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Detecting the retention potential of a reservoir influenced by upstream inputs from metropolitan areas

Fabio Leandro da Silva
Post-doctoral researcher in Urban Engineering
Universidade Federal de São Carlos, Brazil.
fabioleandro@alumni.usp.br
ORCID iD: https://orcid.org/0000-0001-6002-9030

Ângela Terumi Fushita
PhD in Ecology and Natural Resources, Professor
Universidade Federal do ABC, Brazil.
angela.fushita@ufabc.edu.br
ORCID iD: https://orcid.org/0000-0001-6595-708X

Marcela Bianchessi da Cunha-Santino
PhD in Ecology and Natural Resources, Professor
Universidade Federal de São Carlos, Brazil.
cunha_santino@ufscar.br
ORCID iD: https://orcid.or/0000-0001-6048-0745

Irineu Bianchini Júnior
PhD in Ecology and Natural Resources, Professor
Universidade Federal de São Carlos, Brazil.
irineu@ufscar.br
ORCID iD: https://orcid.org/0000-0002-9121-3794

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Detectando o potencial de retenção de um reservatório influenciado por aportes de áreas metropolitanas

RESUMO

Objetivo - avaliar a capacidade de retenção de um reservatório hipereutrófico (Reservatório de Barra Bonita - RBB, Estado de São Paulo, Brasil), influenciado por afluentes fortemente impactados por ações antropogênicas em regiões metropolitanas.

Metodologia – emprego de um modelo de zero dimensional, utilizando dados limnológicos de 2010 a 2019, considerando duas estações a montante (rios Piracicaba e Tietê) e um ponto a jusante. As seguintes variáveis da água foram analisadas: nitrogênio amoniacal, demanda bioquímica de oxigênio, oxigênio dissolvido, condutividade elétrica, coliformes termotolerantes, cloreto total, nitrato, nitrito, pH, fósforo total, sólidos totais e turbidez. Para cada variável, foi verificada a capacidade de retenção (parâmetro alfa), resultando em 649 determinações. Uma correlação de Spearman (p-valor: 0,05) foi realizada para explorar as relações entre os aspectos físicos do reservatório, as retenções e a precipitação.

Originalidade/relevância - neste estudo empregamos um modelo zero dimensional considerando a capacidade de retenção de um reservatório, considerando a variação temporal.

Resultados - O tempo de retenção variou de 16 a 321 dias, bem como o sistema demonstrou uma grande capacidade de retenção devido aos coeficientes alfa positivos para todas as variáveis analisadas.

Contribuições teóricas/metodológicas - os achados fornecem subsídios importantes para a promoção da gestão da água e a formulação de políticas públicas, visando os usos múltiplos da água.

Contribuições sociais e ambientais - apesar dos impactos antropogênicos, o RBB fornece um serviço ecossistêmico essencial ao melhorar a qualidade da água a jusante, visto a atenuação de cargas poluentes.

PALAVRAS-CHAVE: Serviços Ecossistêmicos. Lagos Artificiais. Modelagem Matemática.

Detecting the retention potential of a reservoir influenced by upstream inputs from metropolitan areas

ABSTRACT

Objective – To evaluate the retention capacity of a hypereutrophic reservoir (Barra Bonita Reservoir – BBR, São Paulo State, Brazil), influenced by tributaries strongly impacted by anthropogenic activities in metropolitan regions.

Methodology – Application of a zero-dimensional model using limnological data from 2010 to 2019, considering two upstream monitoring stations (Piracicaba and Tietê rivers) and one downstream station. The following water quality variables were analyzed: ammoniacal nitrogen, biochemical oxygen demand, dissolved oxygen, electrical conductivity, thermotolerant coliforms, total chloride, nitrate, nitrite, pH, total phosphorus, total solids, and turbidity. For each variable, retention capacity (alpha parameter) was assessed, resulting in 649 determinations. A Spearman correlation analysis (p-value: 0.05) was performed to explore relationships among reservoir physical characteristics, retention processes, and precipitation.

Originality/Relevance – This study applies a zero-dimensional model to assess reservoir retention capacity while explicitly considering temporal variability.

Results – Retention time ranged from 16 to 321 days, and the system exhibited a high retention capacity, as indicated by positive alpha coefficients for all analyzed variables.

Theoretical/Methodological Contributions – The findings provide important support for advancing water management strategies and informing public policy formulation aimed at multiple water uses.

Social and Environmental Contributions – Despite anthropogenic pressures, the BBR provides an essential ecosystem service by improving downstream water quality through the attenuation of pollutant loads.

KEYWORDS: Ecosystem Goods. Man-made Lake. Mathematical Modeling.

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Detectando el potencial de retención de un lago artificiale influenciado por aportes de áreas metropolitanas

RESUMEN

Objetivo – Evaluar la capacidad de retención de un lago artificiale hipereutrófico (Barra Bonita – RBB, Estado de São Paulo, Brasil), influenciado por afluentes fuertemente impactados por acciones antropogénicas en regiones metropolitanas.

Metodología – Empleamos un modelo de cero dimensiones, utilizando un estudio limnológico de 2010 a 2019, considerando dos estaciones aguas arriba (ríos Piracicaba y Tietê) y un punto aguas abajo. Se analizaron las siguientes variables del agua: nitrógeno amoniacal, demanda biológica de oxígeno, oxígeno disuelto, conductividad eléctrica, coliformes termotolerantes, cloruro total, nitrato, nitrito, pH, fósforo total, sólidos totales y turbidez. Para cada variable, se calculó la capacidad de retención (parámetro alfa), resultando en 649 determinaciones. Se realizó una correlación de Spearman (valor p: 0.05) para explorar las relaciones entre los aspectos físicos del RBB, las retenciones y la precipitación.

Originalidad/Relevancia – En este estudio se emplea un modelo de cero dimensiones para evaluar la capacidad de retención de un embalse, considerando la variación temporal.

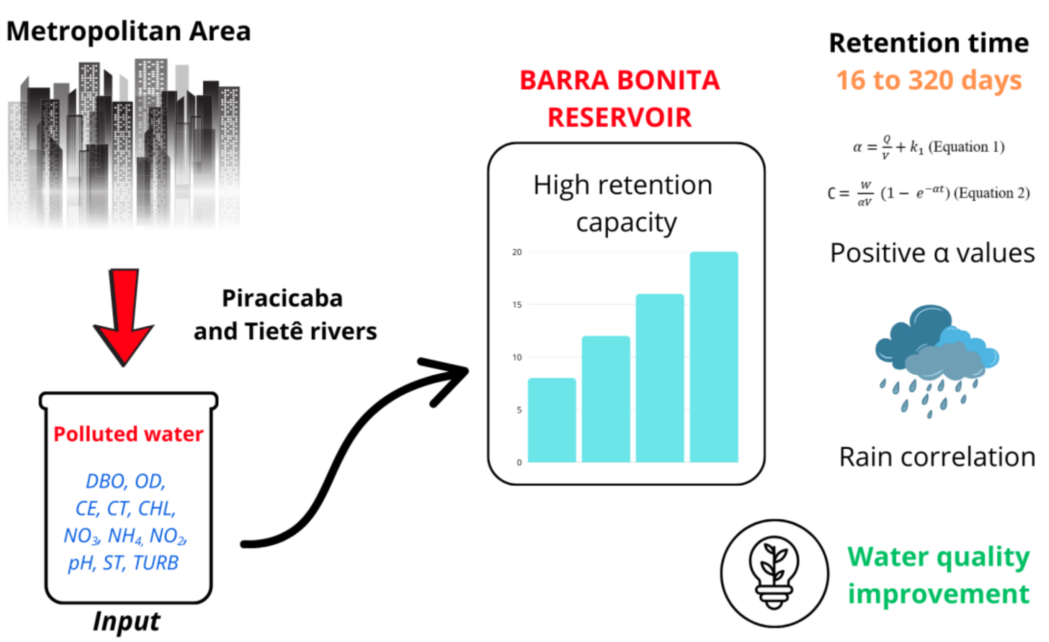
Resultados - El tiempo de retención varió entre 16 y 321 días, y el sistema mostró una elevada capacidad de retención, evidenciada por coeficientes alfa positivos para todas las variables analizadas

Contribuciones Teóricas/Metodológicas – Los hallazgos proporcionan insumos relevantes para el fortalecimiento de la gestión del agua y la formulación de políticas públicas orientadas a los usos múltiples del recurso hídrico.

Contribuciones Sociales y Ambientales – A pesar de las presiones antropogénicas, el RBB proporciona un servicio ecosistémico esencial al mejorar la calidad del agua abajo mediante la atenuación de las cargas contaminantes.

PALABRAS CLAVE: Servicios Ecosistémicos. Lagos Artificiales. Modelado Matemático.

GRAPHICAL ABSTRACT



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1 INTRODUCTION

Artificial reservoirs are part of the global freshwater reserve, influenced by the water cycle, and connected to seas and oceans (Stephens et al., 2020). The damming of lotic environments and the operation of hydroelectric plants alter the hydrological regime, influencing downstream flow, requiring actions to intervene in the direct drivers (Ciria; Labat; Chiogna, 2019; Bravo-Linares et al., 2024). Due to their specific characteristics (e.g., heterogeneity, morphometry, longitudinal gradient, retention time), reservoirs decrease the flow of elements after damming due to the biochemical processes that occur in these environments (Akbarzadeh et al., 2019).

Biological communities (phytoplankton, zooplankton, macroinvertebrates, fish) actively participate in these processes in reservoirs, although, they are influenced by environmental conditions and changes occurring in the environment (Santos et al., 2018; Berberich et al., 2019; Bortolini et al., 2019; Yan et al., 2020). On the other hand, reservoirs are integral components of socio-ecological systems and are strongly influenced by political aspects, interaction with humans (Kellner, 2021; Santos et al., 2025) and landscape change.

Therefore, the metabolism and functioning of these systems are affected by anthropogenic activities, leading to changes in downstream limnological variables. It is essential to assess these environments to understand their functioning and promote effective management (Tundisi, 2018). This need becomes even more pressing in the context of increasing water scarcity and climate change, a scenario that is expected to worsen. Land use and the development of anthropogenic activities compromise the quality of tributaries into reservoirs, resulting in societal impacts and adverse effects on biota, as well as on the provision of ecosystem services. In metropolitan areas, reservoirs are under pressure due to the input of pollutants and changes caused by human activities (Pires et al., 2015; Godoy et al., 2023), as these regions are characterized by high population density and extensive soil sealing.

Considering the qualitative and quantitative loss, using indicators provides a basis for decision-making and favors environmental monitoring (Filippis et al., 2020), influencing the water quality. Modeling can be a tool that supports reservoir management by elucidating patterns and identifying situations that require management strategies (Tundisi, 2018), contributing for multiple water uses.

Indeed, reservoirs are characterized by several negative impacts (social, economic, environmental) and externalities during their construction; contrarily, they can provide ecosystem services, but the estimation of some services is challenging and there is a need of methods to evaluate scenarios (Intralawan et al., 2018; Xie et al., 2024). The residence time of these systems can be used to establish relationships between the reduction or increase in the concentration of limnological variables (Maavara et al., 2020), which is an important supporting ecosystem service.

Considering the above, this study aimed to evaluate the retention capacity of elements in the Barra Bonita Reservoir – BBR (São Paulo, Brazil), one of the most impacted environments in Latin America due to high organic and industrial loads from the metropolitan regions of São Paulo. For this purpose, a zero-dimensional model was used to assess the mass balance of 12 limnological variables from 2010 to 2019. We believed that due to its properties and processes,

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the BBR can retain a significant portion of the concentration of limnological variables, marked by significant anthropogenic interference in the Tietê and Piracicaba rivers.

2 OBJECTIVE

We aimed to evaluate the retention capacity of elements in the BBR (São Paulo, Brazil), due to high organic and industrial loads from the metropolitan regions of Campinas, Piracicaba, and São Paulo, between 2010 and 2019.

3 MATERIAL AND METHODS

3.1. Study Area

BBR was constructed in the 1960s and it is the first in a cascade system on the Tietê River (largest tributary). Its proprieties can be observed in Table 1. Additionally, the man-made lake is formed by the Piracicaba River (upper tributary) (Rotta et al., 2021). The reservoir is in the Sorocaba-Meio Tietê and Piracicaba-Capivari-Jundiaí basins (São Paulo State, Brazil), as shown in Figure 1. The BBR serves important functions for multiple water uses, such as hydroelectricity and navigation (Bernardo et al., 2016). The drainage area is one of the most densely populated regions in Brazil and is characterized by high levels of anthropogenic interference, particularly intense land use, industrial activities, and sanitation issues (Prado; Novo, 2007; Silva et al., 2022). This reservoir is classified as hypertrophic (Novaes; Carvalho, 2013; Alcântara et al., 2017; Oliveira; Ferragut; Bicudo, 2020). According to Tundisi et al. (2008), the region has a climate marked by two distinct seasons: a dry season (from March to October) and a wet season (from October to March), resulting from the transition between subtropical and tropical climates in the area. In this study, two sampling stations were selected upstream (corresponding to the Tietê and Piracicaba Rivers), and one downstream, located near the BBR dam (Figure 1).

Table 1 – Main characteristics of BBR

Characteristics	Data
Initial year of operation	1963
Maximum operating quota (m)	452.50
Watershed area (km²)	32,330
Reservoir área (km²)	324.84
Perimeter (km)	525
Length (km)	788
Volume (m³)	3,160x106
Maximum depth (m)	25
Mean Depth (m)	10.2
Retention Time (days)	30 – 90

Source Tundisi, Matsumura-Tundisi and Abe (2008), Gibertoni et al. (2011).

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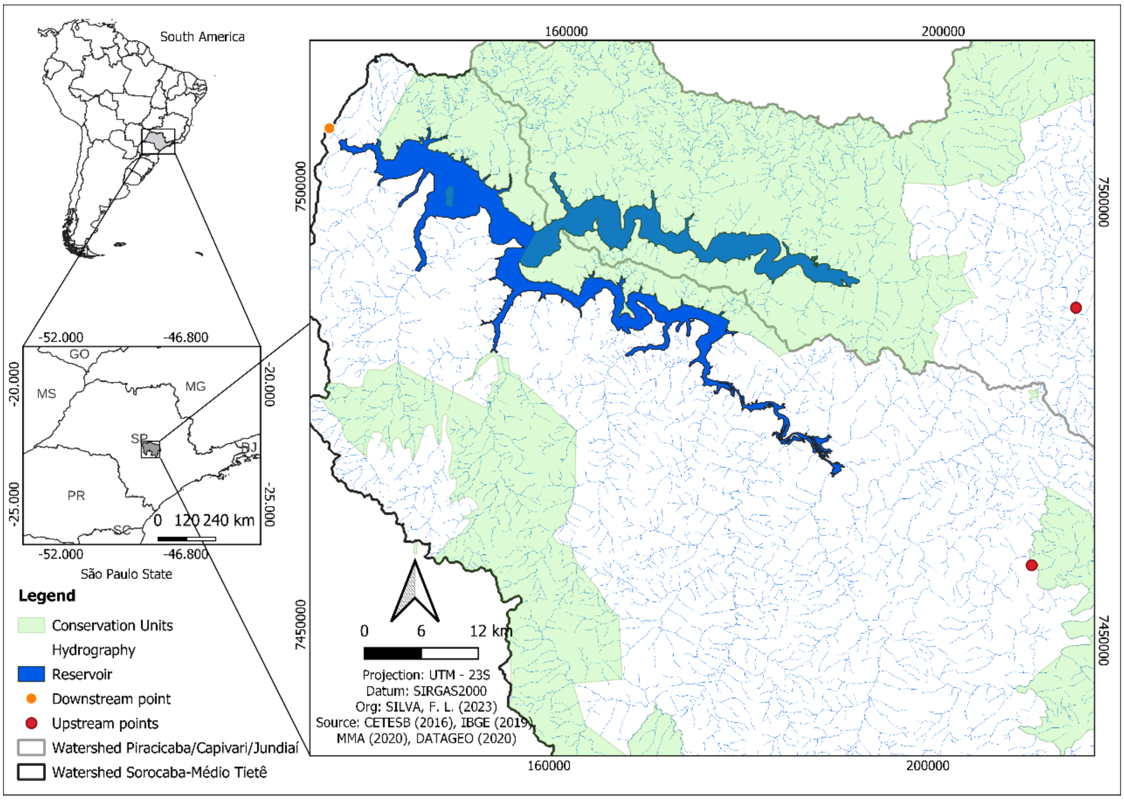
Figure 1 – Geographic location of the study area



Sources: The authors.

3.2. METHODOLOGICAL PROCEDURES

The limnological survey used in this work was conducted by the State of São Paulo Environmental Company from 2010 to 2019, obtained in the mentioned sampling stations and available in electronic reports (Cetesb, 2022). In each year, six water samples were taken and analyzed according to standard procedures (Apha-Awwa-Wef, 2012; Usepa, 2020). The following variables were analyzed: ammonia nitrogen (NH_4), biological oxygen demand (BOD), dissolved oxygen (DO), electrical conductivity (EC), thermotolerant coliforms (FC), total chloride (CHL), nitrate (NO_3), nitrite (NO_2), pH, total phosphorus (TP), total solids (TS), and turbidity (TURB).

The mathematical approach used in this research was based on previous studies that considered the retention capacity of cascade reservoirs and the temporal variation of mass balance for limnological variables (Cunha-Santino; Fushita; Bianchini Jr., 2017; Bianchini Jr; Fushita; Cunha-Santino, 2019; Bottino et al., 2023). Using Equations 1 and 2, the mass balance of the limnological variables was described. We assumed that the reservoir is a system characterized by complete mixing with a constant input flow (Chapra; Reckhow, 1983).

$$\alpha = \frac{Q}{V} + k_1 \text{ (Equation 1)}$$

$$C = \frac{W}{\alpha V}\left(1 - e^{-\alpha t}\right) \text{ (Equation 2)}$$

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Where: α = assimilation factor (d-1 , ∑ sink); k = first order reaction rate constant (d-1); Q/V = hydraulic flushing - HF (d-1), Q = upstream flow rate; V = volume of the reservoir; C = C = steady state concentration (i.e. outlet concentration); W = the loading term (kg d-1), daily load of the limnological variable; t = required time for reach the equilibrium concentration.

The following basic assumptions were made: (i) reservoirs can be represented by a zero-dimensional model (i.e., continuous stirred-tank reactor - CSTR), and (ii) the hydraulic residence time is sufficient for the reservoir to reach equilibrium (Jørgensen; Bendoricchio, 2001; Cunha-Santino; Fushita; Bianchini Jr., 2017). Limnological variables downstream of the reservoir are derived from upstream values, except for elements generated or assimilated within the reservoir during the residence time (Søndergaard; Jensen; Jeppesen, 2003; Teodoru; Wehrli, 2005).

Alpha (α) coefficients were obtained through standardization of losses (e.g., adsorption, sedimentation, biological uptake, chemical processes) or gains of elements in the reservoir compared to the initial values derived from the main inflows. According to Bianchini Jr., Fushita and Cunha-Santino (2019), the following situations can be observed: (i) if the alpha value is positive and greater than the dilution rate (FH), it indicates that the element is retained in the reservoir, and the retention is greater than the flushing; (ii) if the alpha value is equal to FH, the retention is null, and the concentration downstream is the same as upstream; and (iii) if the alpha value is negative or less than FH, it indicates that there is no retention, and the reservoir acts as a source of the element, resulting in a higher concentration downstream than upstream. The categorization of alpha values is based on the following: (i) values > 0 and < 0.5 = moderate retention capacity; (ii) values > 0.5 - 1.0 = good retention capacity; and (iii) values > 1.0 = high retention capacity.

The model parameterization was based on obtaining the alpha coefficient for the limnological variables (NH4, BOD, DO, EC, FC, CHL, NO_3, nitrite, NO_2, pH, TP, TS, and TURB) during six annual sampling campaigns between 2010 and 2019. For this purpose, Equation 2 was used with: (i) the average values of each limnological variable input (W), (ii) the average flow rate, (iii) the residence time, and (iv) the volume. By iteratively substituting the alpha value, the calculated values of the variables (parameter C) were compared with the mean values obtained from the sampling campaigns. The alpha values were calculated using the nonlinear iterative algorithm GRG (Generalized Reduced Gradient; Fylstra et al., 1998), based on the least squares method.

Flow and volume data were obtained from the National Waters and Sanitation Agency (ANA) reservoir database (Ana, 2022), while precipitation (Prec) data were obtained from CETESB (2022). For the input values of the limnological variables and Prec, historical flow data from the Tietê River (1981-2019, mean = 230.80 m³) and Piracicaba River (1994-2019, mean = 135.59 m³) were considered from official sources (Daee, 2022; Sinrh, 2022). Considering that the reservoir is formed by two major inflows, the input values of the variables were determined by a weighted average, considering the average flow of each river, followed by summing them over the evaluated period. Finally, to investigate possible relationships between the number of retention events for the limnological variables, precipitation, and physical aspects of the reservoir (volume, influent flow rate - Vaf, effluent flow rate - Vdef, FH, residence time - RT), a Spearman correlation analysis (p-value: 0.05) was conducted using the R language.

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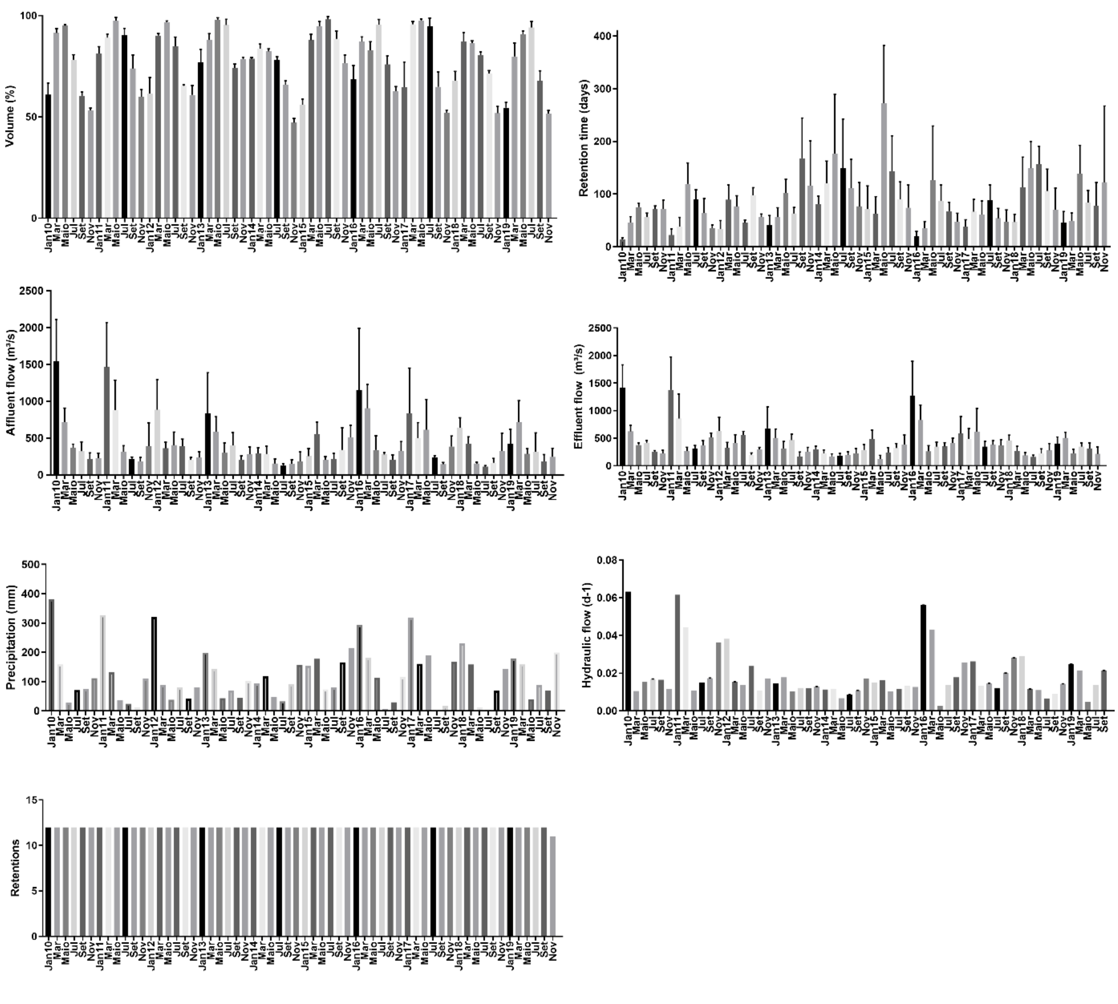
4 RESULTS AND DISCUSSION

BBR is a dendritic reservoir formed by two main tributaries. During the analyzed period, the reservoir's retention time varied from 16 to 321 days, with an average time of 84 days (±65 days). Thus, the reservoir underwent several renewals during the period. The average volume fluctuated around 77% (±15.35%) of the system's capacity. As can be observed, alpha coefficients were positive and greater than FH, indicating that the variable was retained by the system. Low values were observed for FH (mean = 0.018765 d-1 ± 0.012786 d-1) in the interval.

Some variables are presented in Figure 2. The volume exhibited fluctuations from 2010 to 2019, primarily influenced by seasonality and precipitation patterns, which peaked during the initial months of 2010, 2012, 2016, and 2017.

Figure 2 – Temporal variations of flow, volume, inflow, outflow, hydraulic flow, precipitation, and retention of limnological variables in RBB



Source: The authors.

From 2013 to 2015, an increase in RBB's retention time can be observed, along with lower flows (inflow and outflow). The highest FH values were noted in 2010 and 2016. Regarding

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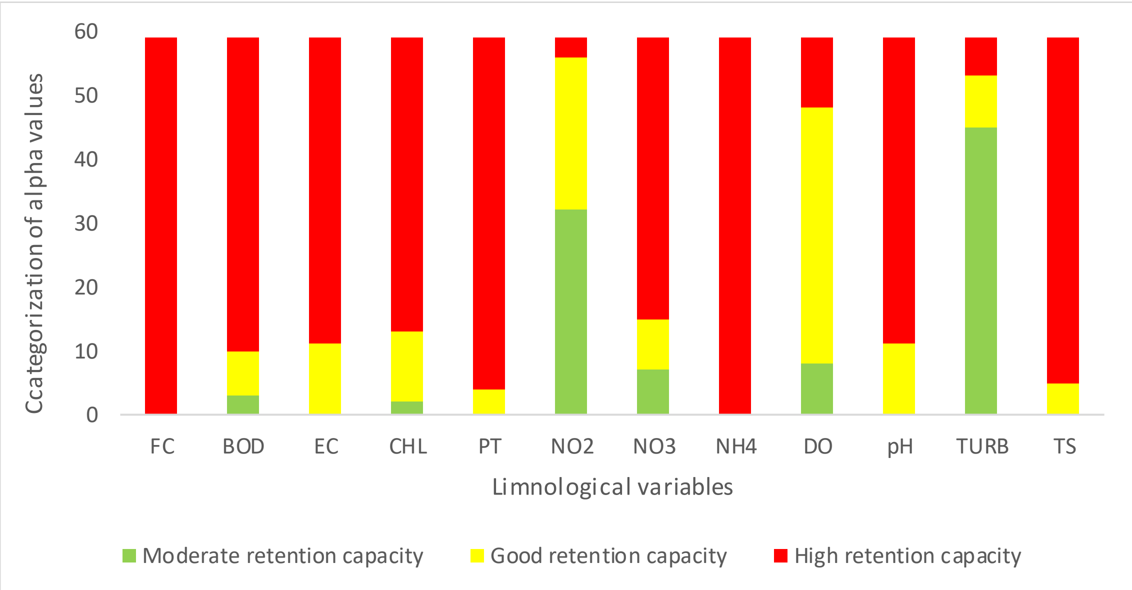
variable retention, 649 determinations were obtained, considering the 12 limnological variables. The values obtained for alpha and FH, through Equations 1 and 2, are detailed by Silva (2022, p. 132 - 139).

No negative alpha values were obtained during the analysis. Regarding alpha values less than FH, this situation was observed during one determination of TURB in September 2019. In the remaining determinations (n = 648), alpha values were positive and significantly higher than FH, by more than an order of magnitude. The scenario indicates that the aquatic system has a good capacity to retain limnological variables. Concerning retention events, except for TURB (n = 58), the other variables each showed 59 retention events. Essentially, all variables were retained by the BRR.

The retention of variables was observed similarly during the dry season (May, July, and September) and the wet season (January, March, and November), as practically the same number of determinations were made in these periods.

In Figure 3, the categorization of alpha values is evident. The categorization values for FC and NH_4 demonstrate that the reservoir has a high retention capacity. On the other hand, concerning the variables NO_2 and TURB, the retention capacity is moderate, given the predominance of alpha values between 0 and 0.5. In the case of TP, the values indicate high retention capacity, except for some situations that demonstrate good capacity. Regarding DO, there is a clear predominance of values indicative of good retention capacity. For the other variables (BOD, EC, CHL, NO_3, pH, and TS), high retention capacity is indicated in many values.

Figure 3 – Categorization of alpha values. Where: ammonia nitrogen (NH4), biological oxygen demand (BOD), dissolved oxygen (DO), electrical conductivity (EC), thermotolerant coliforms (FC), total chloride (CHL), nitrate (NO3), nitrite (NO2), pH, total phosphorus (TP), total solids (TS), and turbidity (TURB); moderate retention capacity: values > 0 and < 0.5; good retention capacity: values > 0.5 and ≤ 1.0; high retention capacity: values > 1.0.



Source: The authors.

The significant Spearman correlations (p-value: 0.05) among the analyzed variables are presented in Figure 3. The positive and negative correlations can be observed. Noteworthy

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positive correlations among the alpha values and other variables include: DO and pH, NO_3 and DO; DO and Prec; DO and FH; DO and Vaf; Vdef and DO; NO_3 and NO_2; NO_3 and TURB; NO_3 and Prec; NO_3 and FH; NO_3 and Vaf; NO_3 and Vdef; NO_2 and TURB; NO_2 and Prec, NO_2 and Vaf; NO_2 and Vdef; TURB and Prec; TURB and FH; TURB and Vaf; TURB and Vdef; TURB and FC, Prec and FH; Vaf and Prec; Prec and Vdef; FH and Vaf; FH and Vdef; Vaf and Vdef; RT and CHL; RT and EC; RT and TS, RT and TURB, RT and Volume, NH_4 and CHL; NH_4 and EC; NH_4 and TS, and CHL and EC. On the other hand, negative correlations were observed: DO and RT; DO and CHL, DO and NH_4; DO and TS, DO and CHL; DO and EC; pH and BOD, NO_3 and RT; NO_3 and NH_4; NO_3 and TS, NO_3 and CHL; NO_3 and EC; TURB and RT; TURB and NH_4; TURB and CHL; TURB and TS, Prec and RT; Prec and NH_4; Prec and EC; Prec and TS, FH and RT; FH and NH_4; FH and CHL; FH and TS; FH and Volume; Prec and Volume; Vaf and RT; Vaf and NH_4; Vaf and CHL; Vaf and EC; Vaf and TS; Vdef and RT; Vdef and RT; Vdef and NH_4; Vdef and TS; Vdef and CHL; Vdef and EC; Prec and Volume; and FH and Volume. Some strong correlations were identified, mainly involving TURB, Vaf, Vdef, CHL, and volume.

The findings highlight potential relationships between physical factors and reservoir precipitation influencing alpha values, which may be associated with the occurrence of biogeochemical processes.

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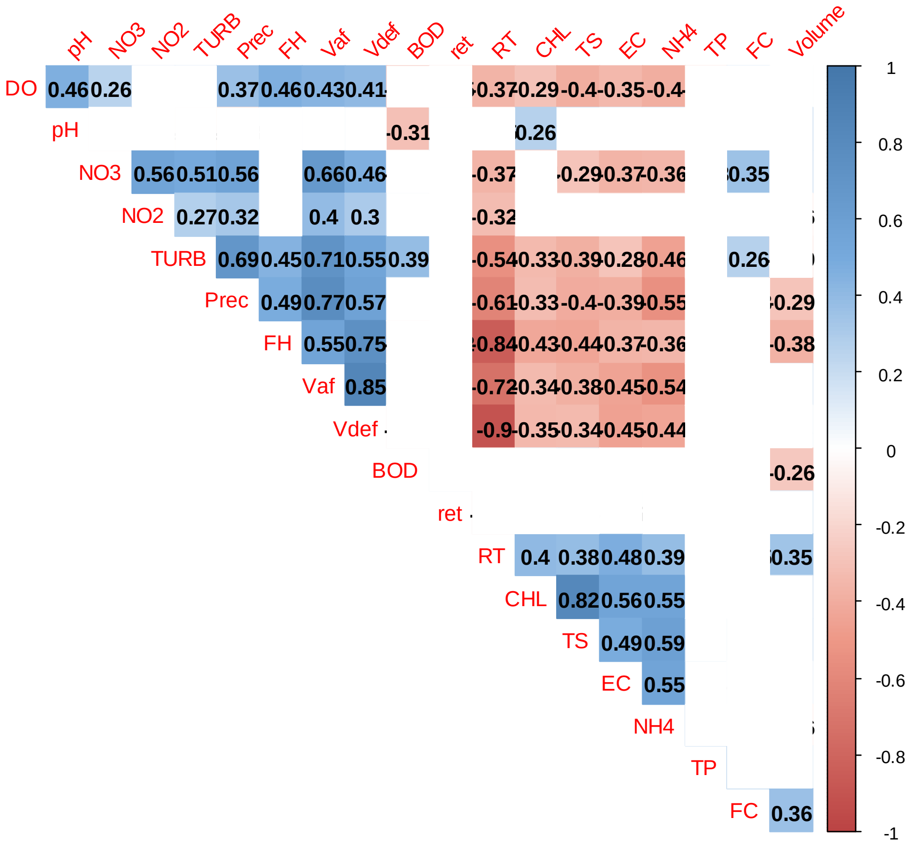
Figure 4 – Spearman correlation matrix. Where: EC = electrical conductivity; FC = thermotolerant coliforms; BOD = biochemical oxygen demand; NH4 = ammonium nitrogen; NO2 = nitrite; DO = dissolved oxygen; TP = total phosphorus; TURB = turbidity; TS = total solids; FD = dilution rate (d-1), Prec = precipitation (mm); Qin = inflow discharge; Qout = outflow discharge; RT = residence time; ret = number of retentions. Blank spaces indicate non-significant correlations (p-value: 0.05).



Source: The authors

The RBB can be considered one of the most degraded aquatic systems in the La Plata basin, a situation primarily resulting from pollution from metropolitan areas and agricultural activities (Nogueira et al., 2021). The compromised water quality in the reservoir is mainly associated with anthropogenic interference in its main tributaries, the Tietê and Piracicaba rivers. It is known that the creation of reservoirs causes adverse environmental impacts, affecting both the direct and downstream contribution areas of the project, given its direct influence on water availability (Zaniolo et al., 2021) and the ecological processes occurring therein.

Reservoirs are systems with a range of biochemical processes contributing to substance cycling and element transformation (Cunha-Santino; Bitar; Bianchini Jr., 2013). It is noteworthy that longitudinal processes and reservoir characteristics (e.g., trophic status, morphometry, heterogeneity) are associated with metabolic processes such as primary production, organic matter degradation, and biogeochemical cycles (Tundisi, 2018; Hasanzadeh et al., 2020). These systems exhibit similar processes to those structuring and governing natural lake ecosystems (Tundisi, 2018).

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The accumulated water volume in reservoirs and the processes occurring therein, such as sedimentation rates of carbon fractions and nutrient retention, contribute to the differentiation of limnological variables downstream and upstream of the ecosystem (Santos et al., 2018). These artificial systems function as biogeochemical reactors, retaining substances and causing differences in input and output concentrations over time (Akbarzadeh et al., 2019).

In the case of the RBB, it became evident how its properties and processes contribute to the retention of a large portion of the analyzed limnological variable values, favoring water quality improvement downstream. The assimilation of compounds by reservoirs can be understood as an ecosystem service (Intralawan et al., 2018). Moreover, it is essential to emphasize all socio-environmental impacts and externalities related to the construction of these environments, both positive and negative.

However, when stabilized, these systems exert a direct influence on element retention and must be considered in the management of adverse impacts such as eutrophication (Akbarzadeh et al., 2019). From 2013 to 2015, a severe water crisis occurred in the state of São Paulo (Jacobi; Buckeridge; Ribeiro, 2021). Thus, the observed variations in the RBB case may be associated with changes in volume and discharge, given the strong influence of rainfall patterns and seasonality.

Other studies have shown that these artificial ecosystems can sequester various limnological variables due to their functioning and metabolism (Smith; Espíndola; Rocha, 2014; Cunha-Santino; Fushita; Bianchini Jr., 2017; Bianchini, Fushita; Cunha-Santino, 2019; Maavara et al., 2020). In this study, the observed retentions may be linked to sedimentation and assimilation processes.

The operational conditions of reservoirs directly influence the flow, and anthropogenic alterations in direct contribution areas interfere with these systems (Gonçalves et al., 2013; Ciria; Labat; Chiogna, 2019), especially in metropolitan areas. Mathematical models for reservoir assessment contribute to the development of management guidelines (Zhou et al., 2016). The mass balance becomes a method used for the quantification of substance retention, such as nitrogen (Akbarzadeh et al., 2019).

The spatial heterogeneity of reservoirs is linked to factors such as morphology, flow, and residence time of reservoirs; thus, changes may occur in the absorption and mineralization of compounds from the aquatic and terrestrial systems (Berberich et al., 2019).

Factors, such as temperature and precipitation volume, directly influence the functioning of reservoirs (Yan et al., 2020). Reservoir management requires implementing institutional and governance processes, given their role in providing water during drought and scarcity situations (Kellner, 2021). Therefore, land use regulation in metropolitan areas, adopting sustainable agricultural practices, and implementing nature-based solutions contribute to improving the quality of these aquatic systems.

Reservoirs are complex systems that are part of socioecological ecosystems, influenced by anthropogenic actions, natural processes, and political-institutional factors (Kellner, 2021). The case of the RBB is no different; management measures are necessary for its long-term maintenance. Investments are needed to improve the water quality of its tributaries. The adopted approach proved useful for verifying the retention capacity of reservoirs in anthropized areas. The findings can contribute to decision-making.

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5 CONCLUSION

Mathematical modeling has proven to be a valuable tool for reservoir assessment. In fact, the RBB can retain a significant portion of the limnological variables from the Piracicaba and Tietê rivers due to its biogeochemical properties and processes. Water quality improvement occurs downstream of the reservoir. Despite being in a subtropical region and experiencing a strong influence of seasonality, no variations were observed in the capacity of retention. However, when compared with the categorization of alpha values, it is evident that retention can be considered either good or very high in most cases. Despite being one of the most polluted reservoirs in the state of São Paulo, the RBB provides an important ecosystem service, given its retention capacity.

6 ACKNOWLEDGMENTS

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REFERERENCES

Agência Nacional de Águas e Saneamento Básico - ANA. **Dados de operação dos reservatórios SIN**. Disponível em: https://www.ana.gov.br/sar0/MedicaoSin?dropDownListEstados=26&dropDownListReservatorios=19040&dataInicial=05%2F01%2F2010&dataFinal=05%2F01%2F2010&button=Buscar. Acesso em: 25 jan. 2022.

AKBARZADEH, Z.; MAAVARA, T.; SLOWINSKI, S.; VAN CAPPELLEN, P. Effects of damming on river nitrogen fluxes: a global analysis. **Global Biogeochemical Cycles**, v. 33, n. 11, p. 1339-1357, 2019. Disponível em: https://doi.org/10.1029/2019GB006222

ALBERTI, M. Cities of the Anthropocene: urban sustainability in an eco-evolutionary perspective. **Philosophical Transactions of the Royal Society B**, v. 379, n. 1893, p. 20220264, 2024. Disponível em: https://doi.org/10.1098/rstb.2022.0264

ALCÂNTARA, BERNARDO, N.; RODRIGUES, T.; WATANABE, F. Modeling the spatio-temporal dissolved organic carbon concentration in Barra Bonita reservoir using OLI/Landsat-8 images. **Modeling Earth Systems and Environment**, v. 3, p. 1-6, 2017. Disponível em: https://doi.org/10.1007/s40808-017-0275-2

APHA; AWWA; WEF. **Standard methods for the examination of water and wastewater 22ª Edition**. Washington, DC, january 2012. Disponível em: http://www.standardmethods.org. Acesso em: 27 maio 2021.

BERBERICH, M. E.; BEAULIEU, J. J.; HAMILTON, T. L.; WALDO, S.; BUFFAM, I. Spatial variability of sediment methane production and methanogen communities within a eutrophic reservoir: Importance of organic matter source and quantity. **Limnology and Oceanography**, v. 65, n. 6, p. 1336-1358, 2020. Disponível em: https://doi.org/10.1002/lno.11392

BERNARDO, N.; WATANABE, F.; RODRIGUES, T.; ALCÂNTARA, E. Evaluation of the suitability of MODIS, OLCI and OLI for mapping the distribution of total suspended matter in the Barra Bonita Reservoir (Tietê River, Brazil). **Remote**

Sensing Applications: Society and Environment, v. 4, p. 68-82, 2016. Disponível em: https://doi.org/10.1016/j.rsase.2016.06.002

BIANCHINI, I.; FUSHITA, Â. T.; CUNHA-SANTINO, M. B. Evaluating the retention capacity of a new subtropical run-of-river reservoir. **Environmental Monitoring Assessment**, v. 191, n. 3, p. 1-15, 2019. Disponível em: https://doi.org/10.1007/s10661-019-7295-5

BOTTINO, F.; CASALI, S. P.; CUNHA-SANTINO, M. B.; CALIJURI, M. D. C.; BIANCHINI JÚNIOR, I. Potential of the retention capability of a Neotropical reservoir (São Paulo State, Brazil). **Acta Limnologica Brasiliensia**, v. 35, p. e4, 2023. Disponível em: https://doi.org/10.1590/S2179-975X6922

BORTOLINI, J. C.; SILVA, P. R. L.; BAUMGARTNER, G.; BUENO, N. C. Response to environmental, spatial, and temporal mechanisms of the phytoplankton metacommunity: comparing ecological approaches in subtropical reservoirs. **Hydrobiologia**, v. 830, n. 1, p. 45-61, 2019. Disponível em: https://doi.org/10.1007/s10750-018-3849-8

BRAVO-LINARES, C.; OVANDO-FUENTEALBA, L.; MUÑOZ-ARCOS, E.; KITCH, J. L.; MILLWARD, G. E.; LÓPEZ-GAJARDO, R.; MARCELA CAÑOLES-ZAMBRANO, M.; DEL VALLE, A.; KELLY, C.; BLAKE, W. H. Basin scale sources of siltation in a contaminated hydropower reservoir. **Science of the Total Environment**, v. 914, p. 169952, 2024. Disponível em: https://doi.org/10.1016/j.scitotenv.2024.169952

CHAPRA, S. C.; RECKHOW, K. H. **Engineering Approaches for Lake Management: Mechanistic Modelling.** Butterworth Publishers, Worbun, 1983.

COMPANHIA AMBIENTAL DO ESTADO DE SÃO PAULO - CETESB. **Publicações e Relatórios**. Disponível em: https://cetesb.sp.gov.br/aguas-interiores/publicacoes-e-relatorios/. Acesso em: 17 mar. 2022.

CIRIA, T. P.; LABAT, D.; CHIOGNA, G. Detection and interpretation of recent and historical streamflow alterations caused by river damming and hydropower production in the Adige and Inn river basins using continuous, discrete and multiresolution wavelet analysis. **Journal of Hydrology**, v. 578, p. 124021, 2019. Disponível em: https://doi.org/10.1016/j.jhydrol.2019.124021

CUNHA-SANTINO, M. B.; BITAR, A. L.; BIANCHINI JR., I. Chemical constraints on new man-made lakes. **Environmental Monitoring and Assessment**, v. 185, n. 12, p. 10177–10190, 2013. Disponível em: https://doi.org/10.1007/s10661-013-3322-0

CUNHA-SANTINO, M. B.; FUSHITA, A. T.; BIANCHINI JR, I. A modeling approach for a cascade of reservoirs in the Juquiá-Guaçu River (Atlantic Forest, Brazil). **Ecological Modelling**, v. 356, p. 48 - 58, 2017. Disponível em: https://doi.org/10.1016/j.ecolmodel.2017.04.008

Departamento de Águas e Energia Elétrica - DAEE. **Hidrologia - Banco de dados hidrológicos**. Disponível em: http://www.hidrologia.daee.sp.gov.br/Default.aspx?dadosorigem=Fluviométricos&ugrhi=UGRHI&cidadeugrhi=PIRACICABA%2FCAPIVARI%2FJUNDIAI&prefixoposto=4D-007. Acesso: 25 jan. 2022.

FILIPPIS, G. et al. Water Quality Assessment: A Quali-Quantitative Method for Evaluation of Environmental Pressures Potentially Impacting on Groundwater, Developed under the MINO Re. Project. **International Journal of Environmental Research and Public Health**, v. 17, n. 6, p. 1835, 2020. Disponível em: https://doi.org/10.3390/ijerph17061835

FYLSTRA, D.; LASDON, L.; WATSIN, J.; WAREN, A. Design and use of the Microsoft Excel solver. **INTERFACES**, v. 28, n. 5, p. 29-55, 1998. Disponível em: https://doi.org/10.1287/inte.28.5.29

ISSN 2318-8472, v. 14, n. 91, 2026

GIBERTONI, R. F. C.; PINTO, R. B.; REBUTINI, I. F. **Avaliação da estabilidade de bordas de reservatório**. XIX Simpósio Brasileiro de Recursos Hídricos, p. 1 - 19, 2011. Disponível em: https://files.abrhidro.org.br/Eventos/Trabalhos/153/5fcd110af5ffc3a0918ea9eb9ef066e1_f37bd4f91b09f3881866218eb898ee89.pdf. Acesso em: 27 out. 2024.

GODOY, R. F. B.; TREVISAN, E.; BATTISTELLI, A. A.; CRISIGIOVANNI, E. L.; NASCIMENTO, E. A.; FONSECA MACHADO, A. L. Does water temperature influence in microcystin production? A case study of Billings Reservoir, São Paulo, Brazil. **Journal of Contaminant Hydrology**, v. 255, p. 104164, 2023. Disponível em: https://doi.org/10.1016/j.jconhyd.2023.104164

GONÇALVES, S. C.; MARTINS, C. R. B.; ROMERO, D. C. G.; OKIMOTO, F. S. Análise das condições ambientais no Ribeirão Baixotes, na bacia hidrográfica do baixo Tietê, em Birigui (São Paulo, Brasil). **Revista Nacional de Gerenciamento de Cidades**, v. 13, n. 89, p. 12-19, 2013. Disponível em: https://doi.org/10.17271/23188472138920256171.

HASANZADEH, S. K.; SAADATPOUR, M.; AFSHAR, A. A fuzzy equilibrium strategy for sustainable water quality management in river-reservoir system. **Journal of Hydrology**, v. 586, p. 124892, 2020. Disponível em: https://doi.org/10.1016/j.jhydrol.2020.124892

INTRALAWAN, A.; WOOD, D.; FRANKEL, R.; COSTANZA, R.; KUBISZEWSKI, I. Tradeoff analysis between electricity generation and ecosystem services in the Lower Mekong Basin. **Ecosystem Services**, v. 30, p. 27-35, 2018. Disponível em: https://doi.org/10.1016/j.ecoser.2018.01.007

JØRGENSEN, S. E.; BENDORICCHIO, G. **Fundamental of Ecological Modelling**, 3 rd ed. Elsevier, Amsterdam, 2001.

KELLNER, E. The controversial debate on the role of water reservoirs in reducing water scarcity. **Wiley Interdisciplinary Reviews: Water**, v. 8, n. 3, p. e1514, 2021. Disponível em: https://doi.org/10.1002/wat2.1514

JACOBI, P. R.; BUCKERIDGE, M.; RIBEIRO, W. C. Governança da água na Região Metropolitana de São Paulo-desafios à luz das mudanças climáticas. **Estudos Avançados**, v. 35, p. 209-226, 2021. Disponível em: https://doi.org/10.1590/s0103-4014.2021.35102.013

MAAVARA, T.; CHEN, Q.; VAN METER, K.; BROWN, L. E.; ZHANG, J.; NI, J.; ZARFL, C. River dam impacts on biogeochemical cycling. **Nature Reviews Earth & Environment**, v. 1, n. 2, p. 103-116, 2020. Disponível em: https://doi.org/10.1038/s43017-019-0019-0

NOGUEIRA, M. G.; PERCHIBE-NEVES, G.; NALIATO, D. O.; CASANOVA, S. M. C.; DEBASTIANI-JÚNIOR, J. R.; ESPÍNDOLA, E. G. Limnology and water quality in La Plata basin (South America)–Spatial patterns and major stressors. **Ecological Indicators**, v. 120, p. 106968, 2021. Disponível em: https://doi.org/10.1016/j.ecolind.2020.106968

NOVAES, J. L. C.; CARVALHO, E. D. Analysis of artisanal fisheries in two reservoirs of the upper Paraná River basin (Southeastern Brazil). **Neotropical Ichthyology**, v. 11, p. 403-412, 2013. Disponível em: https://doi.org/10.1590/S1679-62252013005000002

OLIVEIRA, S. A.; FERRAGUT, C.; BICUDO, C. E. M. Relationship between phytoplankton structure and environmental variables in tropical reservoirs with different trophic states. **Acta Botanica Brasílica**, v. 34, n. 1, p. 83-93, 2020. Disponível em: https://doi.org/10.1590/0102-33062019abb0207

PRADO, R. B.; NOVO, E. M. L. M. Avaliação espaço-temporal da relação entre o estado trófico do reservatório de Barra Bonita (SP) e o potencial poluidor de sua bacia hidrográfica. **Sociedade & Natureza**, v. 19, n. 2, p. 5 – 19, 2007.

ISSN 2318-8472, v. 14, n. 91, 2026

Disponível em: https://www.alice.cnptia.embrapa.br/alice/bitstream/doc/339088/1/a01v19n2.pdf. Acesso: 26 out. 2024.

PIRES, D. A.; TUCCI, A.; CARVALHO, M. D. C.; LAMPARELLI, M. C. Water quality in four reservoirs of the metropolitan region of São Paulo, Brazil. **Acta Limnologica Brasiliensia**, v. 27, n. 4, p. 370-380, 2015. Disponível em: https://doi.org/10.1590/S2179-975X4914

ROTTA, ALCÂNTARA, E.; PARK, E.; BERNARDO, N.; WATANABE, F. A single semi-analytical algorithm to retrieve chlorophyll-a concentration in oligo-to-hypereutrophic waters of a tropical reservoir cascade. **Ecological Indicators**, v. 120, p. 106913, 2021. Disponível em: https://doi.org/10.1016/j.ecolind.2020.106913.

SANTOS, N. C. L.; GARCIA-BERTHOU, E.; DIAS, J. D.; LOPES, T. M.; AFFONSO, I. D. P.; SEVERI, W.; GOMES, L. C.; AGOSTINHO, A. A. Cumulative ecological effects of a Neotropical reservoir cascade across multiple assemblages. **Hydrobiologia**, v. 819, n. 1, p. 77-91, 2018. Disponível em: https://doi.org/10.1007/s10750-018-3630-z

SANTOS, F. S. R.; RIBEIRO, A. P.; OLIVEIRA, A.; GALLEGO, J. L. Indicadores de Eutrofização na Represa Billings, São Paulo: Apoio ao Planejamento Urbano e à Gestão de Mananciais. **Revista Nacional de Gerenciamento de Cidades**, v. 13, n. 89, p. 141-163, 2025. Disponível em: https://doi.org/10.17271/23188472138920255957.

SILVA, F. L. **Modelagem matemática, serviços ecossistêmicos e análise da paisagem como ferramentas no manejo de reservatórios inseridos em áreas antropizadas**. 2022. 149 p. Tese (Doutorado em Ecologia e Recursos Naturais). Universidade Federal de São Carlos, São Carlos, SP. Disponível em: https://repositorio.ufscar.br/handle/ufscar/15796

SILVA, F. L.; FUSHITA, Â. T.; CUNHA-SANTINO, M. B.; BIANCHINI JR, I. Adopting basic quality tools and landscape analysis for applied limnology: an approach for freshwater reservoir management. **Sustainable Water Resources Management**, v. 8, n. 3, p. 65, 2022. Disponível em: https://doi.org/10.1007/s40899-022-00655-8

Sistema Nacional de Informações sobre Recursos Hídricos - SNIRH. **Séries Históricas de Estações - HIDROWEB**. Disponível em: https://www.snirh.gov.br. Acesso: 25 jan. 2022.

SMITH, W. S.; ESPÍNDOLA, E. L. G.; ROCHA, O. Environmental gradient in reservoirs of the medium and low Tietê River: limnological differences through the habitat sequence. **Acta Limnologica Brasiliensia**, v. 26, p. 73-88, 2014. Disponível em: https://doi.org/10.1590/S2179-975X2014000100009

STEPHENS, G. L.; SLINGO, J. M.; RIGNOT, E.; REAGER, J. T.; HAKUBA, M. Z.; DURACK, P. J.; WORDEN, J.; ROCCA, R. Earth's water reservoirs in a changing climate. **Proceedings of the Royal Society A**, v. 476, n. 2236, p. 20190458, 2020. Disponível em: https://doi.org/10.1098/rspa.2019.0458

SØNDERGAARD, M.; JENSEN, J. P.; JEPPESEN, E. Role of sedimentation and internal loading of phosphorus in shallow lakes. **Hydrobiologia**, v. 505, p. 135 - 145, 2003. Disponível em: https://doi.org/10.1023/B:HYDR.0000008611.12704.dd

TEODORU, C.; WEHRLI, B. Retention of sediments and nutrients in the Iron Gate I Reservoir on the Danube River. **Biogeochemistry**, v. 76, n. 3, p. 539-565, 2005. Disponível em: https://doi.org/10.1007/s10533-005-0230-6

TUNDISI, J. G. Reservoirs: new challenges for ecosystem studies and environmental management. **Water Security**, v. 4, p. 1-7, 2018. Disponível em: https://doi.org/10.1016/j.wasec.2018.09.001

TUNDISI, J. G.; MATSUMURA-TUNDISI, T.; ABE, D. S. The ecological dynamics of Barra Bonita (Tietê River, SP, Brazil) reservoir: implications for its biodiversity. **Brazilian Journal of Biology**, v. 68, p. 1079-1098, 2008. Disponível em: https://doi.org/10.1590/S1519-69842008000500015

ISSN 2318-8472, v. 14, n. 91, 2026

USEPA. **SW 846 - Test Methods for Evaluating Solid Waste, Physical/Chemical Methods – Environment Protection Agency, USA**. Disponível em: http://www.epa.gov/waste/hazard/testmethods/sw846/online/index.htm. Acesso em: 27 mar 2021.

XIE, Y.; WANG, S.; XIANG, S.; WANG, Z.; LI, Y.; WANG, Z.; ZHOU, M.; WANG, Y.; GAO, M. Ecological zoning and dynamic assessment of effectiveness in the Three Gorges Reservoir Area, China. **Ecological Modelling**, v. 487, p. 110563, 2024. Disponível em: https://doi.org/10.1016/j.ecolmodel.2023.110563

YAN, M.; Chen, S.; Huang, T.; Li, B.; Li, N.; Liu, K.; ZONG, R.; MIAO, Y.; Huang, X. Community compositions of phytoplankton and eukaryotes during the mixing periods of a drinking water reservoir: dynamics and interactions. **International Journal of Environmental Research and Public Health**, v. 17, n. 4, p. 1128, 2020. Disponível em: https://doi.org/10.3390/ijerph17041128

ZANIOLO, M.; GIULIANI, M.; SINCLAIR, S.; BURLANDO, P.; CASTELLETTI, A. When timing matters—misdesigned dam filling impacts hydropower sustainability. **Nature Communications**, v. 12, n. 1, p. 1-10, 2021. Disponível em: https://doi.org/10.1038/s41467-021-23323-5

ZHOU, B.; XU, Y.; VOGT, R. D.; LU, X.; LI, X.; DENG, X.; YUE, A.; ZHU, L. Effects of Land Use Change on Phosphorus Levels in Surface Waters-a Case Study of a Watershed Strongly Influenced by Agriculture. **Water Air and Soil Pollution**, v. 227, n. 5, p. 1-14, 2016. Disponível em: https://doi.org/10.1007/s11270-016-2855-6

ISSN 2318-8472, v. 14, n. 91, 2026

STATEMENTS

AUTHOR CONTRIBUTIONS

- Study Conception and Design: Fabio Leandro da Silva and Marcela Bianchessi da Cunha-Santino.
- Data Curation: Fabio Leandro da Silva.
- Formal Analysis: Fabio Leandro da Silva, Ângela Terumi Fushita, Marcela Bianchessi da Cunha-Santino, and Irineu Bianchini Júnior.
- Funding Acquisition: Fabio Leandro da Silva.
- Investigation: Fabio Leandro da Silva, Marcela Bianchessi da Cunha-Santino, and Irineu Bianchini Júnior.
- Methodology: Fabio Leandro da Silva, Marcela Bianchessi da Cunha-Santino, and Irineu Bianchini Júnior.
- Writing - Original Draft: Fabio Leandro da Silva.
- Writing - Review & Editing: Ângela Terumi Fushita, Marcela Bianchessi da Cunha-Santino, and Irineu Bianchini Júnior.
- Final Review and Editing: Fabio Leandro da Silva, Ângela Terumi Fushita, Marcela Bianchessi da Cunha-Santino, and Irineu Bianchini Júnior.
- Supervision: Ângela Terumi Fushita and Marcela Bianchessi da Cunha-Santino**.**

CONFLICTS OF INTEREST STATEMENT

We, Fabio Leandro da Silva, Ângela Terumi Fushita, Marcela Bianchessi da Cunha-Santino and Irineu Bianhini Júnior, declare that the manuscript titled " **Detecting the retention capability potential of a hypereutrophic reservoir influenced by upstream inputs from metropolitan areas**":

1. Financial Ties: The authors have no financial ties that could influence the results or interpretation of the work.
2. Professional Relationships: The authors have no professional relationships that could impact the analysis, interpretation, or presentation of the results.
3. Personal Conflicts: The authors have no personal conflicts of interest related to the content of the manuscript.