Formation of the Salto Caxias Reservoir (PR) - an approach on the eutrophication process.

RIBEIRO[1,2], L.H.L.; BRANDIMARTE[2,3] A.L. & KISHI[1], R.T.

[1] Departamento de Meio Ambiente, Instituto de Tecnologia para o Desenvolvimento – LACTEC
Centro Politécnico da UFPR, Curitiba, Paraná, Brasil. C. P. 19067, CEP 81531-990.
e-mail: luiza@lactec.org.br; regina.kishi@lactec.org.br

[2]Programa de Pós-Graduação em Ciência Ambiental da Universidade de São Paulo-PROCAM.

[3]Departamento de Ecologia, Instituto de Biociências da Universidade de São Paulo, rua do Matão, travessa 14, 321, Cidade Universitária, CEP 05508-900, São Paulo, Brasil, e-mail: anabrand@ib.usp.br

ABSTRACT: Formation of the Salto Caxias Reservoir (PR) - an approach on the eutrophication process. This work discusses abiotic and biotic limnological changes after the construction of the Salto Caxias dam in the Iguaçu River (State of Paraná, Brazil). After damming, the main limnological changes were determined by the decomposition of the submerged vegetation, lixiviated soils and contributions from tributaries. There was an immediate depletion of dissolved oxygen, mainly in the hypolimnion, increase~~s~~ in the concentration of phosphorus and nitrogen, and the corresponding increase of phytoplankton biomass (evaluated through chlorophyll-a), especially in the reservoir's arms. After damming, the reservoir's characteristics are more lentic with respect to the river that originated the dam and they favored the sedimentation process and the increase of water transparency towards the dam. During the filling phase of the reservoir, the aquatic environment under study went from oligotrophic to mesotrophic conditions, and during the second year after filling, the limnological instability that was observed was still present, although there was a gradual recovery of the surface oxygen levels.

Key-words: reservoirs, eutrophication, limnological variables, damming, filling phase.

RESUMO: Formação do Reservatório de Salto Caxias (PR) - um enfoque no processo de eutrofização. Este trabalho discute alterações limnológicas abióticas e bióticas ocorridas na formação do reservatório da Hidrelétrica de Salto Caxias, no rio Iguaçu (PR). Após o represamento, por efeitos da decomposição da biomassa vegetal submersa, de material lixiviado dos solos e de contribuições através dos tributários, houve imediata depleção de oxigênio dissolvido, especialmente no hipolímnio, incrementos na concentração de fósforo e nitrogênio e conseqüente aumento da biomassa fitoplanctônica (avaliada pela clorofila-a), especialmente nos braços dos principais afluentes. Características mais lênticas do novo ambiente após o represamento, em relação ao rio que lhe deu origem, favoreceram o processo de sedimentação e o aumento da transparência da água em direção à barragem. Na transformação rio-represa, o ambiente aquático em estudo passou de condições oligotróficas para mesotróficas e no segundo ano de represamento, a instabilidade limnológica, aqui caracterizada, principalmente pela elevação dos teores de fósforo total, nitrogênio total e amoniacal, diminuição de oxigênio dissolvido e tendência a aumento da biomassa fitoplanctônica, ainda se mostrou presente.

Palavras-chave: reservatórios, eutrofização, variáveis limnológicas, represamento, fase de enchimento.

Introduction

Reservoirs are artificial ecosystems, whose characteristics are between lotic and lentic, tending towards one or the other according to their water residence times (Tundisi, 1986; Straskraba & Tundisi, 1999).

One of the fundamental characteristics of reservoir genesis processes is that nutrients, especially phosphorus and nitrogen, are released into the water. These nutrients stem from the decomposition of submerged vegetation and from soils lixiviated by the flood. If in high amounts, they may stimulate an eutrophication of the water body during the first few years after the reservoir is formed (Straskraba & Tundisi, 1999; Agostinho et al., 1999). Besides the nutrient input, the presence of backwater areas originated from the reservoir's irregular shoreline favors the blooming of algae and aquatic macrophytes, especially in tropical environments (Petr, 1978; Junk & Mello, 1990; Bianchini Jr, 1999).

As a result of the submerged vegetation's decomposition a pronounced drop in the dissolved oxygen concentration may occur, which may lead to hypoxia, or even anoxia in the aquatic environment (Baxter, 1977; Junk & Mello, 1990; Matsumura-Tundisi et al., 1991; De Filippo et al., 1999). The degree of oxygen reduction depends fundamentally on the quality and quantity of the submerged vegetal biomass and on the water temperature (Junk & Mello, 1990). In addition, when high decomposition rates occur, high ammoniacal nitrogen concentrations are observed, mainly in the hypolimnion (Matsumura-Tundisi et al., 1991).

Therefore, when compared to the existing conditions in the lotic ecosystem the formation of a reservoir leads to changes in biotic and abiotic variables, which mark a period of limnological instability. This period can be understood as a transition phase, in which occur: high concentrations of organic and inorganic ions, increase of turbidity, reduction of dissolved oxygen and predominance of aquatic communities that are resistant to the adverse conditions that appear in the aquatic environment (Goldman, 1976; Straskraba et al., 1993). The duration of this instability depends on the reservoir's morphometric features which, in their turn, depend on the place selected for the construction of the reservoir (the characteristics of the original valley that was filled) and on the basic principles determined for its operation (Tundisi, 1986; Straskraba et al., 1993; Straskraba & Tundisi, 1999; Agostinho et al., 1999). In general, however, this period is short and is limited to the reservoir's first few years when the full decomposition of organic matter and the reduction of nutrient levels occur (Straskraba et al., 1993; Straskraba & Tundisi, 1999).

Environmental sustainability demands a guarantee with respect to quality and quantity of water. It is important to keep limnological monitoring during the reservoir's formation, if possible obtaining data before and after the damming. Therefore, this work discusses the main physical, chemical and trophic state changes that occurred during the formation of the Salto Caxias Reservoir, by comparing limnological variables measured during the pre and post-filling phases.

Material and methods

The Salto Caxias power plant, owned by the Companhia Paranaense de Energia (Power Company of Paraná) – COPEL, is located in a subtropical region, southwest of the State of Paraná (Brazil). It is the fifth and last on the cascade implanted at the Iguaçu River. The reservoir filling occurred in October 1998. The Salto Caxias Reservoir's area is of 141 km², the total volume is of around 3.6 billion m³, and its main axis is around 96 km long. The reservoir maximum depth is 62 m and its average depth, 25 m. The drainage basin's total area is of 57,000 km², at the reservoir maximum operation level (325 m). The reservoir is dendritic, with a high shoreline development (14.01) and a high involvement factor (404.26), which represents the ratio between the drainage basin area and the total lake area. The theoretical retention time of Salto Caxias Reservoir is 32.5 days. At the regions reached by the flood, the area that was directly affected was covered mostly by grassland (54.4%) and agriculture (27.8%), with little forest (12%), which was concentrated along the Guarani River, a tributary at the reservoir's right margin (COPEL, 2002).

For this study COPEL's limnological database was used. This database results from data collected monthly during the pre-filling (March 1997 to February 1998) and post-filling (February 1999 to March 2001) phases. Nine water sampling stations were selected (Tab. I; Fig. 1): one downstream the dam and eight in the reservoir (three along the central axis and five in the arms that correspond to the main affluents).

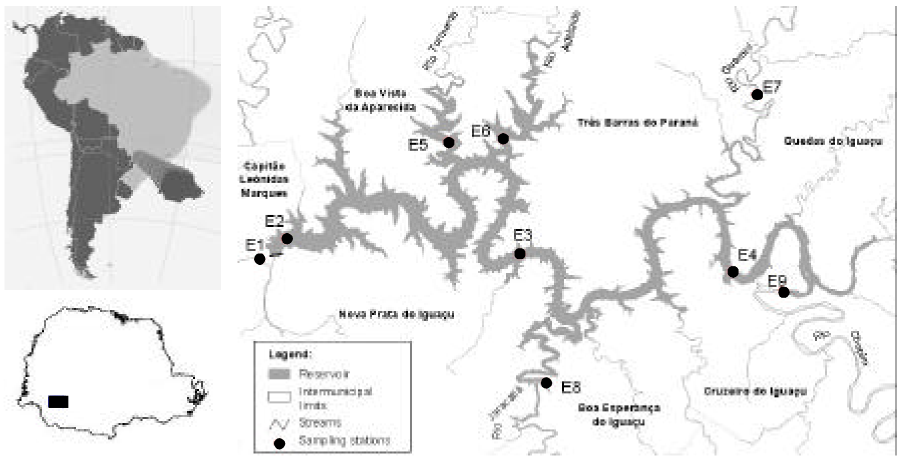

Figure 1: Sampling stations in Salto Caxias Reservoir (Paraná, Brazil).

Table I: Water sampling stations upstream, downstream and in the central axis of Salto Caxias Reservoir (Paraná, Brazil)

Sampling Stations	Description	UTM Coordinates N	UTM Coordinates E	Depth (m)	Dstance to the Dam (Km)
E1	Iguacu River - downstream	7 172 368	248 397	1 to 2	1.4
E2	Reservoir Central Axis – near the dam	7 173 903	250 418	55 to 60	1.8
E3	Reservoir Central Axis - intermediate	7 173 903	268 942	50 to 55	42
E4	Reservoir Central Axis - upstream	7 171 302	285 635	45 to 50	78
E5	Tormenta River Arm – right margin	7 181 868	263 157	8 to 9	30
E6	Adelaide River Arm – right margin	7 181 868	267 593	9 to 10	36
E7	Guarani River – discharge, right margin	7 185 442	287 484	12 to 14	110
E8	Jacacatiá River Arm – left margin	7 162 473	270 982	9 to 10	66
E9	Chopim River – discharge, left river	7 169 806	289 573	4 to 5	90

The limnological variables analyzed at the water surface (around 0.30 m deep) were: dissolved oxygen (DO), with respect to saturation percentage, water transparency measured with a Secchi Disk, total phosphorus, reactive phosphorus, total nitrogen, ammoniacal nitrogen, total solids and chlorophyll-a. By means of a membrane electrode, the oxygen and the temperature were also measured, every meter along the water column at the reservoir's deepest area (E2). The analysis methodologies followed APHA (1998) and chlorophyll-a was determined according to Jeffrey & Humphrey (1975), through a 664nm spectrophotometry, after extraction in 90% acetone. The reservoir's Trophic State Index (TSI) according to Carlson (1977), modified by Toledo (1990), was calculated by the arithmetic mean between phosphorus index (TSI phasphorus= $10 \{6 - [\ln (80.32 / P) / \ln 2]\}$) and chlorophyll-a index (TSI chlorophyll = $10 \{6 - [(2.04 - 0.695 \ln CL) / \ln 2]\}$), where P and CL are phosphorus and chlorophyll-a concentrations, respectively, in mg/L. The evaluation criteria for this index is:

TSI£44=Oligotrophic; 44<TSI£54=Mesotrophic; 54<TSI£74=Eutrophic; TSI>74=Hypereutrophic.

Variance Analysis (ANOVA) was applied to the limnological variables in order to observe those alterations that showed a minimum significance level of 5% (“p”‹0.05). For comparative analysis purposes, the data were treated separately for the three different phases, which were the pre-filling phase, Year 1 post-filling phase (from April 1999 to March 2000) and Year 2 post-filling phase (from April 2000 to February 2001).

For the DO saturation level percentage, which was the variable that showed a normal (or symmetric) distribution, results will be presented through their arithmetic mean value, while the other variables will be presented through their median, once they showed an asymmetric distribution (Girden, 1992). In addition to these trends noticed in the statistical analysis, results will also be presented in terms of the average concentration of each limnological variable that correspond to the reservoir’s pre and post-filling periods, together with the respective Standard Deviation (SD).

Results

In the lake, close to the dam, the Salto Caxias Reservoir showed warm monomictic characteristics (Fig. 2), which are favored by the depth of E2 sampling station (around 60 m). A short circulation period (isothermy) occurred between June and August, and thermal stratification was detected, in general, from September to May. The higher thermal stability occurred between December and March, when the thermocline was between 7 and 10 m deep.

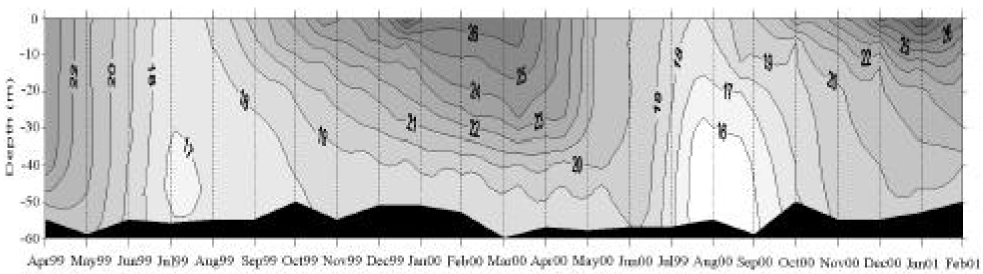

Figure 2: Time series of isotherm depths in Salto Caxias Reservoir.

The dissolved oxygen showed stratification along the water column during most part of the two-year period after damming (Fig. 3). Hypolimnetic anoxia was already noticed during the first months of monitoring and high DO deficits occurred during the months in which there was high temperature and great thermal stability.

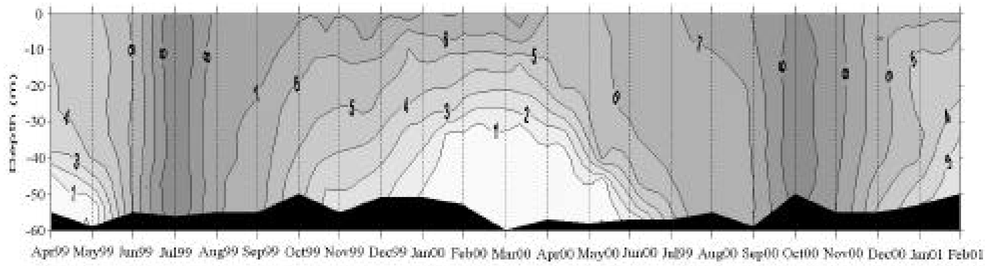

Figure 3: Depth-time distribution of isopleths of dissolved oxygen (mg/L) in Salto Caxias Reservoir.

After damming, most sampling stations showed a tendency to reduction of the DO average levels at the water surface (Fig. 4). Mean saturation levels vary between 86% and 100% during the reservoir's pre-filling period (overall mean value = 90.20 ± 7.22 %), between 77% and 89% during Year 1 post-filling period (overall mean value = 82.63 ± 13.02 %), and between 69% and 95% during Year 2 post-filling period (overall mean value = 82.49 ± 12.53 %).

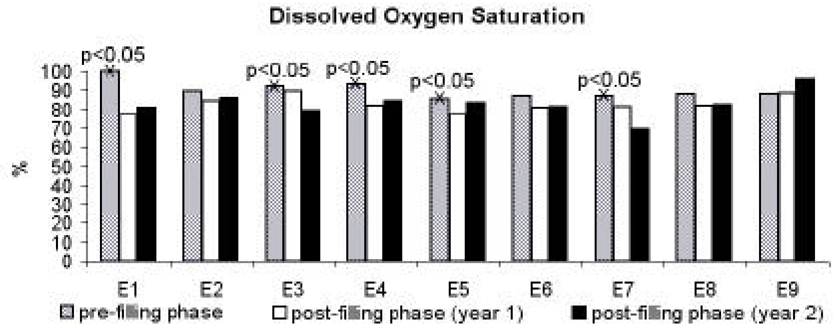

Figure 4: Mean values of DO saturation percentages at the sampling stations in Salto Caxias Reservoir.

Increases of the phosphorus and nitrogen total were registered at the water surface after damming and the latter nutrient had its alterations in a higher significance level. There were significant increases ($p<0.05$) of phosphorus along the upstream axis (E4) and at the Tormenta (E5) and Guarani (E7) arms during the post-filling phase (Fig. 5). For nitrogen, significant increases were found in most sampling stations (Fig. 6). Phosphorus overall mean values were similar during the pre and post reservoir formation periods: 0.036 ± 0.025 mg/L and 0.036 ± 0.009 mg/L, respectively.

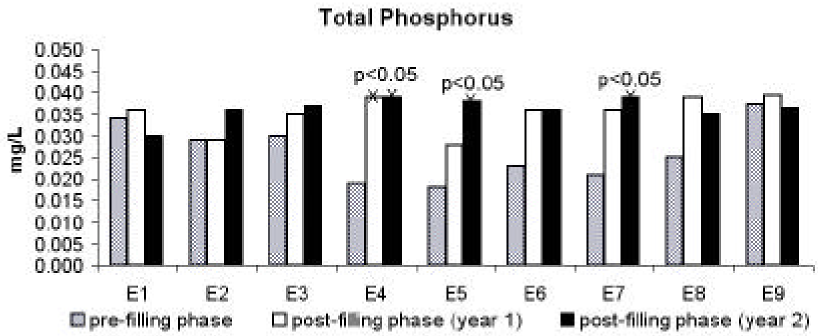

Figure 5: Variations of total phosphorus expressed in medians, at the sampling stations in Salto Caxias Reservoir.

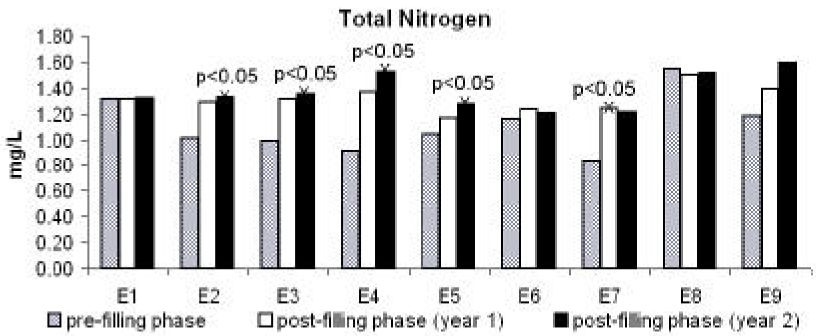

Figure 6: Variations of total nitrogen expressed in medians, at the sampling stations in Salto Caxias Reservoir.

Pulses of total phosphorus occurred during summertime when maximum concentrations coincided with the rain increase at the region. They were higher in the river phase, greater than 0.10 mg/L, than in the reservoir phase, where they did not exceed 0.06 mg/L. The nitrogen overall mean value registered during the pre-filling period was of 1.11 ± 0.34 mg/L and was higher after damming, especially during the second year, when it reached 1.32 ± 0.42 mg/L. At the Jaracatiá River arm (E8), there was a tendency to higher nitrogen concentrations in both phases where maximum peaks were registered between 2.00 and 2.60 mg/L. During the post-filling period, specially during summer, between 2000 and 2001, high magnitude peaks also occurred at the Tormenta River arm-E5 (2.12 mg/L) and upstream the central axis-E4 (3.90 mg/L).

Along the longitudinal axis there was a phosphorus and nitrogen concentration gradient, with reductions towards the dam (E4-E2 direction), especially during the second year after damming.

With respect to the phosphorus inorganic fraction at the water surface, which corresponds to orthophosphate or reactive phosphorus, the concentration generally tended to reduce after damming, especially at the Tormenta (E5) and Adelaide (E6) arms, during the second year (Fig. 7). The overall mean value of reactive phosphorus in the river phase was of 0.006 ± 0.005 mg/L, with a progressive drop in the reservoir phase, reaching 0.004 ± 0.002 mg/L during the second year after filling.

The ammoniacal nitrogen concentrations at the epilimnion showed statistically significant increases at most sampling stations, especially during the second year after the formation of the reservoir (Fig. 8). The overall mean value during the pre-filling period was of 0.35 ± 0.13 mg/L and of 0.39 ± 0.08 mg/L during the second year post-filling.

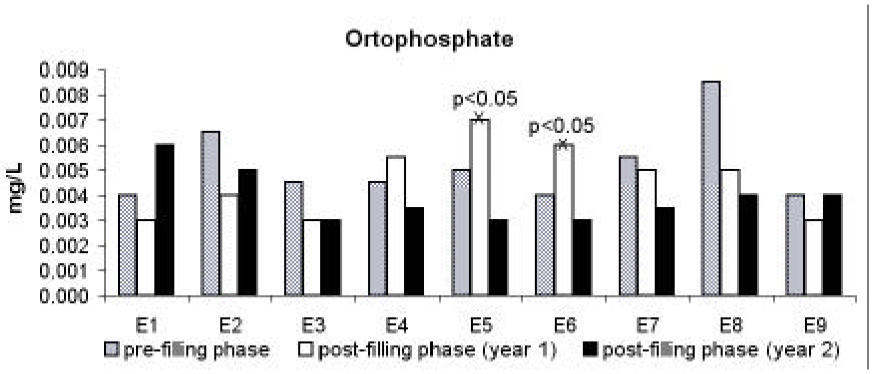

Figure 7: Variations of orthophosphate expressed in medians, at the sampling stations in Salto Caxias Reservoir.

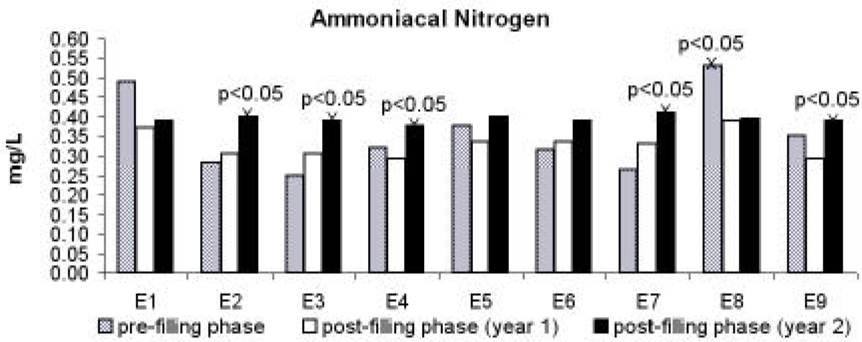

Figure 8: Variations of ammoniacal nitrogen expressed in medians, at the sampling stations in Salto Caxias Reservoir.

Total solids showed significant reductions at most sampling stations after damming (Fig. 9). The overall mean value of total solids in the river phase (66.1 ± 28.1 mg/L) was reduced during the post-filling to 46.7 ± 11.5 mg/L (Year 1) and 45.8 ± 16.8 mg/L (Year 2). In general, during the three analyzed periods, total solids showed higher concentrations at the arms than at the central axis of the reservoir.

After the reservoir's formation, there were significant increases in the water transparency at most sampling stations, with a tendency for higher values along the central axis than at the arms (Fig. 10). The overall mean values were 0.87 ± 0.66 mg/L (pre-filling phase), 1.69 ± 0.69 mg/L (first year after filling) and 1.73 ± 0.92 mg/L (second year after filling). At the arms, smaller values of water transparency were measured at rivers Tormenta (E5) and Chopim (E9).

Along the reservoir's longitudinal axis, towards the dam (direction E4-E2), there was a gradual increase in the water transparency, especially during the second year after the reservoir was filled. The median values were 1.25 m upstream (E4), 2.35 m in the intermediate section (E3) and 2.80 m close to the dam (E2).

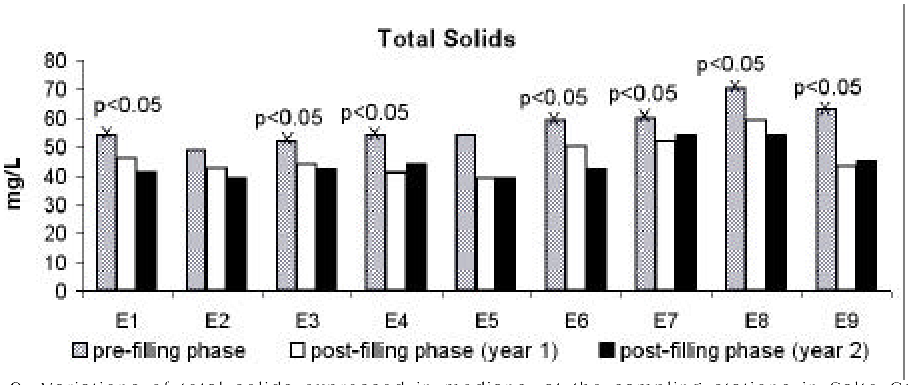

Figure 9: Variations of total solids expressed in medians, at the sampling stations in Salto Caxias Reservoir.

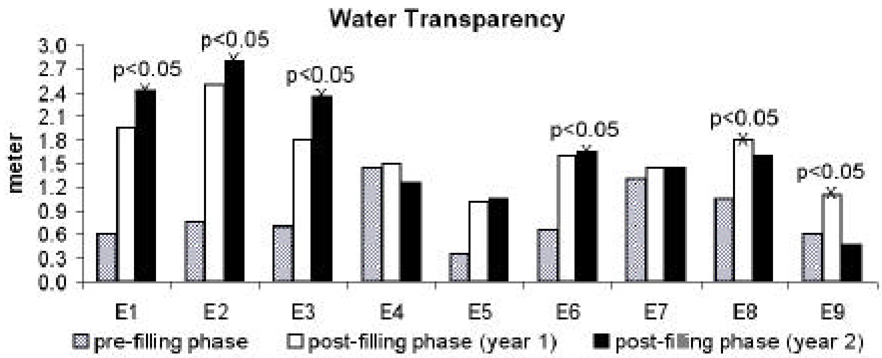

Figure 10: Secchi Disk depth variations expressed in medians, at the sampling stations in Salto Caxias Reservoir.

Increases registered in the values of chlorophyll-a after the formation of the reservoir indicated increases of the phytoplankton biomass, more intensely at the arms (Fig. 11). At these sites, median concentrations were close to 1.1 mg/L during the pre-filling phase and between 4.7 and 6.4 mg/L during the post-filling phase. Maximum chlorophyll-a peaks were registered at the Adelaide (E6) and Jaracatiá (E8) arms, being 22 mg/L and 19 mg/L, respectively, after summer 2000. The overall average in the river phase (1.98 ± 1.95 mg/L) rose to 3.88 ± 2.79 mg/L (Year 1) and 3.85 ± 3.37 mg/L (Year 2) after the formation of the reservoir. The ratio between total nitrogen and total phosphorus concentrations (N:P) at the Salto Caxias Reservoir showed median values between 30 and 40 at most sampling stations, indicating that phosphorus was, probably, the phytoplankton biomass limiting nutrient.

With respect to the trophic condition, at all sampling stations there was a change from oligotrophic, during pre-filling, to mesotrophic state, at reservoir phase, with the sole exception of the station located downstream the dam (E1), which showed oligotrophic conditions throughout the three analyzed periods (Fig. 12).

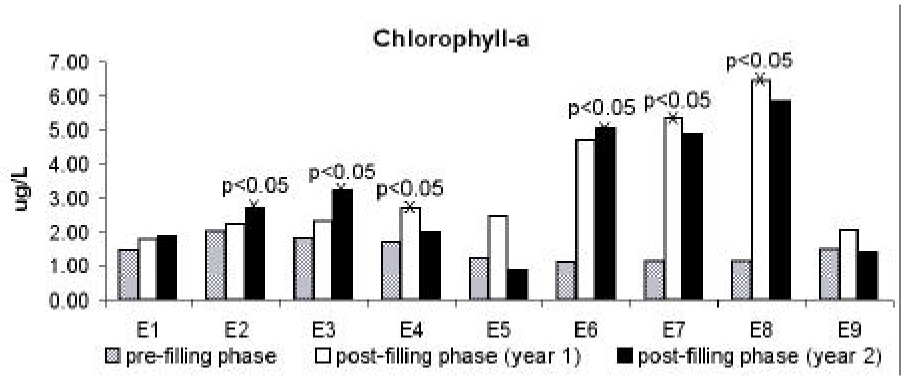

Figure 11: Variations of chlorophyll-a expressed in medians, at the sampling stations in Salto Caxias Reservoir.

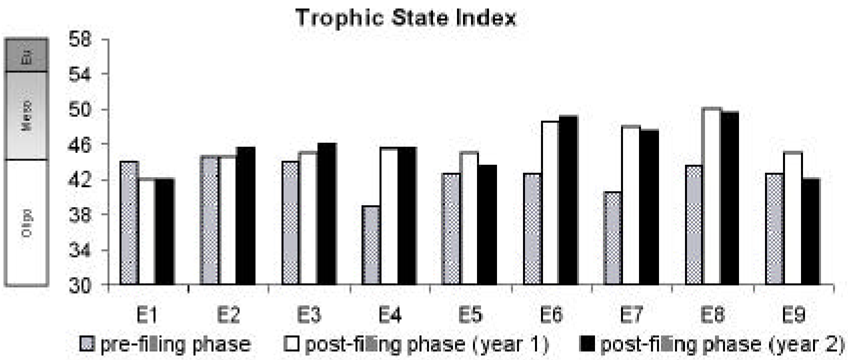

Figure 12: Average variations of Trophic State Index at the sampling stations in Salto Caxias Reservoir.

Discussion

The formation of the Salto Caxias Reservoir resulted in fairly quick changes of biotic and abiotic variables, specially the increase of total phosphorus, total and ammoniacal nitrogen, reduction of dissolved oxygen and a phytoplankton biomass increase tendency, which characterized the existence of a limnological instability during the post-filling phase.

The great reservoir's depth in the lacustrine region is favorable to warm monomictic characteristics that are also observed at the Iguaçu cascade's first two reservoirs (Thomaz et al., 1997; Ribeiro et al., 1999). The immediate decomposition of the biomass submerged by the flood was verified through the anoxia in the hypolimnion, and by the reduction of the surface oxygen levels. Anoxia in the hypolimnion was already registered during the first few months after the formation of the Salto Caxias Reservoir (April to May 1999). The continuous demand for oxygen to decompose organic matter after filling reflected in a persistent DO stratification in its vertical profile, stronger during summertime, when the temperature increase the aquatic organisms' metabolic rates. In reservoirs such as Serra da Mesa (GO) and Samuel (RO), in which large amounts of vegetal biomass were flooded and where high temperatures predominate, anoxia was already registered during the post-filling phase (Matsumura-Tundisi et al., 1991; De Filippo et al., 1999).

Besides the greater demand for oxidative reactions, oxygenation dropped because of significant current speed reductions with respect to the previous fluvial environment. Specially, reduced dissolved oxygen saturation percentages at the Guarani River, still present during the second year after damming, were a reflex of the submerged biomass' quality at this place, most of it made up of forests that belonged to the Guarani River State Park (Ribeiro, 2003).

Those increases in phosphorus and nitrogen concentrations registered at most sampling stations occurred because of the great amounts of nutrients released by the continuous decomposition that happens inside reservoir during the first few years of the Salto Caxias formation. Romanini et al. (1994) and Thomaz (personal communication) also registered gradual increases of nutrient concentration after filling of the Rosana (SP) and Corumbá (MS) reservoirs, respectively.

The phytoplankton biomass increase observed in the Salto Caxias Reservoir indicated intensive phosphorus absorption in the upper layers. The concentration reduction of reactive phosphorus at the epilimnion corroborated this observation.

When compared to the river phase, the increase of the water retention time favored the sedimentation of total solids, resulting in an increase of water transparency. However, although there was a higher availability of light at the reservoir's lacustrine portion, phytoplankton developed less in this area, when compared to the arms. This happened because of smaller nutrient availability, due to sedimentation towards the dam, and because of the constant loss of biological material, downstream, due to a bigger flow. Thomaz et al. (1997) and Thomaz (personal communication) also registered a considerable increase of the phytoplankton biomass after a damming up and the negative effect of sedimentation over this community's primary production. These aspects were observed at the lake and at downstream areas, after the formation of the Segredo Reservoir (Iguaçu River, PR) and of those dams located at the Paraná (PR) and Corumbá (MS) rivers' basins.

During the post-filling phase of the Salto Caxias Reservoir, increases of ammoniacal nitrogen concentrations on the surface layer were justified by the intense ammonification that happened in the hypolimnion, favored by the high deficits of oxygen present in this region. Ammonification is related to the decomposition of the flooded vegetation and was also observed in the hypolimnion of Samuel Reservoir (RO), during the filling phase, and at the Rosana Reservoir (SP), during the post-filling phase (Matsumura-Tundisi et al., 1991; Romanini et al.,1994).

After the formation of the Salto Caxias Reservoir, the aquatic environment under study went from oligotrophic to mesotrophic conditions, and during the second year after damming the limnological instability that was observed was still present, although there had been a gradual recovery of the surface oxygenation levels. These facts, associated to the predominance of grassland areas covered by the flooding, i.e., a relatively small flooded vegetal biomass, and to the fast filling time (around 8 days), were indications that the reservoir's stabilization can be reached in few years, provided external eutrophication factors are controlled.

Von Sperling (1994) notices that reservoirs with a high ratio between the drainage basin area and the total lake area (involvement factor), as is the case of Salto Caxias, receive a significant influence from the inputs of nutrients derived from activities developed in their respective hydrographic basins. At Salto Caxias Reservoir's contour, the potential sources for organic loads are domestic sewage, deposited in rudimentary cesspits or discharged directly, and with no treatment, into the water body, and an expressive soil occupation with agriculture and livestock breeding, especially pig breeding and poultry. At the Jaracatiá arm, high nitrogen concentrations in the water surface suggested a contribution from livestock breeding, which is a strong activity in its watershed. Regarding eutrophication, the process is favored by the reservoir's dendritic characteristics, once there is a tendency to accumulate nutrients and organic matter in its arms.

The use of the Salto Caxias Reservoir for tourism and leisure purposes has created job opportunities and has attracted investments from the municipalities in its neighborhood (COPEL, 2002), which is a positive factor for the population's quality of life improvement. Pollution control over the water is essential, as well as measures for environment sustainability, specially a proper use and occupation of the soil in the region and the identification, quantification and control of the reservoir's nitrogen and phosphorus loads.

Acknowledgements:

We thank COPEL for supplying the limnological data that were the basis for this work.

References

Agostinho, A.A., Miranda, L.E., Bini, L.M., Gomes, L.C., Thomaz, S.M. & Suzuki, H.I. 1999. Patterns of colonization in neotropical reservoirs, and prognoses on aging. In: Tundisi, J. G. & Straskraba, M. (eds.) Theoretical reservoir ecology and its applications. Backhuys Publishers - Brazilian Academy of Sciences, International Institute of Ecology, São Carlos. p.227-265.

APHA (American Public Health Association), AWWA (American Water Works Association), WEF (Water Environment Federation). 1998. Standard methods for the examination of water and wastewater. American Public Health Association, Washington, DC. 1325p.

Baxter, R.M. 1977. Environmental effects of dams and impoundments. Annu. Rev. Ecol. Syst., 8:255-283.

Bianchini Jr., I. 1999. A decomposição da vegetação e o consumo de oxigênio nos reservatórios: implicações ecológicas. In: Henry, R. (ed.) Ecologia de reservatórios: estrutura, função e aspectos sociais. FUNDIBIO - FAPESP, Botucatu. p.627-650.

Carlson, R.E. 1977. A trophic state index for lakes. Limnol. Oceanogr., 22(2): 361-369.

COPEL (Companhia Paranaense de Energia). 2002. Plano ambiental de conservação e uso do reservatório e entorno da usina hidrelétrica Salto Caxias. COPEL, Curitiba. 138p.

De Filippo, R., Gomes, E.L., Lenz-César, J., Soares, C.B.P. & Menezes, C.F.S. 1999. As alterações na qualidade da água durante o enchimento do reservatório da UHE Serra da Mesa – GO. In: Henry, R. (ed.) Ecologia de reservatórios: estrutura, função e aspectos sociais. FUNDIBIO - FAPESP, Botucatu. p.323-345

Jeffrey, S.W & Humphrey, G.F. 1975. New spectrophotometric equations for determining chlorophills a,b,c1 and c2 in higher plants, algae and natural phytoplankton. Biochem. Physiol. Pflanzen, 167:191-194.

Girden, E.R. 1992. ANOVA - Repeated measures. Sage Publications, New York., 88p.

Goldman, C.R. 1976. Ecological aspects of water impoundment in the tropics. Rev. Biol. Trop., 24:87-112.

Junk, W.J. & Mello, J.A.S.N. 1990. Impactos ecológicos das represas hidrelétricas na bacia amazônica brasileira. Estud. Av., 4:126-143.

Matsumura-Tundisi, T., Tundisi, J.G., Saggio, A., Oliveira Neto, A.L. & Espíndola, E.G. 1991. Limnology of Samuel reservoir (Brazil, Rondônia) in the filling phase. Verh. Internat. Verein. Limnol., 24:1482-1488.

Petr, T. 1978. Tropical man-made lakes – their ecological impact. Arch. Hydrobiol., 81:368-385.

Ribeiro, L.H.L., Alberti, S.M., Cunha, R.C. & Pacheco, S. 1999. Qualidade das águas superficiais da Usina Hidrelétrica de Foz do Areia para renovação da licença de operação (Relatório técnico). LACTEC - Instituto de Tecnologia para o Desenvolvimento, Curitiba. 37p.(Relatório Técnico)

Ribeiro, L.H.L. 2003. A eutrofização na formação do reservatório da Usina Hidrelétrica de Salto Caxias (PR): uma análise com vistas ao gerenciamento sustentável. São Paulo, USP, 157p (Master Thesis).

Romanini, P.U., Shimizu, G.Y., Cruz, J.A., Fontana, S.C., Carvalho, M.A.J. & Bicudo, C.E.M. 1994. Alterações ecológicas provocadas pela construção da barragem da UHE de Rosana sobre o baixo rio Paranapanema, SP/PR. Companhia Energética de São Paulo (CESP) – IBUSP, São Paulo. 153p.

Straskraba, M. & Tundisi, J.G. 1999. Guidelines of lake management: reservoir water quality management. International Lake Environment Committee Foundation (ILEC), Kusatsu. 229p.

Straskraba, M., Tundisi, J.G. & Duncan, A. 1993. State-of-the-art of reservoir limnology and water quality management. In: Straskraba, M.; Tundisi, J.G.; Duncan, A. (eds.) Comparative reservoir limnology and water quality management. Kluwer Academic Publishers, Netherlands. p.213-218.

Thomaz, S.M., Bini, L.M. & Alberti, S.M. 1997. Limnologia do reservatório de Segredo: padrões de variação espacial e temporal. In: Agostinho, A.A. & Gomes, L.C.R (eds.) Reservatório de Segredo: bases ecológicas para o manejo. UEM/EDUEM/COPEL, Maringá. p.19-38.

Thomaz, S.M. Comunicação pessoal, 2003 (Universidade Estadual de Maringá – UEM, Núcleo de Pesquisas em Limnologia, Ictiologia e Aqüicultura – NUPELIA, Maringá, Paraná, Brasil).

Toledo Jr, A.P. 1990. Informe preliminar sobre os estudos para obtenção de um índice para avaliação simplificada do estado trófico de reservatórios de regiões quentes tropicais (Relatório Técnico). CETESB, São Paulo. 11p.

Tundisi, J.G. 1986. Limnologia de represas artificiais. Boletim de Hidráulica e Saneamento, 11:1-46.

Von Sperling, E. 1994. Morphometric features of some lakes and reservoirs in the state of Minas Gerais. In: Pinto-Coelho, R. M.; Giani, A. & Sperling, E.Von (eds.) Ecology and human impact on lakes and reservoirs in Minas Gerais with special reference to future development and management strategies. SEGRAC, Belo Horizonte. p.71-76.

Received: 30 October 2004

Accepted: 06 May 2005