Acta Limnologica Brasiliensia

Publication of the Brazilian Association of Limnology

Original Article
*Acta Limnologica Brasiliensia*, 2022, vol. 34, e4
https://doi.org/10.1590/S2179-975X1221
ISSN 2179-975X on-line version

# Taquacetuba Compartment of Billings Reservoir (SP, Brazil): differential influence of the main water body and tributaries in the water quality

## Compartimento Taquacetuba do Reservatório Billings (SP, Brasil): influência diferencial do corpo de água central e dos tributários na qualidade da água

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**Cite as:** Gargiulo, J. R. B. C., et al. Taquacetuba Compartment of Billings Reservoir (SP, Brazil): differential influence of the main water body and tributaries in the water quality. *Acta Limnologica Brasiliensia*, 2022, vol. 34, e4.

**Abstract: Aim:** This research evaluated the water quality of the Taquacetuba Compartment, Billings Reservoir (Brazil), through analyzes of water quality data. The Taquacetuba Compartment has multiple uses such as public water supply and professional fishing activity and is of fundamental importance for the population of São Paulo State. **Methods:** Sampling were conducted at the Compartment entrance (P1), close to the collecting point for public water supply transposition (P2), and in the mouths of the main tributaries (P3 - P6) forming the Compartment. Samplings were concentrated in the wet and dry periods of 2017. The physical and chemical variables measured were temperature, dissolved oxygen, pH, electrical conductivity, turbidity, chlorophyll α, ammonia nitrogen, nitrite, nitrate, total nitrogen, orthophosphate and total phosphorus. **Results:** The Taquacetuba Compartment exhibited impaired water quality evidenced by high electrical conductivity, chlorophyll α and total phosphorus, above the legislation limits, classifying the sampling point as super or hyper eutrophic condition. The P1 sampling point presented the greatest environmental stress with worse water quality during the rainy season, while the other points (P2 - P6) showed an improvement during rainfalls. The P5 and P6, located at the tributaries mouth of the Monos and Curucutu River respectively, presented the best environmental conditions, evidenced by tendency to higher oxygen levels and lower turbidity in the rainy period. **Conclusions:** From the observed result, we recognized two principal sources responsible for the impairment of the water quality in the Taquacetuba Compartment: i) the contribution from the central body of Billing Reservoir, related to the greater negative influence of the water pumping from the Pinheiros River with great organic load, especially in the wet period, and ii) the contribution from the tributaries, being that the Monos and Curucutu tributaries, as they are in an indigenous reserve area have better water quality. This study recognize the importance of land use and soil occupation around the tributaries and contribute with original data to support management measures for improving water quality in the Taquacetuba Compartment.

**Keywords:** water impairment; physical and chemical water quality; eutrophication; tropical reservoir.

**Resumo: Objetivo:** Esta pesquisa avaliou a qualidade da água do Compartimento Taquacetuba, Reservatório Billings (Brasil), por meio da análise de dados da qualidade de água. O Compartimento tem múltiplos usos como abastecimento público de água e atividade de pesca profissional e é de fundamental importância para a população do Estado de São Paulo. **Métodos:** A amostragem foi realizada na entrada do compartimento (P1), junto ao ponto de captação para transposição de água para abastecimento público (P2) e na foz dos principais tributários (P3 - P6) formadores do compartimento. As amostragens se concentraram nos períodos úmido e seco de 2017. As variáveis físicas e químicas analisadas foram: temperatura, oxigênio dissolvido, pH, condutividade elétrica, turbidez, clorofila α, nitrogênio amoniacal, nitrito, nitrato, nitrogênio total, ortofosfato e fósforo total. **Resultados:** O Compartimento Taquacetuba mostrou comprometimento da qualidade da água evidenciado por elevados níveis de condutividade elétrica, clorofila α e fósforo total, acima dos limites da legislação, classificando os pontos de amostragem com super ou hiper condição de eutrofia. O ponto P1, mostrou o maior estresse ambiental, com piora da qualidade da água no período chuvoso, já os demais pontos (P2 - P6) apresentaram melhora na época chuvosa. Os pontos P5 e P6, localizados na foz dos tributários rio Monos e rio Curucutu respectivamente, mostraram as melhores condições ambientais, evidenciadas por tendência aos maiores níveis de oxigênio e menor turbidez no período chuvoso. **Conclusões:** A partir do resultado observado, reconhecemos duas fontes principais responsáveis pelo comprometimento da qualidade da água no Compartimento Taquacetuba: i) a contribuição do corpo central do reservatório Billings, relacionada à grande influência negativa do bombeamento de água do Rio Pinheiros com grande carga orgânica, especialmente durante o período das chuvas, e ii) a contribuição da bacia dos tributários, sendo que os tributários Monos e Curucutu, por estarem em área de reserva indígena, apresentam melhor qualidade da água. Este estudo reconhece a importância do uso e ocupação do solo no entorno dos afluentes e contribui com dados originais para subsidiar medidas de gestão para melhoria da qualidade da água no Compartimento de Taquacetuba.

**Palavras-chave:** comprometimento da água; qualidade físicas e químicas da água; eutrofização; reservatório tropical.

## 1. Introduction

The Billings Reservoir is located (~ 23°50'S, 46°40'W) near the Tropic of Capricorn (23°27 'S) in the São Paulo State (SP), southeastern Brazil, near Serra do Mar. The reservoir is surrounded by the urban and rural areas of six municipalities of the Metropolitan Region of São Paulo (MRSP): São Paulo, São Bernardo do Campo, Diadema, Ribeirão Pires, Rio Grande da Serra and Santo André. Inaugurated in 1927, it was built for storage and to supply water to the Henry Borden hydroelectric plant, located in Cubatão on the coast of the São Paulo State, to produce energy for one of the main industrial municipalities in the country. The Billings is currently a bedside reservoir with a dendritic shape characterized by an elongated central body and eight main compartments (arms) in addition to numerous tributaries. It is currently one of the most important freshwater bodies in the São Paulo State due to its multiple uses which include the dilution of domestic sewage, artisanal professional and amateur fishing, public supply, leisure, and navigation of ferryboats, among others (Gargiulo, 2020).

The reservoir is also used for the hydraulic regulation of Tietê River floods in the urban region of the city of São Paulo. In this case, when the water level of the Tietê River raises due to intensive and prolonged rains, part of the flow is pumped into the Billings Reservoir through ones of its tributary, the Pinheiros River (EMAE, 2021). The large amount of urban sewage in the waters of these rivers, inevitably contributes to the increase in the environmental stress of the Billings system. Thus, reversal of water from the Pinheiros River to the Billings is one of the main causes of organic pollution observed in the reservoir (CETESB, 2018). This input with huge organic load directly affects the central body of the reservoir exactly in the period when the pollutants may be diluted and transported by the increasing rains. In relation to public supply, the collection system are located in the Taquacetuba Compartment (São Paulo, 2010a), by the transposition to the Taquacetuba - Guarapiranga Production System (SABESP, 2008), and in the Rio Grande Compartment (SABESP, 2021). According to São Paulo State Environmental Agency - CETESB (2018, 2019), monitoring point close to the Taquacetuba transposition point shows concentrations of total nitrogen and phosphorus above those established by legislation (CONAMA n. 357, Brasil, 2005), and super eutrophication occurred between 2009 and 2010 (Menezes et al., 2016) and between 2012 and 2013 (Gargiulo et al., 2016). The CETESB, in its annual reports on monitoring of superficial water quality of the State, confirmed this situation of environmental stress in this location (CETESB, 2020).

In that context, the present research evaluated the physic and chemical water conditions of the Taquacetuba Compartment considering its importance for the water supply of the São Paulo city. We intended to evaluate the contribution of the tributaries and the central body of the Billings Reservoir in the water quality of the compartment, assessing the spatial and temporal variation of the water parameters, and determining the trophic state of the sampling points. As far as we known this is the first study in Taquacetuba Compartment to assess the tributaries and central body water quality in an integrated way.

## 2. Methods

### *2.1. Study area*

The Taquacetuba Compartment of the Billings Reservoir (SP) is located in the southeastern portion of the São Paulo State on the border of the municipalities of São Paulo and São Bernardo do Campo (Figure 1). The region presents a mosaic of urban occupation, agricultural activities, fragments of the Atlantic Forest and indigenous lands (São Paulo, 2010b). In this Compartment we choose six sampling points: P1 - entrance of the Taquacetuba arm near the central body of the Billings Reservoir (23°48'11.5"S 46°37'33.1"W); P2 - close to the transposition point for supply purposes (23°50'31.5"S 46°39'19.2"W); P3 - drainage of the "Colônia - Vermelho" tributary stream (23°50'51.7"S 46°40'58.8"W); P4 - drainage of the Taquacetuba stream (23°51'14.4"S 46°39'21.2"W); P5 - drainage of the Monos River (23°52'12.8"S 46°38'46.7"W); and P6 - drainage of the Curucutu River (23°51'44.6"S 46°37'04.8"W).

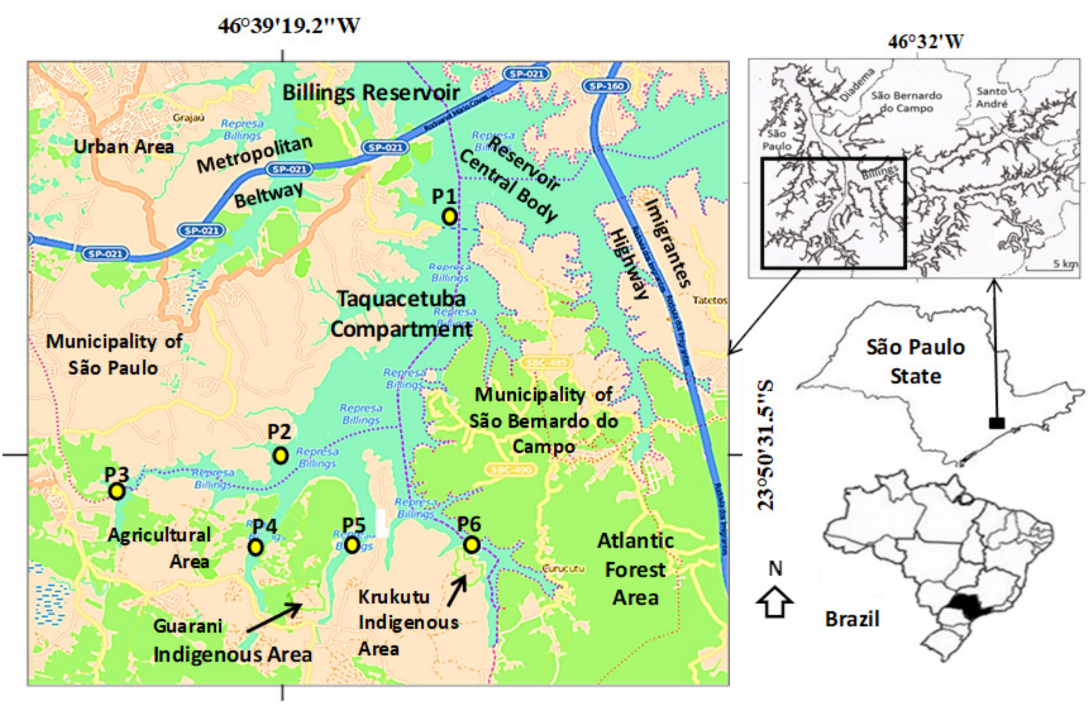


**Figure 1.** Study area and location of sampling points in Taquacetuba Compartment of the Billings Reservoir – São Paulo State (Brazil): P1: Taquacetuba Compartment entrance; P2: close to the transposition point for supply purposes; P3: Colônia - Vermelho Stream; P4: Taquacetuba Stream; P5: Monos River; P6: Curucutu River.

In the catchment of these two last tributaries are located the indigenous areas of "Guarani da Barragem" and "Krukutu" respectively.

The current legislation for assessing surface water quality in the State of São Paulo, are: i) the Decree n. 8468 (São Paulo, 1976), which defines classes of use, and ii) the Decree n. 10755 (São Paulo, 1977), which presents the framework of water bodies for the State. The Taquacetuba Compartment is classified in class 1, which indicates more restrictive limits in relation to water quality, as it use is related to public supply.

*2.2. Sampling*

The sampling occurred in the rainy period (February) and dry period (July) of 2017. In each period, we made three campaigns for water samplings with a weekly interval (2-8-15 of February and 11-18-25 of July). This choice was justified because previous studies, for the same study area (Gargiulo et al., 2016; Menezes et al., 2016; CETESB, 2018) showed the highest variability in the water quality variables in these two periods of the year. The Billings Reservoir, in fact, is in a climatic transition zone between the Tropical Humid Altitude Climate, with a defined dry period, and the Permanently Humid Subtropical Climate (Oliver & Ribeiro, 2014). Sampling took place less than 5.0 meters from the depositional margin in the subcostal zone. We measured maximum depth (m) in situ, with a rope marked every half-meter and we registered the profiles of water temperature (T °C), dissolved oxygen (DO, $mg.L^{-1}$), pH, electrical conductivity (Cond., $\mu S.cm^{-1}$) and turbidity (Turb., NTU) from the subsurface to half a meter from the bottom with the Horiba U-22 multi-probe. Finally, we collected water samples with a *van-Dorn* bottle on the subsurface and at 0.5 meters from the bottom for later determination of chlorophyll α (Chl α, $mg.L^{-1}$) and ammonia nitrogen ($NH_x$, $mg.L^{-1}$), nitrite ($NO_2$, $mg.L^{-1}$), nitrate ($NO_3$, $mg.L^{-1}$), total nitrogen (TN, $mg.L^{-1}$), orthophosphate ($PO_4$, $mg.L^{-1}$), and total phosphorus (TP, $mg.L^{-1}$). The samples were stored in polyethylene bottles for later laboratory analyses.

*2.3. Laboratory analysis*

Immediately after collection, at Limnology Laboratory of the Department of Ecology of the Biosciences Institute of the University of São Paulo - USP (Lablimno/USP), a portion of the water from each sample was prepared to determine the nutrient fractions by Kitassato-vacuum pumping for filtration in glass microfiber filter (47 mm x 0.45 µm), with subsequent conditioning of water filtrate in polyethylene bottles and frozen for preservation. We used the filter to determine the concentrations of chlorophyll α (Wetzel & Likens, 2001). To determine the concentrations of total nutrients, water was stored in polyethylene bottles and preserved by freezing. At Laboratory of Reference in Limnology at the Fisheries Institute of the of Agriculture and Supply Secretary of the State of São Paulo (ULRL/IP/SP), concentrations of ammonia nitrogen, nitrite and nitrate were determined (Mackereth et al., 1978), as well as dissolved inorganic phosphate - orthophosphate (Strickland & Parsons, 1960), and total nitrogen and phosphorus (Valderrama, 1981), according to APHA (2002).

*2.4. Data analysis*

We found no important variation between values measured in the subsurface water and half a meter from the bottom samples, so we chose to use the average of the two samples for successive elaborations.

To investigate the presence of statistical difference between sampling points and periods for each physic and chemical variables, we applied a repeated measures two-way ANOVA via General Linear Model (GLM). GLM is an ANOVA like procedure in which calculations are performed using a least squares regression approach to describe the statistical relationship between one or more predictors and a continuous variable (Zar, 2010). In this case, the considered factors were the sampling periods (two levels: rainy and dry) and the sampling points (six levels: P1 to P6). The *post hoc* Tukey test was applied when significant differences were detected for $\alpha = 0.05$. To meet the requirements of the ANOVA test, we verified the normality and homogeneity of the variances on the residuals using the Shapiro-Wilk and Bartlett tests, respectively. We applied square root and $\log_{10}(x + 1)$ transformation when the assumption of normality were not attended.

For the variables that showed a statistical difference among sampling points or time, we compared our results with the standards recommended by CONAMA resolution n. 357 (Brasil, 2005) and with the data of the monitoring program of the São Paulo Environmental Agency - CETESB (2018). According to CONAMA 357 (Brasil, 2005), for the study area, the following conditions and water quality standards must be observed: dissolved oxygen not less than

6 mg.L$^{-1}$; turbidity up to 40 nephelometric turbidity units (NTU); pH: between 6.0 and 9.0; chlorophyll α not exceeding 10 μg.L$^{-1}$; total phosphorus not exceeding 0.020 mg.L$^{-1}$; nitrite: maximum 1.0 mg.L$^{-1}$; nitrate: maximum 10.0 mg.L$^{-1}$; ammonia nitrogen: 3.7 mg.L$^{-1}$, for pH ≤ 7.5; and total nitrogen: 1.27 mg.L$^{-1}$.

Finally, we investigated the spatial and temporal variability of all the abiotic variables by Principal Component Analysis (PCA). This multivariate approach reduce the number of highly correlated variables with the minimum information loss from the original data (Legendre & Legendre, 1998). We run PCA using the correlation matrix because, before to run the analyses, it automatically normalizes the variables with different measurement units, by dividing each one by its standard deviation. (Hammer, 2021).

For the interpretation of the analysis, we considered the variability explained by the first two PCA axes and discussed the variables that showed the highest correlation with these two components.

We used the statistical approaches described in Rutherford (2001), Sokal and Rohlf (2009) and Zar (2010). The software employed were STATISTICA 7.0 (StatSoft, 2020), Past 3.0 (Hammer, 2021) and Bioestat 5.3 (Instituto Mamiraua, 2020), run in Windows 7.

### *2.5. Trophic State Index*

The trophic state of Taquacetuba Compartment was obtained by the Trophic State Index – TSI according Lamparelli (2004), which is the official index developed by the CETESB monitoring company (CETESB, 2020). It is calculated from the concentrations of total phosphorus (Equation 1) and chlorophyll α (Equation 2) of the subsurface and half a meter from the bottom sample for each sampling point and time, according to:

$$TSI\ (TP) = 10 * \{6 - [1.77 - 0.42 * (Ln(TP) / Ln(2)]\} \qquad (1)$$

$$TSI\ (CL) = 10 * \left\{6 - \left[0.92 - 0.34 * \left(Ln(CL)\right) / Ln(2)\right]\right\} \qquad (2)$$

TSI final: arithmetic average between TSI (TP) and TSI (CL),
where TP= Total Phosphorus; CL= chlorophyll α.
The trophic state category, according to Lamparelli (2004) are:
Ultraoligotrophic (TSI≤47); Oligotrophic (47<TSI≤52); Mesotrophic (52<TSI≤59); Eutrophic (59<TSI≤63); Supereutrophic (63<TSI≤67) and Hypereutrophic (TSI>67).

## 3. Results

### *3.1. Spatial and seasonal variation of water parameters*

The results of repeated measure ANOVA for each variables showed no significant differences for dissolved oxygen, turbidity, chlorophyll α, and orthophosphate. In relation to the other variables, temperature, conductivity and pH showed significant difference only between sampling periods. Temperature ($F_{period}$=721.59, p=0.000), as expected, showed higher values in the wet period, which corresponds to summer in the study area. The pH ($F_{period}$=21.68, p=0.000) and the conductivity ($F_{period}$=31.20, p=0.000) increased in the dry period with a maximum of 6.9 pH unit and 300 μS cm$^{-1}$, respectively. Nitrate showed statistical differences among sampling point (Figure 2A) ($F_{point}$= 4.25, p=0.018) and period (Figure 2B) ($F_{period}$= 20.57, p=0.000), showing P1 statistically different from P4 e P6. In relation to the period, the value of nitrates almost doubles in the dry season. Nitrite and total phosphorus showed statistical difference only among sampling point. In the case of nitrite (Figure 2C) ($F_{point}$= 10.94, p=0.000), P1 showing the higher values and was different from all the other points, while for total phosphorus (Figure 2D) ($F_{point}$=145.03, p=0.000), P1, P2 and P4 presented higher values than the other points.

Total nitrogen (Figure 3A) and ammonia nitrogen (Figure 3B) showed significant interaction between sampling point and period, meaning that the values of the variables are affect by the sampling period. Both the variables were square root transformed and, in the case of TN we excluded two extremes to attend assumptions. The result showed the same tendency for TN ($F_{interaction}$=6.30, p=0.006) and $NH_x$ ($F_{interaction}$=6.66, p=0.003) with higher values for P1 in the wet period, and a great contribution from P3 in the dry period. The results indicate that P1 presented a tendency for decreasing water quality in the rainy season.

In the case of TN, the main result of Tukey's *post-hoc* test showed P3 and P2 with significantly higher concentrations, compared to the other points, during the dry season. In the rainy According to CONAMA 357 (Brasil, 2005), for the study area, period, P1 and P5 showed significantly higher concentrations. Being P1, the only point with a tendency to higher concentrations in rainfall compared to drought.

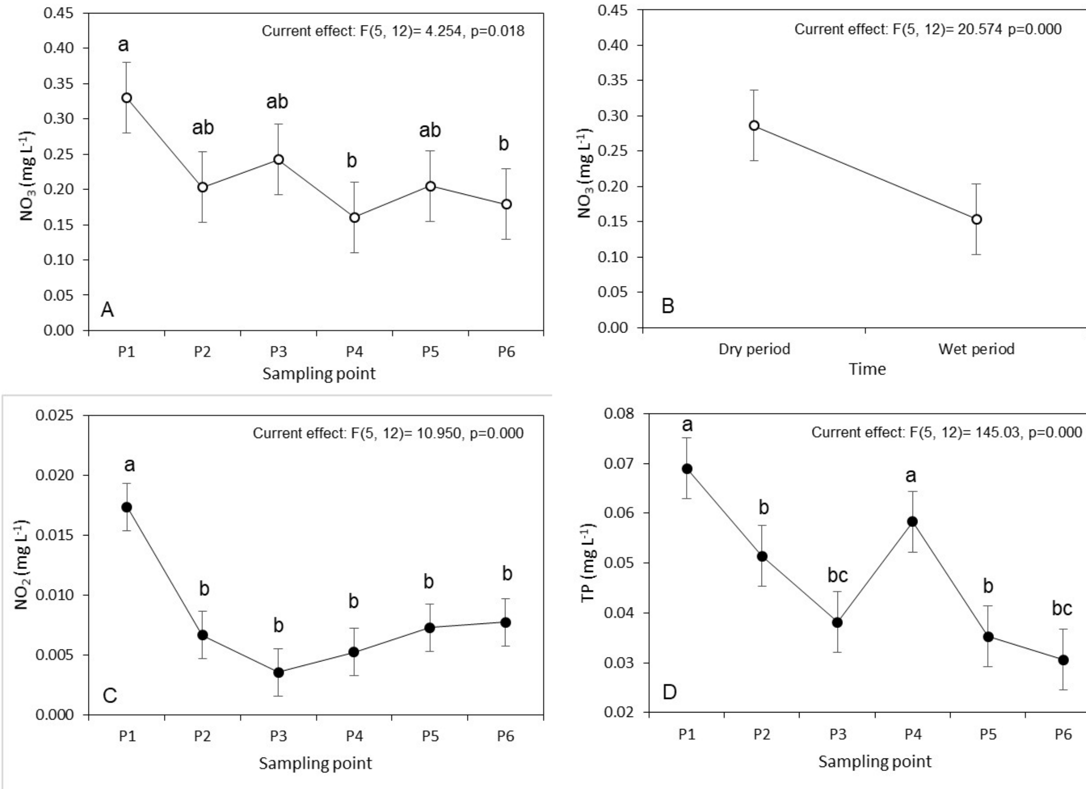


**Figure 2.** Graphs of the effective hypothesis decomposition factor from the two-way Anova for nitrate (A, B), nitrite (C) and total phosphorus (D). Vertical bars refer to the 95% confidence interval. P1: Compartment entrance; P2: close to collecting point for public water supply; P3: Colônia-Vermelho Stream; P4: Taquacetuba Stream; P5: Monos River, and P6: Curucutu River. Equal letters indicate no statistical difference between sampling points for Tukey's *post-hoc test.*

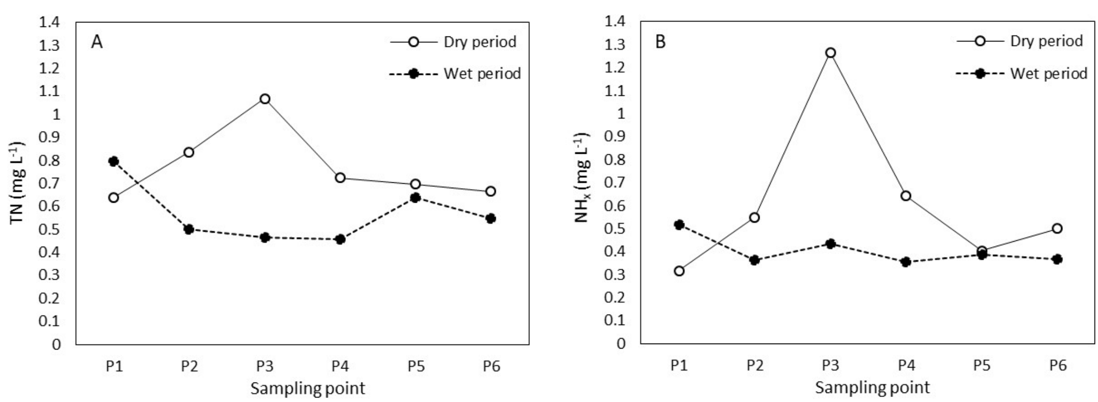


**Figure 3.** Graphs of the effective hypothesis decomposition from the two-way Anova for total nitrogen (A) and ammonia nitrogen (B) showing the interaction of factors (sampling period and sampling point). P1: Compartment entrance; P2: close to collecting point for public water supply; P3: Colônia-Vermelho Stream; P4: Taquacetuba Stream; P5: Monos River, and P6: Curucutu River. We transformed the original data into square root and excluded two extremes in the case of total nitrogen to attend Anova assumptions.

## *3.2. Principal component analysis*

Figure 4 shows the result of the Principal Component Analysis (PCA), in two presentations: by sampling period (A) and by sampling point (B). Conductivity, $NH_x$, orthophosphate and TN were excluded from the analysis due to high Pearson correlation with other variables (|0.7|). The PCA model explained 54.14% of the total variability. Nitrite, nitrate, pH and temperature are the variables with higher correlation with the axes (Table 1). The first axis (29.66% of the variability) is representative of the temporal gradient, separating

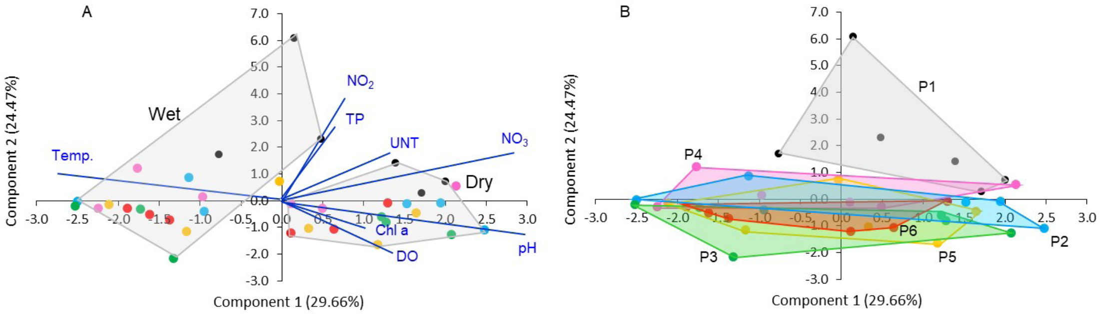


**Figure 4.** Principal Component Analysis represented by sampling period (A) and by sampling point (B). Temp: water temperature, pH; UNT: turbidity; DO: dissolved oxygen; Chl-a: chlorophyll α; NO2: nitrite; NO3: nitrate and TP: Total Phosphorus. Convex hull colors for sampling points (B): black=P1 - Compartment entrance; blue= P2 - close to collecting point for public water supply; green= P3 - Colônia-Vermelho Stream; pink= P4 - Taquacetuba Stream; yellow= P5 - Monos River and red= P6 - Curucutu River.

the rainy period from the dry period (Figure 4A). Temperature is negatively correlated with all the other variables, thus, when the temperature increase, all others decrease, due to the dilution of pollutants in the rainy period (summer). Therefore, in this system, there is a decrease in water quality during the dry period. The second axis (24.47% of the variability) is representative of the quality of the water in relationship to the spatial variability, separating P1 from the other sampling points (Figure 4B). In particular, the P1 samples showed higher concentrations of nitrite and total phosphorus, during the rains and, turbidity and nitrate during the drought. The other sampling points, presents better conditions in terms of dissolved oxygen, pH and chlorophyll $\alpha$, especially in the dry period. The inverse relationship between temperature and dissolved oxygen is also expected, confirming that when nutrients, temperature and turbidity increases, dissolved oxygen, chlorophyll $\alpha$ and pH decreases.

### *3.3. Trophic State Index*

The trophic state index (TSI) results (Table 2), shows that all the sampling points are in the categories supereutrophic and hypereutrophic. The P1 proved to be the only place that showed worse quality in the rainy season compared to the dry season. The P5 and P6 were the only ones that during the rainy season showed a significant improvement in the degree of trophy.

In relation to compliance with local legislation CONAMA n° 357 (Brasil, 2005), the concentrations of ammonia nitrogen, nitrite, nitrate and turbidity were always below the law limits. Total Nitrogen exceeded the limit (1.27 mg. $L^{-1}$) only at P3 in dry season. The pH was below the law limit (6.0 pH unit) in the rainy season at all the sampling points. Dissolved oxygen (≥ 6 mg.$L^{-1}$) was found to be noncompliant only in the rainy season in P1 and P4. The total phosphorus exceeded the limit (0.020 mg.$L^{-1}$) in all samples, with higher values at P1, P2 and P4 (considering both seasons). Chlorophyll α (≤ 10 µg.$L^{-1}$) was noncompliant in all samples, with higher values in the dry period.

**Table 1.** Loading table showing the correlation of the variables with the scores of the first and second axes of the principal component analysis.

| Variables | Axis 1 | Axis 2 |
|---|---|---|
| Nitrite | 0.2128 | 0.7995 |
| Nitrate | 0.7683 | 0.4177 |
| Total Phosphorus | 0.1749 | 0.6492 |
| Chlorophyll | 0.3338 | -0.2795 |
| Dissolved Oxygen | 0.3987 | -0.5232 |
| pH | 0.8124 | -0.3013 |
| Turbidity | 0.3441 | 0.4579 |
| Temperature | -0.8112 | 0.2658 |

## 4. Discussion

The environmental quality requirements for Class 1 freshwater, were only partially achieved, with non-compliance especially in values of dissolved oxygen, TP and chlorophyll α, which has been also demonstrated by CETESB (2018), indicating the degradation associated with eutrophication processes and high values of Cyanobacteria densities near P2. The reservoir has a long history of Cyanobacteria proliferation due to organic pollution (Moschini-Carlos et al.., 2009). Higher chlorophyll α may indicate the presence of cyanotoxins that can compromise the water use as public supply. Wengrat & Bicudo (2011) indicated the central body of the Billings Reservoir and the Taquacetuba

**Table 2.** Trophic State Index (TSI) mean values for sampling point, sampling periods and the entire sample.

| Trophic State Index - TSI | | | | |
|---|---|---|---|---|
| **Sampling points** | **Wet** | **Dry** | **According CETESB (2020)** | |
| P1 | 68.98 | 66.83 | Categories | Ranges |
| P2 | 67.17 | 71.77 | | |
| P3 | 67.04 | 67.29 | Ultraoligotrophic | TSI ≤ 47 |
| P4 | 68.38 | 68.82 | Oligotrophic | 47 < TSI ≤ 52 |
| P5 | 66.29 | 67.29 | Mesotrophic | 52 < TSI ≤ 59 |
| P6 | 64.46 | 68.76 | Eutrophic | 59 < TSI ≤ 63 |
| All sites | 67.26 | 68.91 | Supereutrophic | 63 < TSI ≤ 67 |
| All Samples | 68.16 | | Hypereutrophic | TSI > 67 |

Color categories: red= supereutrophic; purple= hypereutrophic (other categories were not observed) and indication of the value ranges according to CETESB (2020). Sampling Points: P1: Compartment entrance; P2: close to collecting point for public water supply; P3: Colônia -Vermelho Stream; P4: Taquacetuba Stream; P5: Monos River and P6: Curucutu River.

Compartment as places with great environmental stress, especially due to the high nutrient values.

In all samples, the conductivity was above 160 µS.cm$^{-1}$. Similar results were obtained by CETESB (2018) with values around 150 µS.cm$^{-1}$ throughout the year. Cardoso-Silva et al. (2014) also found high conductivity values near Compartment entrance (P1) and close to the collecting point for public water supply transposition (P2). According to (Wetzel & Likens, 2001), values above 100 µS.cm$^{-1}$ are indication of water quality impairment. Thus, the electrical conductivity in Taquacetuba has been an indication of environmental compromise.

The pH was slightly more basic in the CETESB (2018) results, which can be associated to the photosynthetic activity, which could be less intense in our sampling study. In relation to total phosphorus, CETESB (2018) observed annual averages in the central body almost three times greater than that observed in P1. This indicate that the center of the Billings reservoir is more compromised than the Compartment entrance in relation to this nutrient. Close to P2, CETESB found an annual average twice as low as that indicated in this study.

Finally, the trophic pattern (TSI) confirms the impairment of the water quality classifying all the places and times in a super eutrophic or hyper eutrophic condition based on the high levels of TP and chlorophyll α. Wengrat & Bicudo (2011) also classified as super-eutrophic the Taquacetuba branch. The environmental agency classified places close to P1 and P2 in this study with lower degrees of trophy but eutrophic or supereutrophic. The high degree of trophy in the reservoir is a clear sign of environmental impairment. According to Gomes et al. (2016), from a study carried out throughout 2012, close to the P1 of this study, these authors concluded that the condition of hypertrophy in the reservoir affects the composition of food resources available in the reservoir. It can result in a deficiency of long-chain polyunsaturated fatty acids in aquatic food chains, affecting fish nutrition and physiology.

Regarding the water quality at the sampling stations, our study evidenced P1 as the site with the greatest water impairment especially during the rainy period. PCA support this conclusion highlighting the greater correlation between the rainy samples and total phosphorus, nitrite and nitrate at this point. We justified this fact by the proximity of P1 to the central body of the Billings Reservoir, which presents greater environmental stress due to the pumping water from Pinheiros River, restricted to flooding control since 1992 (São Paulo, 2010c). Pinheiros River receives a large discharge of domestic sewages that are transferred to the reservoir without any treatment, causing the worsening of the reservoir water quality in this period. The other sampling points in the Taquacetuba Compartment, on the contrary, showed an improvement in water quality during the rain period, due to the dilution effect, and a tendency to increase the concentrations of nutrients during the drought, especially ammonia nitrogen, nitrate and total nitrogen.

The P2 sampling point, close to the transposition site for water supply, tend to have higher concentrations of chlorophyll α mainly during the drought, confirmed by the TSI, which had a peak value corresponding to the hypereutrophic condition, particularly due to the significantly high concentrations of TP. The areas are influenced by the supply of domestic sewage, as they are occupied by homes that release sewage *in natur*a. Regarding the tributary, P3 sampling points, drainage from the Colônia-Vermelho Stream, showed higher concentrations of ammonia nitrogen, nitrate, and TN. In the dry period, it was the only point with TN values in noncompliance with legislation. The P4 sampling point, drainage from the Taquacetuba Stream, showed a tendency to lower dissolved oxygen values, especially in the dry season, with some samples not in compliance with the legislation. During the rains, there was a tendency to a decrease in the average values of electrical conductivity and nitrate. Considering both sampling periods, the point P4 showed significant higher averages of TP concentration, except compared to P1.

Among the tributaries, points P5 (Monos River drainage) and P6 (Curucutu River drainage) were the ones that presented the best environmental conditions, with dissolved oxygen concentrations in compliance with legislation in both periods. In addition, P5 and P6, showed low concentrations of TP and significant improvement in the trophic state during rains, being the only points classified as supereutrophic in this period. This fact observed in P5 and P6 is probably due to the dilution of pollutants and greater distance from the central body of the Billings Reservoir. These points are located in indigenous areas, Guarani (P5) and Krukutu (P6), which present most preserved surroundings, contributing to the reduction of the impacts of human activity and, consequently, better water quality.

## 5. Conclusion

The observed result allowed us to conclude that there is an indication that also the tributaries contribute with the supply of nutrients and chemical contaminants to the water quality of the Taquacetuba Compartment. In particular, we recognized two principal sources responsible for the impairment of the Taquacetuba Compartment: i) the contribution from the central body of the Billings reservoir, by the greater influence of the pumping from the Pinheiros River (especially in the wet period), and ii) the contribution from the tributaries which, despite the presence of more preserved areas with indigenous occupation (P5 and P6), reveal the effects of different types of anthropic impact as agricultural activities (P3 and P4) and domestic sewage discharges (P2). In this context, the research represents a valuable contribution to the knowledge of the water quality at the mouths of the main tributaries of the Taquacetuba Compartment of Billings Reservoir, never investigated in previous research. This study contributes to support management measures for the improvement of the water quality in the Compartment, recognizing the importance of land use and soil occupation in the tributaries basins. In synthesis, the limitation of the local and diffuse sources of pollution, as well as the implementation of alternative flood control strategies, avoiding the pumping of water from the Pinheiros River to Billings Reservoir, are the first step for the improvement of the water quality in the Taquacetuba Compartment.

## Acknowledgements

We thank the Ciqueto family for providing the main financial support for carrying out this research. To the Billings Reservoir fishing community – Z17 of São Bernardo do Campo (2017) for its support and availability of information. We would also like to thank the professional, friends and laboratories technicians from the UNESP-Sorocaba, Lablimno-IBUSP and Instituto de Pesca - IP, especially the Technician Chemist Luiz Cláudio dos Santos Evangelista for joining efforts during the sampling and laboratory analysis.

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**Received**: 28 February 2021
**Accepted**: 02 February 2022

**Associate Editor:** Victor Satoru Saito.