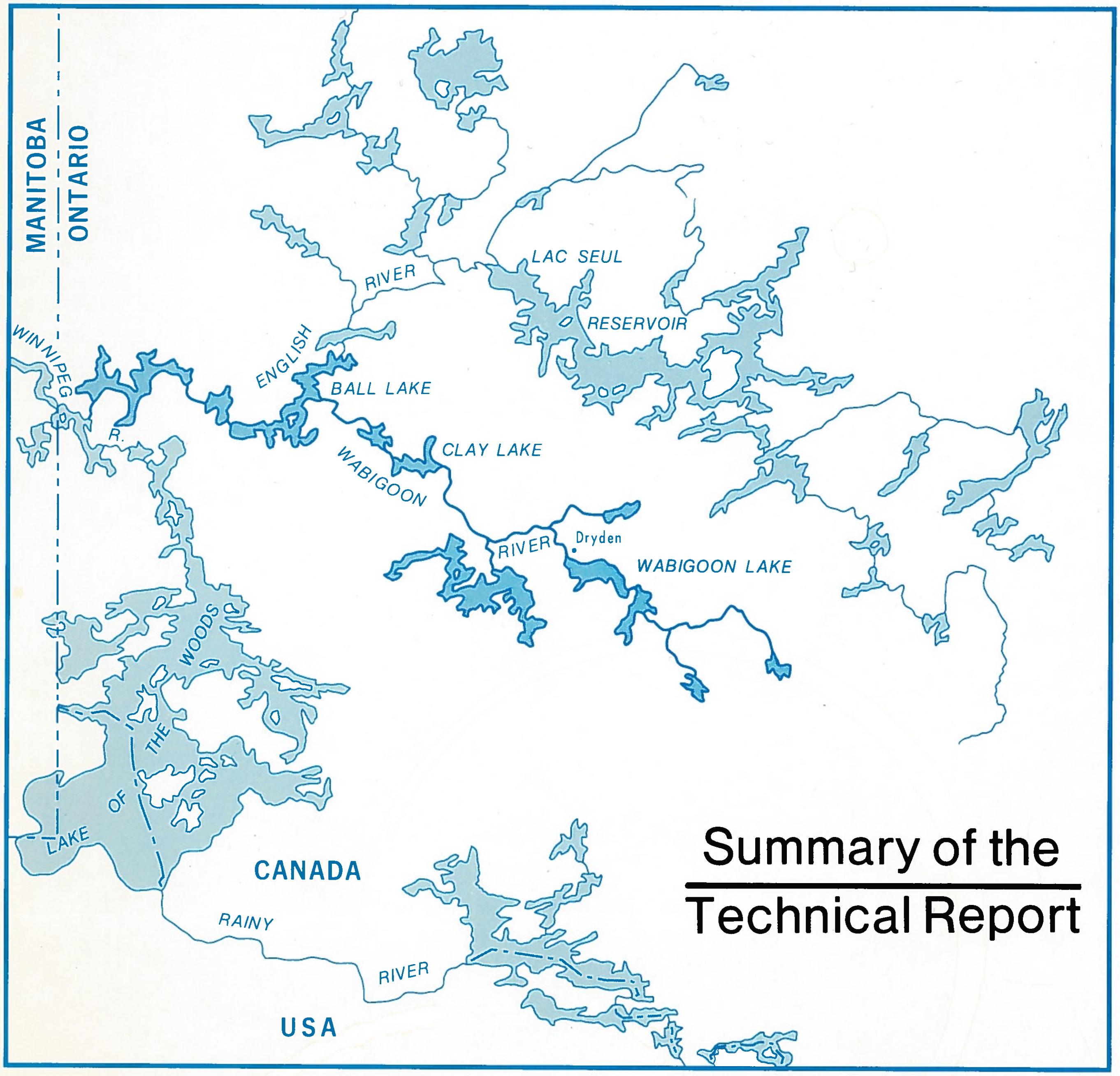
Mercury Pollution in the Wabigoon-English River System of Northwestern Ontario, and Possible Remedial Measures



Summary of the Technical Report

Government of Canada

Government of Ontario

MERCURY POLLUTION IN THE WABIGOON-ENGLISH RIVER SYSTEM OF NORTHWESTERN ONTARIO, AND POSSIBLE REMEDIAL MEASURES

SUMMARY OF THE TECHNICAL REPORT

Prepared by

The Canada-Ontario Steering Committee

1983

From: The Wabigoon-English River Mercury Study Steering Committee

To: The Honourable Charles Caccia, P.C.,M.P.
Minister of the Environment
Ottawa

The Honourable Andrew S. Brandt, M.P.P.
Ontario Minister of the Environment
Toronto

The Honourable Alan W. Pope, M.P.P.
Ontario Minister of Natural Resources
Toronto

Gentlemen:

The Steering Committee of the Canada-Ontario Wabigoon-English River Mercury Study is pleased to submit, herewith, its final report on Mercury Pollution in the Wabigoon-English River System of Northwestern Ontario, and Possible Remedial Measures. The report consists of two volumes. Volume 1 is a Summary which highlights the Problem, the Conclusions of the research and monitoring studies and the Recommendations agreed to by the Steering Committee. Volume 2 is the complete Technical Report and includes all of the details of the individual studies carried out under the Canada-Ontario Agreement Respecting Mercury Pollution in the Wabigoon-English River System.

Respectfully submitted, February 1984.

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ACKNOWLEDGEMENTS

The Steering Committee wishes to acknowledge the assistance of two individuals who have played a major role in this study but whose names are not to be found in either the Summary or Technical Report.

The first is Dr. A.L. Hamilton, presently with the International Joint Commission in Ottawa, who played an important role in initiating government interest in the mercury pollution issue in the Wabigoon River. He has followed the study to its completion, has provided the Steering Committee with critiques of the Technical Report, and has helped to resolve differences of interpretation between the scientific teams.

The second is Mr. W.A. Creighton who has played an important role in managing the provincial part of the study. Mr. Creighton has been an active participant at all Steering Committee Meetings and the final Technical Report has benefitted from his input.

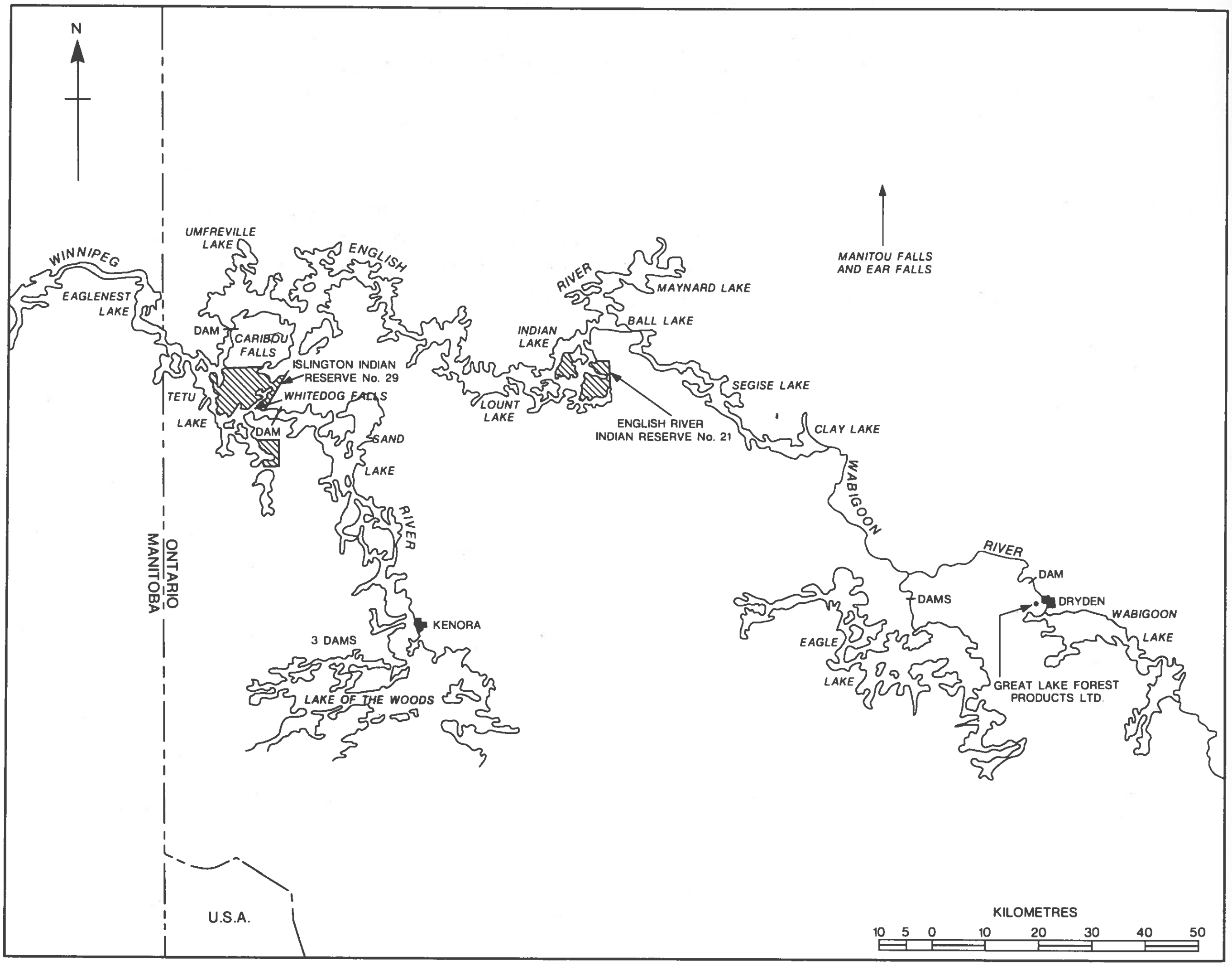

FIGURE 1: LOCATION MAP, ENGLISH - WABIGOON LAKE SYSTEM

INTRODUCTION

The Wabigoon-English River system in northwestern Ontario and eastern Manitoba is one of the more severely mercury polluted waterways of the world (Armstrong and Hamilton 1973). The Ojibway communities of Grassy Narrows and White Dog are located on the banks of the English River downstream from Ball Lake and at the confluence of the English and Winnipeg Rivers respectively. The people of these Bands used to fish the waters of the river-lake system for commercial purposes but also to supplement their own food supply. They were also employed as guides to sport fishermen, mainly from the United States. The economy of the region depends heavily on the pulp and paper industry and tourism, mainly related to wilderness sport fishing, and thus a conflict has arisen in water resource use. This report is primarily concerned with the mercury pollution in the river system and its associated lakes, and with the evaluation of methods which might be employed to accelerate natural recovery of the system. A brief description follows of the river-lake system, a historical sketch of the pollution problem, and the consequences to the native communities.

In northwestern Ontario (Fig. 1), the Wabigoon River leaves Wabigoon Lake and flows through the town of Dryden. The river widens about 53 miles further downstream to form Clay Lake, later entering Ball Lake where it joins the English River. In turn, the English River flows through a chain of lakes and finally merges with the Winnipeg River which empties into the south basin of Lake Winnipeg, more than 160 kilometres west of Dryden. This vast river-lake system stretches across a sparsely populated land of boreal forest, low relief, and Precambrian granitic and greenstone belts overlain by patches of clay and sandy till.

The principal source of pollution in the river-lake system is a paper mill complex presently operated by the Dryden Mill Division of the Great Lakes Forest Products Company (formerly owned by Reed Ltd.). The paper mill has been discharging organic wastes into the Wabigoon River since its construction in 1913 (German, 1969). Consequently, some sections of the riverbed between Dryden and the village of Quibell, near the inflow to Clay Lake, are covered with putrefying wood fragments. Floating masses of foam together with heavy loads of suspended debris were common but current conditions in the river are greatly improved as a result of primary and secondary treatment of mill wastes. Effluent from the Dryden municipal sewage treatment plant is also released into the river after primary and secondary treatment.

The mercury pollution was derived mostly from the effluents of a chlor-alkali plant (Armstrong and Hamilton, 1973; Fimreite and Reynolds, 1972; Troyer, 1977) which operated from 1963 to 1975. From 1963 to 1970, unrestricted quantities of mercury, approximately 9-11 metric tonnes in total, were released into the river. In 1970 when the Ontario Water Resources Commission became aware of the problem, action was taken which reduced the mercury discharge by about 99 per cent. In 1975, the chlor-alkali plant was converted to a process which does not use mercury; however, effluent from the mill complex still contains small and variable concentrations of mercury (5-10 kg per year). Primary treatment of mill wastes installed in September 1980 was not very effective in reducing residual traces of mercury in mill effluent (approximately 20% removal). Secondary treatment which was started in 1983 may effect some further removal of mercury.

Armstrong and Hamilton (1973), Parks (1976), and Jackson (1979) determined the distribution of mercury in the sediments and biota in the system. The mercury pollution has caused high mercury concentrations in fish throughout the river-lake system from Dryden at least as far downstream as the Manitoba border. The mercury concentrations were well over 0.5 parts per million (ppm) (Kenney, 1971; Scott and Armstrong, 1972; Armstrong and Hamilton, 1973; Fimreite and Reynolds, 1973; Annett et al., 1975; Bishop and Neary, 1976), the limit set by the Canada Food and Drug Directorate for edible fish marketed in Canada. Mean mercury levels in pike were consistently greater than 2.0 ppm, all the way from Clay Lake (the first lake downstream from Dryden) to Tetu Lake at the confluence of the English and Winnipeg Rivers. Mercury concentrations in pike in local lakes which are not part of the Wabigoon-English system range from less than 0.5 to 2.0 ppm (Bishop and Neary, 1976). Other aquatic organisms such as crayfish have also been affected (Armstrong and Hamilton, 1973; Vermeer et al., 1973; Annett et al., 1975). Shortly after mercury discharges were reduced, mercury concentrations in biota declined rapidly (Armstrong and Scott, 1979), but the rate of decrease subsequently slowed and mercury concentrations in fish still remain well above recommended levels for unrestricted human consumption.

Commercial fishing was banned in 1971; however, sport fishing continued to be permitted. The Ontario Government provided information and recommendations to the public on mercury concentrations in fish and on restricted consumption of contaminated fish, (Guide to Eating Ontario Sport Fish-Northern Ontario, which is updated annually by the Ministry of Environment and Ministry of Natural Resources).

Mercury pollution has had serious direct and indirect effects on native populations in the region, especially the Ojibways of the Grassy Narrows and White Dog bands. Ojibways employed as guides by owners of fishing lodges catering to sportsmen were exposed to more mercury and possible chronic mercury poisoning owing to their practice of frequently joining their customers in the consumption of shore lunches of freshly-caught fish.

Ever since the potential danger from mercury poisoning became apparent, the Band members have been urged to stop eating the contaminated fish and the Ontario Government has been providing the communities with uncontaminated frozen fish.

Medical surveys conducted between 1971 and 1978 (Health and Welfare Canada, 1973; Clarkson, 1976; Wheatley, 1979) have shown some individuals in both-bands had blood mercury levels exceeding 100 parts per billion (ppb), even in winter when blood levels should be lowest owing to reduced consumption of fish. At blood levels above 100 ppb, a human adult is considered to be at risk (Wheatley et al., 1979). The higher levels were in the range of 100-500 ppb. The maximum value recorded was 600 ppb.

Symptoms of methyl mercury poisoning (or Minamata disease) may be detected first in the most sensitive 5% of adults whose blood levels are in the range 200-500 ppb. Unborn children, however, are more sensitive than adults (Wheatley, 1979; Wheatley et al., 1979). Out of the 40 at risk individuals in Northwestern Ontario who submitted to clinical examination, none was found to have unequivocal symptoms of mercury poisoning as of December 31, 1978, although 10 of them had neurological abnormalities which were possibly attributable to it. Uncertainty regarding cause arises from the fact that symptoms of mild forms of Minamata disease are similar to those of various other conditions, thus making conclusive diagnosis difficult (Wheatley, 1979; Wheatley et al., 1979).

Although the scientific community had produced considerable information about mercury pollution of the Wabigoon-English system, it was not possible to accurately estimate the system's rate of recovery. Therefore, concern about the mercury problem and its continuing effect on commercial fishing, angling and tourism on the Wabigoon and English Rivers led to an Agreement between the Federal and Ontario Governments for joint funding under the Canada Water Act to undertake a $300,000 study to develop a better understanding of the problem. Sources, pathways and fate of total and methylmercury were determined. A better understanding of the mechanisms by which mercury enters fish was expected to lead to the development of remedial measures to reduce mercury contamination and speed the recovery of the river-lake system. The specific objectives of the Agreement were as follows. *"To carry out shared-cost and other projects to evaluate and determine the effectiveness of various mercury amelioration measures in the Wabigoon-English River System, and to include:*

(1) a review of all data on sediment, water and biota mercury levels to determine the adequacy of existing information; and, depending on the findings thereof, a survey of pathways, transport, rates of accumulation and distribution of mercury in the Wabigoon-English River System; and

(2) a review of all available information to determine the factors affecting the availability of mercury for uptake by biota, and, depending on the results thereof, experiments to measure the effectiveness of alternative ways of reducing the availability of mercury in the Wabigoon-English River System."

CONCLUSIONS

The following major conclusions have, to a large extent, been extracted from the comprehensive Technical Reports. Conclusions of a more general nature are in bold print and are followed by more specific conclusions relevant to them.

The specific conclusions documented have been developed by an analysis of data from the river-lake systems, limnocorral enclosures and laboratory research.

I. **The Wabigoon-English River system is gradually improving but, in the absence of intervention, mercury levels in fish are expected to remain unacceptably high for many years. The degree of improvement of mercury levels in fish which would result from remedial action could not be determined from the study results, but the nature of the improvement would be to accelerate the rate of recovery, compared to the natural changes occurring in the system. Mercury levels in biota decline less dramatically with distance downstream from Dryden than do mercury concentrations in sediments. This appears to be related to an increased bioavailability of mercury with increasing distance downstream from Dryden.**

i) Most biota in the system show that there has been a rapid and significant drop in mercury concentration between the early seventies and eighties (Figs. 2, 3 and 4). In the ten years since mercury effluents were treated and controlled, the system has shown a more rapid return toward natural conditions than was envisaged in the middle seventies.

ii) There has been a decrease in mercury concentrations in crayfish since 1970 but most of this decrease took place from 1970 to 1973 and concentrations are now declining at a slower rate (Fig. 2).

iii) Mercury concentrations in adult pike (Fig. 3) and walleye (Fig. 4) have decreased since the middle seventies and these declines are expected to continue, but at reduced rates.

iv) It is anticipated that when the oldest fish, with the highest mercury concentrations, die within the next few years, the calculated mean mercury levels of the walleye population will drop further and become more representative of the present mercury pollution status of the system. There is a lag between the pollution status in terms of surface sediment mercury concentrations and the mercury concentration in the oldest fish which may have accumulated their mercury several years ago.

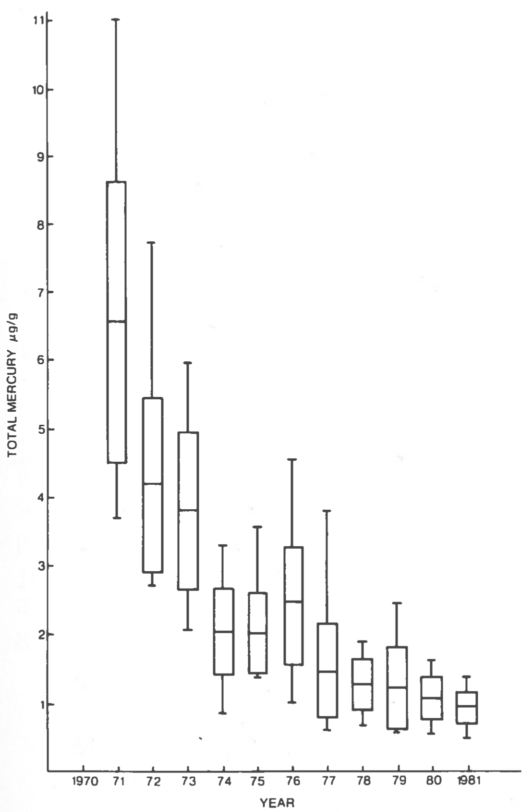

FIGURE 2 MEAN, STANDARD DEVIATION AND RANGE OF MERCURY CONCENTRATIONS IN ABDOMINAL MUSCLE OF CRAYFISH OVER 65 mm IN TOTAL LENGTH, CLAY LAKE 1970-1981 (G.P. McRAE, FRESHWATER INST. WPG.)

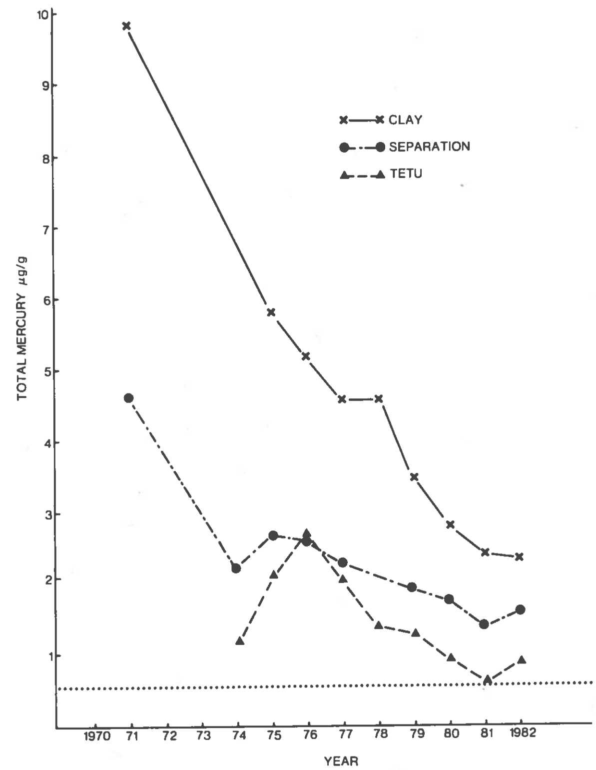

FIGURE 3 MERCURY CONCENTRATIONS IN 60 cm NORTHERN PIKE FROM THREE LAKES IN THE WABIGOON/ENGLISH/WINNIPEG RIVER SYSTEM, 1971-1982 (AFTER BISHOP AND NEARY, 1976). DOTTED LINE REPRESENTS MEAN OF FOUR ON SYSTEM CONTROL SITES.

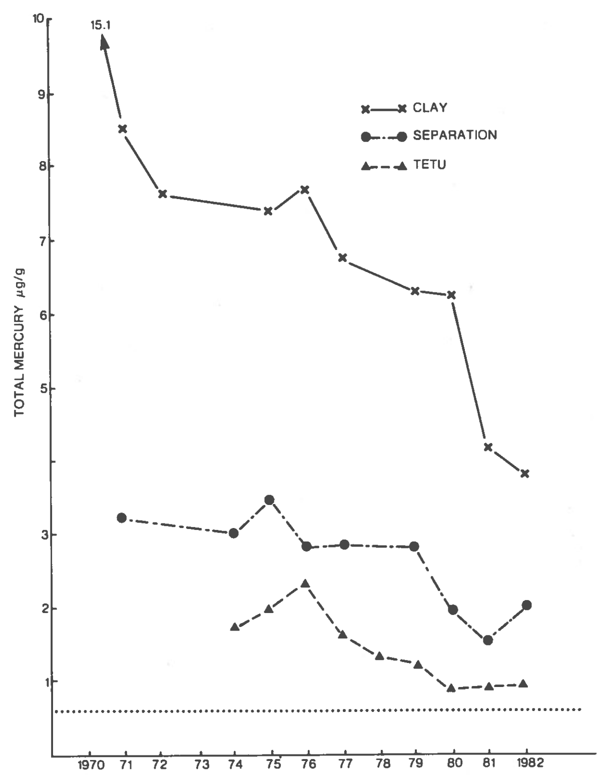

FIGURE 4 MERCURY CONCENTRATIONS IN 50 cm WALLEYE FROM THREE LAKES ON THE WABIGOON/ENGLISH/WINNIPEG RIVER SYSTEM 1970-1982. DOTTED LINE REPRESENTS MEAN FOR FOUR CONTROL LAKES.

v) In the last two years, sufficient declines in mercury levels in the three key sport fish species - northern pike (Fig. 3), walleye (Fig. 4) and whitefish have permitted the publication of less restrictive consumption advisories. Improvements, in terms of species and sizes of fish suitable for limited or unrestricted consumption are the greatest in Tetu Lake in the western portion of the basin. In fact, in comparison to fish data from other waterbodies in nearby areas unaffected by the industrial discharges, mercury concentrations in Tetu Lake fish appear to be approaching background levels. Moving closer to Dryden through Separation and Ball Lakes, consumption advice becomes very restrictive, but again, the trend toward improving conditions can be observed.

vi) Mercury concentrations in fish in Clay Lake, the downstream lake closest to Dryden, are so high that most sport fish are unacceptable for human consumption. However, even in this waterbody, mercury levels in fish have declined (Figs. 3 & 4).

vii) Mercury methylation in the system is driven mainly by microbiological processes.

viii) For the first time mercury methylation has been documented in the water column and in fish intestines. In the fish, this is proportional to intestinal mucus content. Thus, there are two sources of methylmercury in addition to the previously known source from bottom sediments.

ix) Mercury concentrations in biota are related to total mercury (mercury in all forms) concentration and methylmercury (mercury combined with the organic methyl group and regarded as the most toxic form) concentrations in the water column.

II. Measures to increase the water column load of clean lake-derived sediments would accelerate the rate of sedimentation and in turn would lead to decreased mercury concentrations at the sediment-water interface. In addition to reductions in the release of mercury from bottom sediments, the increased suspended sediment load in the water column would reduce the bioavailability of mercury in the water column. Both can be brought about by dredging and resuspending uncontaminated, clay-rich lake sediments.

i) In enclosures, clay sediments reduced mercury in biota by ten times (Fig. 5) compared to two times for selenium and not at all when primary productivity was increased. Resuspended clay-rich lake sediment in enclosures bound mercury much better than the clay from river banks. This may be related to organics (probably "dissolved" organic matter of less than 0.45 μ size) and iron and manganese oxide coatings in the sediments. Mercury remains in the water column because it is associated with particles of small size, but this mercury is not bioaccumulated.

ii) Particulate mercury in the water column was over 98% unextractable by a series of mild reagents and may not be readily "bioavailable".

iii) Mercury in silt was more readily solubilized, and probably more methylated, than mercury in wood chip sediments which are more prevalent close to the industrial complex at Dryden.

iv) Increasing suspended sediment up to 18 mg/L in enclosure experiments did not decrease primary production or fish growth.

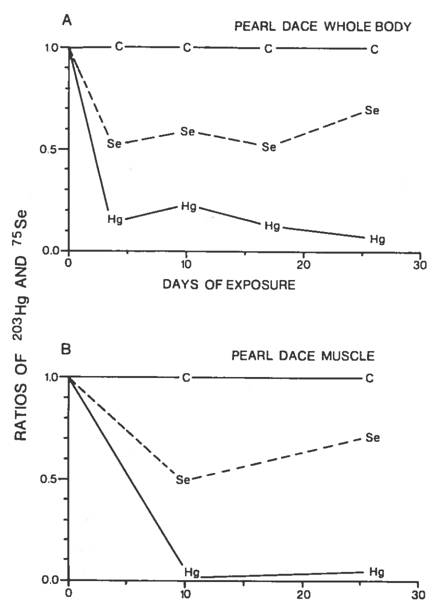

FIGURE 5 INHIBITION OF 203-MERCURY (Hg) AND 75-SELENIUM (Se) BIOACCUMULATION IN PEARL DACE WHOLE BODY (UPPER PANEL) AND MUSCLE SAMPLES (LOWER PANEL) BY ADDITION OF INORGANIC RICH SEDIMENT TO AN ENCLOSURE. THE DATA ARE EXPRESSED AS RATIOS OF ^{203}Hg AND ^{75}Se ACTIVITIES IN THE SUSPENDED SEDIMENT ENCLOSURE DIVIDED BY ACTIVITIES IN THE COMBINED CONTROL ENCLOSURES (C)

III. Sources of mercury in bottom sediments in any specific lake or river bottom area contribute to the mercury problem at any one location in the short term (months) but in the longer term (years) the upstream sources are of continuing importance. The part of the system downstream from Dryden to the inlet of Ball Lake remains very contaminated by any world standard. However, from the outlet of Ball Lake to the Manitoba border the problem is less severe.

i) Present mill discharges do not appear to be an important source of mercury with respect to Clay Lake and downstream.

ii) Dissolved methylmercury concentrations, and total methylmercury loadings increased downstream in the Wabigoon River from Dryden to Clay Lake.

iii) Between Dryden and the Eagle River confluence, particulate mercury and methylmercury, total soluble mercury and total mercury concentrations in the water were all greatest during the spring flood due to resuspension of contaminated bottom sediments and their downstream transport.

iv) Between Dryden and Clay Lake, the soluble methylmercury concentration was low during the spring but high during the summer.

v) Water mercury concentrations are influenced more by surface than by deep bottom sediments.

IV. The concentration of mercury and its chemical and physical forms in the water column are affected by several variables especially temperature, oxygen, suspended sediment concentrations, and microbial activity. At any given site the partitioning of mercury among surface sediments, water and suspended solids characteristically stabilizes within days; however, there likely are losses from the water surface to the atmosphere which were not measured during the investigations. In this contaminated system the most important source affecting mercury in the water column is the mercury concentration in the surface sediment. The form of mercury influences its bioavailability.

i) Sediments are now the main source of mercury to the water at least from Dryden to below Ball Lake.

ii) Temperature affects mercury concentration in the water at a given time and place (Fig. 6).

iii) The water reaches a maximum mercury concentration for a given temperature within a few days. Mercury release from sediments likely continues as the result of microbial activity but the concentration in the water does not change; thus it appears that mercury is being lost to the atmosphere.

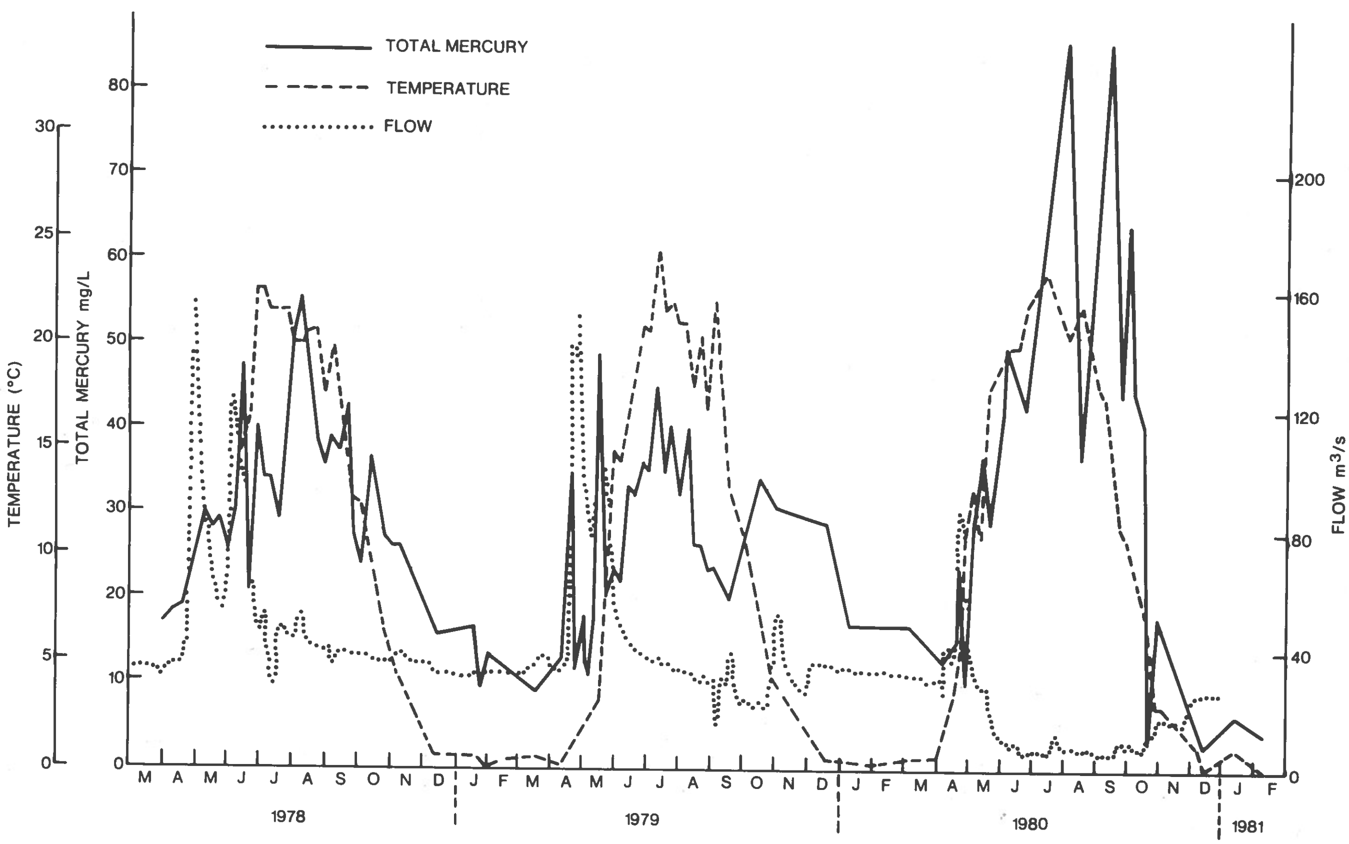

FIGURE 6 TOTAL MERCURY AND TEMPERATURE DATA, INFLOW TO CLAY LAKE. FLOW AT QUIBELL. MARCH 1978 TO FEBRUARY 1981

iv) In summer, when water temperatures were elevated and during the absence of resuspended particulates, dissolved methylmercury was related to total dissolved mercury in the water. In the spring when sediments were resuspended, dissolved and suspended methylmercury did not relate to total mercury concentrations.

v) The ratio of methyl to total mercury concentration in surface sediments increases with increasing distance from Dryden. The ratio of methyl to total mercury in water also increases down the system but the average concentrations of methyl and total mercury generally decrease. The one exception is the increase in methylmercury concentration across Clay Lake.

vi) Methylmercury concentrations in the water are a varying function of total mercury concentrations, with the ratio of one to the other changing down the system (Fig. 7).

vii) Methylmercury and mercury were bound to sediment in different ways. Methylmercury was associated with sulphur and with iron oxides. Mercury was associated with humid-iron material and with easily-extractable iron and manganese.

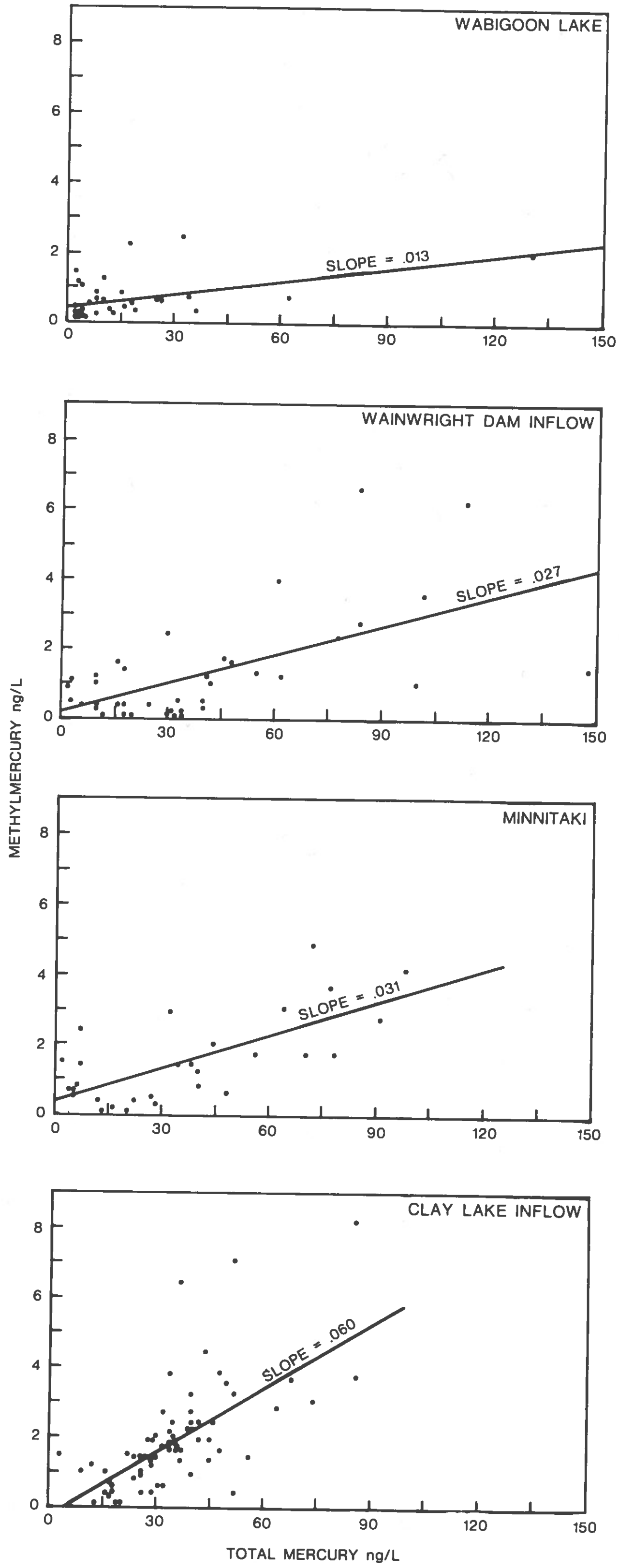

FIGURE 7: RELATIONSHIP BETWEEN METHYLMERCURY AND TOTAL MERCURY FOR NON-HIGH FLOW PERIODS, WABIGOON LAKE - CLAY LAKE, 1978 - 1980.

V. A number of other amelioration procedures were explored as part of this study. Selenium was investigated as a possible agent for mercury amelioration. Literature reports indicate that mercury is less toxic to the consumers of fish if it is associated with selenium. The experiments were designed to see whether or not selenium would be taken up by the fish along with the mercury. While selenium supplementation seems to be effective, more research is required before its use could be seriously considered. Other techniques found to be less suitable included: addition of sulphate which was intended to immobilize mercury in sediments as insoluble mercuric sulphide; and addition of algal nutrients which was intended to enhance fish growth thereby reducing the mercury concentrations of fish by dilution. Ploughing of surface sediments to reduce mercury concentrations was not attempted because of expected technical difficulties.

i) The mercury to selenium ratio in fish is high, due to high mercury concentrations, but also due to abnormally low selenium concentrations in this system.

ii) A 100 ppb concentration of selenium in water reduced mercury uptake in fish by 50% (Fig. 8). This effect is transmitted via the food web rather than by the water.

iii) Mercury reduction in sport fish could be expected from increased selenium concentrations in water. Some reduction can occur even at selenium concentrations as low as 1 ppb (Fig. 8).

iv) Toxicity tests as a literature review indicate a low safe concentration for selenium. The Canadian drinking water guideline is 10 ppb.

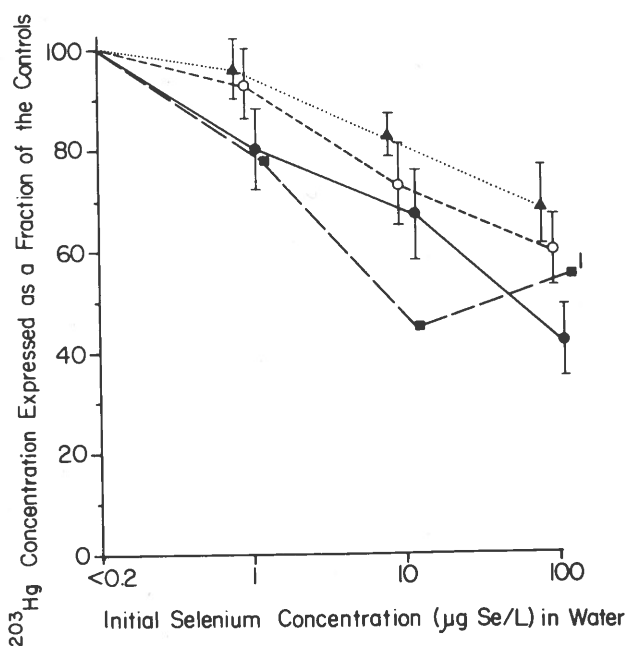

FIGURE 8

MERCURY-203 ACCUMULATION IN WHOLE BODIES OF ADULT CRAYFISH (O), ADULT PEARL DACE (▲), YOUNG-OF-THE-YEAR YELLOW PERCH (●), AND JUVENILE WHITE SUCKER (■) IN THE Se ENCLOSURES. DATA ARE EXPRESSED AS RATIOS IN WHICH ^{203}Hg ACTIVITIES IN Se-EXPOSED ANIMALS ARE DIVIDED BY THE MEAN ACTIVITIES OF THE COMBINED CONTROLS. MEANS (±SE). OF THE SEVERAL SAMPLING PERIODS (CRAYFISH: 4, DACE: 6, PERCH: 4, AND SUCKER: 1) ARE PRESENTED FOR EACH ORGANISM. ONLY ONE SUCKER WAS RETRIEVED FROM THE 100 µg Se/L ENCLOSURE (SUPERSCRIPT 1).

RECOMMENDATIONS

The recommendations which follow are listed in order of priority for action. They have been limited to those which can be arrived at on the basis of the conclusions described previously. These, in turn, are supported by the Technical Report which contains many other important conclusions. Our recommendations are limited to those remedial actions judged to be technically feasible in bringing about some amelioration of the mercury pollution status of the river. We expect that they would result in a more rapid recovery of the system, but the degree of expected improvement of mercury levels in fish could not be determined quantitatively.

Clearly, although the pollution is the disease, the symptoms are primarily the impact on the Native populations, local fishermen, sport fishermen and fishing lodge owners.

We are aware that the use of funds for amelioration may not, in the larger context, be the most worthwhile response to the problem. In particular, there is clear evidence that the system continues to exhibit natural recovery.

The recommendations of the Committee are:

I. THAT THE MERCURY MONITORING AND THE FISH CONSUMPTION GUIDELINE PROGRAM BE CONTINUED

Annual sampling and testing of fish from the four routinely tested waters (Clay, Ball, Separation and Tetu Lakes) should be continued. Testing of sport fish in all other previously tested "on-system" and "off-system" lakes in the Wabigoon-English system should be undertaken in the next two years to update all previous consumption advisories and evaluate mercury trends in other parts of the system.

II. A PILOT PROJECT FOR SEMI-CONTINUOUS RESUSPENSION OF NON-MERCURY CONTAMINATED SEDIMENT INTO THE SYSTEM AT CRITICAL POINTS BE CONDUCTED AND ASSESSED

On the basis of the conclusions, the resuspension of lake-derived sediments represents a promising technique for the rehabilitation of the Wabigoon-English River System. However, there are a number of factors which may affect the successful implementation of this technique in a complicated lake/river system like the Wabigoon-English.

A pilot project to semi-continuously resuspend sediments could be conducted using:

(a) Deep sediments from Wabigoon Lake injected into the Wabigoon River;

(b) Deep sediments from eastern Clay Lake injected into western Clay Lake and downstream;

(c) Deep sediment from the north basin of Ball Lake injected into the English River system.

Given these three site choices, we propose that option (b) has the greatest potential for environmental response in terms of monitoring changes in mercury concentration in fish and thus proving the technique to be successful. Resuspension would be effective in the short term by reducing bioavailability of mercury in the water column and in the long term by reducing the concentrations of mercury in surficial sediments.

If successful at site (b), we would recommend that additional sediment resuspension operations be implemented in the future at site (c) and then at site (a) above.

We wish to emphasize that the non-mercury polluted sediments which are resuspended must come from the river or lake bed and cannot be bank sediments, which have been shown to be ineffective.

It is assumed that sufficient sediment would be resuspended to reduce bioavailability of mercury in the water column and effectively reduce the surficial bottom sediment mercury concentrations.

The pilot project would be necessary both to assess the technical feasibility of the method and to provide cost estimates of applying the technique.

III. THE SEDIMENT BETWEEN DRYDEN AND CLAY LAKE BE REMOVED BY DREDGING

Sediments in the Wabigoon River, between Wabigoon Lake and Clay Lake, contain substantial quantities of mercury and will continue to be a major source of mercury in the river system.

Mercury concentrations in the water column are related to the mercury concentrations in the bottom sediments at each particular stretch of the river. Thus, upstream, contaminated sediment must be removed first in any dredging and off-river disposal plan. Thus, dreding should start at Dryden and proceed to Clay Lake. Burial of sediments in this stretch of the river is not feasible in the long term because the new sediment would be eroded and the original contaminated sediments re-exposed. Dredging operations downstream of Clay Lake are not considered to be worthwhile.

The cost of removing contaminated sediment between Dryden and Clay Lake as outlined above and confining the contaminated sediment in suitable on-land disposal areas constructed at sites near the Wabigoon River has been estimated at $19 million (1981 dollars). Some refinement of these cost estimates for dredging and confinement of contaminated sediments could be obtained by undertaking field surveys to provide better engineering design data (for example, sonar surveys, to assess river bed profiles and the number of logs in the river, soil conditions at disposal sites, etc.). These studies would have to be made prior to a final decision on the dredging option which would also be influenced by the results of the sediment resuspension project.

Although Wainwright reservoir was shown to be neither a source nor sink of mercury on an annual basis, it is a source of mercury in the spring runoff period and for effective downstream improvement, the mercury contaminated sediment in Wainwright reservoir should be completely dredged or partially dredged and a clean, deep sediment cover pumped over the remaining debris.

IV. ADDITIONAL SCIENTIFIC INVESTIGATIONS

As a result of the scientific studies which have occurred to date, two promising areas of scientific investigation were identified:

(a) Loss of Mercury to the Atmosphere

There is a distinct possibility, based on the temperature related, summer increase in mercury concentrations in river waters that mercury is being released at this time to the atmosphere. Research studies should be designed to quantify this pathway.

(b) Further Tests of the Effectiveness of Selenium on Mercury Pathways

Although, it was not as effective as suspended sediment, selenium was shown to reduce mercury uptake by biota. Selenium concentrations were also shown to be abnormally low in the system due to natural geological conditions. The necessary water concentration of selenium to have an effect on reducing mercury concentrations in biota is about 1 ppb. This concentration is well below drinking water standards and to raise the concentration to this level by adding selenite salts to the river would be by far the least costly amelioration procedure. Nevertheless, the toxicological effects on various biota in the limnocorrals and the literature review of selenium toxicity indicate that it would be unwise to pursue this amelioration technique without extensive further studies, especially whole lake experiments.

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