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THE EUTROPHICATION OF LAKE SAVA

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INTRODUCTION

Lake Sava, Belgrade, Yugoslavia, is a highly eutrophic lake. Formed towards the end of 1966 by constructing dikes at the upper and lower ends of an old river channel, it is mainly used for recreation and water supply purposes (recharge of groundwater aquifers below the lake used for the water supply of the city of Belgrade). Initially the lake served its intended purposes well. However, the industrial and agricultural development in the watershed of the river Sava whose waters are used for filling the lake, has been rapid and was unfortunately not followed by an appropriate development of the required infrastructure and wastewater treatment facilities. As a result, the water quality of the river Sava has significantly deteriorated since 1966, this being reflected in the accelerated eutrophication processes in the lake to the point that its intended uses are now threatened.

The Lake Sava system consists of two sections: a 17 ha sedimentation basin and a 75 ha recreation and infiltration lake. The length of the lake is 5 km, its average width 200 m and average depth 6 m (maximum depth 12 m). The lake gets all of its water by pumping it from the river Sava at a rate that depends on the evaporation rate and infiltration. As a result, the retention time of the water in the lake varies from 1.5 to 2 months during the summer season while it is slightly longer during the winter when both evaporation and the water use are reduced.

From the very beginning of its existence, the specific morphology of the lake and the local climatic conditions along with the major external influences that effect determined its destiny to be a highly eutrophic aquatic eco-system.

METHODS

Starting in April 1983, a water quality monitoring program was initiated for Lake Sava. Samples were collected monthly from three stations in the lake, one station in the sedimentation basin and one station on the Sava river at the point of water withdrawal for pumping into the Lake Sava. Each of the lake stations had three sampling points along the cross section with depth sampling at each point too. Besides the water samples, sediment samples were also taken on a regular basis.

All the samples were analyzed for the selected physical, chemical and biological constituents in accordance with the Standard Methods for Examination of Water and Wastewater (AWWA, 1981). Besides the above, "in situ" measurements were done of the primary productivity in the lake (light and dark oxygen method), the temperature, CO_2 and oxygen stratification of the lake.

RESULTS AND DISCUSSION

Table 1. is a summary of the results of the water quality monitoring study. Detailed results have been published elsewhere (Perisic, Marjanovic, 1983, 1984).

From the obtained results it is evident that the major factors effecting the water quality of the Lake Sava are a result of anthropogenic elements very much beyond the control ability of the lake management staff. The water quality in the river Sava (a major wastewater recipient in Yugoslavia) varied greatly but it was always below the water quality desired for filling the lake. High concentrations of both phosphorous and nitrogen and excess quantities of trace nutrients are always present in the river Sava water. As a result, primary productivity in the lake is continually stimulated by the high nutrient input from the river Sava. It is only at times of very intensive photosynthetic activity in the system and at times of a temporary stratification that the phosphorous pool in the euphotic zone of the lake may be exhausted and the photosynthesis may be phosphorous limited. At all other times, the productivity of the system is limited by other physical factors such as are light intensity, the degree of mixing and the retention time.

Other major sources of nutrients that the study has identified are the recreational users of the lake (some 200000 bathers per day at the peak of the summer season) and air pollution, the last being especially true during the winter months because of the coal and fuelwood burned by domestic and industrial appliances and installations not equipped with adequate air pollution control devices, a practice still widely used in Belgrade and in the nearby communities.

Our results also show that the internal processes of nutrient recycling also contribute to the accelerated eutrophication of the lake. Lake Sava is a typical polymictic shallow impoundment which frequently stratifies for short periods of time in summer and fall and occasionally freezes during the winter. When frozen it is inversely stratified. The intensive biomass production in the system is responsible for the continuous biochemical degradation of the organic matter in the system and the extremely rapid nutrient recirculation within the system.

The observed variations of the phosphorous concentrations were significant both along the length of the lake and its depth. The minimum detected PO_4 concentration of 2 mg/l was observed in the epilimnion at the time of the most intensive photosynthetic activity in the lake. The maximum concentration of 350 mg/l was observed during the winter ice cover and at the time of inverse stratification and anoxic conditions at the lake bottom. The maximum total phosphorous concentration in the epilimnion coincided with the period of the maximum photosytnthetic activity in the system and was 395 mg/l as P. The minimum total phosphorous concentration in the epilimnion followed shortly after and was observed just after the minimum orthophosphate concentration that triggered of the decline in the algal population and the intensive settling of the cells. Similar dynamic changes were observed at different depths along the water column but the major influence of the phosphorous released from the sediments was observed during the periods of stratification.

The intensive productivity within the system did not have as pronounced effect upon the concentrations of the different forms of nitrogen in the lake water. This can be explained by the fact that the nitrogen did not limit the productivity and by the significant contribution to the nitrogen pool of the system made by the dry fallout and recreational use of the lake. The observed variations were mainly the result of the variations in the nitrogen inputs to the system. However, our results show that significant amounts of nitrogen were lost from the system, this indicating that intensive nitrification-denitrification processes occurred continuously at the sediment water interface.

Even though almost all the major metals were detected in the lake water, the results indicate that relative to the input loading of the system, an overall reduction of the metal occurs within the system. Metals are mainly immobilized either in the biomass or in the sediments but some do escape to the groundwater. When compared with the concentrations in the inlet waters, a reduction of the concentrations of lead, arsenic, cadmium zinc, chromium, aluminium, iron and manganese was observed. A point worth noting is that the observed concentrations of arsenic and cadmium in the inlet waters were at all times above the standards set for drinking water. The immobilization of these metals in the biomass and sediments is probably the only positive effect that the eutrophication of the Lake Sava had on its water supply use. Under the anoxic conditions prevailing in the sediments, a release of iron and manganese from the sediments was observed.

The typical productivity profile in the lake is shown in Figure 1. From the obtained results we estimated the primary productivity in the lake to be at a level of 670 g org. C/m^2/year. According to the classification given by OECD (Clasen, 1982) this productivity makes Lake Sava a hyper eutrophic lake. Our results show that the primary productivity falls to zero at a depth that corresponds to 2.5 secchi disc depths and this is in agreement with the results of Middlebrooks (1976). The algal biomass production estimated from the primary productivity measurements and the empirical formulae (Stumm and Morgan, 1970; Archivela, 1981) amounts to 6500 t/year.

Chlorophyll "a" concentrations of 2 to 50 mg/m^3 were observed during the study period. The correlation between the chlorophyll "a" concentration and the secchi depth is shown in Figure 2. The data agrees with that of Goldman (1983) and indicates that small changes in the level of productivity (as measured by Chlorophyll "a" concentration) can have a major effect upon the value of the lake waters used for recreation purposes.

The macrophyte biomass production in the lake was estimated at 1100 t/year. Comparing this with the biomass production of algae it is obvious that the algal production is much more important in Lake Sava. However, an evaluation of the data obtained by other researchers points out that there is a tendency towards a more intensive macrophyte production in the future. According to Jankovic (1983), if no remedial measures are taken immediately the lake will soon become a swamp.

The results of the study show that the net production of the organic matter in the system on an annual basis results in a significant sediment accumulation in the lake. Furthermore, the sediments have a high content of organic matter and a very high concentration of heavy metals, pesticides and nutrients. This makes sediment removal and its disposal a major problem. A separate study is needed to determine the most suitable means for disposing of the sediments from Lake Sava.

The biological water quality studies have shown that all the major phytoplankton groups are present in Lake Sava. However, the diversity of the species is relatively small and the qualitative composition greatly varies with time. Only a small number of species reaches high abundance.

In the summer of 1983, an intensive bloom of the Pediastrum species was observed. This was followed by a bloom of the single cell silicate algae Stephanodiscus and Pyrrhophyta (Ceratium).

During the 1983/84 winter the filamentous algae Cyanophyta (Phormidium) became dominant but the Pediastrum species were still present in significant numbers. Also present were some silicate algae.

In the spring of 1984, the Cyanophyta population decreased and the Bacillariophyceae become dominant. Towards the end of spring 1984 and in early summer the dominant group of algae was Chlorophyceae with a relatively high abundance of Bacillariophyceae and Cyanophyta. This was followed with an intensive bloom of the Pediastrum species in June of 1984 as had been the case in 1983.

In general the overall phytoplankton dynamics in Lake Sava indicate a highly eutrophic system. The absence of blue green algal blooms is an indication of the absence of a nitrogen limitation in the system. This is a favorable situation considering the effects the blue green algal blooms would have upon the use of Lake Sava for water supply purposes.

The zooplankton population of Lake Sava consists of Protozoa, Rotatoria, Cladocera, Copepoda and Ostracoda species. The overall situation is characterized by sudden changes in the dominant species and their abundance. The most pronounced abundance maxima were in late spring. Throughout most of the year, the zooplankton population was characterized by Rotatoria species and only temporarily do other collected species become abundant.The observed dynamics are typical when referring to the relationship between the phytoplankton and zooplankton population succession. The sudden and unpredictable internal or external loading of the system can trigger of an even more sudden bloom of certain organisms and their subsequent conversion to organic sediments with all the negative consequences upon the use of the lake for the designated purposes.

CONCLUSIONS

Overall, the integrated influences of anthropogenic factors and the resulting physico-chemical and biological internal processes in Lake Sava are responsible for the high degree of variation of the water quality in the lake throughout the year.

It is evident that major management and remedial measures have to be implemented if the eutrophication of Lake Sava is to be controlled.

It is reasonable to assume that the water quality of river Sava will not improve significantly in the foreseeable future. It is therefore necessary to implement measures for the nutrient removal from the water pumped to Lake Sava from the river Sava. With respect to this, physico-chemical treatment is recommended for the reduction of the phosphorus loading while new developments with artificial wetlands offer a feasible means for the nitrogen loading control. The conversion of the existing sedimentation basin to artificial wetland is especially promising with regards to the nitrogen removal from the system.

Since the sediments of Lake Sava are a historical record of the water quality of the river Sava and of the internal processes within the lake itself, they represent a "permanent" source of nutrient input into the system so that without their removal any other measures that may be implemented would be pointless.

In light of the above, we recommend that the major portion of the sediments from Lake Sava should be removed as the first step towards a controlled system. However, without the implementation of other recommended measures for controling the external loading of the system, the eutrophication process of the lake will continue and the existing problems related to the lake water quality and its use will remain.

REFERENCES

1. AWWA, APHA, WPCF, 1980, Standard Methods for Water and Wastewater Examination, 15th Edition, US 1980

2. Perisic, M., Marjanovic, P., 1984, Eutrophication of the Sava Lake, Annual Conference of the Yugoslav Society for Water Pollution Control, Proceedings from, Novi Sad, 1984.

3.Clasen, 1982. Eutrophication of Waters, Monitoring, Assesment and Control, OECD, Paris, 1982.

4. Middlebrooks, E.,J., 1976. Modelling the Eutrophication Processes, Michigan 1976, Marcel Dekker Inc, 1976.

5. Stumm, W., Morgan, J., J., 1970. Aquatic Chemistry, Wielly Interscience, New York, 1970.

6. Archivala, S., J., 1981. Wastewater Treatment and Disposal, Marcel Dekker Inc., New York, 1981.

7.Goldman, C., R., Horne, A., J., 1983. Limnology, McGraw-Hill Book Company, New York, 1983.

8. Jankovic, M., 1984. Macrophytes of the Sava Lake and the Effects of the Measures Implemented for Their Control, Institute "Sinisa Stankovic", Belgrade, 1984.

Table 1. Water Quality of Lake Sava - Major parameters - Summary

PARAMETER	LAKE SAVA			RIVER SAVA		
	minimum	maximum	average	minimum	maximum	average
pH	7.7	9.8	8.5	7.7	8.4	8.1
T.Hardness, mg/l $CaCO_3$	120	185	160	135	210	170
SiO_2, mg/l	2.5	3.8	3.4	2.7	3.9	3.5
Chlorides, mg/l	14.3	20	16.4	15	19	17.1
Sulphates, mg/l	32.8	40	39.4	33	51	41
Dissolved Oxygen, mg/l	7.7*	20.4	16.3	6.4	11.6	9.3
Orthophosphate P, µg/l as P	2	350	210	50	245	195
Total P, µg/l as P	40	395	295	90	310	284
Chlorophyll "a", mg/m3	2.5	47	18.5	0.05	0.75	0.2
Nitrites, mg/l as N	0.001	0.03	0.004	0.001	0.035	0.012
Nitrates, mg/l as N	0.01	0.95	0.37	0.39	1.15	0.67
Ammonia, mg/l as N	0.04	0.16	0.11	0.04	1.17	0.74
Iron, mg/l	0.01	0.18	0.06	0.12	0.27	0.18
Manganese, mg/l	0.01	0.1	0.02	0.01	0.13	0.06

* in epilimnion

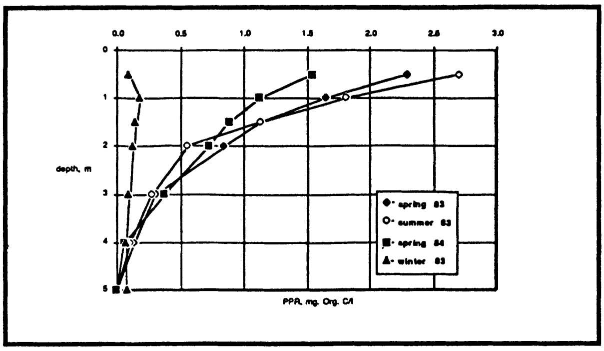

Figure 1. Typical Primary Productivity Profiles for Lake Sava

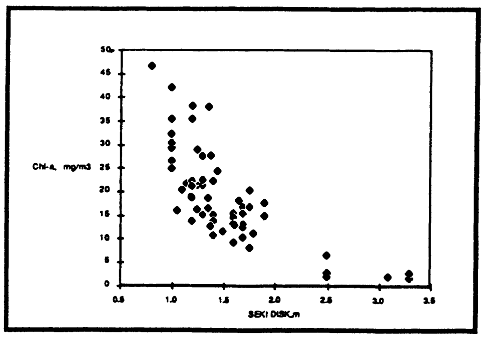

Figure 2. Correlation between the concentration of Chlorophyll and Secchi Depth