# The ionic composition of ten reservoirs in southern Brazil

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## Abstract

*The ionic composition of ten reservoirs in São Paulo State is analyzed, based on samples taken in the euphotic zone, during the wet and dry seasons.*

*The reservoirs showed low values of conductivity and alkalinity excepting Americana Reservoir, largely influenced by sewage discharge in the impounded river.*

*According to their concentrations, the cations recorded can be arranged in the following order : Na > Ca > K > Mg. Bicarbonate was the dominant anion. The quite unusual dominance of sodium was due to the low calcium concentration in the water bodies, as a result of the edaphic features of the watersheds.*

*The relative composition observed is similar to that of other freshwater bodies in Central Southeastern Brazil.*

Key words : Chemical composition — Tropical lakes — Reservoirs — South America — Freshwater.

## Résumé

### La composition ionique de dix réservoirs du sud du Brésil

*La composition ionique de dix réservoirs de l'État de São Paulo est analysée à partir d'échantillons obtenus dans la zone euphotique, durant les saisons sèche et pluvieuse.*

*Les réservoirs ont présenté de faibles valeurs de conductivité et d'alcalinité, exception faite pour le réservoir d'Americana, fortement influencé par les rejets d'eaux usées.*

*En fonction de leur concentration, les cations se présentent dans l'ordre suivant : Na > Ca > K > Mg. L'anion qui domine est le bicarbonate. La quantité inhabituelle de sodium est provoquée par la faible concentration de calcium, résultant des caractéristiques édaphiques des bassins.*

*La composition relative observée est semblable à celle d'autres plans d'eau douce du centre et sud-est du Brésil.*

Mots-clés : Composition chimique — Lacs tropicaux — Réservoirs — Amérique du Sud.

## Resumen

### La composición ionica de diez embalses en el sur de Brasil

*La composición ionica de diez embalses nel Estado de São Paulo es analizada con base en muestras obtenidas en la zona eufótica, en las estaciones seca e lluviosa.*

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*Los embalses presentaron valores bajos de conductividad y de alcalinidad, con excepción de la Represa de Americana, altamente influenciada por águas servidas descargadas en el rio represado.*

*De acuerdo con sus concentraciones los cationes pueden ser presentados en el orden siguiente : Na > Ca > K > Mg. La inusitata predominancia de sodio se debe a la baja concentración de calcio en los cuerpos de agua, resultante de las caracteristicas edáficas de las cuencas.*

*La composición relativa encontrada es semejante a las de otros cuerpos de agua dulce del centro e sudeste del Brasil.*

PALABRAS CLAVES : Composición ionica — Embalses tropicales — America del Sur.

## INTRODUCTION

The knowledge on the ionic composition of continental waters until the first decades of this century led to the assumption that calcium bicarbonate was the dominant ion in freshwater bodies. However, further investigations in African and Australian lakes (TALLING & TALLING, 1965; BAYLY & WILLIAMS, 1973; VISSER, 1974, among others), representing a significant amount in the world freshwater volume, has changed this image. These environments present dominance of magnesium or sodium bicarbonate, and sodium chloride. Many African lakes have saline water inflows or are located in closed basins with high evaporation rates, which ascribe peculiar characteristics to these waters, increasing conductivity to high levels and influencing the ionic proportions.

With the purpose of providing data on the ionic composition of the scarcely known Brazilian water bodies, thus enlarging the possibility of world wide comparisons, this paper presents an ionic composition analysis of reservoirs located in Southern Brazil. This study is part of a major project "Typology of Reservoirs of São Paulo State" (TUNDISI, 1981).

General hydrological, physical, chemical and biological features are given in ARCIFA *et al.* (1981 a, b), and detailed studies on zooplankton and primary productivity in ARCIFA (1984), and GIANESELLA GALVÃO (1985), respectively.

### Geologic and climatic Features

Most of the reservoirs and their watersheds are located in pre-Cambrian terrain (IGG, 1963), whose soils are acid (ph < 5.5) and poor in calcium and magnesium (GARGANTINI *et al.*, 1970). Americana Reservoir is situated in more recent terrain from the Upper Carboniferous, with intrusions of basic rocks from the Tertiary, richer in calcium.

Excepting Americana Reservoir, located in tropical climate (maximum rainfall 1 100 mm per year), all the others are situated in a transition zone between tropical and subtropical climate, with annual average rainfall between 1 500-2 000 mm. Ribeirão do Campo is located near the Serra do Mar escarpment, characterized by exceptional rainfall, attaining 4 500 mm per year (MONTEIRO, 1973).

Grassland and cultivated areas surround Americana and Taiaçupeba Reservoirs. Ribeirão do Campo and Pedro Beicht Reservoirs are located in the Atlantic Forest and Cabuçu Reservoir is surrounded by a reforestation area. A mixed vegetation comprising grassland, secondary forest, cultivated or reforested areas surrounds the other reservoirs. Both Americana and Taiaçupeba are being affected by cultural eutrophication.

## MATERIAL AND METHODS

The reservoirs are located between 22°42′ S to 23°44′ S and 45°16′ W to 47°17′ W (fig. 1). Seven of them belong to the Tietê River Basin, namely, Ribeirão do Campo, Taiaçupeba, Cabuçu, Pedro Beicht, Cachoeira, Atibainha and Americana, and three to the Paraíba do Sul Basin: Paraibuna, Santa Branca and Jaguari.

Water samples were taken at one station, on the deepest area of the main body of each reservoir, excepting Paraibuna, where three stations were established due to the large size and dendritic shape of the reservoir.

Samplings were carried out in 1979, two during the wet season (summer : March and December) and two during the dry season (winter : May and August).

Samples were taken with a Van Dorn bottle, in a vertical profile within the euphotic zone corresponding to the levels of 100, 50, 25, 10 and 1 % of surface light if allowed by the height of the water column. Samples for ion analysis were filtered through Millipore Ap 20 and the filtrate preserved with $HNO_3$ to pH 2.0. Samples for pH and alkalinity analysis were taken carefully in special bottles, avoiding bubbles.

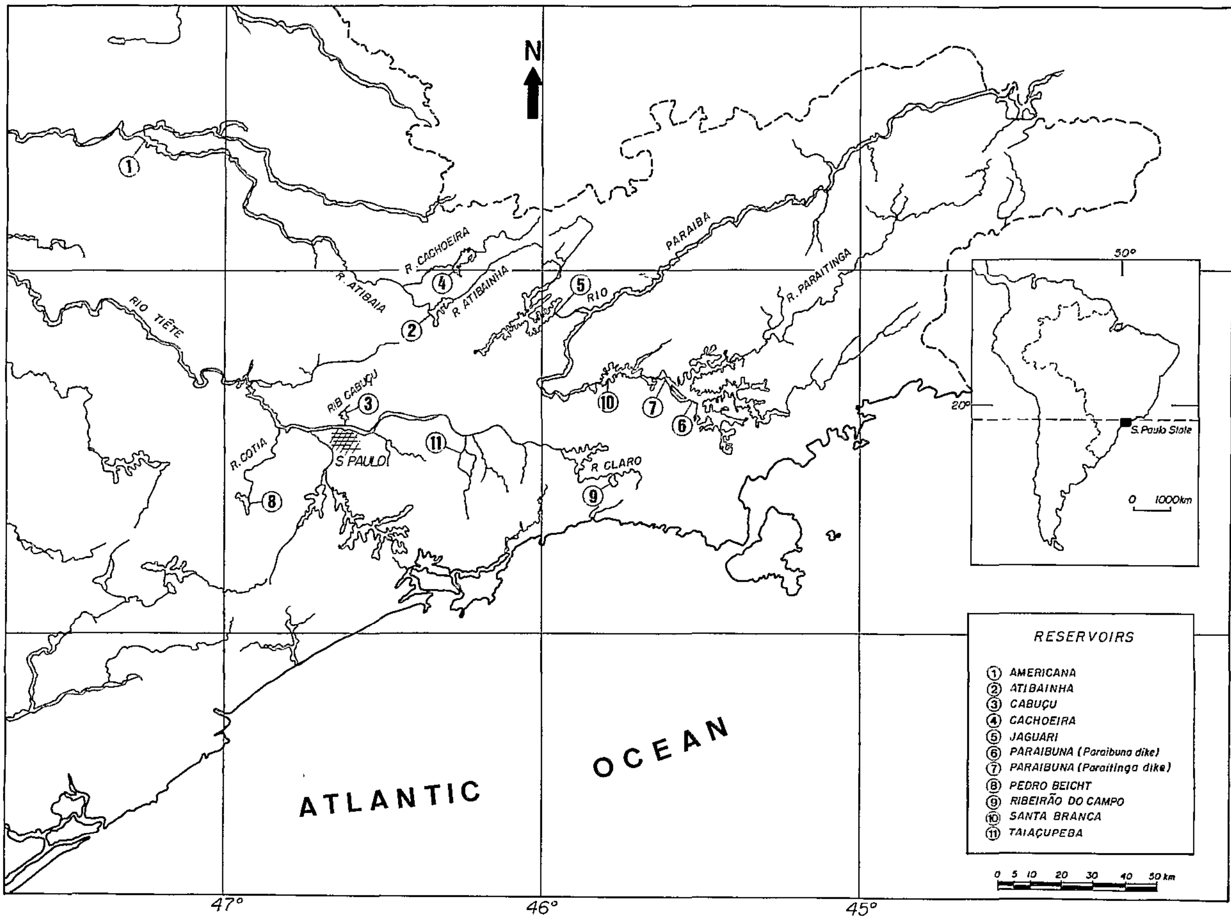


FIG. 1. — Map of the region with the location of the reservoirs. *Carte de la région avec la localisation des réservoirs*

Conductivity measurements were corrected for 25 °C. Alkalinity was determined by acid titration according to MACKERETH *et al.* (1978).

Calcium, magnesium, iron, copper, manganese and zinc were analyzed by plasma spectrometry (PONGAR & THOMPSON, 1978) sodium and potassium by flame spectrometry (Perkin-Elmer, 1973).

Chlorides were determined by colorimetry in flow injection (BERGAMIN *et al.*, 1978) and sulphates by flow injection turbidimetry (KRUGG *et al.*, 1977). Carbonates were estimated from temperature, pH, conductivity and alkalinity according to MACKERETH *et al. (op. cit.)*.

## RESULTS AND DISCUSSION

The analysed ions $Ca^{++}$, $Mg^{++}$ and $Zn^{++}$ presented a vertical homogeneous distribution in the euphotic zone of the reservoirs throughout the year, but $Fe^{++}$, $Mn^{++}$ and $SO_4^{--}$ were sometimes stratified in relation to thermal stability (ARCIFA *et al.*, 1981 a).

The general physical and chemical data obtained are summarized in Tab. I. Conductivity values were very low — 12 to 50 $\mu S.cm^{-1}$ — except in Americana Reservoir, where values ranged from 136 to 159 $\mu S.cm^{-1}$. The lowest conductivity values were observed in Ribeirão do Campo and Pedro Beicht Reservoirs, located at the headwaters and surrounded by forest.

The low ionic content of the reservoirs is a consequence of the paucity of the old soils of Paraiba and Tietê watersheds, located mostly in pre-Cambrian terrains, poor in cations such as $Ca^{++}$ and $Mg^{++}$ (GARGANTINI *et al.*, *op. cit.*).

A recent paper by MAIER & TAKINO (1985) dealing with seventeen reservoirs of São Paulo State showed a similar conductivity range (4 – 55 $\mu S.cm^{-1}$), excepting for three of them which receive a heavy

TABLE I

General physical and chemical data
*Résultats généraux physiques et chimiques*

| Reservoirs | pH | Alkalinity meq $l^{-1}$ | Conductivity $\mu Scm^{-1}$ | $Ca^{2+}$ | $Mg^{2+}$ | $Na^{+}$ | $K^{+}$ | $SO_4^{2-}$ | $HCO_3^{-}$ | $Cl^{-}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | concentration mgl $^{-1}$ | | | | | | |
| Americana | 7.7 | 0.791 | 136.0 | 6.29 | 1.65 | 16.88 | 3.08 | 12.17 | 48.10 | 7.21 |
| | 7.5 | 0.855 | 159.0 | 8.00 | 1.65 | 27.10 | 4.01 | 22.19 | 71.10 | 8.52 |
| Atibainha | 8.0 | 0.236 | 25.0 | 1.07 | 0.53 | 2.28 | 1.07 | <1.00 | 14.18 | 0.40 |
| | 7.1 | 0.256 | 28.0 | 1.66 | 0.67 | 1.98 | 1.58 | <1.00 | 15.52 | <0.10 |
| Cabuçu | 6.9 | 0.294 | 33.0 | 1.87 | 1.27 | 2.18 | 0.63 | 2.19 | 17.93 | 0.70 |
| | 6.8 | 0.276 | 46.0 | 2.34 | 1.39 | 2.61 | 1.03 | 1.22 | 16.83 | <0.10 |
| Cachoeira | 8.3 | 0.234 | 25.0 | 0.98 | 0.46 | 2.30 | 0.96 | <1.00 | 14.05 | 0.40 |
| | 7.8 | 0.219 | 25.0 | 1.52 | 0.60 | 2.68 | 1.31 | <1.00 | 12.88 | <0.10 |
| Jaquari | 7.4 | 0.282 | 30.0 | 1.03 | 0.55 | 2.36 | 1.58 | <1.00 | 17.14 | 0.27 |
| | 6.7 | 0.206 | 28.0 | 1.45 | 0.69 | 2.36 | 1.56 | <1.00 | 12.62 | <0.10 |
| Paraibuna | 7.3 | 0.285 | 31.0 | 1.35 | 0.74 | 2.84 | 1.30 | 0.66 | 17.41 | 0.82 |
| | 6.7 | 0.224 | 31.5 | 1.74 | 0.81 | 2.92 | 1.75 | 1.64 | 13.84 | 0.25 |
| Pedro Beicht | 6.2 | 0.058 | 14.5 | 0.25 | 0.20 | 1.69 | 0.40 | <1.00 | 3.54 | 1.33 |
| | 6.5 | 0.069 | 14.5 | 0.47 | 0.32 | 2.05 | 0.63 | 2.31 | 4.21 | 0.61 |
| Ribeirão do Campo | 5.6 | 0.044 | 12.5 | 0.12 | 0.12 | 1.63 | 0.24 | 3.50 | 2.71 | 1.35 |
| | 5.6 | 0.060 | 15.0 | 0.29 | 0.23 | 1.61 | 0.49 | 2.80 | 3.66 | 0.27 |
| Santa Branca | 7.5 | 0.269 | 33.5 | 1.47 | 0.82 | 2.90 | 1.39 | 1.25 | 16.44 | 1.35 |
| | 6.8 | 0.271 | 35.0 | 1.69 | 0.87 | 3.15 | 1.87 | 2.25 | 16.56 | 0.59 |
| Taiaçupeba | 6.8 | 0.242 | 50.0 | 2.68 | 1.17 | 4.01 | 1.59 | 3.00 | 14.57 | 4.85 |
| | 6.6 | 0.170 | 48.0 | 2.92 | 1.07 | 5.30 | 1.85 | 4.13 | 10.36 | 5.19 |

First line : mean of two samplings in the wet season (3-5 samples in the euphotic zone).
Second line : mean of two samplings in the dry season (3-5 samples in the euphotic zone)

sewage load from São Paulo city, for which the values were generally high (290 – 440 $\mu$S.cm$^{-1}$, in the euphotic zone). In the Pantanal region, SILVA (1980) recorded values between 4.8 and 36.4 $\mu$S.cm$^{-1}$ throughout the year, and RIBERO (1978) found conductivity values between 4 – 62 $\mu$S.cm$^{-1}$ in five lakes in the Central Amazon region.

In spite of the acid nature of the watershed soils, pH values of the reservoirs were in general neutral (Table I). The measurements were always made during the daytime, when photosynthetic processes take place. These may contribute for an increase in pH, more pronounced in those environments with low buffering capacity.

For the majority of the reservoirs, the photosynthetic rates observed in the same occasions (GIANESELLA-GALVÃO, 1985) presented medium-low values (1.0 – 22.0 mg C.m$^{-3}$.h$^{-1}$) but were sufficient to maintain the pH of the reservoirs around neutrality during the daytime. A relatively high pH – 8.7 – was observed in Cachoeira Reservoir, simultaneously with one of the highest photosynthetic rates measured in this reservoir (15.9 mg C.m$^{-3}$.h$^{-1}$), indicating a low buffering capacity of the system. On the other hand, an effective buffer capacity was found in Americana, where alkalinity was threefold higher than that of Cachoeira, and despite its high primary productivity rates (34.19 – 160.34 mg C.m$^{-3}$.h$^{-1}$), pH values remained below 8 (Tab. I).

The lowest pH values were observed in Ribeirão do Campo, the surrounding forest and high rainfall accounting for the humic acids which are carried to the reservoir, resulting in the typical brown colour and low pH related to the low buffering capacity of those substances (WILSON, 1979).

Pedro Beicht Reservoir presents several similar features to Ribeirão do Campo such as depth, surrounding vegetation, low alkalinity, conductivity and ionic composition. However, it differs from the latter by not presenting brown waters. Besides, higher mean chlorophyll concentration is found in Pedro Beicht (64.8 mgchl*a*.m$^{-2}$, ARCIFA *et al.*, 1981 b) in contrast to Ribeirão do Campo (14.0 mg chl*a*.m$^{-2}$).

In most of the reservoirs the dominant ions were sodium and bicarbonate. Cation and anion sum determines the ionic balance and the results should agree closely, as occurred in the reservoirs (Tab. II).

TABLE II

Major ions composition (meq.l$^{-1}$) and ionic balance of the reservoirs. Mean values of four sampling periods (3-5 samples in the euphotic zone)

*Composition des principaux ions (mq.l$^{-1}$) et équilibre ionique des réservoirs. Valeurs moyennes de 4 périodes de prélèvements (3-5 échantillons dans la zone euphotique)*

| Reservoirs | $Ca^{2+}$ | $Mg^{2+}$ | $Na^{+}$ | $K^{+}$ | $SO_4^{2-}$ | $HCO_3^-$ | $Cl^-$ | Σ cations | Σ anions | Order of dominance for cations | Order of dominance for anions |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Americana | 0.35 | 0.13 | 1.12 | 0.09 | 0.39 | 0.81 | 0.22 | 1.69 | 1.42 | Na > Ca > Mg > K | $HCO_3 \gg SO_4 > Cl$ |
| Atibainha | 0.05 | 0.05 | 0.09 | 0.03 | 0.02 | 0.24 | 0.05 | 0.22 | 0.31 | Na > Ca ≃ Mg > K | $HCO_3 \gg Cl > SO_4$ |
| Cabuçu | 0.10 | 0.11 | 0.10 | 0.02 | 0.04 | 0.28 | 0.03 | 0.33 | 0.35 | Na ≃ Ca ≃ Mg > K | $HCO_3 \gg SO_4 \simeq Cl$ |
| Cachoeira | 0.06 | 0.04 | 0.09 | 0.03 | 0.02 | 0.22 | 0.00 | 0.21 | 0.24 | Na > Ca > Mg ≃ K | $HCO_3 \gg SO_4 > Cl$ |
| Jaguari | 0.07 | 0.04 | 0.11 | 0.03 | 0.02 | 0.24 | 0.00 | 0.25 | 0.26 | Na > Ca > Mg ≃ K | $HCO_3 \gg SO_4 > Cl$ |
| Paraibuna | 0.07 | 0.06 | 0.12 | 0.04 | 0.03 | 0.25 | 0.02 | 0.29 | 0.30 | Na > Ca > Mg > K | $HCO_3 \gg SO_4 \simeq Cl$ |
| Pedro Beicht | 0.01 | 0.02 | 0.08 | 0.01 | 0.01 | 0.06 | 0.03 | 0.12 | 0.10 | Na > Ca ≃ Mg ≃ K | $HCO_3 > Cl > SO_4$ |
| Ribeirão do Campo | 0.01 | 0.02 | 0.07 | 0.01 | 0.06 | 0.05 | 0.03 | 0.11 | 0.14 | Na > Ca ≃ Mg ≃ K | $SO_4 \simeq HCO_3 > Cl$ |
| Santa Branca | 0.08 | 0.07 | 0.13 | 0.04 | 0.04 | 0.27 | 0.06 | 0.32 | 0.37 | Na > Ca > Mg > K | $HCO_3 \gg Cl > SO_4$ |
| Taiaçupeba | 0.08 | 0.09 | 0.20 | 0.10 | 0.08 | 0.20 | 0.16 | 0.47 | 0.44 | Na > K > Mg > Ca | $HCO_3 > Cl > SO_4$ |

The signal ≃ was used when the difference between the means was ⩽ 0.01 meq.l$^{-1}$

In general, the order of ion dominance recorded was :

Cation: $Na^+ > Ca^{2+} > K^+ > Mg^{2+}$
Anion : $HCO_3^- > SO_4^{2-} > Cl^-$

Usually in temperate freshwater bodies, the order of dominance is (WETZEL, 1975) :

Cation : $Ca^{2+} > Mg^{2+} > Na^+ > K^+$
Anion : $CO_3^- > SO_4^{2-} > Cl^-$

The dominance of sodium is a common feature of several Brazilian water bodies. In lakes of the Pantanal region (SILVA, *op. cit.*) sodium is the dominant cation followed by potassium, calcium and magnesium. Sodium is also the dominant cation in natural lakes of the Rio Doce Valley, in Minas Gerais State (PONTES, 1980; BARBOSA & TUNDISI, 1980), as well as in other reservoirs in São Paulo State (MAIER & TAKINO, *op. cit.*). GIBBS (1972) relates the notably low calcium content in the Amazon River and RIBEIRO *(op. cit.)* studying the mentioned five lakes in central Amazon also observed sodium as the dominant cation. Otherwise, in the Amazonian Lake Castanho, calcium is the dominant ion (SCHMIDT, 1973).

At least in the Central-Southeastern region (São Paulo, Minas Gerais and Mato Grosso do Sul States) it has been verified that the predominance of sodium is usual. A comparison between these water bodies and those from temperate regions (WETZEL, *op. cit.*) reveals that sodium dominance in the former is rather due to an absolute low value of calcium than to a relative increase in sodium.

The dominance of bicarbonates in relation to sulphates and chlorides in the reservoirs agrees with the general trend in freshwater bodies. The sulphate dominance in relation to chloride, as is normally expected in temperate regions (WETZEL, *op. cit.*) was not conspicuous in our observations, since very often the difference among these ions was very small in absolute values and the reproductivity and sensitivity of analyses is low at these levels.

TABLE III

Trace element concentrations (mg.l$^{-1}$) for the reservoirs
*Concentration des éléments trace (mg.l$^{-1}$)* dans les réservoirs

| Reservoirs | Fe | Mn |
|---|---|---|
| Americana | 0.12 | 0.06 |
| Atibainha | < 0.10 | 0.05 |
| Cabuçu | 0.10 | < 0.01 |
| Cachoeira | 0.21 | 0.02 |
| Jaguari | < 0.10 | < 0.01 |
| Paraibuna | 0.63 | 0.33 |
| Pedro Beicht | < 0.10 | 0.01 |
| Ribeirão do Campo | 0.26 | 0.03 |
| Santa Branca | 0.60 | 0.02 |
| Taiaçupeba | 0.62 | 0.04 |

Each data represents the mean of four sampling periods (3-5 samples in the euphotic zone)

Tab. III shows the concentrations of trace-elements observed. A low sensitivity method was used for the determinations and data are presented in $mg.l^{-1}$.

Iron, in the dissolved form, filtrable through Ap20, although named a trace-element, was actually recorded in concentrations of the same order of magnitude as those of macro-elements in several of the reservoirs. These concentrations reached maximum values in Paraibuna (3.10 $mg.l^{-1}$, after circulation) and Sta. Branca reservoirs (1.89 $mg.l^{-1}$, after circulation), the last one downstream of the former.

Both copper and zinc were lower than detection limits, $< 0.02$ $mg.l^{-1}$ and 0.01 $mg.l^{-1}$ respectively, for all the reservoirs except Taiaçupeba that presented zinc in detectable amounts in one occasion (0.33 $mg.l^{-1}$). The occurrence of zinc in the water was probably a consequence of the neighborhood of this reservoir to industrial area. According to GOLDBERG (1976) the presence of this metal in water may result from cement plant activities.

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