# THE ISOLATION OF RIO GRANDE FROM BILLINGS RESERVOIR, SÃO PAULO, BRAZIL: EFFECTS ON THE PHYTOPLANKTON

[O isolamento do Rio Grande da Represa Billings, São Paulo: efeitos sobre o fitoplâncton durante um ciclo hidrológico completo]

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#### ABSTRACT

The Rio Grande Reservoir belongs to the Billings System which detains the highest water volume stored in the metropolitan area of the city of São Paulo. In 1981, a dam was built to isolate it from Billings Reservoir in order to improve the water supply of some cities in São Paulo State. The effects of the isolation on the phytoplankton were evaluated through the relationships with environmental variables. Phytoplankton and environmental variables were studied from March 1985 to March 1986 at Stations 1, 2 and 3, located respectively at 1, 6 and 10 km from the dam, in the depths correspondents to 100; 25; 1 and 0% of transparency to the Secchi Disc. Among the 45 identified genera, 44% were green algae, 27% flagellated, 16% blue-green and 13% diatoms. Previous studies showed dominance of Cyanophyceae/ Cyanobacteria and Chlorophyceae, whereas after the isolation Chlorophyceae and Bacillariophyceae were dominant, indicating water quality improvement. However, in August-1985 (winter) a bloom of Asterionella formosa (dominance = 96%) inversely correlated with the water Si content (Rs = -0.51 \*\*\*), reported at 1% of transparency depth in Station 1, was registered just when a smell of benzene hexachloride caused problems in the drinking water. Other bloom, of Staurastrum species (> 80%) was registered in January-86 (summer) at 25% of transparency, in Stations 2 and 3. The results indicate that the improvement attained was still fragile and could have been easily reversed, allowing problems to the supply, triggered even by climatic events.

**Key words:** water supply; phytoplankton; Billings Reservoir; *Asterionella formosa*; *Staurastrum* spp; light attenuation depth

### RESUMO

A represa do Rio Grande pertence ao sistema Billings, que detém o maior volume de água armazenado na Região Metropolitana de São Paulo. Em 1981 foi construída uma barragem isolando-a da Represa Billings, com o objetivo de melhorar o suprimento de água. Avaliaram-se os efeitos deste isolamento no fitoplâncton, à luz das variáveis ambientais estudadas simultaneamente entre março de 1985 e março de 1986. As amostras foram obtidas nas estações 1, 2 e 3, respectivamente a 1, 6 e 10 km da barragem nas quatro profundidades correspondentes a 100; 25; 1 e 0% da transparência ao Disco de Secchi. Entre os 45 gêneros de algas identificados, 44% eram verdes, 27% flageladas, 16% azuis e 13% diatomáceas. Estudos prévios evidenciavam a dominância de Cyanophyceae/Cyanobacteria e Chlorophyceae. Após o isolamento, Chlorophyceae e Bacillariophyceae passam a dominar, indicando uma possível melhora da qualidade da água. Entretanto, em agosto/85 (inverno) uma floração de Asterionella formosa (dominância = 96%), inversamente correlacionada ao teor de Si na água (Rs = -0.51 \*\*\*), foi registrada na Estação 1, na profundidade correspondente a 1% de transparência, simultânea à ocorrência de um odor de hexacloro benzeno (BHC) que causou problemas ao abastecimento. Em janeiro/86 (verão), uma floração de espécies de Staurastrum (>80%) ocorreu nas estações 2 e 3, a 25% de transparência. Estes resultados indicam que a melhora não foi suficiente para impedir a ocorrência de florações problemáticas ao abastecimento, até mesmo as favorecidas por eventos climáticos.

**Palavras-chave:** abastecimento público; fitoplâncton; Represa Billings; *Asterionella formosa*; *Staurastrum* spp; profundidade de atenuação da luz

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### Introduction

In the early decades of the XX century, the relatively low human population and the abundance of waterbodies near the city of São Paulo meant that the environmentally responsible authorities were not concerned about water pollution. As in most other cities in the world, the depuration capacity was considered unlimited.

The main water supply for São Paulo State is the great basin of Tietê - Paraná Rivers to which the Billings System belongs (Figure 1). The High Tietê Basin currently includes three reservoirs: Guarapiranga, which provides 30% of the water supply for the city of São Paulo (BEYRUTH, 1996), Rio das Pedras, which stores water exclusively for energy generation, and the Rio Grande reservoir.

The Billings System is a dendritic artificial lake located near the city of São Paulo between 23° 42' and 23° 45' S and 46° 26' and 46° 42' W at an altitude of 760 m (TUNDISI, 1981). The word "System" is used because it is constituted by rivers from the Tietê Basin, artificially pumped to another basin, the Cubatão Basin, in order to supply water to the Henry Borden Energy Plant. Other uses of this system include leisure, fisheries, flow control, domestic and industrial wastewater reception, and prevention of saline intrusions from the estuary through the river Cubatão (CETESB, 1996a).

It took around ten years for Billings Reservoir to be completely filled (1927-1937). At its highest water level, it covers 127 km<sup>2</sup> and the total water volume is 1200 x 10<sup>6</sup> m<sup>3</sup>. Their 900 km of perimeter were mostly surrounded by a sub-tropical forest (HUELK, 1956). The drainage basin (560 km<sup>2</sup> large) includes several rivers, streams and brooks: Grande, Pequeno, Capivari, Pedra Branca, Taquacetuba, Alvarenga, Bororé and Cocaia. The highest air temperatures for the region typically occur from December to March (21 - 22°C), while the lowest ones occur in June - July (14 -15°C). Rainfall is higher in January (214 mm), lower in July (39 mm). The system is polymictic, stratificating only in warm summer days and its peculiar morphology produces simultaneous and different patterns of heat and chemical distribution at each one of its branches (CHREA, 1996).

During the construction of the Via Anchieta highway in the 1940's, Rio Grande Reservoir branch was partially isolated from Billings Reservoir, with only a narrow by-pass linking both under a bridge of that highway (ROCHA, 1984). From 1958 on, the water from Rio Grande Reservoir has been collected in order to supply water to satellite cities such as São Bernardo do Campo, Santo André and São Caetano do Sul, and a treatment plant was built in the basin, providing water at 2 m<sup>3</sup> s<sup>-1</sup>. Now it provides 3.25 m<sup>3</sup> s<sup>-1</sup> and also serves the cities of Ribeirão Pires and Rio Grande da Serra.

Billings Reservoir was relatively free from pollution until 1950, but for many years a large part of the sewage and industrial wastes generated in the city of São Paulo have been discharged into Billings Reservoir, having a negative effect on the water quality (CETESB, 1996a; b). In 1958 due to the increasing pollution, limnologic and sanitary surveys began, and blooms of *Microcystis aeruginosa* were reported near the intake for the public water supply (Branco, 1959, *apud* ROCHA, 1992; PEREIRA, 1987; PALMER, 1960).

Among 17 reservoirs studied in 1979, Rio Grande was classified by physical and chemical parameters, including chlorophyll-*a*, as one of the three most eutrophic reservoirs of São Paulo State, surpassed only by the main body of Billings and by Rio das Pedras Reservoirs, the latter being fed by the effluent of Billings itself (MAIER and TAKINO, 1985a; b). The high Cyanophyta/Cyanobacteria and total phytoplankton densities (>3800 org.ml<sup>-1</sup>), allowed XAVIER; MONTEIRO-JÚNIOR; FUJIARA (1985) to classify this reservoir as eutrophic.

The high demographic growth in the region during the last decades, has demanded a change in management practices to maintain a suitable water quality. So, in 1981 the Rio Grande branch was definitively isolated from Billings Reservoir through the Anchieta dam located under Via Anchieta. During 50 years the trophic state of Rio Grande reservoir had been mainly due to sewage received indirectly from the city of São Paulo via the Tietê and Pinheiros rivers, pumped into Billings Reservoir. After the isolation, its original contributor rivers, Ribeirão Pires and Rio Grande, became its major tributaries again. One of the intended benefits of this isolation was to improve the water quality to guarantee the water supply intake.

The Rio Grande Reservoir, classified by MAIER and TAKINO (1985a) as polymictic and eutrophic, is situated

at 23° 46' S and 46° 38' W, in the altitude of 746.5 m and in a tropical wet climate. Its mean depth is 10 m with circulation between May and September. The polymictic circulation pattern was suggested by the low amplitude of temperature, dissolved oxygen, pH and conductivity variations in the water column. The fluctuation in the termic profile indicates an unstable thermal regime with short periods of daily and nightly circulation and stratification (MAIER; TAKINO; SANTOS, 1983). The analyses of physical and chemical parameters during 1982-83 showed



Figure 1. Sampling Stations; Station1: 1 km from the Dam; Station 2: 6 km; Station 3: 10 km, at Rio Grande Reservoir, in 1985-1986

that the decreasing ionic content after the isolation was due to dilution (TAKINO and MAIER, 1986).

The purpose of this research was to study how the complete isolation of the Rio Grande branch has affected the phytoplankton community and its relationship with environmental conditions and the quality of the water produced.

# Methodology

From March 1985 to March 1986, the water of three stations in Rio Grande Reservoir, located at 1; 6 and 10 km from the dam (Figure 1), were monthly sampled for environmental and phytoplankton analyses. At every station, unconcentrated water samples (350 ml) were taken at the depths correspondents to 100; 25; 1 and 0% of the transparency to the Secchi Disc, totalizing 1.4 L by sampling station, used for quantitative analyses of phytoplankton by sedimentation method (SOURNIA, 1978). At least 4 ml of water was sedimented and 200 organisms counted by sample.

Phytoplankton data were related to the following environmental variables (analyzed according to APHA, 1984): precipitation (PPT), water temperature (WT), color (COL), turbidity (TUR), alkalinity (ALK), conductivity (COND), pH (pH), depth (DEP), transparency – 100; 25; 1 and 0% (TRN), dissolved oxygen (DO), biochemical oxygen demand (BOD), oxidability (OX), Secchi Depth Extinction (SDE), phosphorus (PO<sub>4</sub>), ammonium (NH<sub>4</sub>), nitrate (NO<sub>3</sub>), nitrite (NO<sub>2</sub>), silica (Si) and iron (Fe).

Indices of the community structure such as density and number of taxa were used (ODUM, 1988). The relationship between phytoplankton and environmental variables was shown with the Spearman rank correlation test (SIEGEL, 1975), being P<=0.005, 0.05 < P < 0.025 and P < 0.050 described by \*\*\*; \*\*; and \*, respectively, and with the detrended canonical correspondence analysis. The sample scores were weighed by mean genera scores with data transformed by ln(x+1), according to TER BRAAK (1986).

The sum of the differences of population densities between successive samples was used to indicate the level of changes in the phytoplankton composition.

In order to investigate whether the desired conditions were attained and maintained, trends of species dominance observed throughout this study were compared to those obtained in studies made before the isolation of this branch and also to results obtained in more recent studies.

### **Results and Discussion**

The population densities of *Asterionella formosa*, *Mougeotia* sp., *Peridiniopsis* sp., *Staurastrum* spp. and others recorded through time and space during the study period are shown in Figure 2, and richness of each sample (S) in Figure 3. The mean number of taxa was generally high in Station 3 and higher at 25% than at 100% water transparency, which may be related to the optimal light level for photosynthetic activity, as shown by PALMER (1960).

Station 1, the closest to the dam, eventually received copper sulfate to control algae nuisances, which may explain the relatively low phytoplankton densities and lower richness found there. This station presented its higher densities in August (winter), with a conspicuous dominance (greater than 96%) of Asterionella formosa. The lowest densities at this station occurred in early and late spring and in early autumn. At all depths, Station 2 and 3 showed maximum densities in January (summer), with Staurastrum species dominant at greater than 80%. At Station 2 the dominance exceeded 89% and the number of taxa was low. However, at Station 3 the highest number of taxa was recorded in January. Basically the species richness increased from Station 1 to 3. Higher densities generally occurred at 100 and 25% water transparency, while the lowest ones occurred at 0% water transparency, as expected.

Asterionella formosa and Staurastrum spp. were the main dominant taxa between 1985-86. Density of Staurastrum increased from Station 1 to 3, except for the maximum at 25% transparency. Asterionella formosa decreased from Station 1 to 3. The isolation of Rio Grande from Billings Reservoir



**Figure 2.** Phytoplankton density at stations 1;2;3 and at transparency depths of 100; 25; 1 and 0%, at Rio Grande Reservoir, in the period 1985-1986



**Figure 3**. Phytoplankton richness at stations 1; 2; 3; and at transparency depths of 100, 25, 1 and 0%, at Rio Grande Reservoir, in 1985-1986

Copper sulphate has been used to control alga nuisances at Station 1, but it was not effective against this diatom. The highest peak of nutrients in the reservoirs of São Paulo State was usually recorded in June due to concentration during the dry cold season, but another less conspicuous peak may occur during the rainy, warm season in January, due to runoff and water mixing resulting from climatic events such as storms and wind, even in less eutrophic basins (MAIER, pers. com., and BEYRUTH, 2000). Table 1 shows range and medians of the environmental variables.

In the warm, wet summer, high values of water turbidity, color, iron,  $PO_4$ , BOD, conductivity and alkalinity were registered. These values were due to water circulation and high inputs from runoff. *Staurastrum* was dominant, reaching its highest density, 3900 org. ml<sup>-1</sup>, at 25% water transparency. In the dry, cold winter, water stability and transparency were high and *Asterionella formosa* was dominant, reaching its highest density, 1900 org.ml<sup>-1</sup>, at 1% water

transparency. Its density was inversely correlated to the Si content of the water (Rs=-0.51\*\*\*). The Si concentration was higher in June, immediately before this bloom, indicating a considerable uptake of this nutrient by *Asterionella*.

From the results of RDA, CCA and DCCA, the latter is being used due to its highest eigenvalues and percentages of explanation of the first two axes. The results of the DCCA analyses are expressed by the Figures 3, 4 and 5. Figure 3 shows the distribution of the environmental variables along the first two axes, Figure 4 the species scores and Figure 5 the stations scores, centered.

Axis 1 of the DCCA analysis can be interpreted as the gradient between the wet, warm, dilution conditions of summer, to the dry, cold, concentration conditions of winter with the extreme conditions in January and June-July-August (Figure 6). During the intervening period along this gradient established from summer to winter, some other algae such as *Mougeotia, Trachelomonas*, or *Peridiniopsis* spp

**Table 1.** Environmental variables: total range (TR), and median of the total (TM) and medians (M) for each station and depth (station. % of transparency), at Rio Grande Reservoir, in 1985 - 1986

	(TR) TM	Μ	Μ	Μ	Μ	Μ	Μ	Μ	Μ	Μ	Μ	Μ	Μ
		1.100	1.25	1.1	1.0	2.100	2.25	2.1	2.0	3.100	3.25	3.1	3.0
РРТ	(78-321) 5	78	78	78	78	78	78	78	78	78	78	78	78
DEP	(7.5-11) 3.1	10.0	10.0	10.0	10.0	7.5	7.5	7.5	7.5	5.0	5.0	5.0	5.0
TRN	(0-100) 0	100	25	1	1	100	25	1	0	100	25	1	0
SDE	(2.2-10) 0	0.00	1.73	5.60	5.60	0.00	1.60	4.45	6.50	0.00	1.40	2.83	4.03
WTE	(23.95-29) 16	24.3	23.5	24.0	24.0	24.0	24.0	22.3	22.0	24.0	23.0	24.0	24.0
рН	(7-9.5) 6.1	7.00	7.05	7.00	7.00	6.95	7.05	7.2	7.00	7.15	7.25	6.90	7.00
Si	(1.3-10.3) 0.05	1.05	1.01	1.22	1.22	1.28	1.29	1.28	1.30	1.28	1.40	1.50	1.62
TUR	(5.5-100.0) 1.6	3.4	3.4	3.6	3.6	5.5	5.7	6.4	6.4	7.5	7.5	7.8	8.4
ALK	(15.9-27.0) 6.7	14.16	13.48	15.73	15.73	15.73	15.93	17.84	17.98	15.93	16.86	16.85	16.96
COND	(200-400) 150	200	190	200	200	200	200	205	210	200	200	200	202.5
COL	(50-190) 5	32.5	37.5	35.0	35.0	50.0	55.0	60.0	65.0	65.0	70.0	90.0	95.0
DO	(7.9-10.0) 1.4	7.9	7.8	7.4	7.4	8.3	8.5	7.7	6.3	8.9	8.3	8.4	7.4
BOD	(2.1-7.1) 0.2	1.3	1.4	1.2	1.2	1.8	2.3	2.0	2.1	2.8	3.2	4.0	3.7
OX	(3.3-8.7) 0.4	2.90	2.92	2.67	2.67	3.10	3.11	2.92	3.65	4.33	4.25	3.52	3.69
Fe	(0.49-5.04) 0.04	0.49	0.49	0.42	0.42	0.7	0.49	0.33	0.67	0.49	0.53	0.52	0.82
N-NH4	(0.7-1.6) 0.02	0.55	0.53	0.55	0.55	0.75	0.82	0.86	0.92	0.97	0.98	0.95	0.88
NO <sub>2</sub>	(2.0-34.4) 0.18	2.30	2.85	2.00	2.00	1.75	2.00	1.20	1.75	1.80	2.00	2.00	1.50
NO <sub>3</sub>	(0.17-1.43) 0.01	0.14	0.19	0.17	0.17	0.22	0.15	0.19	0.115	0.19	0.2	0.215	0.15
PO <sub>4</sub>	(30-110) 2.9	35.00	30.00	26.02	26.02	28.37	30.00	25.00	30.00	20.00	30.06	30.00	27.00

**Environmental variables:** 

PPT (mm); DEP (mg); TRN (%); SDE (m); WTE (°C); pH; Si (mg.L<sup>-1</sup>); TUR (NTU); ALK (mg.L<sup>-1</sup>); COND (µS.cm<sup>-1</sup>25°C); COL (mg.L<sup>-1</sup> Pt); DO (mg.L<sup>-1</sup>); BOD<sub>54</sub> (20°C) (mg.L<sup>-1</sup>); OX (mg.L<sup>-1</sup>); Fe (mg.L<sup>-1</sup>); N-NH<sub>4</sub> (mg.L<sup>-1</sup>); N-NO, (mg.L<sup>-1</sup>); N-NO<sub>3</sub> (mg.L<sup>-1</sup>); PO<sub>4</sub> (mg.L<sup>-1</sup>).

The isolation of Rio Grande from Billings Reservoir



**Figure 4.** Results of DCCA Analysis: Environmental Variables of Rio Grande Reservoir, 1985-86. (PPT=precipitation; WT= water temperature; BOD=biochemical oxygen demand; COL=color; TUR=turbidity; ALK=alkalinity; COND=conductivity; TRN=transparency; DO=dissolved oxygen; SDE= Secchi Depth Extinction; OX=oxydability; DEP=depth; pH; Fe; Si; NO<sub>2</sub>; NO<sub>3</sub>; PO<sub>4</sub>; NH<sub>4</sub>)





Actinastrum (Acti); Anabaena (Anab); Aphanocapsa (Apha); Asterionella (Aste); Aulacoseira (Aula); Chlamydomonas (Chla); Chlorella (Chlo); Closterium (Clos); Coelastrum (Coel); Coelosphaerium (Coep); Cosmarium (Cosm); Crucigenia (Cruc); Cyclotella (Cycl); Cylindrospermopsis (Cyli); Dictyosphaerium (Dict); Dinobryon (Dino); Errerella (Erre); Euglena (Eugl); Eunotia (Euno); Glenodinium (Glen); Golenkinia (Gole); Gymnodinium (Gymn); Hyalotheca (Hyal); Kirchneriella (Kirc); Lepocinclis (Lepo); Micractinium (Micc); Microcystis (Micr); Monoraphidium (Mono); Mougeotia (Moug); Navicula (Navi); Oscillatoria (Osci); Pandorina (Pand); Pediastrum (Pedi); Peridiniopsis (Perp); Phacus (Phac); Phacotus (Phat); Planktosphaeria (Plan); Scenedesmus (Scen); Sphaerocystis (Spha); Staurastrum (Stau); Synedra (Syne); Tetraedron (Tetr); Trachelomonas (Trac). Dominance: highest ; high BEYRUTH and PEREIRA



Figure 6. Results of DCCA Analysis: Centered Station Scores of Rio Grande Reservoir, 1985-86.

eventually dominated when environmental conditions were favorable. All blue-green genera were positioned under axis 1, more associated with higher pH, conductivity and PO<sub>4</sub>, conditions expressed by the negative side of axis 2. *Coelosphaerium* and *Cylindrospermopsis* were associated with high precipitation and water temperature on the negative side of axis 1. The remaining blue-green genera were positioned on the positive side of this axis, tolerating the conditions of low temperature and precipitation associated with higher values of NO<sub>2</sub>, NO<sub>3</sub> and NH<sub>4</sub>. *Microcystis* density showed positive correlation with NH<sub>4</sub> (Rs=0.19\*\*).

*Trachelomonas* and *Peridiniopsis* species dominated in April and May. Chlorophyceae dominated over a broad range of environmental conditions, while other algae dominated over a narrower one. Green algae were responsible for the highest densities and number of genera, and occurred all along the gradient expressed by axis 1 and eventually by axis 2. *Mougeotia* and *Staurastrum* of the Zygnemaphyceae were among the dominant ones.

Axis 2 can be interpreted as the gradient of solubility along the water column, negatively

associated with pH and positively associated with Si, NO<sub>2</sub>, transparency and dissolved oxygen. Changes in water level, one possible indicator of solubility gradient are determined by management according to supply needs, flood control and electrical energy generation demand, in this reservoir, thus they do not usually follow seasonal patterns.

In the warm, rainy period from December to February, precipitation made its maximum contribution to dilution, and increased the input of nutrients as phosphorous, as well as organic matter from the drainage basin. By this time a second change in the dominance trends occurred, and Staurastrum spp. became dominant. Eventually, Mougeotia and Peridiniopsis species showed considerable growth. Mougeotia spp., as already mentioned, was frequent during all seasons in 1979. However, in 1985-86, their dominance was not as conspicuous and frequent, which could be due to the lower precipitation recorded during this study. Mougeotia species contribute to open water algal density mainly during summer when they can be detached from the littoral zone by storm and wind events (BEYRUTH, 1996).

The sum of differences between successive phytoplankton samples confirmed the importance of seasonality, and expressed the changes in the community mostly in regard to algal blooms. It was positively correlated to Si ( $R_S = 0.30^{**}$ ) and oxidability ( $R_S = 0.19^{*}$ ); negatively to precipitation ( $R_S = -0.44^{***}$ ), conductivity ( $R_S = -0.44^{***}$ ), water temperature ( $R_S = -0.40^{***}$ ), BOD ( $R_S = -0.32^{**}$ ), Fe ( $R_S = -0.24^{**}$ ), alkalinity ( $R_S = -0.21^{**}$ ), phytoplankton density ( $R_S = -0.39^{**}$ ), green algae density ( $R_S = -0.43^{**}$ ), blue-green algae density ( $R_S = -0.23^{**}$ ) and number of genera ( $R_S = -0.39^{***}$ ). These results indicate that the major trends in the sequence of algae dominance were allogenically determined by climatic and nutrient conditions.

The most important changes in the trends of the dominant species sequence occurred from May-July, which is dry and cold in São Paulo. In that period the autochthonous nutrients were concentrated and there was fast growth of Asterionella formosa. DUSSART (1966) noted the high capacity of this species to remove phosphorous from the water. This species is familiar and ubiquitous in meso and eutrophic lakes, showing high photosynthetic efficiency in low irradiance (REYNOLDS, 1993). This author mentions that LUND (1978), in his study of Blelham Tarn, found higher densities of this species when the previous two months were relatively dry, which also occurred in our case. The minimum precipitation was 5 mm and the mean was 110 mm, reinforcing that this period was particularly dry for the region (pers.comm. Dr. F. FUNARI, Climatology Dept. IAG-USP).

Asterionella formosa was positioned on the inferior side of axis 2 and showed positive correlation with NH<sub>4</sub> (Rs=0.32\*\*), and negative correlations with precipitation (Rs= - 0.51\*\*\*), pH (Rs = - 0.48\*\*\*), water temperature (Rs = - 0.27\*\*), Fe (Rs = - 0.26\*\*), Si (Rs = - 0.51 \*\*\*), BOD (Rs = - 0.24\*\*) and color (Rs = - 0.20\*\*). These results agree with those of VAN DAM; MERTENS; SINKELDAM (1994), who reported that Asterionella formosa was tolerant to elevated concentrations of organically bound nitrogen. The other diatoms remained on the positive side of axis 2, and were not related to the environmental exhaustion of Si, as *Asterionella*. *Eunotia* and *Synedra* were associated with the higher circulation of the rainy season.

Along with the bloom, a conspicuous BHC (benzene hexachloride) odor in the drinking water caused considerable problems and increased the costs of water treatment. It was the first report of BHC odor related with Asterionella. This odor has usually been associated with the presence of certain blue-green algae, particularly with high densities of Anabaena species in São Paulo waters, especially in Guarapiranga and Americana reservoirs (PEREIRA, 1987). Asterionella can secrete oils which impart a fishy or aromatic odor to the water (GRAY, 1994). According to PALMER (1980), Asterionella is considered one of the worst offenders among the diatoms because its geranium-like odor changes to a fish smell when their density is high. In addition to being a potential sanitary problem for the public supply, Asterionella formosa may interfere with flocculation and obstruct filters (BRANCO, 1986).

Even an extreme low density will not prevent a species to become dominant, according to SOMMER (1983) and PADISÁK (1992). The occurrence of potential toxin producers is always a matter for attention or concern in supply reservoirs exposed to eutrophication like Rio Grande. It is extremely important to determine the conditions, which favor the development of those species, because this knowledge will be useful to support management decisions taken in order to prevent alga nuisances.

Cyanophyta/Cyanobacteria did not become dominant during this period, but among those algae, *Microcystis aeruginosa*, *Anabaena* spp., *Coelosphaerium* spp. and *Oscillatoria* spp. were found and have been mentioned in the literature from São Paulo State as potential producers of toxins (BEYRUTH *et al.*, 1992; PEREIRA, 1978). *Cylindrospermopsis rasciborskii*, found in this reservoir during 1985-86, has produced blooms associated with fish death in several environments in São Paulo State during the summer in recent years. Around 1990, this species caused a bloom in Billings Reservoir, which was severely toxic to *Daphnia* during laboratory tests (CETESB, 1996a; b). In this reservoir, the conditions established during the warm season – from January to March – favored the development of *Cylindrospermopsis rasciborskii*.

Studies done before the isolation of the Rio Grande Branch showed dominance of Zygnemaphyceae, represented by Mougeotia sp., and Cyanophyceae, represented by Microcystis aeruginosa and Anabaena spiroides which often produced blooms before construction of the Anchieta dam (XAVIER, 1981a; b; Branco, 1986; Palmer, 1960; Rocha, 1984). The phytoplankton in Billings Reservoir were studied by XAVIER (1981a; b) in the years 1977-1978, with one station near our Station 3, and showed high diversities and low densities in the rainy, warm season and high densities and low diversities in the dry, cold season. Another study carried out in 1979 in Riacho Grande showed that Mougeotia and Staurastrum were dominant in March, Pediastrum in June, Synedra and Mougeotia in August, Mougeotia and Synedra in November, with Chlorophyta showing the highest densities. This reservoir was classified as eutrophic when Mougeotia spp. dominated (XAVIER; MONTEIRO-JÚNIOR; FUJIARA, 1985). Comparing the patterns of dominance before and after isolation of the Rio Grande Branch, a change from Cyanophyceae and Chlorophyceae to Chlorophyceae and Bacillariophyceae dominance was observed. The trophic conditions seemed to have returned to a less eutrophic state, but not yet sufficient to guarantee the necessary quality for supply once it was easily reversed directly or indirectly by climatic events.

Immediately after the isolation of the Rio Grande reservoir, some changes could be observed along its banks such as the establishment of industries and several recreational clubs. Some decrease in agricultural and fishing activities was also observed. Two sites in the basin of the reservoir were being used for solid waste disposal. However, none of these potential sources of pollution seemed to have severely affected the water quality until that time. The intensive biodegradation of organic matter and decreasing of nutrient inputs due to dilution could have explained the fast mineralization also observed by ROCHA (1984). By this way, the low densities found in 1992-93 near the Dam could be interpreted as indicator of a continuous and progressive improvement in the water quality, from 1986 to 1993. However, the highest level of copper among several stations sampled in Billings Reservoir by the Environmental Agency was found near the Dam (CETESB, 1996a; b), due to the intensive use of copper sulphate to control alga development. This Agency also recorded a contamination of water and sediments by mercury, from 1990 to 1993, in their annual monitoring. This shows that the low densities cannot be considered as indicator of water quality improvement, neither the autodepuration capacity of the reservoir should be overestimated, once eutrophication still persist in the reservoir, in spite of the effects of copper sulphate control and/or mercury contamination on the phytoplankton.

The phytoplankton community showed a conspicuous seasonal fluctuation. Population densities were higher in late winter and mid summer. Climatic factors, particularly precipitation and temperature, were the main forces acting upon the physical, chemical and phytoplankton variables analyzed. Climatic events with their strong influence on the hydrodynamics, interfere with nutrient and contaminant balance. Summer storms increase erosive processes, promotes water-column mixing, regeneration and input of nutrients and contaminants from the sediments and land, and are coincident in the tropics and sub-tropics, with seasonal temperature increase. In consequence, primary production intensifies, stimulating the growth of undesirable species. Climatic conditions in the tropics and subtropics in the presence of eutrophication are conducive to the development of potentially harmful opportunistic species of blue-green algae (BEYRUTH *et al.*, 1992; BEYRUTH, 2000), as well as macrophytes such as *Eichhornia crassipes* and *Pistia stratiotes* (BEYRUTH, 1992, 1994) which have been controlled in Billings System during recent decades (PALOMBO; LEMOS; PALOMBO, 1991), providing useful nutrients to the growth of the phytoplankton species.

### **Conclusions and Recommendations**

After the isolation of the Rio Grande Branch, the water quality could have been improved due to the interruption of nutrient input from the main body of Billings Reservoir. However, this study indicates that this reservoir still showed signs of eutrophication, lower than before its isolation, but sufficient to sustain blooms that interfered with water treatment.

The distribution of the phytoplankton varied with depth. This fact could be explored for the management of water intake.

The presence of potential toxin producers among the Cyanophyta/Cyanobacteria, especially *Cylindrospermopsis rasciborskii*, indicates that supplementary measures to reduce the nutrient input should be taken by managers to slow down the eutrophication process.

In spite of the belief that in tropical and subtropical environments autodepuration processes support more nutrient inputs than the temperate ones, tropical and sub-tropical environments show a higher potential for primary production during all seasons, and in most cases eutrophication processes create problems for water use related to the high productivity of environmentally harmful species, mainly of Cyanophyta and free-floating macrophytes, that have high growth rates and are able to exploit this situation.

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