32nd WEDC International Conference, Colombo, Sri Lanka, 2006

SUSTAINABLE DEVELOPMENT OF WATER RESOURCES, WATER SUPPLY AND ENVIRONMENTAL SANITATION

Cyanobacteria in Water Supply Reservoirs and Strategies for Their Control

Eduardo von Sperling, Lenora Nunes Ludolf Gomes, Amilton Diniz e Souza, Brazil

The paper describes the problems related with eutrophication in water supply reservoirs. One of the most relevant impacts is the growth of cyanobacteria, which are able to generate very powerful toxins. This situation is more critical in tropical regions, where all metabolical processes are faster and where generally there is lack of financial resources for implementation of adequate monitoring programs. A case study(Vargem das Flores Reservoir) is presented, with emphasis on the study of eutrophication development based on N/P relationship. It was found that low N/P values did not favour here the dominance of cyanobacteria, as generally reported in the technical literature. The paper also discusses the adoption of some preventive and corrective techniques for avoiding cyanobacteria blooms in water supply reservoirs.

Introduction

EUTROPHICATION of water supply reservoirs is one of the most severe problems in the management of these water bodies. Causes of eutrophication are closely related to the nutrient input from point sources (usually sewage discharge) as well from diffuse sources (agriculture and other antropic activities) in the drainage basin. The onset of eutrophication can bring severe impairments to the water quality, such as algal blooms, oxygen deficit, bad odours and excessive macrophyte growth. Blooms of cyanobacteria (or Cyanophyceae algae) is a serious concern for Brazilian authorities, since the worldwide first reported deaths of human beings, caused by the ingestion of water contamined with cyanotoxins, were registered in this country (Azevedo et. al., 1996). Since that time, a strong surveillance of the quality of water supply reservoirs has been carried out. Considerable efforts have been dedicated to the control of nutrient input in such reservoirs as well in implementing measures to tackle the problem of cyanobacteria growth. These management techniques are represented by preventive measures (point and diffuse pollution control) and corrective ones (aeration, dredging, deep water discharge, macrophyte removal, use of algicides, biomanipulation of the trophic web).

Characteristics of tropical reservoirs

Due to high water temperatures, tropical aquatic systems present quite specific characteristics, such as an enhanced dynamics in all metabolical processes The main characteristics of tropical lakes and reservoirs are summarized below (von Sperling, 1996):

a) Intense solar radiation and high water temperatures accelerate nutrient uptake by the algae;
b) Phytoplanktonic population peaks are less frequent in comparison with temperate aquatic environments;
c) High nutrient assimilation capacity, associated with high recycling rates, lead to the prevalence of an intense degree of productivity;
d) Nutrient concentrations are generally low; as a consequence many water bodies can be classified as oligotrophic in spite of their high productivity;
e) There is a frequent occurrence of low phytoplankton densities, which are however associated with high growth rates;
f) High mineralization rates lead to an accelerated oxygen depletion and to the formation of sediments that are poor in organic matter; consequently there is no direct connection between hypolimnetic oxygen deficit or content of organic matter in the sediment and the productivity of the water body.

Case study: Vargem das Flores Reservoir

Vargem das Flores Reservoir is located close to the city of Belo Horizonte, Brazil. It has a surface area of 5.5 km^2, a volume of 0.044 km^3 and a maximum depth of 23 m. The main uses of the water body are human and industrial supply, as well as recreational activities.

Local climate presents two well defined periods: rainy season (October to March) and dry season (April to September), with an average yearly precipitation of 1500 mm. Air relative humidity ranges from 65 % (August and September) to 80 % (December), with an insolation average value of 2600 hours/year. The evaluation of the water quality in Vargem das Flores Reservoir has been carried out by the staff of the Department of Sanitary and Environmental Engineering of the Federal University of Minas Gerais, under the coordination of the first author.

Contamination of Vargem das Flores Reservoir is caused, in large scale, by the discharge of untreated sewage in the tributaries of the water body. The most important corrective measure currently in course is the construction of wastewater treatment plants (activated sludge and anaerobic digestion). Non-point sources in Vargem das Flores Reservoir are originated from run-off of urban areas, forest coverage and agricultural use in the drainage basin.

Results

Vargem das Flores Reservoir is strongly stratified for most of the year with deep mixing occurring once during the middle of the cool, dry season (June to August). According to the thermal structure the reservoir is a warm monomitic aquatic system. This feature leads to the formation of an anoxic hypolimnion and to the onset of internal fertilization processes.

Average values of the most relevant water quality parameters are given bellow:

- Secchi depth: in the range 0.8 to 2.3 m; higher values in the winter period (generally from July to September);
- Dissolved oxygen: higher in the winter period due to enhanced gas dissolution; epilimnion: 6 to 7.5 mg/L; metalimnion: 3 to 7 mg/L; hypolimnion: 1 to 4 mg/L
- pH: surface: 7 to 8; bottom: 6.5 to 7.5;
- Turbidity: surface: 3 to 20 NTU; bottom: 3 to 100 NTU; seasonal variations, with lowest values in April, highest values in the rainy season (November-March); homogeneity during circulation;
- COD: surface: 2 to 25 mg/L; bottom: 2 to 15 mg/L; parameter with low spatial variations;
- Fe: surface: 0.1 to 3 mg/L; bottom: 0.1 to 9 mg/L (resuspension during circulation period);
- Total phosphate (PO_4): surface: 0.01 to 0.2 mg/L; bottom: 0.01 to 0.35 mg/L; resuspension during circulation; higher values in cold periods, due to reduced phytoplankton assimilation;
- Ammonium nitrogen ($N\text{-}NH_4$): surface: 0.1 to 1 mg/L; bottom: 0.1 to 2 mg/L;
- Nitrate nitrogen ($N\text{-}NO_3$): surface: around 0.01 mg/L; bottom: 0.05 to 0.4 mg/L;

The phytoplankton density presented over the last decade mean values of 10000-20000 cel/mL. Since 2004, when sewage diversion was implemented, density reached a maximum value of 8000 cel/mL, showing the effect of this restoration measure. However algae populations are still high, indicating the importance of diffuse pollution for the phytoplankton growth. The currently dominant cyanobacteria taxon is *Microcystis,* which is able to release cyanotoxins (microcistin).

Limiting nutrient

The determination of the limiting nutrient is a fundamental step in the understanding of the ecological behaviour of cyanobacteria. Generally in tropical climates eutrophic waters are N limited while oligotrophic waters are P limited (Ryding and Rast, 1989). Reasons for N limitation in polluted tropical waters are sewage discharge (low N/P), denitrification (N lost from the bottom of the lake) and P release from sediment (internal fertilization, with consequent decrease of N/P). On the other hand further processes, such as nutrient excretion by zooplankton and metabolism of algae and bacteria) can significantly change N/P values. Researches carried out in a tropical urban reservoir (Pampulha Lake, Brazil) have shown a clear increase in N/P ratios proportional to the distance from sewage discharge, i.e., in this case phosphorus was turning progressively limited. (Pinto-Coelho et. al., 2003).

Table 1 shows the average N/P relationship in two depths: 0,5 m and 5 m. It can be seen that the highest N/P values are registered in July, i.e., shortly after the onset of the circulation process. The lowest values are found in March/April, following the rainy period. The limnological explanation of this pattern is probably the larger phosphorus assimilation by the algae in periods of higher water transparency, what happens in the winter time. N/P values are higher at the surface of the water body, where phosphorus uptake is enhanced. All results show that phosphorus play the role of limiting nutrient (values over 16). This shortage of phosphorus should avoid the dominance of cyanobacteria, as extensively reported in the technical literature (Forsberg and Ryding, 1979; Shapiro, 1990 and 1997; Cooke et. al., 1993; Chorus and Bartram, 1999). However an opposite trend has been registered in Vargem das Flores Reservoir, where blooms of *Microcystis aeruginosa* and *Cylindrospermopsis raciborskii* could not be coupled with low N/P ratios. Researches in Salto Grande Reservoir, Brazil (Deberdt,

Table 1. Average N/P relationships at different depths

	O.5 m	5 m
January	114	59
February	65	24
March	46	26
April	19	23
May	84	20
June	111	16
July	173	100
August	115	81
September	127	55
October	135	78
November	130	73
December	99	42

2002) have also shown a reverse trend to the conventional assumption, i.e., cyanobacteria growth has been registered under conditions of high N/P. This means that other factors (grazing, sedimentation) may be involved in the complex relationship between N/P values and cyanobacterial blooms. Moreover it should be observed that high N/P values do not obligatorily means phosphorus deficiency. This could point out to high phosphorus recycling rates, which are a frequent issue in tropical aquatic systems.

Management strategies

For the restoration of Vargem das Flores Reservoir some preventive and corrective measures are currently under implementation. Since the point source pollution can be effectively controlled by one single action, i. e. the construction of wastewater treatment plants, especial attention has been dedicated to combat the more complex non-point pollution. Some of the adopted measures include limitation of agricultural use in the watershed (through the enforcement of current legal determinations), control of recreational activities (by limiting the number of visitors and by introducing a strong movement of environmental education), erosion control by hydroseeding (at the steeper slopes of the drainage basin) and use of natural wetlands. Moreover specific techniques are now being tested in order to avoid algae input in the water abstraction tower: the installation of plastic barriers, similar to those used for oil pollution control and the construction of an air curtain device, which should also prevent phytoplankton from reaching the abstraction point.

Conclusions

The results of thirty years of monitoring in Vargem das Flores Reservoir point out to an increasing deterioration of the water quality over the time. The reasons for this behaviour can be summarized in the existence of point sources of pollution (sewage discharge), as well as diffuse sources (agricultural and recreational uses, run-off from urban areas). Cyanobacteria blooms occur frequently in the water body, leading to a serious concern about the production of toxic metabolites. Dominance of cyanobacteria is not coupled with low N/P values, as usually assumed in the technical literature. The implementation of preventive and corrective techniques should drastically change the current situation.

References

Azevedo, S.M.F.O., Evans, W.R., Carmichael, W.W. and Namikoshi, M. (1996). First report of mycrocystins from a Brazilian isolate of the cyanobacterium *Microcystis aeruginosa. Journal of Applied Phycology* Vol. 6, pp. 261-265.

Chorus, I. and Bartram, J. (1999). *Toxic cyanobacteria in water: a guide to public health consequences, monitoring and management.* World Health Organisation. London.

Cooke, G.D., Welch, E.B, Peterson, S.A. and Newroth, P.R., (1993). *Restoration and management of lakes and reservoirs.* Lewis Publishers, Boca Raton.

Deberdt, G.L.B. (2002). *Cyanobacterial studies in reservoir with high trophic degree* (in Portuguese). PhD Thesis, University of São Paulo, Brazil.

Forsberg, C.G. and Ryding, S.O. (1979). Eutrophication parameters and trophic state indices in 30 Swedish waste water receiving lakes. *Arch. Hydrobiol.* Vol. 89, pp.189-207.

Pinto-Coelho, R., Bezerra-Neto, J.F., Giani, A., Macedo, C.F., Figueiredo, C.C. and Carvalho, E.A. (2003). The collapse of *Daphnia laevis* (Birge, 1878) population in Pampulha Reservoir, Brazil. *Acta Limnologica Brasiliensia* Vol. 15, pp. 53-70.

Ryding, S. and Rast, W. (1989). *The Control of Eutrophication of Lakes and Reservoirs.* UNESCO, Paris.

Shapiro, J. (1990). Current beliefs regarding dominance by blue-greens: the case for the importance of CO_2 and pH. *Verh. Internat. Verein Limnol.* Vol.24, pp. 38-54.

Shapiro, J. (1997). The role of carbon dioxide in the iniciation and maintenance of blue-green dominance in lakes. *Freshwat. Biol.* Vol. 37, pp.307-323.

von Sperling, E. (1996). Mechanisms of eutrophication in tropical lakes. *Environmental Pollution* Vol. 3, pp.434-439.

Contact addresses

Eduardo von Sperling,
Professor, Department of Sanitary and Environmental Engineering, Federal University of Minas Gerais, Av. Contorno 842; 30110-060, Belo Horizonte, Brazil.
Email: eduardo@desa.ufmg.br

Lenora Nunes Ludolf Gomes,
Biol. PhD Student, Federal University of Minas Gerais, Brazil.

Amilton Diniz e Souza, Biol., PhD in Sanitary Engineering, Federal University of Minas Gerais, Brazil.