LAKES: THE VALUE OF RECENT RESEARCH TO MEASURE EUTROPHICATION AND TO INDICATE POSSIBLE CAUSES

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ABSTRACT

Excessive plant growth in lakes and rivers is probably the most serious impediment to economic use of fresh waters throughout the world. The growth results from artificial enhancement of the fertility of the water, and this eutrophication is caused by large amounts of nutrient salts draining from highly developed catchments. Industrial and sewage effluents probably provide the most important sources of nutrient salts in the continents of America and Europe.

Research on the water and nutrient budget of Lake Rotorua, calculated for the year June 1967–8, shows that though sewage is an important source of eutrophication, run-off from agricultural land is probably a more important source of plant-fertilizing salts such as nitrate and phosphate. Certain thermal effluents provide the major source of ammonium salts. Data collected during a flash flood on a small experimental catchment showed brief but greatly increased leaching of salts from the pasture. The conclusion that agricultural development is the most important cause of eutrophication of local lakes is supported by results published by workers in other parts of New Zealand.

INTRODUCTION

Eutrophication, an increase in the fertility of water, can be regarded as an acceleration of the natural evolution of lakes and rivers. It is followed, often immediately but sometimes only after a period of years, by a large increase in the plant and animal life supported by the water; this large increase creates serious and urgent problems for those using the waters. As a result of much investigation since about 1950 the consequences of eutrophication are now fairly well known. Briefly they include a reduction in the numbers of salmonid-like fish such as the trout or char and an increase in the numbers of cyprinid-like fish such as the perch or carp; a change from a light and diverse population of bottom fauna to a much heavier one often dominated by chironomid flies; and a similar change from a sparse to a heavy plant growth of either plankton or water weeds. The outstanding feature after eutrophication is not the change in species but the change from a small to a much larger standing crop of organisms.

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Changes brought about by eutrophication do not, in themselves, cause acute danger to local communities, but they do result in loss of valuable, perhaps essential, amenities provided by clean, clear water. The fertilized waters require extensive filtering for economic use and become offensive to see, smell and taste. They also make poor areas for recreation, which is vital to the health of well-balanced communities (Norling, 1968). With the increase in leisure time of workers, suitable outdoor recreation must be made available so that activities may be directed toward socially acceptable outlets.

Eutrophication has become widespread. Most lakes in Europe and America are already affected in varying degrees. Unfortunately water pollution by eutrophication has proved very difficult to control. At first great efforts were made to reduce the effects by treatment with pesticides, but these methods proved expensive, ineffective and dangerous. Modern methods of control are now concentrated on cleaning inflows of fertilizing material and depend for their success on early treatment.

Lack of success may often be due to a 'phosphate sparing' effect. Although the growth of algae may be wholly limited by the amount of phosphate present, these limiting concentrations of phosphate vary from lake to lake. It has therefore not been possible to determine a precise minimum phosphate concentration in waters that is necessary for the growth of algae. A possible explanation of this phenomenon has recently been found by Shapiro *et al.*, (1969), who showed that as the total concentration of dissolved salts, especially magnesium salts, is increased in a water the minimum amount of phosphate that permits the growth of many common algae is decreased.

The effect of water movement on phytoplankton populations is also often difficult to interpret. Experimental work in America demonstrated that the artificial circulation of stagnant lake water caused a considerable decrease in these populations (Symons *et al.*, 1967). Similar work on reservoirs in England showed that such stirring caused the populations to increase (Windle Taylor, 1965). These and other studies on the consequences of eutrophication make it clear that both the causes and effects of this pollution are complex and still far from being fully understood.

It is possible that few New Zealand lakes and rivers have been affected by eutrophication, but little information is available about most waters. However, unwelcome signs of change have been detected in waters that are easily accessible and popular (Fish, in press). Naturally the smaller lakes are more susceptible to pollution than the larger ones and so the coastal dune lakes of New Zealand, which are not usually bigger than 40 hectares in surface area (Cunningham *et al.*, 1953), are prominent among lakes that have become eutrophic. Tomahawk Lagoon, near

Dunedin, is a particularly interesting example (Mitchell, 1967). It is highly productive, but alternates between supporting a heavy bloom of planktonic algae and growing masses of water weeds. However, sheer size does not confer immunity, for our longest river, the Waikato, has reached an advanced stage of eutrophication and even Lake Taupo is beginning to show an ugly rash of excessive weed growth around some of its bays.

Effective action to protect our fresh waters can be taken only if, firstly, there is early warning that a lake or river has started to deteriorate and, secondly, that at least some of the more important causes of pollution have been identified and studied. The information needed to meet these two requirements will undoubtedly be obtained by analysis of the biology and chemistry of polluted and unpolluted lakes throughout the country, but at present such data are very few. However, Fisheries Research Division is now concerned with this aspect of lake research, for it has been shown that the crop of trout supported by a eutrophic lake is much smaller than that supported by an unaffected clearwater lake (Fish, 1968). A project was therefore started in 1967 to study the physical, chemical and biological features of Lakes Rotorua and Rotoiti. Both are moderately eutrophic, but Rotorua is shallow and its waters are well mixed at all seasons. It was decided to try to estimate the amounts of fertilizing materials that entered and left Lake Rotorua during the period of study. Some of these data are presented here.

METHODS

Analyses for dissolved phosphate, nitrate and ammonia were made by use of methods recommended by Strickland and Parsons (1968). Water samples were collected fortnightly from nine major inflows and the outflow of Lake Rotorua. Flow rates on the collection dates were supplied by the Hydrological Survey, Ministry of Works, and the New Zealand Meteorological Service provided rainfall and evaporation data from their weather station at Rotorua Airport on the shores of the lake. The evaporation data were reduced by a factor to give an estimate of the amount of evaporation from the surface of the lake (Finkelstein, 1961) and this estimate was subtracted from that of rainfall over the lake area to provide a figure for the water increment by net precipitation. Annual totals were calculated by assuming constant conditions between sampling dates, but the ammonia data are approximations. Routine analyses for ammonia were not started until June 1969. Mean concentrations in the various waters were obtained during the next three months and were used to calculate the probable amounts of this nitrogen form during the 1967–8 period.

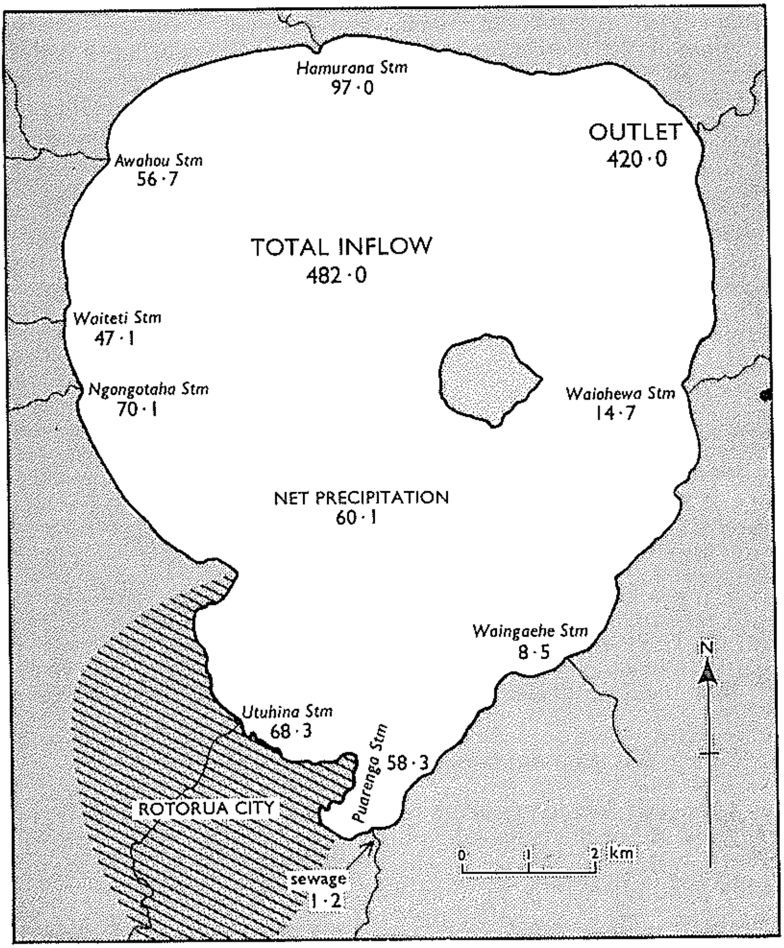

FIG. 1 — Nine inflows and the single surface outflow (as $m^3 \times 10^6$) in Lake Rotorua totalled for the period June to May 1967–68.

RESULTS

Lake Budgets

Fig. 1 shows the annual water budget for 1967–8. The largest source of water was in fact rain falling on the lake area (126.7×10^6 m^3), though only the net increment by precipitation has been given in the figure. On the other hand, the cold-water springs may be a much larger source of water to the lake. The water from these springs varies little in flow rate and its temperature and chemical composition appear to be independent of seasons compared with those in the rivers. The river water is likely to be supplied from shallow drainage in the catchment, and the possibility that all the springs tap a single large source from deep underground cannot be discounted on the present data. The Hamurana Spring provides the largest surface inflow to the lake, but much of the flow of the Awahou, Waiteti, and Ngongotaha Streams is also from springs rising near the lake shores.

The data supplied in Fig. 1 are subject to three sources of error which cannot at present be estimated. Firstly, there is a possibility of change in flow rates caused by changes in the river bed between gauging dates. The pumice sand and gravel forming the substrate of the river beds is fairly light and easily moved by changes in water currents. A second source of error in the budget lies in the changes that may occur between readings. For instance, the banks of the outflow are well defined, and inevitably there is resistance to the free passage of water. Any large increase of influent volume is therefore accommodated for variable periods by a rise in lake level rather than by an immediate equivalent increase in effluent flow. A third source of error results from the water movement by seepage and underground flow which probably occurs but has not been estimated. However, for the purpose of investigating sources of eutrophication the data in Fig. 1 have been found useful for compiling the nutrient budget presented in Table 1.

The difference between the estimated inflow and outflow of plant nutrient salts in Lake Rotorua is very large and may partly be explained by the enormous biomass of aquatic plants growing round the lake shores and in the open water. These plants absorb the dissolved salts and when they die, much of the nutrient material is retained in the tissues and accumulates in the bottom deposits. A proportion only of the sedimented phosphorus and nitrogen is returned in a soluble form to the water by decomposition. This cycle of events is further complicated with the nitrogen salts by the activities of nitrogen-fixing and denitrifying organisms. The very small amounts of nitrate and ammonia leaving the lake suggest that denitrifying activity may be high.

Sewage provides the most concentrated source of phosphorus and ammonia of all the inflows, but as its flow is by far the smallest, it does not contribute the most of any nutrient studied. Most of the phosphate entering the lake comes from the Hamurana Spring, the water of which has a rather low phosphate content, but the spring's flow rate is consistently high. The two streams Utuhina and Puarenga also supply large amounts of phosphate and this is confirmed by the fact that both flow through urban areas to the lake.

Most nitrate is supplied by the Awahou Stream and it is probably significant that of all the inflows this stream has the highest proportion (85%) of pastoral land in its catchment (D.

TABLE 1 — The inflows and outflow of phosphate phosphorus and soluble nitrogen in Lake Rotorua during the period June to May 1967–68. The data for each nutrient are expressed as estimates of the total amount. These amounts are expressed next as concentrations in the estimated water totals and finally as percentages of the figure for total inflow.

Inflows and outflow	*Phosphate-P*			*Nitrate-N*			*Ammonia-N (approximate)*		
	kg	*kg/m³×10⁶*	*%*	*kg*	*kg/m³×10⁶*	*%*	*kg*	*kg/m³×10⁶*	*%*
Waingaehe	1,037	122	3.0	2,203	260	2.0	350	41	0.2
Waiohewa	873	60	2.5	4,177	285	3.8	95,500	6,500	66.5
Hamurana	7,692	79	22.3	22,581	233	20.6	382	4	0.3
Awahou	3,918	69	11.3	30,583	540	28.0	18	0.3	0.1
Waiteti	1,986	46	5.8	16,482	350	15.1	4,740	100	3.3
Ngongotaha	2,416	34	7.0	13,178	186	12.1	625	9	0.4
Utuhina	5,019	74	14.5	14,415	211	13.2	2,160	32	1.5
Puarenga	5,857	100	17.0	1,571	27	1.4	1,750	30	1.2
Sewage	4,885	4,200	14.2	0	0	0	28,500	24,400	19.9
Rainfall	811	6	2.4	4,148	33	3.8	9,690	77	6.7
Total inflow	34,494	72		109,338	267		143,715	298	
Surface outflow	14,371	34	41.6	449	1	0.4	13,200	31	9.2

Knowles, pers. comm.). Nitrogen fixation by legumes is a well-developed feature of New Zealand pastures and the nitrate ion is easily leached from the soil. No nitrate at all has been detected in the sewage effluent, probably owing to its chemically reduced state.

The ammonia content of all the inflows is low except for the sewage, which supplies nearly 20% of the total, and the Waiohewa Stream, which supplies over 66%. It is to be expected that the high organic content of the sewage will result in high ammonia concentrations in its effluent, but the presence of ammonia in the stream was unexpected. Serial sampling the water along its length identified the source of ammonia as the effluent from some of the geysers in the Tikitere thermal region. These geysers derive their water from deeper sources than most of those found near the city of Rotorua and have an effluent characteristically rich in ammonia and other salts (Glover, 1967).

Catchment Events of Special Interest

Consecutive analyses of inflow samples varied little except on one occasion during February 1969 in the Waingaehe Stream. Although this stream has the smallest catchment area (17.8 km^2) of all the inflows studied, the proportion of pasture land is high (83%). On 17 February 1969 and for some weeks previously the stream water contained 0.09 ppm of phosphate phosphorus. The pastures were then topdressed by air with superphosphate and by the next sampling date, 31 February, the concentration of dissolved phosphate had risen to 8.9 ppm. This concentration dropped as quickly as it had risen, for at the next routine sampling, the phosphate content of the water was only 0.1 ppm. However, even if the high concentration was maintained for only a few days, the 100-fold increase over background values represents a large increment to the amounts of phosphate discharged into the lake.

Some water samples have been analysed from the Puruki catchment, near Mihi. This catchment, a subcatchment of the Purukohukohu Experimental Basin controlled by the Hydrological Survey, Ministry of Works, is very small, but it has been accurately surveyed and the drainage flow is frequently monitored. It is one of several catchments being studied to determine the hydrological regime in productive farmland and it consists of 0.016 km^2 of stable grass-clad slopes. The water samples were collected during a brief flash flood between 2 and 3 April 1969 and the amount of nutrient in the discharge water is presented in Table 2 to show the changes in water quality as flood conditions rise and recede. These data show that the sediment carried away by this sudden flood was rich in phosphorus and that the leaching of soluble nitrogen and phosphorus from the surface of the catchment over the period of flooding was also considerable.

TABLE 2 — The discharge of nutrient salts in grams per hour in water samples taken from the Puruki Stream over a period of flood conditions.

Date	2.4.69	3.4.69	3.4.69	10.4.69
Time	1522	1255	1355	1335
Phosphorus in suspended sediment	0	450	610	0
Phosphorus in dissolved phosphate	0.09	44	875	0.045
Nitrogen in dissolved nitrate	0.14	27	197	0.087
Nitrogen in dissolved ammonia	0	1,200	3,650	0

DISCUSSION

The causes of eutrophication in many overseas fresh waters have been intensively investigated. In Europe this pollution is generally associated with both industrial and sewage discharge. Lakes Zurich (Hasler, 1947) and Constance (Deufel, 1965) were more seriously affected by sewage, but in the Rhine and many English rivers (Department of Scientific and Industrial Research, 1964) industrial effluents seem to be the more important. Lakes Mälaren (Willén, 1968) and Norrviken (Ahlgren, 1967) in Sweden are also mainly affected by industrial effluents, though towns in the catchment area make sewage an important factor. In the United States, sewage seems to be regarded as a more important cause of eutrophication than industrial or agricultural effluents and this is supported by the reviews of limnological research by Hasler (1947) and Edmondson (1968).

The data are too few yet to enable any general conclusions on the causes of eutrophication in New Zealand to be reached, but local evidence is suggestive, as the nutrient budget of Lake Rotorua provides a good guide to the possible sources of nutrients. The springs and sewage effluents are major and constant contributors to eutrophication, but the budget serves to put the importance of sewage into perspective as a large but not a paramount source of nutrients.

The data collected after topdressing and flooding support the view that eutrophication may be largely a result of local agricultural practice. Too much reliance may have been placed on isolated instances, but undoubtedly for a short time the discharge of nutrients exceeded background values by two or more magnitudes. In other words, the flow for three days during these isolated instances could contribute as much nutrient material as that provided by normal flow for a whole year. It is interesting that O'Connor (1968) has also expressed concern at the amounts of fertilizing nutrients lost from land during agricultural development and at their eutrophic effect on receiving waters. He collected many of his data from South Island sources and so it seems likely that the causes of low water quality may be similar throughout New Zealand.

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