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Eutrophication Experience in the Laurentian Great Lakes

By:
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Eutrophication Experience in the Laurentian Great Lakes

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Abstract

The experience in controlling nutrient pollution in the Great Lakes was generally positive. Scientific predictions about the degree of phosphorus load reduction needed were mostly accurate. Simple technologies of phosphorus precipitation and replacement of detergent phosphorus were successful. Enhanced technologies of sewage plant optimization and perhaps filtration will be needed in some areas to maximize restoration. Non-point source nutrient control has been largely driven by economics and is still a large problem. Restoration of embayments and harbours requires very stringent nutrient control. The concentration of agricultural waste from industrial type feedlots is a growing concern. The control of eutrophication appears to be an ongoing problem well into the future.

Key words: Great Lakes, phosphorus, algae, agriculture, non-point sources

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Résumé

En général, les résultats des mesures de limitation de la pollution causée par les nutriments dans les Grands Lacs étaient positifs. La plupart des prévisions scientifiques concernant le degré de réduction des charges de phosphore nécessaire étaient très précises. On a appliqué avec succès de simples mesures comme la précipitation du phosphore ou son remplacement dans les détergents. Afin d'obtenir le meilleur rétablissement possible, il faut appliquer, dans certains secteurs, des technologies améliorées pour optimiser l'exploitation des stations d'épuration des eaux usées, et peut-être aussi celle des installations de filtration. La limitation des sources non ponctuelles de nutriments est fortement influencée par des facteurs économiques, et pose encore beaucoup de problèmes. Le rétablissement de l'état des enfoncements et des ports nécessite des mesures très strictes de limitation des nutriments. La concentration des déchets agricoles des parcs d'engraissement est de plus en plus préoccupante. Il semble que la limitation de l'eutrophisation continuera à poser des problèmes pour bien des années encore.

Eutrophication Experience in The Laurentian Great Lakes

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Management Perspective

Great Lakes 2000, Lake Erie LaMP, Hamilton Harbour RAP, phosphorus management policy,

- The Great Lakes phosphorus load reduction program was a success resulting in %50 lower phosphorus concentrations and corresponding algal populations in Lakes Erie and Ontario.
- Reduction in P load in the Great Lakes was mainly through reduction of detergent P and P precipitation at sewage plants.
- Strong nutrient control actions are still needed in many restricted areas of intense pollution.
- Non-point source control in agriculture has been mainly through no-till farming and the use of buffer strips near water courses.
- Advances in sewage plant efficiency can be made through objective monitoring and evaluation of operating practices and construction engineering.
- Recovery from intense nutrient pollution requires large load reductions before benefits can be seen.
- Availability of P sources to algae should be considered before deciding on which sources are most important.
- Internal sediment recycling does not represent a new source of phosphorus; depending on the system, recovery may be delayed but is seldom prevented.

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Résultats des mesures de limitation de l'eutrophisation dans les Grands Lacs laurentiens

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Sommaire à l'intention de la direction

Grands Lacs 2000, Plan d'aménagement panlacustre du lac Érié, PA du port de Hamilton, politique de gestion du phosphore

- Le programme de réduction des charges de phosphore dans les Grands Lacs a été couronné de succès; il a abaissé de 50 % les teneurs en phosphore, ainsi que les populations d'algues qui s'en nourrissent dans les lacs Érié et Ontario.
- Cette réduction des charges de P dans les Grands Lacs est surtout due à la diminution du P des détergents et à la précipitation de cette substance dans les stations d'épuration des eaux usées.
- Des mesures énergiques de limitation des nutriments sont encore nécessaires dans de nombreuses zones limitées, mais fortement polluées.
- En agriculture, la limitation des sources non ponctuelles se fait principalement par la culture sans labour et pour l'utilisation de bandes tampons près des cours d'eau.
- On peut améliorer l'efficacité des stations d'épuration des eaux usées par des mesures de surveillance strictes, ainsi que par l'évaluation des pratiques d'exploitation et des techniques de construction.
- Lors du rétablissement de zones touchées par une forte pollution due aux nutriments, il faut de fortes réductions des charges avant l'apparition de résultats positifs.

- Avant de pouvoir classer les sources par ordre d'importance, il faut déterminer la disponibilité des sources de P pour les algues.
- Le recyclage interne des sédiments ne constitue pas une nouvelle source de phosphore; selon le système examiné, cela peut retarder le rétablissement, mais l'empêche rarement.

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Introduction

The history of European settlement in the Great Lakes area extends back only 150 years. Progressively, the forests were cleared and more and more land was used for agriculture. Eventually, cities and industrial activity developed that used the Great Lakes for transport . Deforestation led to non-point source pollution of the lakes by erosion and by agricultural chemicals. Initially, the growing cities had a small effect but eventually the use of phosphate based detergents and the advent of sewage collection systems caused a large increase in phosphorus load to the lower Great Lakes. A joint plan to reduce nutrient loads in the Great Lakes Water Quality Agreement (GLWQA) in 1972 between the governments of the USA and Canada resulted in less phosphorus load and better overall water quality especially in Lake Erie and Lake Ontario. There remained 43 areas of intense pollution and specific "Remedial Action Plans" were constructed for the ongoing restoration of these areas. Non-point source pollution is a continuing problem both from agriculture and cities. Phosphorus is thought to be the main limiting nutrient in the area.

Lake Erie

The Lake Erie eutrophication situation is probably the case most recognized internationally from North America. Building on the increased load caused by deforestation and agriculture there was a sharp increase in phosphorus load in the period 1940 to 1970 (Chapra, 1977) with the use of detergents, increased population, and increased numbers of people served by inadequate sewage plants. Already by the late 1920s there were problems of water quality and fish availability. By 1970 there were intense algal blooms and oxygen depletion problems that stimulated much public concern. Finally, there was an understanding that there were large anthropogenic changes that must be reversed; The GLWQA between Canada and the U.S. was the result. Phosphorus load reductions of roughly %50 were integral to the agreement.

The agreement was successful in that phosphorus loading decreased by more than %50 by the mid 1980s in Lake Erie as illustrated by Fig.1 using data from Dolan, 1993, Fraser, 1987 and Lesht et al. 1991 and Dolan, D.M. personal communication. This was achieved by constructing new sewage plants and by instigating phosphorus precipitation at existing plants. A key step was the phase out of phosphate builders for detergents which amounted to about 25% of the load. All large sewage plants were to have an effluent total P of no more than 1mg/L. The majority of the load decrease came from reduced municipal sources via sewage plants.

The effect of the phosphorus load change was unevenly distributed in Lake Erie. There is a strong west to east gradient in concentrations of phosphorus and algae which is consistent with most of the load occurring in the west basin (Fig. 2, Charlton et al. 1999).even today. This is

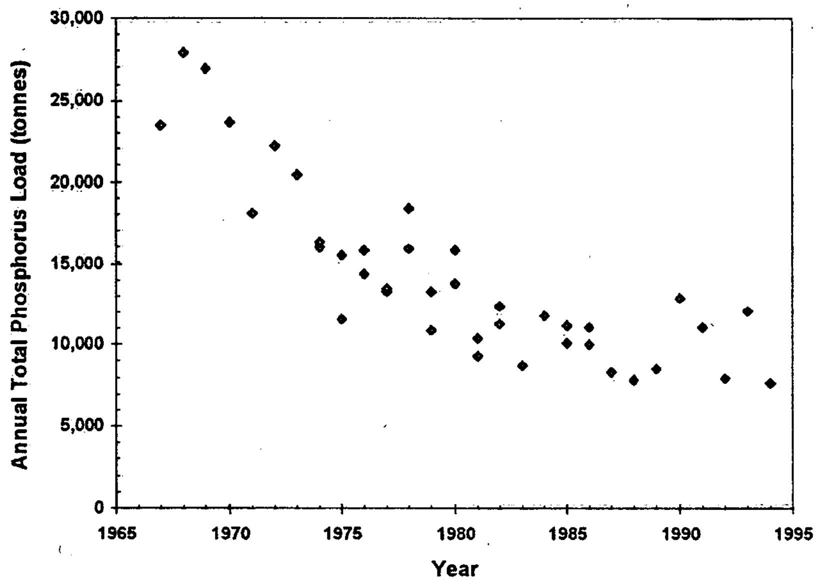


Figure 1. Annual total phosphorus load in Lake Erie

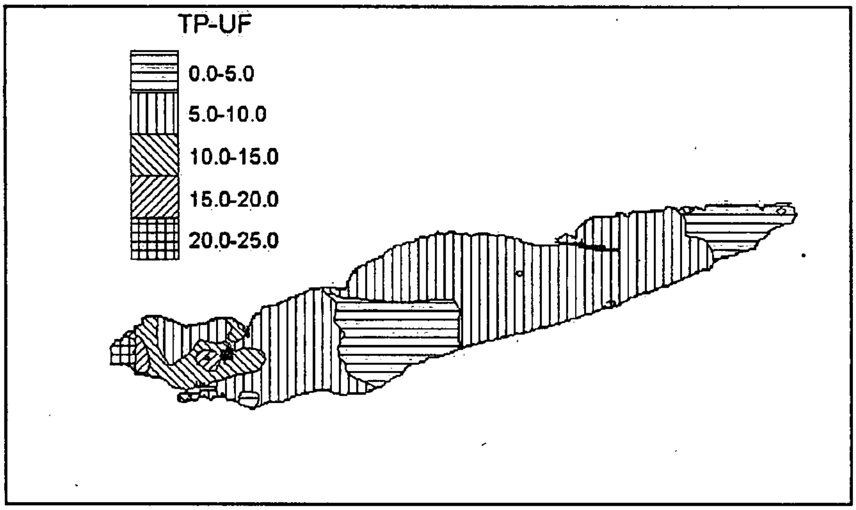
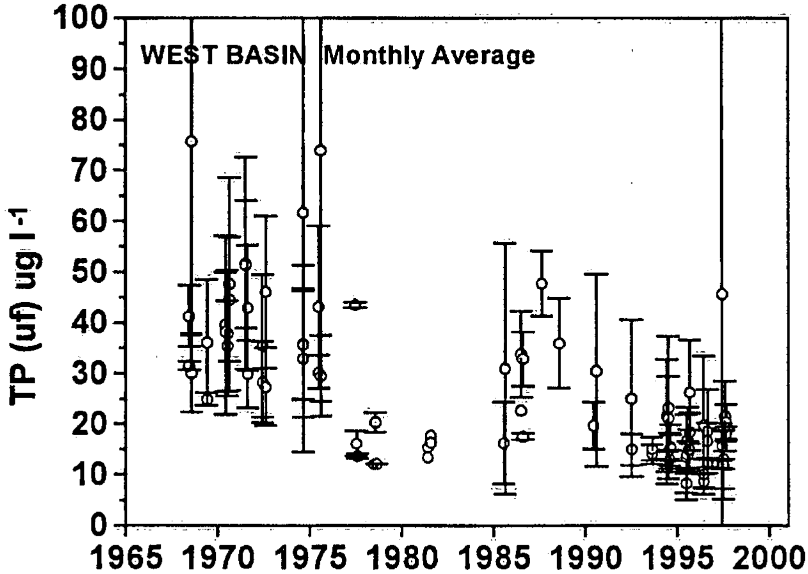


Figure 3. Phosphorus (ug/L) gradient in Lake Erie, May 1997 (from Charlton et al. 1999)

consistent with high agricultural loads and the remaining substantial load from cities in Michigan and Ohio. The reduction in nutrient load had the most effect on the west basin as can be seen in Figure 3. In the period of nutrient reductions between 1968 and 1988 total phosphorus decreased



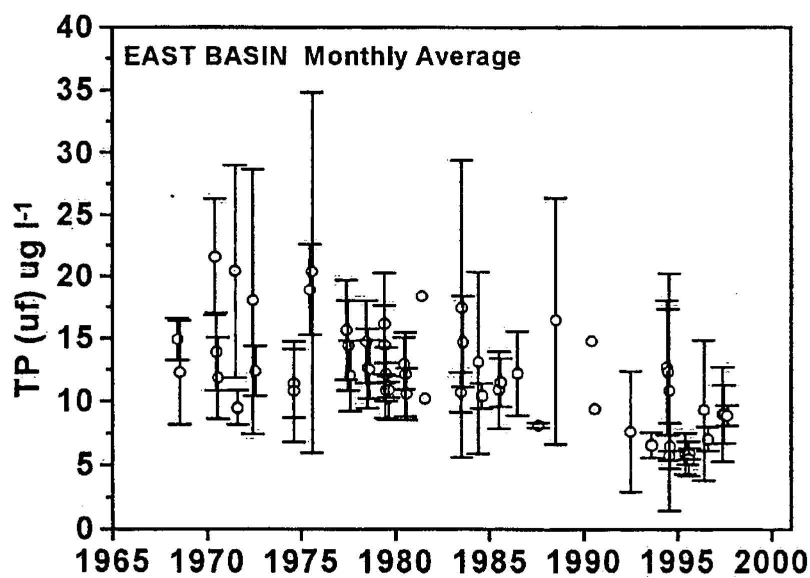


Figure 3. Total phosphorus trend in west and east Lake Erie

by 5.7 ug/L in the west basin compared to 2.8 ug/L in the east basin and chlorophyll decreased by 5.5 and 2.1 ug/L respectively (Charlton et al. 1999). Because most of the recovery occurred in the west basin, I speculate that the majority of the damage due to increasing loads occurred in the west basin. The recovery has, however, not been full. There remain substantial nutrient loads from sewage and agriculture far above those of pre-European times. It is estimated that non-point source phosphorus loads now make up about one half of the total since municipal loads have been reduced. The ability of these loads to grow algae in the lake is complicated by the fact that much of the phosphorus is in eroded soils. Thus, much can be lost to sedimentation before algae can be stimulated. Control of agricultural runoff has been a slow process with much left to be done.

Nitrogen contamination has developed differently than phosphorus. Nitrogen is not removed to a large extent at sewage plants whereas the removal of phosphorus can exceed %90. Thus, the amount of nitrogen discharged in sewage has likely increased while the algal demand has decreased due to decreased phosphorus in the water. In addition, there are non-point sources from the atmosphere and runoff from agricultural operations. The result has been a steady increase in nitrate in Lake Erie and the other Great Lakes. In terms of mass, the increase in nitrate has been one of the largest man-made changes. Lake Erie's nitrate has increased by 0.44 mg/L in the west basin and 0.22 mg/L in the east basin since 1968 (Charlton et al. 1999). That these changes are largest in the west basin is consistent with the notion they are related to the decrease in municipal phosphorus load but other sources cannot be discounted. As yet, there does not seem to be any environmental effect at the ambient concentrations. Nevertheless, the nitrate increases are another sign of the ability of un-recycled nutrients to alter the lake environment.

In the late 1980s Lake Erie was colonized by zebra mussels thought to have arrived in ballast water in ships from Europe. Now both Lake Erie and lake Ontario show localized signs of the filtering effect of the mussels. In terms of productivity it is likely that the nutrient load reductions made the most difference in the last 30 years with exotic mussels effecting the most change towards clearer water in the west basin of lake Erie and in embayments (Charlton et al. 1999).

In general, the experience in Lake Ontario has been similar. Phosphorus load was cut in half and concentrations in the water decreased by half. Before significant P load reduction, spring concentrations were about 20 ug/L and about one half of that was soluble reactive phosphorus. Now, soluble reactive P is almost undetectable and total P is typically 10 ug/L. One main difference between Lake Ontario and Lake Erie is the nutrient load is spread more evenly around Lake Ontario - thus the results of nutrient reduction have occurred more or less evenly in the lake. Most discharges are close to shore within the first two km; about the same distance offshore as the water intakes for drinking water. There is a tendency for higher nutrient concentrations near shore. As the volume of treated sewage flows increase there may again be a long term degradation of near shore quality. This is because the treated sewage P concentration is 500 to 1000 ug/L whereas the desired in-lake concentration is 10 ug/L. Thus treated sewage is very active biologically and the dilution characteristics of the near shore govern the concentrations to be found there. Increased volumes of sewage may have to be both treated better as well as discharged further from shore.

One of the targets of the nutrient controls was the elimination of obnoxious algal blooms and elimination of obnoxious accumulations of the attached alga *Cladophora*. Paradoxically, there have been blooms of *Microcystis spp.* in west Lake Erie and the shallow east basin of Lake Ontario lately. These may relate to the amount of grazing pressure exerted by the exotic mussel population on other smaller algae species and the still considerable nutrient load. *Cladophora* seems to be stimulated by zebra mussels as the mussels excrete soluble nutrients that can be readily assimilated. This, plus the increased clarity of some waters allowing photosynthesis to greater depths, can result in a prodigious *Cladophora* accumulation on shorelines even if the density per unit area is not large. Recently deleterious accumulations of *Cladophora* have occurred on some Lake Erie shorelines despite ambient phosphorus concentrations of 10 ug/L or less. Thus, the mussels have complicated the assessment of the success of nutrient load reductions and have tended to exacerbated attached algae problems that otherwise may have virtually disappeared.

Phosphorus concentrations in the Great Lakes were never very high relative to other polluted lakes around the world. Yet governments and the public were shocked to realize that they were no longer unaffected by the municipal and industrial activities. People in North America had assumed that the lakes were so large they would not be affected. Happily, once the danger signs were recognized, strong measures were taken to control point source phosphorus by about %50 and this prevented further damage. Not only has further damage been avoided but eutrophication has been reversed and systems have recovered from the worst effects. The success of the GLWQA in nutrient control is perhaps a useful example worldwide showing that cultural eutrophication can be reversed.

Remedial Action Plans and Lakewide Management Plans

The 1987 version of the GLWQA stressed that Lakewide Management Plans (LaMP) and Remedial Action Plans (RAP) should be developed. LaMPs evolved out of bi-national efforts to cooperate on controlling toxic chemicals and today they encompass many issues such as nutrient management and fisheries habitat. The RAPs were instigated to address problems in 43 areas of intense pollution identified around the Great Lakes. The RAP process considers all components in the ecosystem and strives for a balance between people, environment and the economy. The public and user groups are heavily involved in Stage One processes which amount to problem definition. Stage Two activities involve development of solutions to the problems. Stage Three is reached when all beneficial uses are restored. Public consultation occurs throughout the process. Many RAPs are in the implementation phase leading up to Stage Three. Although the RAP process was agreed to by both the U.S. and Canadian governments it was not accorded any legal or regulatory status. Instead the RAP process is designed to be a cooperative venture of all levels of government. The bi-national International Joint Commission monitors and advises the governments on the progress of the LaMP and RAP processes.

The Hamilton Harbour RAP identified several eutrophication problems. There are four sewage plants discharging into the harbour. The two main sewage plants are at Hamilton (400,000 m3/d) and at Burlington (93,000 m3/d). Also, there is a combined sewer system that had many overflow events (CSOs) in which raw sewage would be discharged during rains. In addition, there is urban, rural, and agricultural runoff. Phosphorus concentrations were high enough to produce unsightly algal blooms and severe oxygen depletion while the raw sewage discharges undermined any aspirations to increase recreational use of the harbour. The turbid waters restricted aquatic plant growth which, in turn, restricted important fish habitat. Hamilton harbour is typical of many RAP areas in that the sewage treatment plants were meeting standards under the GLWQA but those standards were not stringent enough for discharges into restricted harbours and embayments.

Investigation of phosphorus sources revealed that further control of municipal phosphorus load from the main sewage plants and CSOs would have the fastest and most important effect on improving water quality. Further phosphorus controls were among the 50 recomendations of the Stage Two report (Rodgers et al. 1992). Phosphorus controls have lowered the concentration of phosphorus in the water considerably (Fig. 4). The early annual data show a large decrease that

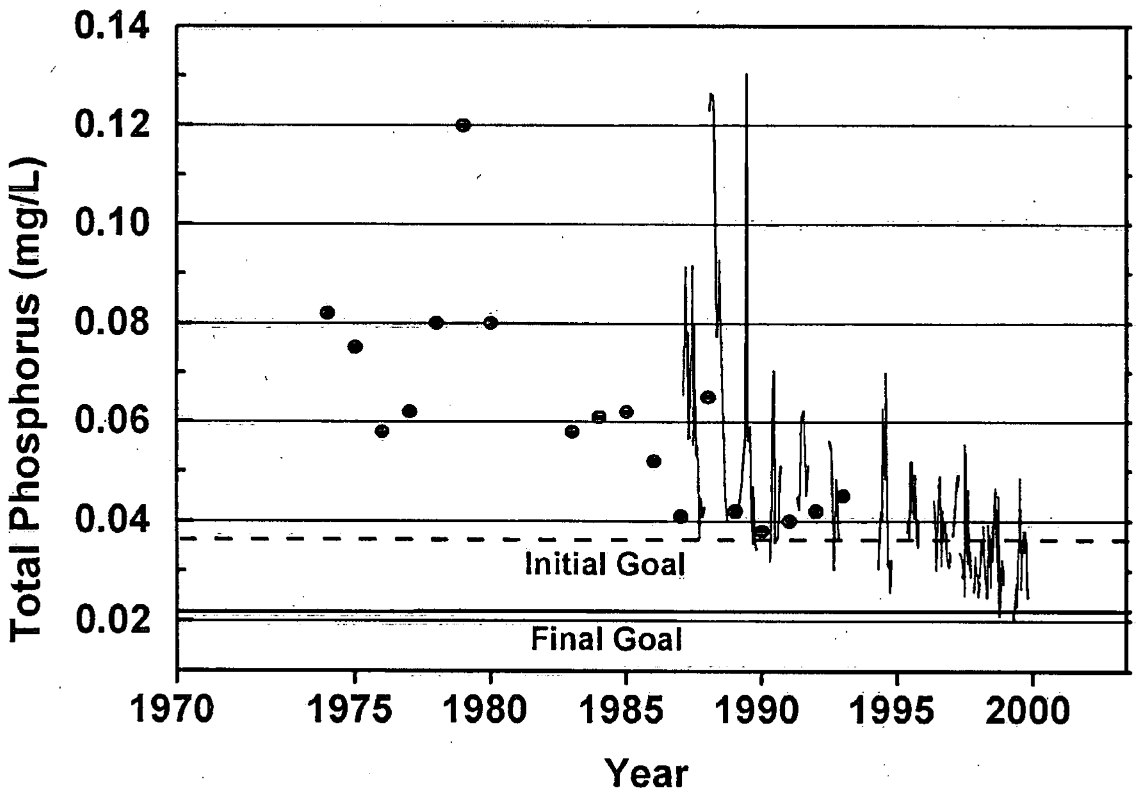


Figure 4. Total phosphorus trend in Hamilton Harbour

corresponds mainly to the construction and instigation of phosphorus precipitation at the Hamilton sewage plant. These changes were largely brought about due to the initial efforts mandated under the GLWQA. Subsequent daily data show gradual downward trends until the late 1990s when a marked downward shift occurred. That latter shift corresponds to process optimization at the Burlington sewage plant.

Originally it was thought that the Burlington plant was too small to make much difference. When expansion of the plant was needed there was an intense audit of operations that revealed more loading than previously recognized. Moreover, the audit and engineering studies showed that the plant processes could be optimized to extend the life of the plant and provide better treatment. As soon as optimization was completed in 1997 we saw lower phosphorus levels in the Harbour. Thus, the municipality has saved money and the Harbour has been cleaned up somewhat. While much improvement is still needed at the large Hamilton plant these results show how important good operation can be at even relatively small plants. They add impetus and hope that the phosphorus levels in the water can be brought down to the initial goal of 34 ug/L and eventually to the final goal of 17 ug/L. At the same time it must be realized that expenditures of about $600M CDN are required to improve the sewage plants - this is not a small amount locally and will take many years to mobilize.

One of the problems facing North American urban areas is the accumulation of nutrients. Food grown elsewhere, often using imported fertilizers, is transported to cities. Often, however, there is no return of nutrients to agriculture and accumulation occurs in water and soil. Higher removal efficiency at sewage plants causes the production of more sludge which must be disposed of on land. Ideally, the sludge would be used to grow more food and that is what is now happening with the sludge from Hamilton and Burlington. One problem with sewage sludge is the high water content that makes transport expensive. Technologies are now being developed internationally in sewage plants to crystallize phosphate compounds that can be used for raw material in fertilizer production. Approaches such as this are needed to ensure an efficient re-cycle of nutrients instead of a deleterious accumulation.

Non-point source control has been mainly through prevention of CSO discharges. Large tanks have been constructed to capture and store CSO water until a rain event passes. Then, the stored water is pumped back into the sanitary sewer system to receive treatment at the main Hamilton sewage plant. Although these systems prevent most CSO discharges they cannot prevent discharges resulting from the largest rainstorms. Nevertheless, they have allowed some beaches to open for the first time in decades and the incidents of visible sewage discharge have decreased. Non-point source emissions from land use are being slowly addressed by stewardship programs. These are voluntary programs that encourage land owners including farmers to modify their practices to enhance stream water quality and hence the quality of Hamilton Harbour.

General Comments

Non-point source pollution from agriculture has improved somewhat in the Great Lakes Basin. For decades farmers have been exhorted to decrease erosion by proper plowing direction on slopes and by allowing natural vegetation areas (buffer strips) near water courses and to apply fertilizers and manures at the best times of the year. The majority of progress has been in the development of "no-till" farming. This is a system in which the new crop seeds are planted through the stubble of the last year's crop without plowing or tilling. "No-till" offers a labour and energy saving that farmers are finding attractive regardless of the implications for decreased erosion. It remains to be seen as techniques are further developed whether the uses of pesticides and herbicides which may be higher with "no-till" are consistent with environmental improvement. The major advances have come when farmers have sensed an economic advantage in decreasing non-point pollution. At the same time fields are increasingly underlain with drainage systems that can conduct agricultural chemicals to water courses. Although it is well known that loss of topsoil is a long term threat to agricultural productivity there is little thought given to the long term thus it is fortuitous that concern for aquatic ecosystems has generated additional interest in agricultural practices. An increasing concern is the intensification of industrial style feedlot operations for pigs, cattle, and fowl. These operations with sometimes thousands of animals have caused a further concentration of waste buildup with concerns for water courses and even for groundwater quality. In general, the economic and political systems are not in place to bring about wide scale changes in agricultural practices that would minimize the effect of non-point sources to water from agriculture. Rather than expend vast resources attempting to enforce a myriad of regulations governments have chosen to enforce a smaller number of key regulations and have chosen a long term persuasive approach. Success of this approach awaits the development of attitudes consistent with sustainable ecological/economic hygiene.

Even though the Great Lakes were not grossly polluted on an international scale strong action was required. Large decreases in phosphorus loads are needed to bring about improvements. Computer modeling suggested a %50 decrease was required for Lake Erie. When that action was taken the ambient concentrations decreased accordingly. Similarly, a massive decrease in phosphorus load has been needed in Hamilton Harbour. Our waters in the Province of Ontario seem to need a phosphorus concentration of under 20 ug/L in order to avoid excessive algae populations. Our problematic areas had 40 to 50 ug P/L and this meant no less than drastic action would bring results. In the case of Hamilton Harbour the phosphorus concentrations were so high that, in the early days of more control, large load decreases did not result in better water quality. This was because the water was completely overloaded and algae were light shaded and unable to grow in proportion to the nutrient concentration. Where there is serious pollution serious action must be taken. To avoid disappointment in pollution control, the ultimate scale of load reductions needed should be accepted and the apparent ineffectiveness of early control efforts should be anticipated.

There is often skepticism that point source nutrient control will have a beneficial effect in relation to all the other sources. In some systems a large portion of the annual load can appear from non-point sources so it may appear, mathematically, that point source control would have a minor effect. Yet, the highly available point source loads occur every day whereas non-point loads are often event driven and may be dominated by soil P at non productive times of year. The timing and availability of sources to algae should be considered. Another consideration is so called internal loading or sediment regeneration. Sometimes high rates of internal loading are used as evidence that reductions in external loads would be ineffective. Internal loads are actually re-cycling mechanisms. When there is a flux of phosphorus from sediment to water then there can be a net loss from the lake due to flushing. Assuming the sediments represent storage of externally loaded P to begin with then regeneration from sediments should decrease with time if external loads are reduced. Laboratory experiments on sediment regeneration can be misleading because the physics of important water movements over the sediment cannot be duplicated and the experiments cannot show the net sediment water interaction which includes sedimentation as well as regeneration. Thus, the estimates of internal loading may distort the true effect of the lake bottom on the water. Nevertheless, sediment regeneration can slow response to reduced external load but it is the author's opinion that in most cases reduction of external load is still justified. The Bay of Quinte, Lake Ontario, for example, has high rates of internal loading and yet this ecosystem has responded well to sewage load reduction (Nicholls, 1999).

Summary

- The Great Lakes phosphorus load reduction program was a success resulting in %50 lower phosphorus concentrations and corresponding algal populations in Lakes Erie and Ontario.
- Reduction in P load in the Great Lakes was mainly through reduction of detergent P and P precipitation at sewage plants.
- Strong nutrient control actions are still needed in many restricted areas of intense pollution.
- Non-point source control in agriculture has been mainly through no-till farming and the use of buffer strips near water courses.
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Figures

Management Perspective

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Aquatic Ecosystem Management research Branch
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Current Status:

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