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Hydrological Characterization of a Whitewater Lake at Amazon Floodplain - Brazil

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Abstract

Hydrological aspects were carried out on a spatial-temporal series in six sampling sites in a whitewater lake in Solimões River basin at the Central Amazonian - Brazil between 2004 and 2009. Bathymetry and morphometric relations, wind velocity, temperature, pH, conductivity, total density and ionic balance in vertical and horizontal profiles were investigated. Weak thermal stratification was observed with mean temperature in the surficial layer of 27.9±0.32ºC and in the bottom of 26.0±0.43ºC. EC tended to decrease from Solimões border to internal lake with mean of 60.1±24.8µS.cm^{-1} to surface and of 46.2±14.4µS.cm^{-1} to the bottom. Daily polymictic processes destroy the thermal stratification inducing complete vertical mixing of the water column, and components as flood-pulse, winds, morphometry and macrophytes banks influenced the mixture. Ions levels were distributed $HCO_3^- + CO_3^{2-} > Ca^{2+} > Cl^- > SO_4^{2-} > Na^+ > Mg^{2+} > K^+$. However, the great differential of water types in Amazonian are the cations, mainly calcium. With different magnitudes, the flood-pulse from Solimões River and the forest-rivers had strong influence and perturbation on the water column stability. The seasonality was clear and the flood-pulse was more significant to the water level than the local rainfall.

Keywords: Bathymetry, hydrological budget, conductivity trend, stratification process, flood-pulse.

Introduction

Brazilian Amazon is covered with a rain dense forest associated to great rivers, many lakes and a large floodplain area, which are wetlands periodically inundated by the lateral overflow of the rivers. The Amazon floodplain, denominated *várzea*, occupies part of the Central Amazon. It is flanked by a sequence of marshes and many over bank deposits, with longitudinal ribbons of sediment and depressions that conserve former stream patterns in relation to the main channel. Extensive plains become visible exhibiting erosional and depositional textures in continuous alternation. The erosion processes are responsible by the high concentration of suspended matter transported from highlands to diverse channels into the floodplain. Furthermore, the sediment accumulates in the areas of major depression, further narrowing the channels until the lakes become isolated. In these areas, the sediments predominantly formed by sand and silt are also responsible for the construction of small banks between river and lakes.

In the várzea, where many lakes are observed, the suspended matter from the main river is slowly carried into lake by diverse channels of distribution. The process of developing natural levees tends to raise riverbanks above the level of the surrounding floodplain, and it is fundamentals to accumulate nutrients and so to establish biota in Amazon floodplain. The floodplain supports the *igapó* that consists of characteristic associations of a limited number of tree and bush species with water depth apparently controlling the local predominance of one or the other. This exceptional and highly complex system is responsible by many life forms, establishing diverse networks of innumerable interdependence between biotic and abiotic systems into the Amazonian landscape.

Seasonal studies of the solids and dissolved loads transported in association to hydrological data are commonly applied to understand of ecological patterns and the water quality of the tropical waters[1,2]. Limnological and hydrological investigations and geological processes in Amazon have been collected since the early 1950s[3-6], mainly on optical characteristics, humic compounds, and content of suspended matter, and more recently on the seasonal aspects of *várzea* lakes[7-10]. This research has been conducted between 2004 and 2009 to offer basic original data on the hydrology and limnology of whitewater lakes in Amazon River basin, with emphasis to relationship between bathymetric-morphometric aspects and the stratification processes.

Material and Methods

Study Area: Poraquê Lake (03º57'S-63º10'W) is a small and shallow lake of whitewater in Amazon-Solimões River basin (Central Amazonian, Brazil) 18.5km away from Coari City and 2.5km upstream at the Petrobrás Solimões Terminal – TESOL (figure-1). The lake is a typical Amazonian floodplain lake connected with the Solimões River by channels, and formed by various forest-rivers, which serves as the natural drainage course for a lake drainage basin. The floodplain forest on seasonally inundated land around Lake Poraquê can be classified as seasonal várzea forest according to classification system for the Amazon[11]. The climate is equatorial hot and wet according to Köppen classification and average annual precipitation between North Peripheral Amazon and Central Amazon is 2400mm. year^{-1}. The great seasonal variability of the limnological parameters is characteristic of aquatic floodplain ecosystems[12], and the annual inundation of the Central Amazon River floodplain causes profound changes in the aquatic environment and provides a variety of habitats where shelter and food become available to fish[13].

Proceeds: The sampling sites were determined using Global Positioning System (GPS) and the bathymetric map was established based on these measurements. Bathymetric measures were developed in both low and high waters, and a 1/250 bathymetry map were developed and calculated with Global Mapper 11.01©2009 and Google Earth© 2013. The digital bathymetry was then integrated to get the hypsometric curves relating the level of the lake with its volume and surface. In the last step, polynomials were used to represent these curves. Water level of the Poraquê Lake and Solimões River near Coari City were obtained from weather station of the Petrobrás in Urucu River and in the meteorological databank at the Manaus Harbor. Wind speed (U_w m.s^{-1}) was obtained from a weather station of the Petrobrás located at the Urucu River with dates obtained in TESOL[14]. Water samples were collected with 1 liter Ruttner sampler, stored in polyethylene bottles, and kept nearly at about 4ºC immediately after sampling to avoid any contamination or alteration as much as possible. Temperature (ºC), pH and electric conductivity - salinity (EC µS.cm^{-1}; Salt ‰) were measured each three months at 0.25m intervals from the surface to bottom in six sampling sites (see figure-1) between 2004 and 2009 with a WTW OXI-197 thermistor electrode of accuracy ±0.1ºC and corrected to 25ºC for EC. Filtered water samples with Whatman GF/C glass-fiber filters (ϕ= 0.7µm) were utilized for ions determination. Concentrations of Na^+, K^+, Ca^{2+} and Mg^{2+} were measured by flame atomic absorption spectrophotometry; Cl^- by titration with $Hg(NO_3)_2$ using a mixed indicator of biphenyl-carbazona and bromphenol blue; bicarbonates were determined by acid titration to pH 4.6, using a mixed indicator of methyl red and bromcresol green, and SO_4^{2-} was measured by the $BaCl_2$ method with Na-EDTA acid. The results were associated with flood-pulse in the region. Sampling and preservation were done following international methodological procedures[15,16]. Total density of the water at depth z (ρ_z) was determined considering mainly temperature (ρ_T), and was calculated for each 1 m depth at each sampling period according to Martin and McCutcheon[17] (equation-1).

$$\rho_T = \left[1 - \frac{T + 288.9414}{508929.2\,(T + 68.12963)}(T - 3.9863)^2\right] \qquad \textbf{(1)}$$

Where: ρ_T is water density in g.cm^{-3}, and T is temperature in ºC.

The salt amount present in the samples was estimated by the sum of the major ions (Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, and HCO_3^-/CO_3^{2-}), and a regression equation was developed (equation-2).

$$EC = 1.6559x\ [major\ ions] + 26.917 \qquad R^2 = 0.9661 \qquad \textbf{(2)}$$

Where: EC is the specific conductance in µS.cm^{-1}.

Density was correlated with salt content considering that 1g.L^{-1} of salt would increase the density by 0.00085g.cm^{-1} (Ruttner[18]), and then the total ions for each depth were converted to density. Total density (ρ_z) was plotted against EC and temperature to determine its trend. Vertical and horizontal profiles of the EC were determined at about 235 meters intervals from littoral zone of the Poraquê Lake (sampling site P1) to Solimões River basin border (sampling site P6) to define the salt/ionic wedge. For the interpretation, the dates were analyzed with Pearson correlation statistical test and polynomial regression with theirs respectively standardized residual plots were performed on the flux data to estimate significant relationships between density, temperature and EC.

Results and Discussion

The Amazon River basin has diverse lakes in its boundaries formatted by the hydrological processes. Poraquê Lake is a typically small and shallow lake in an area with declivity inferior to 20mm by km. This condition of low declivity and the flood-pulse in the region are very important to volume oscillation of the lake during hydrological cycle. The morphometric and bathymetric data are summarized in table-1 and hypsometric curves showed in figure-1. The surface area and volume of Poraquê Lake at maximum pool are 229,134m^2 and 343,701m^3. The lake boundary began to enter the surrounding forest during the flood-periods. There is abundance of macrophytes in the lake, with predominance to the semi-aquatic grasses *Paspalum repens* and *Echynochloa polystachya*. These grasses grow along the perimeter and in clearings of the floodplain forest. This condition makes difficult to get morphometric measures, such as determination of perimeter and real surface area. Fast vegetative reproduction of these plants ensures quick colonization of the vast areas of the wetlands that become available. However, this development is interrupted by the reduction in area during low water periods, sometimes with a loss of more than 90%[19,20] of the aquatic vegetation. At low water levels, remnant populations of these macrophytes as well as floating plants *Eichhornia crassipes* and *Pistia stratiotes* persist on shore, rooted in the mud. Even if most part of the plants dies at dry periods (of October-December), a reduced population portion survives on the reduced banks of the lake or on the mud/soil as seeds, spores or by development of special terrestrial characteristics due to large morphological and/or physiological plasticity. Upon stream, these plants grow up and float at the water surface transforming the landscape once again with big banks of plants. The banks of macrophytes have two very important limnological actions on the lake: i. to reduce the surface tide and so to keep the suspended matter in flood periods; and ii. to supply ions from decomposition processes, mainly in low water periods.

Table-1
Morphometric data of the Poraquê Lake

Perimeter	4260 m	Maximum depth[b]	5.2 m
Surface area[a]	229,134 m^2	Minimum depth[b]	0.3 m
Volume[a]	343,701 m^3	Medium depth[b]	1.5 m
Maximum length	670 m	Relative depth	0.96 m
Minimum length	368 m	Maximum breadth	340 m
Medium length	586 m	Minimum breadth	129 m
Major diagonal	526 m	Medium breadth	228 m
Minor diagonal	324 m		

[a]Maximum pool; [b]Measures in sampling site P2

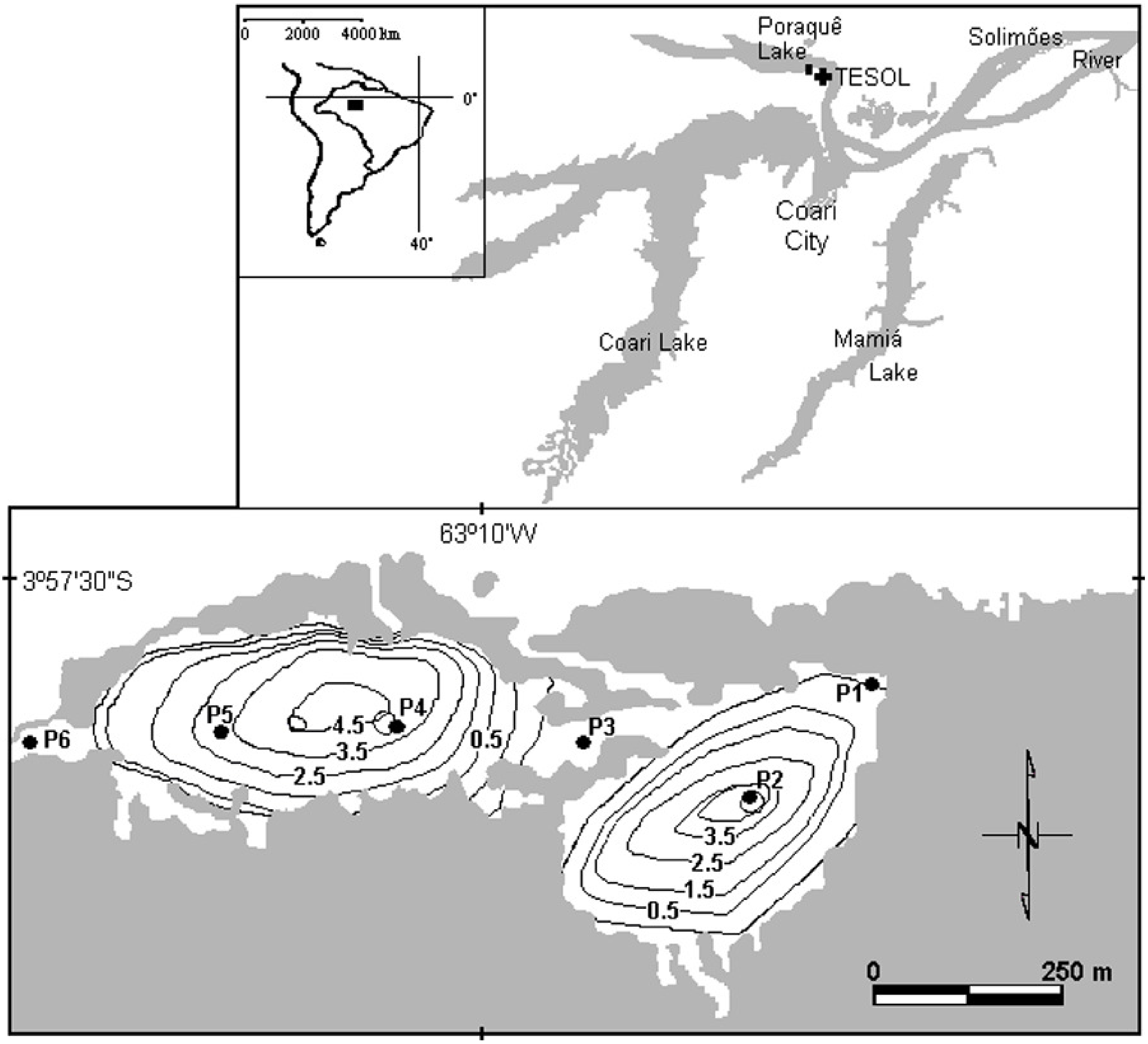

Figure-1
Bathymetric map of Poraquê Lake with the sampling sites and hypsometric curves

The seasonality is very clear in the region, with strong spatial and temporal variations of the level water in the lake. The effects of the thermal profile and natural wind forcing on the mixing processes and aeration of the lake were evaluated during the entire summer for comparison. The summer was considered from December to February. The lake level varied severely over the study period, with a minimum depth as high as 0.3m in the summer of 2005 and maximum as low as 5.5m in the winter of 2004 (hypsometric curves in figure-1 and figure-2A). The relative depth, which relates the maximum depth with the area of the lake, was in 0.96m. The lake level decreased considerably in the summertime due to two forces acting simultaneously: the low water flux and evaporative losses. This one is very expressive in lows latitudes of the equatorial region, mainly into the tropical forest. During low water periods, the lake limits retracted from the inundated area, and the outflow decreased gradually during this period until it ceased about on December. The lake volume can reduced until 70% during dry period due to evaporative water loss exceeded rainfall on the lake.

In the summer of 2005 was observed a deep dry in the Amazon, and so, many small lakes disappeared with great damage for fish population. Many municipal districts located to the margins of the Amazon River were also isolated and areas whose economies are set in the fishing were prejudiced. This strong dry was result of *El Niño* intervention in the region, although for some ecologists and climatologists, the global climate changes have its contribution too. Contribution of forest-rivers and ground water were reduced and the lake level decreased slightly in 2005 with that found in the other periods. In other hand, the lake level increased in the winter due to high connectivity between the river and lake. However, is important to remember that the high connectivity river-lake is consequence of high precipitations from Amazon River headwater in the North Peripheral Amazon. In fact, local rainfall was not as significant to the water budget and physical-chemical properties of the lake as high inflow of the fluvial water (flood-pulse). The low declivity of the Amazon plain ($0.2m.km^{-1}$) is responsible by the enormous inundated area. According to Junk[21], during the rising water stage, river floodwaters temporarily fill wetlands connected to the channels of the river, inundating an immense area for the whole basin. Depth-area relations of Poraque Lake (figure-2B) showed the most part of the lake is situated in floodplain area with low depth, and only the channels are more depth with medium to intense declivity. Three channels carry water and suspended matter from the river to the lake, but only one channel resists until the beginning of the low water period, interrupting its flow later on. It is possible to see with very distinction the phases of high and low water, as well as the dry periods of the hydrological cycle.

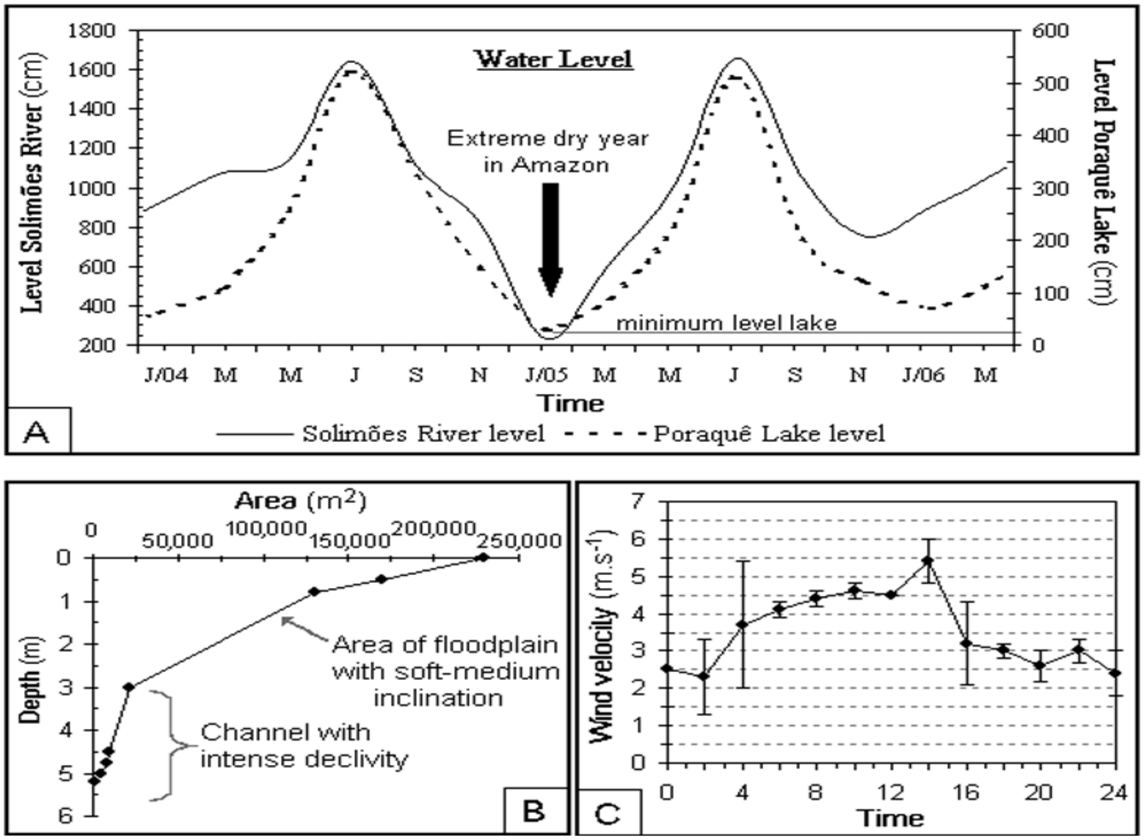

Figure-2

(A) Water level of Poraquê Lake and Solimões River near Coari City; (B) depth-area relations in the lake, and (C) wind velocity mean for 24 hours cycle between flood and flood-crest periods

Wind forcing of lakes is normally periodical because of the periodicity in the climate conditions. Sustained by studies developed in the TESOL zone[14], it was observed that the wind over Poraquê Lake has a dominant wind-forcing return period of 24/25 hours, with maximum speed at ≈14h, minimum at 2h and maximum variation at 5h (figure-2C). It was also observed that the wind-induced turbulences in the lake have periods of similar size/agitation, and are resulting from short winds forces. There was a moderated to elevated level of wind energy at 24h, mainly in highest rainfall periods. Given that the natural and forcing frequencies during this time coincided, was concluded that the resultant vector from short winds forces was responsible for the energy in the wind-induced turbulence at these times. Circulation patterns in great lakes and rivers are influenced by winds predominating in a region, including several atmospheric time-space scales. The diary breeze circulation, when occurring over floodplains, has great influence in the suspended material and flooding macrophytes trajectory, since flux transverse wind component can provoke boundaries material accumulation. The trend of accumulation of flooding plants and suspended material in the littoral region of the lake was observed periodically during this study. The high levels of dissolved load transported by the fluvial inflow are responsible by ions enrichment of the water column. In general, in whitewater lakes at the Amazon River basin the mean suspended matter concentration ranges from 60 to 120mg.L^{-1} with Secchi ≤0.6m (note of the authors), sufficient levels to influence in the transparency of water and so the heat budget and thermal properties of the water column. Light penetration and short-wave radiation inputs to surface waters depending on transparency of water[22], and the short-wave radiation is responsible by the heating of the up layers in lake, besides is one of the mechanisms at the stratification process.

In the study area, vertical and horizontal distribution of the temperature, EC, and total density of the lake are summarized in figure-3. There was often weak horizontal variation of temperature from sampling site P1 to P6 in both surface and bottom layers with temperature in the superficial layer ranged from 27.5 to 28.2ºC (mean 27.9±0.32ºC), and in the bottom ranged from 25.6 to 26.4ºC (mean 26.0±0.43ºC, figure-3A). Apparently, the results are not much different from one another. However, in the vertical component, *t*-Tests assuming asymmetrical variances were performed comparing each period/year with another, and a test resulting in a *t*-value (8.6823; n=456) higher than the *t*-critical value for $p<0.05$ considering two groups of data to be much different from one another, showing a modest-weak thermal stratification in the lake. Electrical conductivity tended to decrease from Amazon River limit to internal lake (figure-3B), with average of 60.1±24.8µS.cm^{-1} to surface layer and average of 46.2±14.4µS.cm^{-1} to the bottom. Exception was observed in maximum dry in 2005, when the lakes in Amazon's boundary showed conductivities higher (up to 3x) than normal conditions (≥200µS.cm^{-1}, authors unpublished data). That fact occurred due to strong reduction of the volume of the lakes with total isolation in most of the cases, and consequent salt ions concentration. Strong evaporative concentration of 2005 (due to *El Niño* action) increased the EC and so the shallow lakes salinity. The result from *t*-Tests for the EC showed a *t*-value (1.1854; n=456) lower than *t*-critical value for $p<0.05$ indicating statistically insignificant differences in the water column. Stratification with more than 2ºC in 4m should have important consequences for the vertical heat and mass exchange in the lake. Nevertheless, this is not a typical permanent thermal stratification and although they occur over different time scales, daily polymictic processes destroy the thermal stratification inducing complete vertical mixing of the water column. Diverse approaches on polymictic processes involving persistent thermal stratifications have been reported in floodplain lakes at the Brazilian Amazonian in flood-pulse[9,23-25]. Normally, surficial heat loss creates unstable thermal profiles and the resulting nocturnal convection homogenizes temperature in the upper water column, thus reducing the density difference across the thermocline, and then disrupting it. During daily stratification, there is a recurrent pattern of major changes in the upper water column because permanent heating by diffuse radiation, which occurs very slowly due to the high concentration of suspended matter from Andes geological processes. Breeze thermoclines, established and maintained by the lightest winds, are rapidly formed and dislocated, usually before any significant chemical differences (chemocline) that can develop in the water column. The thermocline depth was considered between 1 and 2 meters, and the sampling site P3 was the differential site with higher density (lower temperature) from this to the internal lake and lower density from this site to Amazon River (figure-3C). Morphology of the sampling site P3 narrower (figure-1) associated with macrophyte banks there contributed reducing tide velocity and increasing the sedimentation process.

The total water density was calculated to be, in mean, 0.99631 ±8x10^{-5}g.cm^{-3} in the surface, and 0.99683 ±1.1x10^{-4}g.cm^{-3} in the bottom, meanwhile the water flowing through the channel had a density in the thermocline of 0.99660 ±2.5x10^{-4}g.cm^{-3}. A trend curve for electrical conductivity was developed from littoral zone of the lake (sampling site P1) to the Amazon River border (sampling site P6) with the respective polynomial equation and square variance of 0.9702 (figure-4A). In the maximum flood, the three channels contributed with electrolyte-rich waters associated with sand-silt from Amazon River to the lake, and an ionic wedge was formed with extremity of 45µS.cm^{-1} EC near sampling site P1 at 1 meter depth (figure-4B). The vertical profile showed in figure-4B intensify the idea that the morphological and morphometric aspects, typically of floodplains lakes at the Central Amazonian, they probably are responsible by macrophytes accumulation in the perimeter of the lakes, and consequent sedimentation of suspended matter and reducing of the conductivity.

It was observed that the total density gradient associated with both temperature and salinity (salt ions) should cause disequilibrium in the layers of water moved from its original position[26], which will cause a type cascading destabilization reaction. However, during the movement of any water layer, irreversible changes occur over a limited space-temporal range. Maximum stability of the thermal gradient in the lake, and consequently of the density, was observed in low waters periods. During the filling and drainage phases, the system is more dynamic with stronger perturbation forces originated from Amazon River, which begin cascading reactions decreasing transparency and increasing suspended matter load and temperature in the water column. That perturbation continues in the lentic system for few weeks until a new stability. The forest-rivers, nevertheless, are small but with continuous forces in all hydrological cycle, including in the low water phases. If the equilibrium condition were unstable, then a relatively small perturbation force is initiated in cascading reactions causing the system to move for a new state of equilibrium[26]. The total densities of water (ρ_z) were correlated for *n*= 456 samples with temperature and EC at 25ºC (figure-5). The dependence of density on temperature and EC was determined with quadratic regression (equation-3).

$$\rho_z \ vs\ temp \begin{cases} \rho_z = -5\ x\,10^{-6}T^2 - 8\ x\,10^{-6}T + 1.0003 \\ R^2 = 0.9991;\ t = -193.9293\ and\ \ p < 0.00001 \end{cases} \qquad \textbf{(3)}$$
$$\rho_z \ vs\ EC \begin{cases} \rho_z = 1\ x\,10^{-7}\,EC^2 - 2\ x\,10^{-5}\,EC + 0.9975 \\ R^2 = 0.4810;\ t = -5.7241\ and\ \ p < 0.0001 \end{cases}$$

Comparing the results of the regression is possible to observe that the temperature had an influence more clear (R^2 = 0.9991) than EC (R^2 = 0.4810) on the total density. This occurred due to influence of the waves from Amazon River than show more heats in opposite with colder waves from forest-rivers. It was observed that although density differences due to changes in temperature are the dominant factor affecting circulation in freshwater systems, an assessment of more salt content influence on density due to biogeochemical reactions is warranted in more geochemically complex systems[27].

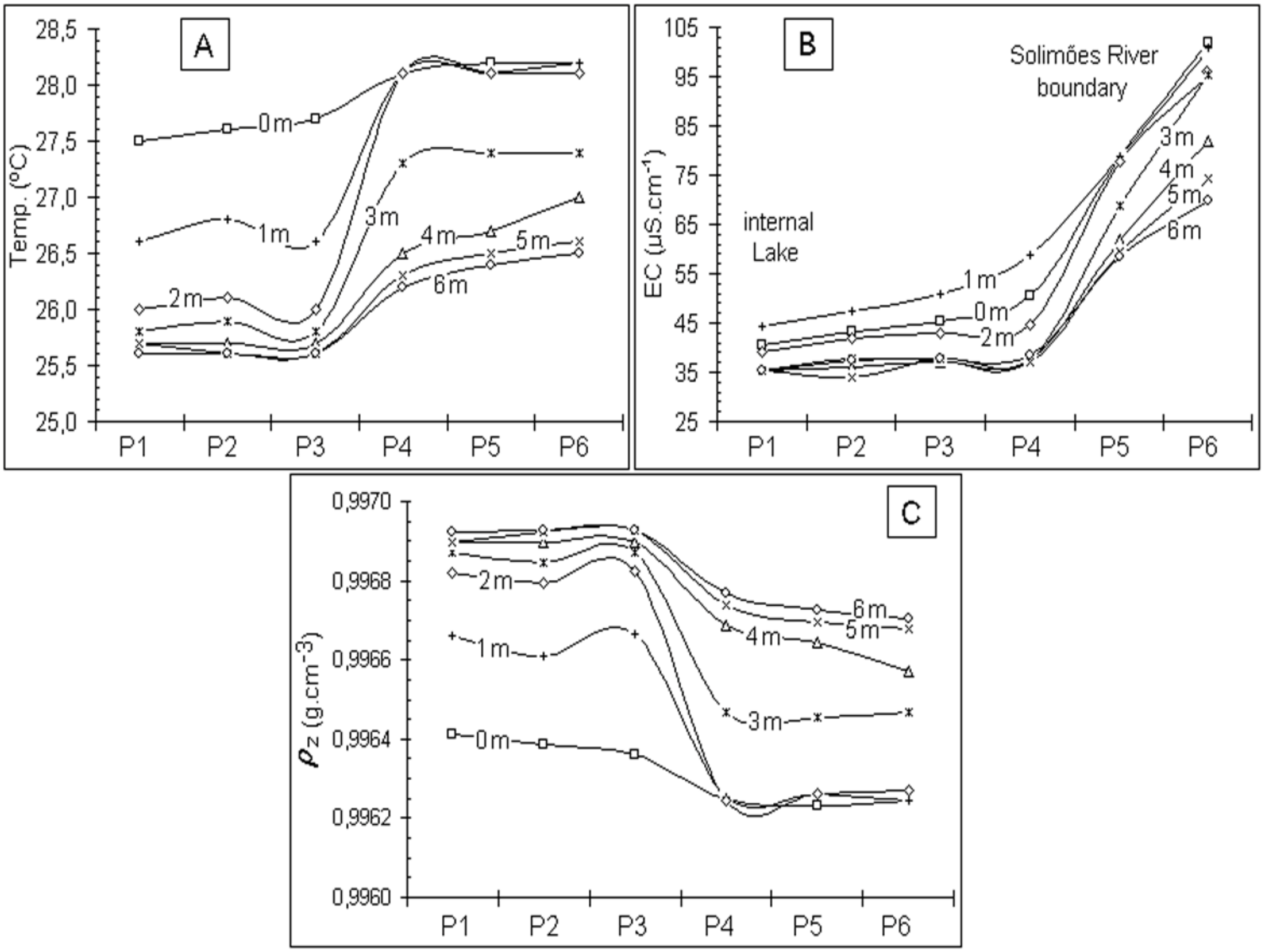

Figure-3
Vertical-horizontal profiles of the (A) temperature, (B) EC, and (C) total density of Poraquê Lake water

Some characteristics of the whitewater chemical composition were observed in the piper diagram (figure-6). All the sampling sites studied had low load in electrolytes when compared with the world average (a maximum ion content of ≈30% of the world average). With characteristics lightly acids, the salt-ions occur in the weathered tertiary sediments that cover immense areas of the Central Amazonian floodplains. The anionic equilibrium was observed with levels of $HCO_3^- + CO_3^{2-} > SO_4^{2-} > Cl^-$ and with bicarbonates as the main anions in most of the water column. However, the main forms of inorganic carbon are associated to CO_2 free plus H_2CO_3 due to acid trend of the whitewater of the lake with pH ranged from 5.74 to 6.32 and average 5.85. In any time, there was not dominance of the chloride on the bicarbonates, even in the closest point of the river (sampling site P6). According to Fittkau[28], chloride levels in Amazonian waters are between 1.7 and 3.1 mg.L^{-1}, and in this study the levels ranged from 2.05 to 3.08 mg.L^{-1}. Unlike coastal lagoons and saline lakes from Pantanal System, where Cl has conservative behavior and is very used in models and trends, in the Amazon the Cl content does not permit an obvious distinction between the different types of water. The great differential between these is in the cations concentration, mainly the calcium. This shows significant differences between the electrolyte-poor waters (e.g., black-waters from Negro River and forest-rivers) and electrolyte-rich waters (e.g., whitewater from Amazon River). In general, the cations levels were distributed $Ca^{2+} > Na^+ > Mg^{2+} > K^+$ except in the sampling site P5, where potassium was dominant on magnesium. Calcium shows higher levels in all sampling sites ranged from 3.96 to 6.85 mg.L^{-1}. The calcium is easily precipitates with carbonates at pH >8.0, but in lightly acid conditions associated with flood-pulse, nocturnal convection, and winds-cyclonic movement of the water, it stays in suspension. Differences in the water chemistry composition in the Brazilian Amazon were strongly associated with geological and geochemical properties of the source regions of the water[5,10,23,28]. In the most of the Amazonian, the nutrient elements are scarce and the region is one of low fertility[29,30], however, geologically young sediments from Bolivian Andes are carried in large scale by the Amazon River and are deposited on the banks in the floodplain. The resulting alluvial land is part of the small are of fertile land in Amazonian[7,20] with much importance for many species of animals and plants. The close interaction between the terrestrial and aquatic environments is reflected in the structure of the food webs in the Amazon. The flood-pulse is the immense force that transports electrolyte-rich waters from whitewater rivers discharge, and it is responsible by the terrestrial and aquatic life maintenance in the Amazon floodplain. Thus, we can say that the importance of the inundation forest as a food source for biota is clear. Diverse species of fishes are herbivorous and they occur in large numbers in the várzea and in lakes where the aquatic macrophytes, transported by the flood-pulse, serve as important food items for these species. It is important to highlight yet the paper of the morphological and morphometric aspects of the floodplain lakes in Amazon River basin, which to contribute with the storage of nutrients and so with the aquatic life maintenance.

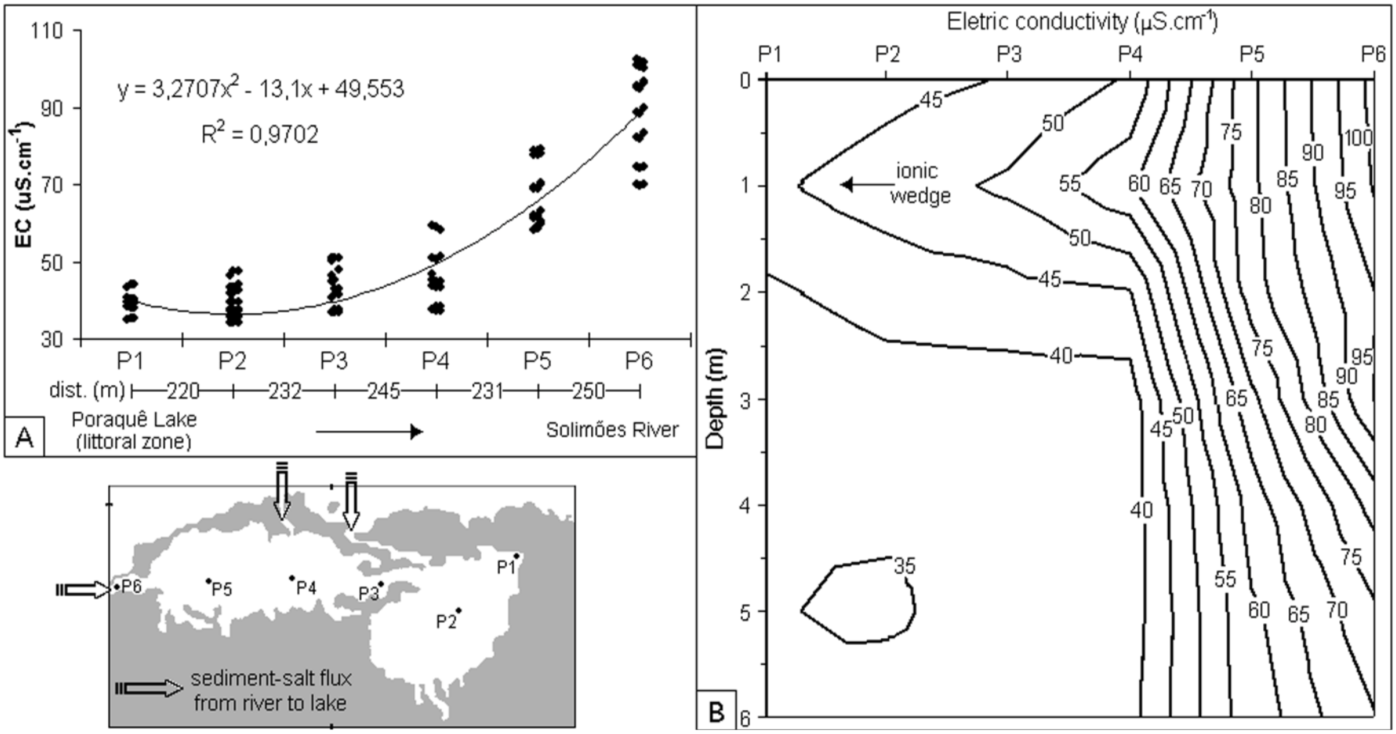

Figure-4
(A) Trend curve for EC, and (B) identification of the salt wedge

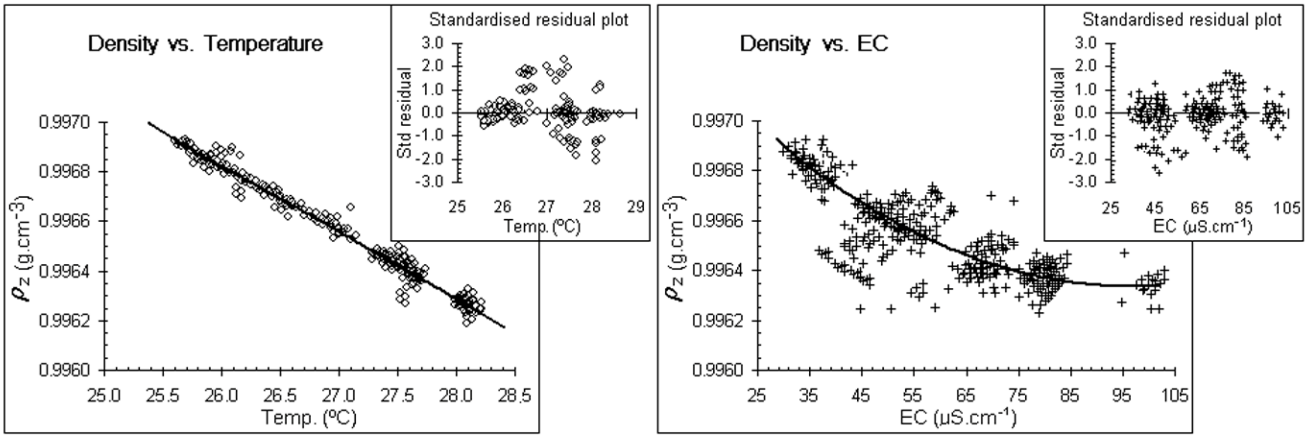

Figure-5
Density of Poraquê Lake water *vs*. temperature and conductivity for samples collected from surface to bottom between Feb/04 and Mar/06

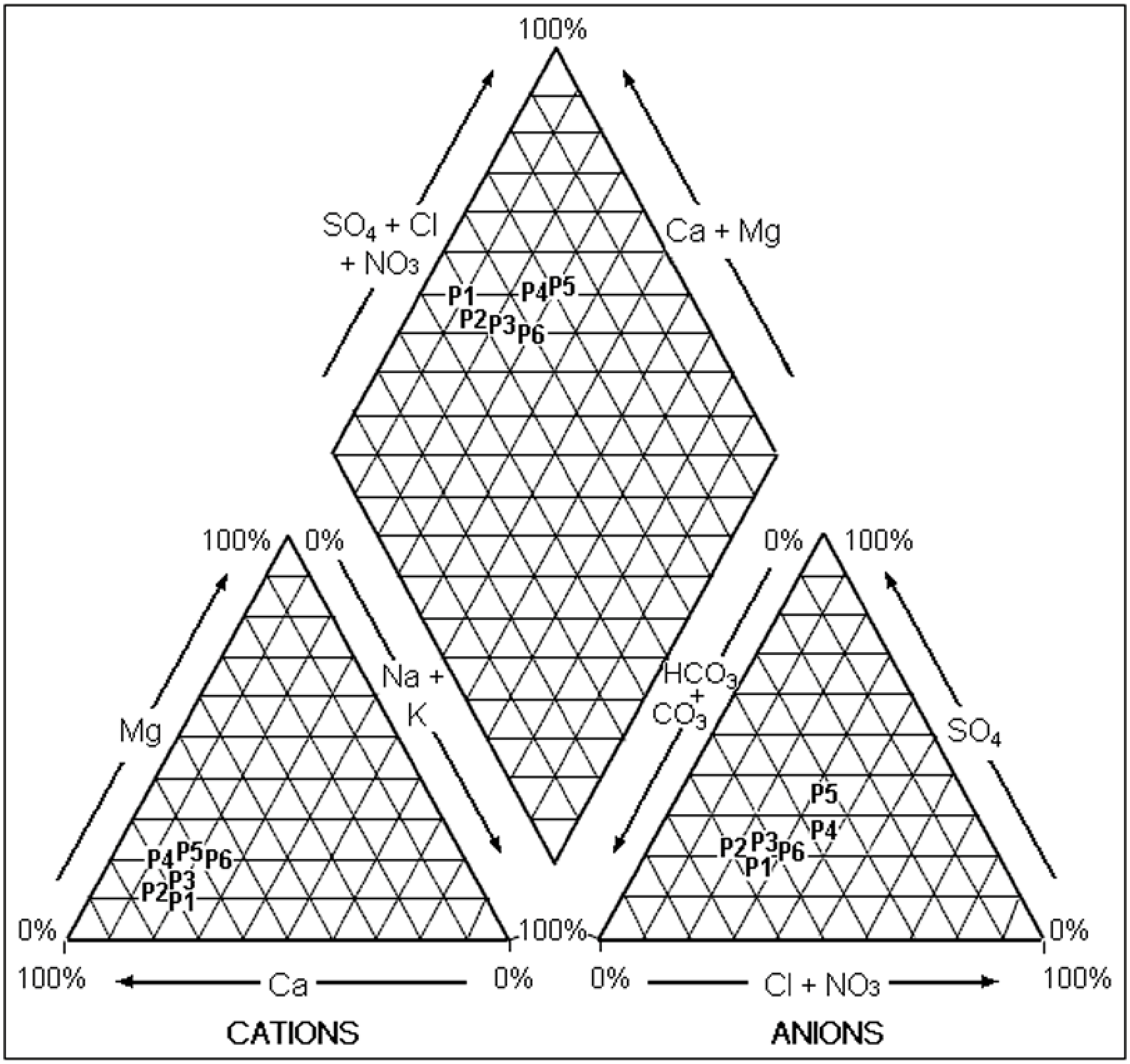

Figure-6
Piper tri-linear diagram for Poraquê Lake

Conclusion

Poraquê Lake is a typical shallow lake of the Amazon floodplain, where low declivity condition and flood-pulse were imperative to volume oscillation of the lake during hydrological cycle. The macrophytes banks had great participation on the reducing of the surface tide and on the keeping of the suspended particulate matter, mainly in high water periods. There were a strong relationship between morphologic-morphometric aspects, the profile of thermal stratification, and the sedimentation processes. The thermal stratification profile observed was polymictic, with nocturnal convection forces homogenizing the temperatures in the upper water column, and reducing the density difference across the thermocline. With different magnitudes, the flood-pulse from Amazon River and the forest-rivers had strong influence and perturbation on the water column stability. However, the system was more dynamic during the filling and drainage phases with stronger perturbation forces originated from Amazon River. The seasonality was clear in the region, and the flood-pulse was more significant to the water level than the local rainfall. The waters of the Amazon River basin and a series of várzea lakes influenced by it, including the Poraquê Lake, have the highest ion content of the Amazonian region, particularly distinct differences in the levels of calcium and bicarbonates. Calcium was the main differential component between the ions studied, permitting an obvious distinction between the different types of water.

These results should contribute to a better understanding of the limnological processes of lakes in the Central Amazon. Furthermore, this research has also an ecological relevance because its results can be used in studies on abundance and distribution of aquatic biota in whitewater lakes in Amazon basin.

Meteorological factors have an important contribution in lake mixing processes and thermal stratification. Therefore, in future researches will be decisive to have more meteorological data. Other significant contribution will be the hydrological balance including river discharge, groundwater flow, and precipitation plus condensation and evaporation, which are the main components of the water balance studies.

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References

1. Salahuddin K., Virendra S., Manish V., Chirag G. and Zofair S.M., Limnological studies of Narsinh Mehta Lake of Junagadh District in Gujarat, India, *Int. Res. J. Environment Sci.*, **2(5),** 9-16 **(2013)**
2. Shah I.K. and Shah H., Physico-chemical dynamics in littoral zone of Nageen Basin of Dal Lake, Kashmir, *Int. Res. J. Environment Sci.*, **2(3)**, 11-14 **(2013)**
3. Sioli H., Das wasser in Amazonasgebiet, Forsh, *Fortschr.*, **26**, 274-280 **(1950)**
4. Sioli H., Zum alterungsprozess von Flüssen, und Flusstypen im Amazonasgebiet, *Arch. Hydrobiol.,* **43**, 267-283 **(1951)**
5. Sioli H., Sedimentation in Amazon asgebiet, *Geol. Rundschau*, **45**, 608-633 **(1957)**
6. Sakamoto T., The development of the Amazon. *Min. Geol.*, **8(28)**, 89-100 **(1958)**
7. Junk W.J., Áreas inundáveis: um desafio para Limnologia. *Acta Amazônica*, **10(4)**, 775-795 **(1980)**.
8. Furch K., Junk W.J., Dieterich J. and Kochert, N., Seasonal variation in the major cátion (Na, K, Mg and Ca) content of the water of Lago Camaleão, in Amazonian floodplain-Lake near Manaus, Brazil, *Amazoniana*, **8(1)**, 75-89 **(1983)**
9. Junk W.J., Bayley P.B. and Sparks R.E., The flood pulse concept in river-foodplain systems. In: Dodge D.P. (Ed.), Proceedings of the International Large River Symposium, *Can. Spec. Publ. Fish. Aquat. Sci.,* 106, 110-127 **(1989)**
10. Irion G., Junk W.J. and De Mello J.A.S.N., The Large Central Amazonian river floodplains near Manaus: geological, climatological, hydrological and geomorphological aspects. In: Junk W.J. (Ed.), The Central Amazonian Floodplain: Ecology of a Pulsing System, Springer-Verlag, New York, Ecological Studies 126, **(1997)**
11. Prance G.T., Notes on the vegetation of Amazonia, 3, The terminology of Amaznonian forest types subject to inundation, *Brittonia*, **31**, 26-38 **(1979)**
12. Sioli H., Introduction: History of the discovery of the Amazon and of research of Amazonian waters and landscapes. In: Sioli H. (Ed.), The Amazon: limnology and landscape ecology of a mighty tropical river and its basin, Monog. Biol. 56, Dr. W. Junk Publishers, Dordrecht, The Netherlands, 1-13 **(1984)**
13. Soares M.G.M., Menezes N.A. and Junk W.J., Adaptations of fish species to oxygen depletion in a central Amazonian floodplain lake, *Hydrobiologia*, **568**, 353-367 **(2006)**
14. Silva M.P.R., Torres Júnior A.R., Silva R.M. da and Landau L., Estudo sobre a influência da circulação de brisa em modelo de transporte de poluentes no rio Solimões, 4º PDPETRO, Campinas, SP, 21-24/Outubro/2007, ABPG. 6.2.0062:1-9 **(2007)**

15. Wetzel R.G. and Likens G.E., Limnolgical analysis, W.B. Saunders Co., Philadelphia, 357 **(2000)**

16. American Public Health Association (APHA), American Water Works Association (AWWA) and Water Environment Federation (WEF), Standard Methods for the Examination of Water and Wastewater, APHA/AWWA/WEF, USA, 22nd ed., **(2012)**

17. Martin J.L. and Mccutcheon S.C., Hydrodynamics and Transport for Water Quality Modeling*,* Lewis Publications, Boca Raton, FL, **(1999)**

18. Ruttner R., Fundamentals of Limnology, Univ., Toronto Press, Toronto, CA, 242, **(1953)**

19. Junk W.J., Investigations on the ecology and production-biology of the "floating meadows" (Paspalo-Echinochloetum) on the Middle Amazon. I. The floating vegetation and its ecology, *Amazoniana*, **2**, 449-495 **(1970)**

20. Junk W.J. Investigations on the ecology and production-biology of the "floating meadows" *(Paspalo-Echinochloetum*) on the Middle Amazon, II. The aquatic fauna in the root-zone of floating vegetation, *Amazoniana*, **4**, 9-102 **(1973)**

21. Junk W.J., Amazonian floodplains: their ecology, present and potential use, *Rev. Hydrobiol. Trop.*, **15(4)**, 285–301 **(1982)**

22. Wetzel R.G., Limnology: Lake and River Ecosystems, 3rd ed., Academic Press, San Diego, CA, **(2001)**

23. Schmidt G.W., Seasonal changes in water chemistry of a tropical lake (Lago do Castanho, Amazonia, South America), *Int. Ver. Theor. Angew. Limnol. Verh.*, **18**, 613-621 **(1972)**

24. Rai H. and Hill G., Classification of Central Amazon lakes on the basis of their microbiological and physico-chemical characteristics, *Hydrobiologia*, **72**, 85-99 **(1980)**

25. Melack J.M. and Fisher T.R., Diel oxygen variations and their ecological implications in Amazon floodplain lakes. *Arch. Hydrobiol.*, **98**, 422-442 **(1983)**

26. Kepner Jr. R., Kortyna A., Wharton Jr. R., Doran P., Andersen D. and Roberts E., Effects of research diving on a stratified Antarctic Lake, *Water Res.*, **34(1)**, 71-84 **(2000)**

27. Balistrieri L.S., Tempel R.N., Stillings L.L. and Shevenell, L.A., Modeling spatial and temporal variations in temperature and salinity during stratification and overturn in Dexter Pit Lake, Tuscarora, Nevada, USA, *Applied Geochemistry*, **21(7)**, 1184–1203 **(2006)**

28. Fittkau E.J., Zur Ökologischen Gliederung Amazoniens. I. Die erdgeschichtliche Entwicklung Amazoniens, *Amazoniana*, **5**, 77-134 **(1974)**

29. Furch K. and Klinge H. Towards a regional characterization of the biogeochemistry of alkali and alkali-earth metals in northern South America, *Acta Cient. Venez.*, **29**, 434-444 **(1978)**

30. Irion G. Soil infertility in the Amazonian rain forest, *Naturwissenschaften*, **65**, 515-519 **(1978)**