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LIMNOLOGICAL TRENDS in WOOD LAKE, B.C. (1971-1981) with SOME IMPLICATIONS for LAKE MANAGEMENT

C.B.J. Gray

and

S. Jasper

Inland Waters Directorate
Pacific and Yukon Region
Vancouver, B.C.

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C.B.J. Gray and S. Jasper
National Water Research Institute
Inland Waters Directorate
Pacific and Yukon Region
4160 Marine Drive
West Vancouver, B.C.

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ABSTRACT

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This report comments on the historical and present trophic condition of Wood Lake, B.C. and discusses several options for improving the water quality of the lake.

Based on a small-scale study by the National Water Research Institute, Pacific and Yukon Region, in 1980, the lake would be presently classified as mildly eutrophic. However, several indicators (water clarity, oxygen depletion rates, phytoplankton biomass and species succession) suggest that there has been a slight improvement over the last decade. A possible factor is higher nitrate levels in the spring since 1975. Future increases in nitrate levels, by intentional additions in the spring or early summer, may further improve the lake's condition. The use of mechanical aerators (with or without destratification), however, is not recommended because of their prohibitive cost and possible adverse ecological effects.

Suggestions are also given for future monitoring of Wood Lake in order to ascertain whether water quality conditions will continue to improve. This would involve measurements of nutrients, oxygen content, water clarity and the frequency and magnitude of blue-green algal blooms.

Résumé

Gray, C.B.J. et S. Jasper. 1982. Tendances limnologiques (1971-1981) dans le lac Wood, en Colombie-Britannique, et quelques répercussions pour la gestion lacustre. Rapport de la Direction générale des eaux intérieures, Vancouver, C.-B.

Dans le présent rapport, on commente les conditions trophiques historiques et actuelles au lac Wood, en Colombie-Britannique, et discute de plusieurs façons d'améliorer la qualité des eaux du lac.

Si l'on se base sur une étude modeste réalisée en 1980 par l'Institut national de recherches sur les eaux, de la région du Pacifique et du Yukon, le lac se classerait présentement comme étant légèrement eutrophique. Cependant, à l'examen de certains paramètres (clarité de l'eau, taux d'épuisement de l'oxygène, biomasse du phytoplancton et succession des espèces), il semble s'être produit une faible amélioration au cours de la dernière décennie, laquelle pourrait s'expliquer par une plus forte teneur en nitrates des eaux au printemps depuis 1975. Si l'on augmente par la suite la teneur en nitrates des eaux par des déversements intentionnels de cette substance, soit au printemps ou au début de l'été, on pourra possiblement améliorer d'avantage les conditions du lac. On déconseille toutefois l'utilisation des aérateurs mécaniques (avec ou sans déstratification) en raison de leur coût excessif et des incidences néfastes qu'ils pourraient avoir sur le milieu.

Le rapport renferme en outre des suggestions concernant la surveillance future du lac Wood afin d'établir si la qualité des eaux continuera à s'améliorer. Il s'agit notamment de mesurer la teneur de l'eau en substances nutritives, en oxygène, la clarté de l'eau ainsi que la fréquence et l'ampleur de la floraison de l'algue bleue.

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A. INTRODUCTION

In recent years there have been increased expressions of public concern about an apparent deterioration in the water quality of Wood Lake in the Okanagan Valley, B.C. In response to this situation, the Okanagan Basin Implementation Board (OBIB) established a small federal-provincial working group to evaluate in-lake restoration methods for improving water quality conditions. In reviewing previous investigations of the lake (Williams, 1973a, b; Water Investigations Branch, 1974; Nordin, 1980) it became apparent that fundamental data gaps and differences in interpretation existed and that further limnological research was needed before an assessment of restoration alternatives could proceed. To this end the Inland Waters Directorate, with the financial assistance of the OBIB, undertook a small study of the lake between April 1980 and March, 1981. The results of the study, carried out as part of the ongoing regional limnology program of the National Water Research Institute, are reported elsewhere (Jasper and Gray, 1982). The present report summarizes the limnological trends in Wood Lake over the last decade and comments on future restoration options. The conclusions were first presented to the OBIB in August, 1981.

B. LIMNOLOGICAL TRENDS

1. Trophic Status 1980

Wood Lake would be classed as a mildly eutrophic lake in 1980. This conclusion is based on levels of chlorophyll, algal species composition, water clarity and oxygen depletion rates. These indicators were in the mesotrophic to low eutrophic ranges (Jasper and Gray, 1982).

2. Limnological trends 1971-1980

Certain aspects of the surface water quality have improved over the decade, especially in the last few years. Other indicators of water quality have shown no meaningful change.

a) Water clarity

Water clarity, as measured by Secchi disk, has shown a consistent trend toward improved light penetration, especially in the last two years (Figure 1). It is difficult, however, to relate these changes directly to changes in phytoplankton biomass since variations in species composition, bloom frequency and non-algal turbidity may have had an effect (Jasper and Gray, 1982). For instance, some of the increases in 1979 and 1980 could have been due to lower suspended sediment inputs resulting from below-average freshet flows. Peak discharges in 1974-1978 ranged between 3.1 and 7.3 m^3/second, whereas 1979-80 peak flows were 1 to 2 m^3/second (Table 1). Low freshet peaks were recorded in 1970, 1971 and 1973, however, and water clarity in those years was not as good as that in 1980. It is our judgement that, despite the complications, some of the water clarity increases observed in the last two years have been due to lower biological production in the surface waters of Wood Lake.

b) Oxygen depletion in the bottom waters (hypolimnion)

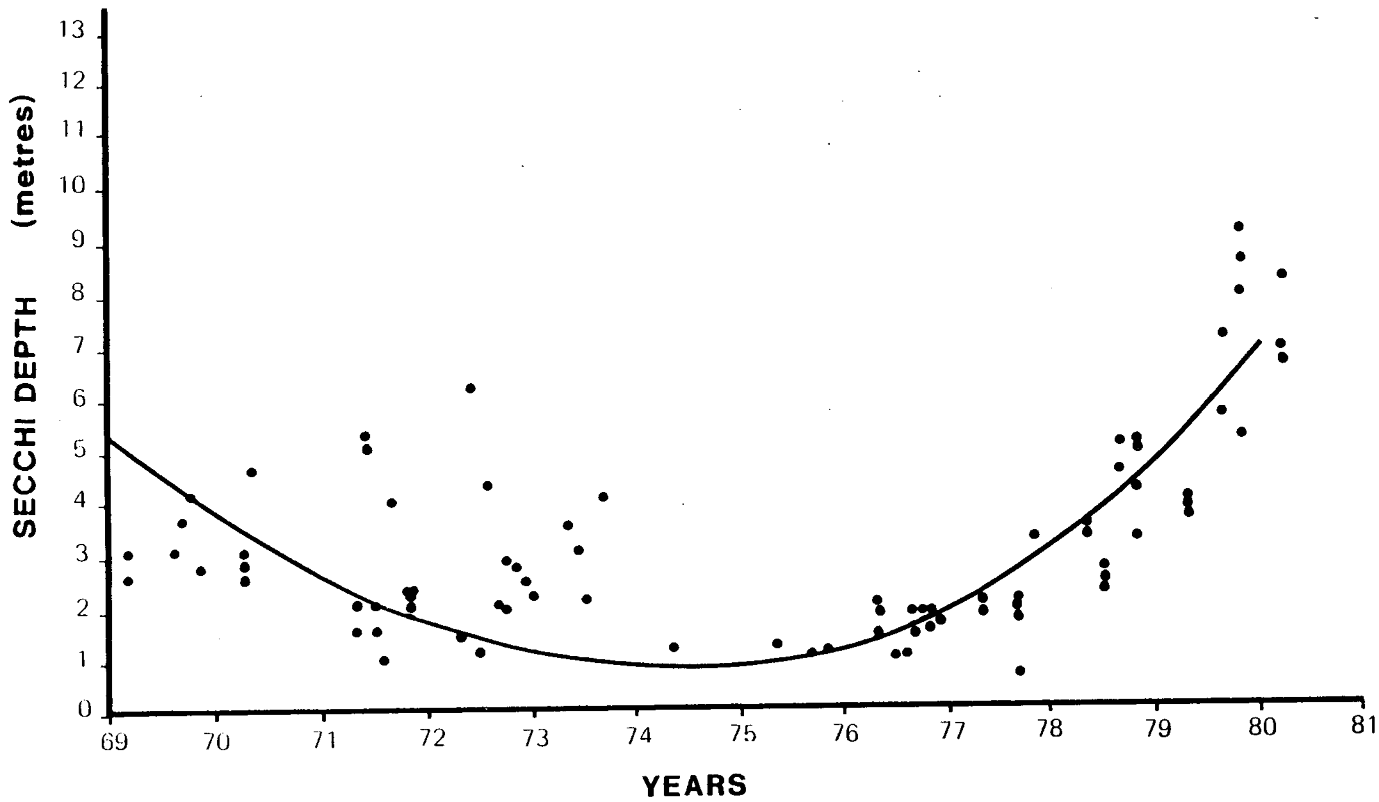

FIG. 1: Wood Lake Secchi disk depths, 1969 to 1980. (Nordin, 1980)

Table 1. Hydrology of Vernon Creek 1970-1980. (Inland Waters Directorate, 1980)

Year	Annual Discharge (10^6 m^3/yr)	Peak Flow (m^3/s)	Date	Filling Time (Years)
1970	1.93	0.184	Feb 17	103
1971	4.91	0.479	June 28	40.6
1972	20.8	3.85	June 1	9.6
1973	6.82	1.19	April 27	29.3
1974	26.6	7.31	May 28	7.5
1975	12.0	4.73	June 5	16.6
1976	19.2	3.15	May 21	10.4
1977	13.1	5.04	May 7	15.2
1978	17.4	4.25	May 29	11.5
1979	10.3	1.96	May 23	19.4
1980	6.64	1.02	April 2	30.0
average 1970-1980	12.7	3.05		15.7

The extent and rate of hypolimnetic oxygen depletion should reflect the inputs of organic carbon produced in the surface layers of the lake as well as inputs of organic matter from the drainage basin. In Wood Lake most (approximately 90%) of the organic carbon comes from in-lake production (NWRI, unpublished data), so that decreases in the depletion rate could be linked to decreased biological production.

The rate of oxygen depletion in the hypolimnion seems to be variable with no clear trend emerging (Table 2). Unfortunately an unknown amount of this variability is probably due to the different computational methods used in each study. Nevertheless the depletion rate in 1980 was the lowest on record and coincides with the highest water clarity. In addition, the profile of dissolved oxygen concentrations on October 16, 1980 (Figure 2), showing the extent of depletion, indicates that the lowest concentrations exist below 25 m. In other years concentrations below 1 mg/L have been observed as shallow as 15 m (Williams, 1973a; Ministry of Environment data).

c) Phytoplankton Biomass and Species Composition

The measures of phytoplankton biomass obtained since 1971 suggest that there may have been some change in annual average chlorophyll. For instance, average annual values in 1971 were several times higher than 1972 (46 versus 10 mg/m^3). We have no explanation for this dramatic decrease. Chlorophyll levels in 1972, however, were similar to 1980 (5.5 mg/m^3).

Species composition has shown some change. Until recently, the blue-green algae were the dominant type of organism during the growing season (Stein and Coulthard, 1971; Buchanan and Kirk, 1974). Diatoms, however, now tend to dominate during the spring bloom (M.O.E. unpublished data; Deimert and Kelso, 1980), while the summer is dominated by the bloom-forming nitrogen-fixing alga, *Anabaena flos-aquae*. Algae present in the lake following this bloom in 1980

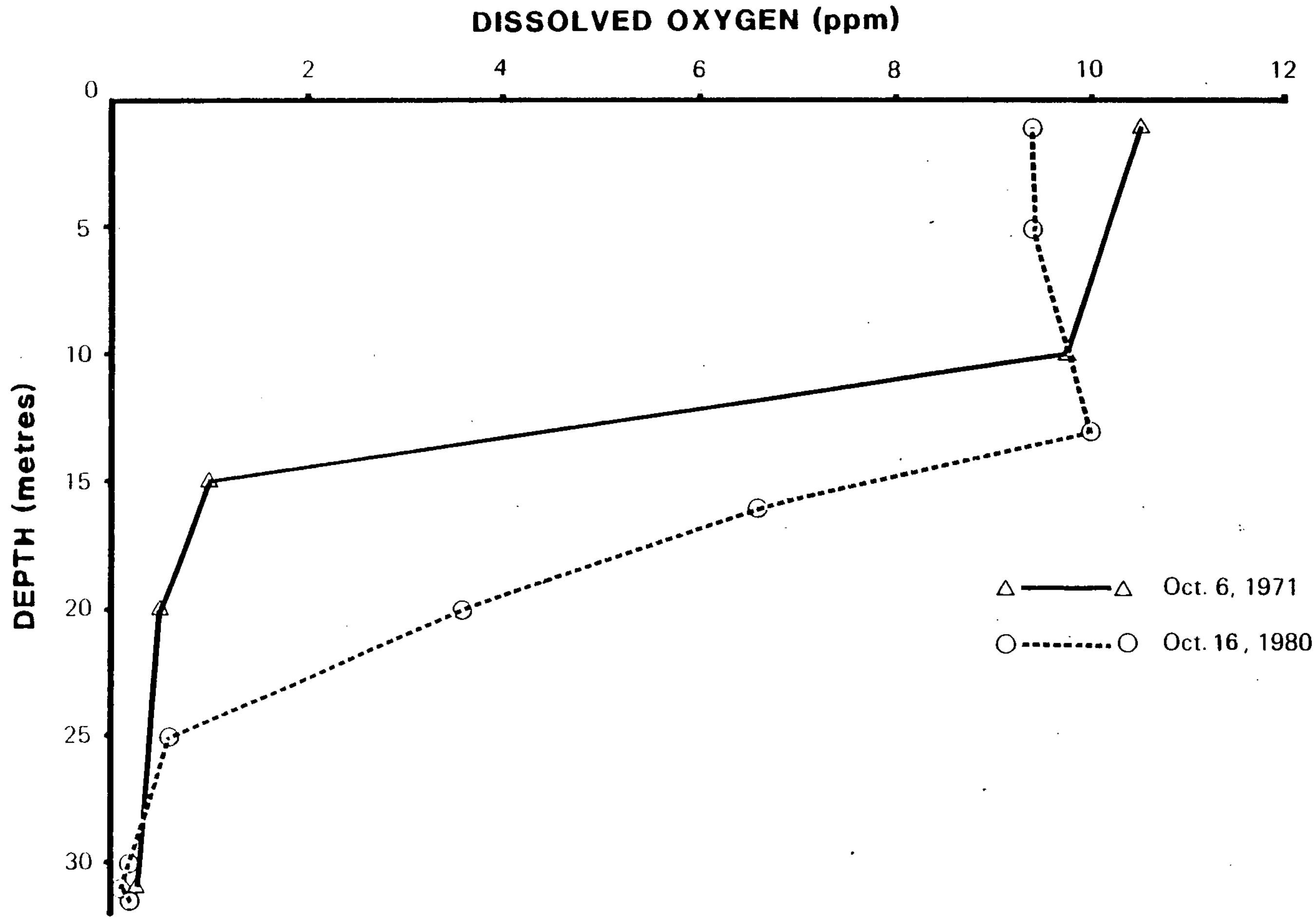

FIG. 2: Wood Lake dissolved oxygen concentrations 6/10/71 (Williams, 1973a) and 16/10/80 (Jasper and Gray, 1982).

Table 2. Hypolimnetic Oxygen Depletion Rates Wood Lake, 1971-1980

Year	Areal Depletion Rate ($g/m^2 \cdot day$)	Reference
1971	0.65	CCIW, Williams (1973a)
1972	1.21	B.C. Research (1974) Howard, Birtwell and Leach
1973	1.48	B.C. Research (1974) Howard, Birtwell and Leach
1977	0.88	MOE, Nordin (personal comm.)
1978	0.81	MOE, Nordin (personal comm.)
1979	1.01	MOE, Nordin (personal comm.)
1980	0.49	NWRI, (Jasper and Gray, 1982)

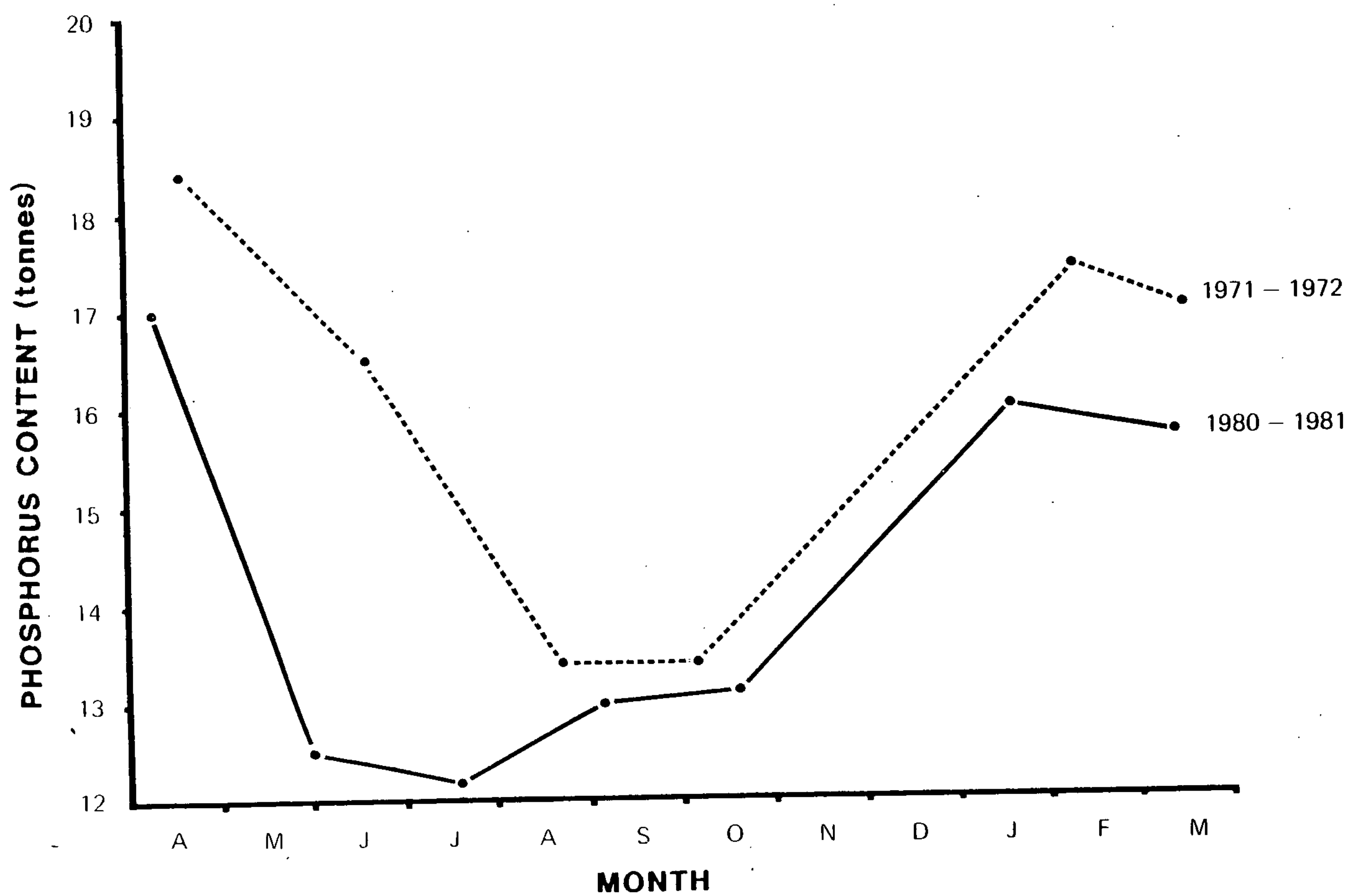

FIG. 3: Wood Lake seasonal phosphorus content, 1971-1972 (Williams, 1973b) and 1980-1981 (Jasper and Gray, 1982).

were shown to be limited by phosphorus (Jasper and Gray, 1982). Physiological measurements, such as ^{32}P turnover times and alkaline phosphatase enzyme levels, both show a high demand for P in late summer and fall.

Since the sedimentation of these blue-green algal blooms in August cause the most rapid decrease in hypolimnetic oxygen, increases or decreases in summer phosphorus concentration or supply rate could have a strong influence on the eventual extent of anoxia.

d) Nutrient Concentrations and Internal Budgets

The concentrations of nitrate in spring have varied over the decade. Nitrate was very low in the early seventies (less than 50 micrograms N/L) but increased dramatically in 1976 to 220 micrograms N/L (Nordin, 1980). Concentrations during the spring of 1980 (180 micrograms N/L) were lower than the maximum observed in 1978 (360 micrograms N/L), but still remain about 2 to 3 times higher than they were during the years 1971 to 1975.

There is no trend in the spring phosphorus concentrations over the decade. The concentrations, which range between 60 and 90 micrograms P/L in spring, are high by Canadian standards. The time-course of phosphorus content in the water column during 1980 demonstrates that there was no net internal loading of phosphorus (Figure 3). If there had been, the phosphorus content in late summer would have been higher than the spring overturn content. As well, the time course for 1971 shows no net internal loading (Williams, 1973b). The lack of large increases in phosphorus in the water column during the anoxic period (August-October) suggests that phosphorus release from adsorption sites in the sediment, mediated by reducing conditions, is not an important process in this lake. This was also found to be the case elsewhere, for instance, in Lake Mendota (Lee et al., 1976), which is similar to Wood Lake in its hardness and nutrient chemistry. At present it appears that there is not a large reservoir of phosphorus at the sediment-water interface which can be quickly released when anoxia develops. Whether this is always the case is not certain. The amount of phosphorus released and regenerated may in some periods be much higher than that observed in 1971 and 1980. For instance, the phosphorus samples taken between 20 and 28 m by the B.C. Ministry of Environment from 1976 to 1979 show higher values than those from 1971 and 1980.

There was a greater rate of phosphorus disappearance in 1980 than in 1971. A possible explanation would be that higher nitrate concentrations in the spring of 1980 allowed for a greater utilization of the phosphorus by the nitrogen-limited spring phytoplankton. The changes in the nitrate concentrations have altered the nitrogen to phosphorus ratio of the nutrient supply for the algae from less than 0.5 in 1971 to 4 in 1978 and 3 in 1980. Ratios less than 5 are indicative of a nitrogen-limited system, so that Wood Lake by this criterion has varied from extreme to mild nitrogen limitation in spring.

3. Interpretations and Explanations

The increased nitrate concentrations have caused some changes in the Wood Lake ecosystem. With increases in the N:P ratio, diatoms have now replaced blue-greens as the dominate algal group in spring. In addition, the extra nitrogen has allowed a greater amount of phosphorus to be taken up by these spring populations. Because these algae settle out of the epilimnion, there remains a smaller pool of phosphorus to supply the blue-greens in mid-summer. In 1980, the mid-summer phytoplankton populations were shown to be limited by phosphate. If phosphorus concentrations during mid-summer were decreased, the extent and frequency of blue-green blooms would also decrease.

The supply of phosphorus in mid-summer has three sources; the first is the unutilized phosphorus in the epilimnion, the second is the stream inputs, and the third is the interchange of phosphorus from the hypolimnion to the epilimnion during stormy periods in summer. In years with high freshet flows extending into late June and early July, the fresh supply of phosphorus from the streams may be important in supporting blue-green algal blooms. However, the basic change in the mid-summer phosphorus supply has resulted from reductions in the epilimnion supply left over after the spring bloom and this seems to be controlled by the nitrogen supply in spring.

The inorganic nitrogen supply in spring is the sum of the supplies produced or redistributed throughout the lake over autumn and winter plus the stream and groundwater inputs during the same period. Whether in-lake supplies have increased cannot be deduced from the existing data. However, there were definite increases in the concentration of nitrate (plus nitrite) in Vernon Creek in 1975, and these are still observed today in the autumn and winter (Figure 4). The increase was not gradual, suggesting that a new source of nitrate had suddenly been introduced. One potential source is the effluent treatment facility of the Hiram Walker and Sons Okanagan Distillery. The distillery imports 2 to 4 million cubic meters of water per year from Okanagan Lake and approximately 5% of this is used for processes which require the elimination of BOD in a bio-oxidation pond. Ammonia is added to the ponds to aid complete BOD removal. These effluents, which are high in nitrate after oxidation of the added ammonia, are then discharged to infiltration ponds constructed on the outwash gravels of Vernon Creek above Ellison Lake. It is noteworthy that the nitrate increases in Vernon Creek were paralleled by sulphate increases (Figure 4) and that sulphate is a major component of the distillery bio-pond effluent.

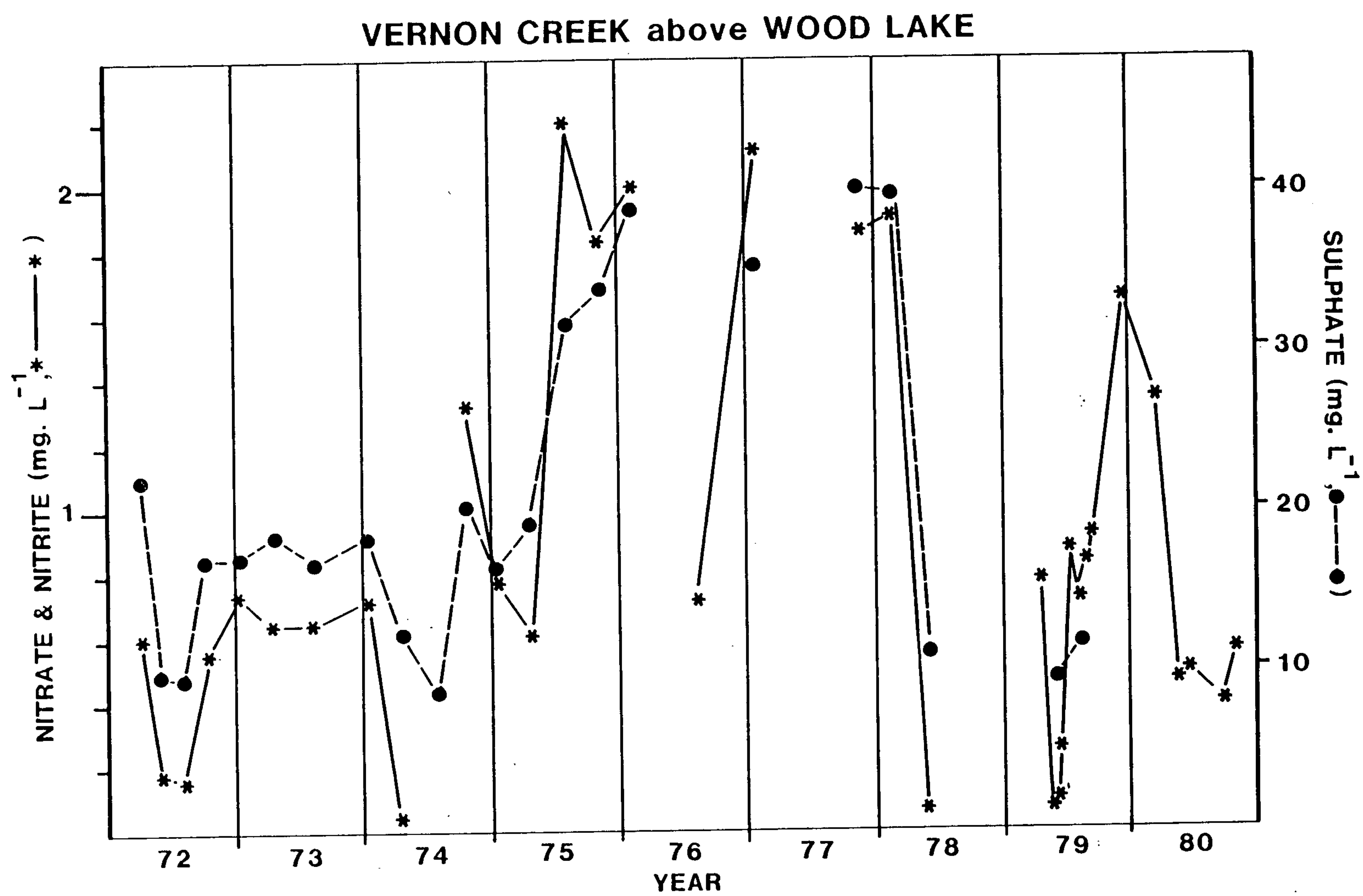

FIG. 4: Nitrate + nitrite nitrogen and sulphate concentrations in Vernon Creek above Wood Lake from 1972-1980 (Ministry of Environment data).

C. FUTURE MANAGEMENT OPTIONS

1. Establish the water quality trend over the next 3 years.

   It is not known whether the water quality of Wood Lake in 1980 has stabilised or whether it is the beginning of a trend to improved conditions. By examining the routine surveillance data presently collected by the Waste Management Branch, the trend or lack of trend can be identified. The monitoring should be up-graded, however, to allow a more complete analysis of the processes controlling lake water quality. Recommendations for such a monitor are included in Appendix 1.

2. Decide what is the acceptable water quality condition for present or future uses.

   For recreational purposes, Wood Lake appears to have acceptable water quality for most of the year, since, in 1980, only one blue-green algae bloom was observed. In our opinion acceptable water quality would be attained if this bloom was reduced or eliminated. However, further monitoring should be done to establish whether 1980 was typical of the frequency and magnitude of the blue-green blooms to be expected in the future. (Weather conditions, for example, play a role in determining the appearance and severity of blooms.) Any decisions to improve the water quality of the lake should be delayed until this monitoring is completed.

3. Take action to inhibit the bloom-forming blue-green algae in mid-summer if future conditions do not improve over 1980.

   There are several ways to inhibit blooms of blue-green algae such as *Anabaena flos-aquae*. One method is to produce a change in the physical environment so that growth conditions are unsuitable. Another method is to decrease dramatically the phosphorus supply in the surface water of the lake during mid-summer.

a) Physical habitat manipulation.

Destratification of the water column by pumping air into the lake at depth has been successful in some lakes in inhibiting blue-green algae (Toetz et al., 1972). This is not recommended for Wood Lake for several reasons. It would be very expensive (the cost estimate for the more expensive procedure of hypolimnetic aeration exceeded one million dollars). Second, destratification can replace blue-green algal blooms with blooms of other algae which are not inhibited by the deeper mixing zone (Nicholls et al., 1980). Such techniques might also increase the nutrient loading to Kalamalka Lake because nutrient concentrations in the surface outflow zone would be higher in summer. Lastly, the effects of destratification on fish have not been determined in other studies and may be deleterious.

b) Decreased phosphorus supply.

The phosphorus supply to the blue-green algae in mid-summer can be decreased by reducing the annual nutrient loading (or at least the summertime loading), by decreasing the spring concentration of phosphorus through nutrient precipitation reactions in the lake or by increasing the uptake of phosphorus by algae in the springtime so that little remains to support the blue-green populations during summer.

Reducing phosphorus loadings to the lake would not be easy or cheap because of the diffuse nature of the inputs. Future growth in the Winfield area may be dense enough to warrant sewage systems with tertiary treatment; however, the effects of reducing the loading (presently 2-3 Mg/yr) would take a long time to be noticed because of the small reductions that would occur in the total lake phosphorus content (16-18 Mg).

The spring overturn concentrations of phosphorus have been reduced in severely polluted lakes by the use of hypolimnetic aerators during the preceeding year (Fast, 1971). The aerators maintain oxygen concentrations at a level which prevents the release of large quantities of phosphorus from precipitates which are solubilized under very low oxygen conditions. This sudden release of phosphorus was not observed in 1971 or 1980. In Wood Lake, then, the use of hypolimnetic aerators would not decrease the phosphorus concentration in the bottom waters during summer or subsequently during overturn. The phosphorus concentrations can also be reduced by Alum treatment, but results of a pilot study in 1975 on Wood Lake showed that this would not be economical (B.C. Research, 1976).

It is possible that algal growth and uptake of phosphorus during spring could be enhanced by the addition of inorganic nitrogen to the surface of Wood Lake after stratification has been established (late April). If successful the phosphorus levels in early to mid-summer would be reduced. Using 1980 conditions as a guide, approximately 7 tonnes (Mg) of nitrogen would be required to utilize the phosphorus left over from the spring bloom. If ammonium nitrate were used as the nitrogen source about 20 tonnes of fertilizer would be required to treat the lake. At current prices, the cost would be less than $5,000. Another alternative nitrogen source with different properties is calcium nitrate, but 40 tonnes would be required. It, however, has the advantage that carbonate precipitation might be initiated and subsequent adsorption and sedimentation of phosphorus in calcium carbonate particles might then occur. Calculation of the application costs have not been attempted. Nitrogen fertilization procedures may have to be done every year.

D. GENERAL COMMENTS

Wood Lake presents a challenge for limnologists partly because of its highly variable hydrology. Lake filling times have varied between 7 and 103 years in the last eleven years, the amount of water lost via evaporation on a year to year basis is large but unknown (approximately one third of the inflow) and the exchange of water with Kalamalka Lake is not known. Another difficulty for analysis of trends is the lack of understanding of the ultimate source of nutrients. The fluctuating levels of nitrate in the lake suggest that large changes can occur in the sources of nitrogen, yet these sources have not been accurately identified. Phosphorus concentrations from year to year seem to be fairly stable yet it is not known whether this situation will change in the long term because the ultimate source of the high phosphorus concentrations is unknown.

Interpreting the biological trends from monthly or bi-monthly monitors has proven to be difficult. Some form of sampling is required on a weekly basis because the algae can bloom and disappear on this time-scale. It is obviously not feasible to do a complete biology monitor on a weekly basis, but a monitor with very limited objectives could be designed. The critical unknown in the lake's biology is the frequency and extent of algal blooms through the year (particularly in June, July and August). A limited sampling program on a weekly basis could answer this question (Appendix 1).

In contrast to biology, the internal budgets of nutrients and oxygen can be obtained with as little as three monitors a year. Complete profiles of nutrient concentrations are needed for proper analysis, but these are not available for most of the past years. To establish the limnological state of Wood Lake and estimate future trends, good internal budgets of oxygen and nutrients are required.

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APPENDIX

Wood Lake Monitoring Proposal

There are two characteristics of Wood Lake which should be better known. These are the internal metabolism of the lake as demonstrated by the contents of nutrients and dissolved oxygen, and the extent and frequency of algal blooms. To monitor these items effectively two different strategies are required. The internal contents or budgets can be obtained by sampling the water column completely three times a year. The extent and frequency of algal blooms, however, can only be obtained with weekly sampling.

1) Internal Nutrient and Oxygen Budgets

a) Sampling frequency

It is recommended that the sampling occur in mid-March (or as soon as the ice melts after this date), early June and late September. These sampling periods are chosen for specific reasons. The mid-March sampling is required to obtain the spring overturn concentrations of nutrients before any significant algal uptake occurs. In some years, algal growth can begin by late March. The early June sampling gives a good indication of the extent of algal uptake of nutrients during the April-May spring bloom as well as oxygen depletion for the period since stratification in early April. The late September sampling provides important information on the extent of nutrient accumulation in the hypolimnion and on oxygen depletion before significant mixing in the upper layers of the hypolimnion occurs. The data from this sampling program will allow a trend analysis of the nutrient supply each spring, the phosphorus utilization of the spring bloom, the presence or absence of internal loading and the extent of oxygen depletion, all of which should give a good integrated value of the primary production each growing season.

b) Sampling sites

There should be three sites along the center line of the lake with the center station at the deepest location (32 m) and the north and south stations at locations with depths between 20 and 25 metres.

c) Physics and chemistry

At all stations, temperature at 1 metre intervals and a Secchi disk and/or light extinction profile should be obtained. The measurement of temperature can best be done with a bathythermograph or an electronic thermograph to avoid the problems of assigning temperatures to an accurate depth. Having temperature data at the three locations will allow an estimation of the thermocline tilt due to seiches and internal waves. Three Secchi depths and/or light extinction profiles will give an indication of variability and patchiness of biological and suspended sediment components.

Sampling for dissolved oxygen, nutrients and other chemical constituents should take place at the central station.

i) Dissolved oxygen

A profile of dissolved oxygen concentrations should be obtained from samples taken every 2 metres in the water column, except in the thermocline region and in the last 4 metres of water above the bottom, where sampling every metre is required. During mid-March, sampling need only occur every 3 metres except below 28 metres when 1 metre intervals should be used. At least 3 water samples for wet chemistry Winkler titrations are recommended at 1, 20 and 30 metres to standardize the probe readings. This sampling scheme should adequately provide the data for oxygen content especially in the steep gradient areas near the sediment and the thermocline region.

ii) Nutrients

Profiles of total phosphorus, total nitrogen, dissolved phosphorus, nitrate + nitrite, ammonium, total dissolved nitrogen and dissolved silica should be obtained by sampling every 3 metres from 1 to 28 m and at 30 and 31 m for a total of 13 samples. All these samples should be screened through a 110 micron nitex screen to remove zooplankton, which are erratic in their distribution. The samples (except total P and total N) should be filtered through prewashed cellulose acetate membrane filters of 0.45 micron nominal pore size within four hours of sampling.

iii) Background chemistry

Monitoring of conductivity, pH, turbidity and alkalinity should be carried out on each sampling trip. These samples need only be taken at 6 metre intervals in the water column. The annual variations in the ionic species of calcium, magnesium, sodium, potassium, sulphate, chloride and fluoride can be obtained by sampling every 6 metres in March only.

iv) Data reduction

The contents of nutrients, dissolved oxygen and heat should be calculated at 2 metre intervals. This can be accomplished by linear interpolation of those parts of the profiles where samples are not collected at 2 metre intervals. The contents of the epilimnion, mesolimnion and hypolimnion can then be calculated based on the depth intervals of these water masses chosen from the temperature profile.

d) Biology

To ascertain how frequently the algal blooms occur in the lake, a totally different strategy will be required. The central station should be visited once a week from mid-March to late October for the measurement of the Secchi disk depth and the collection of a water sample at 0.5 metres. Part of the water sample (up to 2 L) should be filtered for a chlorophyll analysis and 200 mL should be fixed with Lugol's solution for algal taxonomy. At the end of the growing season, the Secchi disk readings should be reviewed to identify the probable periods of high algal standing stocks. The chlorophyll and algal taxonomy samples for those periods should be analyzed. The remaining samples could also be analyzed if time and money permits.

This sampling scheme might best be handled by a local resident who could measure the Secchi disk depth and send the 2 L water sample to the nearest Waste Management Branch laboratory for analysis.