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State of the Great Lakes Basin Ecosystem Task Force

Peter J. Seidl

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**STATE OF THE GREAT LAKES BASIN ECOSYSTEM TASK FORCE
REPORT TO THE
INTERNATIONAL JOINT COMMISSION**

**TOWARD A STATE OF THE
GREAT LAKES BASIN ECOSYSTEM REPORT**

EDITED BY

PETER J. SEIDL

INTERNATIONAL JOINT COMMISSION

**WINDSOR, ONTARIO
SEPTEMBER 1993**

ACKNOWLEDGEMENTS

I wish to thank the Task Force members, Dr. Tim Allen, Dr. Jon Stanley, Mr. Tony Friend, Mr. Mike McMullen, and Mr. Ron Shimizu for their devotion to complete this document, Ms. Mary Ann Morin who processed the text and Mr. Bruce Jamieson for the final production.

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1.0 INTRODUCTION

1.1 BACKGROUND

In the past, the International Joint Commission through its Water Quality Board, reported on the state of the Great Lakes by summarizing the most recent surveillance and monitoring data submitted by the Parties and jurisdictions. These reports, known as "State of the Lakes", were updated on a biennial basis. Their primary value is to indicate trends as to whether the concentration of a substance is going up or down in specific media over a series of years. They are also used to determine if the specific objectives of the Great Lakes Water Quality Agreement are being met. This type of reporting provides basic information as to whether the actions of the Parties and jurisdictions are sufficient to achieve and maintain the general and specific objectives of the Agreement and, therefore, is used as basis for program evaluation.

Over the past decade, the Commission through its primary advisory bodies, the Science Advisory and Water Quality Boards and the Council of Great Lakes Research Managers, has become aware of the need to explain the ecological significance of these surveillance and monitoring results by taking an ecosystem approach to reporting on the status of the Great Lakes environment.

As knowledge of environmental degradation has increased, scientists, the public, governments, and other sectors of society have become more concerned about the SIGNIFICANCE of growing levels of pollutants in the biosphere. This is particularly true in the Great Lakes Basin Ecosystem where the public has been informed more systematically than anywhere else on this planet about the levels of contaminants being found in various parts of their ecological home, including within their own bodies.

Clearly, emphasis was being placed on producing reports which more directly answered questions like: "What does finding x concentration of a substance in the flesh of fish mean to the health of the fish, to other animals including humans who might eat them, and what does it tell us of the environment we share with the fish?" Obviously, these questions reflect a desire for MEANING beyond information as to whether a specific numerical objective for a specific substance in lake water is being met.

In its written instructions of June 1990, the Commission acknowledged the work being undertaken within the existing "State of the Lakes" reporting and directed its advisory bodies to determine how to provide greater ecological meaning to the surveillance and monitoring data being submitted and what additional information might be required. Within this directive, the Commission requested advice on the development of ecosystem health indicators to enable more interpretive reports on the significance of pollution to the ecosystem.

1.2 ESTABLISHMENT OF THE TASK FORCE ON THE STATE OF THE GREAT LAKES BASIN ECOSYSTEM REPORT

To respond to this request, a tripartite task force of representatives of the Water Quality and Science Advisory Boards and the Council of Great Lakes Research Managers

with the essential assistance of the Commission's Regional Office staff, was established in the fall of 1990 and organized its work around three tasks;

1. to produce a more integrated report emphasizing the interpretation of various monitoring, surveillance and research results with respect to toxic substances reported to the Commission through its "State of the Lakes" reporting program.
2. to develop a coherent perspective and framework for Great Lakes Basin Ecosystem Reporting as a model for future reports.
3. to identify ecosystem health indicators and the kinds of data required to report them.

1.3 TAKING ACCOUNT OF RELATED ACTIVITIES

The task force felt that it was unnecessary to provide a detailed interpretation of the effects of toxic substances because this task has been met by the publication of a comprehensive report, "Toxic Chemicals in the Great Lakes and Associated Effects" (Government of Canada 1991). This report was the result of a three-year intensive scientific review of all pertinent Canadian and United States data regarding the levels and effects of toxic substances detected in water, sediment, fish and wildlife in the Great Lakes basin. The review includes examination of data up to 1989/90 and was conducted by a panel of scientists from the departments of Environment, Fisheries and Oceans, and Health and Welfare.

Also in relation to Task #1, the task force examined the proceedings of roundtables conducted by the Biological Effects Committee of the Science Advisory Board on the effects of toxic chemicals on various biota. This information is briefly summarized in the task force's report and fully reported by the Science Advisory Board (1991).

With regard to the development of a coherent perspective and framework for Great Lakes Basin Ecosystem reporting, the task force has the benefit of the deliberations of the Science Advisory Board and its committees as reported. In its 1991 report (Chapter 2), of particular importance to the work of this task force are the Science Advisory Board's contribution in defining a comprehensive ecosystems approach; in providing its view of State of the Great Lakes Basin Ecosystem reporting; and the need for a comprehensive framework for integrating ecological values in socio-economic decision-making (International Joint Commission 1991). The task force also benefitted from the work of the Council of Great Lakes Research Managers over the past several years which is also summarized in Chapter 12 of the 1991 Science Advisory Board report. Indeed the task force has drawn much from this work and has summarized it in this report.

The task force has included a biennial update of the traditional "State of the Lakes" report based on the most recently available results submitted by the Parties and jurisdictions in accordance with Annex 11 of Canada-U.S. Great Lakes Water Quality Agreement. This update is compiled by the staff of the Commission's Great Lakes Regional Office with the assistance of the Surveillance Subcommittee of the Water

Quality Board and regularly appeared as a State of the Lakes chapter in the Water Quality Board Report up to 1991. The Board, however, has reorganized its operations and structure in 1991 and has requested that this task force include this update in its report.

1.4 FOCUS

In light of the developments mentioned above, this report of the task force reflects a transition toward an ecosystem perspective and framework for Great Lakes Basin Ecosystem Reporting linked to the development of the Ecosystem Health Indicators. To better reflect this new direction the report is entitled "Toward a State of the Great Lakes Basin Ecosystem Report". While this change in direction will broaden the Commission's reporting base, it has still a long route ahead before these reports can be treated as comprehensive state of the Great Lakes Basin Ecosystem reports.

1.5 STRUCTURE OF THE REPORT

- **Overall Theme**
The task force decided, as the principal theme of this report, to focus on the impact that humans are making on the ecosystem, and in turn, the impact that a stressed ecosystem is having on human uses of the Ecosystem.
- **Perspective**
An overview of the accumulated impact of human settlement in the basin since European contact provides a historical perspective in which to place the extent and severity of today's pollution sources.
- **A Discussion of Use Impairments**
A section is devoted to discussing the various use impairments suffered to date in the basin as an example of the stressed ecosystem affecting human and other uses.
- **A Proposed Approach**
A discussion on the conceptual approach to the Great Lakes Basin Ecosystem Reporting and the technical aspects of the various types and uses of indicators is provided. The approach accepts "the Ecosystem Approach" as a fundamental premise and develops a rationale for reporting ecosystem integrity.
- **Conclusions and Recommendations**

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2.0 HUMAN STRESSES

In this chapter the task force discusses the accumulated effects of the last 400 years of human development in the Great Lakes Basin Ecosystem. This examination is important in order to gain a long term perspective and understanding of the magnitude of the impact which humans have had on the material basis of the ecosystem.

Generally, environmental management as practiced today does not account for the accumulated effects of development over long periods of time. Accordingly, a more comprehensive view of the accumulated impact of human development on the Great Lakes environment to date allows us to put into context the current state of the Great Lakes Basin Ecosystem. Moreover, such an understanding is essential to the task of developing indicators of environmental health as well as the implementation of restorative and preventative measures.

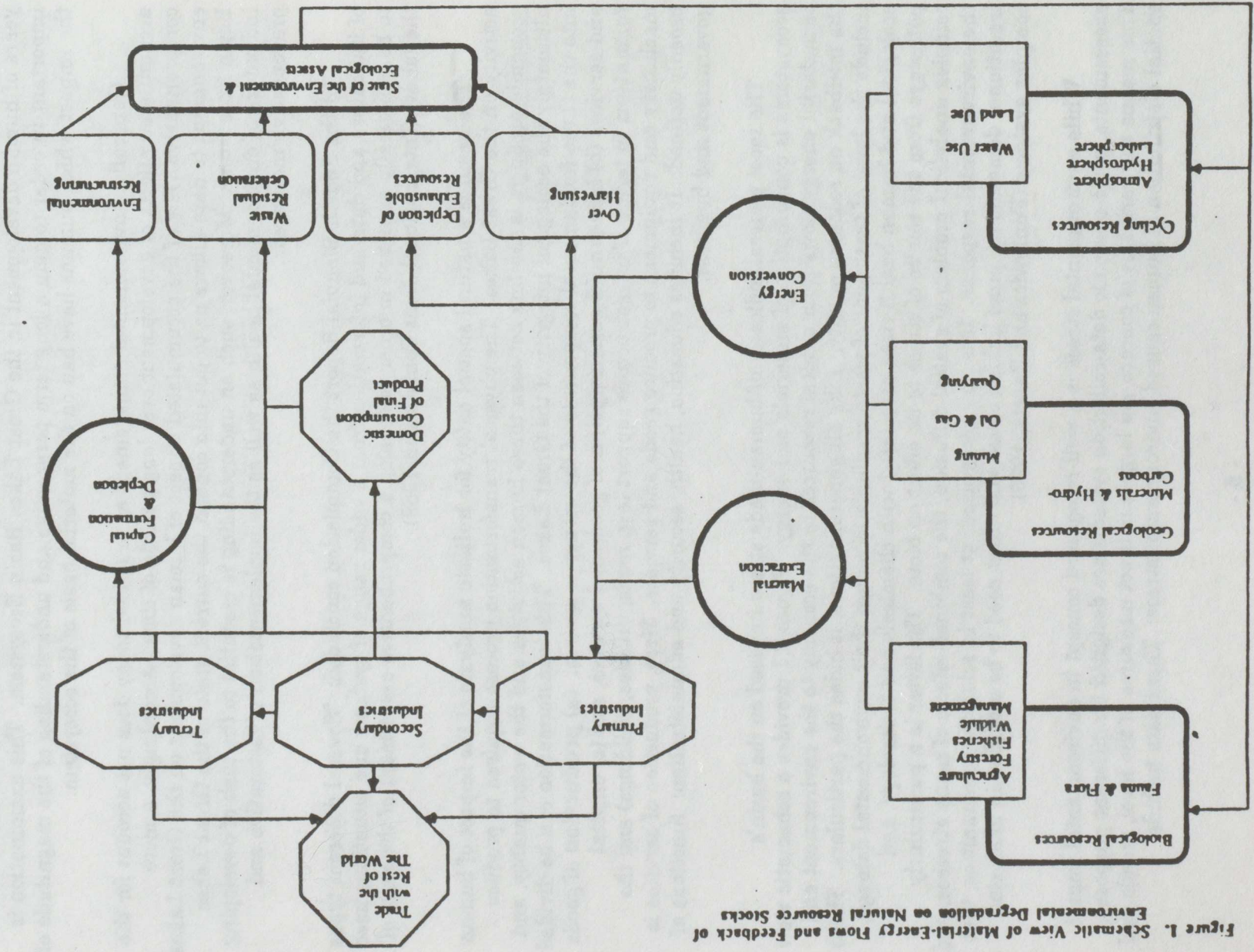
In the Fourth Biennial Report the Commission concluded: "Several different types of indicators and data and information from a wider range of systems and situations need to be holistically analyzed in order to develop a comprehensive assessment of the state of the lakes" (International Joint Commission 1989).

The basin is a natural spatial entity for holistic analysis of the impact of human activity on the Great Lakes. The physical transformation process required to produce economic products is the link between these human activities and the water quality, and ultimately the ecological integrity of the Great Lakes. This transformation can be divided into the three fundamental components of the economic system: (a) production of goods and services (b) household consumption of goods and services, and (c) capital formation in terms of infrastructure support (e.g. roads, utilities, buildings) and the machinery and equipment to produce goods and services. Here, production of services is broadly defined. It includes education, health, security and administration: functions of government and business.

The most general indicator of human-made stress imposed on the basin's ecosystems is consumption of materials and energy. Figure 2.1 provides a schematic view of material energy flows from natural resources to the economy to the environment and the feedback on resource quality. Like all generalizations, it hides the particulars. These include the level of treatment of waste residuals to reduce their environmental damage, ecological and human health risks associated with chemicals and technology, and pathways from the source of stress to its effect on biota. The latter is a particularly complex analytical problem of spatial diffusion, the combined effects of many stresses, and the environmental response. It is now recognized, at least in scientific communities, that traditional demands for proof linking cause and effect need to be modified in analyzing complex systems (Funtowicz and Ravetz, 1990).

While environmental stress is a well-recognized concept in environmental impact assessments, socio-economic data-collection systems are designed for different purposes. This means the variables of concern are largely indirect measures of the level, trends and spatial distribution of human-caused environmental stress. These data include:

Figure 1. Schematic View of Material-Energy Flows and Feedback of Environmental Degradation on Natural Resource Stocks



- a) the quantity and location of harvesting biological resources in the basin's terrestrial and aquatic ecosystems (i.e. forestry, fishing, hunting and trapping); production of food, fibre and seed oils from the basin's arable soils; and extraction of minerals and hydrocarbons from the basin's geological substrata;
- b) pollution loadings from large-scale physical transformations of primary to secondary products. The basin has a relatively large share of North America's chemical and metal smelting industries like iron and steel, non-ferrous metal smelting, pulp and paper, industrial chemicals, petroleum refinery, cement, and thermo/nuclear power generation. Other pollution loadings are from municipalities and nonpoint sources largely associated with automobiles and agricultural runoff;
- c) data quantifying major construction activity and land use change. Critical areas include urbanization processes, large-scale hydro projects and transportation networks: pipelines, electric transmission lines and major roads;
- d) data describing demographic and social trends. This includes a wide range of indicators such as population densities, recreational activities and changes in human behavioural patterns, e.g. recycling of household wastes;
- e) data recording major climatic events. Although these are not human activities, storms, severe winters, droughts, and floods in the basin do influence the Great Lakes and its inhabitants.

Interpreting the significance of human stressor activities in the basin involves social choices. Information required for sound decision making is best shown, in a spatial analytical framework, as overlaying human activities on distinctive ecosystems. Realistic assessments, however, must recognize our limited knowledge of the relationships between stress and ecosystem dynamics. The ecosystem's ability to withstand human disturbances is critical. In general, small perturbations have greater impacts on relatively pristine environments than on areas already heavily modified by cultural stresses. Ultimately, the level of protection and conservation of environmental assets are not determined by science but by socio-ethical choices. Science can gather facts on the environment but decisions on risks to ecosystem integrity is, in the final analysis, political.

2.1 HUMAN POPULATION

The broadest indicator of human stress on basin ecosystems is population density. The basin includes some of the most densely (416 people per square mile in the Erie basin) populated areas of North America. These densities are similar to those of the densely populated areas of Europe. On the other hand, the Superior basin (13.5 people per square mile) is very lightly populated. It is evident that Lakes Michigan, Erie, and Ontario, while comprising half the land area of the entire Great Lakes basin, contain 90% of the population, and much of that within urban clusters (Table 2.1).

Human environmental stress is determined, not only by population weight, but also by the capacity of ecosystems to adapt to human-modified landscapes. Considering the evolutionary time scale of natural adaptations, the rapid growth of European

settlement in the basin is nothing less than a population explosion. Present Great Lakes ecologies developed from natural rehabilitation after the glaciers of the last ice age receded around 11,000 years ago. The first humans appeared perhaps a thousand years later. Between 60,000 and 120,000 people are estimated to have lived in the basin during the first European penetration in the 17th and early 18th century. The First Nations

TABLE 2.1
POPULATION DENSITY FOR EACH OF THE GREAT LAKES

LAKE	LAND DRAINAGE AREA IN SQUARE MILES	POPULATION	POPULATION PER SQUARE MILE OF DRAINAGE AREA (PER SQUARE KILOMETER)
Superior	49,300	663,465	13.5 (5.2)
Huron	51,700	2,461,115	47.6 (18.4)
Michigan	45,600	12,051,200	264.3 (102.1)
Erie	30,140	12,532,770	415.8 (160.5)
Ontario	24,720	7,375,280	298.6 (115.3)

Source: U.S. Bureau of the Census; Environment Canada; Statistics Canada.

people in the southern part of the basin had already established semi-permanent agricultural settlements; migrating, hunting and fishing tribes occupied most of the northern basin.

Before the first European farming settlements were established in the basin 200 years ago, their populations totalled about 60,000 traders and trappers; 50 years later this had increased more than tenfold. By the beginning of the 20th century, the population of the basin was approaching 10 million. Ninety years later, the basin ecosystems carry a population of 35 million people, highly concentrated in a string of urban centers with cities of three, four, and six million people, a vast agricultural area of intense cultivation, and several of the world's great industrial centers. For the ecosystem's adapting processes, these 200 years of human onslaught can only be viewed as a shock wave. The First Nations people were also devastated by this dynamic force of a technologically "advanced culture." They now live on 350 native reserves, with 350,000 Treaty natives occupying seven million acres in the Great Lakes basin.

Human activities in the basin must be analyzed in the context of the slow evolutionary adaptations of natural ecosystems to human stress. Some characteristics of human stressors can be summarized under three fundamental categories:

- Generation of Waste Residuals (pollutant loadings)
- Permanent Environmental Restructuring (land use changes)
- Extraction and Harvesting of Natural Resources

2.2 GENERATION OF WASTE RESIDUALS

Waste residuals are generated from consumption of materials and energy. In the context of environmental stress these are pollution loadings, broadly defined as emissions to air, discharges to water and deposition of waste on land. The level of waste generated has traditionally been related to economic product. Thus, statistics on production and consumption of material goods are indirect spatial and temporal indicators of environmental stress.

In nature, waste is integrated in a nutrient- and carbon-cycling system. Human-generated wastes can be similarly integrated into recycling systems. Currently, however, most waste residuals, including toxic contaminants, are the product of industrial societies and their elimination and disposal is of major environmental concern.

"Assimilative capacity" is a concept that has been employed to determine the "allowable amount" of wastes that can be discharged into the environment. Too often, however, this capacity is based solely on volume, when other factors such as water temperature (rate of biodegradability), the adaptive capacity of the aquatic ecosystem and past accumulation of waste residuals also play a part. The alternative is to map stresses based on density of human activity, the chemical and physical characteristics of waste residuals and trends analysis. The presentation of stress mapping here will illustrate the approach rather than provide a definitive analysis.

2.2.1 General Trends in Industrial Development in the Great Lakes Basin

The Great Lakes basin is the industrial heartland of North America, and many of the Areas of Concern carry the legacy of this development. Economic crises in rust-belt industries since the mid-70s are important in assessing pollution levels in the basin. Not only have heavy industries declined in importance, but modern technologies, including pollution abatement equipment, have drastically reduced the level of pollution per unit of output, as is discussed in Chapter 3 and Appendix 1.

Despite the crises of the 70s, the Great Lakes states and Ontario still hold a predominant position in manufacturing in United States and Canada. In the 1970s, the Great Lakes states produced about 30 percent of manufactured goods in the United States. The economic crises in the early 1980s precipitated a decline in their relative position as the recovery shifted manufacturing to emerging "new technologies" and drew new automobile assembly plants out of the region. Competing imports of steel and heavy machinery, primarily from Japan and Europe, also played a critical role in the relative decline. By 1986, the Great Lakes states accounted for 25 percent of manufacturing output. Ontario, on the other hand, held its share of about 50 percent of Canadian manufacturing output throughout the period.

Analysis of the economic structure based on a "share index" shows that the Great

Lakes region retains a large concentration of technology and capital-intense industries. It is also well represented in resource-based industries. Only in labour-intense industries, (e.g. textiles, furniture, leather goods), does the rest of United States manufacturing have a greater share. Because of Ontario's predominance as Canada's manufacturing center, it has greater concentration in all four categories (Table 2.2).

There has been a steady shift from manufacturing to service sectors. It should not be assumed, however, that material energy consumption in manufacturing is reduced. Efficiency in use of high-cost labour has been a striking feature of recent industrial trends. This is symbolized in "robot technology" in car manufacturing and, perhaps even more significantly, in the computerized automated processes in the petroleum and chemical industries. In the latter, more workers are employed in maintaining equipment than on the production line.

Figure 2.2 compares employment growth in the service sector for the Great Lakes region with United States and Canadian national totals. Growth in service sector employment is greater on the Canadian side of the basin than in the rest of Canada. This is not the case in the United States, where growth in the basin was slower than in the rest of the United States. This is confirmed in the general analysis of economic growth in the basin:

"Some of the same industries that have been responsible for the region's development, namely manufacturing and agriculture, have tended to shed workers as productivity increased. Manufacturing decline has been abetted, no doubt, as world competitors have emerged. So too, many emerging industries have largely bypassed the region because their production process requires neither bulky natural resources nor large scale surface transportation" (Federal Reserve Bank of Chicago 1991).

The decline of the heavy industries on the United States side of the lakes has stimulated efforts to restructure economies by attracting new growth industries associated with "high tech" manufacturing, and service industries. These particularly include such high growth areas as finance, education and business/consumer services. The massive construction of office towers in the core of Chicago in the 1970s and 1980s suggests success but other cities such as Detroit and Buffalo are still struggling for economic revival. While industrial development has drifted toward the southern and western states, Ontario is still an attractive center of industrial development. Table 2.3 shows how Ontario has maintained its share of manufacturing output compared to the Great Lakes states.

2.2.2 Industrial Stressors in the Great Lakes Basin

Some of the industries causing, through environmental stress, large-scale material energy transformation include iron and steel mills, non-ferrous metal smelting and refining, pulp and paper mills, petroleum refinery, industrial chemicals, and cement. A recent Canadian study showed that these six manufacturing sectors account for over 60% of energy use in manufacturing but only 1.2% of establishments (Statistics Canada). High energy consumption (in a confined space) is also associated with thermal power generation

TABLE 2.2

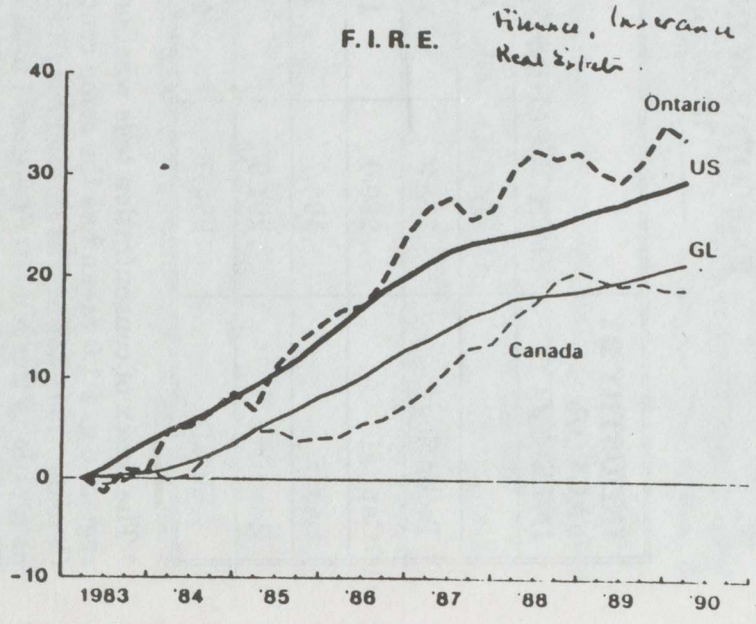
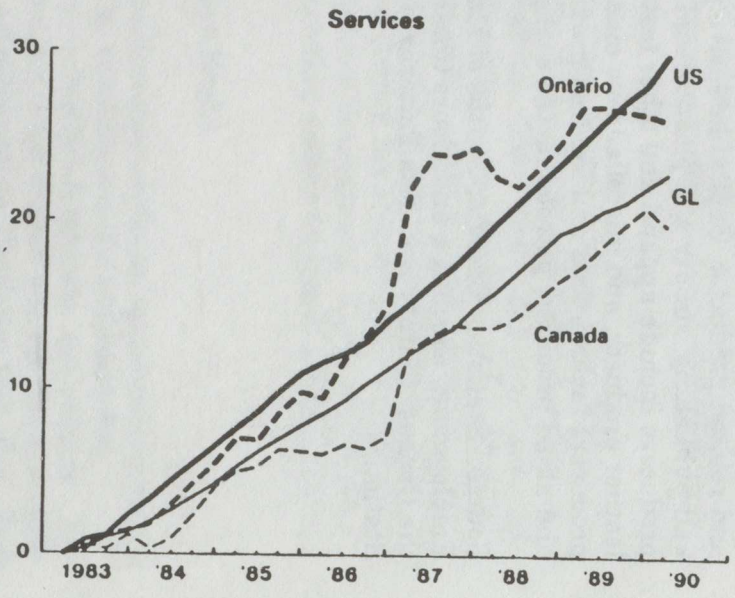
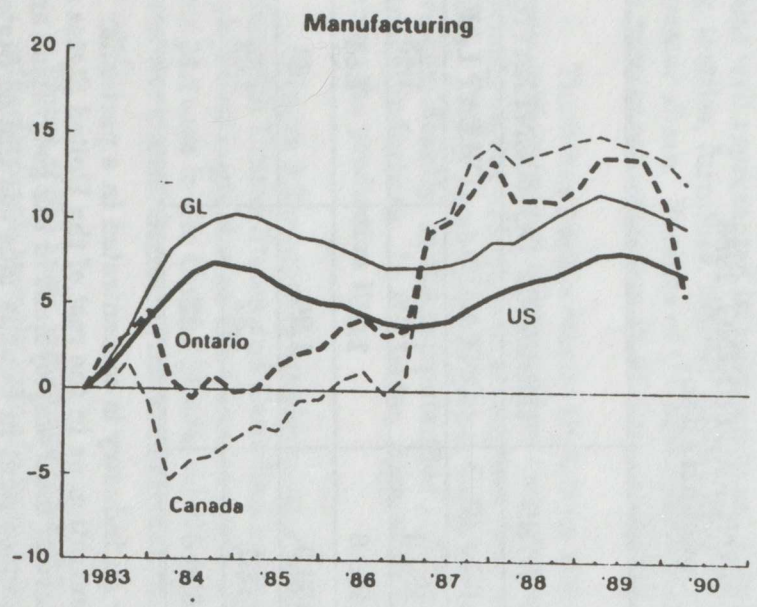
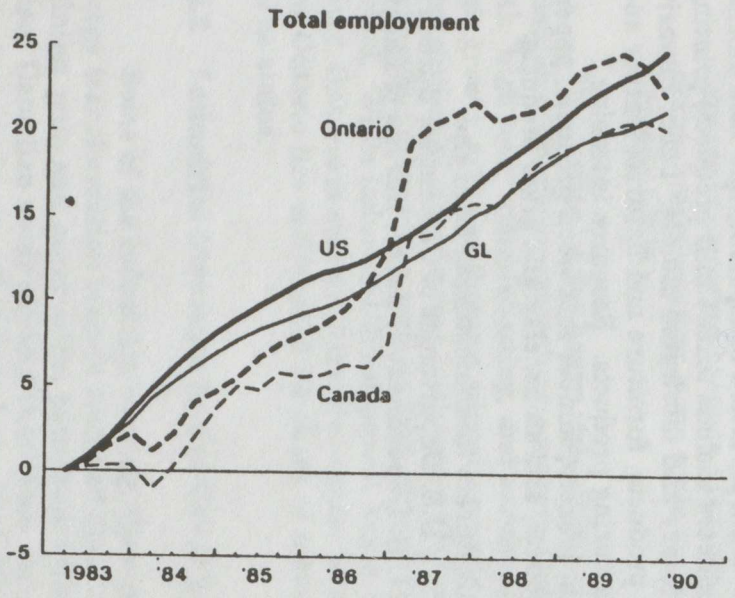
EMPLOYMENT IN MANUFACTURING, 1986
(Index of Concentration)

INDUSTRY BY FACTOR INTENSITY	THOUSANDS OF JOBS		INDEX OF CONCENTRATION*	
	ONTARIO	GREAT LAKES	ONTARIO	GREAT LAKES
Technology	358.3	2,129.3	1.22	1.43
Capital	280.0	1,456.8	1.05	1.44
Labor	104.7	260.0	1.26	.62
Resource	191.9	744.7	1.32	1.02
Total	934.9	4,590.8	1.22	1.26

* The index of concentration tells whether an industry is concentrated in a particular region, e.g. a 1.0 mean has the same concentration as in the rest of the United States and Canada. It is defined as the industry's share of total employment in the geographic area as a ratio to the industry's share of total employment in Canada plus the United States. Technology intensive producers include chemicals and allied products, nonelectrical machinery, electric and electronic equipment, transportation equipment, and instruments and related products. Capital intensive producers include textile mill products, printing and publishing, rubber and plastics, and primary and fabricated metals. Labor intensive producers include apparel and other textile products, furniture and fixtures, leather and leather products, and miscellaneous manufacturing products. Resource intensive producers include food and kindred products, tobacco, lumber and wood products, paper and allied products, petroleum and coal products, and stone, clay and glass products.

Source: Statistics Canada, Census of Manufacturers (manufacturing jobs) and Employment, Earnings, and Hours (total jobs); U.S. Department of Commerce, Bureau of the Census, County Business Patterns, and U.S. Department of Labor, Bureau of Labor Statistics.

FIGURE 1 ~~Chart 1~~ *Figure 2*
Employment growth, 1983Q1-1990Q1
 (percent from base)



concentration in these areas continued to lengthen
 as growth expanded the remainder of the

signs of a sharp drop-off in Ontario's manufacturing
 employment were met

TABLE 2.3

MANUFACTURING OUTPUT AS A SHARE OF NATIONAL OUTPUT IN MANUFACTURING

	ONTARIO AS A	GREAT LAKES AS A PERCENT OF UNITED STATES						
	PERCENT OF CANADA \$1986=100	GREAT LAKES	ILLINOIS	INDIANA	MICHIGAN	MINNESOTA	OHIO	WISCONSIN
1970	n.a.	30.3	7.5	3.9	6.9	1.6	7.9	2.5
1971	50.1	30.6	7.4	4.0	7.4	1.5	7.9	2.5
1972	50.6	30.6	7.3	4.0	7.3	1.5	7.9	2.5
1973	51.1	31.4	7.3	4.1	7.7	1.6	8.0	2.6
1974	50.4	30.6	7.4	4.0	7.0	1.6	8.0	2.7
1975	50.0	29.3	7.1	3.7	6.7	1.6	7.5	2.7
1976	50.3	30.0	6.9	3.8	7.5	1.6	7.4	2.8
1977	50.2	30.1	6.7	3.8	7.9	1.6	7.4	2.8
1978	49.6	29.9	6.7	3.7	7.6	1.6	7.4	2.8
1979	49.9	28.8	6.5	3.6	6.9	1.7	7.2	2.8
1980	48.0	26.9	6.3	3.4	6.0	1.7	6.8	2.7
1981	48.8	26.1	6.0	3.3	5.6	1.8	6.8	2.7
1982	49.4	24.9	5.8	3.1	5.0	1.9	6.4	2.7
1983	50.9	24.9	5.5	3.1	5.3	1.9	6.4	2.7
1984	52.6	25.4	5.5	3.1	5.6	2.0	6.4	2.8
1985	53.5	25.6	5.4	3.1	5.9	2.1	6.4	2.8
1986	54.3	25.5	5.3	3.1	5.8	2.1	6.3	2.8

Source: Statistics Canada, Input-Output Division; and U.S. Department of Commerce, Bureau of Economic Analysis. Taken from Great Lakes Economy, p. 10.

Note: Original dollar values are deflated by industry. n.a. indicates data not available.

and mining. The distribution of major pollution sources from manufacturing plants, mining areas, and thermal/nuclear power stations in the basin closely compares with the Areas of Concern in the Great Lakes (Figure 2.3).

Distinction needs to be made between high stressor industries in relatively isolated and remote areas and those where several establishments comprise a complex industrial area. The latter are associated with the large urban sprawl of industrial communities. This stimulates growth of ancillary manufacturing such as forging of metal parts and manufacturing of heavy machinery and transport equipment. These industrial areas are further linked through a bulk transport system. Indeed, locations were originally determined by the nexus of three factors: access to raw materials, cheap transport and a pool of skilled labour. The heartland of industrial America can be precisely mapped by highly urbanized land use on the south shore of Lake Michigan, the connecting channels of Huron-Lake Erie, the south west shore of Lake Erie, and the north and south shores of Lake Ontario.

The basin of Lake Superior and the northern basin of Lake Huron contain isolated pulp and paper mills and the mining area of Sudbury - Elliot Lake and Algoma Steel (Sault Ste. Marie). Environmental impacts of these high-stressor industries are different from those on the lower Great Lakes. The latter are located in human-modified ecosystems and the pollution loads of one plant add only a marginal burden to already-stressed systems. A solitary, big plant, however, is a massive intrusion on near-pristine ecologies. This can be further exacerbated by the location of nearby First Nations communities dependent upon wildlife and fish for their livelihoods.

2.2.3 Municipal Waste Residuals

Disposal of municipal wastes has reached crisis proportions in many large urban areas. In today's high-consumption society, each individual is estimated to generate two kilograms of waste material per day. Thus, an urban area with four million people must arrange the removal and disposal of eight thousand tons per day. The cost and methods of municipal disposal have now become major political issues confronting local and regional governments. A recent report discussed this point as follows:

"Localities with low tipping fees have found that imports from other jurisdictions threaten to overwhelm local capacity. In the hope of preserving landfill space for local use, municipalities are raising tipping fees substantially. Metropolitan Toronto, for instance, opened a landfill in 1983 that was expected to last for at least 20 years. It is now expected to close by the mid-1990s because of the volume from other areas that has been higher than anticipated. As a result Metro Toronto has increased its rate for private haulers from C\$18 to C\$50 per metric ton (Great Lakes, Great Legacy, 1990).

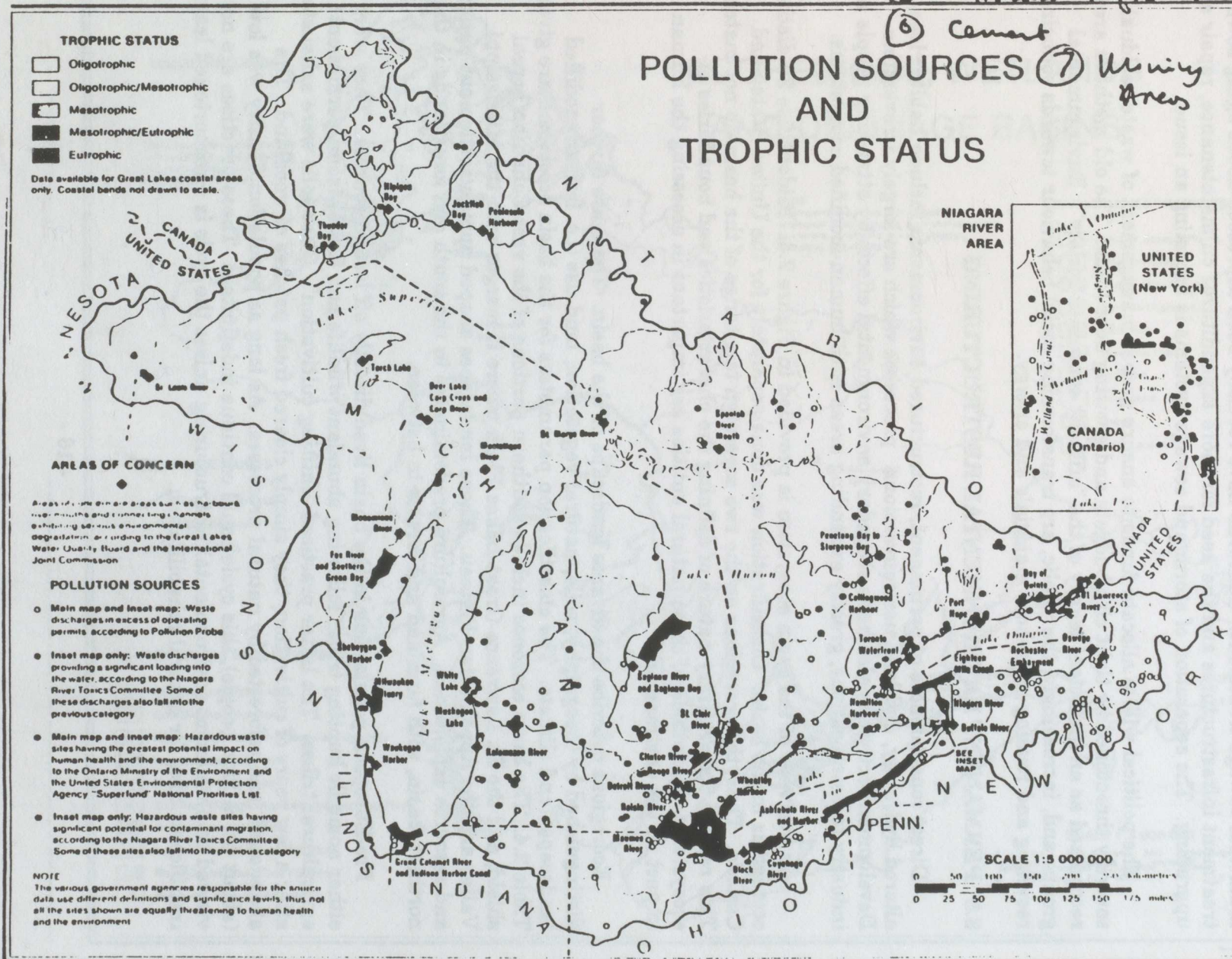
Increasing environmental standards have further raised the costs of suitable locations and preparation of landfill sites. A recent estimate puts the cost of developing a new state-of-the-art landfill site at over \$400,000 per acre (Great Lakes, Great Legacy, 1990).

Waterborne municipal wastes are more efficiently transported but require costly and

MAP 4: Figure 3

Overlay -

- ① Sewage Treatment Plants
- ② Iron + Steel Mills
- ③ Industrial Chemical Est.
- ④ Pulp + Paper Mills
- ⑤ Petroleum Refineries
- ⑥ Cement
- ⑦ Mining Areas



complex treatment before being discharged into surrounding water bodies. Until the 1950s, use of the "assimilative capacity" of the Great Lakes was considered a suitable method of disposing raw sewage. With today's environmental standards and in the hope of rehabilitating the lakes, this method is no longer acceptable. A major tenet of the 1972 Great Lakes Water Quality Agreement was to reduce nutrient inflow by improving municipal sewage treatment. Concerns have recently been expressed about aging sewage treatment infrastructures and the need for more expenditures on maintenance, repair and upgrading. The separation of storm and sewage systems is becoming an issue.

The political will to allocate funds to ensure proper management of waste residuals is severely threatened by tight city budgets and growing debt loads. The old methods are recognized as an inefficient legacy of the "affluent consumer society". Environmental groups and, increasingly, the public, are transforming social behaviour towards reducing, recycling and reusing household materials and energy.

2.3 PERMANENT ENVIRONMENTAL RESTRUCTURING

Direct consequences of permanent, restructured environments include habitat loss, altered hydrology, and land use conversions: processes which are largely irreversible. Development activities also have secondary environmental effects by attracting people and industry to new locations, greatly expanding areas with human-modified ecosystems.

An overview of the basin ecosystem is provided in Figure 2.4. It identifies 20 distinct ecoregions in the basin. Classification was done separately for the United States and Canada. Thus, the ecoregions on the two sovereign territories of the basin do not match. This reflects the arbitrary nature of defining the characteristics and boundaries of ecosystems. Nonetheless, these natural entities are important in assessing the human impact on the environment.

Ecoregions describe the diverse landscape of the basin. These are further distinguished by topography, soils, natural vegetation, land use (i.e. human modified landscape), and climate. The classification parameters for the basin ecosystem are given in Table 2.4. The basin ecozones include southern portions of the vast Canadian boreal shield, and the St. Lawrence-Great Lakes Plain where it merges with the Mississippi Valley and the Appalachian Plateau. These landscapes shaped human settlement patterns and resource exploitation. Agriculture predominates in the south and forestlands in the northern basin, with farmland and forests in between.

Pre-European populations in the basin lived directly off local resources. They were either nomadic hunting tribes following abundant wildlife and fish or (semi-permanent) agricultural tribes. The latter practiced "shifting cultivation". Once soils were exhausted after a few years of cultivation, they simply cleared fresh patches of woodland. The abandoned land reforested by natural processes. As long as population density was low (about 1/2 million people), this cycle could continue indefinitely. These practices are not viewed as permanent environmental restructuring unless the cycle is foreshortened leaving insufficient time for natural rehabilitation.

Map 2 Figure 4

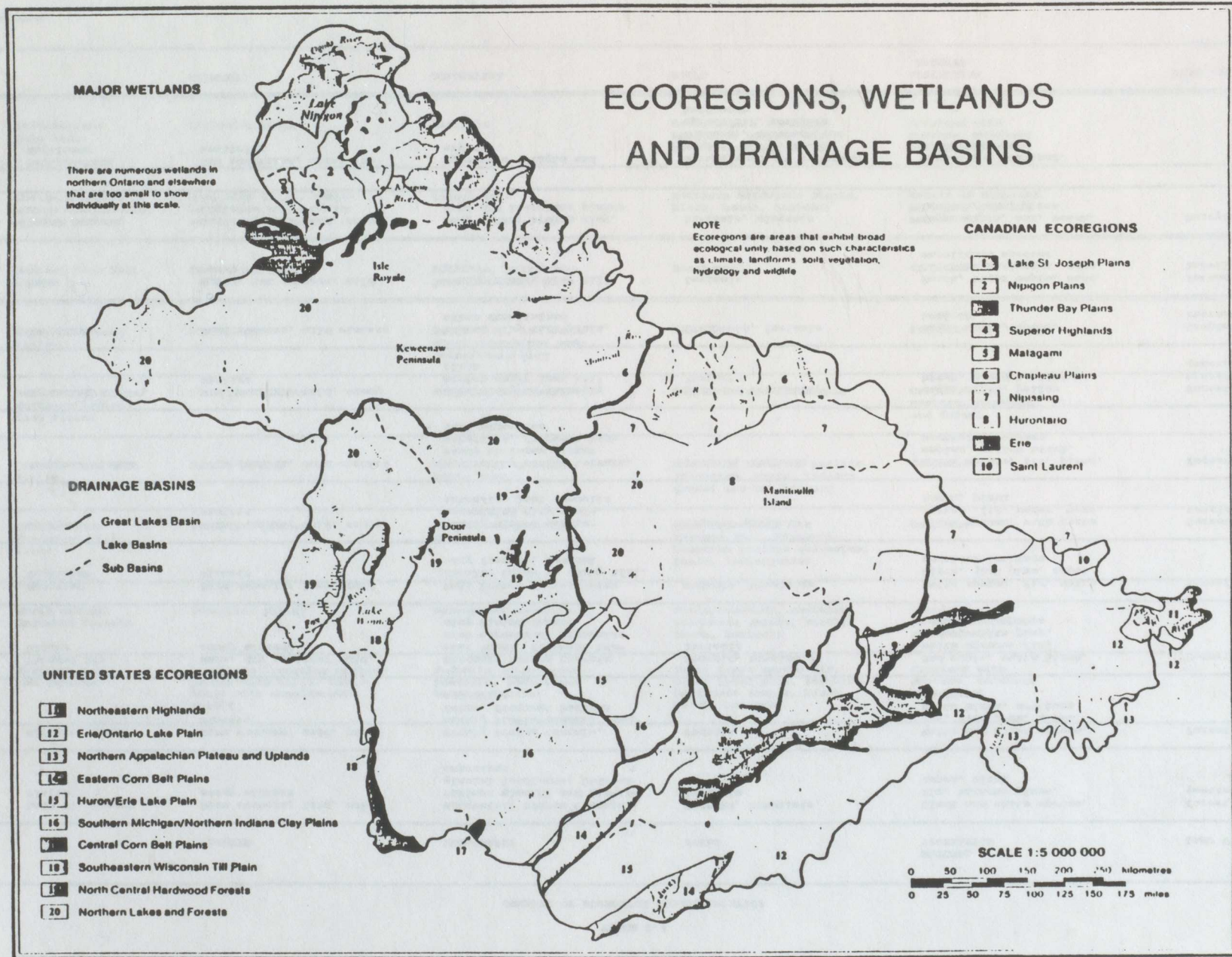


TABLE 2.4
SUMMARY OF ECOREGION CHARACTERISTICS

		CLIMATE	TOPOGRAPHY	SOILS	NATURAL VEGETATION	LAND USE
1.	Lake St. Joseph Plains	Warm summers; long, cold, snowy winters	Moderately broken terrain, various glacial and fluvio-glacial landforms, bedrock exposures	Podzols, brunisols, luvisols	Black and white spruce, fir, various pines, aspen, birch	Forestry, hydroelectric generation
2.	Wipigon Plains	Warm summers; cold, snowy winters	Weakly broken terrain, mainly fluvio-glacial landforms, frequent bedrock exposures	Podzols	White and black spruce, fir, jack pine, aspen, white birch, northern coalifers	Forestry
3.	Thunder Bay Plains	Warm, dry summers; cold, snowy winters	Strongly broken terrain near coast, frequent bedrock exposures; irregular clay plains inland	Podzols, brunisols, luvisols	Red maple, white birch, white spruce, fir, aspen, white pine, northern coalifers	Forestry, tourism
4.	Superior Highlands	Warm summers; long, cold winters	Well broken terrain with shallow sandy to loamy till, very frequent bedrock	Podzols, brunisols	White spruce, fir, white birch, jack pine, aspen, northern coalifers	Forestry, mining
5.	Matagami	Warm summers; cold, snowy winters	Weakly broken glacio-lacustrine clay plain, extensive peat deposits	Organic gleysols	Black spruce, with white spruce, fir, cedar, pine, aspen, birch	Forestry, mining, tourism
6.	Chapleau Plains	Warm summers, cold winters	Moderately broken terrain, sandy to loamy parent materials, frequent bedrock exposures	Podzols, luvisols	White spruce, fir, pines, maples, yellow birch, northern coalifers	Forestry, tourism
7.	Wipissing	Warm summers; cold, snowy winters	Moderately to strongly broken sandy loam till plain	Podzols, brunisols, luvisols	Sugar maple, yellow birch, hemlock, pines	Forestry, tourism, mining, hydroelectric generation
8.	Quebec	Warm summers, mild winters	Broken clay till plain, often drumlinized	Brunisols, luvisols	Sugar maple, beech, hemlock	Cropland and pasture, recreational activities
9.	Erie	Humid, hot summers; mild, snowy winters	Weakly broken clay till plain	Luvisols	Beech, sugar maple, oaks, northern hardwoods, some carolinian species	Intensive agriculture, heavily urbanized
10.	Saint Laurent	Warm summers; cold, snowy winters	Very weakly broken clay, sand and limestone plains	Luvisols, gleysols	Sugar maple, oak, beech, hemlock, elm, pines	Dairying, cropland
11.	Northeastern Highlands	Low mountains, open; low mountains	Spodosols (frigid and cryic)	Spruce/northern hardwoods (maple, birch, beech, hemlock), northeastern spruce/fir, northern hardwoods	Forest and woodland, mostly ungrazed	

Table 2.4 - continued

		CLIMATE	TOPOGRAPHY	SOILS	NATURAL VEGETATION	LAND USE
12.	Erie/Ontario Lake Plains	Irregular plains	Alfisols	Beech/maple, northern hardwoods (maple, birch, beech, hemlock)	Cropland with pasture, woodland and forest, urban	
13.	Northern Appalachian Plateau and Uplands	Open high hills, tablelands with moderate to considerable relief	Inceptisols	Northern hardwoods (maple, birch, beech, hemlock)	Mosaic of cropland, pasture, woodland and forest	
14.	Eastern Corn Belt Plains	Smooth plains	Alfisols, gray-brown podsollic/humic gley	Beech/maple	Cropland	
15.	Wuron/Erie Lake Plain	Flat plains	Humic gley, low humic gley, gray-brown podsollic/humic gley	Elm/ash	Cropland	
16.	Southern Michigan/Northern Indiana Clay Plains	Irregular plains	Gray-brown podsollic	Oak/hickory, beech/maple	Cropland with pasture, woodland and forest	
17.	Central Corn Belt Plains	Smooth plains	Mollisols, brunizem/humic gley	Mosaic of bluestem prairie (bluestem, panic, indian-grass) and oak/hickory	Cropland	
18.	Southeastern Wisconsin Till Plain	Irregular plains	Gray-brown podsollic, udalfs	Maple/basswood, oak savanna (oak, bluestem), bluestem prairie (bluestem, panic, indiangrass)	Cropland	
19.	North Central Hardwood Forests	Irregular plains	Gray-brown podsollic	Maple/basswood, northern hardwoods (maple, birch, beech, hemlock)	Cropland with pasture, woodland and forest	
20.	Northern Lakes and Forests	Smooth to irregular plains, plains with hills, tablelands with considerable relief	Podsollic (gray-brown podsollic, podsol and brown podsollic)	Great Lakes spruce/fir, Great Lakes pine, northern hardwoods (maple, birch, beech, hemlock)	Cropland with pasture, woodland and forest	

The vast basin wilderness did not experience permanent environmental restructuring, however, until the large influx of European settlements in the late 18th and 19th century, when the deforestation and drainage of wetlands in the southern part of the Great Lakes basin began. Core samples of sediment layers from the bottom of these lakes show that these activities were accompanied by a massive increase in the sediment loads carried by rivers flowing through the newly opened agricultural lands. A second stage involved the stabilization and restructuring of shorelines associated with the development of railways and ports for waterborne navigation and commerce. These activities also involved dredging and filling operations and eventually the construction of industrial facilities. The railways and bulk water transport laid the foundation for industrializing the southern parts of the basin, making it the centre of the iron and steel industry. Finally, the internal combustion engine has had perhaps the most visible impact on the environment. Today's vast network of roads, expressways and isolated highways in the northern reaches of the basin is a legacy of American's love of cars. The 16 million motor vehicles in the basin are both the cause and effect of sprawling suburban communities, high levels of NO₂ and CO₂ pollution, and the decline in traditional, environmentally-less-harmful, public transportation.

2.4 EXTRACTION AND HARVESTING OF NATURAL RESOURCES

Biotic matter is a renewable resource; abiotic matter is non-renewable. Thus, minerals or fossil fuels, once extracted, are forever removed from a given stock. Harvesting biota, on the other hand, is assumed to cause temporary depletion of stocks, replaceable by reproduction and growth. This may generally hold true with human cultivation of biota but there is far more uncertainty about renewability when the task is left to nature. The basin has a history of depleting biotic stocks by removing species faster than their capacity to reproduce.

This may be viewed as overharvesting but the causes are more complex than a simple relationship of harvest-reproduction capacity. Ecosystems are dynamic balances between living and non-living worlds, between predator and prey, decay and nutrient cycles, and evolutionary processes of symbiosis and niche specialization. The question of how to maintain healthy ecosystems (natural and human-cultivated) under constant, human-caused stress must remain in the forefront.

The basin can be divided into three major resource zones. First, the arable soil stocks of the southern portion of the basin, second, the forest, wildlife and mineral stocks stretching across the northern basin, and third, the aquatic biota and hydrological assets of the lakes themselves. The latter might include the rivers and other lakes of the basin.

Large scale non-renewable resource exploitation in the Great Lakes basin is confined to a few areas in the boreal shield, among which is the Sudbury basin; one of the great mining areas in the world. Several minerals are mined in the area, most importantly nickel and copper as the area has one of the world's largest nickel mines.

Emissions from the Inco refinery is a major source of SO₂ pollution. Before pollution abatement it was estimated to account for 50 percent of SO₂ sources for Ontario. This has been reduced by the installation of additional pollution abatement equipment. As in manufacturing, there has been a steady decline in the number of workers employed in

mines.

The area between Lake Huron and Lake Erie contains some of the largest reserves of underground salt in North America. Sodium chloride is an important input in the chemical industry and is one of the reasons for locating Canada's largest concentration of chemical plants in Sarnia.

Other major extraction activity is uranium mining in Elliot Lake, and iron ore mining in Wawa. While the Mesabi Hills are just outside the Lake Superior basin, it is important historically because for many decades it was the major source of iron ore for the basin steel mills. Today most ore is shipped from the Ugava region of Quebec/Labrador and other parts of the world such as Brazil. Mesabi's impact on the basin is in the transshipment points at Duluth and other ports on the north shore of Lake Superior.

Sectors associated with the basin's renewable resources are agriculture, forestry, fisheries, hunting and trapping. Agriculture and forestry rank well above other harvesting activity in terms of employment and output contribution to the Great Lakes economy. While commercial fishing is also carried out in the Great Lakes, largely in Lake Erie, the major management preoccupation is sports and recreational fishing. Similarly, hunting of wildlife is treated as recreational activity rather than as a means of livelihood. Nonetheless, trapping fur-bearing animals and hunting and fishing for food is still important for some remote communities on the northern basin of Lake Superior, notably for the First Nations people.

2.4.1 Agriculture

The abundant arable land and favourable growing season in the southern portion of the basin attracted the pioneers. Today the scale of farms, inputs of seeds and agricultural chemicals, and employment of highly mechanized systems have turned farms into productive units, in essence, a business activity. This is reflected in the "urbanized lifestyle" of farm families. While industrialized agriculture is growing as a cultivation technique, the family farm is still the predominant unit.

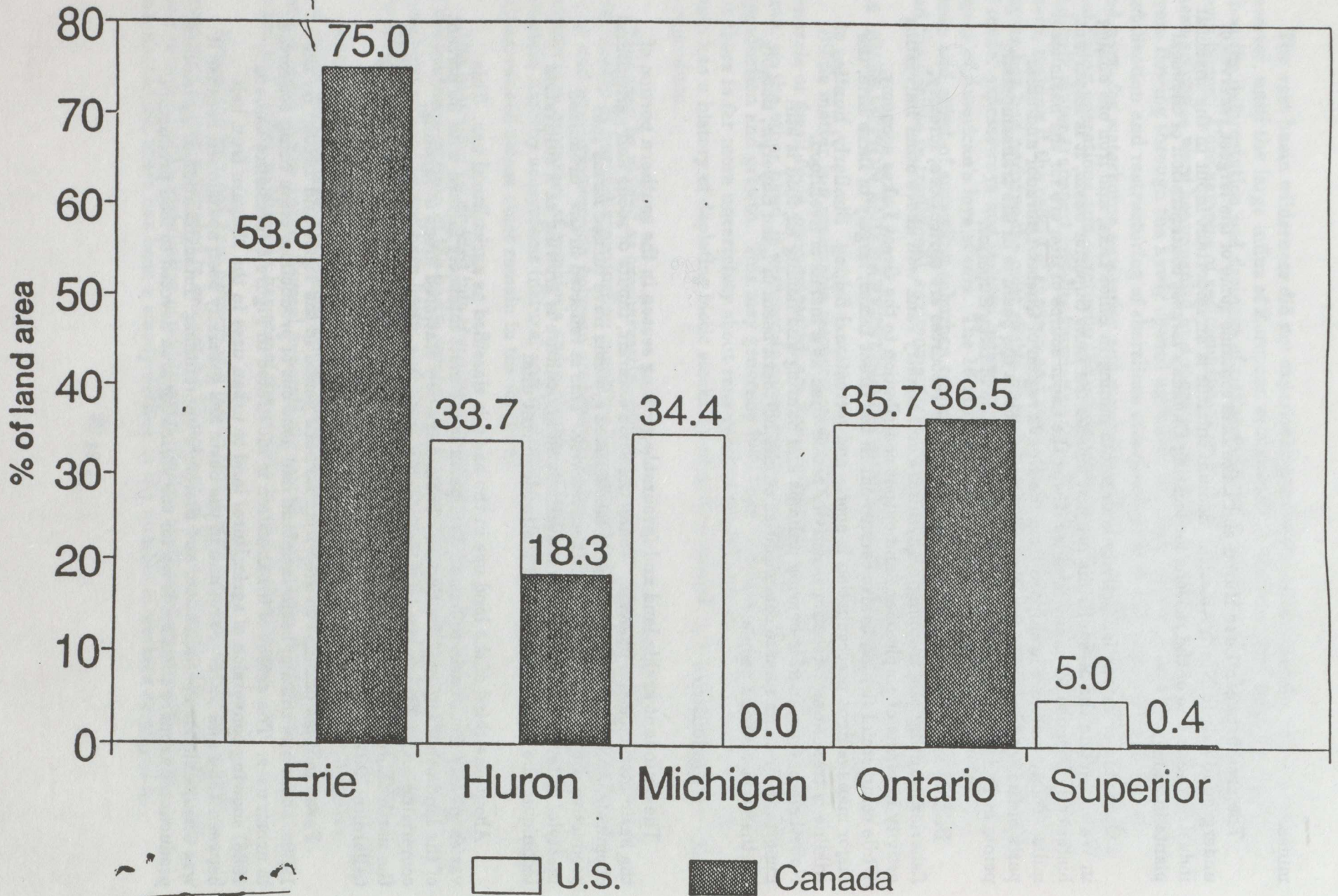
About one-third of the land use in the basin is classified as agricultural use. This varies greatly from basin to basin. Erie basin is the most intensely farmed with 69 percent of the land so classified. The Superior basin has a few scattered areas of farming, comprising about three percent of land use for agriculture. There is very little farming on the north shore basin. Figure 2.5 shows the distribution of farmland in the five basins (Allardice 1991).

Farmland has declined in area from its peak period in the 1930s and 1940s. By the 1980s, about one third of basin farmland had gone out of production, often being converted to urban uses. The extent of urbanization is illustrated in Figure 5 (Statistics Canada 1986) showing conversion of agricultural land to urban uses in the Niagara fruit belt between 1934 and 1975. Farmland in the basin has generally been abandoned because it was unsuitable for specialization, and therefore unprofitable. Intensification of agricultural production has more than made up for the shrinking area devoted to food production.

Figure 5

Farmland in Great Lakes basins

United States (1987) & Canada (1986)



Modern farming methods are of environmental concern. Traditional agricultural techniques were extensions of natural processes. Solar energy, rotating crops, retention of seeds and nutrient recycling drove the system on a sustainable basis. These have been largely supplemented, and in some cases replaced, by inputs from outside the farm. Fossil fuels replaced animal power, fertilizers replaced recycled waste residuals, herbicides replaced mechanical weeding, purchased hybrid cultivators replaced on-farm seeds, pesticides replaced natural predators, and outside finance (for capital equipment) replaced family savings. This resulted in increased specialization, monoculture, hatcheries, and feedlots.

Application of agricultural chemicals (fertilizers and pesticides) has increased about tenfold since the 1940s. Heavy doses of these chemicals are associated with wide-row cropping practices of corn, soybeans, and tobacco among others. In the United States, 85 percent of herbicides and 70 percent of insecticides are applied to wide-row crops. In Ontario, wide-row cropping occupies 35 percent of farmland area but accounts for 85 percent of pesticide use. The major concentration of agricultural chemicals is in the Erie basin (Essex/Lambton County) and the south shore basin of Lake Huron, where agricultural runoff is a major concern.

2.4.2 Forestry

Large-scale forestry takes place mostly in the Superior basin, the north-shore basin of Lake Huron and the northern part of the Lake Michigan basin. The Great Lakes basin experienced massive deforestation in the early 19th century when land was converted from forests to agricultural uses. Although wood was used for building (log cabins), fences and fuel, surplus wood was merely burnt.

The presence of timber harvesting and commercial forestry resulted in the disappearance of the great white pine forests of the basin, widespread clearcut areas and a devastated forest landscape. Modern forest management practices have developed more controlled forest harvesting, and concerns about forest conservation and protection of highly valued forest ecologies have increasingly led to questions about old-style "rotation forest practices" in Ontario. Nonetheless, the scale of forest harvesting activity and the capacity to access remote areas, once again present the danger of overharvesting.

The basin forests are tremendous assets to the Great Lakes ecosystem. Treating forests as merely timber supplies is clearly unacceptable given current concerns about environmental ethics and holistic management. The role of forestlands in maintaining diverse ecologies, global carbon and oxygen cycles, water catchment, habitat for wildlife, recreation for the urban masses, and as the home of woodland First Nations peoples suggests that proper management of forests is both complex and a global responsibility.

Sustainable development encompasses these concerns, not only for the current generation but for future generations. The traditional forester's perception that sustained yield management is sufficient must be replaced with current understanding of the importance of forests in a global context.

It is difficult to assess the state of forests other than in terms of productivity for

economic purposes. In the forested part of the basin, forest industry is the major employer. In the Great Lakes states of Wisconsin, Minnesota, and Michigan, the estimated number employed in 1982 was about 150,000 with an output value of \$15 billion U.S. In Ontario, the number employed in 1989 was around 169,000. With the exception of Michigan, the major part of these forest lands are outside the basin. Several large pulp and paper mills are located in the Superior and Huron basins but wood supplies are obtained both within and beyond basin boundaries.

2.4.3 Fisheries

At the time of early settlement, the Great Lakes had a legendary reputation for fish. The large sturgeon attracted fishermen from far and wide. Atlantic salmon could be caught with great ease as they migrated up the Credit River on the north shore of Lake Ontario. Commercial fishing started in about the 1820s and by the 1890s the catch recorded 134 million pounds per year. From that time, the effects of overfishing were felt, further devastated by the migration of the sea lamprey. Lake fisheries decline was caused by several human stress factors such as loss of suitable spawning and rearing habitat (e.g. wetlands and stream beds), introduction of exotic species (e.g. lamprey, alewife, and rainbow smelt), and nutrient loadings. The effect of toxic loadings has also affected fish health and reproductive capacity.

The commercial fish catch in Lake Erie (which comprises more than all other lakes combined) has remained relatively stable in the last hundred years at about 50 million pounds a year. However, the composition of the fish catch has changed drastically. Until the 1950s catches were directed at high-value species like lake herring, lake whitefish, sauger, and blue pike. As the stocks of preferred species collapsed, they were replaced by less desirable species such as yellow perch and rainbow smelt (Figure 2.6).

Sports and recreational fishing have always been important in the basin. However, the introduction of hatchery bred salmonids to the Great Lakes in the late 1960s has created dynamic and economically profitable sports fisheries, earning an estimated \$2 billion in 1985. Introduced salmonids included imported west-coast salmon, coho and chinook, rainbow trout, as well as the enhancement, through stocking efforts, of native lake trout.

The fish hatchery program was seen as a solution to controlling the proliferation of "nuisance fish," primarily alewives and rainbow smelts. The strategy was to develop a sustainable predator-prey relationship. Moreover, the hope was that these fish would, in time, reproduce in the Great Lakes, thus phasing out annual hatchery introductions. This was not realized as the fish, other than the native lake trout, did not reproduce in sufficient quantities. The growing community of anglers, however, were becoming increasingly dependent on the hatcheries as a source of fish, which resulted in increased demands for inputs of fingerlings and yearlings. With increased stocking of predators and a decrease in the stocks of prey fish, the question arises whether these should not also be augmented by hatchery breeding to maintain this clearly unsustainable system. The demands of a new billion-dollar industry cannot be so easily ignored.

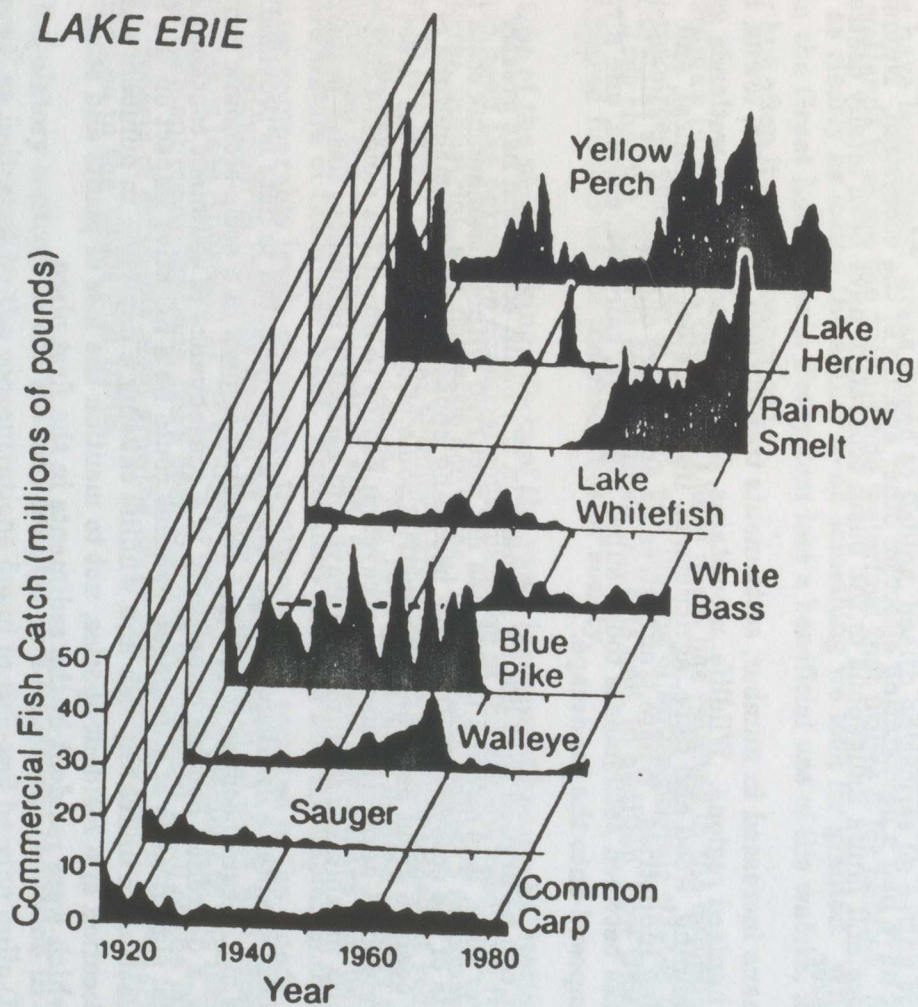


Figure 6: Commercial harvests of major fish species in Lake Erie, 1915-1983. Sources of data: Baldwin et al. (1979) and National Fisheries Center-Great Lakes annual summaries of commercial harvests of fish from the Great Lakes.

2.5 THE GREAT LAKES BASIN ECOSYSTEM - A SUMMARY

This chapter has provided an overview of the key accumulated impacts of human development over the past four centuries. It is clear that the basin which in its current basic form is over 13,000 years old, has suffered a terrific population explosion of humans in only the last several hundred years. This growth has altered the state of the ecosystem in many fundamentally significant ways and continues to impact the ecosystem. The growth in numbers of humans and the activities undertaken in support of their development have had a devastating effect on other species of the ecosystem. Numerous species of flora and fauna indigenous to the basin ecosystem have been totally destroyed and lost forever.

As humans increased in number, settlements transformed into villages, towns, cities and now, urbanized regions. Wildlife, mountains, forests, meadows, and wetlands gave way to fur, mining, wood and fibre, agricultural, iron and steel, petrochemical, and manufacturing industries. Where trails, streams and rivers once served as relatively benign links between settlements today super highways, railways, canals, and airports have been imposed onto the landscape.

While it can be argued that life for humans in the basin ecosystem has greatly improved over time, it is obvious that it has not occurred without tremendous costs to other integral parts of the ecosystem. It is now becoming apparent that the magnitude of such damage has been so great as to begin to restrict some of our basic uses of the Great Lakes Basin Ecosystem. A severely damaged ecosystem begins to affect the range of choices available to its inhabitants in numerous ways and seriously influences usage patterns.

In the next chapter a catalogue of use impairments detected to date is provided. The discussion is significant because it outlines ecological impact in a socio-economic context. For instance, a degraded benthic community is a consequence of sediment contamination. The ecological significance of a damaged benthos could be a negative impact on the food chain, manifesting in unhealthy fish and wildlife causing a depletion in numbers and/or the eventual relocation of a resident species, not to mention the loss of plants and other organisms which were resident in the sediments in the first place.

The socio-economic significance is that contaminated sediments are contributing to the contamination of fish thus lowering their value both as commercial and sports fish. Also, contaminated sediments have become an extraordinarily expensive material to have to manage. Because of a legacy of pollution into our harbours in which shipping channels have to be dredged periodically, the cost of dredging has risen drastically due to the high cost of disposing of severely contaminated sediments which is now relatively strictly regulated.

So while humans have impacted the ecosystem, the impacted ecosystem is now beginning to have serious impacts on humans and this topic is outlined in the following pages.

3.0 USE IMPAIRMENTS

Science assists us in understanding the ecological damage to the Great Lakes Basin Ecosystem, and questions arise addressing the issues that affect the ability of the human inhabitants to use the resources. This happens when a particular use of the lake waters to which we have become accustomed is altered or no longer available to us. Can we swim in the lake, eat the fish and drink the water? These questions reflect the impaired uses of the water. Many of the uses were so common we took them for granted yet over the past 40 years we have suffered a gradual reduction of those uses - bathing beaches have been closed, areas closed to fishing, health advisories on eating sports fish, loss of wetlands to enjoy the wildlife and waterfowl that utilize it for habitat. Nothing speaks as clearly as losing the ability to do something we took for granted. When humans living in the Great Lakes Basin Ecosystem lose a beneficial use of the waters, it too is a tragedy but often it passes unnoticed.

Human intrusion into the Great Lakes basin has resulted in the depletion of natural resources, destruction of habitat, and loading of anthropogenic wastes to the waters. This chapter explores some of those impacts and, in addition, how those impacts have impaired further use of the resources by society.

One of the most striking effects of the rapid increase of human habitation in the basin has been the pervasive chemical contamination of the waters, resulting from agricultural, industrial, and domestic activities. In the main, society's response is reflected in the Great Lakes Water Quality Agreements which are aimed at reducing the discharges of wastes to the Great Lakes. The 1972 Agreement focused largely on phosphorus and the resulting nuisance algal growths in the lower lakes and bays and nearshore waters of the upper lakes. Regulatory controls and the implementation of tertiary (or comparable levels of) sewage treatment have resulted in the steady, continual decrease in phosphorus loadings as well as concentrations in all lakes, and especially in the lower lakes (see Appendix 1). It appears that the target loadings to the lakes, and the objective ambient concentrations, have been reached or exceeded in all of the lakes. Likewise, reports of extensive algal growths, large fish die-offs, and closed beaches are not as common as in the 1960s and 1970s.

Regulatory controls in the 70s also resulted in a significant reduction in many toxic substances, as indicated by the concentrations found in fish and herring gulls (*Larus argentatus*) (Appendix 1). As has been stated in previous reports (Water Quality Board 1987, 1989; Government of Canada 1991) and as continues to be observed, however, is that the initial decreases in contaminant concentrations have levelled off. It is not known whether present fluctuations in contaminant concentrations at some sites results from analytical variability, fluctuation in the abundance and composition of the forage base, or actual increase in loading of contaminant.

The above measures have been useful in characterizing the presence and availability of contaminants in the Great Lakes. However, little can be said regarding the effect those concentrations of contaminants, or the combination of the various contaminants, have upon the organism itself. For example, while the concentration of PCBs in herring gulls have dropped an order of magnitude from the early '70s at some

sites, it is now necessary to determine what effect the current 15-50 mg/kg PCBs have on the herring gulls or on other organisms not monitored. Reductions in the phosphorus loads may indicate that efforts to abate eutrophication have been fully successful; however, consideration of the response of the lakes to those reductions must be considered. Have the occurrences of nuisance algal growth been eliminated in all areas, including nearshore zones; are aerobic conditions maintained in bottom waters to allow recolonization by pollution-intolerant benthic species, and are current controls sufficient to deal with increased human population in the basin expected in the future?

There is a need, therefore, to consider measures of the environmental quality that characterize the health of organisms, populations, communities, and ecosystems. Unfortunately, no routine programs presently exist on a basinwide basis; this is presumably an objective of the 1987 Agreement in its stipulation for the establishment of ecosystem objectives for Lake Superior, and the Parties efforts to develop such objectives for other lakes. There are currently; however, many smaller programs that have been tracking various biological parameters in selected populations of species around the Great Lakes. Such programs include the reproduction and abundance of bald eagles, deformities in double-crested cormorants, reproduction of lake trout (*Salvelinus nameycush*), and mink and otters. It was the health of these species, and ultimately human health, that were the objectives of initiating controls on the toxic contaminants such as DDT, dieldrin, and PCB. Therefore, it is important to systematically monitor how those organisms are responding to the decreases in ambient concentrations.

3.1 IMPAIRMENTS TO FISH AND WILDLIFE

Eagles integrate many aspects of their environment. They rely on suitable breeding habitat and a diverse, clean prey base. Population and breeding performance depend on several different components of habitat quality; an entire suite of physical habitat and water quality factors needs to be present for success. As an integrator of these factors, the eagle can reflect whether the coastal environment of the Great Lakes as a whole is satisfactory. The future presence of bald eagles throughout the basin should reflect the ability of the Great Lakes to support all levels of consumers, including humans.

It appears that the bald eagle population within the entire Great Lakes basin has paralleled the improved status of the species across North America except in shoreline locations (Science Advisory Board 1991). Primary credit has been attributed to the decline in contaminants in eagles and their prey base, particularly DDT and metabolites. Contributing to the improvements has been an aggressive program by natural resource agencies in the management, protection and enhancement of eagles and their habitat, and through programs for public awareness, involvement and education. These efforts have resulted in a documented improvement in adult survival, productivity and numbers of breeding areas on a jurisdictional and regional basis.

Elevated organochlorine residues in Great Lakes bald eagles is consistent with the elevated levels of these contaminants in other Great Lakes biota. The bald eagles' position as an upper trophic level predator enables it to bioaccumulate these persistent chemicals from a diverse prey base. Great Lakes eagles forage on a higher percentage of avian prey, particularly aquatic feeding birds such as gulls, waterfowl and colonial

waterbirds, than eagles nesting inland. This avian prey is itself well elevated in organochlorine compounds above those levels found in fish and other aquatic organisms upon which these species forage. Turtles, which are highly contaminated, are a significant food item in birds nesting in southwestern Ontario near Lake Erie. These additional trophic levels have contributed to some of the highest organochlorine residues in addled eggs and blood ever encountered in eagles.

During the past four years, research and monitoring on the Great Lakes population of double-crested cormorants have shown this species to be a reliable indicator of the levels, trends and effects of persistent toxic substances. Populations of double-crested cormorants in the Great Lakes are increasing dramatically, as a result of increased protection from human disturbance, lack of predators, and restoration of eggshell thickness with decreasing DDE levels. This population increase has been maintained despite the occurrence of Newcastle disease (a bird virus) and associated mortality of adult birds. The fact that populations of a wildlife species are expanding is normally interpreted by wildlife resource managers as a sign that the members of the species are healthy and that therefore no intervention is warranted. Double-crested cormorants have become an important indication of the status of the restoration of the Great Lakes from releases of persistent toxic chemicals. The fact that certain colonies of double-crested cormorants continue to have embryo mortality and congenital deformities argues for increased regulatory intervention to deliver the policy contained in the Water Quality Agreement concerning the virtual elimination of discharges of persistent toxic substances. Indeed, the low incidence of congenital deformities and good survival in most double-crested cormorant colonies could be used as an indicator of the effective delivery of this policy.

There are a number of reasons why persistent organic contaminants are suspected as a cause of the continued reproductive failure of salmonids. The position which salmonids hold near the top of their food chain, combined with their relatively long life span and high fat content, cause them to efficiently bioaccumulate toxic substances from their environment. These species also produce a large egg, with a high-lipid yolk material that carries a significant dose of organic contaminants as the first food for developing young.

The complexity of the problem has presented the major barrier to answering the question of whether or not contaminants are influencing the reproductive ability in wild fish. While in the laboratory variables affecting fish reproduction can be limited to a great degree, in the field this is not possible. Factors that affect population size, spawning habitat quality, normal spawning behavior, as well as other factors that affect gamete quality such as genetics and nutrition influence reproductive success in the field. With very little natural reproduction occurring by lake trout in the lakes, it is extremely difficult to point to any one reason, or to separate out the various causes. For lake trout, reproductive failure is most likely due to a combination of various factors, of which contaminants may contribute to a varying degree in different lakes.

While the role of persistent organic chemicals in the inability of salmonids to maintain a self-sustaining population in the Great Lakes is not fully understood, there is substantial evidence which suggests that these chemicals are a factor in this problem.

Mink and otter may be useful biological indicators of ecosystem health in the Great Lakes basin, with a focus on the role of persistent toxic substances in the reproductive impairment of these two mammals. Mink and otter were discussed by the Science Advisory Board (1991) as possible biological indicators because of the position they hold in the food web and their great sensitivity to PCBs and related toxic substances. As consumers of fish these two mammals are subject to high levels of environmental contaminants which bioconcentrate up the aquatic food chain.

Assessment of the distribution of mink and otters and of the factors affecting their health and abundance has been limited by scientific, as well as, institutional constraints. Responsibility for assessment of stocks of mink and otter rests with the state and provincial governments under their mandates for managing fur-bearing animals. Generally mink and otter stocks are sufficiently abundant for the purposes of trappers and thus research and monitoring of populations would appear not to be warranted. Agencies responsible for managing fur-bearers tend not to be the agencies responsible for environmental quality or human health. And because they are not eaten, human health agencies are not concerned about contaminant levels in their flesh. Thus implementation of the idea of using fur-bearers as indicators of environmental quality will require some creative institutional mechanisms to ensure appropriate allocation of budgets and personnel.

If the institutional constraints can be overcome, the scientific constraints can be addressed. Survey techniques must be developed to assess the age structure, range, distribution, abundance, habitat requirements and reproductive health of these species particularly along the Great Lakes shorelines. In addition, biological research is needed on the dietary habits, disease and parasite status and the relative sensitivity of these species to persistent toxic substances. Finally, it may be possible to undertake measurements of specific biochemical lesions, induced by contaminants, by sampling live, wild animals. After these studies and institutional changes have been undertaken it will be possible to assess whether mink and otter are reliable indicators of the restoration of the integrity of the waters of the basin ecosystem.

Overall, the performance of biological organisms appear to reflect similar trends as the chemical concentrations; viability, reproduction and abundance are improving over past conditions, yet there is still evidence of effects; some at a lower level and others only in specific geographic areas.

3.2 DEGRADATION OF BENTHIC COMMUNITIES IN GREAT LAKES CONNECTING CHANNELS

While the degradation of the benthic communities in the waters of the basin may not directly affect human use of the resource, these organisms serve as a food source for higher level species (fish and wildlife) and transfer accumulated contaminants to those species. The composition, abundance, and diversity of benthic communities can be used as indicators of the health of the community and of the quality of the waters and sediments. It should be recognized, however, that factors other than pollution also affect the quality of the benthic community and need to be considered when monitoring benthos. Such factors include habitat conditions, substrate, and flow rates (Resh and Rosenberg,

1984). In addition, although community level impacts of eutrophication are relatively well understood, those of toxic contaminants are not well understood and community level effects, other than nearly complete elimination of the community, have rarely been demonstrated.

In the connecting channels, the zones of greatest benthic degradation generally correspond with the areas downstream of intense industrial development and sewage treatment plants. These areas include Algoma Steel, St. Marys Paper, and East End Sewage Treatment Plant in the St. Marys River. Despite reductions in pollutant loadings since 1960s, no significant improvements were reported in benthic community structure in the affected areas (Burt et al. 1988). In the St. Clair River, the most severely affected areas correspond with the Sarnia industrial waterfront, adjacent to Dow Chemical. The environmental quality improved in this area 1968 to 1977 (Thornley 1984) and was more improved in 1985 (Griffiths 1989), with a reduction (nearly 50%) in the total length of the affected areas along the Canadian shoreline.

The Detroit River has been designated as the most severely polluted connecting channel based on benthic invertebrate distribution, concentrations of contaminants in water, sediment and suspended sediment (Thornley 1984). The areas of severest degradation are mostly found along the United States shoreline downstream of the industrial complex on and adjacent to the Rouge River (the Trenton Channel area). Some improvements in benthic community structure have been observed since 1968, as indicated by the return of the mayfly (*Hexagenia*) in the unimpacted portions of the river with suitable substrates.

The Niagara River has a large concentration of hazardous waste sites, industrial activity, and municipal outfalls. Some evidence of improvements in the environmental quality of the river since 1970 has been suggested (Jaagumagi et al. 1989). However, benthic information has not been reported in the river from northern Grand Island to Queenston, where the greatest amounts of industrial discharges occur.

The most degraded areas of the St. Lawrence River include parts of the Middle Section and the Cornwall waterfront. There is some indication of improvement in the environmental quality of the river along the Cornwall waterfront in the past 20 years. However, the river remains organically enriched along most of its international section.

For a detailed discussion of the benthic community assessments in the Great Lakes connecting channels, please see the Appendix 3.

3.3 CONTAMINANT MONITORING PROGRAMS IN EDIBLE PORTIONS OF FISH AND FISH CONSUMPTION ADVISORY PROGRAMS

Consumption advisories regarding the level of organic and inorganic contaminants in Great Lakes fish are currently published by all eight Great Lakes states and Ontario. These advisories are designed for use by Great Lakes anglers, enabling them to differentiate between fish species which should and should not be consumed based on contaminant level limits stipulated by individual jurisdictions or by the two federal governments. A major difficulty regarding these programs is that some of the advisories

issued are (or have been) inconsistent between jurisdictions. Differences occur in all aspects of the programs. Selection of "safe" contaminant concentrations have been based on either federal action levels or risk assessment. Issuance of advisories is often based on the amount of fish consumed; thus, the advisories in some jurisdiction are listed in terms of acceptable meals per week or month, or no consumption at all. There exists wide differences in the collection, analysis and processing of the information. Of all contaminants, only PCB and DDT are currently analyzed by all the jurisdictions. Varied approaches (or none at all) are used to account for the effect of multiple contaminants. Finally, even the methods by which the fish are collected and the tissue is removed (skin on, skin off and dorsal versus fillet) vary among jurisdictions. For a more detailed discussion of these various factors and the specific differences among jurisdictions, see Appendix 2.

Because of the variability between the states and Ontario on the method and decisions in issuing advisories, a comparison of the advisories should not be used to determine those locations of most severely contaminated fish (except within a jurisdiction, where common protocols apply). For example, in Lake Huron a full restriction (an advisory of no consumption) exists for all carp and channel catfish and for brown trout greater than 45 cm in Michigan waters. However, in the Ontario portions of the lake, either no total advisories exist in some sections or advisories on walleye (over 65 cm) and smallmouth bass (over 45 cm) in other sections of Ontario waters.

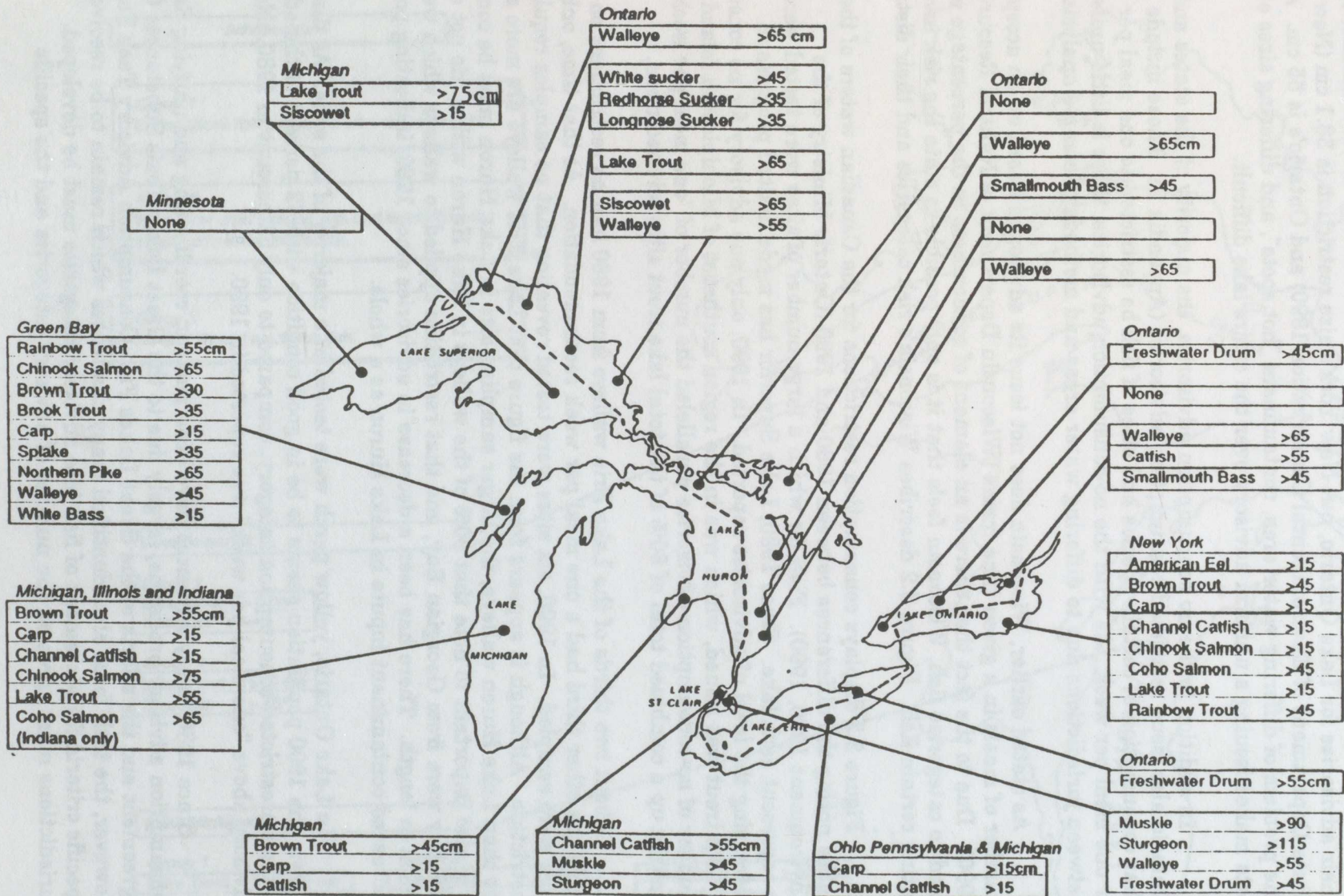
Figure 3.1 describes the full advisories (advice of no consumption of certain fish) within the Great Lakes. Wisconsin is not included in this figure due to their method of issuing advisories, and is therefore discussed later. It is important to note that some differences in numbers of advisories issued between jurisdictions may be attributed to local contaminant "hot spots" where fish may show much higher levels of contaminants than other areas of the lake.

In Lake Superior, Minnesota has no total bans for any fish species (Minnesota Department of Health 1989). Conversely, Ontario (Ontario Ministry of the Environment 1990) and Michigan (Michigan Department of Natural Resources 1990) show advisories, but there is considerable difference between the two jurisdictions. Ontario subdivides its advisories into lake segments, whereas Michigan chooses to issue lake wide advisories. There is also a large difference in the size of siscowet lake trout that are targeted for advisories between countries, and seems to indicate higher contaminant level in Michigan regions of the lake.

In Lake Huron and Lake St. Clair, Michigan does not issue a no consumption advisory for walleye in their "1990 Michigan Fishing Guide" (Michigan Department of Natural Resources 1990), yet Ontario has them in both lakes. Michigan also indicates that catfish above 55 cm are not suitable for human consumption in Lake St. Clair, and Ontario indicates they are. This difference may be attributed to a specific area of contamination in Michigan since both Ontario and Michigan use the same method of issuing advisories in Lake St. Clair (Hesse 1990).

Lake Erie is covered by a uniform advisory from Michigan, Ohio (Ohio Department of Natural Resources 1990) and Pennsylvania, but again Ontario shows a considerable

Figure 3.1
 Advisories on fish consumption in The Great Lakes



difference in species advised upon. Ontario and New York both include channel catfish in their advisories for Lake Ontario, but New York's size restriction is 38.1 cm (New York State Department of Environmental Conservation 1990) and Ontario's is 55 cm. Again, the problem of differing water area, contaminant "hot spots", and differing sizes of data sets makes issuing a uniform advisory over the entire lake difficult.

In addition to the no consumption advisories, the majority of the states and Ontario also issue restricted consumption advisories (Appendix 2). These include advice that consumption of certain species and sizes of fish be restricted to one meal per month or one meal per week. As with the no-consumption advisories, there is little uniformity between jurisdictions due to differing water areas and methods of sample analysis.

As stated earlier, Wisconsin does not issue its advisories based on an acceptable number of meals in a given time frame (Wisconsin Department of Natural Resources 1990). Due to the fact that there is an element of randomness in the percentage method used to categorize fish, Wisconsin feels that it is only possible to state the risk involved in eating certain fish. Figure 3.2 describes Wisconsin's risk categories and their distribution.

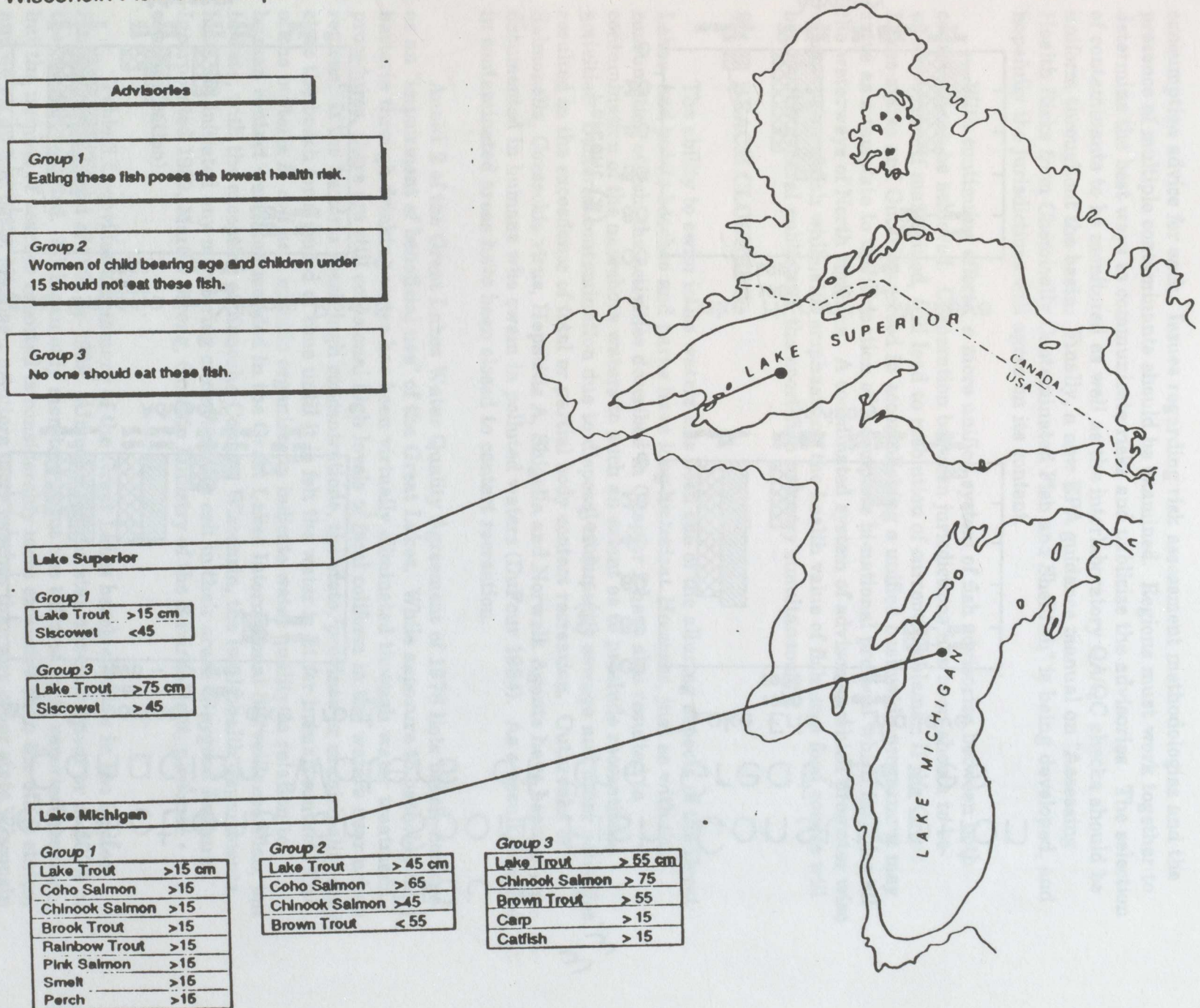
Figure 3.3 displays consumption restrictions for the Canadian waters of the Great Lakes noting the differences between 1980 and 1990 (Ontario Ministry of the Environment 1980, 1990). Fish for which a large number of sites were tested were chosen to represent each lake. Since 1980, Lake Superior has made limited progress in decreasing the level of advisories reported. In 1990, only one advisory for no consumption of lake trout was issued, which was in the region southeast of Michipicoten Island. The number of no-consumption advisories paralleled the number of "one meal per week" making up a combined total of 80% of the total lake trout sites advised upon.

About two thirds of the Lake Erie walleye from 1980 had no restrictions on them while the other third had a one meal per week recommendation. At that time, only three sites were sampled. In 1990, six sites were tested revealing that no samples required restriction. Although it appears from the figure that Lake Erie walleye are more safe to eat than Lake Huron walleye, the larger sampling size in Lake Huron must be considered. It is also important to note that 80% of the walleye in Lake Huron with a "do not eat" advisory were from Georgian Bay, and that restriction applied to walleye which were over 65 cm in length. There has been a decrease in advisories since 1980, indicating possible decreased contaminant inputs in Lake Huron as a whole.

In Lake Ontario, yellow perch were tested at a majority of the sites. As the figure shows, the 1990 population seems to be in good condition with 72 percent of the advisories in the unrestricted consumption category, compared to only 62 percent in 1980. No advisory above "one meal per week" was reported in 1990.

Since 1986, many advances have been made in coordinating and unifying fish consumption advisory programs, largely due to the Great Lakes Toxic Substances Control Agreement and the efforts of the Great Lakes Fish Consumption Advisory Task Force. However, the task force also identified many challenges which remain to be resolved. Specific criteria for placement of fish into advisory categories must be developed. Jurisdictions must agree on the number of advisory categories and the specific

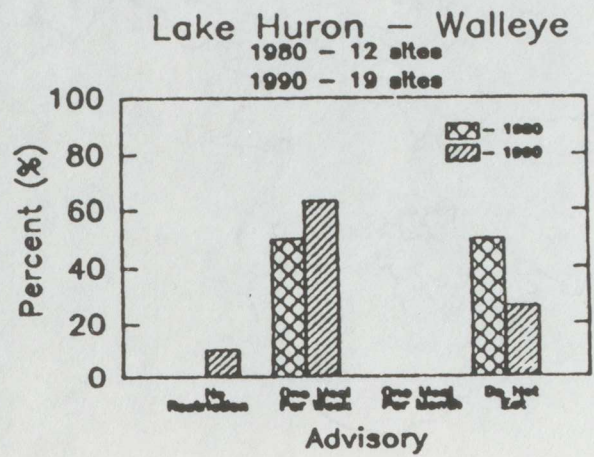
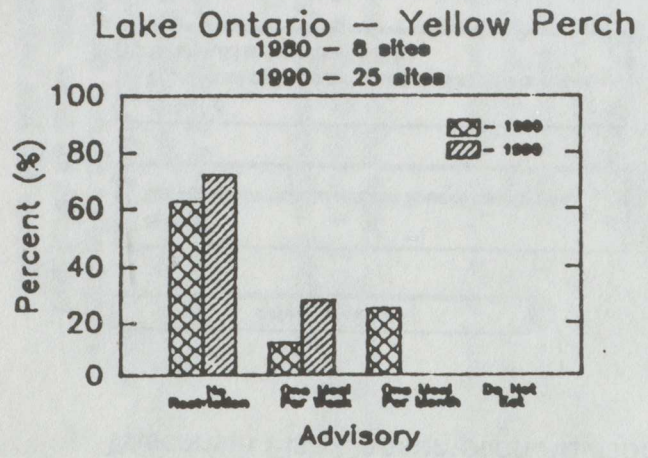
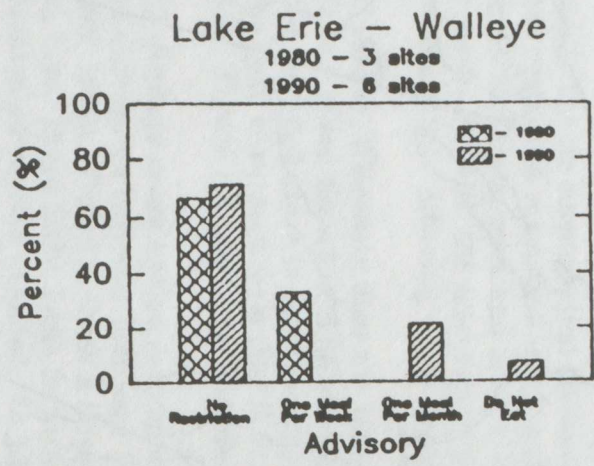
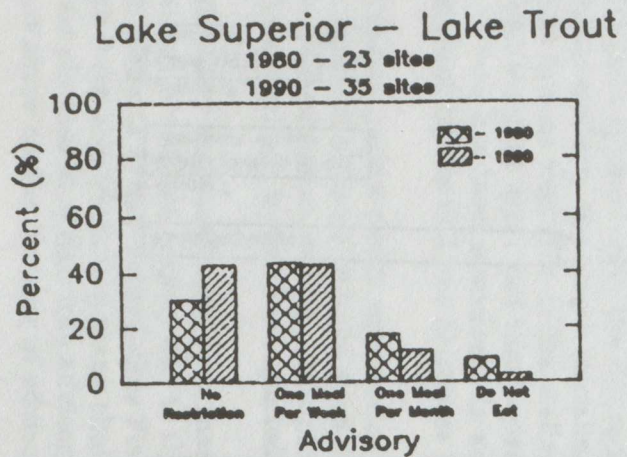
Figure 3.2
Wisconsin Fish Consumption Advisories



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Figure 9

Restrictions on Sport Fish Consumption Canadian Waters of the Great Lakes



(Source : Ontario Ministry of the Environment 1980; 1990)

consumption advice for each. Issues regarding risk assessment methodologies and the presence of multiple contaminants should be examined. Regions must work together to determine the best ways to communicate risks and publicize the advisories. The selection of contaminants to be monitored as well as the interlaboratory QA/QC checks should be uniform throughout the basin. Finally, a new EPA guidance manual on "Assessing Health Risks from Chemically Contaminated Fish and Shellfish" is being developed, and hopefully the jurisdictions will agree on its content.

With continuing efforts, a more unified system of fish advisories between both countries can be achieved. Cooperation between jurisdictions has been shown to be effective, and if maintained, will lead to resolution of current problems. If the Great Lakes states and Ontario succeed in accomplishing a unified basinwide program, it may serve as a template to the formation of a complete bi-national protocol which includes all the waterways of North America. A coordinated system of advisories which promotes wise consumption of fish while still emphasizing the health value of fish as a food source will benefit the general public and the sport fish industry simultaneously.

3.4 BEACH CLOSURES

The ability to swim in its waters has been one of the alluring aspects of the Great Lakes, and public beaches and parks have long histories. However, just as with the consumption of fish, the activities described in Chapter 2 have also resulted in contamination of the nearshore waters to such an extent as to preclude recreational activities. Bacterial contamination due to disposal of domestic sewage and other activities resulted in the exceedence of total or partial body contact recreation. Outbreaks of Salmonella, Coxsackie virus, Hepatitis A, Shigella and Norwalk Agents have been documented in humans who swam in polluted waters (DuFour 1984). As a result, beaches in contaminated areas have been closed to contact recreation.

Annex 2 of the Great Lakes Water Quality Agreement of 1978 lists beach closings as an "impairment of beneficial use" of the Great Lakes. While exposure to pathological bacteria through drinking water has been virtually eliminated through water treatment procedures, there are still occasional high levels of fecal coliform in the waters near urban regions. If the bacteria reach high concentrations, the state, province or municipality may close the beach for a period of time until it is felt the water is fit for human contact. Use of the bacteria *E. coli* as a specific organism to indicate water quality in relation to human contact was recommended in the Great Lakes International Surveillance Plan, but to date, with the exception of Kenosha County, Wisconsin, the local health departments have not initiated any monitoring of *Escherichia coli* in their areas (Baygood Research Incorporated 1989, Martin Strong, Ontario Ministry of the Environment, personal communication).

Table 3.1 provides a summary of the Great Lakes beach closings in the United States for the period of 1981 to 1989. Almost all of the states monitor near or at 100% of the beaches reported. Michigan only monitors about one third of their reported beaches, but the number of beaches reported is considerably more extensive than the other states, and on an annual basis, Michigan monitors more beaches than any other state. Wisconsin monitors only about half of their reported beaches.

TABLE 3.1

SYNOPSIS OF GREAT LAKES BATHING BEACH RESTRICTIONS AND CLOSURES

STATE	YEAR	NUMBER OF BATHING BEACHES REPORTED	NUMBER OF BATHING BEACHES MONITORED	PERCENT OF BEACHES MONITORED	NUMBER OF BATHING BEACHES REPORTED CLOSED OR RESTRICTED	PERCENT BEACHES REPORTED CLOSED OR RESTRICTED	NUMBER OF BATHING BEACHES REPORTED PERMANENTLY CLOSED	PERCENT BEACHES REPORTED PERMANENTLY CLOSED
Illinois	1981	48	48	100.0	43	89.6	0	0.0
	1982	48	48	100.0	47	97.9	0	0.0
	1983	48	48	100.0	40	83.3	0	0.0
	1984	49	49	100.0	3	6.1	0	0.0
	1985	49	49	100.0	28	57.1	0	0.0
	1986	49	49	100.0	8	16.3	0	0.0
	1987	49	49	100.0	45	91.8	2	4.1
	1988	48	48	100.0	5	10.4	2	4.2
	1989	49	49	100.0	35	71.4	0	0.0
Indiana	1981	16	13	81.3	4	30.8	2	15.4
	1982	16	13	81.3	3	23.1	1	7.7
	1983	17	14	82.4	4	28.6	1	7.1
	1984	17	17	100.0	4	23.5	1	5.9
	1985	17	16	94.1	8	50.0	1	6.3
	1986	17	16	94.1	4	25.0	2	12.5
	1987	17	16	94.1	4	25.0	2	12.5
	1988	17	16	94.1	7	43.8	2	12.5
	1989	17	16	94.1	6	37.5	1	6.3
Michigan	1981	238	95	39.9	5	5.3	3	3.2
	1982	241	95	39.4	6	6.3	1	1.1
	1983	243	95	39.1	3	3.2	0	0.0
	1984	296	103	34.8	3	2.9	1	1.0
	1985	292	107	36.6	2	1.9	0	0.0
	1986	277	107	38.6	26	24.3	0	0.0
	1987	293	90	30.7	0	0.0	0	0.0
	1988	288	136	47.2	2	1.5	0	0.0
	1989	293	112	38.2	7	6.3	1	0.9
Minnesota	1981	1	1	100.0	0	0.0	0	0.0
	1982	1	1	100.0	0	0.0	0	0.0
	1983	1	1	100.0	0	0.0	0	0.0
	1984	1	1	100.0	0	0.0	0	0.0
	1985	1	1	100.0	0	0.0	0	0.0
	1986	1	1	100.0	0	0.0	0	0.0
	1987	1	1	100.0	0	0.0	0	0.0
	1988	1	1	100.0	0	0.0	0	0.0
	1989	1	1	100.0	0	0.0	0	0.0
New York	1981	60	56	93.3	4	7.1	3	5.4
	1982	61	57	93.4	3	5.3	2	3.5
	1983	61	57	93.4	4	7.0	2	3.5
	1984	58	56	96.6	3	5.4	2	3.6
	1985	58	50	86.2	3	6.0	2	4.0
	1986	58	48	82.8	4	8.3	2	4.2
	1987	58	48	82.8	3	6.3	1	2.1
	1988	65	65	100.0	4	6.2	1	1.5
	1989	65	65	100.0	3	4.6	1	1.5

Table 3.1 - cont'd.

STATE	YEAR	NUMBER OF BATHING BEACHES REPORTED	NUMBER OF BATHING BEACHES MONITORED	PERCENT OF BEACHES MONITORED	NUMBER OF BATHING BEACHES REPORTED CLOSED OR RESTRICTED	PERCENT BEACHES REPORTED CLOSED OR RESTRICTED	NUMBER OF BATHING BEACHES REPORTED PERMANENTLY CLOSED	PERCENT BEACHES REPORTED PERMANENTLY CLOSED
Ohio	1981	31	31	100.0	8	25.8	4	12.9
	1982	52	52	100.0	7	13.5	2	3.8
	1983	52	52	100.0	18	34.6	2	3.8
	1984	53	53	100.0	2	3.8	2	3.8
	1985	54	54	100.0	5	9.3	2	3.7
	1986	54	54	100.0	9	16.7	1	1.9
	1987	54	54	100.0	2	3.7	3	5.6
	1988	54	54	100.0	2	3.7	3	5.6
	1989	54	54	100.0	3	5.6	3	5.6
	Pennsylvania	1981	40	31	77.5	0	0.0	0
1982		40	40	100.0	0	0.0	0	0.0
1983		40	40	100.0	1	2.5	0	0.0
1984		40	32	80.0	0	0.0	0	0.0
1985		40	32	80.0	2	6.3	0	0.0
1986		40	32	80.0	2	6.3	0	0.0
1987		40	40	100.0	4	10.0	0	0.0
1988		42	42	100.0	6	14.3	0	0.0
1989		42	42	100.0	9	21.4	0	0.0
Wisconsin		1981	57	26	45.6	8	30.8	2
	1982	57	26	45.6	10	38.5	4	15.4
	1983	57	27	47.4	10	37.0	1	3.7
	1984	54	28	51.9	4	14.3	1	3.5
	1985	54	30	55.6	1	3.3	1	3.3
	1986	54	30	55.6	12	40.0	3	10.0
	1987	57	34	59.6	6	17.6	3	8.8
	1988	57	34	59.6	7	20.6	2	5.9
	1989	57	33	57.9	6	18.2	1	3.0

Source: Survey of Great Lakes Bathing Beaches, 1989

In 1989, Illinois reported the most closings and restrictions, with 71% of the beaches closed. The state with the least percentage of closings (excluding Minnesota) was New York, reporting only 4.6% of their 65 beaches closed in 1989. Permanent closings of beaches occurred in the greatest proportion in Indiana, where 6.3% of the beaches were closed permanently (Baygood Research Incorporated 1989).

The status of beaches in Ontario is shown in terms of days closed in Table 3.2. The highest number of days closed for the swimming season of 1990 occurred in Lake Ontario, with 20 times the number of days closed than any other Great Lakes water body. Table 3.3 shows the number of beaches per water body, and what percentage of the season they were closed (the Ontario Ministry of the Environment and Energy designated the 1990 swimming season as 84 days (June 9 to August 31). In Lake Ontario, nearly half of the beaches were closed more than 20% of the season. Both Lake Superior and Ontario had beaches closed more than 80% of the season. In 1986, 40% of the beaches monitored in Lake Ontario were closed between 30 and 100% of the swimming season (International Joint Commission 1987). In 1990, 35% of the beaches in Lake Ontario were closed for the same length of time (Ontario Ministry of the Environment 1990).

There exist substantial limitations in using the number of beach closings in a region as an indication of water quality. There are often no monitoring programs conducted, where programs are in place, the criteria used (to close a beach) and the agencies responsible for monitoring vary from county to county. Some areas do not conduct bacterial analysis but base the closures on visual observation of water clarity. The states and Ontario use different fecal coliform levels to issue a beach closing. Finally, some beaches are closed on the basis of weather conditions, erosion and lack of funding. With all of these variables, deducing water quality from beach closings is speculative at best.

3.5 CONCLUSIONS

As has been documented in previous Water Quality Board reports and elsewhere, the control efforts of the 1970s have resulted in significant decreases in the presence of several contaminants to the lakes, including phosphorus, PCBs, DDT, dieldrin and mirex. Determination of these decreases have been based on the consideration of well-established, long-term monitoring programs conducted by the Parties and jurisdictions.

Evaluations are now focusing on the effects or impairments observed in the basin. The objective is to bridge the gap between the observed concentrations of substances and the need for additional controls. In other words, although levels of toxic substances have been reduced substantially, are the current levels continuing to adversely affect populations of aquatic and wildlife organisms. A cursory evaluation of some of the research information on fish and wildlife indicate that positive changes are occurring; benthic communities are recovering, bald eagles are returning in greater numbers, cormorant populations are increasing, and occurrences of nuisance algal blooms have diminished.

TABLE 3.2

SUMMARY OF CANADIAN GREAT LAKES BEACH CLOSINGS
BY DAILY POSTINGS (1986-1989)

LAKE OR AREA	NUMBER OF BEACHES MONITORED	TOTAL NUMBER OF DAYS CLOSED PER YEAR FOR ALL BEACHES COMBINED				
		1986	1987	1988	1989	1990
Erie	62	0	21	36	4	49
Huron	148	0	24	49	26	48
Ontario	100	957	2,489	1,631	1,750	2,140
Superior	9	0	0	15	0	71
Lake St. Clair	2	0	0	0	0	0
St. Clair River	4	51	86	130	114	119
Bay of Quinte	4	0	7	28	39	51
Georgian Bay	2	0	0	0	0	0
North Channel	5	23	16	13	45	0
St. Lawrence River	23	0	48	65	153	4

TABLE 3.3

SUMMARY OF CANADIAN GREAT LAKES BEACH CLOSINGS
BY PERCENTAGE OF SEASON CLOSED (1990)

LAKE OR AREA	NUMBER OF BEACHES MONITORED	NUMBER OF BEACHES CLOSED BY PERCENTAGE OF SEASON LENGTH (84 DAYS)				
		0-20%	21-40%	41-60%	61-80%	81-100%
Erie	62	60	2	0	0	0
Huron	148	147	1	0	0	0
Ontario	100	53	16	21	6	4
Superior	9	8	0	0	0	1
Lake St. Clair	2	2	0	0	0	0
St. Clair River	4	1	2	0	1	0
Bay of Quinte	4	3	0	1	0	0
Georgian Bay	2	2	0	0	0	0
North Channel	5	5	0	0	0	0
St. Lawrence River	23	23	0	0	0	0

However, there still remain excessive occurrences of severely degraded benthic communities, the Great Lakes eagle populations have not responded as well as those further inland, and lake trout continues to suffer poor natural reproduction. In addition, other more chronic effects may be occurring that reduces the viability of the individual or population. Finally, despite the improvements in some monitored variables, there remains a wide range of fish that are deemed unacceptable for human consumption.

It is apparent that a continued approach to management on a chemical-by-chemical basis will not be sufficient to restoring the beneficial uses of the basin. Likewise, the selection of integrative indicators of the health of various parts of the system will be needed to supplant existing measures of water quality. This chapter has considered only a few of the impairments to beneficial uses; as outlined in Annex 2 of the Great Lakes Water Quality Agreement. Although it is currently difficult to evaluate current trends in the use impairments, the fact that they occur at all necessitates additional control measures. Additional consideration also needs to be given to the choice of indicators to adequately characterize specific use impairments and overall ecosystem health. In the next chapter, some of the necessary considerations in identifying and selecting appropriate indicators are discussed.

4.0 AN APPROACH TO GREAT LAKES BASIN ECOSYSTEM REPORTING

4.1 INTRODUCTION

In the previous chapters to this report, the impact of human development on the Great Lakes Basin Ecosystem and in turn, the impact of the damaged ecosystem on humans is described. This particular theme was chosen in order to emphasize the placement of humans WITHIN the ecosystem as one (albeit very important) component of the ecosystem. This perspective is fundamental to the adoption of the ecosystems approach in restoration and preservation of the Great Lakes Basin Ecosystem.

In the preceding chapter, emphasis was placed on discussing the ecological significance of the contaminants detected in various lifeforms. The effects were discussed in the context of use impairments being suffered by the Great Lakes society. This type of reporting brings us a little closer to understanding the socio-economic implications of living in a contaminated ecosystem.

In this chapter, we discuss directly the idea of State of the Great Lakes Basin Ecosystem Reporting. In our discussions we attempt to explain what kind of reporting it is; how it differs from other kinds of reporting; the underlying premise of such reporting and the need for and selection of environmental health indicators.

4.2 A NEED FOR GREAT LAKES BASIN ECOSYSTEM REPORTING

The language of the ecosystem approach has been in IJC documents for over a decade. However, in the reporting of the state of the ecosystem the full spirit of the ecosystem approach has yet to be implemented. Parameter reporting such as of concentrations of organic toxics in the waters is still an essential component in a program of remedy for an insulted ecosystem. However, it emerges that although such reporting is necessary it is not sufficient. The integrity of the ecosystem demands a more expansive approach to reporting because the problems are so pervasive and complicated. The public has come to suspect, and the scientific community is beginning to show that the feedbacks onto humans are as prevalent as the human inputs to the system, or more so.

The ecosystem approach as a guide to reporting the state of the ecosystem was more radical than first supposed. The closest parallel is the report on the Toronto Waterfront, a report almost unique in its insistence on the ecosystem approach. Even so, there never has been a reporting of the state of an ecosystem as large as that of the entire Great Lakes basin taking the integrative approach.

The necessity of maintaining extant data collecting procedures must not be mistaken for sufficiency. More of what has been reported before is important, but is not enough. The crucial requirement at this time is an identification of integrative measures and protocols that can address the ecosystem as a whole. Accordingly, the word "Toward" appears in the title of this report. The present report represents a first phase, an outlining of the problem and a rationale as to why we cannot do without integrative reporting. Subsequent reports will be able to remove the first word of our title, but the presence of "Toward" is not only honesty in labelling, but it is a flag on how large is the

problem of achieving meaningful protocols and measures for the fully integrated system that we have no choice but to invoke. In the end we will be able to drop down to a practical level that gives the findings of the effects-oriented reporting.

4.3 MEASUREMENT AND THE ABSTRACT ECOSYSTEM

In his "Structure of scientific revolutions," Kuhn (1970) identifies that science works within intellectual frameworks that prescribe what is considered worthy of study and can be considered a valid question and answer. These frameworks, called paradigms, are essential for scientific progress, being the means generating the agreed upon definitions and protocols that keep scientists across a given field working together. Paradigms form around technological options for ways of measuring, but also amount to tacit accords not to ask certain questions.

The requirement to adopt an ecosystem approach is pressing a paradigm change on environmental scientists. With capability limited to measure only local environmental state, scientists accepted assumptions about system mixing so that local measurements might be considered representative of a larger system. The tacit agreement was not to ask how larger scale feedbacks and irregularities across the larger system made the basinwide ecosystems poorly represented by local measurement. The larger system was left essentially undefined, hidden behind general assertions that everything is connected to everything else. It is important that the dynamics of the large scale ecosystem be understood and that the ecosystem be defined. This is not a simple matter. There is no one correct definition, and the scientist must accept responsibility for the subjectivity which is embodied in each definition of the ecosystem.

Unlike the state of a commonplace object, the state of a large abstract entity like the Great Lakes Basin Ecosystem is most problematic. The central problem is that we do not deal with the material ecosystem itself. Rather we deal with descriptions of it. A description is powerful if it is able to ignore much detail but still allow prediction. When we say we know how something works, we can make a powerful description of it. Those powerful descriptions are implied in the definition of the system invoked by good questions.

With the simple commonplace object, the question about its state is often obvious like, "How much does it weigh today?" With a complex like the Great Lakes Basin Ecosystem we wish to know the answer to a large number of questions which may only be marginally related. A further complication is that each question may imply a different type of system because each question considers only some relationships and parts as important. A social system and a nutrient cycle are two different system types, and the relationship between them is not at all transparent.

The name Great Lakes Basin Ecosystem is not just one object, but with a set of ecosystem descriptions, each at its own scale. There is not one true boundary to the system. Sometimes the system will have to be bounded so large as to involve United States foreign trade policy that allows exports of banned pesticides to Mexico, from which the pesticide blows home to the Great Lakes on the wind. That is the system that is needed to answer the question, "How is it that there still appears to be significant input

to the lakes of a toxic that is not, has not, been used in the basin for a decade?" At other times the important system is just the habitat of a local rare species. The question there might be "How can we avoid this population becoming extinct.

Many of the questions encompass physical, biological, and social concerns. To address such problems requires comprehension of the linkages between the ecological system to be protected and the economic system supporting the welfare of the human population. The ecosystem with the human creature inside it is remarkably different from one where humans operate on other biota and physical processes as an outside influence. As humans act on the material world, not only do they change it, they change their relationship to it. The critical object of study shifts from the material system to one defined by human values. Therefore, as we report the state of the Great Lakes Basin Ecosystem, the state of the values of the humans in the ecosystem must be measured. To do this we will have to select ecosystem measurements, as the Agreement requires. Choices about what to measure encompass choices about what is important to maintain or improve, and this requires input about basic human values. To achieve success in remediation of the Great Lakes may require humans to reconfigure their activities to provide a dynamic harmony between their activities and the ecological process operating in the basin. The ecosystem approach expressed in socio-economic terms suggests ethical problems and not just technical ones.

4.4 INDICATORS

The challenge is to identify the state of a system on which there is an infinite number of types of measurements, but only an unknown few of which are important? Worse, the system being complex requires description at different scales. Given the amount of time and scarce resources taken to monitor each synthetic chemical and ecosystem component, measurements of indicators of states must be carefully considered, so that we select only those which are important. Accordingly, this report includes considerations of the general principles that lie behind choosing good indicators for the state of this abstraction we call the ecosystem.

As indicated in the previous chapter, in Appendix 1, and by Government of Canada (1991), several chemicals have declined over the past decade, yet biological and biochemical measurements suggest that contaminants continue to affect the biota of the Great Lakes. Because of the large number of variables it was difficult to unravel the ecological impacts of the combinations of chemicals in the Great Lakes.

To understand the ecological impacts of contaminants, different kinds of measurements may have to be made. The Great Lakes Basin Ecosystem may have to be studied and monitored at a higher scale than previously. There must be an assessment of the kinds of ecosystem indicators that are available and which of these might be used in evaluating effects of chemicals in the Great Lakes. Detecting ecosystem change with appropriate indicators is essential for evaluation progress in meeting the goals of the Great Lakes Water Quality Agreement.

The ecosystem approach to cleaning up the Great Lakes requires action that results in maintenance of the integrity of the system. A three step process is proposed

here. First, in this State of the Great Lakes basin report, an inventory and assessment of potential ecosystem indicators is presented. Second, the governmental agencies with responsibility for monitoring the Great Lakes Basin Ecosystem would select those monitoring tools that fit their mission, and third, those agencies would implement the designated monitoring programs. Only the first step of identification of indicators is covered by this chapter.

4.4.1 Relating Indicator Development to Management Goals for the Great Lakes Region

Implementation of an effective monitoring program for the Great Lakes, or any region, is contingent on the development of explicit, generally accepted ecosystem conditions to be achieved and maintained (i.e. ecosystem objectives). Indicators are selected that are useful in judging the extent to which specific objectives have been achieved, e.g. that selected quality control parameters have remained within an acceptable range. To identify possible ecosystem indicators, the Council of Great Lakes Research Managers commissioned a study by J. Cairns, Jr., et al. (1991), summarized in this chapter.

Recognizing the limitations of the sole reliance on chemical-specific objectives, revisions of the Great Lakes Water Quality Agreement have increasingly emphasized a broader "ecosystem approach" to managing the Great Lakes (e.g. Great Lakes Water Quality Agreement 1978), one which recognizes the interrelation of biotic and abiotic ecosystem components, including humans, and the relationship between the lakes and their surrounding watershed.

The principle goal of management derived from the ecosystem approach has been to restore and maintain "the chemical, physical, and biological integrity of the lakes and their surrounding basins so that beneficial uses are not impaired." In keeping with this goal, objectives previously developed for Lakes Superior (Ryder and Edwards, 1985) and Erie (Edwards and Ryder, 1990) have focused on maintaining a balanced, stable oligotrophic and mesotrophic ecosystem, respectively. Indicator development related to this objective has centered on the identification of surrogate organisms, species which integrate critical physical, chemical, and biological properties of the ecosystem and, thus, can be used to judge the relative health of the ecosystem. Key indicator species chosen for monitoring, the lake trout (Lake Superior) and the walleye (Lake Erie), were determined to be useful not only in gauging ecosystem health, due to their role as top predators in these ecosystems, but for judging potential impacts on human use, as well due to their commercial importance.

The remainder of this chapter will focus on a framework for selecting indicators that can be used to judge the attainment and maintenance of ecosystem conditions in the Great Lakes region compatible with the concept of sustainable development and the "ecosystem approach" as stated in the revised Great Lakes Water Quality Agreement of 1987.

4.4.2 Development of an Indicator Program

It is unlikely that any single indicator can be found that fulfills all of the above-stated purposes. To foster a comprehensive and organized approach to Great Lakes management, development of a comprehensive indicator program is needed. Indicators are needed to judge the attainment and maintenance of ecosystem objectives related to the restoration and maintenance of environmental quality in the Great Lakes region, yet their significance should be readily communicable to the public and policymakers.

Indicators may also provide insight as to the cause of nonattainment of objectives. Information on changes in the quantity or quality of habitat or resources or the water column concentration of a toxic chemical, for example, may be correlated with changes in levels of biological indicators (e.g. changes in lake trout population dynamics). Yet other indicators may serve to: 1) signal impending deterioration in environmental conditions; and 2) judge the need for continued remediation effects. For example, the number of breeding pairs of bald eagles may recover to acceptable levels but eggshell thinning may continue to be detected. Indicators of ecosystem change also allow for management actions to be implemented before conditions have deteriorated.

4.5 EVALUATING AVAILABLE INDICATORS

Indicators for the assessment of current ecosystem conditions need high biological and social relevance to be effective at documenting the health of the environment. Broad applicability to different stressors would permit standardization across Areas of Concern and increase the likelihood that an indicator would also reflect changes in environmental health due to new and unanticipated stressors.

Indicators must be based on the goals and objectives set for a particular ecosystem or region. For example, concentrations of toxic substances may be termed an indicator of the achievement of chemical-specific objectives outlined in the Great Lakes Water Quality Agreement. Indicators of ecosystem and human health are generally not so obvious and, ultimately, selection of these will be based on the ecosystem objectives to be met.

To address ecosystem effects, monitoring may have to be modified or expanded to detect changes in the structure or function of the Great Lakes Basin Ecosystem. Measurements of population, community, and ecosystem levels tend to be more appropriate indicators for judging achievement of ecosystem objectives, which will tend to focus on issues such as the sustainability of target populations and the lake community. Conversely, measurements performed on individuals (e.g. enzyme analyses) will be better warning indicators of stressors (e.g. effects of persistent contaminants on biochemical and physiological processes of individuals).

4.5.1 Individuals and Populations

Candidate indicators of environmental stress within individuals or populations include:

- a) Biochemical effects at the cellular and subcellular level (e.g. enzyme

induction).

- b) Body burdens of chemicals in various tissues of individuals used as an indicator of exposure.
- c) Growth rate of individuals.
- d) Carcinogenesis.
- e) Teratogenesis and congenital defects.
- f) Susceptibility to disease.
- g) Behavioral effects.
- h) Morphological changes in algal cells, etc.
- i) Feminization.
- j) Abundance and biomass of individuals in the population.
- k) Production or yield.
- l) Natality and mortality.
- m) Population age structure.
- n) Population size structure.
- o) Number of breeding pairs.
- p) Geographical range of population.

These parameters have been measured with different species and, obviously, not all of them are applicable to every taxonomic group. A suite of indicator species may be necessary to provide a comprehensive assessment of changes in ecosystem condition related to a multitude of important stressors. Species that are complementary in terms of their sensitivity to various stressors should be identified for this purpose.

Terminal predators are the most widely supported candidate indicator species for assessing environmental conditions largely because of their susceptibility to persistent toxic contaminants, which are magnified as they move up through the biological food web and the commercial and aesthetic value placed on many such species. The three taxonomic groups that include top predators (fish, birds and mammals) have different attributes that recommend for or against their use as indicators. For example, while wild mammals (e.g. mink) may be superior for predicting potential health consequences to humans, they are difficult to monitor because of their elusive habits. Predatory fish such as the lake trout are economically important but may be rather poor predictors of effects

on humans.

Using criteria similar to those proposed in this report, Ryder and Edwards (1985) recommended the lake trout as the optimal indicator species for measuring environmental conditions in oligotrophic (low productivity) ecosystems. Similarly, the walleye was chosen as the primary indicator for gauging the recovery of habitats that were historically mesotrophic (moderate productivity) (Edwards and Ryder, 1990). In addition to their position as top predators in the aquatic food chain, the suitability of these species is enhanced by a thorough understanding of their autecology and their ability to act as 'integrator organisms', one which reflects both direct and indirect effects of various environmental stressors (Ryder and Edwards, 1985).

No 'ideal' indicator organism exists. Companion indicators were, therefore, chosen for both oligotrophic and mesotrophic conditions. The benthic amphipod *Pontoporeia hoyi* was considered to be a suitable complementary oligotrophic indicator species to the lake trout; both its location within the ecosystem and its relative sensitivity to different types of stress are somewhat different from that of the lake trout (Ryder and Edwards, 1985). A second member of the zoobenthos, the mayfly *Hexagenia limbata*, was chosen as a companion indicator to the walleye in mesotrophic habitats (Edwards and Ryder, 1990). Identification of indicator species for Lake Ontario has also focused on *Hexagenia* (Reynoldson et al. 1989).

A reasonably comprehensive data base exists for a second set of terminal predators, fish-eating birds. The devastating effects of pollution, particularly persistent organic contaminants (e.g. organochlorine pesticides), on a number of avian species have been well documented (reviewed in Gilbertson 1988, Peakall 1988). Many useful measures of organismal and population stress have been proposed for species such as the herring gull. Population measures, such as geographical distribution and the number of active breeding pairs for more sensitive species (e.g. the bald eagle and the osprey) may serve as indicators of attainment of ecosystem objectives related to a 'healthy' ecosystem. The potential for public participation in certain monitoring activities (e.g. bird censuses) exist for this group, which generally rank well in terms of public appeal. A number of biochemical and physiological indicators of stress have been developed (e.g. Gilbertson 1988, Peakall 1988).

The herring gull has been one of the most intensively studied species with respect to the impact of pesticides on the Great Lakes. The usefulness of this species has been questioned for several reasons (Ryder and Edwards, 1985); 1) environmental tolerances too broad; 2) opportunistic feeding habits; 3) seasonal migration between the upper and lower lakes; and 4) lack of standardization of commonly used measures (e.g. reproductive success). These criticisms notwithstanding, the herring gull appears to rank high as a candidate indicator species. The herring gull is a widely distributed terminal predator, and populations are present year-round in the lakes region (Gilman et al. 1979).

Other candidate indicator species may have selective sensitivities. Fish-eating mammals such as mink, for example, are particularly sensitive to polychlorinated biphenyls (PCBs), another class of toxic contaminants (e.g. Aulerich and Ringer, 1977; Harris 1988). The phylogenetic similarity between these species and humans makes them

potentially useful indicators for assessing human health as well as environmental effects.

Selection of indicators for monitoring changes in the extent of eutrophication due to phosphorus loading into the lakes might focus on population of primary producers, since they are the biological interface between changes in phosphorus availability and ecosystem impacts. Although undoubtedly affected by toxic materials present in the lakes, algal species have been influenced most strongly by changes in phosphorus loading in the lakes following human settlement (Sicko-Goad and Stoermer, 1988). This makes them a particularly good set of indicators for tracking changes in phosphorus availability and nutrient limitation in the lakes.

The macroscopic chlorophyte *Cladophora* has also been proposed as an indicator of phosphorus loading (Auer et al. 1982) and is included in the Great Lakes International Surveillance Plan for some of the lakes. The abundance of *Cladophora* in the Great Lakes had responded according to changes in available phosphorus in nearshore areas, and prolific growths of this taxa can significantly impair beneficial uses in these areas (e.g. use of public beaches) (Auer et al. 1982). Species such as *C. glomerata* generally grow attached to the substrate, thus making them good integrators of local environmental conditions over time. Simple measures such as biomass are useful for quantifying point source phosphorus loadings, but must be performed rather frequently since substantial sloughing of *Cladophora* may occur during storms.

4.5.2 Communities and Ecosystems

A community/ecosystem level approach to environmental monitoring provides a robust assessment of ecosystem health in the Great Lakes, as it is impacted by the cumulative effects of many stressors ranging from persistent contaminants to the introduction of exotic species.

Numerous measures of community structure and ecosystem functions have been used as indicators of the response of natural ecosystems to stress, and no single measure enjoys unequivocal support as a consistently superior measure of ecosystem integrity.

- a) Number of species;
- b) Relative abundance/dominance;
- c) Biomass;
- d) Foodweb (trophic) structure;
- e) Productivity;
- f) Decomposition;

The ecological community can be broadly defined as all the species present in a given habitat that have the potential to interact. However, the term "community" is generally operationalized so as to encompass only those species of a particular taxonomic

group of interest to the observer. This is not to say that taxonomically dissimilar species do not interact strongly (e.g. fish and zooplankton) but, rather, that available data are largely dictated by taxonomic considerations. Reasonably well studied "communities" in the Lakes region include fish, bird, zooplankton, zoobenthic, meiofauna, phytoplankton, and periphyton.

The most basic parameter defining community structure is that of species diversity. This measure considers both the number of species present in a community (species richness) and their relative abundance (species evenness). Measurement of species diversity is one of the most commonly used parameters for assessing environmental condition. The ability to summarize information on species richness and evenness in a single value using a diversity index undoubtedly explains part of the appeal of these measures. Purported theoretical relationships between diversity and stability have led to a widespread belief that high species diversity is a property of healthy (i.e. stable) ecosystems and that decreases in diversity signal environmental deterioration and the loss of ecosystem integrity (Pontasch et al. 1989).

The biomass or standing crop of a particular community is a coarse indicator of community changes related to environmental stress that is useful in certain instances. For example, the yield of commercially valuable fish from the lakes may, for example, provide a good indicator of success in achieving a self-sustaining fishery. Phytoplankton standing crop (e.g. chlorophyll *a* biomass) is used as a measure for assessing trophic conditions (e.g. Hunsaker and Carpenter, 1990). Biomass estimates alone rarely provide adequate information for assessing environmental conditions but may be useful as part of an integrated index (e.g. trophic state index).

Communities are indicators of different aspects of ecosystem health. For example, communities that encompass populations with short generation times (e.g. microbial communities) can be expected to respond rapidly to acute stress. Communities containing longer-lived species integrate long term effects of stress (e.g. persistent contaminants). Communities containing species that fulfill several roles in the ecosystem (e.g. herbivores, predators, or scavengers) will likely be better integrators of different forms of stress, while those containing species performing very similar functions (e.g. phytoplankton communities) will generally be more diagnostic of particular types of stress (e.g. phosphorus loading). Benthic communities are generally better indicators of local conditions, because of their sedentary nature, while planktonic communities may integrate conditions across larger spatial scales.

Fish communities of the Great Lakes have been well studied and have been impacted by the cumulative effects of a variety of human stressors. These stressors include the introduction of exotic species, such as parasites (e.g. sea lamprey) and competitors (e.g. salmon [*Onchorhynchus spp.*]), commercial exploitation, eutrophication, toxic contaminants, and loss of certain physical habitats (e.g. spawning grounds). As with any community, certain attributes of fish assemblages limit their usefulness in some instances. For example, the mobility of species within these communities may reduce their usefulness as indicators of change in local environmental conditions. However, this same attribute is advantageous for basinwide monitoring since it enhances the ability of these communities to integrate effects of stressors over large spatial scales. Many species

utilize several different habitats within the ecosystem during the course of their life cycle, further enhancing their usefulness for basinwide monitoring. Given the ecological and social importance attached to these communities and the large amount of information available on their structure, they are certainly an essential part of a comprehensive monitoring program in the Lakes.

Models of food web dynamics are used as a predictive tool for ecosystem management. These models are used to forecast the consequences of changes in one biotic compartment (e.g. piscivorous fish) on other organisms in the larger lake community. This type of analysis has several applications to environmental management in the lakes, ranging from the consequences of overharvesting a particular fish species or declines in top predators resulting from contaminants to the accidental or planned introduction of a new species into the ecosystem (e.g. Cohen 1989; Fontaine and Stewart, 1990).

Ecosystem functional processes (e.g. productivity, decomposition) are important indicators of ecosystem stability or "homeostasis" (Odum 1985). Odum (1985), for example, predicts several functional responses to stress that signal imbalance in the ecosystem, including increased maintenance costs (elevated rate of respiration per unit biomass) and an imbalance in the ratio of production to respiration, which should be equal in a stable system. The question as to whether ecosystem structure or function is more sensitive to stress may be answered differently depending on the ecosystem under study. Studies of forest ecosystems generally found that functional changes (e.g. increased loss of nutrients and decreased rates of decomposition and primary productivity) provide an early indication of the onset of ecosystem stress than do structural changes (e.g. shifts in species composition). Just the opposite may be true in aquatic ecosystems, where unicellular algae are the dominant primary producers. In his work in the Experimental Lakes Area, Schindler (1987) found changes in ecosystem structure (i.e. algal species composition) to be a much more sensitive indicator of ecosystem stress, in this case increased acidity, than comparable functional indicators (i.e. ecosystem primary productivity). Thus, structural indicators of stress may be more appropriate in the Great Lakes than functional indicators.

4.5.3 Human Health

For most people, protection of human health is the most important possible goal of environmental management. There is no goal with higher social relevance. Polls have shown that people are unwilling to accept even minimal additional risks to human health as a consequence of environmental degradation from industrial activity, and the majority of people profess a willingness to pay more for products in order to reduce such risks (Gallup 1990, Harris 1990).

In the past five years there has been an improvement in the understanding of the actual effects of persistent toxic substances that have been observed in fish, wildlife and humans. The Water Quality Board (1987) documented detailed information of the status of populations of three top predators; bald eagles, mink and otters. In 1989, the joint publication of "Great Lakes, Great Legacy?" by the Conservation Foundation (United States) and the Institute for Research on Public Policy (Canada) for the first time brought

together much of the literature on the various effects of persistent toxic substances on organisms exposed through Great Lakes food webs. In 1989, the Cause-Effect Linkages Workshop, hosted by the Council of Great Lakes Research Managers, explored the scientific basis for causality and documented the effects of persistent toxic substances on two fish species, one reptile species, various bird species, two mammal species and on humans. The Canadian government has compiled the evidence of the effects and levels of persistent toxic substances in their 1991 publication "Toxic Chemicals in the Great Lakes and Associated Effects" (Government of Canada 1991).

Even with an apparent commitment to the goal of preventing human health effects from environmental degradation, there are serious problems in designing an effective program to monitor human health effects. Gross effects of pollution are always much easier to detect than subtle, rare, or long-term effects. Fortunately, gross effects on human health are rare in these times. It is the subtle, rare, or long-term effects that must be monitored and it is difficult to detect these effects with certainty. Study designs and possible endpoints are outlined in Table 4.1. Categories of indicators that can be monitored in any study design cover all organ systems and all stages of disease progression. Indicators of impact range from the most relevant measures of fully developed disease to quicker, cellular or behavioral measures of stress. The spatial scale of the study will be dictated by the probable route of exposure. For example, exposure through drinking water dictates a local spatial scale, whereas exposure through consumption of open water fish dictates a lakewide spatial scale.

Several International Joint Commission reports have addressed the factors contributing to uncertainty in determining human health effects of a degraded environment (International Joint Commission 1986; International Joint Commission 1990; Colborn 1990). Uncertainty results from the ethical imperative that studies with humans are correlative, not experimental. Studies with humans typically encompass multiple causative agents, not all related to the environment (e.g. adults in a study population sometimes smoke cigarettes). So conclusions about causality linking environmental agents to human health effects are weakened. To address this concern, designed experiments with surrogate species can be used, but animal data may not relate to human health. It is also difficult to detect the long-term effects of environmental degradation on human health in a timely manner. It may be necessary to rely on indicators that occur early in the progression of disease, before the fully developed adverse effect occurs. These indicators are usually small, quick, and relatively unimportant in and of themselves. Ames testing of drinking water, reproductive health of feral sentinel animals, and physiological biomarkers in exposed human populations are possible indicators of human health effects. But their effectiveness depends on the establishment of a clear relationship between these indicators and ones with more obvious biological and social relevance.

Three types of epidemiological studies of exposed human populations provide the evidence of human health effects. These studies have very high social relevance, but they often lack interpretability, timeliness, or generality across stressors. Environmental studies correlate disease incidence (from registries) with general measures of exposure on a gross scale. Retrospective case-control studies compare the health of individuals assigned to groups based on previous exposure. Cohort studies examine the health of

TABLE 4.1

POTENTIAL INDICATORS OF THE RESPONSE OF HUMAN HEALTH TO ENVIRONMENTAL DEGRADATION

A. Study Designs--Assessment approaches with different receptor organisms

- 1) Epidemiological studies on exposed human populations
 - a) Environmental studies
 - b) Case control studies
 - c) Cohort studies
- 2) Studies on sentinel species of exposed feral animals
 - a) mammals; minks, voles
 - b) birds; herring gulls, Foster's terns, bald eagles
 - c) fish; spottail shiners, brown bullhead
- 3) Studies on surrogate species of exposed laboratory animals
 - a) mammals; mice and rats
 - b) nonmammalian systems; tissue culture, bacteria (Ames assays), planaria, hydra, water fleas, fathead minnows

B. Categories of Indicators

- 1) Neurotoxicity
 - a) in vivo
 - regional incidence rates for Multiple Sclerosis, Parkinsons, Amyotrophic Lateral Sclerosis
 - behavioral assays; infant cognitive function, speech, gait, visual disturbance, headaches, memory function
 - biomarkers; biopsy and histopathology, visual-evoked response, electroencephalogram positron emission tomography, CAT scan, electromyography

Table 4.1 - continued

B. Categories of Indicators - cont'd.

1) Neurotoxicity - cont'd.

a) in vivo

-cell culture excitability, synaptic potential, repetitive firing properties, nerve conduction velocity

2) Reproductive toxicity

a) in vivo

-regional incidence rates for birth defects, infertility, miscarriage, stillbirth, low birth weight

-biomarkers; sister chromatid exchanges, sperm counts, motility, and morphological abnormality

3) Carcenogenicity / Mutagenicity / Genotoxicity

a) in vivo

-regional incidence rates

-biomarkers; DNA adducts, sister chromatid exchange, DNA unwinding, histopathology

b) in vitro

-histopathology of tissue cultures

-Ames mutagenicity tests

4) Cardiovascular disease

a) in vivo

-regional incidence rates

5) Immunocompetency

a) in vivo

-blood cell counts

groups subsequent to an exposure event.

Fish consumption is generally thought to present the greatest exposure and risk compared to other routes of exposure; drinking water and breathing aerosols. The most direct evidence for adverse human health effects from environmental pollution is found in a series of studies linking PCB exposure through consumption of contaminated fish to human health effects. Infants of mothers consuming fish from the Great Lakes were smaller than controls (Fein et al. 1984). Such infants also had behavior deficits (Jacobson et al. 1984), and impaired visual recognition, an indicator related to future intellectual functioning (Jacobson and Jacobson, 1988). However, no adverse health effects were clearly related to PCB exposure in fish eating adults (Humphrey 1988). Replicating and continuing these types of epidemiological studies provides the most relevant and convincing evidence of the status of human health. However, to be used as a monitor of environmental condition such studies would need to maintain a broad focus that includes possible effects from stressors other than PCBs. There is some evidence that cognitive function in infants is sensitive to a range of toxic substances and may be a general indicator (Jacobson and Jacobson, 1988).

In contrast to the paucity of direct evidence of adverse effects on human health, there is an abundance of evidence relating health effects on feral species to environmental degradation in the Great Lakes (see reviews by Colburn 1990; Gilbertson 1988). In addition to their intrinsic value, these species may well be effective sentinels for assessment of human health effects. Studies of feral populations have good biological relevance, and some social relevance. Because of differences in the way closely related species respond to the same chemical, there will be uncertainty in predictions of human health effects from observations on sentinel species.

Most assessments of human health effects of environmental pollution have been made using surrogate species. Commonly, a laboratory test exposes a laboratory population of a surrogate species such as mice to a single chemical. Dose-response relationships are determined and used to establish safe concentrations and standards. Because of the many problems in extrapolating from data on response to a single chemical to response to a complex mixtures of chemicals, the biological relevance of such tests is not high.

In studies with humans, sentinels, and surrogates, there are many indicators of health that can be assessed (Table 4.1). These indicators vary across organ systems, across disease progression, and across levels of the biological hierarchy from subcellular to whole organism. The whole organism, fully developed clinical indicators (e.g. cancer mortalities) are more relevant and interpretable but less timely than the subcellular biomarkers or bacterial surrogate indicators (mutagenicity tests). It is necessary to firmly establish the relationships between biomarkers and future clinical expression of disease before biomarkers can be considered sufficient evidence for regulatory action.

The monitoring of human health effects from environmental degradation is clearly one in which current scientific methods are not yet adequate to the task mandated by the public will. Because of the importance of the objective to the public, management action may be encouraged despite considerable uncertainty. But that same uncertainty

compromises the legal defensibility of the indicators and increases the likelihood of legal challenges to proposed management actions. Effort devoted to further development of promising methods is justified.

4.6 LINKAGE TO SOCIAL-ECONOMIC FACTORS

Periodic interviews of shareholders can provide data useful in several areas of policy-making and management. First, overall satisfaction with environmental quality can be assessed and used to provide feedback on the success of environmental management and its importance in the shareholder's quality of life (Milbrath 1978). Second, perceptions of importance of environmental goods and services are subjective. Relative importance may change in response to perceived environmental quality and economic well-being, recent publicity about environmental disasters, etc. Similar non-monetary rankings of aesthetic and ecological values must also rely on public input (Maguire 1988). Interviews of shareholders also serve as a measure of effectiveness of communication on environmental issues. Interviews can determine shareholder awareness of environmental problems, the source of their information, and their awareness of available forums for participating in management decisions. The level of participation in environmental protection activities can also be assessed from membership in sporting or conservation groups, attendance at policy-making forums, energy conservation, carpooling, recycling, etc.

Although interviews of shareholders and a focus on subjective well-being have been used in social impact assessment for environmental impact analysis and in cross-cultural comparisons, they have not been used as a monitoring or assessment tool. Questions on attitudes to the environment are included in polls, but because there is no consistency in phrasing and order of questions, this data cannot be used to assess trends over time. A standardized instrument is necessary for monitoring purposes. An instrument for determining perceived environmental quality and subjective well-being has been devised and tested in the Great Lakes basin (Milbrath 1978).

Linking subjective perceptions of environmental quality to the objective determinations of scientists is an important subsequent step. When the objective and subjective assessments of environmental quality agree that environmental quality is sufficient, management techniques are vindicated. If objective and subjective assessments reach different conclusions action is required. More effective communication of problems and risks to the general public, reformulation of goals more in line with shareholder interest, or reordering of priorities for addressing existing problems may be called for.

5.0 CONCLUDING REMARKS

5.1 REPORTING UNDER THE GREAT LAKES WATER QUALITY AGREEMENT

In light of the Commission's directive to the task force in June, 1990, to improve "state of the lake" reporting, the task force spent some considerable amount of time discussing the whole issue of reporting under the Great Lakes Water Quality Agreement. The task force members concluded that three kinds of reporting seemed appropriate for the International Joint Commission to pursue, given its mandate under the Great Lakes Water Quality Agreement. These are compliance or program evaluation reporting, effects-oriented reporting, and state of ecosystem health reporting.

5.1.1 Compliance or Program Evaluation Reporting

This type of reporting indicates whether a specific objective or program requirement of the Agreement is being met. The objective of this type of report is to evaluate the current water and environmental quality conditions against Agreement objectives, including the determination of the effectiveness of control actions, evaluation of trends of environmental stresses and identification of emerging issues. To date, this has been accomplished by the Commission primarily through the reports of its Water Quality Board and its technical committees which has come to be known as "state of the lakes" report. These reports are compiled by the Board and Commission staff based on the submission of surveillance and monitoring data and program information submitted by the Parties and jurisdictions. The task force agreed that this type of report was required for compliance and program evaluation reasons, to provide timely advice regarding the surveillance results, and to evaluate the trends in specific water quality and ecosystem health indicators. However, in order to adequately address the assessments of the significance of the stresses (i.e. contaminant levels) found in the Great Lakes Basin Ecosystem. The task force recommended two additional reports to be compiled, as described below.

5.1.2 Effects-Oriented Reporting

The task force was mindful that the Commission and its advisory bodies had previously indicated a desire to produce reports which would strive to be more explanatory of the effects of pollutant levels detected in various compartments of the ecosystem. To develop such reports would require more interpretative effort or assessment of the variety of pollution measurements being taken in the Great Lakes environment, including greater emphasis on the impairments observed, as discussed in the summaries prepared by the Biological Effects Committee of the Science Advisory Board which appear in this report and the Science Advisory Board reports. For example, the task force envisaged a report which could focus on wildlife or waterfowl or wetlands and analyze in depth the significance of the effects of contaminants or water levels to these specific parts of the ecosystem. It is felt that these types of reports could be produced within the biennial reporting cycle or longer depending how specific or general the scope of such reports. The task force felt that this type of reporting could be

accomplished in a variety of ways such as literature reviews, synthesis of existing research, workshops or roundtables of invited experts, in partnerships with academia and other private and public bodies. Relatively little extra effort and resources would be required.

5.1.3 State of Ecosystem Health Reporting

The task force agreed that a State of the Great Lakes Basin Ecosystem Report is needed to provide a holistic view of the health of the ecosystem periodically as a basis for strategic analysis and assessment. In dealing with something as large and complex as the Basin Ecosystem, a broad based evaluation in order to ensure that the total effect of specific programs and measures, (all of which may be meeting their individual objectives), is advancing the overall health of the ecosystem and not inadvertently demaging a particular part of it.

State of the Great Lakes Basin Ecosystem Reporting would be a broad-based assessment of ecosystem health. It would be based primarily on information arrayed against a suite of ecosystem health indicators. Such indicators now in development would be based on models of the Great Lakes Basin Ecosystem such as those being constructed by the Council of Great Lakes Research Managers. The task force has begun to address some of these issues in Chapter 4. The emphases for Great Lakes Basin Ecosystem Reporting would be on synthesizing and interpreting information from a variety of sources to draw out the accumulated and synergistic impacts upon the health of the Basin Ecosystem. The information base to be examined extends beyond programatic information routinely submitted to the Commission by the Parties and jurisdictions under the Canada-U.S. Great Lakes Water Quality Agreement. Such information is not being systematically compiled in the Great Lakes basin or elsewhere. It is likely that the report development process would be as important as the product itself. The process should allow for the contribution and active participation of a wide range of basin interests, through workshops, seminars, and colloquia and therefore should be viewed as a two-way communication and education process as well as an assessment process.

5.2 PERSPECTIVE

Each type of reporting has a perspective, particular point of view or an approach to the phenomena it is reporting. The task force adopts the "ecosystem approach" as it is generally understood; the proposition that the interactions of air, land, water and living things make up the Great Lakes Basin Ecosystem and that pollution of those components is effecting the health of the Basin Ecosystem and its parts including humans. This perspective is derived from the purpose of the Canada-U.S. Great Lakes Water Quality Agreement as stated in Article II; "to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem." The task force is of the view that this stated purpose cannot be achieved without taking into account the effects on water by and the effects of water on the other components of the Basin Ecosystem. Current knowledge of the Basin Ecosystem and its parts preclude taking a narrower perspective.

The task force believes that Effects-Oriented and State of the Great Lakes Basin

Ecosystem Reporting are consistent with this perspective, but that the current "State of the Lakes" reporting in and of itself does not adequately reflect the ecosystem approach. The major deficiency of this type of reporting is that it does not provide sufficient assessment and explanation of the ecological significance of the pollution levels being measured. The task force, however, recognizes that from a compliance/program evaluation perspective such reports have been and are useful. Inasmuch as the Canada-U.S. Great Lakes Water Quality Agreement is an institutional device by which transboundary pollution is being controlled it is important to know where Agreement requirements, especially specific water quality objectives are not being met, by how much, by which Party and by what cause. Knowing this allows the Commission, the Parties and the jurisdictions and the general public to determine whether the most basic control and remedial actions are being carried out and whether they are adequate.

5.2.1 Explicitly Placing Humans and their Activities in the Ecosystem Approach

Previous reports, and indeed current regulatory practices, have adopted a contaminant-specific or media-specific approach to evaluating compliance and characterizing the status of the environment. While this approach has been useful and successful to a degree, we now find that there needs to be a consideration of the entire spectrum of the ramifications of control activities. We can no longer focus solely on the reduction of pollutant loadings to the water column of the Great Lakes (i.e. effluent guidelines), but must also consider what those reductions will cost in the terms of increased loadings to other media (air, land, groundwater) and in terms of the translocation of the loadings (out of the basin). Thus, the task force determined that reporting on the state of the ecosystem would not be limited to the state of the biological, chemical, and physical environment, but also include the anthropogenic influences, the social, economical, and human behavioral characteristics that occur and effect the quality of the Great Lakes ecology.

This report reflects a first attempt at describing the framework for reporting on the state of the Great Lakes Basin Ecosystem. This report emphasizes the consideration of the entire system, including the role of humans impacting the environment and being impacted by the environment. The rapid, explosive growth of human habitation in the basin over the past 400 years has had a devastating impact on the ecology of the Great Lakes. This impact can be likened to a shock wave impact when one considers the current basic form of the basin has been in existence for over 10,000 years.

Human activities affecting the basin can be characterized by three fundamental categories; generation of waste residuals (resulting from the production of goods), permanent environmental restructuring, and extraction and harvesting of natural resources. Human use of the resources of the Great Lakes, through commercial fishing, logging, mining and extraction of iron ore, development and stabilization of shorelines, and capital production with the use of the lakes to flush wastes, have led to the expansive growth and attractiveness of the Great Lakes region in previous years. However, although these activities continue, we are now also coping with the effects of these economic activities, in particular, the loading of toxic contaminants, nutrients, radiounclides, and other substances to the waters, the overharvesting of fish communities,

timber, minerals, and perhaps even water, and the devastation of natural habitat, including littoral shoreline areas, wetlands, and tributary streams.

Although improvements have been observed over the past 20 years in regard to contaminant presence and also with some of the related effects, the ability of humans to continue to extract beneficial uses from the Great Lakes is being hindered. Benthic communities continue to show highly degraded conditions in the connecting channels, bald eagle populations continue to lag behind those farther away from the lakes, and the presence of lake trout continues to be reliant on stocking efforts. In addition, guidelines for the consumption of fish from the waters of the lakes continue to be exceeded for some species and locations. More control effects are needed, but should be based on the entire spectrum of persistent toxic chemicals rather than a constituent by constituent basis.

5.2.2 Some Basic Considerations in State of the Great Lakes Basin Ecosystem Reporting

- **Values**

In adopting an "ecosystem approach" in which humans and their activities are considered part and parcel of the ecosystem, the task force raised some very interesting and fundamental issues to address. One obvious question was "What is the Great Lakes Basin Ecosystem?" "Does it exist and how can it be bounded or defined?" Consideration of these types of questions quickly raised related issues such as how to deal with values of the human component in the ecosystem health assessments. The task force began to address these basic issues, through intense discussion which is reflected in Chapter 4. In this regard, the task force acknowledges the work of the Science Advisory Board which has explicitly addressed the need for a "code of ethics" for the protection of the Great Lakes Basin Ecosystem. The existence of such a code of ethics adopted by individuals and public and private institutions of the Great Lakes Basin Ecosystem will provide a standard by which to assess the adequacy of human individual and institutional behaviour. Such an element would be integral to State of the Great Lakes Basin Ecosystem reporting.

- **Conceptual Frameworks and Indicators**

An essential element for State of the Great Lakes Basin Ecosystem reporting is the existence of conceptual frameworks in which significant relationships among variables affecting ecosystem health and integrity are delineated. It is from such frameworks that a suite of indicators will be developed to provide the basis to analyze new and existing data, synthesize information and gain important insights and understanding of the state of the ecosystem. The task force is encouraged that the Council of Research Managers based upon their Great Lakes Vision 2000 project have begun to take steps to construct such frameworks by bringing together a variety of expertise over the past year. Also, the Council of Great Lakes Research Managers with the assistance of the Water Quality Board has taken the initiative to commission work on indicators which is basic to this whole activity. It is important that these basic activities continue as they are essential to the orderly development of a State of the Great Lakes Basin Ecosystem reporting capability.

• The Process of Developing a State of the Great Lakes Basin Report

The way in which a State of the Great Lakes Basin Ecosystem report is developed may be as important as the substance of the report itself. Taking an "ecosystem approach" requires not only a comprehensive perspective and analytical bent but the willingness to invite input of both knowledge and experience from a broad cross-section of the Great Lakes society. Since mid-1960s, the International Joint Commission has been instrumental in the development of a knowledgeable and aware Great Lakes citizenry. In turn, the Great Lakes community has spawned strong centres of knowledge, influence, and commitment which can be readily involved to contribute to the development of a comprehensive state of the ecosystem report.

Therefore, the development of a report must include ample opportunity to receive the contributions of these institutions and individuals in the planning, design, compilation, analysis and writing of the report. The task force is mindful that the development of this type of report provides an excellent educational opportunity for all sectors of society. In designing the reporting process, special attention should be paid to involving the young in creative ways. Lastly, the form of the report should be approached with openness. While written reports remain the norm, it is increasingly evident that information is received in numerous ways. The International Joint Commission already has experience with electronic conferences, and has shown creative interest in the development of educational materials and teacher training. The task force would encourage specific attention be paid to the form of reporting.

The task force sees State of the Great Lakes Basin Ecosystem Reports being produced perhaps once or twice a decade. A comprehensive and holistic analysis does not lend itself to a two or three year reporting cycle. At the same time, it is recognized that a state of the ecosystem reporting requires a continuous effort, to plan, to design, to compile, analyze and synthesize information, to gather new information, to consult, to receive input, to involve others, etc.

5.3 INTERNATIONAL JOINT COMMISSION LEADERSHIP

Convinced of the need for comprehensive Great Lakes Basin Ecosystem reporting, the task force discussed the role of the International Joint Commission. All members agreed that this important task is best carried out by the International Joint Commission. The reasons are compelling. First, the International Joint Commission is uniquely placed within the institutional arrangements for Great Lakes restoration and protection. In addition, it already has the mandate to report on the progress being made in the implementation of the Canada-U.S. Great Lakes Water Quality Agreement. Secondly, the International Joint Commission has a long history of reporting comprehensively on complex matters referred to it by the Governments of Canada and the United States. In compiling this record, it has skillfully utilized the best scientific and technical advice and reports to governments and the public has won widespread respect with citizens and institutions of North America. Thirdly, largely because of the reasons listed above, the International Joint Commission possesses the capacity to involve a large cross-section of the Great Lakes society, both citizens and institutions, in contributing to the development of a comprehensive State of the Great Lakes Basin Ecosystem Report.

The above description of the reporting process essentially serves as a central recommendation of this task force to the Commission. However, in order to effectively conduct this reporting, the selection of monitoring variables (indicators) needs to be carefully considered. The Great Lakes International Surveillance Plan (GLISP) thoroughly describes and identifies various indicators for assessing the achievement of specific objectives and determining trends and status of several indicators. However, while extensive and rigorous analysis went in to the development of GLISP, this plan was produced prior to the 1987 Protocol to the Agreement, and as such does not reflect the current emphasis on monitoring and tracking of effects and ecological health. Therefore, the task force also emphasizes the need to develop and implement the monitoring of additional indicators that more capably reflect the status of the health of the organism, population, and ecosystem.

A comprehensive report on the ecosystem status of the Great Lakes basin will require that increased comparison and linkages be established between the societal activities, those described in Chapter 2 of this report, and the resulting stresses to the environment. Such linkages, once established, will lead to the development of socio-economic variables and indicators for continued evaluation to track the status and trends in the activities of the human inhabitants of the basin as it affects the state of the ecosystem.

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APPENDIX 3

APPENDICES

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- 2 CONTAMINANT MONITORING PROGRAMS IN EDIBLE PORTIONS OF FISH AND FISH CONSUMPTION ADVISORY PROGRAMS
- 3 BENTHIC COMMUNITY DEGRADATION IN GREAT LAKES CONNECTING CHANNELS

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APPENDICES

- 1 STATE OF THE LAKES
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PORTLAND OF WASH AND THE CONSERVATION
PROGRAM
- 3 PLANNED COMMUNITY ORGANIZATION IN GREAT LAKES
CORRECTIVE ACTION

ACKNOWLEDGEMENTS

The Compiler expresses their gratitude to the Surveillance Subcommittee members and others for their contributions to this report. Appreciation is especially due to Dr. Paul Berman (Great Lakes National Program Office), Ms. Melanie Nelson (Inland Waters Directorate), Dr. Karl Soss (Water Pollution Control Board), Mr. Glenn Warren (Great Lakes National Program Office), Mr. Gordon Williams (Canadian Wildlife Service), and Mr. Mike Whittle (Department of Fisheries and Oceans) for their provision of data, analytical discussions, and comments. The Compiler also recognizes the efforts of Mr. Jeff Wynn, Mr. Steve Perry, and Ms. Mary Ann Stone of the Regional Office for graphical data displays and manuscript preparation.

APPENDIX 1

STATE OF THE LAKES

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APPENDIX I

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ACKNOWLEDGEMENTS

The Compilers express their gratitude to the Surveillance Subcommittee members and others for their contributions to this report. Appreciation is especially due to Dr. Paul Bertram (Great Lake National Program Office), Ms. Melanie Neilson (Inland Waters Directorate), Dr. Karl Sun (Ontario Ministry of the Environment), Mr. Glenn Warren (Great Lakes National Program Office), Dr. D.V. Weseloh (Canadian Wildlife Service), and Mr. Mike Whittle (Department of Fisheries and Oceans) for their provision of data, analytical discussions, and comments. The Compilers also recognize the efforts of Mr. Jeff Whyte, Mr. Steve Perry, and Ms. Mary Ann Morin of the Regional Office for graphical data displays and manuscript preparation.

STATE OF THE LAKES

INTRODUCTION

In its 1989 Report, the Water Quality Board announced its intention to move away from the more traditional "state of the lakes" report and provide greater emphasis on the comprehension of the information. This State of the Great Lakes Basin Ecosystem report has moved toward the "ecosystem approach" perspective and provides less emphasis on technical aspects of the data. The Board, however, in this Appendix, has prepared the long-term data that has provided the foundation for assessing the state of the lakes over the last two decades.

Annex 11 of the Great Lakes Water Quality Agreement (GLWQA) outlines the purpose and framework for surveillance and monitoring activities. In particular, this Annex requires that the Parties develop and implement a joint surveillance and monitoring program for the following specific purposes:

1. determining the achievement of general and specific objectives of the Agreement;
2. assessing the degree to which jurisdictional control requirements are being met;
3. identifying emerging problems; and
4. supporting Annex 2 programs (RAPs and LaMPs).

Annex 11 further stipulates that the Great Lakes International Surveillance Plan (GLISP), as developed by the Water Quality Board of the International Joint Commission in 1975 and subsequently modified, is to serve as the model for the binational surveillance and monitoring program. The GLISP provides the framework to ensure data are collected in a consistent and comparable manner by the numerous agencies responsible for its implementation.

The GLISP has been updated as the concerns and focus of the Agreement have shifted. With the 1972 Agreement, concerns were focused on defining and tracking trends in phosphorus loads and trends in dissolved oxygen depletion rates associated with cultural eutrophication. By the time of the signing of the 1978 Agreement and the relative success of controlling phosphorus, concerns had shifted to the loads of toxic chemicals to the lakes as evidenced by their concentrations and impacts on sediments and various biological species (fish, herring gulls, mink, bald eagles) in the Great Lakes basin. Most recently, concerns have focused on the broader aspect of the overall cumulative impacts that these toxic chemicals and other anthropogenic perturbations are causing to the integrity of the Great Lakes basin ecosystem. One particular aspect of this focus is the increased concern for the effects these chemicals have had and continue to have on the developmental, physiological and molecular functions of biological species including fish, predatory birds and humans. While the Water Quality Board has reported in the past on some of these effects (eg. reproductive success in herring gulls; occurrence of tumours in fish; occurrence of congenital abnormalities in fish and birds), they have not been part of the routine

reporting of the Board. There currently exist few monitoring programs to assess the "health" of the Great Lakes Basin Ecosystem. The identification of appropriate indicators of ecosystem health for the development of such programs is the focus of several initiatives (e.g. Council of Great Lakes Research Managers 1991).

The current GLISP (Surveillance Work Group 1986) includes programs to address most aspects of the Annex 11 requirements. Because it is already five years since completion, however, there are unavoidably some gaps as a result of the continually expanding focus of the Agreement and the International Joint Commission. Notwithstanding these, the core programs of the GLISP as outlined in the 1989 Report of the Water Quality Board and listed here in Table 1 have provided the only tracking mechanism for documenting improvements in water quality which the Commission clearly lacked almost two decades ago. In its 1973 report to governments, the IJC stated:

"While there are many indications and suggestions that the quality of the Great Lakes water is improving as a result of remedial programs and other measures undertaken in accordance with the 1972 Agreement, the progress towards meeting the agreed objectives cannot yet be confirmed on the basis of the scientific data and information supplied to the Commission." (International Joint Commission 1973)

With the Water Quality Board's development and endorsement of the GLISP and its implementation, albeit incomplete, by the Parties, the International Joint Commission has been in a much better position to report to the public and governments on the effectiveness of remedial measures implemented by the Parties. The International Joint Commission is currently reviewing its data and information needs. The result of this review will, no doubt, further impact the scope and, therefore, the data requirements of the GLISP.

The following briefly updates the information presented in Chapter IV (State of the Lakes) of the 1989 Water Quality Board Report.

EUTROPHICATION AND NUTRIENTS

As noted in previous Water Quality Board reports, the accelerated rate of eutrophication prevalent during the 1960s and 1970s was the focus of the phosphorus control programs of the 1972 Agreement and the 1983 Annex 3 Supplement to the 1978 Agreement.

Total Phosphorus

Significant decreases in the loads to lakes Erie and Ontario have occurred since the 1970s (Figure 1). In 1989, the Water Quality Board reported that the phosphorus loads to all the lakes were at or below the Agreement target loads. Tables 2-4 confirm this observation. The decreases in loads appear to be a direct result of a combination of the effectiveness of point source controls, including the implementation of full and partial phosphorus detergent bans, and reduced precipitation and flows. It is not yet as apparent what effect non-point source loads to the tributaries are having on the total tributary load

TABLE 1: CRITICAL ELEMENTS FOR EVALUATING PROGRESS UNDER THE AGREEMENT

MATERIALS SAMPLED		PARAMETERS ANALYZED	
GENERAL	SPECIFIC	TOXIC CONTAMINANTS ¹	NUTRIENTS ²
Inputs	Atmospheric	X	X
	Tributaries (Water and suspended solids)	X	X
	Point sources (Compliance and loading)	X	X
Water	Open Lake	X	X ³
	Nearshore	X	X
Sediments	Open Lake	X	X
Biological Exposure	Open Lake Fish (Trout/Smelt)	X	
	Nearshore (Spottail Shiners)	X	
	Wildlife (Herring gull eggs)	X	
Biological Effects	Fish (Open lake and nearshore)	Biological Parameters to Measure Effects of Contaminants have not yet been Developed	
	Invertebrates		
	Wildlife		
	Ecosystem (Food Web Indicators)		

¹Metals and Organics

²Total Phosphorus, Nitrate plus Nitrite

³In the spring, except for Lake Erie

FIGURE 1 : ESTIMATED ATMOSPHERIC, INDUSTRIAL, MUNICIPAL AND TRIBUTARY PHOSPHORUS LOADINGS TO THE GREAT LAKES (1976 TO 1989)

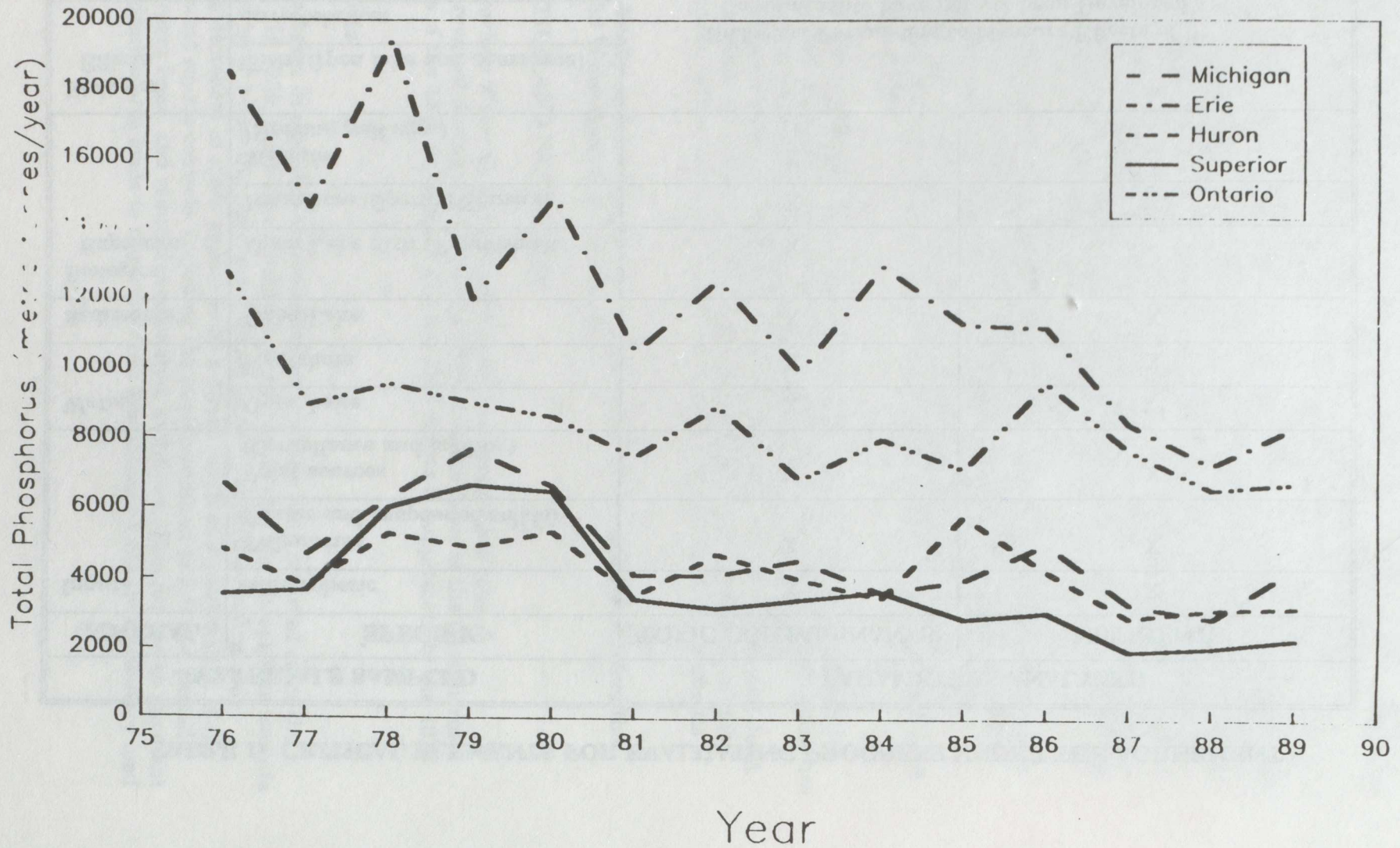


TABLE 2

SUMMARY OF 1987 ESTIMATED ATMOSPHERIC, INDUSTRIAL
MUNICIPAL AND TRIBUTARY PHOSPHORUS LOADING DATA TO THE
GREAT LAKES

(All values are in metric tonnes/year)

	Superior	Michigan	Huron	Erie	Ontario	St. Lawrence River	Total
Atmospheric (standard error)	559 (130)	253 (64)	648 (121)	470 (113)	193 (27)	-	2,123 (222)
Direct IND Discharge (standard error)	74 (7)	44 (5)	16 (2)	44 (5)	25 (2)	23 (2)	227 (11)
Direct MUN Discharge (standard error)	65 (2)	365 (13)	106 (7)	1,767 (56)	1,201 (43)	137 (6)	3,640 (73)
Tributary Monitored (standard error)	703 (108)	2,214 (217)	1,068 (114)	3,727 (120)	1,555 ¹ (72)	95 (15)	9,362 (302)
Adjustment for Unmonitored Area (standard error) ²	549 (118)	422 (37)	414 (60)	1,294 (111)	663 (85)	64 (16)	3,405 (197)
Within Lake Totals	1,949	3,298	2,252	7,301	3,637	318	18,756
From Connecting Channels			657	1,080	4,003	3,801	
OVERALL TOTALS	1,949	3,298	2,909	8,381	7,640	4,119	
Target Loads ³	3,400	5,600	4,360	11,000	7,000		

Totals may not sum due to rounding.

¹Includes Buffalo River

²Standard errors calculated from tributary loading estimates used in making adjustments

³Annex 3, 1978 Great Lakes Water Quality Agreement

TABLE 3

**SUMMARY OF 1988 ESTIMATED ATMOSPHERIC, INDUSTRIAL
MUNICIPAL AND TRIBUTARY PHOSPHORUS LOADING DATA TO THE
GREAT LAKES**

(All values are in metric tonnes/year)

	Superior	Michigan	Huron	Erie	Ontario	St. Lawrence River	Total
Atmospheric (standard error)	647 (80)	396 (80)	524 (73)	372 (78)	181 (23)	-	2,120 (160)
Direct IND Discharge (standard error)	79 (4)	42 (2)	12 (1)	34 (2)	25 (2)	27 (2)	220 (6)
Direct MUN Discharge (standard error)	67 (2)	336 (10)	96 (3)	1,741 (70)	1,108 (24)	132 (4)	3,480 (75)
Tributary Monitored (standard error)	851 (76)	1,656 (76)	1,255 (94)	3,285 (177)	1,505 ¹ (247)	85 (20)	8,637 (336)
Adjustment for Unmonitored Area (standard error) ²	423 (34)	478 (43)	620 (95)	1,329 (205)	492 (48)	63 (21)	3,405 (238)
Within Lake Totals	2,067	2,907	2,508	6,761	3,311	307	17,861
From Connecting Channels			657	1,080	3,210	2,866	
OVERALL TOTALS	2,067	2,907	3,165	7,841	6,521	3,173	
Target Loads ³	3,400	5,600	4,360	11,000	7,000		

Totals may not sum due to rounding.

¹Includes Buffalo River

²Standard errors calculated from tributary loading estimates used in making adjustments

³Annex, Great Lakes Water Quality Agreement

TABLE 4

**SUMMARY OF 1989 ESTIMATED ATMOSPHERIC, INDUSTRIAL
MUNICIPAL AND TRIBUTARY PHOSPHORUS LOADING DATA TO THE
GREAT LAKES**

(All values are in metric tonnes/year)

	Superior	Michigan	Huron	Erie	Ontario	St. Lawrence River	Total
Atmospheric (standard error)	693 (145)	295 (50)	452 (79)	310 (70)	171 (37)	-	1,921 (191)
Direct IND Discharge (standard error)	83 (5)	41 (1)	8 (1)	41 (3)	21 (2)	20 (1)	214 (7)
Direct MUN Discharge (standard error)	72 (6)	320 (8)	86 (5)	1,503 (42)	1,090 (22)	144 (6)	3,215 (49)
Tributary Monitored (standard error)	1,009 (64)	2,746 (279)	1,560 (116)	4,807 (181)	1,552 ¹ (157)	96 (10)	11,770 (391)
Adjustment for Unmonitored Area (standard error) ²	467 (27)	959 (244)	464 (37)	827 (57)	500 (34)	72 (11)	3,288 (257)
Within Lake Totals	2,323	4,360	2,570	7,488	3,334	332	20,407
From Connecting Channels			657	1,080	3,395	4,813	
OVERALL TOTALS	2,323	4,360	3,227	8,568	6,728	5,145	
Target Loads ³	3,400	5,600	4,360	11,000	7,000		

Totals may not sum due to rounding.

¹Includes Buffalo River

²Standard errors calculated from tributary loading estimates used in making adjustments

³Annex, Great Lakes Water Quality Agreement

delivered to the lakes.

The Water Quality Board noted in its 1989 Report that model simulations using surveillance data indicated that reducing the phosphorus loads from point sources not now in compliance to comply with the 1 mg P/L effluent limit will apparently have little long term effect in further reducing in-lake concentrations of phosphorus in the major lake basins. If further significant reductions in phosphorus are to be achieved, non-point source inputs of phosphorus to the Great Lakes basin (including atmospheric inputs) must continue to be addressed. This confirms the critical importance of the Phosphorus Load Reduction Plans being implemented by the Parties despite the present uncertainty on the effect of tributary non-point source loads. The Water Quality Board reiterates, however, the statement made in its 1989 report that the Parties and jurisdictions must continue effective implementation of point source control programs to achieve the 1 mg P/L effluent requirement to ensure that improvements made to date are not jeopardized.

The reduction in phosphorus loads are reflected in the trends in concentrations of phosphorus in the lakes, particularly in Lake Ontario. The Water Quality Board has continued to report on the temporal trends in annual phosphorus measurements taken at open lake stations (i.e. removed from localized inputs) in each of the Great Lakes. Spring (isothermal conditions) surface water samples have been reported for all of the lakes except Lake Erie, where annual averages based on multiple samples over the year are necessary to account for the high variability (Water Quality Board 1989; Surveillance Work Group 1986). Acceptable in-lake concentrations of total phosphorus have been developed for each of the lakes (Phosphorus Management Strategies Task Force 1980; see also Table 17 in 1989 Water Quality Board Report). Figure 2 confirms the observation in the 1989 Water Quality Board Report that in-lake concentrations of total phosphorus in all lakes are now at or below these "objective" concentrations.

While the trend for Lake Ontario is significant ($p < 0.05$) when considered over the period 1968-1989, there has been no significant change since 1985. This levelling off may be due to a similar levelling off in phosphorus inputs from the Niagara River (Kuntz and Tsanis, 1990) which provides 83 percent of the surface tributary flow and about 50 percent of the phosphorus load (Stevens and Neilson, 1987) to the lake. In 1988 and 1989, total phosphorus concentrations in Lake Erie appeared to be well below the acceptable in-lake concentration for the first time since the Agreement was signed in 1972. However, as the Water Quality Board stated in its 1989 report, the latest data are based on a reduced number of ship cruises from previous years, making direct comparison with the "objective" and evaluation of trends difficult. Sampling in 1990 and 1991 has incorporated additional cruises and the results may help to substantiate the 1987-1989 data.

A major goal of the phosphorus control program in Lake Erie is the establishment of year-round aerobic conditions (greater than 0.5 mg O_2/L) in the hypolimnion of the central basin. Annual average oxygen depletion rates of 3 mg $O_2/L/month$ or less are believed necessary to achieve this goal. Gross depletion rates were presented by the Water Quality Board in its 1989 Report. These rates were not adjusted for annual variations in hypolimnion thickness, temperature, vertical mixing or seasonality which are known to

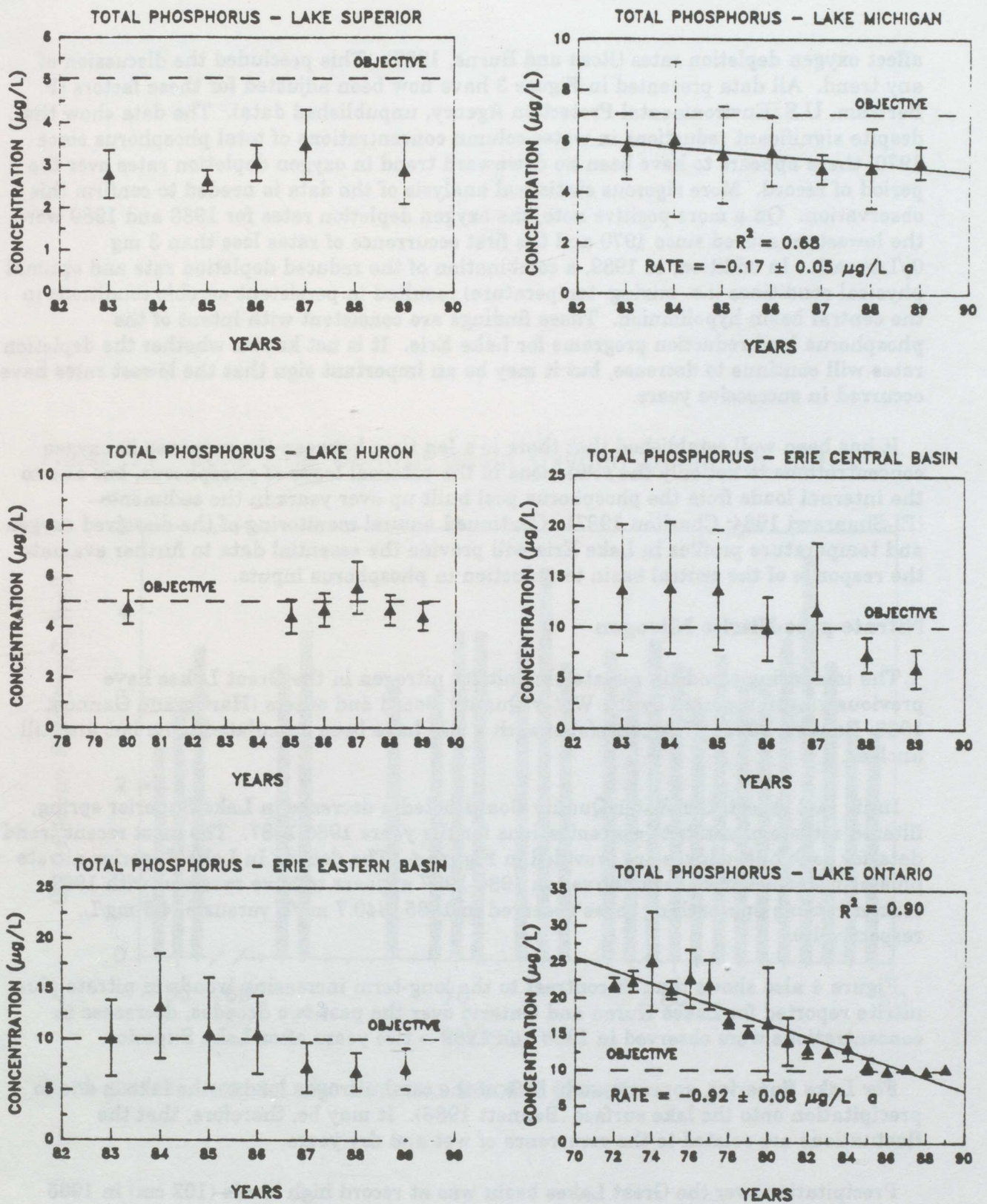


FIGURE 2: PHOSPHORUS CONCENTRATIONS AND TRENDS FOR THE GREAT LAKES

DATA SOURCE: INLAND WATERS DIVISION AND GREAT LAKES NATIONAL PROGRAM OFFICE

affect oxygen depletion rates (Rosa and Burns, 1987). This precluded the discussion of any trend. All data presented in Figure 3 have now been adjusted for these factors (P. Bertram, U.S. Environmental Protection Agency, unpublished data). The data show that, despite significant reductions in water column concentrations of total phosphorus since 1970, there appears to have been no downward trend in oxygen depletion rates over the period of record. More rigorous statistical analysis of the data is needed to confirm this observation. On a more positive note, the oxygen depletion rates for 1988 and 1989 were the lowest measured since 1970 and the first occurrence of rates less than 3 mg O₂/L/month. In addition, in 1989, a combination of the reduced depletion rate and optimal physical conditions (i.e. mixing, temperature) resulted in persistent aerobic conditions in the central basin hypolimnion. These findings are consistent with intent of the phosphorus load reduction programs for Lake Erie. It is not known whether the depletion rates will continue to decrease, but it may be an important sign that the lowest rates have occurred in successive years.

It has been well established that there is a lag time between the response in oxygen concentrations to not only the reductions in the external loads of phosphorus, but also to the internal loads from the phosphorus pool built up over years in the sediments (El-Shaarawi 1984; Charlton 1987). Continued annual monitoring of the dissolved oxygen and temperature profiles in Lake Erie will provide the essential data to further evaluate the response of the central basin to reduction in phosphorus inputs.

Nitrate-plus-Nitrite Nitrogen

The increasing trends in nitrate-plus-nitrite nitrogen in the Great Lakes have previously been reported by the Water Quality Board and others (Hartig and Gannon, 1986; Bennett 1986). The cause(s) of such a rise have been speculated upon but are still unclear.

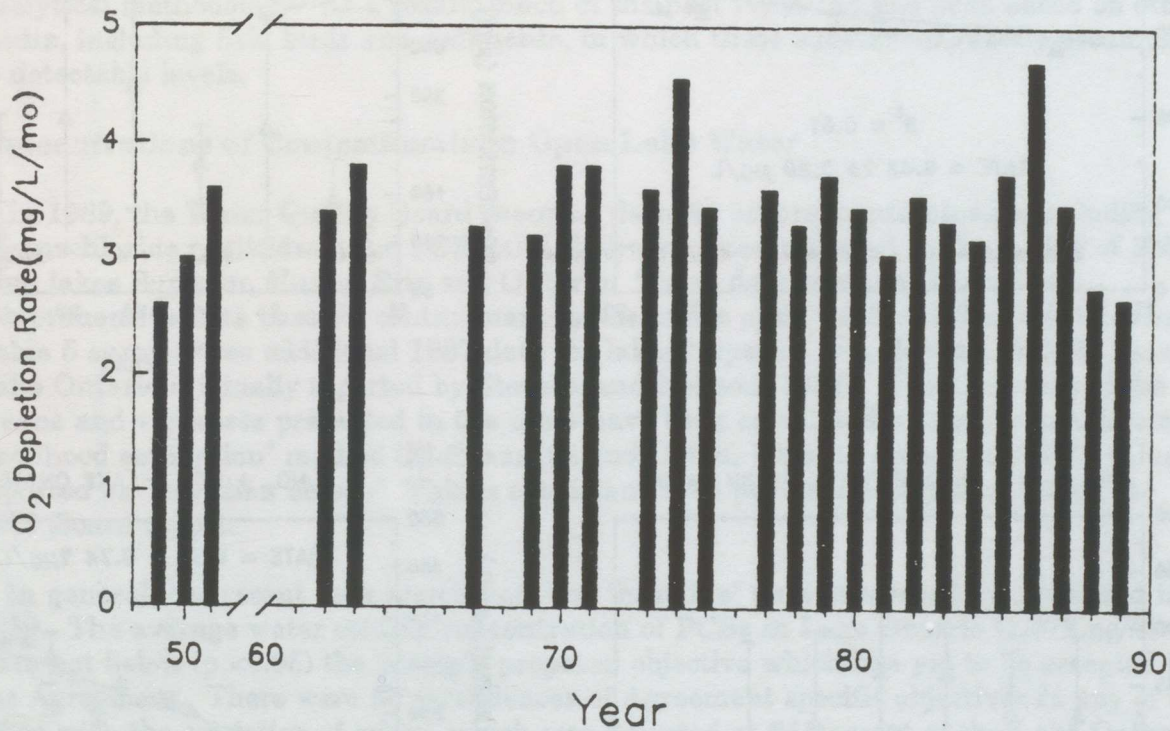
In its last report, the Water Quality Board noted a decrease in Lake Superior spring, filtered nitrate plus nitrite concentrations for the years 1986-1987. The most recent trend data for each of the lakes are provided in Figure 4. The decline in Lake Superior nitrate plus nitrite concentrations observed in 1986-1987 appears to have reversed with 1989 concentrations approaching those observed in 1985 (340.7 mg/L versus 344.6 mg/L, respectively).

Figure 4 also shows that, in contrast to the long-term increasing trends in nitrate plus nitrite reported for Lakes Huron and Ontario over the past two decades, decreases in concentrations were observed in 1988 and 1989 -- two years after Lake Superior.

For Lake Superior, approximately 58% of the total nitrogen load to the lake is due to precipitation onto the lake surface (Bennett 1986). It may be, therefore, that the fluctuations are related to the occurrence of wet and dry years.

Precipitation over the Great Lakes basin was at record high levels (102 cm) in 1985 (Yee *et al.* 1990) and at near-drought conditions in 1986-1987. Associated with the latter were low runoff and high evaporation rates. Conditions returned to average in 1989. Assuming that fluctuations in precipitation reflect corresponding fluctuations in the

FIGURE 3: Lake Erie Central Basin Oxygen Depletion Rates



DATA SOURCE: GREAT LAKES NATIONAL PROGRAM OFFICE

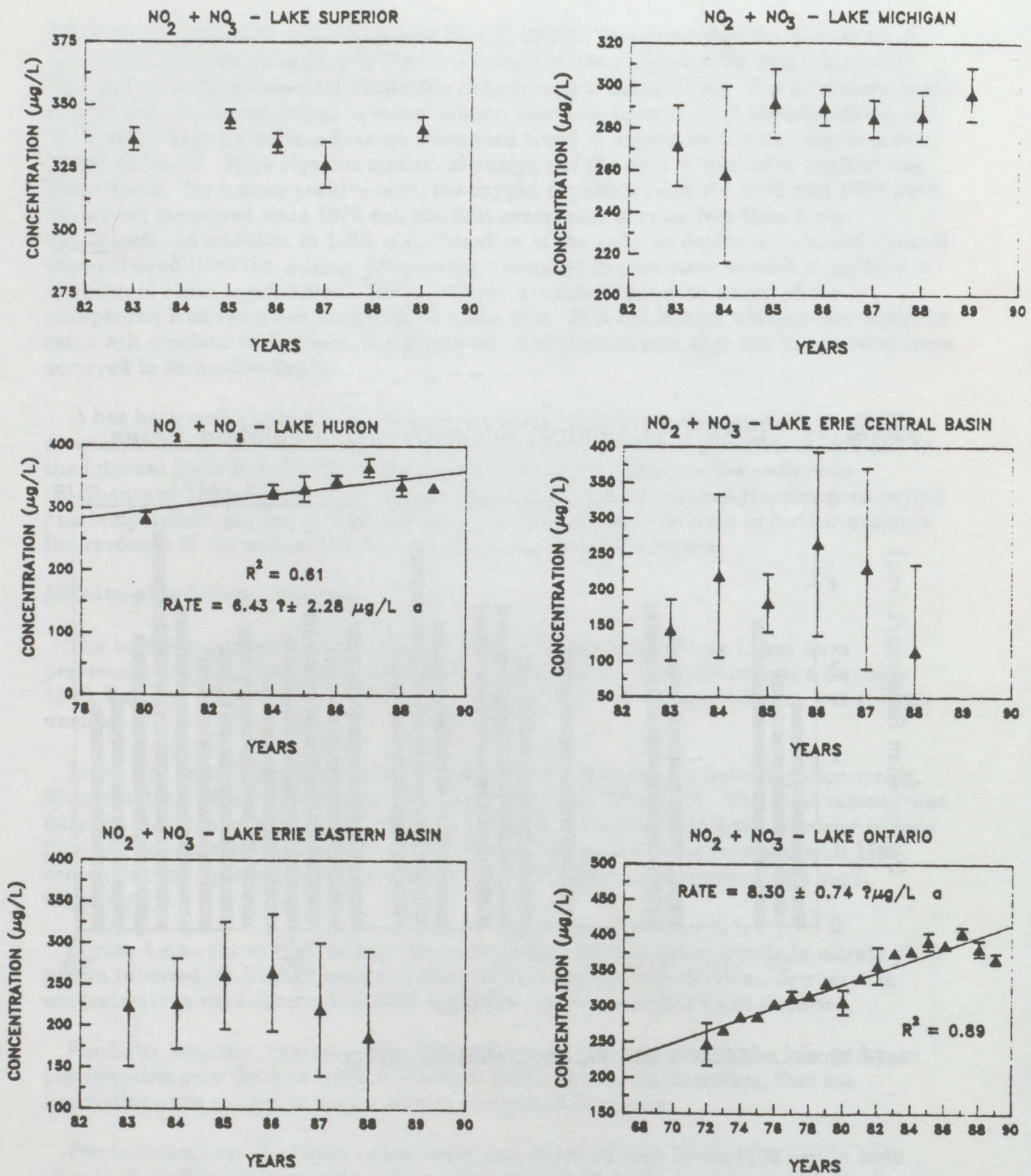


FIGURE 4: NITRATE - PLUS - NITRITE CONCENTRATIONS ON THE GREAT LAKES

DATA SOURCE: INLAND WATERS DIRECTORATE AND GREAT LAKES NATIONAL PROGRAM OFFICE

loading of nutrients directly to the lake and also through runoff via tributaries and that the response of the lake to these loads is rapid, then it appears the fluctuations are driven by changes in precipitation.

In contrast to Lake Superior where the atmosphere is the major source of nitrogen inputs, the major input of nitrogen to Lake Ontario is the Niagara River (Casey and Salbach, 1974; Williams *et al.* 1991). Niagara River loads of nitrate plus nitrite to Lake Ontario decreased in both 1987 and 1988 relative to the 1986 loads. The combined decreases in loads for these two years account for approximately 58% of the total change in the in-lake mass of nitrate plus nitrite in the lake. This is reflected in decreased in-lake concentrations.

CONTAMINANTS

While numerous studies of a variety of contaminants have been published by various researchers, it is only within the last few years that water column concentrations of contaminants have been collected routinely by surveillance programs. In part, this has been because concentrations in water were generally below the detection limits of routine analytical methodology. As a result, much of the past reporting has been based on other media, including fish, birds and sediments, in which these substances readily accumulate to detectable levels.

Concentrations of Contaminants in Open Lake Water

In 1989, the Water Quality Board reported data for several contaminants including organochlorine pesticides, total PCBs and chlorobenzenes collected in the spring of 1986 from lakes Superior, Huron, Erie and Ontario. These data comprised the first comprehensive data base for contaminant levels in the open waters of the Great Lakes. Table 5 summarizes additional 1987 data for lakes Superior and Huron and 1988 data for Lake Ontario originally reported by Stevens and Neilson (1987). The estimates of the means and variances presented in the table have been calculated using the "maximum likelihood estimation" method (El-Shaarawi and Dolan, 1989) to account for data values reported as "less than detect." This is consistent with presentation of the data in the 1989 Board report.

In general, the recent data corroborate the "baseline" data presented by the Board in 1989. The average water column concentration of PCBs in Lake Ontario (1.079 ng/L) were not below ($p < 0.05$) the 1.0 ng/L proposed objective which has yet to be accepted in the Agreement. There were no exceedences of Agreement specific objectives in any of the lakes with the exception of mirex, which was detected at 64 percent of the Lake Ontario stations (objective is "non-detectable"). This represents detection at a greater number of stations than observed in 1986 and is due to the lower analytical detection limit achieved in 1988.

Contaminant Concentrations/Trends in Open Lake Fish

The open-lake fish contaminant surveillance program continued to measure whole-fish residue concentrations of routine organics and trace metals in top predator [lake trout

TABLE 5
ORGANIC CONTAMINANT DATA BY LAKE

COMPOUND	1987		Lake Superior 1987 N = 26		Lake Huron 1987 N = 19		Georgian Bay 1987 N = 10	
	D.L. ng/L	% D	ng/L #	Confidence (96% Interval about α)	ng/L #	Confidence (96% Interval about α)	% D	ng/L # Confidence (96% Interval about α)
Organochlorine Pesticides	.004	100	11.133	(10.372, 11.967)	4.519	(3.938, 5.213)	100	3.031 (2.827, 3.254)
α -BHC	.006	100	1.049	(0.986, 1.116)	0.517	(0.463, 0.579)	100	0.339 (0.314, 0.366)
γ -BHC (Lindane)	.007	31	0.011	(0.005, 0.030)	0		0	
trans-Chlordane	.007	23	0.007	(0.003, 0.021)	0		0	
Heptachlor Epoxide	.007	100	0.066	(0.077, 0.097)	0.121	(0.111, 0.132)	100	0.099 (0.089, 0.111)
Dieldrin	.016	100	0.266	(0.242, 0.292)	0.332	(0.287, 0.386)	100	0.201 (0.179, 0.226)
p,p'-DDE	.010	31	0.009	(0.007, 0.011)	0.013	(0.010, 0.017)	50	0.011 (0.009, 0.013)
Polycyclic Aromatic Hydrocarbons	.350	66	0.563	(0.428, 0.756)	0.961	(0.759, 1.235)	100	0.790 (0.702, 0.894)
Fluoranthene	.040	100	0.216	(0.183, 0.255)	0.117	(0.099, 0.140)	100	0.183 (0.147, 0.233)
1,2,3-Trichlorobenzene*	.040	12	0.072	(0.008, 0.206)	0		0	
1,4-Dichlorobenzene	.030	100	0.416	(0.384, 0.450)	0.331	(0.292, 0.377)	100	0.474 (0.423, 0.532)
1,3,5-Trichlorobenzene	.004	0			0		10**	
1,2,4-Trichlorobenzene	.006	100	0.207	(0.198, 0.217)	0.176	(0.160, 0.192)	100	0.173 (0.114, 0.276)
1,2,3-Trichlorobenzene	.004	100	0.026	(0.024, 0.026)	0.024	(0.022, 0.027)	100	0.024 (0.021, 0.027)
1,2,3,4-Tetrachlorobenzene	.003	100	0.022	(0.021, 0.023)	0.024	(0.019, 0.031)	100	0.017 (0.014, 0.020)
Pentachlorobenzene	.003	100	0.012	(0.012, 0.013)	0.009	(0.006, 0.014)	80	0.008 (0.006, 0.012)
Hexachlorobenzene	.003	100	0.033	(0.031, 0.035)	0.028	(0.026, 0.030)	100	0.024 (0.021, 0.028)
Total PCBs	.430	92	0.751	(0.652, 0.871)	0.520	(0.369, 0.759)	60	0.489 (0.361, 0.680)

COMPOUNDS ANALYZED FOR BUT NOT DETECTED 1987

Organochlorine Pesticides	D.L. ng/L	Organochlorine Pesticides	D.L. ng/L	Polycyclic Aromatic Hydrocarbons	D.L. ng/L
Endrin	.017	p,p'-TDE	.028	Benzo(B)Fluoranthene	.700
Heptachlor	.003	p,p'-DDT	.016	Benzo(L)Fluoranthene	.700
Aldrin	.003	Mirex	.008	Benzo(A)Pyrene	.700
α -Endosulfan	.007	Methoxychlor	.070	Indeno(1,2,3-CD)Pyrene	.700
β -Endosulfan	.015	o,p'-DDT	.026	Benzo(GHI)Perylene	.700

*1,2-Dichlorobenzene co-elutes with 1,3-Dichlorobenzene
**One of 10 samples above the detection limit (concentration = 0.18 ng/L)

Table 5 - cont'd.

Organic Contaminant Data - Lake Ontario 1988

COMPOUND	1988 D.L. ng/L	Lake Ontario 1988 N = 33		
		% D	\bar{x} ng/L	(95% Confidence Interval about \bar{x})
Organochlorine Pesticides				
α -BHC	.004	100	3.468	(2.956, 4.096)
γ -BHC (Lindane)	.006	100	0.863	(0.779, 0.960)
cis-Chlordane	.007	42	0.123	(0.033, 0.978)
trans-Chlordane	.007	27	0.065	(0.013, 1.378)
Heptachlor Epoxide	.007	94	0.281	(0.195, 0.421)
Dieldrin	.016	100	0.366	(0.318, 0.422)
Endrin	.017	67	0.059	(0.040, 0.090)
p,p'-DDE	.012	100	0.050	(0.045, 0.055)
Heptachlor	.003	9	0.001	(0.000, 0.011)
α -Endosulfan	.008	12	0.004	(0.000, 13.14)*
β -Endosulfan	.015	3**		
p,p'-DDT	.027	9	0.007	(0.000, 8.760)*
Mirex	.008	64	0.011	(0.009, 0.013)
Methoxychlor	.070	18	0.044	(0.025, 0.086)
Chlorobenzenes				
1,2-Dichlorobenzene***	.040	94	0.751	(0.492, 1.209)
1,3-Dichlorobenzene	.030	67	0.324	(0.162, 0.754)
1,4-Dichlorobenzene	.030	85	2.523	(1.201, 6.347)
1,3,5-Trichlorobenzene	.004	97	0.028	(0.020, 0.041)
1,2,4-Trichlorobenzene	.006	100	0.430	(0.337, 0.557)
1,2,3-Trichlorobenzene	.004	100	0.104	(0.064, 0.132)
1,2,3,4-Tetrachlorobenzene	.003	100	0.101	(0.072, 0.145)
Pentachlorobenzene	.003	100	0.050	(0.039, 0.064)
Hexachlorobenzene	.003	100	0.069	(0.063, 0.075)
Total PCBs	.430	88	1.079	(0.880, 1.339)

*Confidence intervals estimated using \bar{s}

**One of 33 samples above the detection limit (concentration = 0.069 ng/L)

***1,2-Dichlorobenzene co-elutes with 1,3-Dichlorobenzene

Compounds Analyzed for but not detected 1988

Organochlorine Pesticides	D.L. ng/L
Aldrin	.003
p,p'-TDE	.028
o,p'-DDT	.026

(*Salvelinus namaycush*) or walleye (*Stizostedion vitreum*) and forage fish [rainbow smelt (*Osmerus mordax*)] species at offshore sites in each of the Great Lakes. In its 1989 report, the Water Quality Board presented data through 1987. The current report updates this information through 1989 and provides a statistical assessment of trend data for representative trace metals and organic contaminants over the period 1986 to 1989. Discussion is based only on Canadian data. Comparable United States data have not been available since 1986. All statistical analyses were performed using a multiple range testing procedure (SNK) and the level of significance was set at $p < 0.05$. Further details on sampling and data analysis are discussed in Whittle and Fitzsimons (1983).

In general, since the inception of the program (1977 for Lakes Erie and Ontario; 1980 for Lakes Superior and Huron), concentrations of organic contaminants have declined significantly. Little change has been observed for the most part in the concentrations of trace metals. More recently, total body burdens of organic contaminants have levelled off in both top predator and forage fish species. During the period 1986 to 1989, there have been several cases where organic contaminant levels have increased significantly. The increase has been most evident in Lake Ontario. Lake Ontario fish continue to have significantly higher levels of organic contaminants than the other lakes monitored. Mirex was only detected in Lake Ontario fish. Figures 5 and 6 show the trend data for DDT in lake trout and rainbow smelt for each of the lakes, respectively. Figures 7 and 8 show similar data for PCBs.

Lake trout from each of the lakes exceed the 0.1 mg/kg PCB Agreement objective for whole fish. Similarly, rainbow smelt for each lake, with the exception of Lake Superior, generally exceed this PCB objective. Lake trout from Lake Ontario exceed the Agreement objective of 1.0 mg/kg for DDT. Mercury meets the Agreement objective of 0.5 mg/kg in both lake trout and rainbow smelt from all lakes sampled.

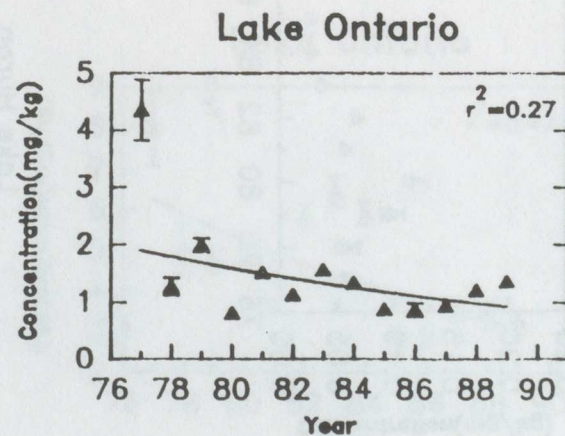
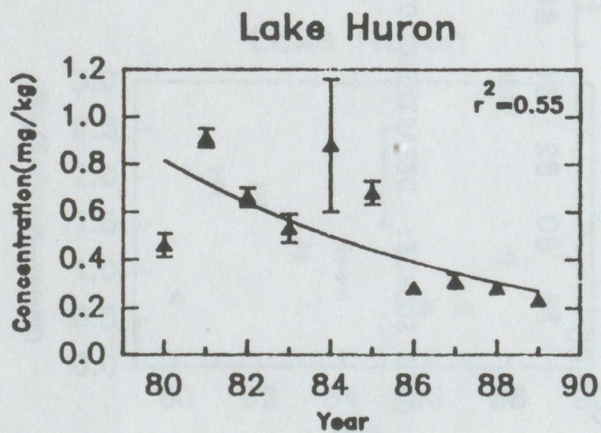
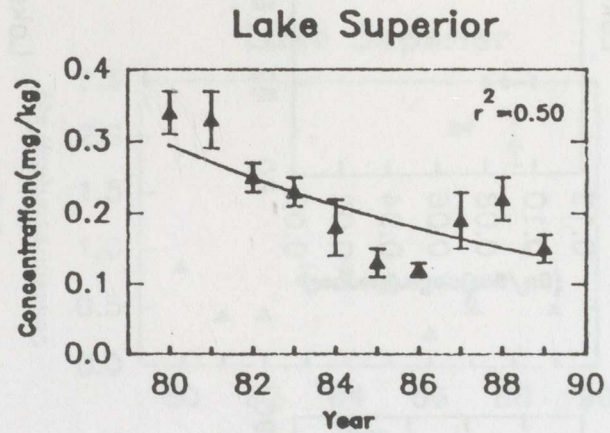
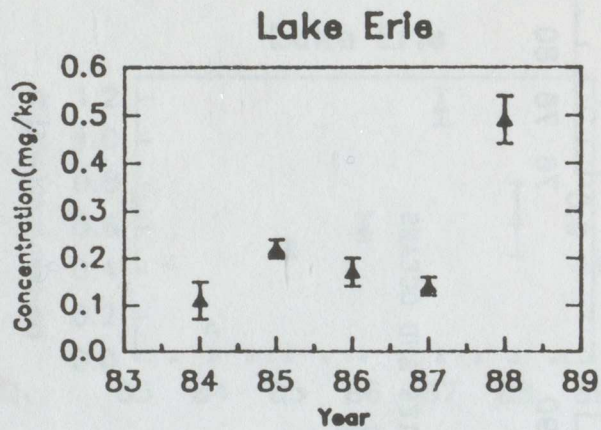
Highlights of the data for each lake are discussed briefly below.

Lake Ontario

Concentrations of PCBs and DDT in lake trout were significantly higher in 1989 than those measured in 1986. PCB concentrations reported in 1985 and 1986 were the lowest reported over the 13 years of Lake Ontario surveys. Despite the increase in 1989 concentrations, they were 48 percent of the concentrations reported in 1977/78. DDT concentrations increased consistently from 1986 to 1989. Dieldrin levels in 1989 were the lowest measured since 1977. Mirex concentrations in 1988 and 1989 (200 ng/kg in 1989) were significantly higher than those measured in 1986 (60 ng/kg).

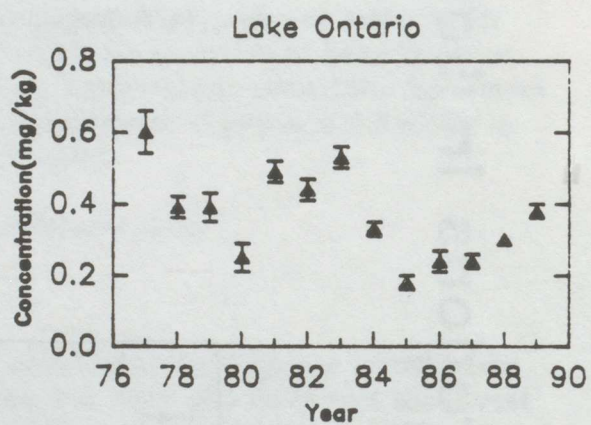
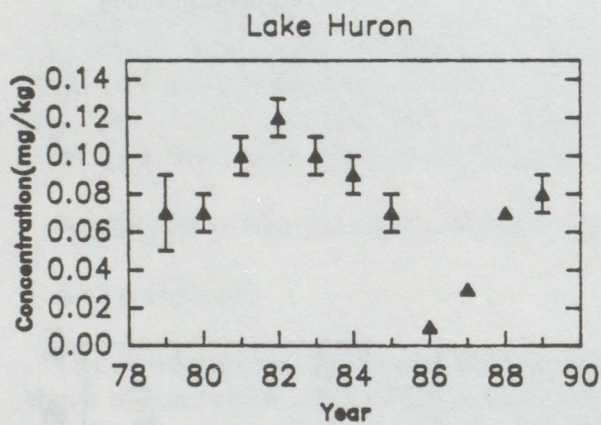
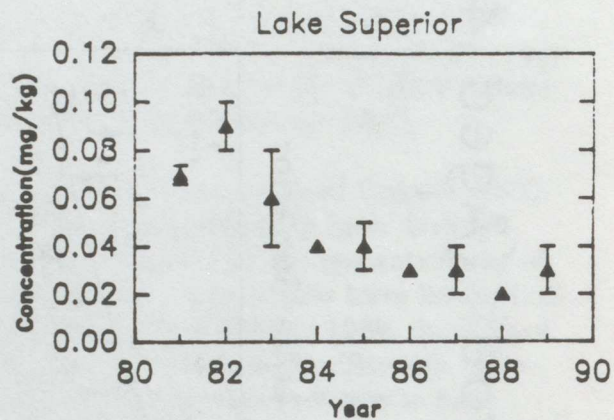
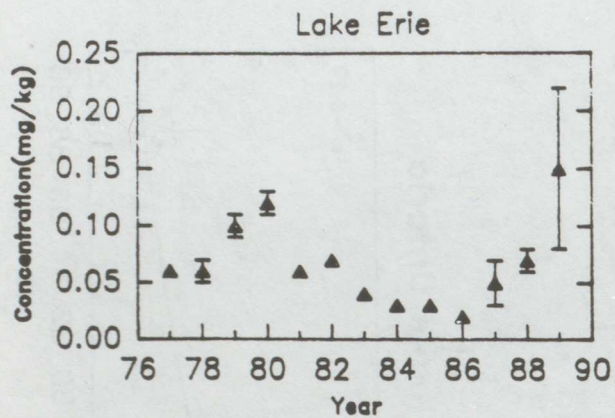
PCB levels of 2.15 mg/kg rainbow smelt in 1988 were the highest reported since 1977. While this appears anomalous compared to data for 1986, 1987 and 1989, the data showed that values were consistently high in all samples collected at four different sites in the lake and there was no statistical difference in concentrations between any of the sites. The 1989 concentrations of PCBs were less than those measured in 1977. DDT concentrations in 1989 were significantly higher than those measured in 1986 and increased consistently over the period. Dieldrin concentrations remained very low (<30 ng/kg) and exhibited no significant trend. Mirex concentrations increased steadily from

FIGURE 5
 DDT Concentrations in Lake Trout (Aged 4+)



DATA SOURCE: DEPARTMENT OF FISHERIES AND OCEANS

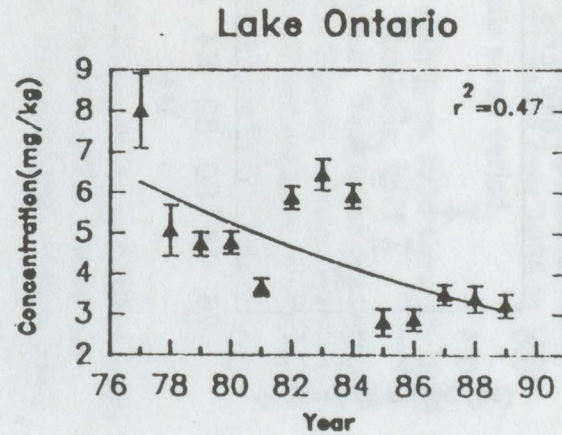
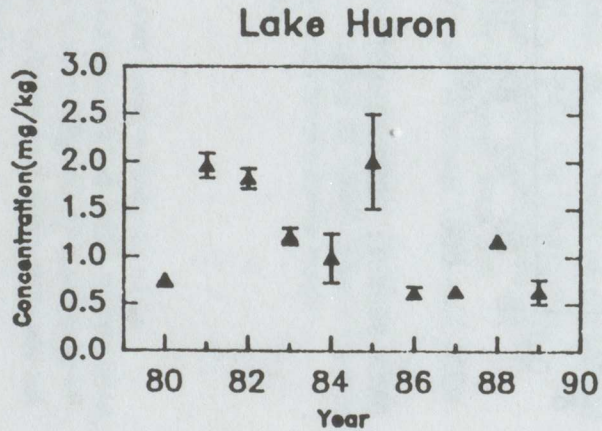
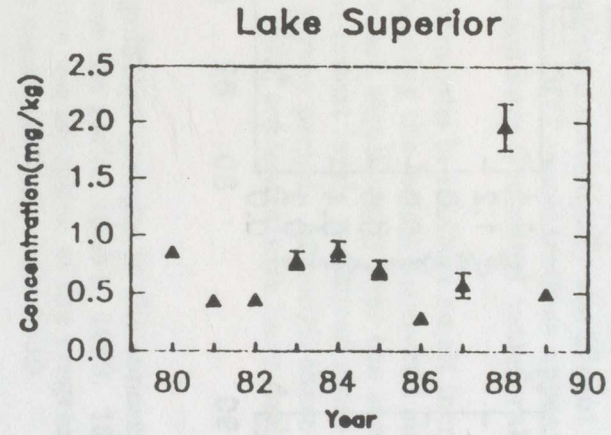
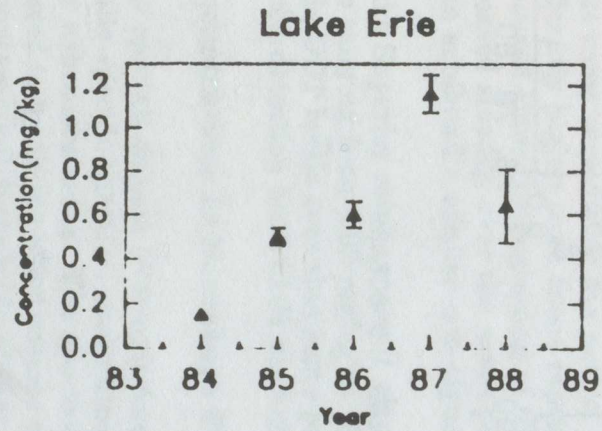
FIGURE 6: DDT Concentrations in Smelt
In the Great Lakes



DATA SOURCE: DEPARTMENT OF FISHERIES AND OCEANS

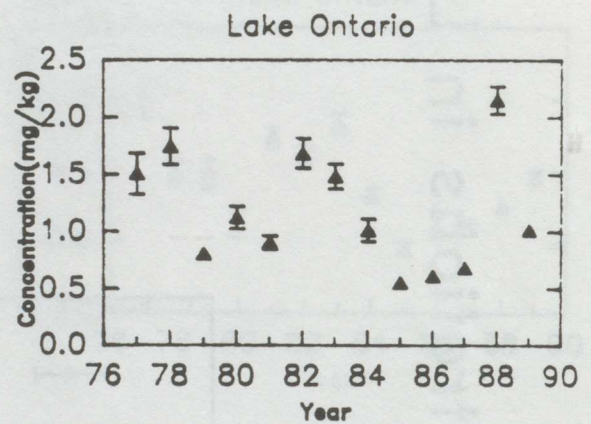
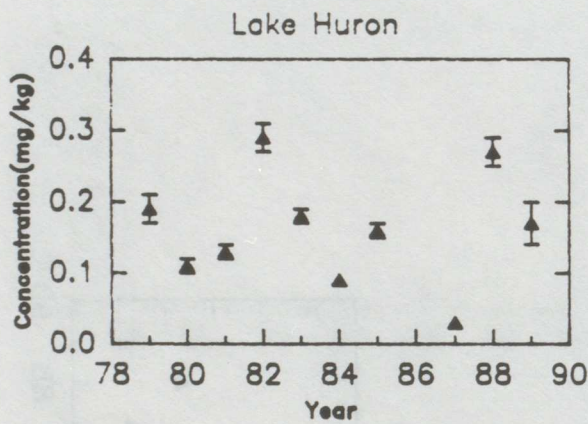
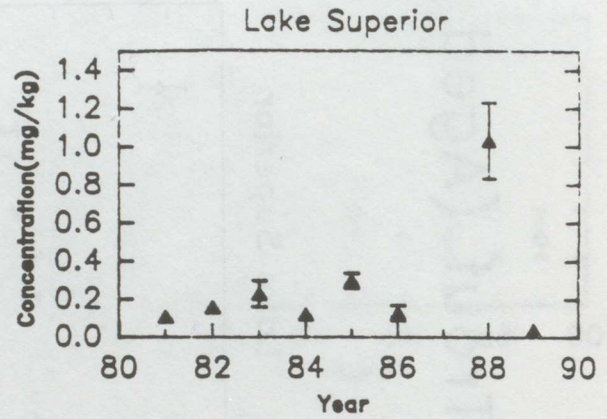
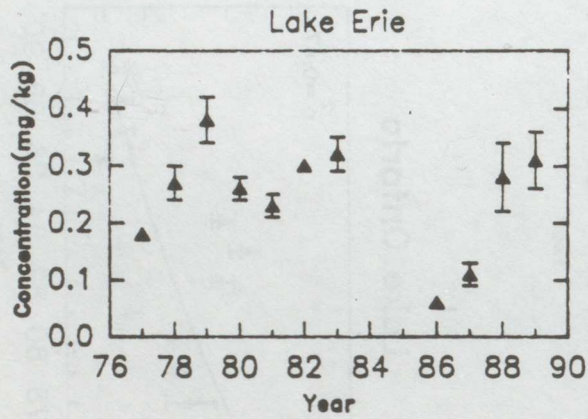
FIGURE 7

PCB Concentrations in Lake Trout (Aged 4+)



DATA SOURCE: DEPARTMENT OF FISHERIES AND OCEANS

FIGURE 8: PCB Concentrations in Smelt
In the Great Lakes



DATA SOURCE: DEPARTMENT OF FISHERIES AND OCEANS

1986 to 1989 with 1989 concentrations being significantly higher than those in 1986.

Lake Erie

Lake trout have only been available in limited numbers in the eastern basin of Lake Erie since 1986, making a statistically significant analysis of trends impossible. In general, both PCB and DDT concentrations appear to have increased over 1986 to 1989. Dieldrin concentrations have fluctuated considerably over this same period.

Mean PCB concentrations in rainbow smelt increased steadily from 1986 through 1989 with the 1986 levels being the lowest measured since 1977. Similarly, DDT concentrations increased significantly over the same time period. This trend represents an increase from the lowest levels measured since 1977 to the highest values reported during the 13-year survey period. Although there was no significant change in mercury levels from 1986 to 1989, concentrations have declined in Lake Erie rainbow smelt.

Lake Huron

There were no significant changes in the concentrations of either PCBs or DDT in Lake Huron lake trout over the period 1986 to 1989. 1989 concentrations of DDT were the lowest measured since the inception of the program in 1980. No significant change has occurred in dieldrin concentrations since 1980.

PCB concentrations in Lake Huron rainbow smelt for 1986, 1988 and 1989 were less than the detection limit (0.1 mg/kg). Although there was no statistically significant change in DDT levels from 1986 to 1989, concentrations increased steadily over this period.

Lake Superior

PCB levels in lake trout varied over the period 1986 to 1989. Concentrations measured in 1989 were significantly higher than those reported for 1986, while the maximum concentrations measured since the beginning of the program in 1980 occurred in 1988. Levels of DDT increased steadily over the same period but the increase was not significant. Dieldrin exhibited a similar non-significant increase between 1986 and 1989.

PCB levels in Lake Superior rainbow smelt also varied considerably from 1986 to 1989 with concentrations ranging from 1.03 mg/kg in 1988 to <0.1 mg/kg in 1989. There was no significant change in DDT levels over this same period. Dieldrin levels have been consistently below the detection limit (0.01 mg/kg) since 1983.

Contaminant Concentrations in Nearshore Fish

Young-of-the-year spottail shiners (*Notropis hudsonius*) have been widely used to identify and track site-specific chemical contaminant problems associated with tributaries, harbours, and other nearshore areas. The spottail shiner is a non-migratory (sedentary) fish. They can be used to track the effectiveness of remedial actions and they provide an important link for contaminant transfer to higher trophic levels.

The following brief discussion updates the information presented in the 1989 Water Quality Board Report. The discussion is based on Canadian data only, collected by the Ontario Ministry of the Environment (Suns *et al.* 1991). At time of writing, similar data were not available from the United States. Of the 129 sites sampled on the Great Lakes, sufficiently large data bases were available for 28 sites for temporal trend assessment.

Statistically significant ($p < 0.05$) reductions in both PCBs and DDT concentrations were observed at most sites for which data were available prior to 1980 (Figures 9 and 10). Exceptions to this were PCBs at sites in Lake Ontario (Burlington Beach, Credit River, and Outlet River), and DDT in sites in Lake Erie (Pike Creek, Thunder Bay Beach) and Lake Ontario (Credit River and Outlet River). Significant chlordane reductions occurred at nine of the 28 sites since the late 1970s, while mirex has declined significantly at only three of the 12 shiner samples collected from Lake Ontario and the Niagara River.

Slight increases were observed at some sites during the 1980s, especially at Leamington and the Detroit River (Amherstburg) for PCBs. Slight upward trends were noted for DDT and metabolites in shiners from Niagara-on-the-Lake, Credit River, Welland Canal and Twelve Mile Creek (Lake Ontario).

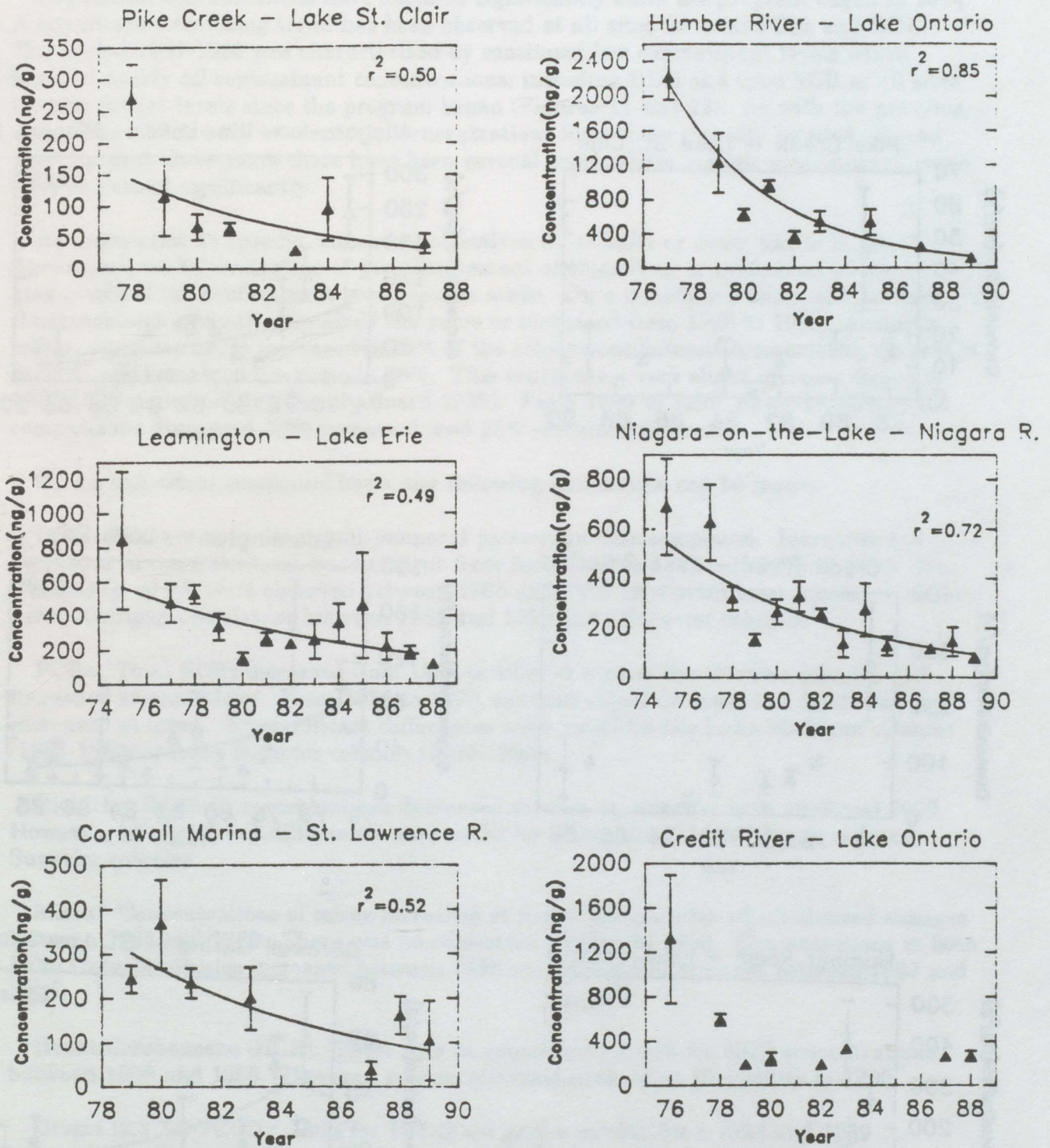
Although contaminant concentrations in the recent (1986 - 1989) spottail shiner collections were generally much lower than concentrations in this species from the mid-1970s, PCBs, and mirex at some sites continued to exceed Agreement specific objectives (Annex 1) for the protection of aquatic life. PCB concentrations exceeded the Agreement objectives (0.1 mg/kg) at 31 of the 82 (38 percent) recent spottail shiner collections from the Great Lakes. Mirex concentrations in spottail shiners from Lake Ontario and the Niagara River exceeded the objectives (less than detect) in three of the 21 (14 percent) samples analyzed. There were no exceedences of the Agreement objective for DDT and metabolites (1.0 mg/g). Octachlorostyrene residues in spottail shiners from some localities exceeded New York State Wildlife Protection Criteria (Newell *et al.* 1987).

Contaminant Concentrations/Trends in Herring Gulls

The Canadian Wildlife Service, in cooperation with the U.S. Fish and Wildlife Service have monitored contaminant concentrations in herring gull (*Larus argentatus*) eggs collected from colonies on each of the Great Lakes since 1974. Since 1986, the data for each colony have been based on a sample of 13 eggs which are then pooled for chemical analysis. Only one lake is chosen each year on a rotational basis to analyze individual eggs from each colony (Lake Michigan in 1989; Lake Superior in 1990). As the Board pointed out in its 1989 report, important information on the variation associated with contaminant concentrations (available for 1974 to 1985 data) has been severely impacted as a result of this change so that only qualitative comparisons can be made among colonies for the most recent data. Comparison with the earlier data (1974 to 1975) is also more difficult. The Water Quality Board reiterates that the current program is still inconsistent with the requirements of the Great Lakes International Surveillance Plan.

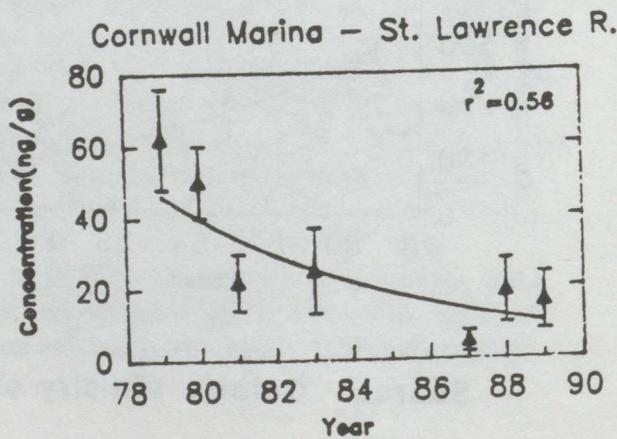
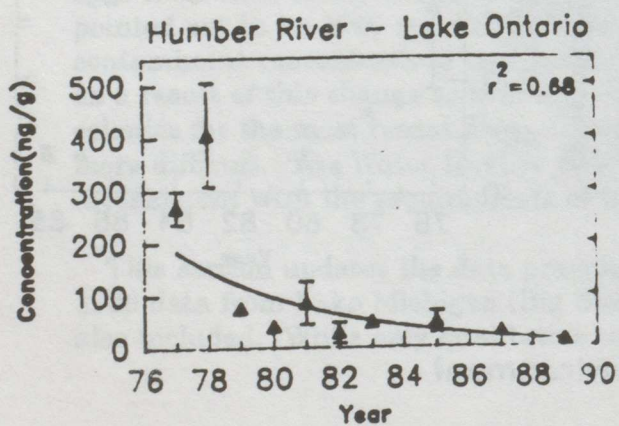
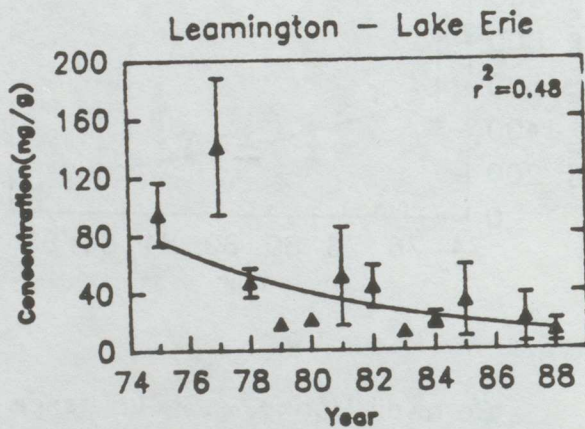
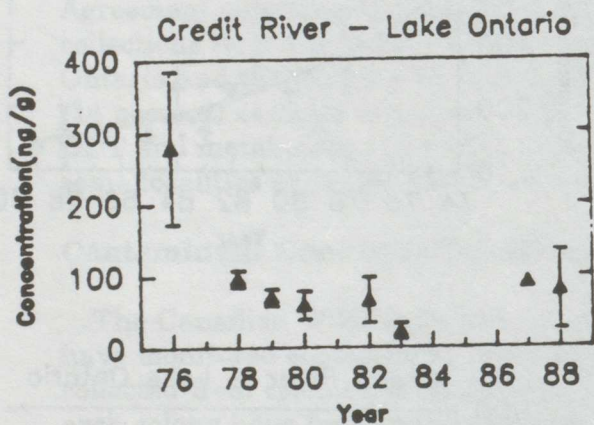
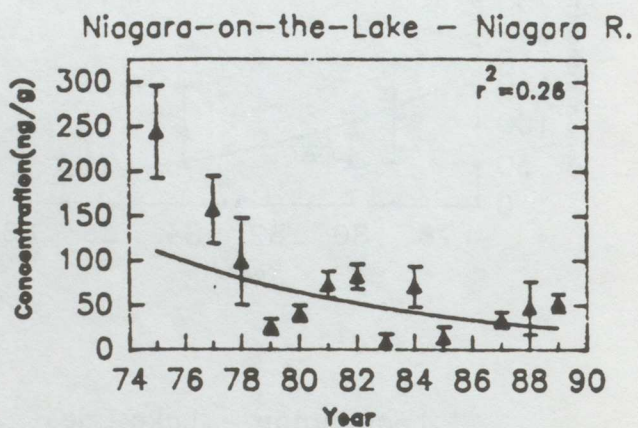
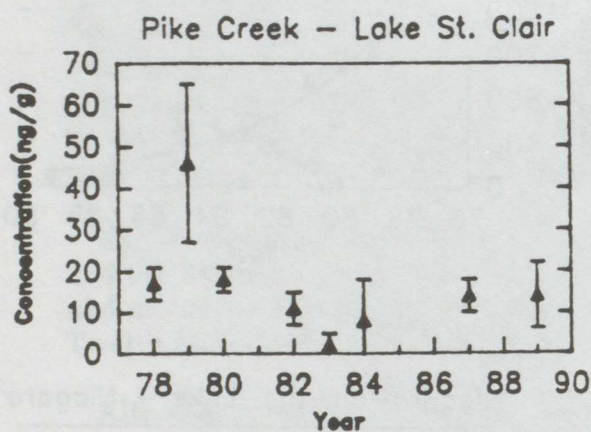
This section updates the data provided in the 1989 Water Quality Board Report. The 1988 data from Lake Michigan (Big Sister Island), which were not available in 1989, are also included. While only qualitative comparisons can be made, observations discussed

Figure 9:
 PCB Concentrations and Trends in Spottail Shiners
 In the Great Lakes



Source: Ontario Ministry of the Environment

FIGURE 10:
DDT Concentrations and Trends in Spottail Shiners
In the Great Lakes



below are not inconsistent with the more detailed information from previous years.

Temporal Trends

In general, concentrations have declined significantly since the program began in 1974. A significant decreasing trend has been observed at all sites for total PCBs and DDE. The period 1987-1990 was characterized by continued low contaminant levels which brought nearly all contaminant concentrations, including DDE and total PCB at all sites, to their lowest levels since the program began (Figures 11 and 12). As with the previous discussion of fish body burdens, the concentrations have more recently levelled off, and over the past three years there have been several cases where organic contaminant levels have increased significantly.

As there exist no specific, numerical objectives for wildlife or avian tissue in the Agreement, no determination of the achievement of objectives, or evaluation of the magnitude of the contaminant levels can be made. On a qualitative basis, contaminant concentrations generally remained the same or increased from 1988 to 1989. Absolute levels of contaminants increased in 37% of the colony-contaminant comparisons, decreased in 25%, and remained the same in 38%. This continues a very slight increase from the 1987-1988 period (Water Quality Board 1989). From 1989 to 1990, however, 55% of the comparisons decreased, 22% increased, and 23% remained the same.

On an individual compound basis, the following summaries can be made:

DDE: There was no consistent temporal pattern for this compound. Increases and decreases in concentrations were evident from both 1988 to 1989 and 1989 to 1990. No changes ($p < 0.05$) were observed between 1985 and 1989 in contaminant concentrations in Lake Michigan colonies, or between 1985 and 1990 Lake Superior colonies.

PCBs: Total PCBs increased from 1988 to 1989 at nine of the thirteen colonies and increased at one colony. From 1989 to 1990, concentrations decreased at eight sites and increased at three. No significant differences were noted for the Lake Michigan colonies (1985-1989) or Lake Superior colonies (1985-1990).

Dieldrin: Dieldrin concentrations decreased at most stations for both 1989 and 1990. However, no significant differences were noted for either the Lake Michigan or Lake Superior colonies.

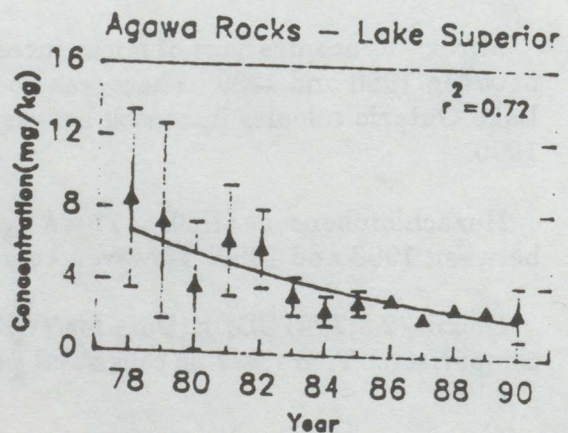
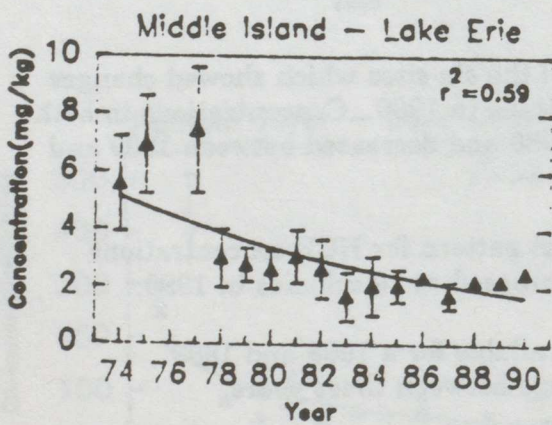
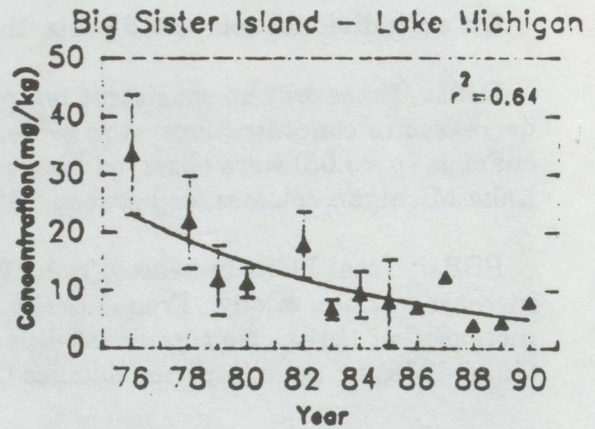
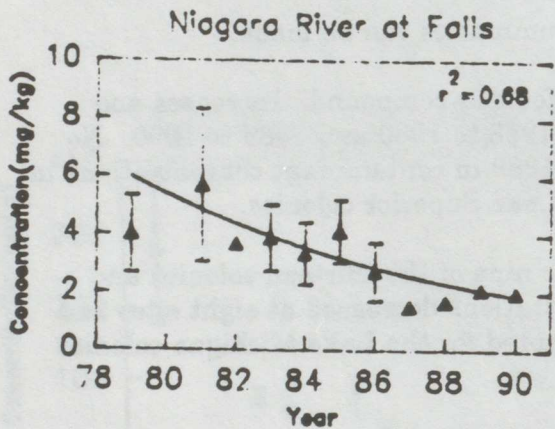
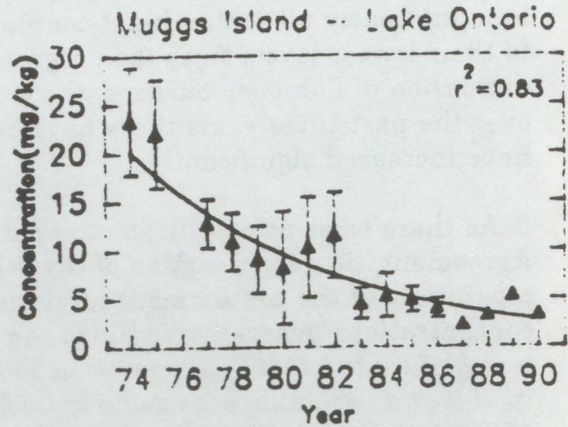
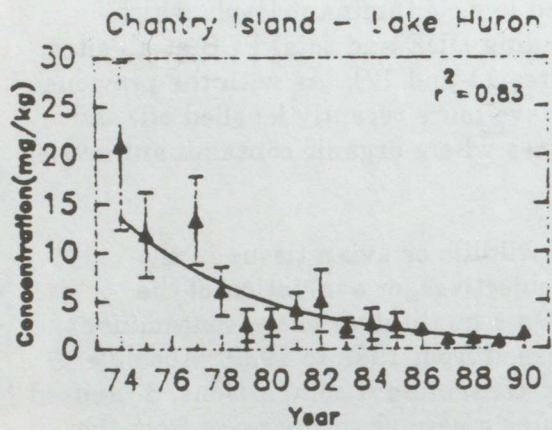
Mirex: Concentrations of mirex increased at five of the six sites which showed changes between 1988 and 1989. There was no consistent pattern in 1990. Concentrations in both Lake Ontario colonies increased between 1988 and 1989 and decreased between 1989 and 1990.

Hexachlorobenzene (HCB): There was no consistent pattern for HCB concentrations between 1988 and 1989. However, concentrations decreased at 10 colonies in 1990.

Dioxin (2,3,7,8-TCDD): Data for TCDD are only available for a 1988 and 1989 comparison. There was no consistent pattern of change between those years.

FIGURE 11:

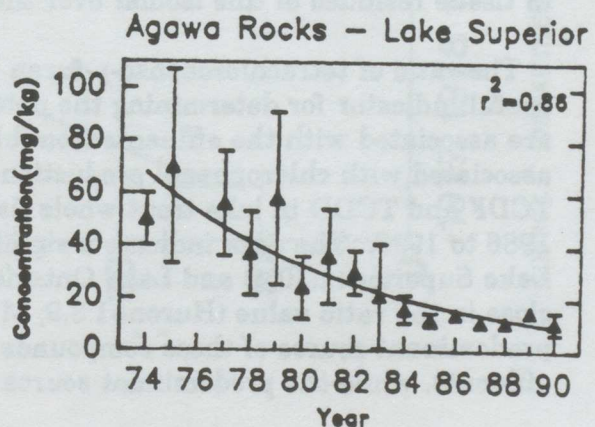
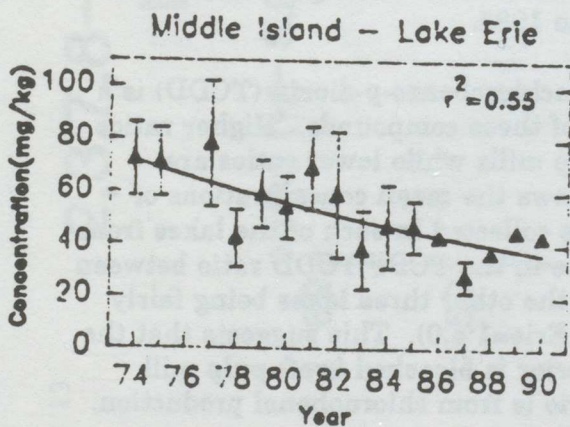
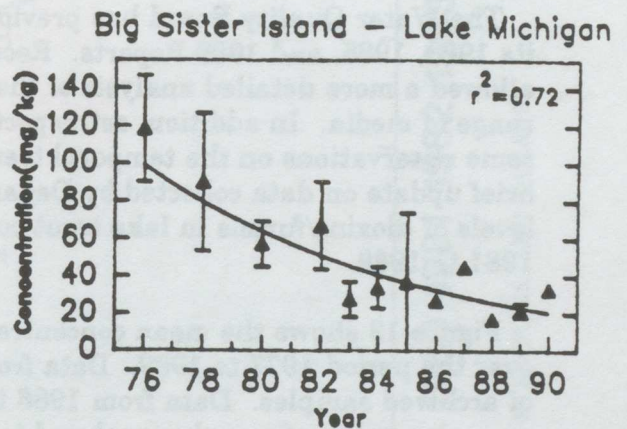
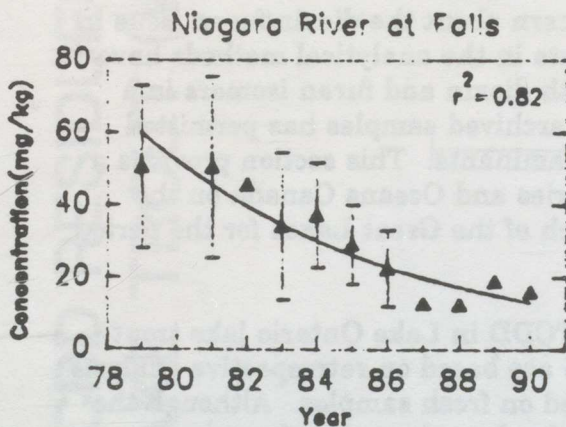
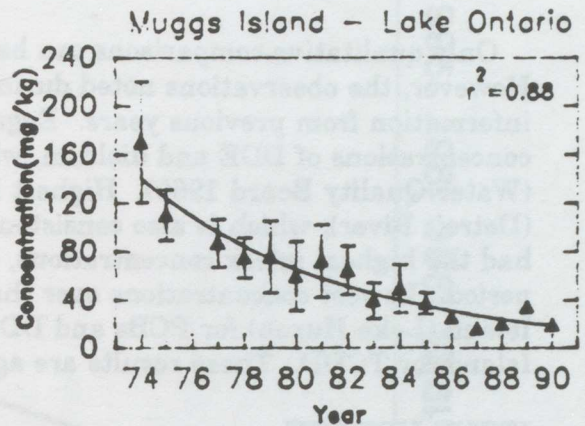
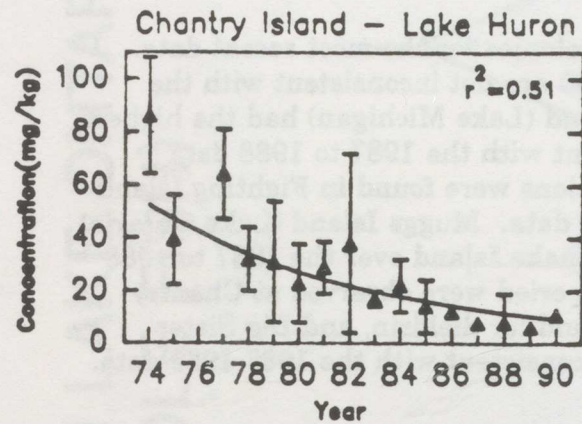
DDE Concentrations and Trends in Herring Gull Eggs In the Great Lakes



DATA SOURCE: CANADIAN WILDLIFE SERVICE

FIGURE 12:

PCB Concentrations and Trends in Herring Gull Eggs In the Great Lakes



DATA SOURCE: CANADIAN WILDLIFE SERVICE

Spatial Patterns

Spatial patterns define at which locations contaminant concentrations are greatest and where they are least. These definitions are important in identifying where contaminants might pose a problem to the environment and where wildlife populations might be most at risk.

Only qualitative comparisons can be made among colonies for the most recent data. However, the observations noted during 1989 and 1990 are not inconsistent with the information from previous years. Eggs from Gull Island (Lake Michigan) had the highest concentrations of DDE and dieldrin, which is consistent with the 1987 to 1988 data (Water Quality Board 1989). Highest PCB concentrations were found in Fighting Island (Detroit River), which is also consistent with previous data. Muggs Island (Lake Ontario) had the highest mirex concentrations, as opposed to Snake Island over the 1987 to 1988 period. Lowest concentrations over the 1989 to 1990 period were observed at Chantry Island (Lake Huron) for PCBs and DDE; Fighting Island for dieldrin, and Big Sister Island for TCDD. These results are again, generally consistent with the 1987-1988 data.

ISSUE UPDATE

Dioxins/Furans in the Great Lakes

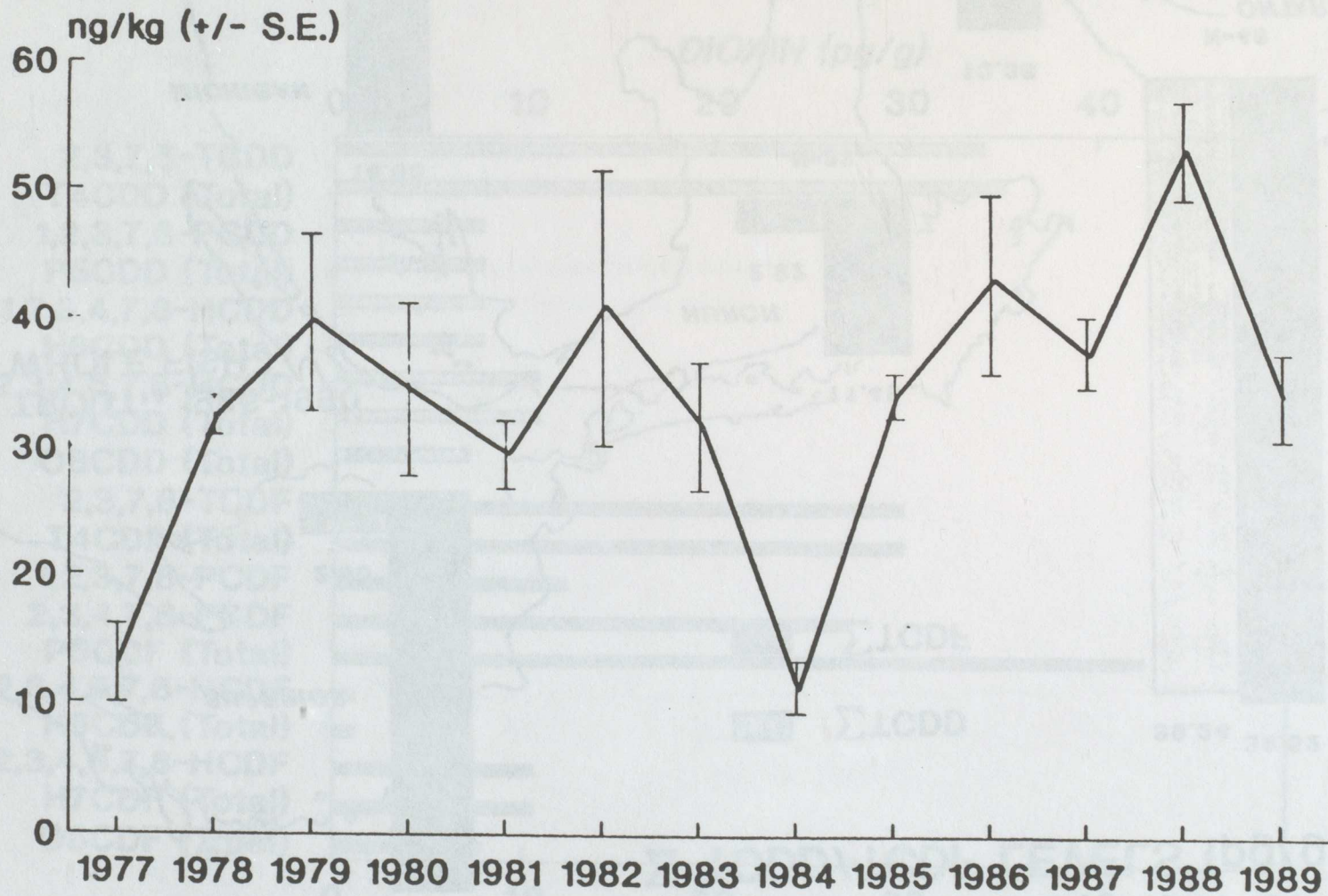
The Water Quality Board has previously raised concern about the dioxin/furan issue in its 1983, 1985, and 1989 Reports. Recent improvements in the analytical methods have allowed a more detailed analysis of the presence of both dioxin and furan isomers in a range of media. In addition, retrospective analysis of archived samples has permitted some observations on the temporal trend of these contaminants. This section provides a brief update on data collected by Department of Fisheries and Oceans Canada on the levels of dioxins/furans in lake trout collected from each of the Great Lakes for the period 1981 to 1989.

Figure 13 shows the mean concentration of 2,3,7,8-TCDD in Lake Ontario lake trout over the period 1977 to 1989. Data from 1977 to 1985 are based on retrospective analysis of archived samples. Data from 1986 to 1989 are based on fresh samples. Although the annual number of samples analyzed is limited (9-25), the data show that despite significant year-to-year fluctuations in concentrations, there has been a general increase in tissue residues of this isomer over the period 1981 to 1985.

The ratio of tetrachlorobenzo-p-furan (TCDF) to tetrachlorobenzo-p-dioxin (TCDD) is a useful indicator for determining the potential sources of these compounds. Higher ratios are associated with the effluents from bleach kraft pulp mills while lower ratios are associated with chlorophenol production. Figure 14 shows the mean concentrations of TCDF and TCDD in lake trout whole fish homogenates collected in each of the lakes from 1986 to 1990. The data indicate a significant difference in the TCDF:TCDD ratio between Lake Superior (1:10.4) and Lake Ontario (1:1.01) with the other three lakes being fairly close in the ratio value (Huron=1:3.9; Michigan=1:5.5; Erie=1:4.0). This suggests that the predominant source of these compounds for Lake Superior is bleached kraft pulp mill effluents, while the predominant source to Lake Ontario is from chlorophenol production.

Figure 13

2,3,7,8-TCDD RESIDUES IN LAKE ONTARIO LAKE TROUT (WHOLE FISH)



SOURCE: DEPARTMENT OF FISHERIES AND OCEANS



Figure 14

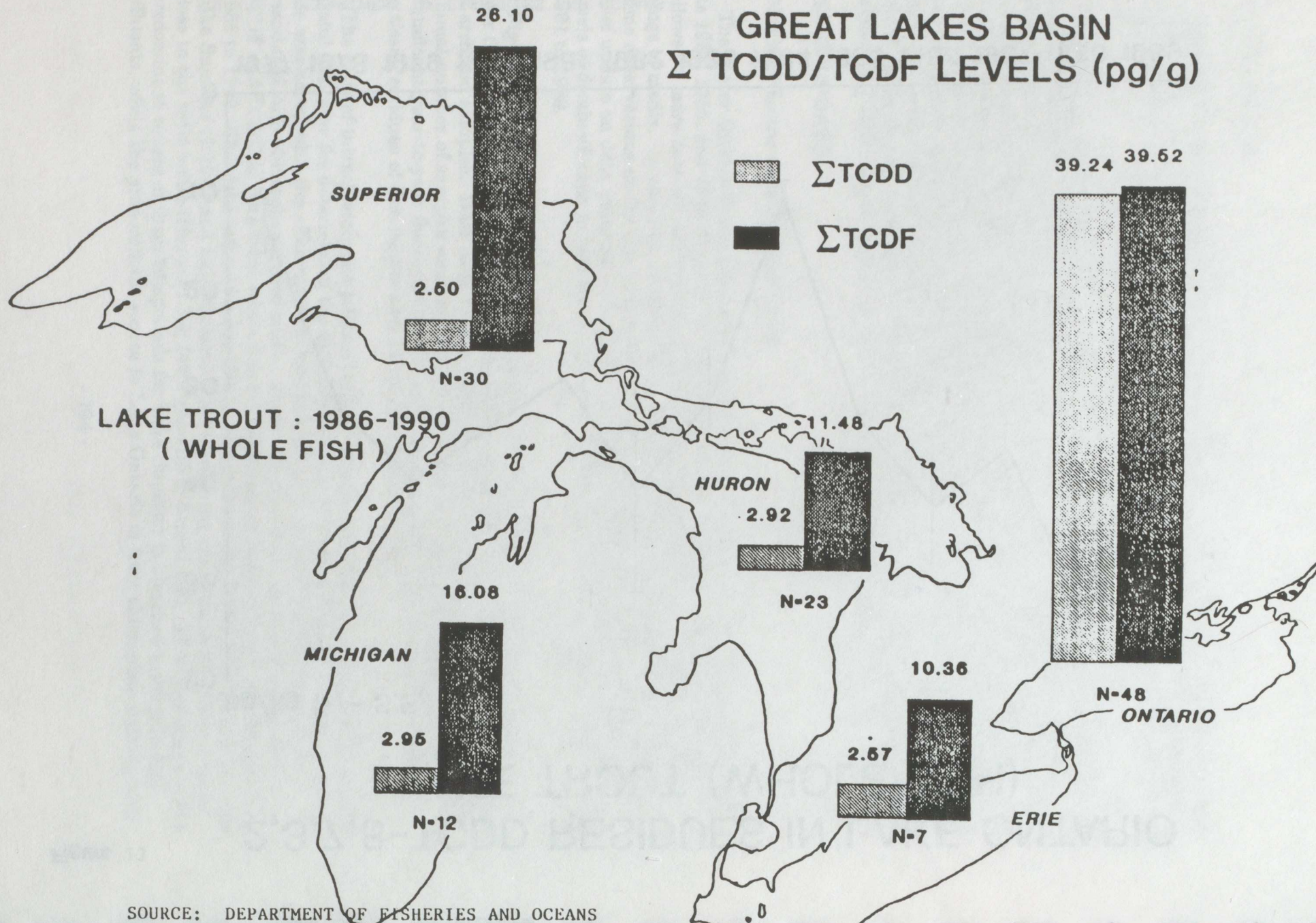
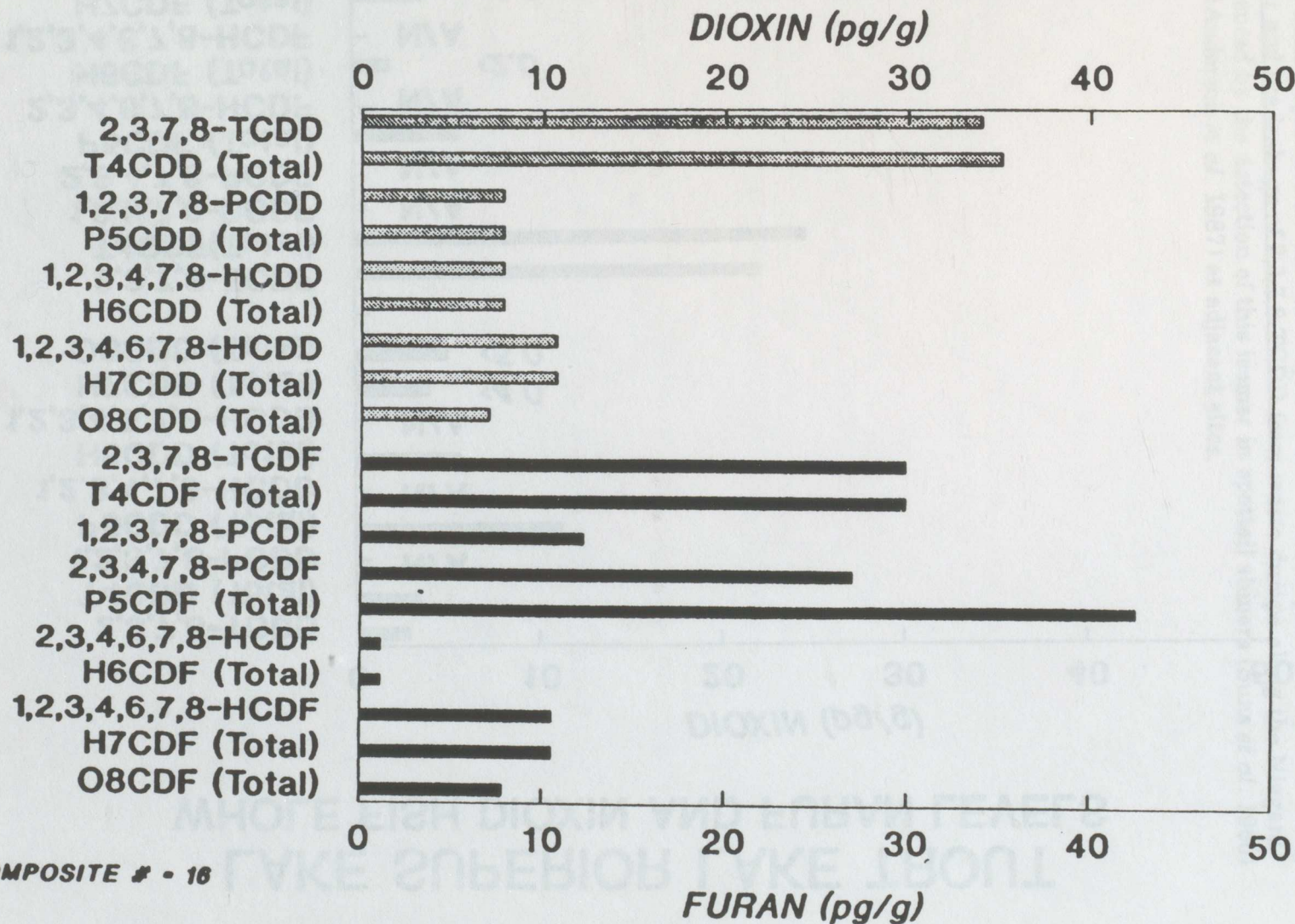


Figure 15

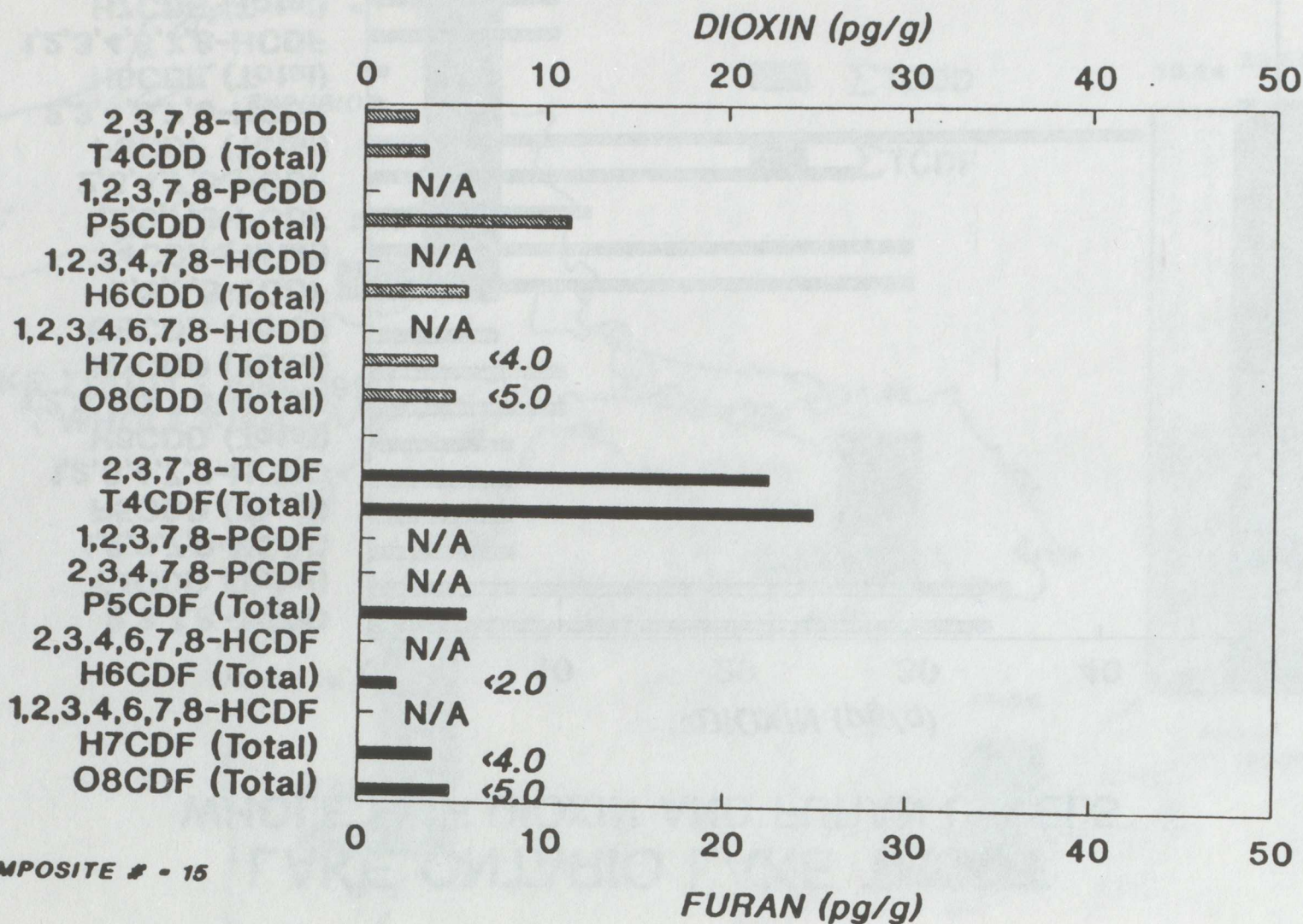
LAKE ONTARIO LAKE TROUT WHOLE FISH DIOXIN AND FURAN LEVELS



COMPOSITE # - 16

Figure 16

LAKE SUPERIOR LAKE TROUT WHOLE FISH DIOXIN AND FURAN LEVELS

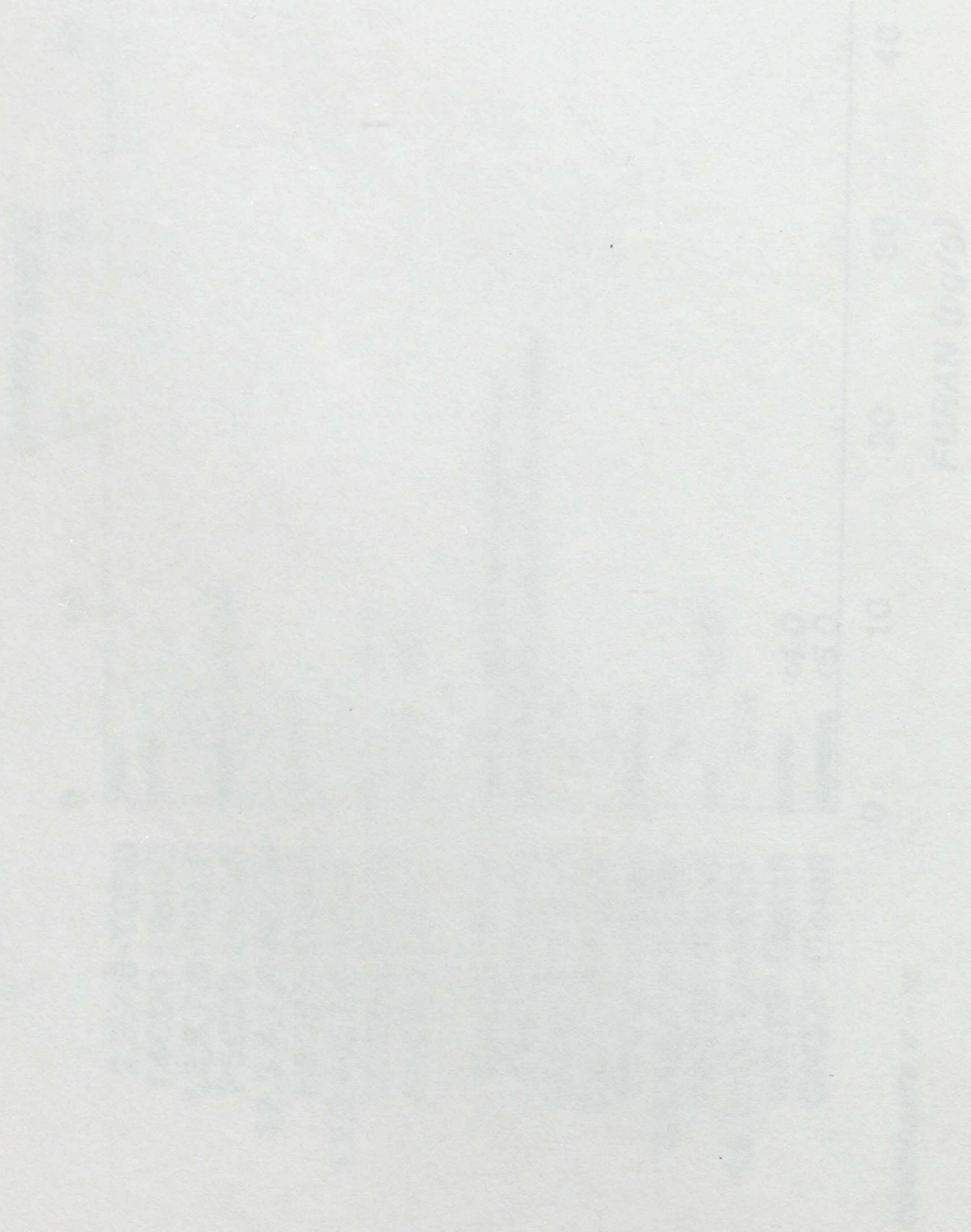


DATA SOURCE: DEPARTMENT OF FISHERIES AND OCEANS

This is further corroborated by the isomer specific analyses for furans and dioxins in these two lakes (Figures 15 and 16). These findings are consistent with the presence of several such mills on Lake Superior and the known production of chlorophenol at plants along the Niagara River and the leakage of 2,3,7,8-TCDD from waste dumps along the Niagara River as evidenced by the detection of this isomer in spottail shiners (Suns *et al.* 1985) and mussels (Anderson *et al.* 1987) at adjacent sites.

This is further supported by the lowest specific activity for dioxin and furan in these two lakes (Figure 10 and 11). These findings are consistent with the presence of several fish in Lake Superior and the lower concentration of dioxin and furan in the Great Lakes and the lower concentration of dioxin and furan in the Great Lakes. This is evident by the location of the lowest activity in the Great Lakes and the lowest activity in the Great Lakes.

LAKE SUPERIOR LAKE THIMBLE WHOLE FISH DIOXIN AND FURAN LEVELS



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CONTAMINANT MONITORING PROGRAMS IN EDIBLE PORTIONS OF FISH
AND FISH CONSUMPTION ADVISORY PROGRAMS

Overview

APPENDIX 2

Consumption advisories regarding the level of organic and inorganic contaminants in Great Lakes fish are currently published by all eight Great Lakes states and Ontario. These advisories are designed for use by Great Lakes anglers, enabling them to differentiate between fish species which should and should not be consumed based on contaminant level limits stipulated by the Federal Health Protection Act or by the individual governments. In most states, public health and natural resources agencies cooperate in order to produce an effective advisory report (e.g. New York State Department of Health and New York State Department of Environmental Conservation). A major difficulty regarding these programs is that some of the advisories issued are for large areas including the entire Great Lakes basin, thus impeding further fish consumption.

CONTAMINANT MONITORING PROGRAMS IN EDIBLE PORTIONS OF FISH
AND FISH CONSUMPTION ADVISORY PROGRAMS

Understandably, the Great Lakes states and Ontario have been working to develop a more coordinated system of monitoring contaminant levels in the Great Lakes. The overall goal is to reduce human exposure to potentially harmful chemicals through enhanced and effective communication with the public (Convention Great Lakes States 1984). Although intense effort from the Great Lakes states and Ontario to coordinate fish consumption advisories has been exerted, many discrepancies still exist. Since 1986, much of the unifying effort has come from the Great Lakes Fish Consumption Advisory Task Force.

by

REVIEWERS OF ESTABLISHING GUIDELINES AND ISSUING ADVISORIES

Jeff J. Whyte, International Joint Commission
Great Lakes Regional Office, Windsor, Ontario

As reported in the Great Lakes Fish Consumption Advisory Task Force Report (1988), the determination of a contaminant level at which an advisory should be issued is a matter of all states except Minnesota is determining if an advisory should be issued, while Ontario follows guidelines set by Health and Welfare Canada's Table 11. Guidelines in action levels for major contaminants (e.g. PCBs, dioxin and DDT) exist between countries, however, the majority of contaminants have distinctive standards or no standard established by either country. Use of federal action levels has been termed a 'black and white' approach to issuing fish advisories, since fish are safe to eat if they are below the action level and unsafe to eat otherwise above the action level. An alternative approach, termed 'judicious' or 'grey' approach, is an attempt to assess risk in issuing advisories. Minnesota, Ontario, Michigan and Wisconsin have all adopted some form of risk assessment in issuing their advisories. Federal agencies generally assume that the probability of cancer is proportional to dose and therefore zero only at zero dosage. Using a risk assessment approach, limited quantities of "unsafe" fish could be consumed without incurring an unacceptable increase in risk of cancer, while consumption of certain species and size classes of safe fish could pose unreasonable risk even by a limited number of meals per year.

March 30, 1991

Both methods have drawbacks involved. Because of not using FDA action levels

CONFIDENTIAL
1970-1971
WATER QUALITY

WATER QUALITY
CONFIDENTIAL

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CONTAMINANT MONITORING PROGRAMS IN EDIBLE PORTIONS OF FISH AND FISH CONSUMPTION ADVISORY PROGRAMS

Overview

Consumption advisories regarding the level of organic and inorganic contaminants in Great Lakes fish are currently published by all eight Great Lakes states and Ontario. These advisories are designed for use by Great Lakes anglers, enabling them to differentiate between fish species which should and should not be consumed based on contaminant level limits stipulated by individual jurisdictions or by the two federal governments. In most states, public health and natural resource agencies cooperate in order to produce an effective advisory report (e.g. New York State Department of Health and New York State Department of Environmental Conservation). A major difficulty regarding these programs is that some of the advisories issued are (or have been) inconsistent between jurisdictions. A major step towards unifying fish consumption advisories was the Great Lakes Toxic Substances Control Agreement, signed by all eight Great Lakes states in May 1986. In 1988, Ontario and Quebec signed a memorandum of understanding with the states to implement the agreement in Canada (Council of Great Lakes Governors 1988). The agreement acknowledged the need for a more coordinated system of handling contaminant issues in the Great Lakes. The overall goal is to reduce human exposure to potentially harmful chemicals through balanced and effective communication with the public (Governors-Great Lakes States 1986). Although intense effort from the Great Lake states and Ontario to coordinate fish consumption advisories has been exerted, many disagreements still exist. Since 1986, much of the unifying effort has come from the Great Lakes Fish Consumption Advisory Task Force.

METHODS OF ESTABLISHING GUIDELINES AND ISSUING ADVISORIES

An important issue in the design of fish consumption advisories is the determination of which concentrations of contaminants are considered "safe". The United States Food and Drug Administration action levels are currently applied in some manner by all states except Minnesota in determining if an advisory should be issued, while Ontario follows guidelines set by Health and Welfare Canada (Table 1). Similarities in action levels for major contaminants (e.g. PCBs, mirex and DDT) exist between countries, however, the majority of contaminants have dissimilar standards or no standard established by either country. Use of federal action levels has been termed a "black and white" approach to issuing fish advisories, since fish are safe to eat if they are below the action level and unsafe to eat if they are above the action level. As an alternative approach, some jurisdictions also use risk assessment to an extent in issuing advisories. Minnesota, Ontario, Michigan and New York all apply some form of risk assessment in issuing their advisories. Modern risk assessment methodologies generally assume that the probability of cancer is proportional to dose and becomes zero only at zero dosage. Using a risk assessment approach, limited quantities of "unsafe" fish could be consumed without incurring an unacceptable lifetime increased risk of cancer, while consumption of certain species and size classes of "safe" fish could pose unreasonable risks even for a limited number of meals per year.

Both methods have drawbacks involved. Reasons for not using FDA action levels

TABLE 1

ACTION LEVELS FOR CONTAMINANTS IN FISH TISSUE

UNITED STATES		
CONTAMINANT	U.S. FDA ACTION LEVEL	HEALTH & WELFARE CANADA HEALTH PROTECTION GUIDELINE
PCB	2.0 ppm	2.0 ppm
DDT and metabolites	5.0 ppm	5.0 ppm
Methyl Mercury	1.0 ppm	0.5 ppm
Mirex	0.1 ppm	0.1 ppm
Toxaphene	5.0 ppm	3.0 ppm ¹
Dioxin	10.0 ppt ²	20.0 ppt
Aldrin/Dieldrin	0.3 ppm	
Endrin	0.3 ppm	
Benzene Hexachloride (BHC)	0.5 ppm	
Heptachlor Epoxide	0.3 ppm	
Chlordane	0.3 ppm	
Lead		1.0 ppm

¹Tentative Level.

²This is not a U.S. FDA level, but is used by some states (e.g. New York and Wisconsin).

NOTE: Contaminants not listed have no established level of concern (Illinois Environmental Protection Agency 1990).

Sources: Illinois Environmental Protection Agency 1990.
Ontario Ministry of the Environment 1990.

include 1) they are outdated (established in 1970s or earlier) and do not take into consideration newer risk assessment approaches, 2) FDA cannot document the amount of influence of non-health factors upon the final number, and 3) the action levels are developed to protect the "average" U.S. citizen, not sensitive populations nor heavy fish consumers (Hesse 1990). Risk assessment has its limitations also. There is a high level of uncertainty associated with risk assessment assumptions in extrapolating from animal toxicology data to human populations. In addition, using worst case assumptions tends to lead to such a conservative number that it essentially eliminates a major food source from the human diet. Taken to the extreme, this could lead to a problem of "oversaturation", where so many fish have a restriction on them that people simply ignore the advisory altogether.

Organic Contaminants

In 1987, Wisconsin, Illinois, Indiana, and Michigan agreed to use a similar method in applying FDA action levels to organics in Lake Michigan fish. Three groups are designated as follows:

- Group 1 -- Low risk; fish which 0 to 10 percent of the samples tested exceed the FDA action levels for one or more contaminants.
- Group 2 -- Intermediate risk; fish which 11 to 49 percent of the samples tested exceed the FDA action levels for one or more contaminants.
- Group 3 -- High risk; fish which 50 percent or more of the samples tested exceed the FDA action levels for one or more contaminants.

A no consumption advisory is issued for group 3 fish by all of the Lake Michigan states. Illinois, Michigan and Indiana recommend that for fish in group 2, consumption be limited to one meal per week for the general population, and no consumption by children, nursing mothers, pregnant women, or women who intend to have children. These three states also allow unlimited consumption of group 1 fish. Wisconsin does not issue their group 1 and 2 advisories in terms of how much fish a person can eat in a given time frame. Instead, they state that children under 15 and women of childbearing age should not eat group 2 fish, and that the rest of the public should limit their overall consumption of group 2 fish and follow the special fish cleaning and cooking advice given in the guide. Group 1 fish are felt to have the lowest health risk, but again cooking and cleaning advice should be followed (Wisconsin Department of Natural Resources 1990).

Ohio and Pennsylvania do not use a percentage, but rather determine the mean concentration in composite samples (both states use five fish in their composites). If the mean is less than the action level, no restriction is issued.

A general advisory is issued in New York stating that no one should eat more than one half-pound meal of fish per week from any freshwater bodies. In this way, areas not tested are covered. In order to set guidelines, the individual ratios of the concentration of each contaminant as it compares to the corresponding action level are added for all organic contaminants. If the sum of these ratios equals or exceeds 1.0, a "one meal per

week" advisory is issued for the general public, and a no consumption advisory for infants, children under 15, and women of childbearing age. If the sum of the ratios exceeds 3.0, a no consumption advisory is issued to everyone.

Ontario maintains that fish exceeding the federal action levels for any of the organic contaminants should not be eaten more than 1 or 2 times per month for long term consumers, or 1 or 2 times per week for people who eat fish only 1 to 3 weeks out of the year. It is recommended that women of childbearing age and children under 15 not eat any of the fish exceeding the federal action levels. Regression analysis documenting the size at which fish generally exceed the action level is used to set guidelines rather than comparing mean concentration to action levels. No upper bound for organic contaminants has been established which would cause a "no consumption" advisory to be issued.

Minnesota does not utilize the federal action levels in setting their guidelines. Advice is developed using a risk assessment-based method using the 95% upper bound lifetime risk of developing cancer associated with exposure to individual contaminants (Foran and VanderPloeg, 1989). Advisories are set to ensure that the risk of developing cancer does not exceed 1×10^{-6} (i.e. one excess occurrence of cancer in one hundred thousand exposed persons). Advice is issued which ranges from a do not eat advisory to 14 meals per week. The level of concern for contaminants is developed by determining the point at which one meal per week will result in a cancer risk equal to 1×10^{-6} . As stated earlier, women of childbearing age and children under 15 receive special advice regarding fish consumption.

Inorganic Contaminants

The only inorganic contaminant being detected in the Great Lakes at concentrations considered high enough to advise upon currently is mercury (Hg), but again, the Great Lakes states and Ontario disagree on acceptable limits. The FDA suggests an action level of 1.0 ppm. Previously, this action level was 0.5 ppm, but was raised as a result of a court order in 1979 due to the economic impacts of the 0.5 ppm standard on the marketability of several marine fish species. Wisconsin and Michigan use 0.5 ppm as the level to issue a restricted consumption advisory. Illinois, Indiana, Ohio, Pennsylvania, and New York all use the current FDA standard of 1.0 ppm. Health and Welfare Canada maintains a 0.5 ppm federal action level which Ontario follows.

Minnesota follows the risk assessment approach and has applied an EPA generated Reference Dose of 0.3 ug Hg/kg body weight/day. The advisory groups are as follows: Hg below 0.16 ppm - unlimited consumption; Hg 0.16 to 0.65 ppm - 1 meal/week; Hg 0.66 to 2.81 ppm - 1 meal/month; Hg above 2.81 ppm - no consumption.

Advisories for Women and Children

At the May 1990 meeting of the Great Lakes Fish Consumption Advisory Task Force, differences between states in regards to advisories for women and children were resolved as all jurisdictions agreed to note the sensitive population as being "children under 15 and women of childbearing age" (Hesse 1990). As of the 1987 Report on Great Lakes Water Quality, all states had different restrictions, so this was a major accomplishment.

Multiple Contaminants

While Wisconsin, Pennsylvania, Ontario, and Minnesota do not compensate for multiple contaminants, New York does use an additivity approach as described in the organic contaminant section earlier. Illinois states that if fish had a number of contaminants which were all just below the guidelines, an advisory would be reported. Michigan includes all fish exceeding any of the FDA action levels in calculating percentages over the action levels. Indiana stated that they would move a species into the next higher category if there are multiple contaminants present at the cutoff points. In one river, Ohio used the presence of multiple contaminants in sediments as the basis for an advisory. Scientists still feel effects of multiple contaminants in regards to synergism and antagonism must be studied further. In the May 1990 meeting, the Great Lakes Fish Consumption Advisory Task Force felt that additive effects should be examined when data sets show an effect on the same organ system.

METHODS OF DETERMINING GUIDELINES AND ISSUING ADVISORIES

Contaminant Testing in Fish

Among the jurisdictions throughout the Great Lakes basin, variation occurs as to which contaminants are analyzed. PCBs and DDT are currently the only contaminants which all Great Lakes states and Ontario agree to test for, as Table 2 illustrates. Other contaminants commonly tested for include chlordane, aldrin, dieldrin, toxaphene and hexachlorobenzene. The majority of the states do not test for metals other than mercury*. Pennsylvania has indicated that they will probably stop testing for arsenic due to zero detection over the past few years (R.F. Frey, Pennsylvania Department of Environmental Resources, pers. comm., 1991). Testing for pesticides has increased in many of the states. Indiana and Minnesota now test for DDT, aldrin and dieldrin. Toxaphene and dioxin are also now being tested for in many areas. It is not known if this is due to increased concentrations being detected or if states are just becoming more thorough in their programs. A possible explanation is that methodologies for such analyses have just recently become available within their jurisdiction.

Sample Preparation and Analysis

Currently the largest difference in the method of fish sample preparation for analysis lies between the states collectively and Ontario. Ontario analyzes a skinless dorsal

* - Correction:

In the 1987 Report on Great Lakes Water Quality (International Joint Commission 1987) it was stated that Pennsylvania did not test for any metals. This was incorrect, as Pennsylvania has tested for mercury, copper, cadmium, chromium, arsenic, and lead since 1979. Zinc was analyzed for in 1989, but its future status is unclear at this time (R.F. Frey, Pennsylvania Department of Environmental Resources, pers. comm., 1991).

TABLE 2
CONTAMINANTS ANALYZED IN GREAT LAKES SPORT FISH CONTAMINANT
ADVISORY PROGRAMS

CONTAMINANT	IL	IN	MI	MN	NY	OH	PA	WI	ONT.
Mercury	X		X	X	X		X	X	X
Copper		X					X		X
Nickel									X
Zinc							X		X
Cadmium		X			X		X		X
Manganese		X							X
Chromium		X					X		X
Arsenic		X					X		X
Selenium									X
Lead		X			X		X		X
Aluminum					1				
Total PCB	X	X	X	X	X	X	X	X	X
DDT + Metabolites	X	X	X	X	X	X	X	X	X
Mirex	X				X				X
Photomirex					X				
Lindane	X				X		X		X
Chlordane	X	X	X		X	X	X	X	X
Aldrin/Dieldrin	X	X	X	X	X	X	X	X	X
Endrin	X			X	X	X	X		
Heptachlor Epoxide	X		X		X		X		X
Octachlorostyrene			X						X
Benzene Hexachloride (BHC)	X				X		X		X
Methoxychlor	X						X		
Toxaphene	X					X		X	X
2,3,7,8-TCDD (dioxin)					X			X	X
Terphenyl			X						
FBB			X						
PAHs					1				X
Dibenzofurans					X				X
Hexachloroethane									X
Hexachlorobutadiene									X
1,3,5-Trichlorobenzene									X
1,2,4-Trichlorobenzene									X
1,2,3-Trichlorobenzene									X
1,2,4,5-Tetrachlorobenzene									X
1,2,3,4-Tetrachlorobenzene									X
Pentachlorobenzene									X
Hexachlorobenzene (HCB)	X		X		X	X			X
2,4,5-Trichlorotoluene									X
2,3,6-Trichlorotoluene									X
Pentachlorostyrene			X						
Hexachlorostyrene			X						
Heptachlorostyrene			X						
Chlorinated Phenols									X

1 - Tested upon request.

Sources: Hesse 1990.

- Illinois Environmental Protection Agency 1990.
- Indiana State Board of Health 1990.
- Michigan Department of Natural Resources 1990.
- Minnesota Department of Health 1989.
- New York State Department of Health 1990.
- Ohio Department of Natural Resources 1990.
- Pennsylvania Department of Environmental Resources 1989.
- Wisconsin Department of Natural Resources 1990.
- Ontario Ministry of the Environment 1990.

section of tissue on an individual fish basis (Ontario Ministry of the Environment 1990). They feel that the portion is representative of the way anglers are recommended to prepare their fish (i.e. skinned and trimmed). The states prefer to assume that not all people will follow the preparation advice, and therefore choose a more conservative approach. Wisconsin, Indiana and New York use untrimmed skin-on fillets analyzed as individual fish. Michigan prepares samples as either in skin-on or skin-off depending on the species and the most frequent method of preparation for consumption (Usually skin-on and analyzed as individual fish). Minnesota, Illinois, Ohio and Pennsylvania perform analysis on five-fish composites of untrimmed skin-on fillets within each defined size range. Pennsylvania uses composited skin-off fillets for catfish (Hesse 1990).

One problem involved in using different sample preparation methods is that skin-on untrimmed fillets will retain more organics in the fatty tissue than the skinless dorsal sections, giving incompatible data between jurisdictions. A possible solution to this problem would be to use lipid normalized values for contaminant levels in fish. By adjusting the contaminant concentration according to the percent lipid in a sample, values could be examined from a common reference point. Introducing a common practice for sample preparation would allow for more data exchange between jurisdictions, but there is a concern that long term trend data within a jurisdiction would be disrupted if they were to change sampling procedures. This, in turn, would lead to inconsistency in providing advice to the public.

Quality Control and Quality Assurance

In order to increase the coordination of data sets among jurisdictions, chemists representing each area met between 1985-87 to exchange laboratory techniques and analytical procedures, hoping to attain a common inter-laboratory quality control and assurance program. Problems hindering this include the fact that Ohio and Pennsylvania are dependent on a variety of several separate in-state laboratories for data, which complicates quality control compatibility efforts. The U.S. Fish and Wildlife Service laboratory in Ann Arbor is currently preparing some fish tissue check samples for use towards comparisons among jurisdictions. They are also willing to develop appropriate homogenates of fish samples for contaminant analysis around the Great Lakes basin.

A continuing difficulty occurs due to the fact that most Great Lakes states only list sport fish in their advisory leaflets which exceed the contaminant guidelines. This leads to some misconception in regards to the number of contaminated fish in relation to the total fish population.

Currently, due to insufficient funding, only Minnesota and Ontario are able to list results where no guideline was exceeded (Minnesota Department of Health 1989; Ontario Ministry of the Environment 1990). This data can be used to calculate a rough ratio of contaminated to uncontaminated fish. As Ontario has a site specific advisory program, regions where this ratio is large could be indicative of an area of concern for contaminant loadings.

DISTRIBUTION OF ADVISORIES

Table 3 summarizes the current coverage of fish consumption advisories in the Great Lakes basin in regard to the number of locations with advisories in effect, as well as the number of species advised on. Michigan and Ontario show more numerous advisory locations due to their extended Great Lakes shorelines, and in addition, Ontario has a large annual site-specific program in effect. It should be noted that Minnesota and Ontario report on all statistically valid fish contaminant data even if no federal contaminant criterion is exceeded, and in Ontario, over 92% of sampling locations have at least some sizes of fish with no restrictions (Minnesota Department of Health 1989; Ontario Ministry of the Environment 1990), but in Table 3 only restrictions issued are listed.

Figures 1 through 4 describe restricted advisories within the Great Lakes. Note that these advisories apply only to adult males and women not in childbearing ages. The states and Ontario give special consideration to children and women of childbearing age as described earlier. Wisconsin is not included in these figures due to their method of issuing advisories, and are therefore discussed later. It is important to also note that some differences in numbers of advisories issued between jurisdictions may be attributed to local contaminant "hot spots" where fish may show much higher levels of contaminants than other areas of the lake.

Advisories which suggest no consumption of certain fish are displayed in Figure 7 (page 33). In Lake Superior, Minnesota has no total bans for any fish species. Conversely, Ontario and Michigan show advisories, but there is considerable difference between the two countries. Ontario subdivides its advisories into lake segments, whereas the United States chooses to issue lake wide advisories. Possibly the reason Ontario has more species restrictions than Michigan is that the ministry chooses to include all valid fish samples regardless of species in their report. This includes some less appealing fish such as the gizzard shad which is a good indicator of contaminant availability (Ontario Ministry of the Environment 1990). There is also a large difference in the size of siscowet advised on between countries, and seems to indicate higher contaminant level in Michigan regions of the lake.

In Lake Huron and Lake St. Clair, Michigan does not issue a no consumption advisory for walleye in their "1990 Michigan Fishing Guide" (Michigan Department of Natural Resources, 1990), yet Ontario has them in both lakes. Michigan also indicates that catfish above 55 cm are not suitable for human consumption in Lake St. Clair, and Ontario indicates they are. This difference may be attributed to a specific area of contamination in Michigan since both Ontario and Michigan use the same method of issuing advisories in Lake St. Clair (Hesse 1991, pers. comm.).

Lake Erie is covered by a uniform advisory from Michigan, Ohio and Pennsylvania, but again Ontario shows a considerable difference in species advised upon. Ontario and New York only agree on the fact that channel catfish should be advised on in Lake Ontario, but New York's size restriction is 38 cm and Ontario's is 55 cm. Again, the problem of differing water area, contaminant "hot spots", and differing sizes of data sets makes issuing a uniform advisory over the entire lake impossible.

TABLE 3
GREAT LAKES SPORT FISH CONSUMPTION ADVISORIES

JURISDICTION	# OF LOCATIONS ADVISED ON	# OF SPECIES OF FISH ADVISED ON
UNITED STATES		
Illinois ¹	1	11
Indiana ²	1	6
Michigan ³	5	19
Minnesota ⁴	1	3
New York ⁵	2	11
Ohio ⁶	1	2
Pennsylvania ⁷	1	2
Wisconsin ⁸	2	12
CANADA		
Ontario ⁹		
Lake Ontario	41*	24
Lake Erie	15	17
Lake Huron	38	14
Lake Superior	29	8

* Not including the Niagara River.

¹Illinois Environmental Protection Agency 1990.

²Indiana State Board of Health 1990.

³Michigan Department of Natural Resources 1990.

⁴Minnesota Department of Health 1989.

⁵New York State Department of Health 1990

⁶Ohio Department of Natural Resources 1990.

⁷Pennsylvania Department of Environmental Resources 1990.

⁸Wisconsin Department of Natural Resources 1990.

⁹Ontario Ministry of the Environment 1990.

Figure 1
 Advisories on fish consumption in The Great Lakes

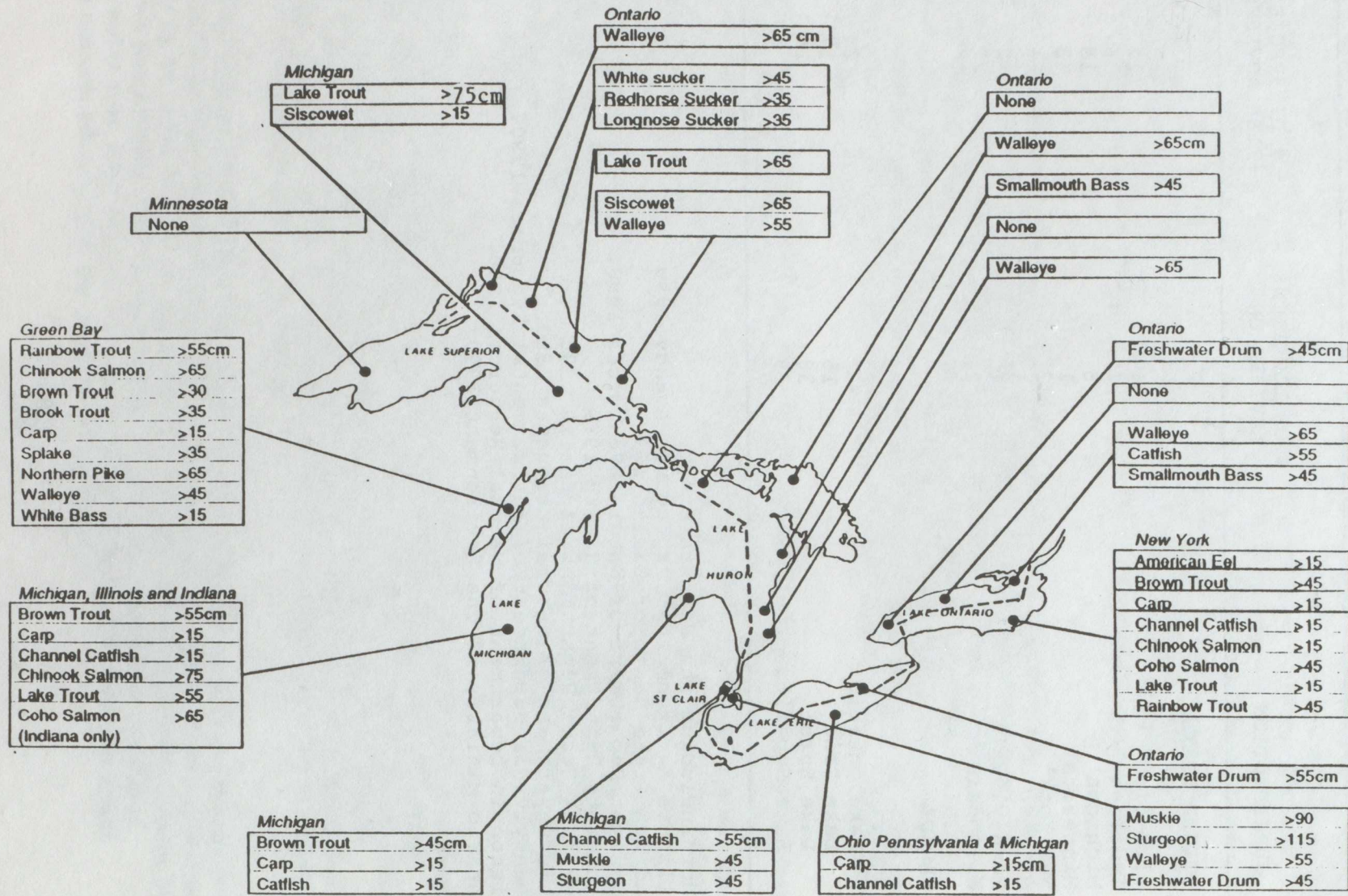


Figure 2
 One meal per month fish consumption Advisories in the Great Lakes

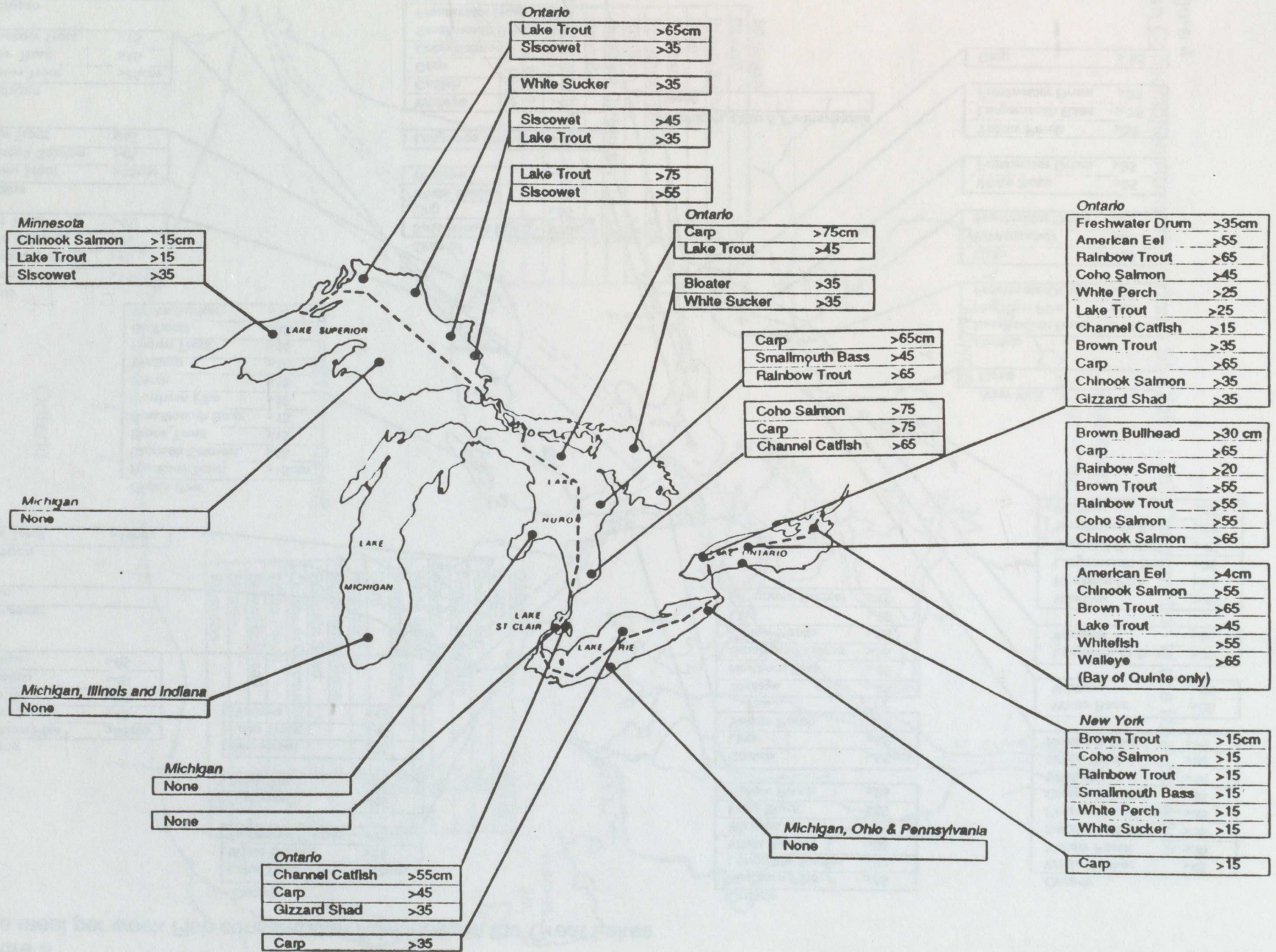


Figure 3
One meal per week Fish consumption Advisories in the Great Lakes

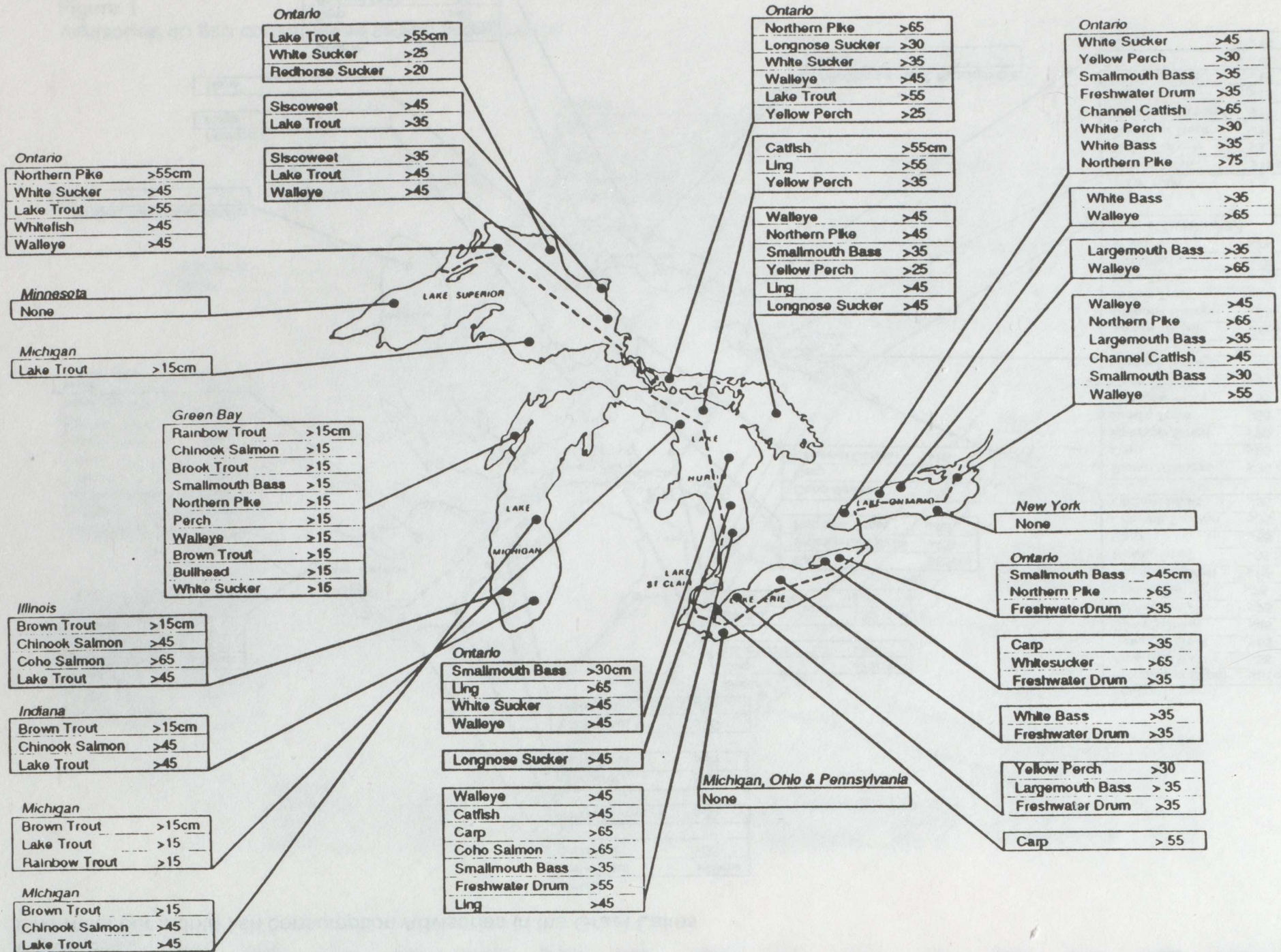
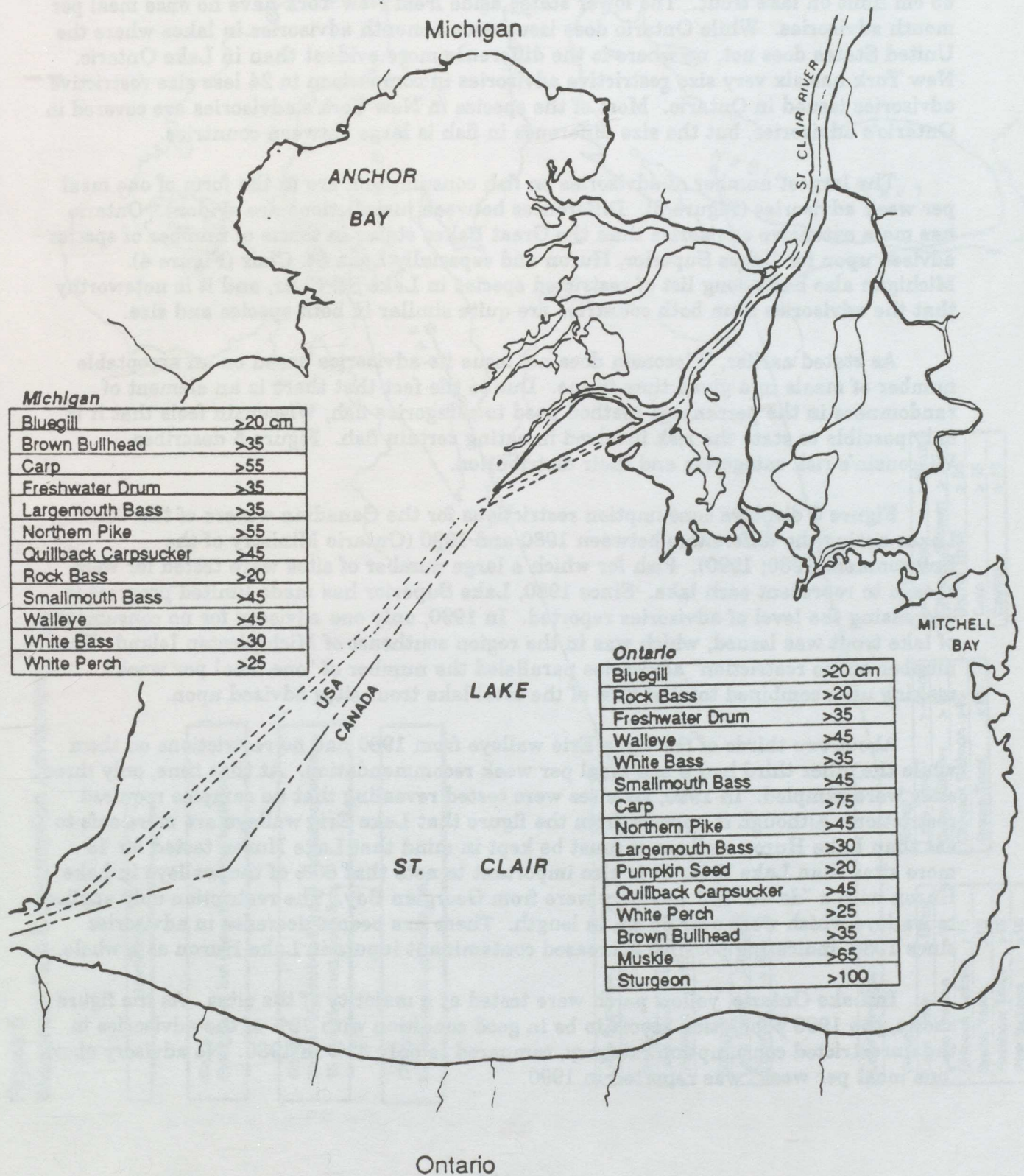


Figure 4
 Fish Consumption Advisories in Lake St. Clair - Limit Consumption to one Meal per week



One meal per month consumption advisories are depicted in Figure 2. In Lake Superior, Minnesota has very restrictive warnings on lake trout and chinook salmon, indicating that basically any size catch is restricted. Ontario has no ban on salmon, and a 65 cm limit on lake trout. The lower states aside from New York have no once meal per month advisories. While Ontario does issue once a month advisories in lakes where the United States does not, no where is the difference more evident than in Lake Ontario. New York has six very size restrictive advisories in comparison to 24 less size restrictive advisories issued in Ontario. Most of the species in New York's advisories are covered in Ontario's advisories, but the size difference in fish is large between countries.

The largest number of advisories on fish consumption are in the form of one meal per week advisories (Figure 3). Differences between jurisdictions are evident. Ontario has more extensive advisories than the Great Lakes states in terms of number of species advised upon for Lakes Superior, Huron and especially Lake St. Clair (Figure 4). Michigan also has a long list of restricted species in Lake St. Clair, and it is noteworthy that the advisories from both countries are quite similar in both species and size.

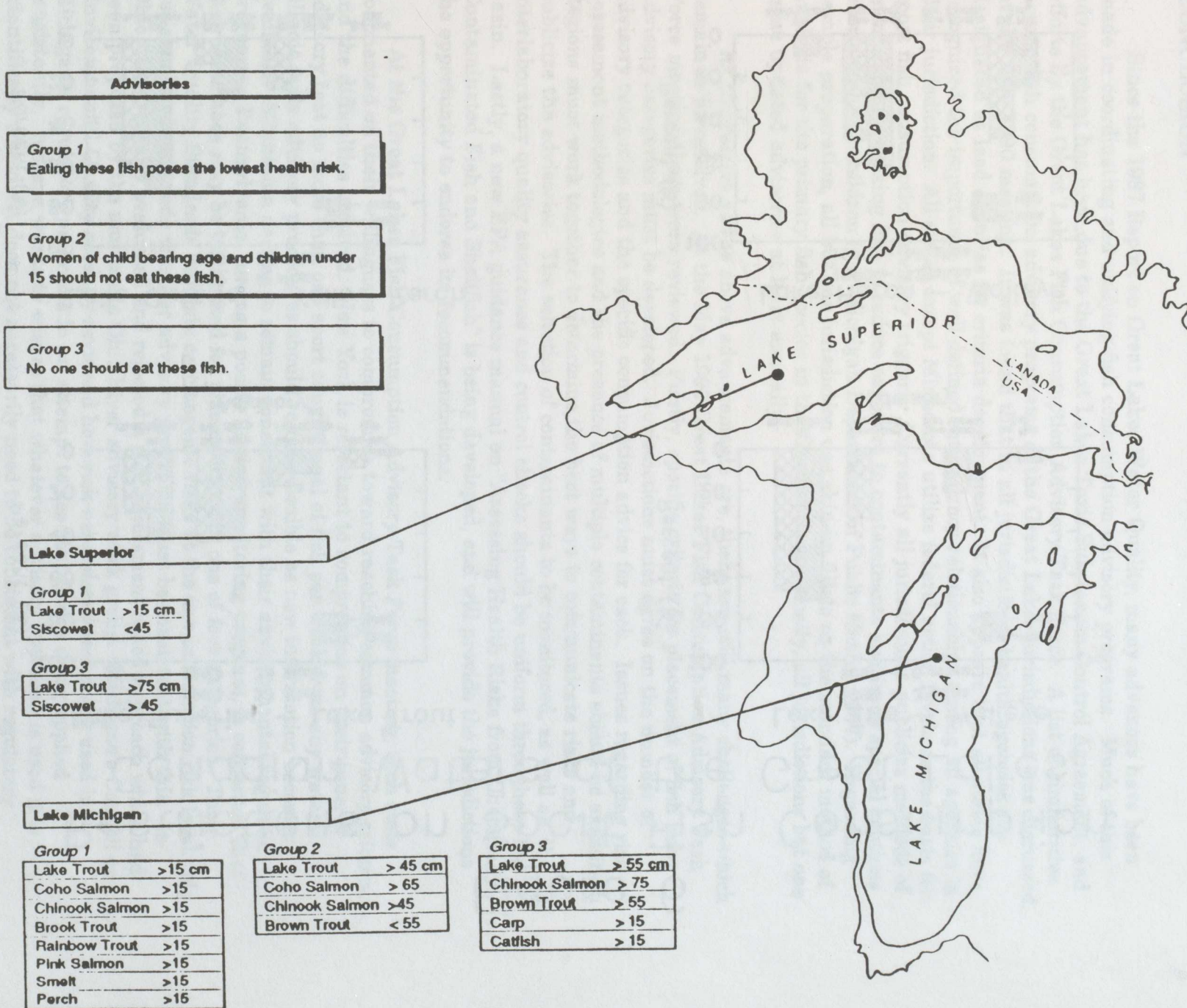
As stated earlier, Wisconsin does not issue its advisories based on an acceptable number of meals in a given time frame. Due to the fact that there is an element of randomness in the percentage method used to categorize fish, Wisconsin feels that it is only possible to state the risk involved in eating certain fish. Figure 5 describes Wisconsin's risk categories and their distribution.

Figure 6 displays consumption restrictions for the Canadian waters of the Great Lakes noting the differences between 1980 and 1990 (Ontario Ministry of the Environment 1980; 1990). Fish for which a large number of sites were tested for were chosen to represent each lake. Since 1980, Lake Superior has made limited progress in decreasing the level of advisories reported. In 1990, only one advisory for no consumption of lake trout was issued, which was in the region southeast of Michipicoten Island. The number of "no restriction" advisories paralleled the number of "one meal per week" making up a combined total of 80% of the total lake trout sites advised upon.

About two thirds of the Lake Erie walleye from 1980 had no restrictions on them while the other third had a one meal per week recommendation. At that time, only three sites were sampled. In 1990, six sites were tested revealing that no samples required restriction. Although it appears from the figure that Lake Erie walleye are more safe to eat than Lake Huron walleye, it must be kept in mind that Lake Huron tested for 13 more sites than Lake Erie. It is also important to note that 80% of the walleye in Lake Huron with a "do not eat" advisory were from Georgian Bay. The restriction only applied to walleye which were over 65 cm in length. There has been a decrease in advisories since 1980, indicating possible decreased contaminant inputs in Lake Huron as a whole.

In Lake Ontario, yellow perch were tested at a majority of the sites. As the figure shows, the 1990 population seems to be in good condition with 72% of the advisories in the unrestricted consumption category, compared to only 62% in 1980. No advisory above "one meal per week" was reported in 1990.

Figure 5
Wisconsin Fish Consumption Advisories



Advisories

Group 1
Eating these fish poses the lowest health risk.

Group 2
Women of child bearing age and children under 15 should not eat these fish.

Group 3
No one should eat these fish.

Lake Superior

Group 1
Lake Trout >15 cm
Siscowet <45

Group 3
Lake Trout >75 cm
Siscowet >45

Lake Michigan

Group 1

Lake Trout	>15 cm
Coho Salmon	>15
Chinook Salmon	>15
Brook Trout	>15
Rainbow Trout	>15
Pink Salmon	>15
Smelt	>15
Perch	>15

Group 2

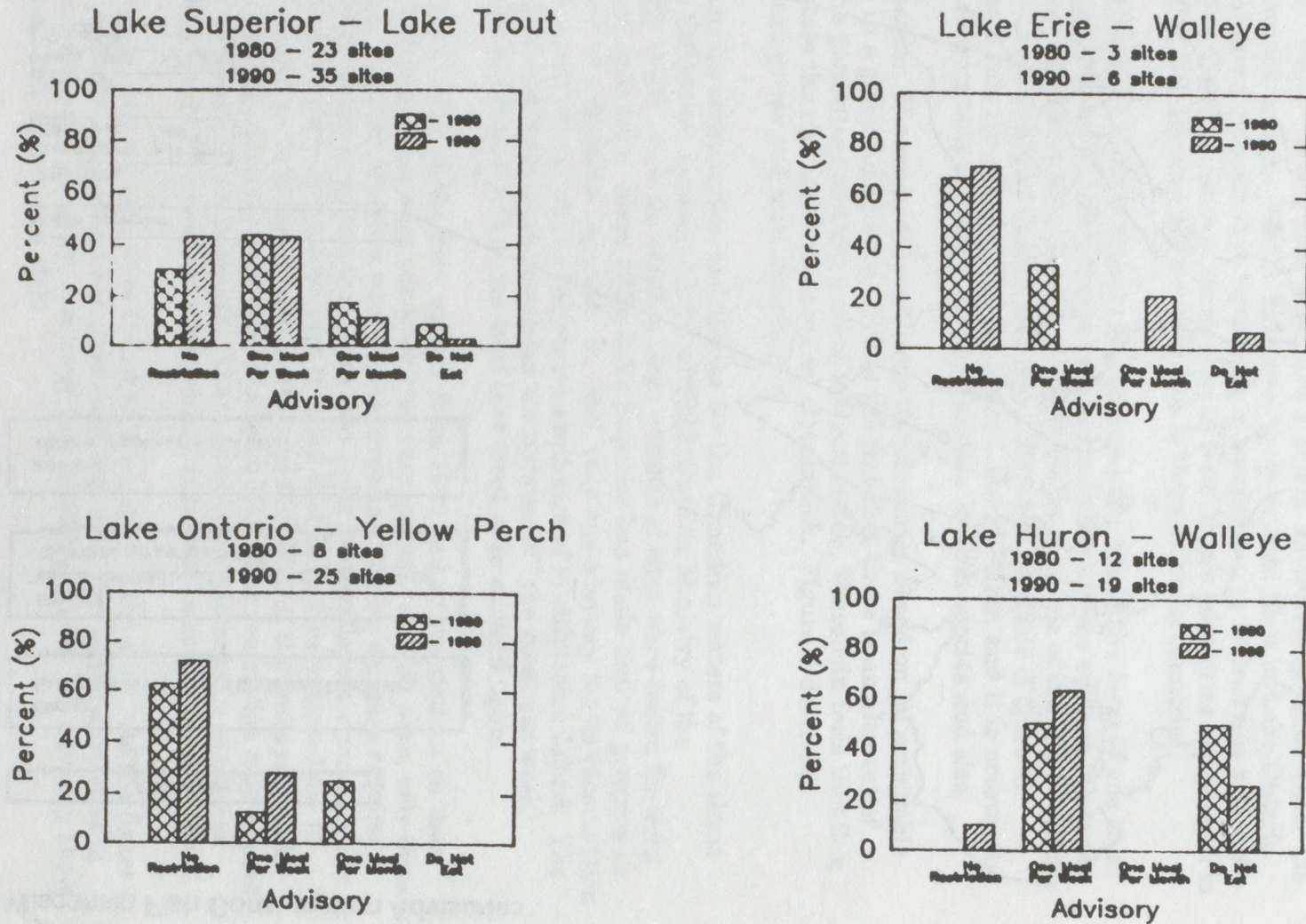
Lake Trout	>45 cm
Coho Salmon	>65
Chinook Salmon	>45
Brown Trout	<55

Group 3

Lake Trout	>55 cm
Chinook Salmon	>75
Brown Trout	>55
Carp	>15
Catfish	>15

Figure 6

Restrictions on Sport Fish Consumption Canadian Waters of the Great Lakes



(Source : Ontario Ministry of the Environment 1980; 1990)

CONCLUSION

Since the 1987 Report on Great Lakes Water Quality, many advances have been made in coordinating and unifying fish consumption advisory programs. Much of this advancement has been due to the Great Lakes Toxic Substances Control Agreement, and efforts by the Great Lakes Fish Consumption Advisory Task Force. A list of similarities among fish consumption advisory programs of the Great Lakes jurisdictions was discussed at the May 1990 meeting. It was found that in all jurisdictions, health agencies are designated as lead agencies for criteria development. It also appears that all states have recognized the importance of well defined interagency relationships among all agencies in their jurisdiction. All states except Minnesota utilize federal action levels as the basis for sport fish consumption advisory triggers. Currently all jurisdictions publicize methods of trimming and cooking fish to reduce exposure to contaminants and issue special cautions for women and children (e.g. Michigan Department of Public Health 1987). Regarding sample preparation, all but one jurisdiction use skin-on fillets as the standard method of analysis for the primary fish species in the Great Lakes. Finally, all jurisdictions but one issue updated advisories at least annually.

As impressive as the above advancements are, there are still many challenges which remain to be resolved. At the May 1990 Great Lakes Fish Consumption Advisory Task Force meeting these were reviewed. Firstly, specific criteria for placement of fish into advisory categories must be developed. Jurisdictions must agree on the number of advisory categories and the specific consumption advice for each. Issues regarding risk assessment methodologies and the presence of multiple contaminants should be examined. Regions must work together to determine the best ways to communicate risks and publicize the advisories. The selection of contaminants to be monitored, as well as, the interlaboratory quality assurance and control checks should be uniform throughout the basin. Lastly, a new EPA guidance manual on "Assessing Health Risks from Chemically Contaminated Fish and Shellfish" is being developed, and will provide the jurisdictions the opportunity to endorse its recommendations.

At the Great Lakes Fish Consumption Advisory Task Force meeting, each state commented on their willingness to compromise toward reaching common advisory criteria, and the difficulties involved. New York is reluctant to compromise on their general advisory (eat no more than one sport caught meal of fish per week from any waters). Illinois feels advisory procedures should remain flexible as new information becomes available. Minnesota desires to remain consistent with their environmental regulatory programs. Pennsylvania, having a poorly funded monitoring program, is concerned that their data base may be too limited for placing fish into one of four categories. Their Water Quality Standards regulate carcinogenic risks at the one in a million risk level. No decision has been made whether advisory programs must be consistent with this. In Ohio, they recently evaluated and rejected a risk assessment based approach which had been proposed by the multistate Ohio River advisory work group. Michigan's Council on Environmental Quality recently reviewed how risk assessment was being used in Michigan's regulatory programs in an attempt to see that it was being applied consistently. Indiana wants to ensure that whatever advisory approach is used it is scientifically sound. It does not necessarily need to be consistent with regulatory programs. Wisconsin agreed with this position. Ontario maintains that criteria must be

consistent with the regulatory approach established by Health and Welfare Canada.

With continuing efforts, a more unified system of fish advisories between both countries can be achieved. Cooperation between jurisdictions has been shown to be effective, and if maintained, it will lead to resolution of current problems. If the Great Lakes states and Ontario succeed in accomplishing a unified basinwide program, it may serve as a template to the formation of a complete bi-national protocol which includes all the waterways of North America. A coordinated system of advisories which promotes wise consumption of fish while still emphasizing the health value of fish as a food source will benefit the general public and the sport fish industry simultaneously.

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APPENDIX 3

INTRODUCTION

Pollution resulting from human activities has caused a variety of impairments in Great Lakes biological communities. Much of recent research documenting such impairments has focused on the impacts of toxic chemicals on biota. Benthic macroinvertebrate communities of Great Lakes connecting channels have been surveyed repeatedly by United States and Canadian government agencies since 1969. These studies have provided valuable data regarding sources and types of pollutants affecting the connecting channels, as well as the resulting impacts on benthic communities. The report was initiated to synthesize available information regarding the extent and type of benthic community degradation in Great Lakes connecting channels.

DEGRADATION OF BENTHIC COMMUNITIES IN GREAT LAKES

CONNECTING CHANNELS - A REVIEW

Degradation of benthic communities in Great Lakes connecting channels was the subject of the 1978 Great Lakes Water Quality Agreement, specifically one of the 16 criteria for designating protected areas of the Great Lakes as "Special Concern". According to the "Guiding Principles Governing the Great Lakes Area of Special Concern" (International Joint Commission 1980), benthic communities are important because they are structurally and functionally diverse, they are sensitive to pollutants, and they are important in the food chain. In addition, they are important in the study of sedimentation and erosion processes. The report is intended to provide a general overview of the general approach to the study of benthic community degradation in Great Lakes connecting channels, and to provide a synthesis of the information available on the characteristics of degraded benthic communities.

by

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APPENDIX 2

DECLARATION BY BIRTHDAY COMPANY TO THE GREAT BRITAIN
CONNECTING CABLES - A REVIEW

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BENTHOS DEGRADATION IN GREAT LAKES CONNECTING CHANNELS

INTRODUCTION

Pollution resulting from human activities has caused a variety of impairments in Great Lakes biological communities. Much of recent research documenting such impairments has focused on the impacts of toxic chemicals on biota. Benthic macroinvertebrate communities of Great Lakes connecting channels have been surveyed repeatedly by United States and Canadian government agencies since 1980. These studies have yielded valuable data regarding sources and types of pollutants affecting the connecting channels, as well as the resulting impacts on benthic communities. This report was initiated to synthesize available information regarding the extent and type of benthos degradation in Great Lakes connecting channels, as part of an effort to update the state of knowledge on biota impairments caused by human activities in the Great Lakes.

Degradation of benthos, identified as use impairment (vi) in Annex 2 of the 1987 Protocol to the 1978 Great Lakes Water Quality Agreement, currently serves as one of the 14 criteria for designating polluted areas of the Great Lakes as "Areas of Concern". According to the "Listing/Delisting Guidelines for Great Lakes Areas of Concern" (International Joint Commission 1990), benthic communities are degraded when community structure significantly diverges from those at unimpacted control sites of comparable physical and chemical characteristics. In addition, significantly higher toxicity of sediment associated contaminants at a site compared to controls also indicates degradation. Although use of these specific criteria to detect degradation is not implicit in all benthic surveys, the general approach employed in surveys (comparison of study sites to control sites, toxicity testing of sediments) tends to ensure reasonable compliance with the above definition of degraded benthos.

Benthic communities of freshwater systems play a crucial role in energy transfer from primary producers and sediment organic material to higher trophic levels, and in the processing of sediment detrital material (Resh and Rosenberg, 1984). Unimpacted benthic communities tend to reflect the physical environment (esp. substrate characteristics, dissolved oxygen, and flow regime), the biotic environment (predation by fish or other invertebrates, competition for food and space, presence/absence of aquatic vegetation), and resource availability (Resh and Rosenberg, 1984). In general, healthy communities exhibit high diversity (a measure of distribution of organisms among taxonomic groups) and taxonomic richness (number of species or taxa), high spatial heterogeneity, the absence of excessively dominant organisms (evenness), and the presence of pollution intolerant taxa (stoneflies, mayflies, caddisflies, crustaceans, pollution sensitive oligochaete and chironomid species).

BENTHIC COMMUNITY ASSESSMENT

Standardized procedures for conducting benthic surveys are described in the report entitled "Procedures for the Assessment of Contaminated Sediment Problems in the Great Lakes" (International Joint Commission 1988). Reynoldson and Zarull (1989) also

described an integrated strategy for the biological assessment of contaminated sediments, with special emphasis on establishing cause-effect relationships between sediment contaminants and benthic communities. These authors and others agree that studies designed to assess the state of a benthic community at a given location using benthic community data alone are inadequate. Relevant habitat variables, the extent of pollution, and sediment toxicity must also be quantified to arrive at valid conclusions. Only when one cannot account for the type of community present based on habitat variables, and has demonstrated the presence of polluting substances in potentially harmful quantities, should anthropogenic impacts be implicated. Toxicity testing of field-collected sediments is an important first step in linking specific polluting substances to observed effects in the field.

The pollution indicator approach is frequently employed in benthic community assessment. It allows the investigator to qualitatively assess the presence/absence and extent of benthic habitat degradation, based on the relative abundances of species of macroinvertebrates with known organic pollution tolerance. This approach is especially useful in combination with more quantitative analytical techniques to evaluate the effects of organic pollution.

Although well designed benthic surveys tend to yield reliable information regarding the general health of the waterbody studied, a number of factors often complicate data interpretation. The large degree of spatial and temporal variation in benthic communities renders accurate community assessment difficult without extensive sampling designs (Barton 1989). In addition, the effects of sampler type, timing of sampling, processing, sorting, and analytical methodology, difficulties in taxonomy (esp. immature invertebrates), and poor understanding of life cycles of many species may significantly influence inferences regarding community structure (Barton 1989, Jaagumagi et al. 1989). As a result, quantitative benthic community data is often difficult, if not impossible, to compare among surveys.

HUMAN IMPACTS

The following major types of human impacts have been observed in Great Lakes connecting channels:

Organic Pollution

Community level effects of organic pollution, caused by inputs of organic material or nutrients, are relatively well understood. Initially, or under conditions of slight organic enrichment, a general increase in densities of most benthic taxa tends to occur, in response to increased food availability (Wiederholm 1984). Upon continued nutrient input, this is followed by a decline in oxygen concentrations in and above the sediment, due to the increased oxygen demand of the microflora associated with the polluting material (Cook and Johnson, 1974). This results in a progressive decline in densities of organisms sensitive to low dissolved oxygen levels (stoneflies, mayflies, caddisflies, crustaceans, sensitive chironomid and oligochaete species), with a concurrent increase in densities of tolerant invertebrates, able to exploit the available resources (usually oligochaete and chironomid species; Wiederholm 1984). This process eventually results in

complete exclusion of sensitive organisms, accompanied by a pronounced decline in taxonomic richness and diversity (Wiederholm 1984). Under extreme organic pollution, the community is usually reduced to oligochaetes only (typically *Tubifex tubifex* and *Limnodrilus hoffmeisteri*), at enormous densities (Cook and Johnson, 1974; Wiederholm 1984).

Toxic Contaminants

The effects of toxic contaminants (metals, pesticides, industrial organic chemicals, oils) on benthic communities are poorly understood. Although the tendency of metals and organochlorines to accumulate in tissues of invertebrates in contaminated waterbodies has been extensively documented (Eadie et al. 1988; Nalepa and Landrum, 1988), clear community level effects of contaminants, other than nearly complete defaunation, have rarely been demonstrated. Density and taxonomic richness may decline in response to contaminants due to toxicity, but few field studies have clearly documented these effects (Fitchko 1986; Nalepa and Landrum, 1988). Decreased production of benthos has also been noted in response to increasing sediment contaminant concentrations, as well as exclusion of mayfly larvae by oil on the sediment surface (Schloesser 1988, Edsall et al. 1991). However, most of these effects are correlational or observational, with little evidence of solid cause-effect relationships. In the laboratory, exposure to contaminants has been shown to cause mortality, as well as various physiological stresses, exhibited in reproductive impairment, biochemical effects, increased frequency of deformities, effects on survival, growth, and metabolism, and possibly other impairments (Fitchko 1986).

Combinations of Pollutants

In polluted areas of the Great Lakes, toxic contaminants usually occur in complex mixtures, and often in combination with organic pollution. The large number of toxic substances and the potential for interactions between them frequently precludes identification of effects of individual contaminants. In addition, organic pollutants may reduce the bioavailability of toxic contaminants, due to the tendency of hydrophobic contaminants to sorb to organic material in aquatic systems (Chapman et al. 1982). Thus, combinations of pollutants greatly complicate attempts to determine the impacts of toxic contaminants in the field.

Dredging and Navigational Use

Dredging may result in considerable benthic habitat alteration and destruction. In the short term, mortality and morbidity due to habitat disruption, and resuspension of contaminants resulting in increased bioavailability to benthic animals may occur (Liston et al. 1983; Rice and White, 1987). Long-term effects include a decline in invertebrate densities and altered taxonomic composition in affected areas (Haynes and Makarewicz, 1982). Vessel traffic in shallow waterbodies may result in small-scale habitat disruption and sediment resuspension (Greenwood 1983). These effects are widespread in Great Lakes connecting channels, which serve as important shipping routes, but are limited to harbours and shipping channels (Environment Canada and U.S. Environmental Protection Agency, 1988; Liston et al. 1983).

Species Introductions

Significant benthic community alteration may occur due to the relatively recent introduction and rapid spread of the zebra mussel (*Dreissena polymorpha*). This invader has the potential to exclude other mussel species from their native habitats, displace filter-feeders and grazers from hard substrates, and due to the increased transfer rates of nutrients to the sediments, may cause an increase in densities of some benthic invertebrates (Mackie et al. 1989). Other, non-benthic recent invaders (spiny water flea, ruffe) are less likely to have significant effects on Great Lakes benthic communities.

ENVIRONMENTAL QUALITY ZONES IN THE CONNECTING CHANNELS

This review focuses on the impacts of pollution (toxic chemicals and organic pollution) on benthic communities. Information is presented in the form of zones representing areas with relatively homogeneous environmental quality. Benthic community type, sediment contamination, and most likely factors responsible for the existing community types within zones are discussed, based on results of several surveys of each connecting channel. To minimize perceived variation in community types due to temporal trends in response to pollution abatement, only relatively recent studies (1979 to 1991) were reviewed.

Zonation patterns reported by the most recent large scale studies were adopted. In general, zones in each river were delineated by a cluster analysis of sites based on biological data (abundances of taxa). This was followed by a discriminant analysis of physico-chemical data (sediment particle size distribution, contaminant concentrations, current velocity, aquatic plant cover, etc.) using *a priori* grouping determined by the cluster analysis. This technique allowed identification of the most likely physico-chemical variables responsible for the zonation pattern. However, since data for each survey were analyzed independently, biological and physico-chemical characteristics of zones are not comparable among connecting channels or surveys. Boundaries of zones should be considered as approximate, due to potential variation in spatial distribution of benthic invertebrates, temporal variation in benthic community structure during the years reviewed, and occasionally, inadequate resolution of sampling designs.

In the Niagara and Detroit rivers, several zones were designated as potentially degraded, based on the combined results of a number of surveys. In these parts, either data are suggestive of degradation but conclusive evidence is lacking, or results of studies are inconsistent with respect to the occurrence of degradation. In addition, zones designated as unimpaired may include areas where sampling intensity was inadequate to identify pollutant impacts. However, unless specifically identified, such areas are not known to receive significant inputs of pollutants.

Throughout the following discussion of environmental quality zones, the terms pollution "sensitive" and "tolerant" refer to responses to organic enrichment and not to toxic chemicals.

ST. MARYS RIVER

A number of recent studies investigated the effects of pollutants on the benthic fauna of the St. Marys River (Figure 1; Greenwood 1983; Liston et al. 1983; Burt et al. 1988; Environment Canada and U.S. Environmental Protection Agency, 1988; Schloesser 1988; Jaagumagi et al. 1991). Most of these studies, with the exception of Liston et al. (1983) and Greenwood (1983), concentrated on the Canadian shoreline of the mid-reaches of the river, where known pollution sources exist (Environment Canada and U.S. Environmental Protection Agency, 1988).

Although inputs of chlorinated organic chemicals and heavy metals were significantly reduced over the past 20 years, large quantities persist in sediments of the mid-reaches, as the result of historical contamination and ongoing inputs by the steel industry and pulp and paper mills. Oil contamination of the sediments extending along the Canadian side from the Algoma Slip to the northern part of Lake George was documented by most of the above studies. Hiltunen and Schloesser (1983) and Schloesser (1988) suggested that the absence of the mayfly *Hexagenia* from this reach is caused by oil contamination, based on the negative relationship between visible oil on the surface of sediments and the distribution of *Hexagenia* larvae. Limited bioaccumulation of sediment associated contaminants (metals and PAHs) near the Canadian shoreline was reported by Jaagumagi et al. (1991) and Environment Canada and U.S. Environmental Protection Agency, 1988). In addition to industrial discharges, sewage treatment plant effluents were also identified as significant pollution sources to river sediments (Burt et al. 1988). Despite reductions in pollutant loadings since the 1960s, no significant improvements were reported in benthic community structure in affected areas (Burt et al. 1988; Environment Canada and U.S. Environmental Protection Agency, 1988).

Zones of degraded benthos correspond to those outlined by Burt et al. (1988). Although reports of the locations and extent of benthos degradation are relatively consistent among studies, Pope (1990) found no correlation between the components of the invertebrate community and various contaminants at five sites located in zones 2-4.

Environmental Quality Zones

1. Severely Impaired

Severely impaired benthic communities occur in the Algoma Slip area (downstream of Algoma Steel outfalls) and in embayments downstream of other industrial and municipal sources (St. Marys Paper, East End STP). Sediments in these areas are organically polluted (esp. near East End STP), and contain high concentrations of iron, zinc, and PAHs, as well as oil at variable levels (Burt et al. 1988, Jaagumagi et al. 1991).

Benthic communities are characterized by low taxonomic richness (mean of 12 taxa per site), dominance of pollution tolerant oligochaetes, presence of tolerant chironomid species, and large numbers of nematodes (Burt et al. 1988). Nearshore benthic communities along the Sault Ste Marie waterfront and in parts of the Algoma Slip consist exclusively of pollution tolerant oligochaete worms at very low densities, suggesting chemical toxicity (Burt et al. 1988). Although insignificant mortality was detected during

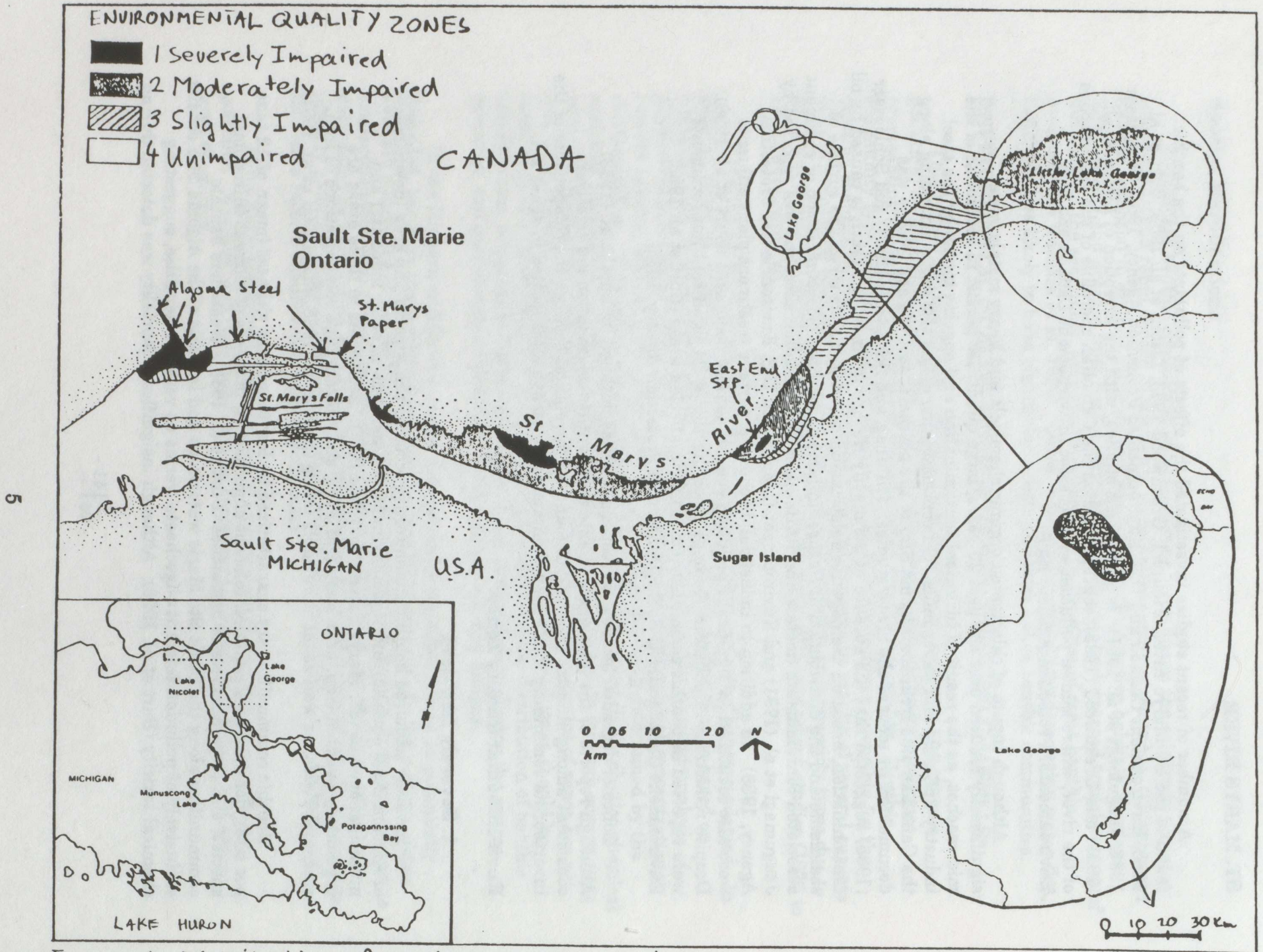


Figure 1. Distribution of environmental quality zones in the St. Marys River.

short term (10 day) mayfly and fathead minnow toxicity bioassays, chronic sublethal effects are likely along the Canadian shoreline from the Algoma Slip to Lake George (Jaagumagi et al. 1991).

2. Moderately Impaired

This zone extends along the Ontario shoreline from St. Marys Falls to Little Lake George with occasional sections of improved environmental quality. Part of Zone 2 also occurs in northern Lake George. Sediments are characteristic of organically enriched depositional areas, and are dominated by silt, usually with a surface sheen of oil (Burt et al. 1988). Sediment metal concentrations (iron and zinc) are high, and levels of PCBs and pesticides are elevated (Burt et al. 1988, Jaagumagi et al. 1991).

Benthic communities are dominated by pollution tolerant oligochaetes, though densities of tolerant chironomids and nematodes are also high (Burt et al. 1988, Pope 1990, Jaagumagi et al. 1991). Communities are characterized by high density and reduced diversity and taxonomic richness, with a mean of 15 taxa per site (Burt et al. 1988). Sediment bioassays detected no toxicity in this zone.

3. Slightly Impaired

The populations of benthic organisms was only slight depressed with increasing distance from point sources of pollutants (Burt et al. (1988). This zone contains sediments of coarser texture than Zone 2, with low to moderate levels of contaminants, and the occasional presence of oil on the sediment surface (Burt et al. 1988, Jaagumagi et al. 1991).

Invertebrate densities are moderate, and Burt et al. (1988) reported a mean of 23 taxa per site. Although tolerant oligochaetes are still a major component of communities, nematodes, polychaetes, an occasionally gastropods, isopods, and larvae of mayflies and caddisflies are also present, indicating improved environmental quality. Sediment toxicity data is not available for sites in this zone.

4. Unimpaired

This zone includes the upper reaches, lower reaches, and the entire U.S shoreline of the river. Although slight oil contamination of sediments occurs in limited areas, which may negatively affect mayfly populations (Schloesser 1988), sediment contaminant levels are non-detectable to low (Jaagumagi et al. 1991; Burt et al. 1988; Environment Canada and U.S. Environmental Protection Agency, 1988).

Benthic communities are diverse and productive, with the exception of areas of unsuitable substrates and navigation channels, where substrate alteration by dredging operations and turbulence due to vessel traffic resulted in reduced diversity and density (Greenwood 1983; Liston et al. 1983; Environment Canada and U.S. Environmental Protection Agency, 1988; Jaagumagi 1988). The upper to middle reaches of the river tend to be dominated by chironomids, whereas the lower reaches and depositional areas of the upper and middle reaches support large populations of *Hexagenia*, oligochaetes, and

chironomids (Greenwood 1983; Duffy et al. 1987; Environment Canada and U.S. Environmental Protection Agency, 1988; Schloesser 1988). Other pollution intolerant taxa (molluscs, crustaceans, caddisflies and other aquatic insects) exist at variable densities, depending on their respective habitat requirements. Low diversity, low density, chironomid dominated communities, suggestive of unimpaired oligotrophic conditions occur in parts of the upper river (Pope 1990).

ST. CLAIR RIVER

Benthic invertebrate communities of the St. Clair River (Figure 2) were surveyed by Hudson et al. (1986), Jaagumagi (1988), Jaagumagi et al. (1989), and Griffiths (1989). Results of a number of earlier surveys, conducted in the 1970s, were summarized in the Upper Great Lakes Connecting Channels Study (Environment Canada and U.S. Environmental Protection Agency, 1988).

The St. Clair River is a fast flowing large river, with longitudinally varying substrate characteristics. Sediment types vary from primarily coarse substrates (gravel) in the upper river to increasing proportions of finer substrates in the lower river (Hudson et al. 1986). The river receives high quality water from Lake Huron. Pollutant inputs are located on the Canadian side, in the section adjacent to a concentration of chemical and petrochemical industry south of the City of Sarnia. Due to the fast current velocity of the river, little lateral mixing occurs, and contaminants remain near the Canadian shoreline (Environment Canada and U.S. Environmental Protection Agency, 1988). The upper river also receives loadings of municipal sewage from Port Huron and Sarnia. Although a large number of different chemicals were detected in St. Clair River water and sediments, mercury, hexachlorobenzene, and organic chlorines were identified by the Upper Great Lakes Connecting Channels Study as the contaminants of major concern. Contaminant bioaccumulation at all levels of the foodchain is significant in the St. Clair River (Environment Canada and U.S. Environment Protection Agency, 1988).

Thornley (1985) documented an improvement in benthic habitat quality along the entire river from 1968 to 1977, exhibited in more diverse communities and increased density of pollution sensitive organisms, especially along the Canadian shoreline. Further improvements were noted in 1985 by Griffiths (1989), as evidenced by the reduction of the total length of affected areas along the Canadian shoreline from 21 km to 12 km.

Zones of benthos impairment summarized below correspond to those delineated by Griffiths (1989).

Environmental Quality Zones

1. Severely Degraded: Toxic

The most severely affected benthic communities of the St. Clair River are located in this relatively short (approx. 1.5 km) and narrow area along the Sarnia industrial waterfront, adjacent to Dow Chemical Canada Inc. (Thornley 1985; Griffiths 1989). Sediments contain high concentrations of chlorinated hydrocarbons, oil and grease, heavy metals (esp. mercury), and elevated levels of organic matter.

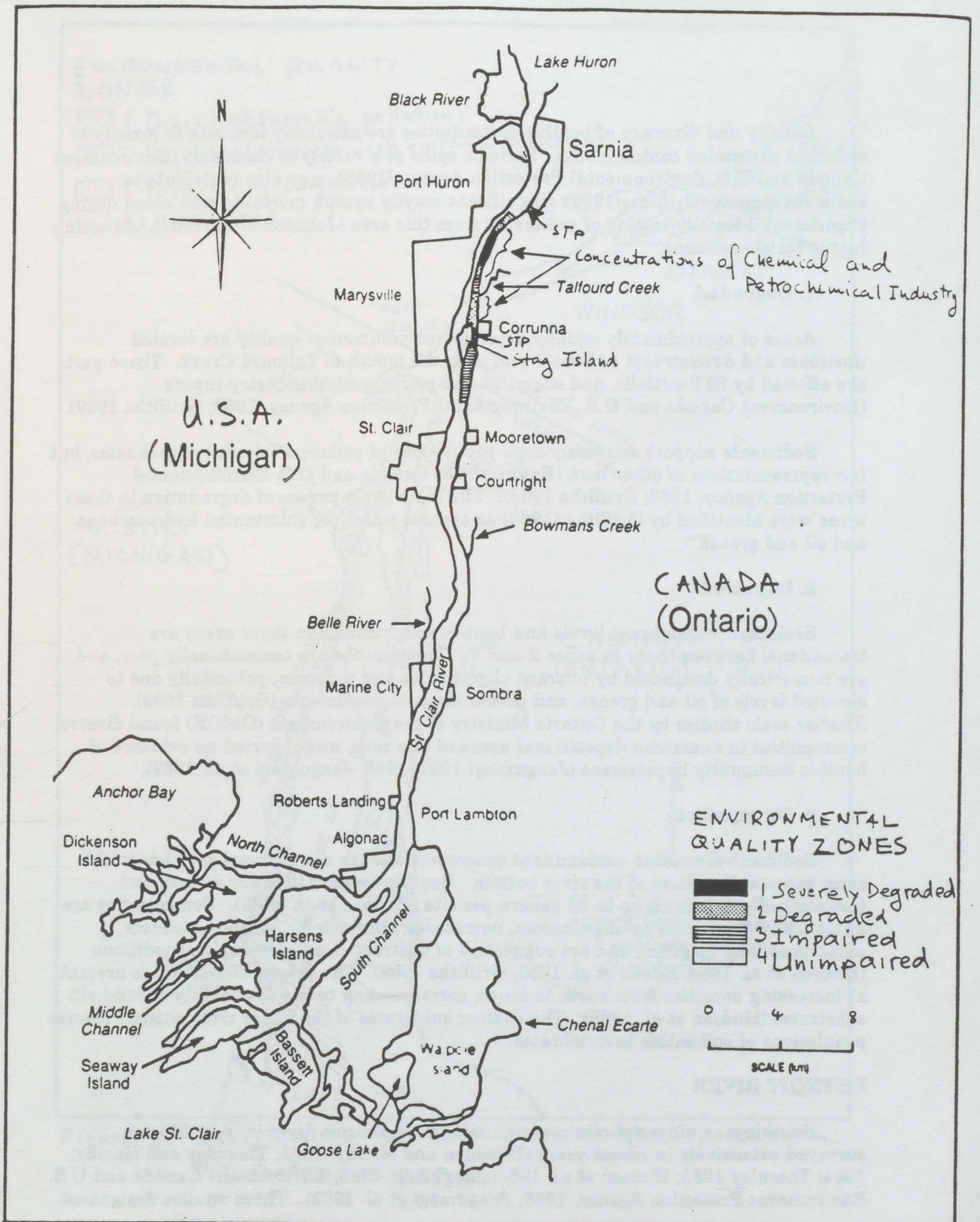


Figure 2. Distribution of environmental quality zones in the St. Clair River

Density and diversity of benthic communities are extremely low, due to toxicity of sediment associated contaminants. Periodic spills of a variety of chemicals (Environment Canada and U.S. Environmental Protection Agency, 1988), may also contribute to sediment toxicity (Griffiths 1989). Significant mayfly nymph mortality was noted during experimental toxicity testing of sediments from this area (Johnson et al. 1987), indicating highly toxic conditions.

2. Degraded

Areas of approximately equally degraded environmental quality are located upstream and downstream of Zone 1 and near the mouth of Talfourd Creek. These parts are affected by STP outfalls, and chemical and petrochemical industry inputs (Environment Canada and U.S. Environmental Protection Agency, 1988; Griffiths 1989).

Sediments support extremely high populations of pollution tolerant oligochaetes, but few representatives of other taxa (Environment Canada and U.S. Environmental Protection Agency, 1988; Griffiths 1989). The most likely causes of degradation in these areas were identified by Griffiths (1989) as organic pollution, chlorinated hydrocarbons, and oil and grease.

3. Impaired

Sediment contaminant levels and benthic communities in these areas are transitional between those in zones 2 and 4. Communities are taxonomically poor, and are numerically dominated by tolerant oligochaetes and molluscs, potentially due to elevated levels of oil and grease, and pesticides in the sediments (Griffiths 1989). Smaller-scale studies by the Ontario Ministry of the Environment (OMOE) found diverse communities in nearshore depositional areas of this zone, and reported no evidence of benthic community impairment (Jaagumagi 1987, 1988, Jaagumagi et al. 1989).

4. Unimpaired

Sediment-associated contaminant concentrations are non-detectable to low in this zone, representing most of the river bottom. Benthic communities are diverse and taxonomically rich, with up to 38 genera per site (Hudson et al. 1986). Communities are numerically dominated by oligochaetes, nematodes, chironomids, various molluscs, amphipods, and mayflies, and are suggestive of unstressed meso-eutrophic conditions (Hudson et al. 1986, Edsall et al. 1988, Griffiths 1989). The mayfly *Hexagenia* is present at increasing densities from north to south, corresponding to the availability of sand-silt substrates (Hudson et al. 1986). The coarser substrates of the upper river support diverse populations of epibenthic invertebrates.

DETROIT RIVER

Benthic macroinvertebrate communities in the Detroit River (Figure 3) were surveyed extensively in recent years (Hiltunen and Manny, 1982; Thornley and Hamdy, 1984; Thornley 1985; Hudson et al. 1986; Jaagumagi 1988; Environment Canada and U.S. Environmental Protection Agency, 1988; Jaagumagi et al. 1989). These studies designated

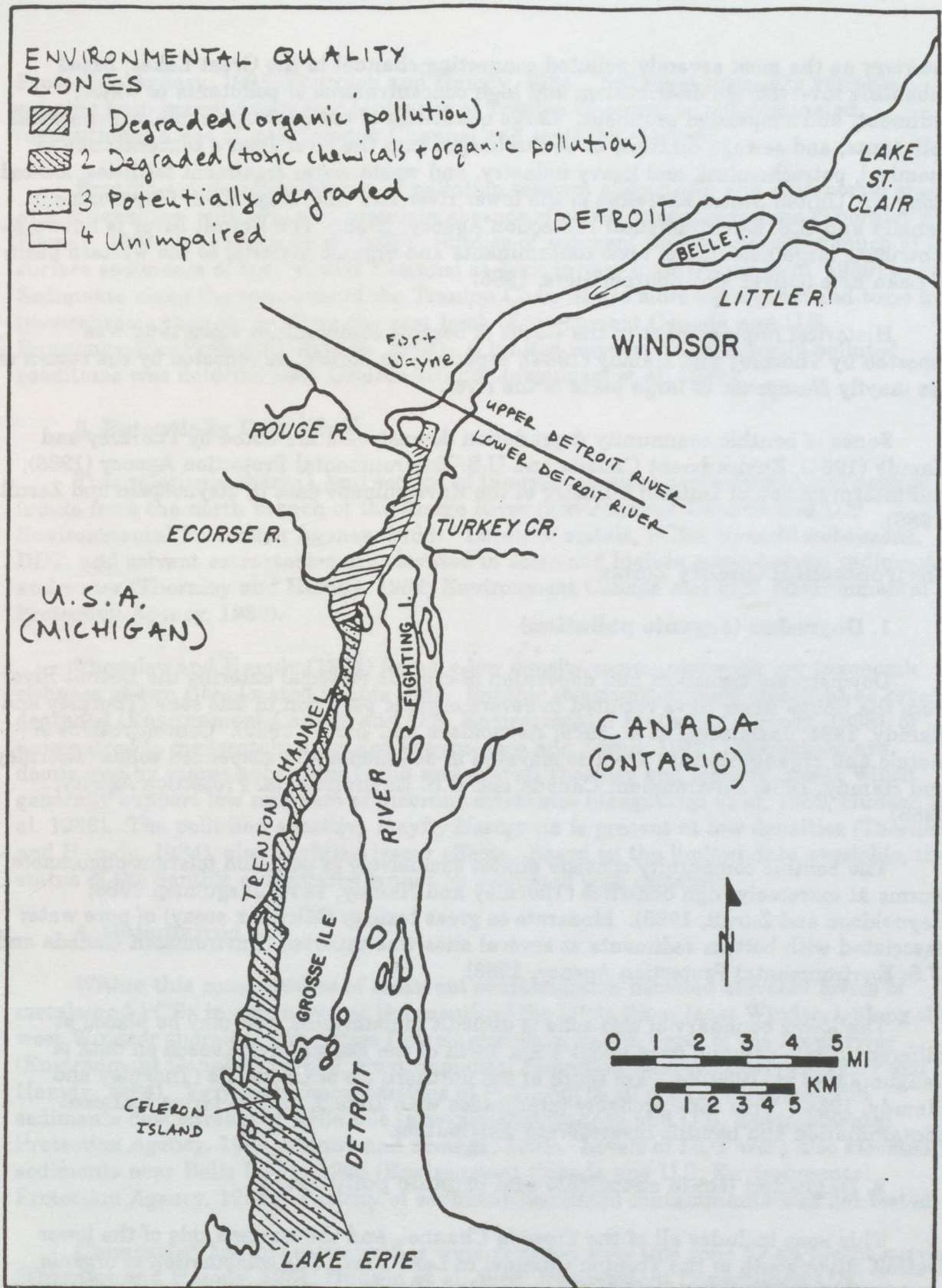


Figure 3. Distribution of environmental quality zones in the Detroit River.

the river as the most severely polluted connecting channel in the Great Lakes, based on benthic invertebrate distribution, and high concentrations of pollutants in water, sediment, and suspended sediment. Large quantities of toxic contaminants, conventional pollutants, and sewage continue to be discharged into the river from a concentration of chemical, petrochemical, and heavy industry, and waste water treatment facilities, located along the United States shoreline of the lower river and the Rouge River (Environment Canada and U.S. Environmental Protection Agency, 1988). The Detroit River is known to contribute large amounts of toxic contaminants and organic material to the western basin of Lake Erie (Oliver and Bourbonniere, 1985).

Historical improvement in the status of benthic communities since 1968 was reported by Thornley and Hamdy (1984), especially in Zone 4, as reflected by the return of the mayfly *Hexagenia* to large parts of the river.

Zones of benthic community degradation downstream are noted by Thornley and Hamdy (1984), Environment Canada and U.S. Environmental Protection Agency (1988), and interpretation of Ontario Ministry of the Environment data by Reynoldson and Zarull (1989).

Environmental Quality Zones

1. Degraded (organic pollution)

Downstream transport and deposition of organic material entering the Detroit River from the Rouge River have resulted in severe organic pollution in this zone (Thornley and Hamdy, 1984; Jaagumagi et al. 1989; Reynoldson and Zarull, 1989). Concentrations of metals and organochlorines are also elevated in sediments and suspended solids (Thornley and Hamdy, 1984; Environment Canada and U.S. Environmental Protection Agency, 1988).

The benthic community consists almost exclusively of pollution tolerant oligochaete worms at extremely high densities (Thornley and Hamdy, 1984; Jaagumagi 1988; Reynoldson and Zarull, 1989). Moderate to great toxicity (Microtox assay) of pore water associated with bottom sediments at several sites was reported (Environment Canada and U.S. Environmental Protection Agency, 1988).

The lower boundary of this zone is difficult to determine, and may be placed at different points ranging from about 1 km north of the Ecorse River (based on data of Jaagumagi et al. 1989) to 1 km south of the northern tip of Grosse Ile (Thornley and Hamdy, 1984). This zone probably intergrades with Zone 2, both in terms sediment contamination and benthic invertebrate distribution.

2. Degraded (toxic chemicals and organic pollution)

This zone includes all of the Trenton Channel, and the western side of the lower Detroit River south of the Trenton Channel to Lake Erie. The combination of organic enrichment and high levels of PCBs, pesticides, oil and grease, metals, and cyanide have severely impaired benthic communities (Environment Canada and U.S. Environmental

Protection Agency, 1988; Thornley and Hamdy, 1984). Sediment types are variable, ranging from gravel-dominated (entrance of Trenton Channel) to silt-dominated (depositional areas of mid-Trenton Channel and southern reaches).

Benthic communities consist of pollution tolerant oligochaete and chironomid species at low densities, with a nearly complete absence of pollution sensitive taxa (Thornley and Hamdy, 1984; Jaagumagi et al. 1989). Studies of sediment toxicity classified much of the surface sediments of the Trenton Channel as toxic to very toxic (Rosiu et al. 1989). Sediments along the west side of the Trenton Channel are more mutagenic and toxic to invertebrates than those along the east bank (Environment Canada and U.S. Environmental Protection Agency, 1988). A limited recovery to organically polluted conditions was detected near Celeron Island (Jaagumagi et al. 1989).

3. Potentially Degraded

This relatively short (1 km) section of the river receives contaminant and sewage inputs from the north branch of the Rouge River (Environment Canada and U.S. Environmental Protection Agency, 1988). Levels of metals, PCBs, hexachlorobenzene, DDT, and solvent extractables are elevated in some and high in other bottom sediments and water (Thornley and Hamdy, 1984; Environment Canada and U.S. Environmental Protection Agency, 1988).

Thornley and Hamdy (1984) found a low density community with low taxonomic richness at two sites located in this zone. Benthic communities were classified as severely degraded (Environment Canada and U.S. Environmental Protection Agency, 1988), or unimpaired to moderately degraded (Reynoldson and Zarull, 1989). Sediments are dominated by coarse substrates (sand and gravel; Thornley and Hamdy, 1984), which generally support low numbers of macroinvertebrates (Jaagumagi et al. 1989, Hudson et al. 1986). The pollution sensitive mayfly *Hexagenia* is present at low densities (Thornley and Hamdy, 1984), also implying lesser effects. Based on the limited data available, the status of the benthic community cannot be evaluated with certainty.

4. Unimpaired

Within this zone, studies of sediment contamination detected elevated levels of metals and PCBs in sediments at the mouth of the Little River (east Windsor), along the west Windsor shoreline, the entire Detroit shoreline, and in parts of the lower river (Environment Canada and U.S. Environmental Protection Agency, 1988; Thornley and Hamdy, 1984). Very high concentrations of PCBs (up to 40 mg/kg) were found in sediments downstream of Belle Isle (Environment Canada and U.S. Environmental Protection Agency, 1988; Manny and Kenaga, 1991). Levels of DDT were also elevated in sediments near Belle Isle in 1985 (Environment Canada and U.S. Environmental Protection Agency, 1988). Toxicity of sediment associated contaminants was not tested.

Unimpacted benthic communities were reported from this zone by all recent surveys (Thornley and Hamdy, 1984; Hudson et al. 1986; Environment Canada and U.S. Environmental Protection Agency, 1988; Jaagumagi 1988; Jaagumagi et al. 1989). Deep channel habitats with sand-gravel dominated substrates generally support lower densities

of invertebrates than shallow nearshore areas with finer substrates and macrophytes (Jaagumagi et al. 1989, Manny et al. 1988). Taxonomic richness ranges from 22-30 genera (Hudson et al. 1986). Benthic communities are characterized by pollution intolerant taxa, including mayflies (esp. *Hexagenia*), caddisflies, amphipods, gastropods, and pollution sensitive oligochaete and chironomid species. The benthic community along the Windsor shoreline was noted to exhibit slight degradation, with the resultant increase in numbers of pollution tolerant organisms (Environment Canada and U.S. Environmental Protection Agency, 1988; Reynoldson and Zarull, 1989). Benthic communities characteristic of slight organic enrichment were also reported in the lower Detroit River, along the eastern shore of Grosse Ile (Hudson et al. 1986; Reynoldson and Zarull, 1989).

NIAGARA RIVER

Pollution problems affecting the Niagara River (Figure 4) were documented by a number of studies (Allen et al. 1983, Fox et al. 1983, Kauss 1983, Kuntz 1984, Creese 1987). A large concentration of hazardous waste sites (over 200), industry (33 major outfalls as of 1983), and municipal outfalls have released a variety of pollutants into the river, including PCBs, pesticides and of other organic chemicals, metals, and sewage (Allen et al. 1983). The river is a major source of metals and chlorinated organic contaminants to Lake Ontario (Thomas 1983). Benthic macroinvertebrate communities were surveyed on a small scale (8-9 sites) by the Ontario Ministry of the Environment (Jaagumagi 1988, Jaagumagi et al. 1989) and the New York State Department of Health (Simpson 1980, 1982) and on a larger scale by the Ontario Water Resources Commission (Veal 1968) and the Ontario Ministry of the Environment (Creese 1987). Recent benthic surveys (Creese 1987, Jaagumagi 1988, Jaagumagi et al. 1989) found evidence suggestive of improvement of environmental conditions since the 1970s. Although the reach extending from the northern tip of Grand Island to Queenston receives the greatest amounts of industrial discharges along the entire river (Allen et al. 1983), benthic communities in this section have not been surveyed.

Distinct zones of homogeneous benthic communities were not identified. The following discussion is based on results of Creese (1987), Jaagumagi (1988), and Jaagumagi et al. (1989).

Upper Niagara River

Sediment nutrient concentrations and levels of oil and grease are elevated at the mouth of the Buffalo River. Benthic communities are characterized by low diversity and biomass, and are dominated by organic pollution tolerant oligochaete species (Creese 1987). Conditions suggestive of degradation due to organic enrichment (Jaagumagi 1988, Jaagumagi et al. 1989), and chemical contamination (Creese 1987) exist along the entire Buffalo shoreline. In contrast, diverse, unimpacted communities were found on the central and western parts of the Niagara River mouth (Creese 1987).

Along the United States shoreline, adjacent to the southern tip of Grand Island, elevated levels of copper, mercury, and oil and grease may have caused slight degradation of benthos (Creese 1987), as suggested by lower taxonomic richness, and elevated numbers

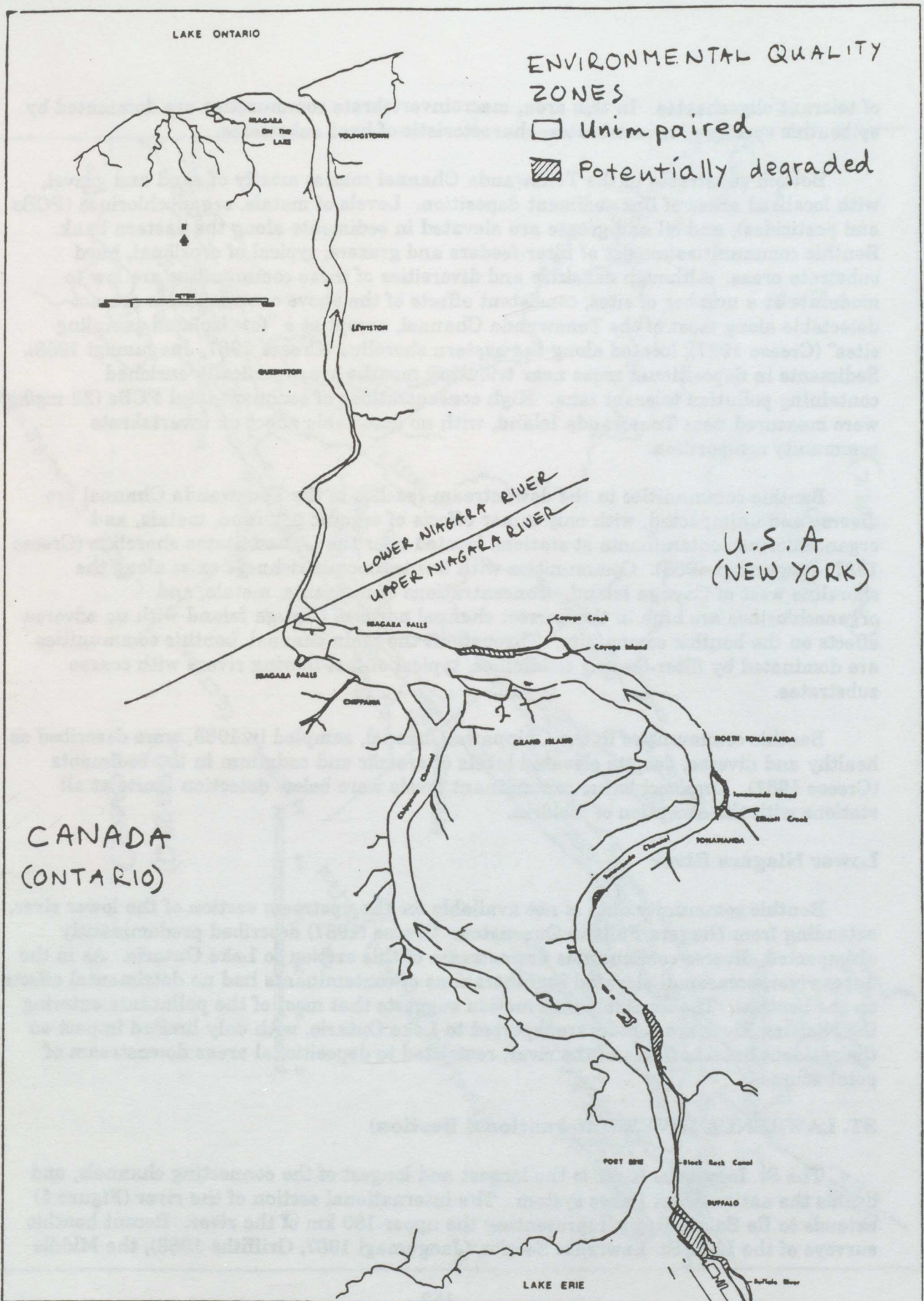


Figure 4, Distribution of environmental quality zones in the Niagara River.

of tolerant oligochaetes. In this area, macroinvertebrate communities are dominated by epibenthic species of invertebrates, characteristic of hard substrates.

Bottom substrates in the Tonawanda Channel consist mostly of sand and gravel, with localized areas of fine sediment deposition. Levels of metals, organochlorines (PCBs and pesticides), and oil and grease are elevated in sediments along the eastern bank. Benthic communities consist of filter-feeders and grazers, typical of erosional, hard substrate areas. Although densities and diversities of these communities are low to moderate at a number of sites, consistent effects of the above contaminants are not detectable along most of the Tonawanda Channel, except at a "few isolated sampling sites" (Creese 1987), located along the eastern shoreline (Creese 1987, Jaagumagi 1988). Sediments in depositional areas near tributary mouths are organically enriched containing pollution tolerant taxa. High concentrations of sediment total PCBs (22 mg/kg) were measured near Tonawanda Island, with no detectable effect on invertebrate community composition.

Benthic communities in the downstream reaches of the Tonawanda Channel are diverse and unimpacted, with only minor effects of organic pollution, metals, and organochlorine contaminants at stations located near the United States shoreline (Creese 1987, Jaagumagi 1988). Communities with low taxonomic richness exist along the shoreline west of Cayuga Island. Concentrations of nutrients, metals, and organochlorines are high in the narrow channel north of Cayuga Island with no adverse effects on the benthic community. Throughout the main channel, benthic communities are dominated by filter-feeding caddisflies, typical of fast-flowing rivers with coarse substrates.

Benthic communities in the Chippawa Channel, sampled in 1983, were described as healthy and diverse, despite elevated levels of arsenic and cadmium in the sediments (Creese 1987). Organochlorine contaminant levels were below detection limits at all stations with the exception of dieldrin.

Lower Niagara River

Benthic community data is not available for the upstream section of the lower river, extending from Niagara Falls to Queenston. Creese (1987) described predominantly unimpacted, diverse communities downstream of this section to Lake Ontario. As in the upper river, occasional elevated concentrations of contaminants had no detrimental effects on the benthos. The available information suggests that most of the pollutants entering the Niagara River are rapidly transported to Lake Ontario, with only limited impact on the resident benthic fauna of the river, restricted to depositional areas downstream of point sources.

ST. LAWRENCE RIVER (International Section)

The St. Lawrence River is the largest and longest of the connecting channels, and drains the entire Great Lakes system. The international section of the river (Figure 5) extends to Ile Sainte-Regis, representing the upper 180 km of the river. Recent benthic surveys of the Lake St. Lawrence Section (Jaagumagi 1987, Griffiths 1988), the Middle

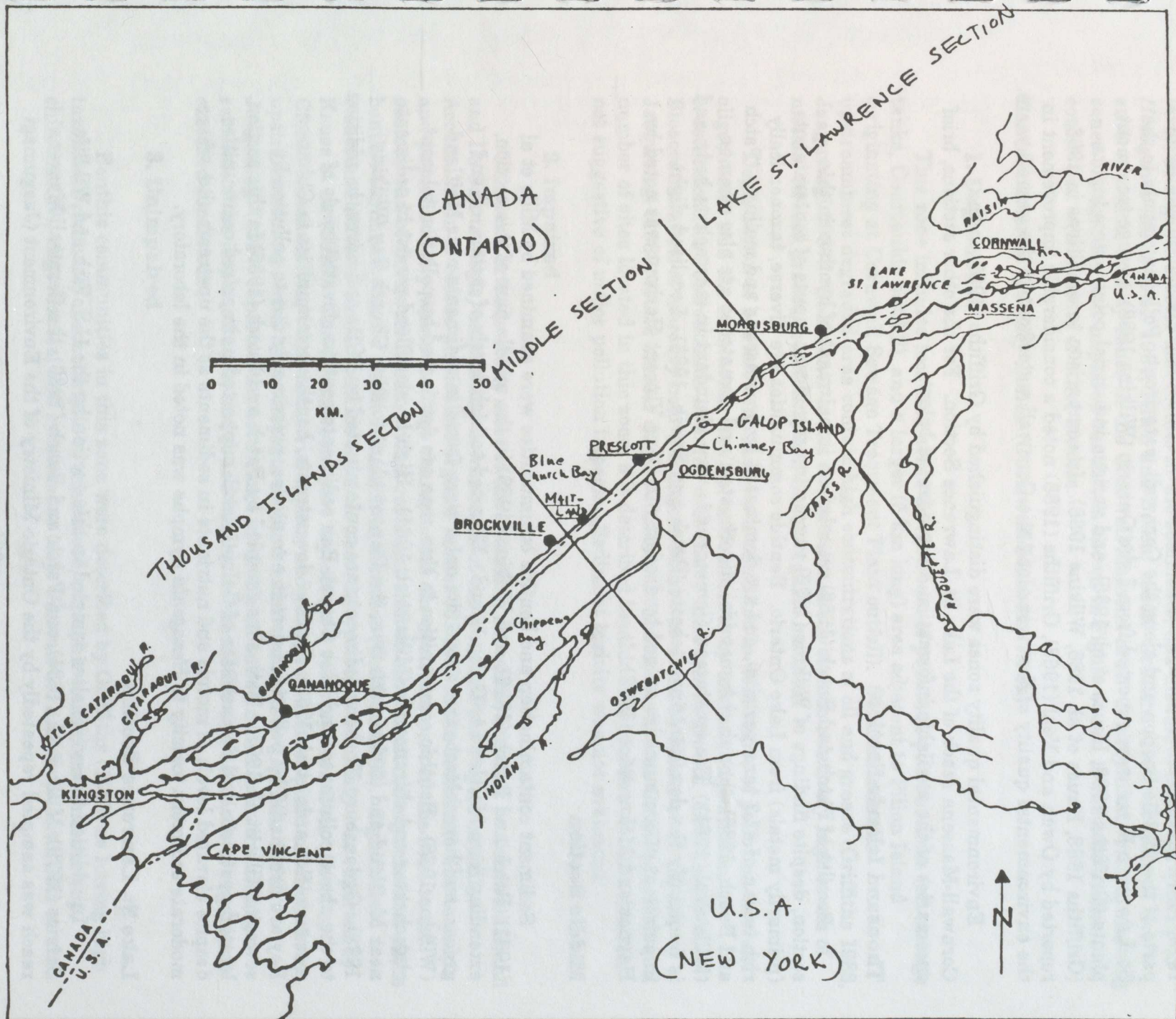


Figure 5. The international section of the St. Lawrence River.

Section (Mills et al. 1981) and sites in all three sections (U.S. Fish and Wildlife Service 1979; Patch and Busch, 1986) documented areas of degraded environmental quality in parts of the Middle Section and along the Cornwall waterfront. Pollutant inputs to the St. Lawrence River were reported from Lake Ontario (Wilkins 1988), sewage treatment plants (Griffiths 1988, Kauss et al. 1988), and various industrial point source inputs (Griffiths 1988, Kauss et al. 1988, Wilkins 1988). In comparison to conditions in 1966, reported by Owen and Veal (1968), Griffiths (1988) noted a considerable improvement in the environmental quality of the river along the Cornwall waterfront in the past 20 years.

Environmental quality zones were distinguished by Griffiths (1988) in the Cornwall-Massena reach of the Lake St. Lawrence Section. For the other sections, brief summaries of the available information are presented below.

Thousand Islands Section

Results of Patch and Busch (1986) revealed no impairment of benthos in this section, despite findings of Wilkins (1988) suggesting significant inputs of contaminants (primarily metals) from Lake Ontario. Benthic communities are diverse, taxonomically rich (mean of 47.7 taxa per site), and are dominated by crustaceans and molluscs (Patch and Busch, 1986), though chironomids, oligochaetes, and nematodes are also common (Mills et al. 1981). The crustacean *Gammarus* is very abundant in macrophyte beds, and is frequently the dominant invertebrate (Patch and Busch, 1986). Localized slight impairment of communities caused by dredging in Cape Vincent Harbour was noted by Haynes and Makarewicz (1982).

Middle Section

Sediment contamination and benthic communities were examined by Mills et al (1981), Patch and Busch (1986), and Wilkins (1988) in the middle part of this section, extending from Maitland to Galop Island. Elevated to high levels of metals, oil and grease, and hexachlorobenzene (one site only) were found in sediments near Maitland (Wilkins 1988). Benthic communities in this area are dominated by pollution tolerant oligochaetes and chironomids (Mills et al. 1981). High levels of lead persist in sediments near Maitland and in the reach from the Dupont plant to Blue Church Bay (Wilkins 1988). Ogdensburg Harbour sediments are contaminated by PCBs and mirex, in addition to the above pollutants, and Blue Church Bay sediments contain elevated levels of mercury (Edwards et al. 1989). Farther downstream, benthic communities in Chimney Bay are dominated by pollution tolerant nematodes, presumably due to pollution by sewage (Mills et al. 1981). Both sites sampled by Patch and Busch (1986) in this section, located upstream and downstream of Galop Island, supported unimpaired communities, despite elevated levels of metals and nutrients in sediments at the upstream site, where moderate sediment toxicity to *Hexagenia* nymphs was noted in the laboratory.

Lake St. Lawrence Section

In addition to several sites sampled in this section by the U.S. Fish and Wildlife Service (1979), Mills et al. (1981), and Patch and Busch (1986), the Cornwall/Massena reach was sampled repeatedly by the Ontario Ministry of the Environment (Jaagumagi

1987, Griffiths 1988). Communities upstream of Lake St. Lawrence were described as diverse, being dominated by insects (esp. chironomids), despite the occurrence of elevated levels of organic matter and metals in the sediments, and moderate sediment toxicity to *Hexagenia* (Mills et al. 1981; Patch and Busch, 1986). Griffiths (1988) delineated five environmental quality zones in the Cornwall/Massena area. A simplified version, showing zones of degraded and impaired benthos is shown in Figure 6, and is described below, in connection with results of other studies.

Environmental Quality Zones (Cornwall/Massena Area)

1. Degraded

This zone includes localized areas downstream of pollutant point sources (oil storage tanks, Courtaulds outfall), and a larger (5 km long) area adjacent to Pillon Island (originating at Cornwall Sewage Treatment Plant outfall). Sediments in the upstreammost degraded area contain high concentrations of oil and grease (Griffiths 1988, Jaagumagi 1987). Sediments in the downstream areas contain relatively high levels of metals, oil and grease, nutrients, and coarse organic material.

Degradation of benthic communities is exhibited in dominance of pollution tolerant oligochaetes and the crustacean *Asellus*, or dominance by tolerant oligochaetes, crustaceans, and chironomids in areas with heavy macrophyte growth (Griffiths 1988). Bioaccumulation of mercury near Farlingers Point was noted by Kauss et al. (1988). Jaagumagi (1987) found similar degree of sediment contamination as Griffiths (1988) at a number of sites located in this zone, but described benthic communities as more diverse, not suggestive of major pollution impacts. Sediment toxicity was not evaluated.

2. Impaired

This zone extends along most of the Canadian shoreline, adjacent to Cornwall Island and Ile Sainte-Regis, originating downstream of the Domtar Fine Papers outfall. Accumulation of coarse particulate organic matter (CPOM) in the sediments due to pulp and paper industry waste loadings characterizes the upstream part of this zone to the eastern end of Cornwall Island, with a resultant shift in the functional organization of the benthic community and a slight reduction in densities (Griffiths 1988). Significant bioaccumulation of zinc in benthic animals near the upstream boundary was reported by Kauss et al. (1988). The downstream part represents a recovery zone from effects of CPOM accumulation, other industrial inputs, and sewage treatment plant effluents from upstream sources, with lesser impacts on the benthic community (Griffiths 1988). Jaagumagi (1987) reported the occurrence of visible oil in sediments from the middle reaches of the impaired zone, and found benthic communities characteristic of organically enriched conditions.

3. Unimpaired

Benthic communities in this zone were described by Griffiths (1988) as having high taxonomic richness, characteristic of unstressed, eutrophic conditions. Insects (esp. chironomids), oligochaetes, and crustaceans (esp. *Gammarus*) are abundant (Mills et al.

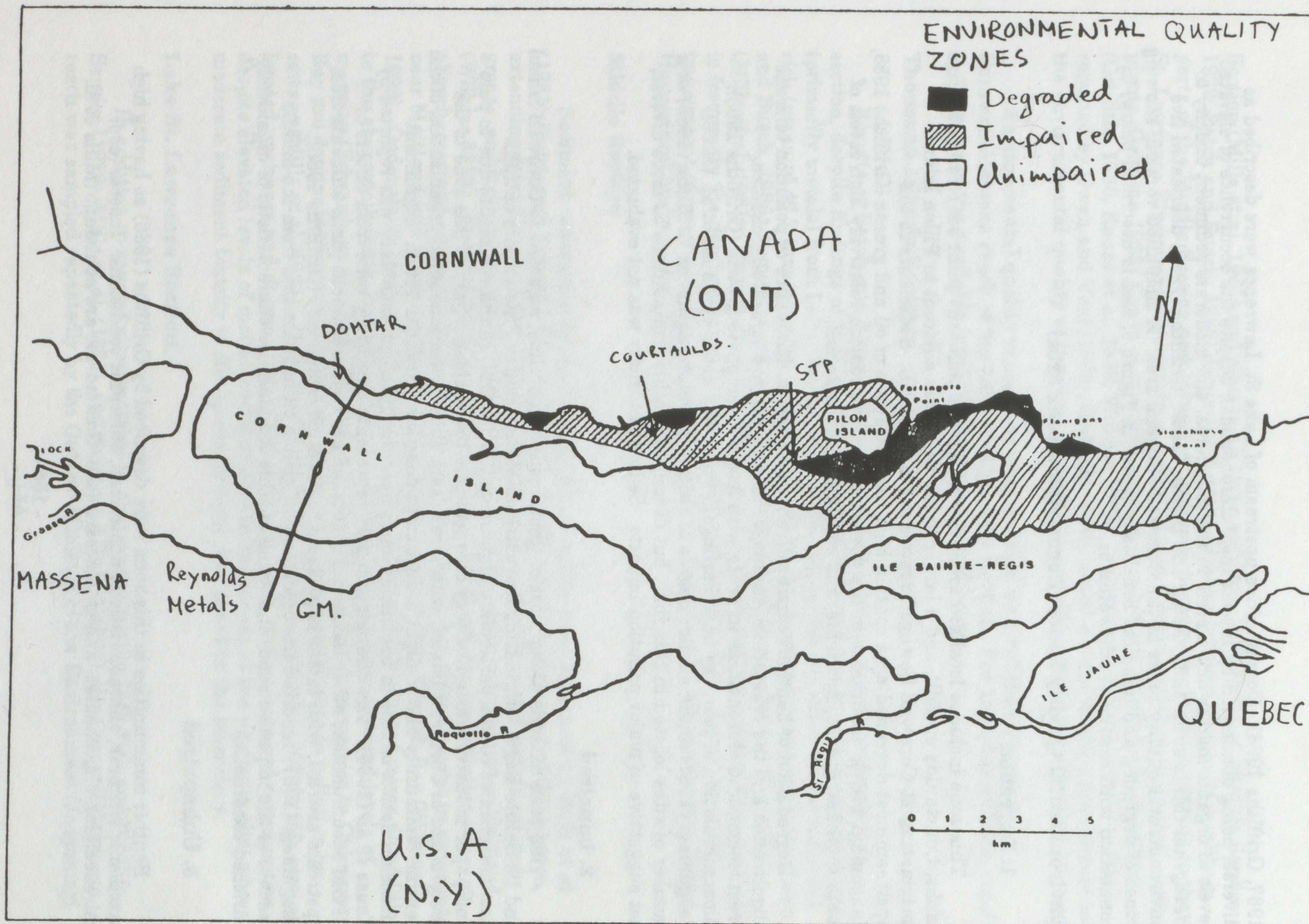


Figure 6. Distribution of environmental quality zones in the Cornwall - Massena area of the St. Lawrence River.

1981; Patch and Busch, 1986; Griffiths 1988). Diversity is reduced in channelized areas of the southern part of this zone (Patch and Busch, 1986). Patch and Busch (1986) found moderately toxic sediments (*Hexagenia* bioassay), moderately to heavily polluted by metals and nutrients at sites located along the United States shoreline. Also in this area, benthic communities with reduced densities and biomass were found at sites with oil-contaminated sediments, adjacent to Reynolds Metals and across from the mouth of the Grasse River (U.S. Fish and Wildlife Service 1979). Sediments adjacent to General Motors and Reynolds Metals were reported to contain high concentrations of PCBs (New York State Department of Environmental Conservation (NYSDEC) 1990). Kauss et al. (1988) reported considerably greater bioavailability and sediment levels of PCBs along the United States shoreline than along the Canadian shoreline. Griffiths (1988) found unimpacted benthic communities near the United States shore, suggesting that effects may be limited or localized.

SUMMARY AND CONCLUSIONS

Recent studies reported degradation of benthos in all Great Lakes connecting channels. Most severely affected areas include the Canadian shoreline of the middle St. Marys and upper St. Clair rivers, the United States side of the lower Detroit River, and parts of the Middle Section and the Cornwall waterfront of the St. Lawrence River. In the Niagara River, recent studies documented areas of localized benthos impairment, but the benthos in relatively long sections remains unstudied.

In light of this review, it is evident that significant knowledge gaps exist regarding the status of benthic communities in sections of the Niagara and St. Lawrence Rivers. Even for frequently surveyed rivers (e.g. Detroit River), quantitative data reported by different studies are not comparable due to considerable variation in sampling, sorting, and analytical techniques. In addition, the effects of toxic chemicals on benthos remain poorly understood, limiting one's ability to establish cause-effect relationships, especially in areas receiving multiple contaminant inputs. The available toxicity data for connecting channel sediments is also inadequate, and suffer from inconsistencies in methodology and test organisms.

Benthic surveys were, however, successful in monitoring the effectiveness of pollution abatement measures and provided baseline information for future comparisons. Most recent surveys documented significant improvements in response to reduction of nutrient loadings, but also identified areas of gross pollution in all connecting channels. It is encouraging, that nearly all recent benthic surveys examined for this review used the "ecosystem approach," as described by Jaagumagi et al. (1991), consisting of the evaluation of benthic community structure, habitat variables, pollutant levels in environmental media, sediment toxicity, and bioaccumulation.

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