important step towards attaining the goal of sustainable development.* page 36

13. *We urge the International Joint Commission to recommend on an emergency basis that the Parties bring the appropriate groups together to formulate a reference, pursuant to Article VII of the Great Lakes Water Quality Agreement, on the impact of aquatic nonindigenous nuisance species in the Great Lakes-St. Lawrence River basin, initially examining the impact of zebra mussels on the Lake Erie ecosystem. (In response to such a Reference the International Joint Commission would preferably work with the Great Lakes Fishery Commission and its collaborators).* page 39

and $No_x$ than other forms of energy. Combustion of coal releases arsenic (900 - 1500 grams/tonne) and various other substances into the atmosphere (Cikrt 1990). Few coal burning power plants have pollution control equipment, and for those that do, the equipment is inefficient and prone to failure (French 1990).

In the eight Great Lakes states, the most significant energy sources in order of importance are petroleum, coal and natural gas. In Ontario, petroleum, natural gas and nuclear power are widely utilized (Colborn et al 1991). In Canada as a whole, coal ranks third, ahead of both nuclear and hydroelectric power, in terms of energy market share (Indicators Task Force 1991). A substantial proportion of total emissions of conventional air pollutants for Canada and the United States is generated in the Great Lakes region. In 1985, sources in the eight Great Lakes states accounted for 41 percent of all $SO_2$ and 28 percent of all $NO_x$ emissions in the United States (Colborn et al 1990). Sources in Ontario were responsible for 38 percent of $SO_2$, 28 percent of $NO_x$, 20 percent of particulates, 29 percent of CO and 30 percent of hydrocarbons emissions in Canada (Colborn et al 1990). Ground level ozone, volatile organic compounds, metals such as cadmium and arsenic, and various toxic emissions such as benzene and toluene are serious concerns.

Automobile emissions are a substantial concern in Eastern Europe and the CIS. Many East European cars are older models with two stroke engines that burn an oil and gas mixture. The combustion of this mixture releases more hydrocarbons, particulates and aldehydes than Western cars (Walsh 1990). The continued use of poor quality leaded gasoline is a concern, particularly in urban areas. In Budapest, Hungary, atmospheric lead levels were measured at thirty times the standard (French 1990). Although leaded gasoline has been phased out in the Great Lakes, many other substances including: hydrocarbons; alkanes, alkenes and aromatics such as benzene, toluene and xylene are released from gasoline (Wixtrom et al 1992).

On a local scale, toxic emissions from various industries may be harmful to human health, particularly around foundries, power stations and chemical plants. Some of these atmospheric contaminants present at potentially harmful levels include carbon monoxide (CO), ammonia ($NH_3$) fluorine (F), chlorine (Cl), volatile hydrocarbons, phenol, hydrogen sulphide ($H_2S$), arsenic (As), lead (Pb), formaldehyde, ozone ($O_3$) and polyaromatic hydrocarbons (PAHs) such as benzo(a)pyrene [B(a)P] (Russell 1990; French 1990; Sroczy ski et al 1986). Most of these substances are generated through various industrial processes and fuel combustion (Russell 1990).

**Water**

Water contamination is extensive throughout Eastern Europe. An estimated 60 percent of primary water supplies in Hungary are contaminated; in Romania 85 percent of the water from main rivers is not potable; and one-third of the rivers and 9000 lakes in Eastern Germany are "biologically dead" (Russell 1990; French 1990). Both surface and groundwater are significant sources of human exposure to contaminants. A great deal of this pollution can be traced to a completely inadequate waste water treatment system. Industrial and municipal wastes are often released into open waterways either completely untreated or with minimal treatment. Leaking waste sites, agricultural nutrient and pesticide runoff into surface waters, and percolation and leaching into groundwater creates further contamination. Atmospheric deposition and acid precipitation result in acidification of surface waters. Some of the most serious contaminants identified include nitrates, arsenic, mercury, and in the CIS, bacterial pollution, radioactive materials and oil products.

There is little information about the status of groundwater in the Great Lakes. However, toxic contamination of groundwater from hazardous waste sites and transport of toxic waste through groundwater into surface water is a concern (Colborn et al 1990). Surface water quality issues include nutrient loadings and toxic contaminants particularly those on the critical pollutants list; polychlorinated biphenyls (PCBs), mirex, hexachlorobenzene (HCB), dieldrin, DDT, dioxin, 2,3,7,8,-TCDF, toxaphene, B(a)P, mercury and alkylated lead (TCGLAE 1991).

**Food**

Deposition of atmospheric pollutants, improper waste disposal, and acid and toxic rain has resulted in contamination of soil and damage to vegetation and animal life. Soil contamination is a very serious concern because contaminants can accumulate in vegetation and livestock. Consumption of these foods is considered to be a significant source of exposure to some toxic substances (TCGLAE 1991). In Poland, an estimated 20 percent of all food products are considered too contaminated for human consumption (Kramer 1985). In Gdansk Bay, which opens into the Baltic Sea, high levels of mercury have been found in herring, cod and flatfish (Pudlis 1982). In CSFR and Poland, there is evidence of substantial contamination of the food supply, particularly crops, with cadmium, lead, mercury, nitrate and nitrites (Krelowska-Kulas 1991; Smigiel et al 1987; Marzec and Bulinski 1990; Bilczuk et al 1991). In one study, 68 percent of vegetables grown near a glassworks (lead and fluorine emissions) contained lead levels that exceeded the Polish standard (Zommer-Urba ska et al 1991). Chlorinated hydrophobic organics have

been detected in livestock such as beef, poultry and pork (Moldan and Schnoor 1992).

PCBs have been detected in various foods in this region at levels that may pose a threat to human health: canned cod livers in Poland (Falandysz et al 1992), vegetables in Yugoslavia (Jan and Adami 1991) and Baltic sea fish such as salmon and herring (Svensson et al 1991). Baltic Sea fish may also be an important source of exposure to PCFDs, PCDDs and polychlorinated napthalenes (Svensson et al 1991). In the CSFR, food contamination from toxic organics such as B(A)P, PCBs and HCB; and heavy metals, including cadmium, lead, mercury and arsenic have been reported (Moldan and Schnoor 1992). However, the levels of exposure and health impacts are not clear. In the Great Lakes, health advisories have been placed on some fish species due to accumulation of these substances in the fatty tissues of fish (TCGLAE 1991).

### Cause-Effect Linkages

The majority of information that is available on environmental degradation and health in Eastern Europe is anecdotal. Therefore, appropriate studies must be undertaken. The emphasis on health related environmental research in Eastern Europe has primarily focused on air pollutants (particularly $SO_2$, $NO_x$ and TSP) and to a lesser extent, heavy metals (particularly lead and cadmium). By comparison, Great Lakes research has begun to explore the ramifications of long term, low level exposure to toxics, particularly those on the critical pollutants list. Some of our greatest concerns are for the subtle and intergenerational impacts of toxins, and while these are concerns for Eastern European scientists as well, only the obvious health problems have received attention.

It is extremely difficult, even under the best of conditions, to demonstrate a link between a particular contaminant and a specific health problem. Particularly in Eastern Europe, socioeconomic factors complicate study further. Most of the countries of Eastern Europe have higher smoking rates, greater alcohol consumption and higher levels of fat in their diets than people living around the Great Lakes basin (Hertzman 1991). A lack of funds and the neglect of environmental health studies make it very difficult to show the effects that extreme pollution has had on the health of the people of this region, but there is no doubt that the health of East Europeans is substantially poorer than that of people living in the Great Lakes basin. In all Eastern European countries, with the exception of East Germany, life expectancy decreased from the mid 1970s to the mid 1980s. However, smoking is a significant confounder (Börzsönyi 1990; Cikrt 1990; Rudnai 1991), therefore, making it difficult to determine the extent to which the health of Eastern Europeans is affected by environmental pollution or lifestyle factors.

Regional incidence rates for particular diseases are useful as an indicator (CGLRM 1991); however, in Eastern Europe rates are usually only available for broad geographic areas. These broad figures do not give an accurate picture of the situation in highly contaminated areas incidence rates for a particular disease may be very high, but not reflected in overall figures. A few regional and subregional studies have been completed that indicated a relationship between certain disorders and environmental exposures. However, a reliable overall picture of the health impact of pollution in Eastern Europe and the CIS is not available.

### Toxic Substances

There are indications of health effects from exposure to the following substances:

#### Nitrates/Nitrites

In Slovakia, CSFR, 2255 cases of methaemoglobinaemia from nitrate contamination of the water supply were reported from 1971 to 1985 (Hertzman 1991). Methaemoglobinaemia occurs when nitrates are reduced to nitrites. Nitrites change haemoglobin in blood to methaemoglobin that cannot provide oxygen to the tissues. Other health effects that may be related to long term exposure, including gastric cancer, birth defects, cardiovascular diseases and effects to the thyroid gland, are being studied. There may be additional health impacts related to the synergistic effects of high levels of nitrates and pesticides (Ben s et al 1989). Exposure to nitrates from fertilizers has been associated with premature birth and "psychological disorders" in the CIS (Friendly and Feshbach 1992). The Canadian standard for nitrates is 10 mg/L (Gillham 1990), and while rising nitrite/nitrate levels in the Great Lakes are a concern, the values range from approximately 100 - 375 µg/L, and are not considered a threat to human health (Colborn et al 1990). There is some indication that nitrate levels in groundwater may exceed standards in the Great Lakes region, particularly in areas of intensive agriculture. Samples taken in the Hillman Creek watershed, on the shores of Lake Erie, and the Alliston aquifer, north of Toronto indicate levels of nitrates ranging up to ten times the Canadian standard. However, no comprehensive analyses of groundwater have been completed. Nitrate levels have been measured in the intensively farmed Elbe river basin, CSFR, at 20 - 150 mg/L in streams and 1 - 300 mg//L in groundwater (Moldan and Schnoor 1992).

#### Heavy Metals

Arsenic contamination is a serious problem, particularly in Hungary. An estimated 400,000 Hungarians are exposed to arsenic in drinking

water. Some studies of the health effects this exposure have been carried out (Börzsönyi et al 1992). Among the possible effects observed were statistically significant increases in spontaneous abortions and stillbirths. About 270,000 people are exposed to arsenic in concentrations that are two times the allowable level of 0.05 mg/I (Hertzman 1991), with highest levels greater than 0.1 mg/I (Csanady et al 1985). Among those exposed to higher levels, there is evidence of arsenic melanosis, arsenic keratosis, intestinal colic, increased heart disease mortality, spontaneous abortions and stillbirths (Hertzman 1991). By comparison, in Ontario in 1986, residual levels of arsenic in water were measured up to 0.003 µg/L (TCGLAE 1991).

Exposure to lead via soil, water, air and food is fairly well documented. Airborne lead concentrations in Eastern Europe can range from 0.5 - 2.6 µg/M$^3$ in hot spots. Concentrations of lead in soil in contaminated areas typically range from 200 - 500 ppm, but in some areas, these values can be much higher. In Northern Bohemia, intake of lead from food sources amounted to 0.46 mg per day for a 60 kg person (Moldan 1990). Various other studies document significant lead intake from foods (Kucharksi et al 1989; Zommer-Urbadamicanska et al 1991; Zalewski et al, 1989; Chorazy et al, 1987). In Canadian hot spots, airborne lead can range from 0.4 - 1.0 µg/m$^3$. Lead in soil near South Riverdale, Ontario (Located near a secondary smelter) has been measured at 641 ppm. The equivalent Canadian dietary intake for lead would be 0.066 - 0.126 mg per day (TCGLAE 1991). In Eastern European children, common lead concentration levels in blood, for those living in hotspots range from 15 µg/dL - 40 µg/dL (Hertzman 1991). However, one study of lead in children living in Northern Bohemia, CSFR, showed levels in the blood of 300 - 450 µg/dL. This is three times the concentration determined to be neurotoxic by American standards (Moldan and Schnoor 1992). That compares with levels in Vancouver, where there are almost no point sources of lead, that average 5.3 g/dL in two to three year old children (Hertzman 1991). Lead, even at low levels, can cause a number of health problems, particularly in children. These include kidney damage, interference with blood cell formation, damage to the central nervous system, intellectual impairment and even death (Nadakavukaren 1990). A study of children in Katowice, Poland determined that there was a 13 point difference in the IQ of those children with the highest and lowest levels of lead in their blood. In addition, two-thirds of the children were anaemic, one-third suffered from chronic digestive tract problems, more than three-quarters had changes in electroencephalograms and almost all had chromosomal abnormalities (Hertzman 1991). Another study of children from Miasteczko Slaskie, Poland found that a fifth had levels of cadmium and lead in their blood above 35 g/dL. From this study a "significant correlation" between blood lead concentration and intellectual development was noted (Norska-Borowka 1990; Hertzman 1991).

Exposure to cadmium has been documented from a variety of sources (Moldan 1990; Waters 1990). The dietary intake for a 60 kg person in Northern Bohemia, CSFR would amount to 0.56 mg per day, while the Canadian intake level is 0.042 - 0.066 mg per day. A study in Prague found high levels of cadmium in breast milk (Waters 1990). Cadmium exposure can cause kidney damage, emphysema and arteriosclerosis in adults (Nadakavukaren 1990) however, there is little indication of the effect of chronic exposure to this substance. Higher incidence rates for congenital defects, haematological and dermatological diseases among children under 4 were related to exposure to lead, cadmium, and zinc in the atmosphere (Norska-Borowka 1990). A study with perhaps more significant implications, linked long term exposure to microtoxic levels of lead and cadmium to chromosomal aberrations and "affected" spermatogenesis in men. Cadmium interfered with fetal development and increased risk of spontaneous abortion; however, no details of the methodology of this study were given (Norska-Borowka 1990.)

The Polish Academy of Sciences released a report in 1985 that relates an "appalling increase" in mentally handicapped children in Upper Silesia to high levels of metals, particularly lead (Collit 1984; Rich 1985). Soil samples taken from gardens in the region had concentrations of lead, zinc, cadmium and mercury 30-70 percent higher than WHO standards for soil in which food is grown (Pudlis 1982). Mercury contamination of drinking water is a problem in some areas. In Krasnik Lubelski, water in local wells contains mercury in concentrations six to 26 times the standard of 1 mg/L (Pudlis 1982). This standard is high compared to the Great Lakes Water Quality Agreement (GLWQA) objective for mercury of 0.2 g/L (TCGLAE 1991). People in this region have high rates of mental illness and cancer which may be connected to this exposure (Pudlis 1982).

**PCBs**

In the CSFR, one quarter of women were found to have PCB levels in their breast milk above the acceptable limit of 2500 ng/g of milk fat (Hruba et al 1988) with levels as high as 3 mg/kg (Moldan and Schnoor 1992). In Canada in 1982, PCBs averaged 697 ng/g of milk fat (TCGLAE 1991). Initial studies in the Great Lakes have linked PCBs with developmental problems in children (TCGLAE 1991), however, knowledge of the health effects of such exposure is very limited.

**DDT/Dioxin**

Dioxin contamination of food and soil has been noted (Friendly and Feshbach 1992). Close to a third of soil samples taken in Azerbaijan in 1989 contained high levels of dioxin and one quarter of vegetation samples had "traces" of dioxin (Friendly and Feshbach 1992). DDT residues have been detected on 24.7 million acres of agricultural land in the CIS at levels above the acceptable maximum of 0.1 mg/kg of soil. In Azerbaijan, Armenia, Moldova and Uzbekistan, CIS, the values ranged from 2 - 8 times the acceptable limit (Wolfson 1990). Despite the fact that DDT was officially banned by the Public Ministry of Health, it was used extensively in various regions of the CIS, including Kazakhstan and Turkmenia, up until at least 1988 (Friendly and Feshbach 1992; Wolfson, 1990). In Kemerovo, Siberia, during the 1980s residents were exposed to aerial spraying of DDT. In 1987, fish in local surface waters had DDT levels which ranged from 0.09 - 4.24 percent by weight (Friendly and Feshbach 1992). "Significant increases" in incidence rates for cardiovascular disease, diabetes, tumours and allergies were observed in the exposed population (Friendly and Feshbach 1992). A comparison of disease incidence on two farms where workers were exposed to DDT between 1970 and 1988 found that among children under 6, skin diseases and "nutritional and metabolic" illnesses were more prevalent than on the "less" polluted farm (Friendly and Feshbach 1992).

**Sulphur Dioxide, Oxides of Nitrogen, TSP**

The clearest connection has been demonstrated between exposure to air pollutants such as $SO_2$, $NO_x$ and TSP and effects on the respiratory and cardiovascular system. In Eastern Europe, average ambient levels of $SO_2$ and TSP range from 0.4 - 636 g/m³, respectively. Short term exposures in areas such as Katowice, Poland and Northern Bohemia, CSFR, can be much higher than these levels. These types of exposures have been linked to high incidence rates for chronic bronchitis, asthma, acute respiratory disease, eczema, allergies and conjunctivitis (Hertzman 1991; Cikrt 1990; Liroff 1990; Rudnai 1990; Adveenko et al 1990; Martinovic et al 1990; Torbus and Kalacinski 1989; Wojtyniak and Wysocki 1989; Kucerova et al 1990; Rudnai 1990). In Leuna, East Germany, $SO_2$ values average 300 to 400 g/m³, however, they can be as high as three to four times that level. Nearly two thirds of the population suffers from respiratory ailments, and there are high rates of chronic bronchitis and conjunctivitis in children (Charles 1990; Liroff 1990). Using spirometry, respiratory development was measured in a group of children from Dimitrovgrad, Bulgaria, exposed to high dust levels, sulphur dioxide, hydrogen sulphide, lead and hydrogen fluoride. By age 14, the difference in lung capacity between the exposed group and the control group was 800 mL, which is considered a large difference (Hertzman 1991). Acting multiplicatively with smoking and occupational exposure, exposure to air pollution increases the risk for lung cancer (Zemilianaya et al 1990; Jedrychowski et al 1990). In Canada, typical exposures to $S0_2$ and TSP range from 0.2 - 45 g/m³ and 17.0 - 100 g/m³ respectively.

**PAHs**

B(a)P is one of the few PAHs for which there are documented exposure levels in Eastern Europe. In the Ural River basin, near Chelyabinsk in the CIS, exposure to PAHs was correlated with the rate of esophageal cancer (Belyakova et al 1988). An Ames mutagenicity assay or urine samples from children in Upper Silesia, Poland, found increased proportions of mutagenic samples for those exposed to very high levels of B(a)P (100-228 ng/m³). Increased mortality rates in urban areas from cardiovascular, digestive tract disease and cancer mortality were correlated with high levels of B(a)P in food, industrial effluents and the atmosphere (Hertzman 1991). Atmospheric B(a)P levels in the Great Lakes Region have been recorded at 0.61 ng/m³ in Windsor (1987-1988) and 0.3 ng/m³ in Toronto (1984-1986) (Hilborn and Still 1990). In Canada, the highest levels (9-15 ng/m³) are found near point sources such as coke ovens and aluminum smelters (Hilborn and Still 1990).

**Health Effects**

Increases in the incidence rates for some illnesses such as tuberculosis, pneumoconiosis, bronchitis and developmental problems among children have been associated with a generally contaminated environment in regions such as Northern Bohemia, CSFR and Upper Silesia, Poland (Rostowski 1984). A comparison of the development of children from Dimitrovgrad, Bulgaria was undertaken. This comparison found that just 18 percent of the children from Dimitrovgrad fell into the "developing normally category" versus 72 percent in the control group (Hertzman 1991). In Northern Bohemia, CSFR, there is evidence of the following health impacts; delayed bone maturation in close to a third of the children (Hertzman 1991); rates of congenital anomalies double the expected rate, that began to rise concurrently with air pollution in the 1970s (Hertzman 1991); altered resistance in children exposed to air pollutants including $NO_x$, trimethylamines, phenylchlorisilanes and traces of cyanide (Wagner et al 1990); higher incidence rates for infant mortality, low birth weight, chronic kidney/urinary tract diseases, non-specific lung and airways diseases, allergies, mental illness, skin diseases and endocrine disorders among children (Hertzman 1991). An increased rate of structural chromosome aberra-

tions in the residents of Semic, Yugoslavia may be related to inappropriate handling of industrial chemicals in the area (Tretjak et al 1990). In Upper Silesia, incidence of circulatory illness, cancer and respiratory illness is higher than in the rest of Poland (Kabala 1985). Rates of complications during pregnancy are as high as 45 percent in this region (Sobelman 1989).

Some illnesses have been linked to particular industries. The extensive chemical industry in Ventspils, Latvia has been associated with extremely high rates of sterility (50 percent) and birth defects (40 percent) (Świft 1990). In Ontario, between 1980-1989, the incidence rate for all anomalies was just over five percent (Johnson 1992). In Razlog, Bulgaria, a significant increase in morbidity for asthma and conjunctivitis followed the opening of a pulp and paper mill. The release of chlorine gas from a chemical plant has been associated with skin, eye and lung disorders that affect an estimated 70 percent of area children (Graff 1992). Aluminum smelters have been connected to elevated incidence rates for rickets in children and bladder cancer (Hertzman 1991; Friendly and Feshbach, 1992). People exposed to high levels of hydrogen chloride emissions died from cardiovascular disease 7.5 years earlier (Friendly and Feshbach 1992). In the CIS, intensive pesticide use in agricultural regions have been related to gastric and intestinal infectious disease, "disturbances" in fetal development, hepatitis, gall bladder and pancreas disorders, mental retardation, "blood diseases," anaemia, tuberculosis and acute respiratory tract infections (Khublarian 1989; Friendly and Feshbach, 1992). Incidence rates for waterborne disease such as diarrhea, paratyphoid, viral hepatitis and dysentery were higher in areas of the CIS with contaminated groundwater (Khublarian 1989).

**Mortality**

The countries of Eastern Europe and the CIS have a lower life expectancy than Western countries such as Canada and the Unites States. One theory for this gap in life expectancy between East and West is that exposure to a contaminated environment via soil, water, air and food is partially responsible for morbidity from asthma, lead poisoning, respiratory diseases, some cancers, congenital anomalies and cardiovascular diseases. Additionally, the psychological sense of well being is undermined by living in contaminated conditions thus making people less responsive or concerned about lifestyle modifications that may improve long term health (Hertzman 1991; Bōrsōnyi 1990). However, quality of health care, diet and socioeconomic factors must also be taken into consideration as significant factors (Eberstadt 1989; Hertzman 1991).

On a regional level, Katowice, Lodz and Walbrzysk in Poland and Northern Bohemia in CSFR all have higher rates of adult female and male mortality which may be related to high levels of air pollution. A comparison of the causes of adult mortality in mining and non-mining districts in Northern Bohemia found that cancer mortality made the difference between regions. Incidence rates for lung, colon and stomach cancer were higher in the contaminated districts (Hertzman 1991).

Infant mortality rates are significantly higher in Eastern Europe, particularly in highly polluted regions such as Northern Bohemia, CSFR. One study examined infant mortality in relation to social factors, $SO_2$, TSP and $NO_x$ in the Czech republic. The findings suggested that as much as 15 percent of infant mortality and half of post-neonatal respiratory mortality could be related to air pollution levels (Bobak 1991).

**Conclusions**

The consequences of environmental neglect in Eastern Europe are important for a variety of reasons. Not only because of the information about the health impacts of exposure to certain substances that can be derived from the experiences of this region, but also on a direct basis; Canada receives pollution from Eastern Europe in the form of fallout and we import a variety of food products from this region.

The Great Lakes and Eastern Europe share some common environmental concerns. These include; heavy metal contamination (particularly lead, mercury and arsenic) as a result of common economic activities; $SO_2$, $NO_x$, and TSP; PAHs particularly B(a)P; and PCBs. There is evidence of DDT and dioxin contamination in the CIS, but little information on the health impacts of this exposure. Another similarity exists with respect to the interjurisdictional nature of pollution in Eastern Europe and in the Great Lakes basin. In Eastern Europe, air pollution emissions from the CSFR are a problem in Hungary, water pollution from the CIS flows into Poland and toxic waste generated in West Germany is shipped to East Germany. The experience in the Great Lakes in dealing with transboundary pollution, particularly on a political and legislative level, could be very valuable. With respect to international institutional arrangements to deal with this situation, the IJC and the GLWQA could serve as models for a similar framework in Eastern Europe.

In many respects, Eastern Europe today parallels the Great Lakes region twenty years ago. Health studies initiated in Eastern Europe thus far, have examined the effects of conventional air pollutants and to a lesser extent, heavy metals. Although exposure levels are generally higher in Eastern Europe, the information regarding the health effects of these substances may be useful. A

substantial portion of the health impact data simply relates incidence rates to generally high levels of exposure to a variety of substances. Little hard cause-effect data are available. There is little indication of long term, low level impacts of any pollutant. Furthermore, few comprehensive data on exposures to many of the substances important in the Great Lakes region (i.e. those on the critical pollutants list), have been compiled for the countries of Eastern Europe.

A comprehensive picture does not yet exist of either the health status, or exposure levels for those living in Eastern Europe and the CIS. In the Great Lakes basin, environmental concerns have been addressed for the last twenty years. Point sources of pollution, the problems associated with nutrient loadings and untreated sewage, acid rain and control of air pollution through the use of scrubbers are just some of the issues that have been dealt with in this region. The focus has turned towards the difficult job of managing nonpoint source pollution and long term, persistent toxic contamination.

On a more positive note, interest in the health impacts of environmental deterioration in Eastern Europe and the CIS has grown. Several exchanges and conferences between academics, scientists and various experts in the East and West have taken place. WHO's European office has taken a leading role by initiating various health studies through the Teplice project. A group of Czech scientists will be working with the U.S. EPA, European Community, WHO and the IARC, among others, to study air pollution and health in the following areas:

1. Biomarkers of exposure and cancer risk study
2. Reproductive effects study
3. Respiratory effects study
4. Neurobehavioral effects study
5. Assessment of exposure to air pollution study

Within a few years, more substantial and relevant information should be available.

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# *Appendix II*

## *Council of Great Lakes Research Managers Terms of Reference*

**SECTION 1**

The Council of Great Lakes Research Managers (referred to herein as "Council") functions under the authority of the International Joint Commission (referred to herein as "Commission" and established under the Boundary Waters Treaty of 1909) to assist the Commission in discharging its responsibilities under the Great Lakes Water Quality Agreement of 1978 (referred to herein as "GLWQA").

**SECTION 2**

The general objective of the Council is to enhance the ability of the Commission to provide effective leadership, guidance, support and evaluation of Great Lakes research programs with particular reference to programs required or funded pursuant to the provisions of GLWQA.

**SECTION 3**

*In pursuing the general objective in Section 2, the Council may:*

(a) promote interjurisdictional and interdisciplinary planning and co-ordination of research related to the implementation of GLWQA;

(b) encourage preparation and dissemination of syntheses of research findings to government and non-government bodies concerned with the Great Lakes management and bring policy implications of the aforementioned findings to the attention of the recipients;

(c) compile and summarize current and planned research programs related to the implementation of the GLWQA;

(d) identify research needs and establish priorities; and

(e) keep under review the impact of research recommendations made by itself, the Great Lakes Science Advisory Board (referred to herein as the "SAB"), the Great Lakes Water Quality Board (referred to herein as the "WQB") and the Commission.

**SECTION 4**

*The members of the Council:*

(a) will be composed of persons responsible for research programs related to the implementation of the GLWQA and, in addition, two members of the SAB to be designated by that body;

(b) may be nominated by the Council and others for consideration by the Council Co-chairs, who will then submit nominations to the Commission for consideration and appointment by the Commission;

(c) will serve at the pleasure of the Commission, but will usually be appointed to three-year terms, staggered so as to provide continuity;

(d) shall, as will members of the Council working groups, serve in a personal and professional capacity and not as representatives of their employers or organizations; and

(e) may be selected to chair working groups of the Council.

**SECTION 5**

*The Council:*

(a) may make rules for the convening of meetings which shall be held at least once every six months;

(b) shall provide for attendance at meetings of any observers requesting to attend and who represent federal, provincial, state or international authorities and agencies as well as industrial, educational or other non-governmental bodies; members of the SAB, the WQB and other Commission institutions, as appropriate;

(d) shall participate in the Commission's biennial priorities setting process and shall submit for Commission approval its work plans and budgetary proposals, including proposals for public involvement where appropriate;

(e) shall participate as appropriate in task forces and other institutions established by the Commission; and

(f) may, with the approval of the Commission, establish or modify such working groups (made up of Council members and others) it deems necessary to discharge its responsibilities effectively.

**SECTION 6**

*The Council Co-chairs:*

(a) will be appointed by the Commission and shall serve at the pleasure of the Commission;

(b) shall be joint Chairpersons of the Council and shall assume an active role in maintaining liaison between the Council and the Commission and between the Council, the SAB and the WQB, the International Air Quality Advisory Board and other Commission institutions; and

(c) shall serve on the SAB Executive Committee.

**SECTION 7**

*The Council shall report to the Commission:*

(a) at least annually on all its activities; and

(b) periodically, with respect to specific functions set forth in Section 3, on its own initiative or if requested by the Commission.

**SECTION 8**

The Secretariat of the Council will be maintained at the Commission's Great Lakes Regional Office and all pertinent records and supporting documents shall be maintained at that office.

**SECTION 9**

These Terms of Reference will come into force upon approval by the Commission.

Approved by the Commission,
April 9, 1991

# *Appendix III*

# *Council of Great Lakes Research Managers Membership*

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# *Appendix IV*

## *The Following IJC Publications Resulted from Council Initiatives from 1985-1993*

*PCBs: A Case Study. Proceedings of a Workshop on Great Lakes Research Coordination held November 20-22, 1985.* Council of Great Lakes Research Managers. Windsor, Ontario. February 1988.

*Remedial Action Plan Research Needs.* Report to the Great Lakes Science Advisory Board by C.B. Gray and D. Rathke. Windsor, Ontario. October 1988.

*Proceedings of the Workshop on Cause-Effect Linkages held March 1989.* Council of Great Lakes Research Managers. Windsor, Ontario. March 1989.

*Great Lakes 2000: Building a Vision. Summary Report of the Workshop of the Council of Great Lakes Research Managers on Futures.* Windsor, Ontario. July 1991.

*Great Lakes 2000: Building a Vision. Proceedings of the Workshop on the Council of Great Lakes Research Managers on Futures September 20-22, 1989.* Windsor, Ontario. July 1991.

*A Proposed Framework for Developing Indicators of Ecosystem Health for the Great Lakes Region.* Council of Great Lakes Research Managers. Windsor, Ontario. July, 1991

*Report on an Ecosystem Framework Roundtable held July 28-31, 1991.* Council of Great Lakes Research Managers. Windsor, Ontario. (in draft)

*Great Lakes-St. Lawrence Research Inventory 1990-1991.* Compiled by the Council of Great Lakes Research Managers. Windsor, Ontario. April 1992.

*Development of a Great Lakes-St. Lawrence Ecosystem Model Framework.* December 4-6, 1990. Council of Great Lakes Research Managers. Windsor, Ontario. April 1992.

*Great Lakes-St. Lawrence Research Inventory 1991-1992.* Council of Great Lakes Research Managers. Windsor, Ontario. August 1993. (in editing)

*Health Effects in Eastern Europe.* Council of Great Lakes Research Managers. June, 1993. (in draft)

# *Appendix V*

## *Classification Codes Used in the Research Inventories*

**1.0 Toxic Substances**

1.01 Polluting Substance

- 1.01.01 Identification
- 1.01.02 Physico-chemical Properties
- 1.01.03 Sampling/Analytical Methods

1.02 Sources/Loadings

- 1.02.01 Not Specified
- 1.02.02 Industrial
- 1.02.03 Chemical Use
- 1.02.04 Chemical Transport
- 1.02.05 Sewage Treatment Plants
- 1.02.06 Incineration
- 1.02.07 Urban
- 1.02.08 Agricultural
- 1.02.09 Landfill
- 1.02.10 Confined Disposal Facility
- 1.02.11 Atmosphere

1.03 Levels, Transport, and Fate

- 1.03.01 Atmosphere
- 1.03.02 Surface Water (Water/Sediment)
- 1.03.03 Soil/Groundwater
- 1.03.04 Modeling

1.04 Exposure

- 1.04.01 Pathways and Routes
- 1.04.02 Concentrations in Organisms
  - 1.04.02.01 Taxon Not Specified
  - 1.04.02.02 Bacteria
  - 1.04.02.03 Phytoplankton
  - 1.04.02.04 Macrophytes
  - 1.04.02.05 Zooplankton
  - 1.04.02.06 Benthos
  - 1.04.02.07 Fish
  - 1.04.02.08 Amphibians/Reptiles
  - 1.04.02.09 Birds
  - 1.04.02.10 Mammals
  - 1.04.02.11 Humans
  - 1.04.02.12 Specimen Banking
- 1.04.03 Toxicokinetics
- 1.04.04 Indicators of Contamination
- 1.04.05 Socio-Economic Research
- 1.04.06 Legal Research

1.05 Effects

- 1.05.01 General (Unspecified)
- 1.05.02 Ecosystem Level Effects
- 1.05.03 Community Level Effects
- 1.05.04 Population/Individual Level Effects
  - 1.05.04.01 Taxon Not Specified
  - 1.05.04.02 Bacteria
  - 1.05.04.03 Phytoplankton
  - 1.05.04.04 Macrophytes
  - 1.05.04.05 Zooplankton
  - 1.05.04.06 Benthos
  - 1.05.04.07 Fish
  - 1.05.04.08 Amphibians/Reptiles
  - 1.05.04.09 Birds
  - 1.05.04.10 Mammals
  - 1.05.04.11 Humans
- 1.05.05 Cellular/Molecular Toxicology
- 1.05.06 Effects Modeling/Prediction
- 1.05.07 Indicators
- 1.05.08 Hazard/Risk Assessment
- 1.05.09 Socio-Economic Research
- 1.05.10 Legal Research

1.06 Remediation/Management

- 1.06.01 Treatment/Remedial Methods
  - 1.06.01.01 General (Not Specified)
  - 1.06.01.02 Biological
- 1.06.02 Contaminated Sediment
  - 1.06.02.01 General (Not Specified)
  - 1.06.02.02 Capping
  - 1.06.02.03 Solidification
  - 1.06.02.04 Chemical Treatment
  - 1.06.02.05 Photodegradation
  - 1.06.02.06 Biological Treatment
  - 1.06.02.07 Removal and Treatment
- 1.06.03 Industrial Waste/Wastewater
- 1.06.04 Groundwater/Soil
- 1.06.05 Sewage
- 1.06.06 Stormwater
- 1.06.07 Agricultural Runoff
- 1.06.08 Landfill/Confined Disposal Facility
- 1.06.09 Spills
- 1.06.10 Wetlands/Habitat
- 1.06.11 Effectiveness Evaluation
- 1.06.12 Prevention
- 1.06.13 Socio-Economic Research
- 1.06.14 Legal Research

**2.0 Eutrophication**

2.01 Sources
2.02 Levels, Transport, and Fate

2.02.01 Atmosphere
2.02.02 Surface Water (Water/Sediment)
2.02.03 Soil/Groundwater

2.03 Effects
2.04 Remediation/Management

2.04.01 Treatment/Remedial Methods
2.04.02 Prevention
2.04.03 Effectiveness Evaluation

2.05 Socioeconomic Research
2.06 Legal Research

**3.0 Nonindigenous Species**

3.01 Spread/Distribution
3.02 Biology/Life History
3.03 Ecosystem Effects

3.04 Control and Mitigation
3.05 Prevention of Introduction
3.06 Socioeconomic Research

**4.0 Climate Change**

4.01 Basic Research
4.02 Forcing Functions
4.03 Effects of Physical Environment
4.04 Effects on Biological Communities
4.05 Socio-Economic Implications
4.06 Strategies to Reduce Impacts

**5.0 Ecosystem Components and Processes**

5.01 Physical Environment (Components/Processes)
5.02 Organism (Taxonomy/Distribution/Life History/Ecology)

5.02.01 Taxon Not Specified
5.02.02 Bacteria
5.02.03 Phytoplankton
5.02.04 Macrophytes
5.02.05 Zooplankton
5.02.06 Benthos
5.02.07 Fish
5.02.08 Amphibians/Reptiles
5.02.09 Birds
5.02.10 Mammals
5.02.11 Humans

5.03 Habitat (Mapping/Classification/Evaluation)
5.04 Ecological Processes/Ecosystem Functioning
5.05 Ecosystem Integrity
5.06 Socioeconomic Research

**6.0 Other Impacts and Issues**

6.01 Water Level Fluctuations
6.02 Pathogens/Bacterial Pollution
6.03 Erosion/Sedimentation
6.04 Agricultural Practices
6.05 Forestry Impacts
6.06 Thermal Inputs
6.07 Brine Inputs
6.08 Radionuclides
6.09 Land Use Impacts
6.10 Other

**7.0 Education**

**8.0 Logistical Support**