THE SOCIAL AND ECONOMIC IMPLICATIONS OF EUTROPHICATION IN THE CANADIAN GREAT LAKES BASIN

(Draft for PLUARG)

By
A. Sudar
Policy Research & Social Analysis Division
Inland Waters Directorate - Ontario Region
Burlington, Ontario

January 1978

TABLE OF CONTENTS

INTRODUCTION

Eutrophication is not synonymous with pollution. Accelerated eutrophication has been called nutrient pollution, but it is much more complex than such a label would indicate. This complexity makes the process of eutrophication more difficult to deal with than, for example, toxic substances.

The proceedings of the Uppsala Symposium [1] outlined six factors affecting the trophic status of a lake:

1) Size and shape of the basin, especially water depth, the circumstances of its origin, and its world location.

2) Spring concentrations of nutrients, the annual input of nutrients, and the overall lake metabolism.

3) Thermal stratification.

4) Rate of volumetric water change.

5) Period of ice coverage.

6) Sediment-water exchange of materials, especially nutrients.

The only one which man has any control over is Number 2, the input of nutrients.

The presence of excessive amounts of nitrogen and phosphorus compounds can have a direct effect on water quality when ammonia exerts an increased chlorine demand and when the various phosphates affect the coagulation of particulates in the water with iron and aluminum salts [2]. However, such direct effects of nitrogen and phosphorus are minimal compared to the indirect effects of these nutrients which are manifested in excessive growths of algae and other aquatic plants. The social and economic effects of eutrophication examined in this paper will be the social and economic effects of the increased algae which is caused by accelerated eutrophication.

IMPACT ON MUNICIPAL WATER SUPPLIES

Certainly drinking would top the priority list of Great Lakes water uses, as water is indispensable to life. Table 1 shows the approximate number of Canadians who drink Great Lakes water, 4.5 million. This figure represents 71% of the total basin population. In Lake Ontario, the most urbanized of the Canadian basins, the percentage is 93.

As population and industrial demands increase and ground water supplies become inadequate, more and more cities and villages in Ontario will be turning to the Great Lakes for their water supplies. The city of London has already constructed a pipeline to Lake Huron to supply its population with adequate water.

The Kitchener-Waterloo area has been looking at the Great Lakes as a possible source of water supply since 1948. A study of urban water supply alternatives in the Grand River basin [3] found that people preferred the purest water, not the purest in scientific terms, but the least contaminated by man. The perceived quality of the water was much more important in the decision process than the cost factor.

Lakes Huron, Ontario, and Erie are all possible water sources for the Kitchener-Waterloo, Guelph, and Brantford areas. Lake Erie is, by far, the most economical alternative, being cheaper to build and maintain than the other three. It also has the advantage of no international complications because the water would be drawn from and returned to the same lake. However, Lake Erie has a bad reputation in the eyes of the

TABLE 1

APPROXIMATE NUMBER OF CANADIANS
WHO DRINK GREAT LAKES WATER

LAKE BASIN	NUMBER OF PEOPLE	PERCENT OF BASIN POPULATION
Superior	112,000	79
Huron	136,000	15
Erie	623,000	41
Ontario	3,573,000	93
Great Lakes	4,544,000	71

public. This relative unpopularity of Lake Erie as a water source is well illustrated by the fact that Lake Huron scored the same number of preferences of Brantford residents although it is 50 miles farther away.

In large quantities, algae can cause problems in the treatment of municipal water supplies. However, comparatively low concentrations of most algae are often an asset rather than a liability, and they can actually improve a water supply.

The algae that collect and grow on the surface of a slow sand filter as a gelatinous, slimy film gradually reduce the flow through the filter, but they also perform a useful service by adding oxygen to the water, thereby permitting the bacterial decomposition of organic matter to remain aerobic.

High levels of algae necessitate the treatment of water by coagulation and sedimentation prior to filtration. Most of the treatment plants in Ontario already employ this process. Efficient coagulation and sedimentation can remove 90 to 95% of the algae from the raw water. However, the algae remaining in the water may still be sufficient to cause gradual or even rapid loss of head in the filter. The clogged filter must then be taken out of service and cleaned or backwashed. In extreme cases, filter runs are reduced to the point where more water is needed to backwash the filters than can be produced. So far, the situation in Ontario has not reached this critical point.

Another way to remove algae from the raw water is by use of a microstrainer. Several plants in Ontario have found it necessary to install microstrainers (Dunnville, located in the eastern Lake Erie basin; Union Water Supply, located in the western Lake Erie basin; and Belleville on the Bay of Quinte).

Certain types of algae can cause taste and odour problems in water. These problems are usually corrected by the use of carbon or other substances which absorb odours. Ironically, the Lake Huron Water Supply System, which draws water from oligotrophic Lake Huron at Grand Bend, is the only water treatment plant in Ontario which is severely troubled by algae. This is a direct filtration plant (no sedimentation takes place prior to filtration). This process uses considerably lower dosages of alum than conventional systems with similar raw water quality. The problem here is high concentrations of diatoms at certain times of the year which clog the filters and considerably shorten filter runs. Shorter filter runs mean that a greater proportion of the treated water must be used to backwash the filters. An Ontario government study of this problem [4] found that, on the worst day in July 1969, the filter runs were reduced to 4.5 hours and backwash water rose to 27% of the total treated water. The water treatment plant is designed for a backwash water supply of 5% of the treated water.

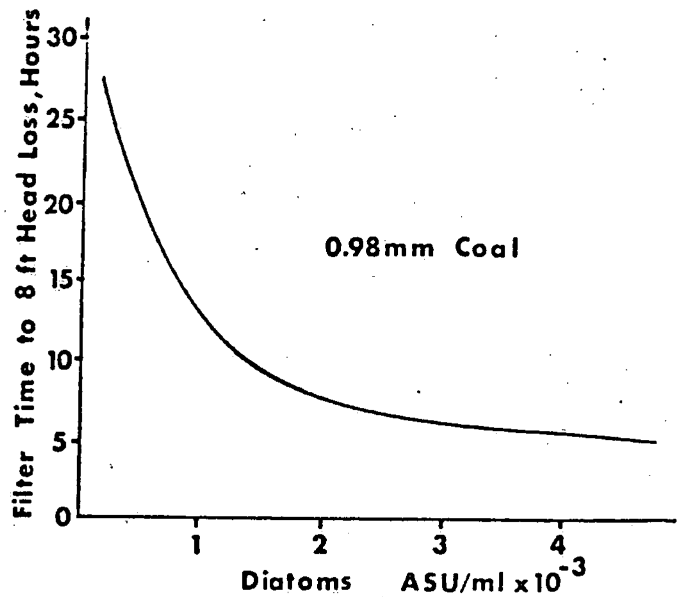
The diatom levels seem to reach their peak in early summer when water demand is also at its highest level. Filter runs as short as 1-3/4 hours have been recorded for diatom levels of 8,000-9,000 Areal Standard Units (ASU) per ml. In 1974, algae levels greater than 1,500 ASU per ml lasted for almost a month and reached a peak of 9,000 ASU per ml. Figure 1 shows the relationship between the level of diatoms and the length of filter runs for a plant filter containing coal with an effective size of 0.98 mm. This problem can be alleviated by using coarser coal in the filters. However, the course coal requires more frequent use of a filter aid polymer than the finer coal sizes, and a backwash rate of 20 Igpm/sq. ft. is required to ensure a good filter backwash.

Algae, particularly diatoms, can have a strong influence on the length of filter runs even at levels below 400 Asu/ml, especially if the filter is made up of fine coal. Table 2 shows the differences in filter runs at algae levels normally considered to be low.

Although algae certainly cause problems in the treatment of municipal water supplies in Ontario, further study is needed to assign a dollar value to these problems. A comparison was made between two plants which employ the same treatment process, but have different amounts of algae in their raw water. The Dunnville plant draws water from the eastern Lake Erie basin and has average algae levels in the 600-900 Asu/ml range. The Union Water Supply System takes its water from the highly eutrophic western Lake Erie basin where average algae levels are 3,000 to 4,000 Asu/ml. Treatment costs were considerably lower at the Dunnville plant and rose with rising algae levels. However, at the Union plant, algae levels declined and treatment costs increased. Obviously, there are many other factors involved besides algae levels in the determination of water treatment costs.

FIGURE 1

DIATOM CONCENTRATION
vs
FILTER TIME



Source: Hutchinson, W. R., Operational Variables and Limitations of Direct Filtration, Research Report No. W54, Ontario Ministry of the Environment, January 1975.

TABLE 2

EFFECT OF LOW ALGAE LEVELS ON FILTER PERFORMANCE

Run	Coal e.s. (mm)	Run Length to 8' H.L. (hrs.)	Headloss Distribution Coal (%)	Sand (%)	Algae Asu/ml
4	0.9	25.5	85	15	300
	1.05	37.5	56	44	300
	1.55	45.5	26	74	300
23	0.9	40	71	29	70
	1.05	43	40	60	70
	1.55	50	25	75	70

Filter Rate 4 Igpm/sq. ft.

Alum 6 ppm

Source: Hutchinson, W. R., Operational Variables and Limitations of Direct Filtration, Research Report No. W54, Ontario Ministry of the Environment, January 1975.

Table 3 contains some water treatment costs for selected Ontario water treatment plants. Water quality does not seem to be a major determinant of water treatment costs.

This may be due to the relatively good quality of Great Lakes Water. Algae levels greater than 100,000 Asu per ml have been experienced in the White River in Indiana [5]. If algae counts reached this level in the Great Lakes, they might be a major factor in water treatment costs.

TABLE 3

WATER TREATMENT COSTS FOR
SELECTED ONTARIO WATER TREATMENT PLANTS - 1977

LOCATION	WATER SOURCE	COST PER THOUSAND GALLONS (¢)
Dresden	Sydenham River	6.1
Lakeview (Peel)	Lake Ontario	10.5
Grand Bend	Lake Huron	8.5
Belleville	Bay of Quinte	16.1
Brantford	Grand River	21.0
Amherstburg	Detroit River	47.0

Source: Mr. Missingham, Ontario Ministry of the Environment.

IMPACT ON SHORE PROPERTY VALUES

One measurable result of eutrophication which reflects numerous intangibles is the effect that accumulations of algae on beaches (cladophora in particular) have on shore property values. Cladophora grows on a solid substrate in water up to about 10 feet deep. When it is mature, some of it detaches and is washed up on beaches and other shorelines.

These shoreline accumulations vary in depth from a few inches to three feet and from a narrow band at the water's edge to strips 50 or more feet wide. This happens during the months of July and August, the very time when Canadians want to use their beaches.

The algae which is out of the water dries up, but that which is in the water decomposes and turns black, giving off an odour so foul that it literally drives people away. The smell is offensive up to half a mile away, and many people have mistaken this rotting algae for sewage sludge.

A study done in connection with the Great Lakes Levels Board [6] found that algae has a definite effect on real estate values on the northeast shore of Lake Erie. The study area extended from Port Dover to Fort Erie, and lake frontage with algae accumulations was consistently lower in value than frontage without algae in each township. Shore properties fronted with mounds of stinking algae averaged 80 to 85% of the value of properties with clean shorelines. Other factors which affect property values were taken into account so that this difference of 15-20% was due specifically to the algae.

Another interesting finding of Ormerod's study [6] was that, in the Niagara area, certain cottage assessments make an allowance for algae. Reductions of this nature ranged from 8 to 15%.

An EPA study [7] approached this phenomenon from a different aspect, measuring the increase in property values which can be attributed to an improvement in water quality. The results showed that, where people perceived large water quality improvements, there were substantial impacts on property values. A multiple regression technique was used to separate the effects of water quality improvement from the other determinants of property values.

As would be expected, visual pollutants such as floating debris, scum, bottom sludge, and algae were very important in determining people's perception of water quality.

Most of the symptoms of eutrophication are things which can be seen and smelled and, therefore, are readily perceived by water users. Because of this, eutrophication has a more immediate effect on shore property vlaues than obscure water quality problems such as toxic substances.

The EPA study referred to above [7] concluded that a substantial water quality improvement in a badly polluted water body will increase the value of nearby (up to 4,000 feet from the shore) urban residential property. The study measured pollution abatement benefits of from 3% to 25% for single family waterfront residences. Benefits declined as distance from the water increased, but they were measurable for properties up to 4,000 feet inland. Findings also showed that rural land suitable for development near a large body of water is also increased in value by pollution abatement. This study observed increases attributable to pollution abatement of from 65 to 100% for waterfront land on the Willamette River near Portland, Oregon.

The Ontario Water Resources Commission (OWRC) (now Ontario Ministry of the Environment) published annual reports on the distribution of cladophora growths and beach accumulations in the 1960's [8]. The pattern of shoreline accumulations varied somewhat due to predominant winds, but they were usually found in sandy bays, the places which are used most by tourists and private cottage owners.

Although the western basin of Lake Erie is the most eutrophic area of the Great Lakes, cladophora does not grow there due to lack of a suitable substrate. The part of Lake Erie which experiences algae problems is the eastern section, from Port Maitland to Fort Erie.

The OWRC reported cladophora accumulations on one-third of the 95 miles of shoreline between Toronto and Presquille Point with heaviest accumulations at Presquille Point, Cobourg, Port Hope, Oshawa, and Frenchman's Bay. The entire shoreline from Toronto to Burlington and from Van Wagner's Beach in Hamilton to Jordan Harbour was also affected.

In Lake Huron, algae fouled beaches at Goderich, Port Elgin, Southampton, and in the Thornbury-Meaford vicinity of Georgian Bay.

The total value of shore properties in the above-mentioned areas is $425 million [9]. This value is quite likely an underestimate because:

a) the information was collected in 1973 (five years ago) and, even at that time, many of the values were assessed rather than market values; and

b) since the odour of rotting cladophora can be unbearable at distances of up to half a mile, certainly more than just the waterfront properties will be affected.

Nevertheless, $425 million is still quite a substantial figure, representing quite a lot of property taxes. A 15 or 20% decline in this value due to the presence of algae, or a corresponding increase due to its disappearance, would constitute a sizeable sum of money, 65 to 85 million dollars.

IMPACT ON FISHERIES

Lake Erie possesses the most valuable fishery in the Great Lakes. The commercial fishing industry harvests 50 million pounds of fish annually from Lake Erie (one-third of the total Great Lakes harvest), and 30 million pounds of this catch is harvested by Ontario fishermen [10].

The Lake Erie commercial fishery employs 600 fishermen and has a fleet of 146 vessels, the largest freshwater commercial fishing fleet in the world. Total investment in boats, gear, and shore installations exceeds $8 million. Total annual dockside value of the Ontario harvest is $5.5 million [11]. Unfortunately, such information does not exist on the sports fishery in Ontario.

Since the Great Lakes basin became settled by people, some species of fish have disappeared completely and others have appeared and multiplied explosively. Before the 1940's, most investigations of this phenomenon concluded that the great declines in such valuable species as the lake herring, lake whitefish, and lake trout were due mainly to overfishing. However, since then, greater and greater significance has been placed by fishery scientists on the influence of environmental changes related to pollution and eutrophication on the fishery resources of the lakes [12].

The species affected most by changes in Lake Erie were the cold water types (lake herring, lake trout, and lake whitefish). These fish were at the extreme southern end of their zoogeographical range in Lake

Erie to begin with. They require cold, adequately oxygenated bottom waters for a summer habitat and silt-free river or lake spawning areas for successful reproduction. Had they not been wiped out earlier by exploitation, they probably would have succumbed to eutrophication in Lake Erie. The warm water species (white bass, channel catfish, brown bullheads, gizzard shad, alewives, spottail shiners, emerald shiners, carp, and goldfish) have not declined greatly. First of all, they were not highly valued for human food, so they were not overfished. Secondly, the spawning habits of these species allow them to minimize or avoid the stresses of sedimentation and low oxygen levels that affect the cold water bottom spawners.

The ways in which eutrophication causes the decline and disappearance of oligotrophic fish are not well known, but the sequence in which eutrophication seems to adversely affect groups of fish in the Great Lakes is: 1) salmonines; 2) coregonines; and 3) percids. Although the mechanisms are not well understood, it seems that the order of decline of families and species within families is related to proximity to the southern extremity of their natural range.

Environmental deterioration is believed to have played a minor role in the decline of fish stocks in Lake Huron. The invasion of the sea lamprey is cited as the most important factor there [13].

In Lake Ontario, whose fish stocks are the most impoverished of the Great Lakes, overfishing was the primary disrupting factor [14].

All of these changes in Great Lakes fish populations resulted, in one way or another, from human settlement in the watershed. From the point of view of economic return to society, it has been a sequence of degenerative changes.

The present state of water quality in some areas of the Great Lakes and its continuing degradation poses the most serious threat to the success of any program aimed at restoring or improving the fishery resources of the Great Lakes. If water quality trends continue, the ultimate result would be sparcity of any fish in the deep water region (which constitutes most of the volume of the Great Lakes) and a succession of less and less desirable species in shallow areas [15].

IMPACT ON RECREATION

Recreation is the fastest growing use of water. In fact, swimming is the recreational activity with the highest participation rate in Ontario, 64.9% [16]. The Ontario recreation industry has been valued at $500 million and, certainly, water-oriented recreation constitutes a large proportion of this.

In the past, it was not necessary for water to be pleasing to users, only safe and not detrimental to their health. However, a recent Environment Canada study [17] found that 70% of the recreation participants at Saskatchewan lakes were attracted for aesthetic reasons.

The presence of algae and 'weeds' can significantly inhibit water-oriented recreation, and the reduction of such activities can result in significant primary and secondary costs to certain service industries. The appearance, smell, and taste of water largely determine people's perception of its quality. The symptoms of eutrophication can usually be seen and smelled, and they do affect recreational behaviour.

Results of the above-mentioned study [17] show that, for each activity, a certain amount of reduction in the recreation period was experienced by the user population due to water quality problems. In Saskatchewan, in 1971, swimming was reduced by one-third due to poor water quality conditions (mainly algae blooms). Fishing was reduced by 15% for the same reason, water skiing by 28%, and boating by 10%.

Another study of public attitudes and recreational behaviour in Green Bay, Wisconsin had similar results [18]. The location of use patterns of boating, fishing, and swimming were related to the quality and characteristics of Green Bay water.

Boating is a 'non-contact', water-based activity and, compared to fishing and swimming, is less demanding of water quality. This is exemplified by the popularity of Hamilton Harbour to sailors. Fishing is an 'indirect-contact' sport, requiring certain water qualities (oxygen, clarity, temperature), depending on the species fished. Swimming, a 'direct-contact' activity, is most demanding of high water quality.

As for the future, this quotation seems appropriate:

> "Deterrents such as crowding may become much more difficult problems than they are now. But they would be, in a sense, happier problems. When there is no available oxygen in the water, and consequently no fish, crowds of fishermen will not be a problem. When a secchi disc vanishes in 2 feet of water, or a foot vanishes into a foot of muck, crowds of swimmers will not be a problem. When gases are released from rotting algae and other debris on the surface, crowds of boaters will not be a problem." [18]

The manifestations of eutrophication have a negative impact on water-oriented recreation. This impact is greatest for direct contact water sports such as swimming, but it also affects fishing and boating, and the ability of an area to attract recreationists.

GENERAL BENEFITS OF ALGAE

Who would expect to find that major world processes depend upon inconspicuous creatures with names like nostoc and ulothrix? But, indeed they do. All living things (including humans) are now, and always have been, entirely dependent on the chloroplast and its ability to capture the energy of the sun and transform it into sugar and carbohydrates. Evolution began with algae, sometimes referred to as the aquatic grazing fields. Not too long ago, these simple green plants were considered to be mere biological curiosities. However, accelerated eutrophication in the Great Lakes has made algae a household work, and the interactions between people and algae have increased considerably.

The usual concept of the 'social status' of algae is that they are lowly, primitive plants, retarded and unrefined, but recent research in the field of phycology has uncovered several potential benefits of algae [19]. It is believed that algae could provide wonderful drugs against bacteria and viruses. They could also replace (very cheaply) complicated and expensive syntheses of organic substances and provide a type of 'green manure' which would enable cultivation of tropical or difficult soils. Algae also has a role to play in the world food crisis; it is a renewable resource which, up to now, has been very underutilized.

Maybe, rather than trying to starve all the algae to death (a goal which, if accomplished, would lead to our demise as well), we should try to find beneficial uses for it.

Even cladophora, notorious for its ability to render beaches and shorelines uninhabitable because of the odour of its decomposition products, does have positive attributes. Black ducks and mallards feed extensively on it and it serves as cover for small and young fish. Cladophora is actually a 'clean water' algae and will not grow where turbidity levels are high. It was present in the western basin of Lake Erie before the first white settlers, and it is one of the few survivors from that ecosystem of presettlement western Lake Erie.

Cladophora could be used for animal fodder. Studies [20] have shown that it is similar or a little better than prime quality alfalfa meal with respect to total protein. An estimated value of cladophora for this use would be $100 per ton.

Another use for cladophora is fertilizer and mulch for gardens. In a study done by Judd in 1972 [21], comparative observations were made on grass, corn, and beans grown in soil and sand at two levels of cladophora mixes (25% and 50%). It was concluded that the monocots (grass and corn) showed the greatest response, especially in sand, and the major benefits were moisture retention, soil aeration, and added fertility.

Edkert and LaLonde [22] have found biocidal products in cladophora; and another study [23] stated that it had a potential use as a fibre for paper making.

IMPACT ON POWER AND INDUSTRIAL USES

Excessive growths of algae and other aquatic plants can interfere with industrial and power uses of water by clogging intakes. Most industrial users have, however, engineered around this problem by building submerged intakes.

Thermal generating stations which formerly had surface intakes for cooling water have found it necessary to construct submerged intakes at costs in the millions of dollars. Ontario Hydro officials are quick to say that such expenses cannot be wholly attributed to eutrophication, but it certainly was a contributing factor.

Algae also affects hydro-electric generating stations by reducing head in the cleaning racks. The situation became so critical at the Saunders Generating Station in Cornwall that all 430 sets of trash racks had to be removed. This action seems to have solved the problem and now everything just goes right through.

However, ever since the dam was built at Cornwall in 1958, plants and dead fish have accumulated behind it. These accumulations are greatest during the period June to September and cause quite an odour problem. Approximately six truckloads per week are hauled away during the summer period, at an annual cost of $5,000 to $6,000 [24]. No large changes in the amount of plants and fish accumulating there have been observed over the last 20 years.

Algae and other plants do not present problems in the cooling water intake at the Saunders Generating Station [24]. At this writing, detailed responses from the rest of Ontario Hydro's generating stations have not been received. Officials in the Toronto office are checking into the matter, but they show symptoms of the 'no problem syndrome' so common in Ontario Ministry of the Environment staff. More time and effort is needed to establish the total cost of eutrophication borne by power plants.

SUGGESTIONS FOR FURTHER RESEARCH

This report constitutes what information could be gathered in the time allotted (two man-months), but it is by no means a thorough investigation of the subject. More work needs to be done to determine the thresholds where different water quality parameters have significant effects on different water uses. Other parameters besides algae should be investigated.

Primary research needs to be done on:

a) public perception of water quality in the Great Lakes;

b) the effects of these perceptions on recreational behaviour; and

c) the financial implications of changes in the pattern and extent of water-oriented recreation.

There seems to be a dearth of information on sport fishing in Ontario. Quantitative data needs to be generated on this form of recreation before the impact of water quality changes on fishing can be assessed. An interesting study would be the investigation of:

a) the awareness of toxic substances in fish among Great Lakes fishermen; and

b) the effect which this awareness has on participation in fishing.

CONCLUSIONS

Eutrophication is neither altogether good nor altogether bad. The various human uses of Great Lakes water have different thresholds of tolerance for the side-effects of eutrophication (excessive algae and aquatic plants). In the case of algae on shore properties, the threshold seems to be very low; quantitative reductions in property values occur with even slight amounts of algae present.

Water-oriented recreation also appears to have a relatively low threshold of tolerance for eutrophication because its manifestations are so obvious to the human senses. The appearance, smell, and taste of water largely determine people's perception of its quality and, when people perceive water to be of poor quality, their participation in water-oriented recreational activities is reduced. Such reductions are greatest for contact sports such as swimming and water skiing, less for fishing, and less again for boating.

Industrial and power users seem to have passed one threshold by the use of submerged intake pipes, but another threshold may be reached in the future.

Although MOE officials insist that, no matter how eutrophic the lakes become, the water can still be made potable, there must be a threshold here too, beyond which treatment is impractical, if not impossible. More research is needed to determine what this threshold might be, but the consequences of reaching it would certainly be disastrous. The

Great Lakes are a last resort for the 4.5 million Ontarians who drink from them. Traditionally, people have preferred to drink ground water, but found it necessary to utilize surface water sources when ground water supplies became inadequate. If the Great Lakes became undrinkable, there would be no other source large enough to replace them.

Another point is the fact that phosphorus moves through our ecosystem in an incomplete cycle. It moves easily from land to water, but there is no natural mechanism whereby it can be returned to the land again. Before the Great Lakes basin was settled and urbanized, there was not very much movement of nutrients from the terrestrial sphere to the aquatic sphere and the system was in equilibrium. Now, phosphate fertilizer is imported to replace what is lost to the lakes, but this cannot go on forever because the world supply of phosphorus is finite. Maybe part of the strategy of Great Lakes water management should be the recycling of phosphorus.

The primary socio-economic justification for the reduction of phosphorus loadings to the Great Lakes seems to lie in the beneficial impacts of improved water quality on the recreation industry, shore property values, and general aesthetic considerations.

REFERENCES

[1] Milway, C. P., Uppsala Symposium on Eutrophication in Large Lakes and Impoundments, Organization for Economic Cooperation and Development, May 1968.

[2] Lee, Fred G., Eutrophication, Occasional Paper No. 2, University of Wisconsin, Water Resources Center, September 1970.

[3] MacIver, Ian, Urban Water Supply Alternatives (Perception and Choice in the Grand Basin, Ontario), Research Paper No. 126, University of Chicago, Department of Geography, 1970.

[4] Hutchinson, W. R., Operational Variables and Limitations of Direct Filtration, Research Report No. W54, Ontario Ministry of the Environment, January 1975.

[5] Palmer, C. M., Algae in Water Supplies, Illustrated Manual on the Identification, Significance, and Control of Algae in Water Supplies, U.S. Department of Health, Education, and Welfare, Washington, D.C., Public Health Service Publication No. 657, 1962.

[6] Ormerod, G. K., The Relationship Between Real Estate Values, Algae, and Water Levels, Great Lakes Water Levels Study, Lake Erie Task Force, Department of Public Works, Canada, July 1970.

[7] Dornbursch, D. M. and S. M. Barrager, Benefit of Water Pollution Control on Property Values, U.S. Environmental Protection Agency, Washington, D.C., October 1973.

[8] Ontario Water Resources Commission, Reports on Cladophora Investigations in Ontario, 1958 to 1967, reprinted May 1973.

[9] Coastal Zone Atlas, Canada-Ontario Great Lakes Shore Damage Survey, 1975.

[10] Kendall, S., J. R. Paine, and W. F. Sinclair, Lake Erie Fisheries Management Plan, Southwestern Region, Ontario Ministry of Natural Resources, April 1977.

[11] Adams, G. and D. Kolenosky, Out of the Water: Ontario's Freshwater Fish Industry, Ontario Ministry of Natural Resources, Toronto, 1974.

[12] Hartman, W. L., "Lake Erie: Effects of Exploitation, Environmental Changes, and New Species on the Fishery Resources", Journal of the Fisheries Research Board of Canada, 29:899-912.

[13] Berst, A. H. and G. R. Spangler, "Lake Huron: Effects of Exploitation, Introductions, and Eutrophication on the Salmonid Community", Journal of the Fisheries Research Board of Canada, 29:877-887.

[14] Christie, W. J., "Lake Ontario: Effects of Exploitation, Introductions, and Eutrophication on the Salmonid Community", Journal of the Fisheries Research Board of Canada, 29:913-929.

[15] Smith, Stanford H., "The Future of Salmonid Communities in the Laurentian Great Lakes", Journal of the Fisheries Research Board of Canada, 29:951-957.

[16] Ontario Statistics 1976, Volume 1, Social Series, Ministry of Treasury, Economics and Intergovernmental Affairs, 1976.

[17] Parkes, J. G. M., Public Perceptions of Water Quality and Their Effect on Water-based Recreation, Social Science Series No. 8, Inland Waters Directorate, Water Planning and Management Branch, Ottawa, Canada, 1973.

[18] Ditton, R. and T. Goodale. Marine Recreational Uses of Green Bay: A Survey of Human Behaviour and Attitude Patterns, Technical Report #17, University of Wisconsin Sea Grant Program, December 1972.

[20] Neil, J. H., Cladophora in the Great Lakes, prepared for the standing committee on Eutrophication, Great Lakes Research Advisory Board, IJC, Limnos Ltd., Dec. 1974.

[21] Judd, J. H., Environmental Effects of Cladophora Glomerata in the Great Lakes, Unpublished Report, New York State Sea Grant Program, 1972.

[22] Eckert, D. J. and R. T. LaLonde, Cladophora Extracts: Effect on Mosquito Larvae, Unpublished Final Report to: N.Y. State Sea Grant Program, College of Environmental Science and Forestry, Oswego, 1974.

[23] Leopold, Bengt and Renata Marton, Papermaking Potential of Certain Marine Weeds, Unpublished Final Report to: N.Y. State Sea Grant Program, Empire State Paper Research Inst., SUNY College of Environmental Science and Forestry, Syracuse, N.Y., 1974.

[24] Personal Communication with John Keon, Saunders Generating Station, Cornwall, January 1978.