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INLAND WATERS ~~BRANCH~~

DEPARTMENT OF THE ENVIRONMENT

Development of Nutrient Control Policies in Canada

A.T. PRINCE and J.P. BRUCE

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The role of scientific information in the formulation of government policies is becoming increasingly important. This is especially true where policies designed to restore and protect the environment are concerned.

An interesting example of the importance of the contribution of scientific information and judgment is seen in the recent attempts by governments to control the causes of eutrophication in Canadian lakes.

Eutrophication, the process of over-enrichment of water by nutrients and the subsequent oxygen depletion caused by the decay of massive growths of aquatic vegetation, is one of the most vexing environmental problems in the developed countries of the world (1). A valuable summary of the extent of eutrophication in the world's most important lakes is given in a report of a conference sponsored in 1968 by the Organization for Economic Co-Operation and Development (2).

PHOSPHATES AND THE CANADA WATER ACT

Many of Canada's resort lakes, particularly in Ontario, Quebec and British Columbia, are deteriorating rapidly due to the effects of cultural eutrophication. The most extensive manifestations of this problem are found in Lakes Erie and Ontario. The results of studies of eutrophication and other pollution problems in the lower Great Lakes carried out by Advisory Boards to the International Joint Commission over the period from 1965 to 1969 were reported to the International Joint Commission (3). The Advisory Boards, recognizing that nutrients, particularly phosphates, were the major contributors to the process of eutrophication, recommended an extensive program of nutrient discharge control with the most important step being control of phosphate discharges to the lower Great Lakes.

Three means of achieving the objective of effective phosphate control were recommended: 1) phosphates in detergents would be replaced by substances less harmful to the environment by the year 1972; 2) a phosphate removal program would be implemented at sewage treatment plants in all large cities discharging to the Lakes; and 3) the input of agricultural phosphates from the drainage basins would be brought under control.

The report of the Advisory Boards to the International Joint Commission was the subject of a series of public hearings held early in 1970, at which representatives of government, industry, and universities, as well as private citizens, presented arguments which supported or opposed the proposal for a phosphate control program. The argument against the efficacy of the proposed control program was carried largely by industrial representatives and by some scientists, and involved a difference of opinion in two main areas: first, in establishing the causes of eutrophication, i.e. the relative importance of phosphorus as compared to other nutrients; and second, in deciding which of these nutrients can be controlled most readily and what is the most effective means of control?

Following the hearings, the Commission issued an interim report in April 1970 (4) and a final report in December 1970 (5), confirming the recommendations of the Advisory Boards.

The Governments of Canada and of Ontario, after a study of the Board's recommendations, and concurrently with the formulation of the IJC's recommendations, agreed that the federal government should introduce legislation to control the use of nutrients in cleaning products. The Canada Water Act, then under consideration, was deemed the most appropriate vehicle for this purpose. An amendment to the Act containing a clause covering nutrient control was introduced. This clause did not itself specify any particular limitation on the chemical composition of detergents or cleaning products. It did, however, permit the Government, by Order in Council, to regulate the amounts of nutrients in cleaning products.

The nutrient control clause evoked vigorous debate, first in the House of Commons Committee which considered the Act and later by the Senate Special Committee on Science Policy. Not unexpectedly, the arguments against control of detergent formulation paralleled the arguments advanced earlier in the public hearings before the International Joint Commission.

The Canada Water Act, incorporating the clause on nutrient control, passed the Commons and Senate in the early summer of 1970 and the first regulations under the nutrient control clause became effective August 1, 1970. The detergent industry had been informed in January 1970 of the government's intentions concerning regulations under the Act. The regulations limit the amount of phosphates in detergents, excluding dishwashing detergents, to a maximum of 20% expressed as phosphorus pentoxide (P_2O_5). Prior to the regulations most detergent powders had P_2O_5 contents from about 16% to 38%. This initial limitation is estimated to reduce the amount of detergent phosphates entering Canadian lakes and rivers by 25% to 30%.

The arguments advanced in opposition to the nutrient section in the Canada Water Act and the counterargument which led to parliamentary approval of the section are discussed in this paper.

SCIENTIFIC ASSISTANCE TO LEGISLATORS

The highly scientific nature of the arguments and counterarguments rendered any objective appraisal by legislators in the Commons and Senate extremely difficult. To help overcome this, the scientific staff of the Canada Centre for Inland Waters, Burlington, the Inland Waters Branch, Ottawa, and the Freshwater Institute of the Fisheries Research Board, Winnipeg, prepared a nine-page pamphlet on the control of eutrophication (6), outlining in lay terms the rationale for a program of nutrient control and in particular a program to control the use of phosphates in detergents.

The pamphlet discussed at some length the two important questions involved in any consideration of nutrient control: first, what is the relative importance of the different nutrients in algal growth, or to put it another way, which of the various nutrients limits algal growth most frequently; and second, which of the key nutrients can most readily be controlled by man?

ALGAL GROWTH AND THE RELATIVE IMPORTANCE OF CARBON, NITROGEN AND PHOSPHORUS

The argument against instituting control of phosphorus was based on a difference of opinion on the relative importance to the eutrophication process of phosphorus as opposed to other nutrients, particularly carbon. This argument emphasized the great importance of carbon and carbon dioxide in algal growth and the symbiotic relationship between bacteria stimulated by organic wastes and the excessive growth of algal blooms.

There is no question that many different substances dissolved in water are required for algal growth, among which carbon, nitrogen and phosphorus are the most important. Substances such as iron, manganese, molybdenum as well as calcium, potassium, magnesium, sulphur and silica are also required, but in smaller quantities. Phosphorus, nitrogen and carbon have been demonstrated to be growth-limiting in a number of lakes. Similar growth limitation has been reported, though less frequently, for some of the other elements. A rough indication of the relative supply of each of the three principal nutrients required to sustain extensive algal growth, assuming other nutrients to be present in adequate quantity, is the fact that for every ton of phosphorus in the algal biomass, there are about 40 tons of carbon and 7 tons of nitrogen.

Carbon

Carbon is available in lakes from a large number of natural sources. Surface waters are usually saturated with carbon dioxide (CO_2) from the atmosphere. Bicarbonates and carbonates are present in abundance in most lakes due to natural chemical processes, and are readily converted to CO_2 by a well-known chemical reaction. The fact that the pH of waters with algal blooms frequently increases to values between 9 and 10 indicates that algae can use bicarbonate ions during growth. In the near-surface growing zone carbon in the form of bicarbonate and carbon dioxide can be continually supplied from tributaries, turbulence in the main water body, and atmospheric exchanges, and in most lakes these sources alone are sufficient to support the observed biomass.

Work in an experimental lakes project by the Fisheries Research Board of Canada suggests that carbon can be limiting in very soft waters with inorganic carbon less than 6 mg C/ℓ (7). Even in such lakes, however, it has been shown that the introduction of inorganic fertilizers high in phosphorus and nitrogen stimulates excessive algal growth (unpublished results by R.R. Langford, University of Toronto and D.W. Schindler, Freshwater Institute, Winnipeg).

In polluted lakes, sewage wastes are another source of carbon. The strength of these wastes is usually measured as BOD (Biochemical Oxygen Demand) a measure of the oxygen required to decompose organic substances by bacterial activity under controlled laboratory conditions. It has been claimed that carbon from BOD is an important source for algae to produce algal blooms (8).

To obtain some idea of the relative importance of these sources of carbon in a natural lake system, consider Lake Erie. The annual loading of BOD_5 (BOD in 5 days at 20°C) to the whole lake is estimated at 200,000 tons with a carbon equivalent of 75,000 tons. The supply of inorganic carbon from tributaries to Lake Erie is in the order of 3.5 million tons to 4.2 million tons per year, about half of which is available for photosynthesis. The additional supply of CO_2 from the atmosphere is difficult to estimate but certainly this source cannot be neglected in a complete carbon budget. Hence, the carbon supply from natural sources is at least 25 times as much as the carbon from sewage wastes.

Another way to consider this question is by estimating the average algal biomass which, according to studies made by the Fisheries Research Board detachment at the Canada Centre for Inland Waters, is in the order of 60,000 tons ash free dry weight in the uppermost 5 m of Lake Erie, with a carbon equivalent of about 30,000 tons. During periods of algal blooms the phytoplankton biomass could be 4-5 times as much as this average. Assuming an average photosynthesis rate of 0.4 g/m^2day (in accord with direct measurements) the time needed to produce this algal mass is in the order of days, and hence, the carbon from sewage would be completely insufficient to support the biomass.

Nitrogen

Nitrogen usually enters lakes in the form of nitrates, ammonia, and organic compounds. These come from a variety of natural sources including natural drainage from soils and precipitation from the atmosphere. In addition, farm fertilizers, manure, and organic wastes from municipalities contribute to the nitrogen load.

It has been observed that if sufficient phosphorus is available in the water in spring before growth starts, nitrogen can become limiting later in the summer. Sawyer's work (9) of 1947 on lakes in Wisconsin suggests that inorganic nitrogen concentrations in late winter of about 200 - 300 μg/ℓ (ppb) are needed along with inorganic phosphorus concentrations of at least 10 - 20 μg/ℓ (ppb) to stimulate blooms of algae later in the growing season. Some species of blue-green algae and bacteria can use dissolved molecular nitrogen.

An additional source of nitrogen can be by fixation of molecular nitrogen by a number of blue-green algae and nitrogen-fixing bacteria. This source, however, is likely of some importance only if other nitrogen forms have been used up by algae, and, is of importance primarily in lakes with high productivity for other reasons.

Phosphorus

Phosphorus does not occur as abundantly in nature as either carbon or nitrogen, and even though it is required by algae in smaller quantities it is generally recognized that it frequently triggers eutrophication and is the substance limiting the overall extent of algal growth. Vollenweider in 1970 (10) analyzed some data published by Thomas (11) on 46 Swiss lakes and related the decrease in carbon, nitrogen and phosphorus in the lakes during the growing season to the initial concentrations of these same elements in the spring. The lakes ranged widely from clear, oligotrophic waters to highly-enriched eutrophic waters. The seasonal decreases in carbon, nitrogen and phosphorus are due largely to uptake of the nutrients by the biomass. Significant correlation was found between spring concentration and decrease during the growing season for each nutrient (carbon, nitrogen, phosphorus) calculated separately but the highest correlation coefficient was found for phosphorus availability and phosphorus decrease. Further, a cross correlation analyses showed high correlation between phosphorus availability, and nitrogen and carbon decrease but low and insignificant correlation between carbon or nitrogen availability, and phosphorus decrease. This illustrates the dominant function of phosphorus availability in the lake metabolism. Phosphates appear to be the key substance governing the production of algae in these 46 Swiss lakes.

In Lake Erie the ratio of the available carbon in bicarbonates to total phosphorus in the waters is 175:1 in the western basin and 700:1 in the other basins. If the average C:P ratio in algal cells is taken as 40:1, then there is *4 times more bicarbonate-carbon available in the western basin and 17 times more in the lake as a whole than would be required for algal growth to completely deplete the water of phosphorus.*

Similar calculations show that in the western basin of Lake Erie slightly more nitrogen is present than needed for the maximum biomass that could be generated by available phosphorus, and in the other two basins there is a two-to-three-fold surplus of nitrogen, assuming an average N/P ratio in the biomass.

To some extent these findings are corroborated by considering the annual loadings of phosphorus:nitrogen:carbon which - according to the report to the IJC - are 1.06 and 6.8 g/m^2 year for phosphorus and nitrogen respectively, and about 150 g/m^2 carbon from bicarbonates (half of which is available for photosynthesis) for the lake as a whole.

Accordingly, the nitrogen and phosphorus loading ratio is in the order as required for biomass build-up, but the available carbon from bicarbonates alone is greatly in excess of need.

Vallentyne (12) has pointed out that the concentration of bicarbonates in the lower Great Lakes has not changed appreciably in the last 100 years, whereas algal growth has increased immensely, showing that bicarbonate carbon has not been an important factor.

In summary then, these mass balance calculations show that in Lake Erie as a whole phosphorus is generally the limiting growth factor, and work on many other lakes in North America and Europe shows that this is true for a large number of lakes in the world. In addition, if one wishes to give a general sequence of importance, it can be said that phosphorus is most frequently the limiting element followed in order of decreasing importance by nitrogen and carbon.

CONTROLLABILITY OF NUTRIENTS

The second important question in considering a nutrient control program is which of the three principal nutrients can most readily be controlled by man.

By far the largest source of soluble carbon in Canadian lakes, except those in Pre-Cambrian areas, is due to solution of calcium carbonate and magnesium-carbonate sediments in the drainage basins. The resulting bicarbonate ions which arise from natural chemical processes appear to be present in quantities much more than adequate to meet the demands of biomass production. The quantity of carbon in this form is not controllable by man, nor for the most part is it created by man's activities.

Nitrogen enters lakes from rain, snow and dustfall (approximately 16,000 tons per year to Lake Erie and 12,000 tons per year to Lake Ontario). Leaching from natural soils and from soils that are artificially fertilized is another source. In Lakes Erie and Ontario 60%-70% of the nitrogen comes from diffuse sources including agriculture, which are not readily controlled.

By contrast, 70% of the phosphates entering Lake Erie and nearly 60% entering Lake Ontario are from directly controllable point sources such as municipalities and industries. Throughout Europe and North America it is generally found that more phosphorus inputs to lakes are from point sources of municipal or industrial wastes than is the case for nitrogen. Thus, not only is phosphorus a key element in algal growth, but because it is introduced primarily by man's activities it is also the most readily controlled of the three principal elements which are essential in algal growth.

DETERGENT REFORMULATION AND SEWAGE TREATMENT

It is estimated that approximately 50% of the municipal phosphate discharge in Canada to Lakes Erie and Ontario is from detergents; in the United States the corresponding figure is 70%. (3) On this basis, detergent phosphates account for about 40% of the total phosphorus loading to the lakes.

Prior to the institution of nutrient control regulations in August 1970, detergents sold in Canada had a very wide range of phosphate content. As noted earlier, laundry detergent powders contained from 16% to 38% phosphates expressed as P_2O_5 (phosphorus pentoxide) or 28% to 66% expressed as STP (sodium tripolyphosphate). Liquid detergents had, and still have, less than 1% STP.

It was argued before the legislative committees which examined the draft nutrient control legislation that the most effective way of solving the problem would be to remove the phosphates and other nutrients by sewage treatment methods, and that if this were done, reformulation of detergents would not be necessary.

There is no doubt that nutrient removal at treatment plants is a very important part of any effective nutrient control program, but there are three strong reasons for requiring detergent reformulation as an essential additional measure. The first involves timing, the second is concerned with costs of treatment facilities, and the third recognizes that many phosphate sources will remain for a long time to come beyond the reach of control facilities.

Timing

In the view of many scientists, a number of Canada's lakes are fast approaching the state where a major change in the rate of deterioration will occur unless remedial measures are introduced quickly. Lake Ontario may already be in this position. The International Joint Commission recommended that, in the case of Lakes Erie and Ontario, nutrient removal facilities at treatment plants be completed by 1975. Many financial and political problems have to be overcome, however, before this objective can be met and it was essential that a start be made on reducing the phosphorus loading without waiting until adequate treatment facilities became available. An immediate reduction in the phosphate content in detergents was the obvious course.

Costs of Treatment Facilities

In treatment plants which use alum to remove the phosphorus, the amount of treatment chemical required is in proportion to the amount of phosphorus to be removed from the sewage. In other cases, where, for example, lime is used in the treatment process, chemical costs do not increase in proportion to the amount of phosphorus entering the system, but sludge removal costs will likely rise with an increase in the phosphorus precipitated. While it is very difficult to assess the extent of the savings, it is clear that the operating costs of nutrient removal facilities at sewage treatment plants will be decreased by reducing the amount of phosphorus entering the plant.

Uncontrolled Sources of Nutrients

Nutrient removal by sewage treatment will eventually be a very important element in nutrient control programs, but there are sources of nutrients which will remain indefinitely beyond the reach of control facilities. These include the combined storm and sanitary sewer systems of Canada's older cities, small municipalities for which it would be uneconomical to provide sewers and treatment facilities, and cottage and resort areas where sewage and waste treatment facilities would be prohibitively expensive and where the health and recreational value of the smaller lakes depends heavily upon the success achieved in curbing cultural eutrophication.

Effectiveness of Phosphate Control

There is some scientific doubt as to whether a phosphate control program will in itself be sufficient to overcome the problem of lakes in an advanced stage of eutrophication. Reports by Edmondson (13) on the effects of a complete sewage diversion scheme to remove all the polluting substances being discharged into Lake Washington reveal that by far the most significant correlation exists between the reduced phosphate in lake waters in the winter or early spring and the reduction of algal blooms in the lake. In this particular scheme at least, control of phosphates appears to be the most important factor.

Although there is little doubt that a phosphate control program should be the cornerstone of any program to control eutrophication, in some cases additional measures such as nitrogen reductions may well be necessary.

THE PROBLEM OF INTERNATIONAL CONTROL

During the discussions on the nutrient control clause of the Canada Water Act, some doubt was expressed regarding the wisdom of Canada's instituting a detergent phosphate reduction program when Canada's contribution of nutrients to the lower Great Lakes is significantly less than that of the United States.

In the case of Lake Erie, Canada does indeed contribute very little of the phosphate input. Only 2% to 3% of the total input comes from detergent sources in Canada. To save Lake Erie from the effects of worsening eutrophication, therefore, the responsibility for action lies largely with the United States.

In Lake Ontario, on the other hand, excluding the phosphorus input from Lake Erie via the Niagara River, the phosphorus load from Canadian sources is about equal to that from the United States. Detergent sources in Canada contribute about 19% of the total phosphorus input to Lake Ontario and about 43% of the total Canadian phosphorus load. (3) Obviously, a reduction in Canada's contribution of phosphorus would be significant to the lake as a whole. In addition to the benefits to Lake Ontario, a general program of phosphate control will benefit resort and recreational lakes in other parts of Canada.

REPLACEMENTS FOR PHOSPHATES

The substance which appeared most promising as a replacement for phosphates in detergents was NTA (sodium nitrilotriacetate) and small quantities of this substance were used in some Canadian detergents following the introduction of the August 1, 1970 regulation limiting the use of P_2O_5 to 20%.

The Government of Canada is vitally interested in the potential environmental hazards of any substance that may be introduced to replace phosphates, and has participated in a co-ordinated three-nation study to determine the potential environmental and health impact of large amounts of NTA in lakes and rivers. The countries involved in the study, in addition to Canada, were the United States and Sweden. Canada's participation was undertaken by the Canada Centre for Inland Waters, Burlington, Ontario and the Freshwater Institute of the Fisheries Research Board, Winnipeg, Manitoba.

Recent findings by the U.S. Public Health Service, based on preliminary results of experiments with rats and mice, indicate the possibility that NTA may cause potentiation of the teratogenic effects of mercury and cadmium. Because of this, major detergent companies in Canada and the United States have temporarily discontinued the use of NTA.

There is as yet no evidence of human health or biotic toxicity problems associated with the use of NTA in small quantities. While there is not as yet any firm Canadian government policy in the matter, it is the general view that findings of the U.S. Public Health Service require verification. However, the results suggest the need for caution in the use of large quantities of NTA until further research is completed.

It should be emphasized here that the goal of detergent reformulation to reduce phosphate to very low levels does not depend on the suitability of NTA as a substitute. Experiments are being carried out on other substitutes which will provide the complexing capability needed in a detergent. Among them are sodium citrate or citric acid. It may be possible also to achieve satisfactory results by using different washing procedures. The senior author has found that, on the basis of more than a year of continuous use in a home laundry, a low-phosphate liquid detergent plus washing soda will give completely acceptable laundry performance.

SUMMARY

Cultural eutrophication is a serious problem affecting all too many lakes. The most readily controllable of the elements essential for algal growth and the key element in the lower Great Lakes and in many lakes throughout the world, is phosphorus.

On the basis of existing scientific knowledge, a program of phosphate control is the most practical way to combat eutrophication in lakes presently affected, and to prevent the deterioration of lakes where the problem is not yet acute.

An effective program to control phosphates must have three principal aims: the reduction and eventual removal of phosphates from detergents, the removal of phosphates and possibly other nutrients at waste treatment plants, and the control of phosphates from agricultural sources. In response to the recommendations of the International Joint Commission, the Government of Ontario has announced a policy of nutrient removal at the larger municipalities in the drainage basin of the lower Great Lakes. Research on improved agricultural practices to reduce nutrient discharges is under way.

The worsening situation in many of Canada's lakes, particularly the lower Great Lakes, demanded that some effective and immediate action be taken. The construction of nutrient removal facilities at waste treatment plants, eventually to be one of the key factors in the control program, could not, because of anticipated delays resulting from financing and other problems, be relied upon to furnish the immediate action needed. The obvious course was to institute a program of detergent reformulation and this was done through the medium of government legislation which limits the phosphate content in detergent products. The legislation permitting the government to institute controls on nutrients in detergents is written into the Canada Water Act.

The government is taking steps also to ensure that any substances which are introduced as replacements for phosphates do not themselves present health or environmental hazards.

The formulation of government policy in the complex area of environmental restoration and preservation presents legislators with the difficult problem of appraising often conflicting interpretations of research information. Involved in these decisions are important economic, public health and public interest considerations. The task of providing the information on which policy can be built, and providing it in a form relatively easy to assimilate, falls to economists and social scientists as well as their colleagues in the natural sciences.

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