RECOVERY OF THE LAURENTIAN GREAT LAKES, 1970-1985: EUTROPHICATION ASPECTS

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NWRI Contribution No. 88-44

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Abstract

Eutrophication of the Laurentian Great Lakes accelerated exponentially during the first half of this century. Canada and the United States recognized this fact and signed the 1972 Great Lakes Water Quality Agreement. Since then, coordinated activities have resulted in a massive cleanup, unprecedented in history. Major wastewater treatment programs have been implemented. With expenditures totaling over eight billion dollars, industrial controls and phosphate limitations in detergents produced a reduction and even a reversal of the eutrophication process. The long-term trend of total phosphorus concentrations have been downward since the mid 70's when legislation on phosphorus reduction was put into effect. Nuisance algal blooms are no longer a common occurrence and Cladophora infestations of nearshore areas are declining.

Concurrently, with the success in phosphorus control, new phenomena were identified, namely, increases in nitrates, N:P ratios, taste and odor problems and interactions between the nutrients and toxic contaminants. This overview highlights characteristic examples of the recent reversals in long-term trends of some water quality parameters related to eutrophication. It also identifies historic peak periods of nutrient pollution and discusses future projections and lake rehabilitation strategies with the focus on near-shore Areas of Concern.

Résumé

L'eutrophisation des Grands Lacs du bassin du Saint-Laurent s'est accélérée de façon exponentielle pendant la première moitié du siècle. Le Canada et les États-Unis ont reconnu cette réalité et ont signé en 1972 l'Accord relatif à la qualité de l'eau dans les Grands Lacs. Depuis lors, la coordination a permis de mener des activités d'assainissement à grande échelle, fait sans précédent dans l'histoire. On a mis en oeuvre des programmes d'envergure pour le traitement des eaux usées. La réduction de la pollution industrielle et la réduction des phosphates contenus dans les détergents, obtenues à un coût total de plus de huit milliards de dollars, ont produit une réduction du phénomène d'eutrophisation et même un renversement de la situation. La tendance à long terme de la concentration totale de phosphore est à la baisse depuis le milieu des années 70, c'est-à-dire depuis le moment où est entrée en vigueur la législation relative à la réduction du phosphore. La prolifération d'algues nuisibles n'est plus un phénomène courant et l'infestation des rivages par Cladophora est sur le déclin.

En même temps que se confirmait le succès de la lutte contre le phosphore, on découvrait de nouveaux phénomènes, à savoir l'augmentation des nitrates, le rapport N:P, des problèmes de goût et d'odeur et l'interaction entre les nutriments et les contaminants toxiques. On expose ici des exemples caractéristiques du renversement récent de la tendance à long terme de certains paramètres de la qualité de l'eau liés à l'eutrophisation. On précise aussi les pics historiques de la pollution par les nutriments et l'on examine diverses projections et stratégies de restauration des lacs en insistant tout particulièrement sur les eaux littorales critiques.

Management Perspective

This is an invited paper presented at the 3rd ILEC Conference "Balaton 88" held in Hungary, Sept. 11-17, 1988, to be published in the Conference proceedings. It summarizes achievements of phosphorus controls in the Great Lakes between 1970 - 1985.

Concurrently, with the success in phosphorus control, new phenomena were identified, namely, increases in nitrates, N:P ratios, taste and odor problems and interactions between the nutrients and toxic contaminants. This overview highlights characteristic examples of the recent reversals in long-term trends of some water quality parameters related to eutrophication. It also identifies historic peak periods of nutrient pollution and discusses future projections and lake rehabilitation strategies with the focus on near-shore Areas of Concern.

Résumé schématique

Il s'agit d'une communication sollicitée présentée à la troisième conférence de l'ILEC (Comité international de l'environnement lacustre) intitulée "Balaton 88" qui s'est tenue en Hongrie du 11 au 17 septembre 1988. L'article est publié dans les actes de la Conférence. Il résume les réalisations obtenues dans le domaine de la réduction du phosphore dans les Grands Lacs entre 1970 et 1985.

En même temps que se confirmait le succès de la lutte contre le phosphore, on découvrait de nouveaux phénomènes, à savoir l'augmentation des nitrates, le rapport N:P, des problèmes de goût et d'odeur et l'interaction entre les nutriments et les contaminants toxiques. On expose ici des exemples caractéristiques du renversement récent de la tendance à long terme de quelques paramètres de la qualité de l'eau liés à l'eutrophisation. On précise aussi les pics historiques de la pollution par les nutriments et l'on examine diverses projections et stratégies de restauration des lacs en insistant tout particulièrement sur les eaux littorales critiques.

INTRODUCTION

The Laurentian Great Lakes, with a drainage basin comparable in size to Central Europe, contain about twenty percent of all freshwater on the Earth's surface. They represent a major natural resource for both Canada and the United States. Thirty percent of Canada's population (7.5 million people) and twenty percent of the United States population (40 million people) live in the Great Lakes drainage basin. Twenty-four million people depend on the Great Lakes for drinking water supply. Considerable industrial development (e.g. 50% of U.S. steel production; 62% of Canadian steel production) has occurred within the basin because of the availability of abundant, inexpensive water and accessible, efficient transportation (Thomas and Hartig, 1988).

Since the days of early extensive settlement in the late 1880's accompanied by agricultural and industrial development, the population has been increasing exponentially in the basins of Lake Erie and Ontario (Dobson, 1981). This development led to human mismanagement and accelerated deterioration of water quality, recognized soon by both countries. After several epidemics of cholera and typhoid fever - caused by discharges of human waste - the Boundary Water Treaty was signed by the United States and Canada in 1909 and established the International Joint Commission as a unique binational organization seeking to reach consensus on solutions to common problems, including water and air pollution, lake levels, power generation, and other issues of mutual concern. Industrial growth was followed by oil pollution (1940s) and accelerated eutrophication in the 1960s, as a result of uncontrolled input of nutrients from municipal sewage containing detergents, industrial wastes and agricultural runoff. By the late 1960s the degradation had become extreme in some areas, primarily the Western and Central Basins of Lake Erie, Green Bay in Lake Michigan, Saginaw Bay in Lake Huron, Hamilton Harbour in Lake

Ontario and others. Massive algal blooms were occurring frequently and a number of municipal and industrial areas were devoid of visible aquatic life (Forde, 1969). There were massive die-offs of fish (mostly "alewives") in Lakes Michigan and Ontario, severe oxygen depletion in hypolimnetic waters of Central Lake Erie and deterioration of fisheries. At the same time, the 1960s also saw a dramatic increase in public concern about the degraded state of these areas, with headlines like "Is Lake Erie dead?" appearing in the news.

In response to this catastrophic situation, the International Joint Commission initiated a review of the state of the lower Great Lakes (Erie and Ontario). The results were released in 1969 and marked the beginning of official action, unprecedented so far in history, with the objective to stop further degradation and initiate restoration.

This review, prepared for the international audience of the 3rd International ILEC Conference "Balaton 88", summarizes major achievements of the concentrated remedial effort in both countries over the period of the past 15 years with the intention to demonstrate an example to be followed in the basins of the world's other large lakes.

PHOSPHORUS CONTROL PROGRAMMES IN THE GREAT LAKES BASIN.

Despite a strong controversy about the key nutrient controlling eutrophication process (Legge and Dingeldein, 1970) and thanks to dedicated effort of some individuals and groups (Vallentyne 1970, a,b) it was finally accepted that it is phosphorus that is the limiting and at the same time the only controllable nutrient. Analysis of phosphorus sources revealed that inputs were chiefly from laundry detergents, used in households, human waste and agricultural runoff (Chapra, 1977). These three major sources were chosen as the primary targets for coordinated reduction of P-loadings, in the 1972 Great Lakes Water Quality Agreement (GLWQA), signed by both countries. Specific tables and goals for annual phosphorus loading reductions were developed for both countries and each lake (GLWQA, 1973), (i.e., for Lake Erie, total reduction between 1972 and 1976 was set for about fifty percent, from 32,000 tons per year to 16,100 tons in 1976; for Lake Ontario, from 18,700 to 10,000 tons per year).

Overall long-term objectives of the phosphorus reduction programs was to minimize eutrophication problems in the Great Lakes. It was anticipated that successful implementation of these programs would accomplish the following results:

(a) Restoration of year-round aerobic conditions in the bottom waters of the central basin of Lake Erie;

(b) Reduction in present levels of algal growth in Lake Erie;

(c) Reduction in present levels of algal growth in Lake Ontario, including the International Section of the St. Lawrence River;

(d) Stabilization of Lake Superior and Lake Huron in their present oligotrophic state.

The Parties, in cooperation with the State and Provincial Governments, and with the International Joint Commission, committed themselves to monitor the extent of eutrophication in the Great Lakes and the progress being made in reducing or preventing it.

Gradual implementation of these programs took several years and was completed in principle around 1973-1976, with some additional improvements stipulated in 1978 and 1984 revised GLWQ agreements. Phosphate ban legislations for laundry detergents was accepted in Ontario and most of the U.S. states, except Ohio and Pennsylvania (Ohio introduced the legislation only in 1988). Upgrading of sewage treatment plants to increase chemical removal of phosphorus and significant improvements of agricultural wastes management and land practices were instrumental in the P-reduction programs: the total cost is estimated to be 20 billion dollars.

Specific effluent requirements were established (i.e.

daily average of 1 mg/L of P in municipal wastewater after treatment), as well as timetables for gradual reduction of phosphate levels in laundry detergents from pre-agreement levels of 30-40 % as P_2O_5 down to 5% (The 20 % limit was introduced before the signing of the Agreement, in summer of 1970 (Bruce and Higgins, 1977). The funds for these major operations were provided by both governments in the form of loans and grants to municipalities, the agricultural sector, industries and research.

LONG-TERM RESULTS OF PHOSPHORUS CONTROLS - ANALYSIS OF LONG TERM TRENDS.

Phosphorus loadings.

As a result of the successful implementation of measures introduced during late the early 70's as expressed in the 1972 GLWQA, the P loadings, particularly from municipal sources, dropped dramatically (Table 1) and by early 80's approached the target loadings established by the 1973 and 1978 Agreements. The loading reductions over the period were most pronounced in Lake Erie and Lake Ontario (approx. 80%). In the Upper Great Lakes the corresponding reductions were over 50% (Table 1).

TAB. 1. REPORTED MUNICIPAL PHOSPHORUS LOADINGS IN THE GREAT LAKES BASINS (tonnes per year). From IJC 1987

LAKE BASIN	1972 ESTIMATE	1975	1976	1977	1978	1980	1981	1982	1983	1984	1985	% REDUCTION 72(75)-85
SUPERIOR												
United States		224	222	184	142	94	70	64	85	89	94	80.0
Canada		62	71	108	97	109	100	115	68	58	83	14.8
MICHIGAN												
United States		2,325	2,336	1,660	1,314	1,047	934	885	928	919	894	61.5
HURON												
United States		414	370	340	273	232	244	248	219	205	201	51.4
Canada		210	208	217	222	195	231	168	216	243	261	inc.24.2
ERIE												
United States	13,870	6,719	5,678	6,147	5,250	3,287	2,642	2,199	2,356	2,499	2,176	84.3
Canada	1,390	232	262	259	228	213	232	250	274	268	273	80.3
ONTARIO												
United States	4,750	1,847	1,815	2,089	1,761	1,535	1,194	1,166	1,005	872	772	83.7
Canada	5,110	2,373	1,267	1,000	967	977	1,014	949	906	952	938	81.6

Phosphorus concentrations and algal biomass.

Phosphorus loading reductions were clearly reflected in corresponding open lake concentrations of both total P (TP) and soluble reactive phosphorus (SRP) over the study period. The data are presented in Figure 1 together with chlorophyll a values as a measure of the phytoplankton biomass.

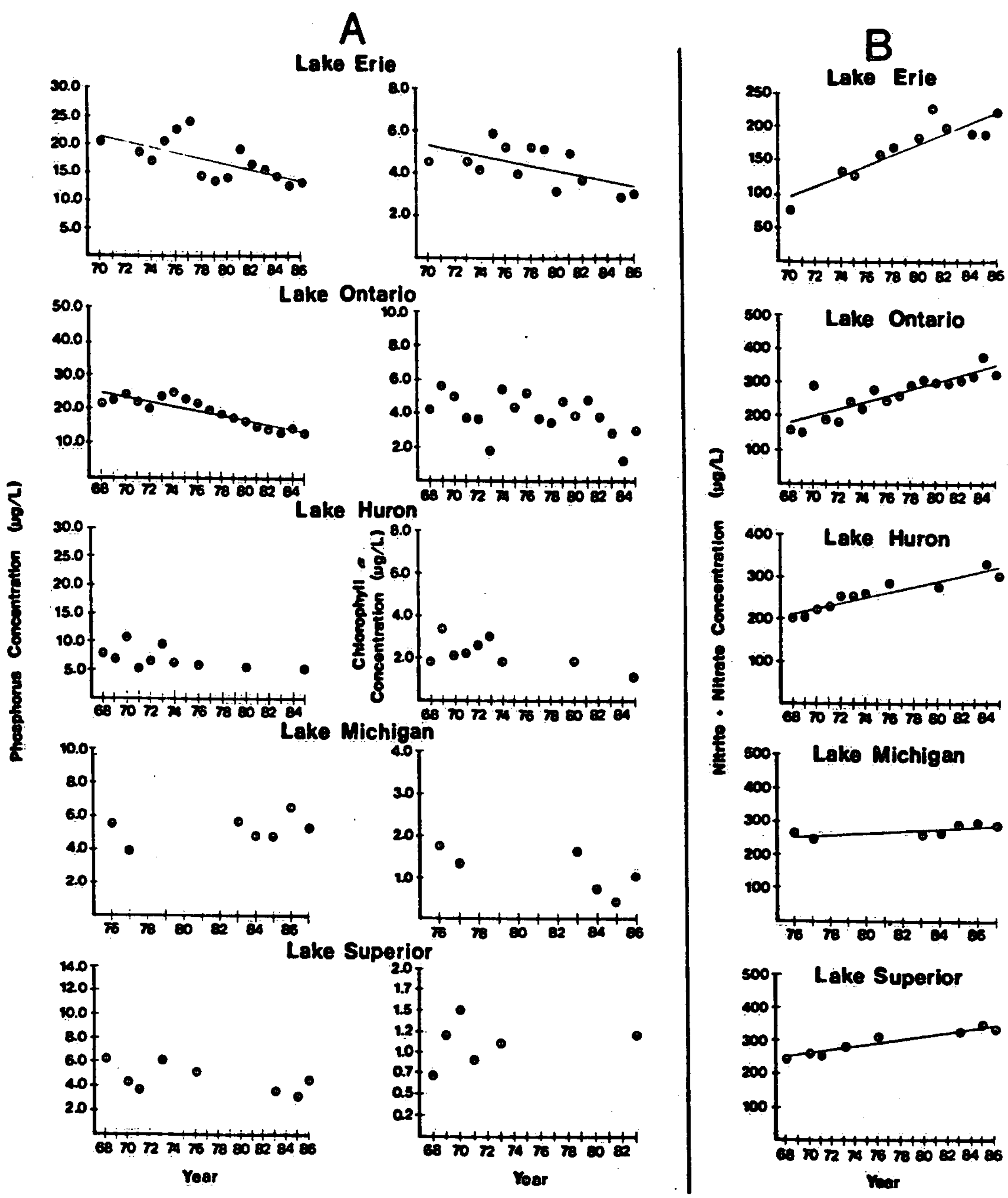

Fig. 1. Long term trend in total phosphorus, chlorophyll a and nitrite plus nitrate nitrogen concentrations in the Great Lakes (from IJC, 1987).

While total phosphorus long-term trends show a definite decline corresponding to reductions of P loads, chlorophyll a decreases are not so straightforward. This is due to the fact that the open waters of the Great Lakes, for which the trends are presented had relatively low starting concentrations of chlorophyll a and analytical "noise". While the trends presented in Figure 1 are statistically significant (IJC, 1987), SRP spring data for Lake Ontario (Dobson, 1984 and pers. comm.) present an even more convincing picture, with SRP values peaking during early 70, and steadily decreasing since (Figure 2). At the same time, Cladophora tissue phosphorus content decreased significantly over the period (Painter and Kamaitis, 1985, Fig.3).

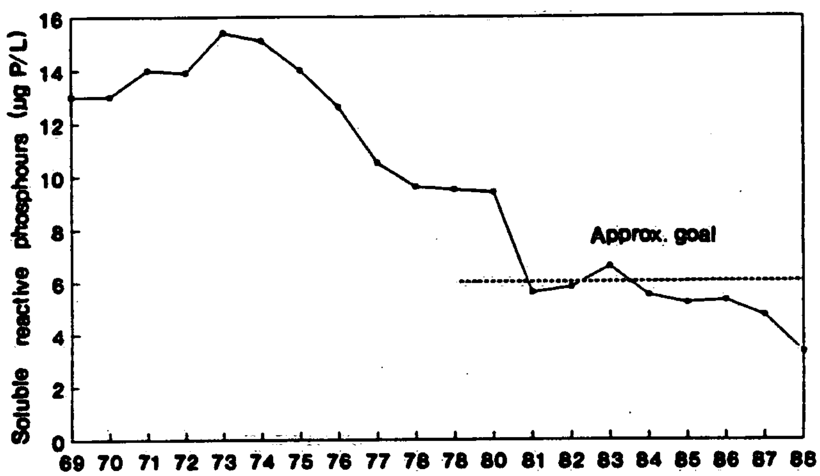

Fig. 2. Lake Ontario. Soluble reactive phosphorus in offshore, near-surface waters during March and April, 1969-1987. Great Lakes Surveillance data, CCIW, Burlington. Courtesy of H. Dobson, NWRI.

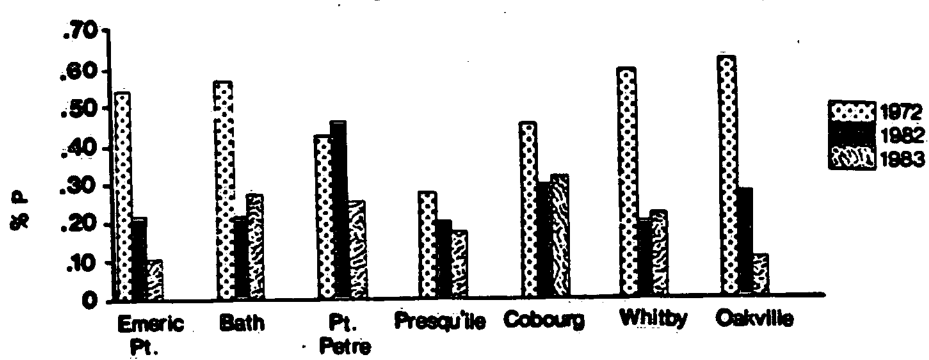

Fig. 3. Tissue phosphorus content of Cladophora before (1972) and after phosphorus controls (1982-1983). From Painter and Kamaitis, 1985.

Figures 1-2 were all based on spring concentrations. Kwiatkowski's (1982 and 1984) analysis of these parameters, considering their annual mean values also presents significant trends, but not as clearly visible as the spring concentration.

Perhaps even more convincing are the data on phytoplankton biomass from the near-shore areas where eutrophication has been historically more advanced. Bird and Rapport presented examples from two such areas in Bay of Quinte in Lake Ontario (Fig.4) demonstrating a significant reduction of phytoplankton biomass, and from Saginaw Bay in Lake Huron with altered phytoplankton composition and reduction of Cyanophytes as a result of P controls (Fig.5). Munawar and Munawar (1986) noted significant shifts in algal composition in the open water of the Great Lakes as well.

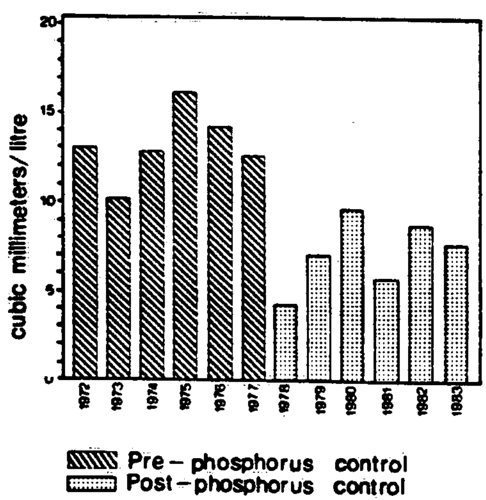

Fig. 4.

Concentration of phytoplankton in Bay of Quinte (Lake Ontario), before and after phosphorus controls, 1972-1983. From Bird and Rapport 1986.

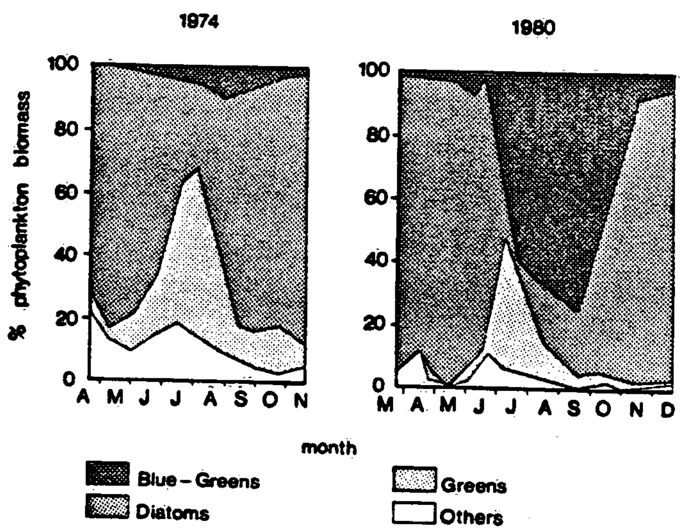

Fig. 5.

Concentration of phytoplankton crop composition before and after phosphorus controls in Saginaw Bay (1974 and 1980). From Bird and Rapport 1986.

It can be concluded that the P controls were successful and met in principle the expectations, except for some remaining problems in near-shore areas, as discussed later.

NEW PHENOMENA AND DEVELOPMENTS.

The Great Lakes Water Quality Agreement of 1972 generally reflected a state of knowledge in the 60s. A number of new water quality related issues have surfaced over the following decade. The most significant of them is the toxic contaminants problem (metals and organics) which has become the highest priority issue in the basin (treated separately by R.J. Allan in these proceedings) and incorporated in the 1978 update of the Great Lakes Water Quality Agreement.

Besides the toxics issue, there has been some other unexpected and noteworthy developments:

<u>Slow Lake Erie hypolimnetic oxygen recovery.</u>

It was assumed that P controls would have an immediate impact on improvement of hypolimnetic oxygen conditions in Lake Erie. One of the GLWQA's objectives was a year-round restoration of oxygen conditions. However, the fact is that the hypolimnetic oxygen depletion rates continued to increase over the study period (Figure 6). This controversy was subjected to a separate analysis (Barica 1981) concluding that the effect of P controls will take more time to be clearly noticeable than expected due to morphometry and internal loading of P in Lake Erie (Charlton, 1980, Rosa and Burns, 1987).

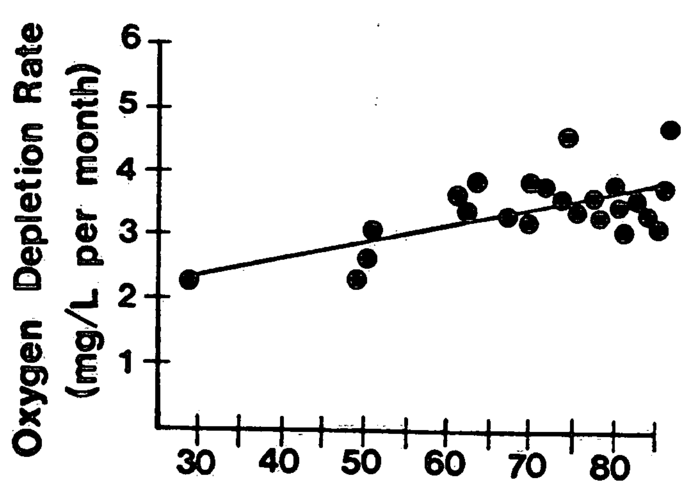

Fig. 6. Hypolimnetic oxygen depletion rates in Lake Erie, 1930 - 1985. From IJC 1987.

Increases of nitrate concentrations and N:P ratios.

Concurrently, with the success in phosphorus control, a new phenomenon became noticeable: the nitrate concentrations in the lake water increased alarmingly, exceeding levels of the 60's several fold. Dobson (1981) presented trends of springtime nitrate in Lake Superior, Lake Huron and Georgian Bay, Lake Ontario and Eastern Lake Erie, between 1960 and 1980, based on extensive data from Great Lakes water quality surveillance programmes. While the concentrations were still low from the health and drinking water quality point of view (0.3 - 0.4 mg/L NO_2-NO_3-N, as compared to 10 mg/L for drinking water; Health & Welfare Canada, 1978), the relative increases over the past twenty years were between 30 to over 200%, with highest percentage increases in the most populated and agriculturally productive basins of Lake Ontario and Lake Erie. The recent trends from IJC data were presented in Figure 1. It should be kept in mind that these data come from open lake sampling sites. However, the Great Lakes abound with numerous large and small nearshore embayments, with limited water exchange with the main lakes. In Hamilton Harbour, which is such an embayment, the nitrate increases have been even more dramatic. Between 1948 and 1979, the average annual concentrations of nitrate in Hamilton Harbour increased six-fold (Forde 1979). Significant increases have been observed also in the Bay of Quinte, Lake Ontario (Robinson 1986) and Severn Sound, in Georgian Bay on Lake Huron (MOE Remedial Action Plan Report, 1987).

Despite these increases, the lake water itself and its quality does not seem to be directly affected by nitrate or to be in danger for the foreseeable period of time (Concentrations less than 1 mg/L of nitrite and nitrate nitrogen together, as measured in Great Lakes Surveillance programmes).

Impact on lake water quality is so far indirect, mainly through alteration of N:P ratios. Low ratios are known to govern phytoplankton succession, particularly the onset of blue-green algae and formation of algal blooms. The low values

(5:1 or less, Allan and Kenney, 1980) are characteristic of eutrophic systems, while values over 30:1 are typical of oligotrophic lakes (Forsberg 1979). Increases of nitrate raise total dissolved nitrogen levels and thus N:P ratios. This is even more pronounced if P values decrease concurrently during the same period. This has been the case of the Great Lakes since introduction of phosphorus control legislation in Canada and the U.S. in the early seventies. Stevens and Neilson (1987) estimated that the total phosphorus (TP) loading to Lake Ontario has declined from 14,000 t/yr in 1969 to 8,900 t/yr in 1982, with corresponding TP mid-lake spring concentrations decreasing from a maximum of 31 ug/L/yr in 1973 to 13 ug/L/yr in 1982. During the same period, spring nitrate (measured together with nitrite) has increased at a rate of 9.5 ug/L/yr causing N:P ratios to increase from 10 to 32.

N:P ratio increases have been reported from the Bay of Quinte (up to 24.4, Robinson 1986) and Severn Sound (threefold increases between 1969 and 1986 - up to 37.8 from 12.0; MOE Remedial Action Plan Report 1988). In all these cases, the increases of N:P ratios were due to a combined effect of nitrate increases and simultaneous phosphorus decreases by P control measures (upgrading of sewage treatment plants by chemical P-removal). This is a relatively beneficial phenomenon causing an "oligotrophicating" effect, and further improvement of Lake Ontario's trophic state, provided that P control measures are maintained. Relaxation of phosphorus controls would allow catastrophic eutrophication when such a large pool of nitrogen is already present.

An analysis of possible causes and impacts of nitrifying the Great Lakes was presented (Barica, 1987). It was concluded that the increases of nitrate in the Great Lakes are a combined result of several factors of differing relative importance. In the lower Great Lakes, the increased human population, increased use of fertilizers in agriculture and large-scale phosphorus reductions are predominant. In the upper Great Lakes (Huron, Superior) atmospheric deposition of nitrate in acid rain is the most important factor.

Taste and odour problem.

Since the mid 70's, instances of taste and odour incidents in drinking water supplies in some Great Lakes communities supplied with Lake Ontario water became more frequent than in the past.

The two most frequent causes of taste and odour in lake water are geosmin (trans, trans-1, 10-dimethyl-9-decalol) and 2-methylisoborneol (MIB, 1, 2, 7, 7-tetramethyl-exo-bicyclo[2.2.1]heptan-2-ol). They are produced by actinomycetes and Cyanophytes. Under certain conditions, actinomycetes can grow on decaying Cladophora to produce tastes and odours (Persson 1983).

In the summer of 1983, geosmin was identified in a municipal water supply drawn from western Lake Ontario. The geosmin concentrations were 0.01-0.07 ug/L, within the range for threshold odour concentration of 0.01-0.2 ug/L. 2-methylisoborneol was not detected. The odour 'event' coincided with a dieoff of Cladophora in the lake, but a direct link between the dieoff and geosmin production was not established. Decomposing Cladophora in shoreline areas produced a strong odour in the air. 3-Methylindole, elemental sulfur, dimethyl tetrasulfide, and dimethyl pentasulfide were tentatively identified in water samples collected from these areas, but geosmin and 2-methylisoborneol were not detected (Brownlee et al., 1984). The cause of increased incidence has not yet been identified.

Nutrient - contaminants interactions.

Over the past years it was observed that the fish from Lake Ontario are more contaminated than those from Lake Erie (Bird and Rapport, 1986). Loadings of contaminants in both lakes are fairly comparable. It was speculated that the contaminants in a more advanced eutrophic system become masked or removed by sedimentation within the food chain and do not reach the fish. Some preliminary observations from other lakes in the Great Lakes basins indicate similar conclusions (J. Carey, pers. comm.). Research is underway to elucidate this phenomenon and to assess water quality management implications (Allan, this issue).

STRATEGIES FOR THE 80'S AND 90'S; REMEDIAL ACTION PLANS

Stopping and even reversing the eutrophication process in the Great Lakes is probably the greatest large-scale environmental success in history. The total cost is estimated around 20 billion and there are no questions as to whether or not this investment was worthwhile. The Great Lakes are positively of better quality now than 15-20 years ago - this applies to the contaminants isssue also (Allan, this issue).

However, the improvements so far have been documented for open waters of the Great Lakes, since these were the primary objective of the U.S.-Canada Water Quality Agreements, based on the Boundary Treaty of 1909. This discrepancy was noted in 1985, when the IJC - after realizing that some, mostly near-

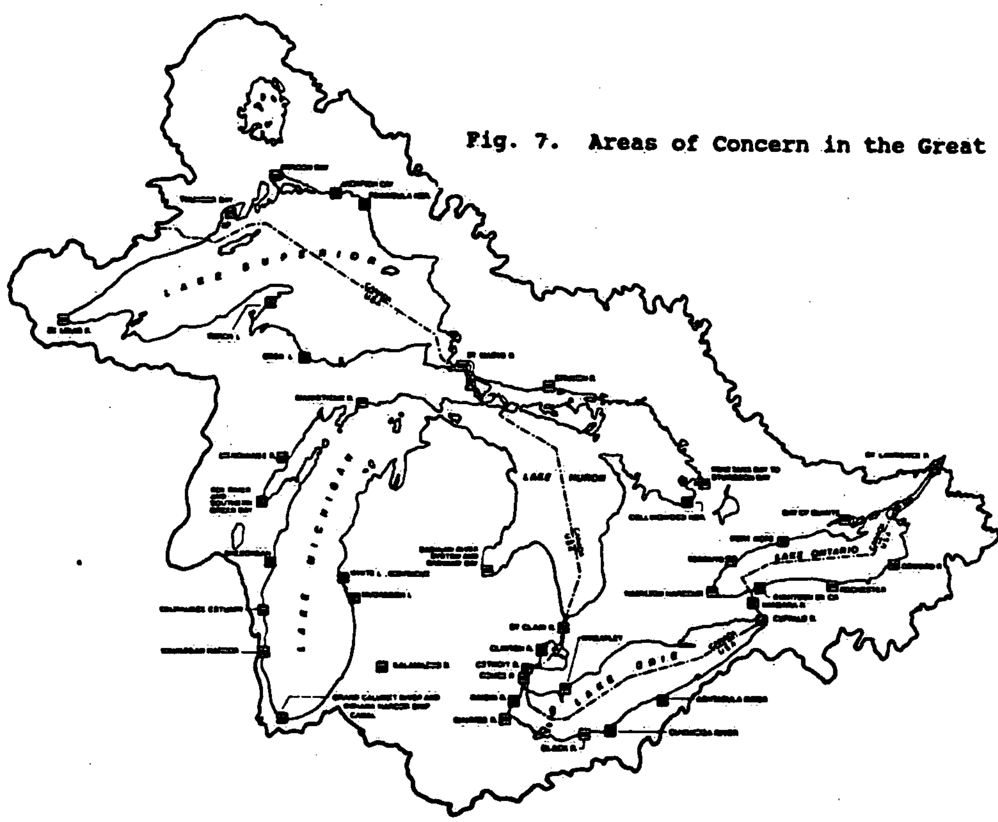

Fig. 7. Areas of Concern in the Great Lakes Basin.

shore areas - do not present visible improvements and a number of serious problems remain. The IJC has identified 42 Areas of Concern in the Great Lakes basin (Fig.7). In each of these areas, GLWQA objectives or jurisdictional standards, criteria or guidelines established to protect uses have been exceeded and remedial measures are necessary to restore beneficial uses, such as municipal and industrial water supplies, recreation and aquatic life. Areas of Concern include the major municipal and industrial centers on Great Lakes rivers, harbours and connecting channels.

As a result of the 1985 Report of the Water Quality Board, the eight Great Lakes states and the Province of Ontario have committed themselves to developing a remedial action plan (RAP) to restore all beneficial uses in each Area of Concern within their political boundaries. A remedial action plan should identify specific measures necessary to control existing sources of pollution, abate environmental contamination already present and restore beneficial uses.

These programs include, but are not limited to, municipal and industrial wastewater treatment, hazardous waste management, nonpoint source pollution control, groundwater, fisheries and wildlife management, dredging and harbour maintenance, land use planning and recreation. Remedial action plans represent the first systematic and comprehensive effort to restore beneficial uses in the Areas of Concern, and are thus consistent with the ecosystem approach outlined in the 1978 Agreement to protect the waters of the Great Lakes system.

Shifting the focus and emphasis from the open lakes- where improvements are satisfactory - to the Areas of Concern, can be considered a major change in the remedial strategy of the 80's and a challenge for the 90s.

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