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# EVOLUTION IN NUTRIENT LOADS OF MOUNTAIN RIVERS THAT FLOW INTO A RESERVIOR, MAGDALENA RIVER MID-BASIN, COLOMBIA

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## ABSTRACT

Nutrient enrichment in aquatic ecosystems takes place due to multiple natural and human factors. The accumulation of nutrients in bodies of water can lead to undesired consequences for water quality. Considering that there is limited information on nutrients in tropical aquatic ecosystems, especially in Colombia, it is important to carry out research projects aimed at the conservation and proper management of water resources. In this context, a study of the spatial and temporal changes in nutrient loads into the Amaní reservoir (Magdalena River mid-basin, Colombia) was carried out considering interbasin water transfers from the Guarinó River to the La Miel River. In order to compare the trophic status in the reservoir before and after transfer operations have begun, simple eutrophication models were implemented.

**KEY WORDS:** Nitrogen, phosphorus, nutrients, reservoir, transfer.

# EVOLUCIÓN EN LA CARGA DE NUTRIENTES DE RÍOS DE MONTAÑA QUE FLUYEN A UN EMBALSE, CUENCA MEDIA DEL RÍO MAGDALENA

## RESUMEN

El enriquecimiento de nutrientes en ecosistemas acuáticos se da por múltiples factores naturales y antrópicos; la acumulación de éstos en los cuerpos de agua puede traer consecuencias en la calidad del recurso y teniendo en cuenta que la información en términos de nutrientes en ecosistemas acuáticos tropicales, específicamente en Colombia es limitada, es importante realizar investigaciones orientadas hacia la conservación y manejo adecuado del recurso hídrico. En este contexto se realizó un estudio de los cambios espaciales y temporales de las cargas de nutrientes al embalse Amaní (cuenca media del río Magdalena, Colombia), considerando las transferencias de agua entre cuencas, desde el río Guarinó hacia el río La Miel. Se implementaron además modelos simples de eutrofización como método comparativo entre momentos, es decir, antes y después de la puesta en operación del trasvase y así conocer el estado trófico del embalse Amaní.

**PALABRAS CLAVE:** Nitrógeno; fósforo; nutrientes; embalse; trasvase.

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# EVOLUÇÃO NA CARGA DE NUTRIENTES DE RIOS DE MONTANHA QUE FLUEM A UM RESERVATÓRIO NA BACIA DO RIO MAGDALENA

## RESUMO

O enriquecimento de nutrientes em ecossistemas aquáticos é dado por muitos fatores naturais e antrópicos; o acúmulo destes corpos d'água pode ter consequências sobre a qualidade do recurso e considerando a informação em termos de nutrientes em ecossistemas aquáticos tropicais, especificamente na Colômbia é limitado, é importante a realização de pesquisas para promover a conservação e o manejo adequado dos recursos hídricos. Em este contexto foi realizado um estudo das alterações espaciais e temporais em cargas de nutrientes para o reservatório Amani (bacia média do rio Magdalena, Colômbia), considerando as transferências entre as bacias desde o rio Guarinó para o rio La Miel. Se implementaram modelos simples de eutrofização como um método comparativo entre os momentos, ou seja, antes e após do início da operação de transferência e, assim, saber o estado trófico do reservatório Amaní.

**PALAVRAS-CHAVE:** nitrogênio; fósforo; nutrientes; reservatório; transferência.

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## 1. INTRODUCTION

In order to counteract the negative effects of water scarcity, hydraulic works have been proposed as a possible solution, especially inter-basin transfers. These inter-basin transfers have been planned and executed in order to increase available water resources and solve problems of water deficits (Cornare, 2007).

Water transfers between basins with chemical, physical, and biological differences can alter the dynamic of the receiving ecosystem, possibly affecting water quality. Furthermore, an excessive load of nitrogen and phosphorus often causes eutrophication, affecting the physical health and biological integrity of river systems, with undesirable causes such as algal blooms, a reduction in water transparency, and anaerobic processes that produce odors and tastes, increasing the cost of water treatment. It is therefore necessary to apply management strategies that allow for the identification of problems in terms of the quantity and quality of the resource affected by the project (Fornarelli y Antenucci, 2011). The sources of pollution can be isolated or diffuse and be strongly associated with seasonal precipitation patterns (Zhang et al., 2008).

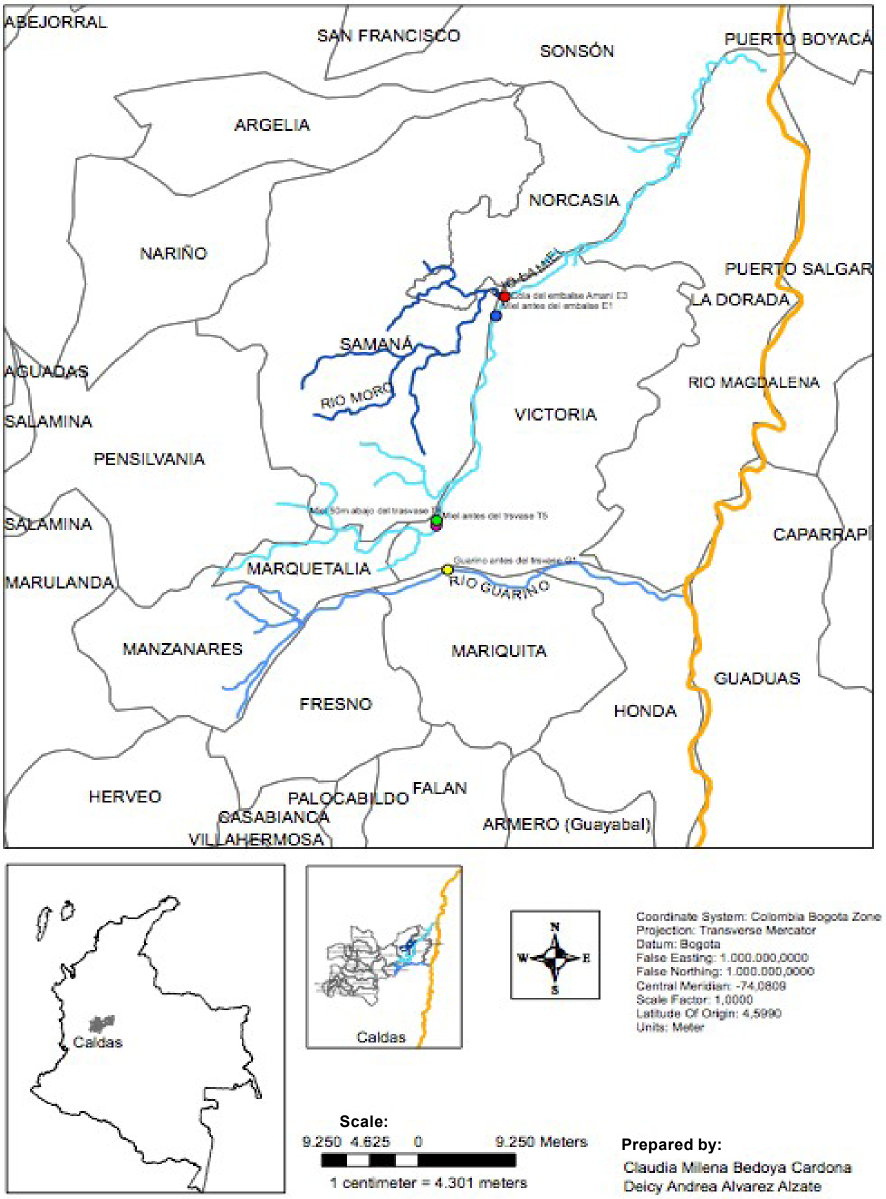
There is little information available in Colombia regarding transfers, but it is known that the Department of Antioquia has a chain of reservoirs with water transfer works for energy production. However, at the time of construction, environmental legislation was deficient, and this situation is therefore poorly documented. One specific case is the La Fe reservoir, one of whose tributaries, the Pantanillo River, imports water from the Buey River and the Piedras River (Román, 2011). Other cases are the water transfers in the reservoir chain of the San Carlos and Troneras hydroelectric plants, as well as the Guarinó Transfer, which takes water from the Guarinó River to the La Miel River in the eastern part of the Department of Caldas, Colombia. This water project is the object of this study and was constructed in order to increase the hydroelectric capacity of the Miel I plant. However, due to the extraction of water from one basin to another, chemical variations can occur not only in the donor basin (Guarinó), but also in the receiving basin (La Miel), and in this particular case, when the water flows into the Amaní Reservoir, where the Miel I plant is located. It therefore becomes necessary to carry our studies and research for hydroelectric power plants and thereby determine the temporal and spatial changes in the nutrient load. If we know the source of conflicts, we can make more adequate proposals for their management and mitigation. This article is the result of information obtained through the academic agreement ISAGEN – Universidad Católica de Oriente. The information and results described herein are the intellectual property of both institutions.

## 2. MATERIALS AND METHODS

### 2.1. Research area

The Guarinó Transfer project is located in the Department of Caldas near the border with the Department of Tolima on the western slope of the Cordillera Central (Central Andes) in its middle-low basin near the municipality of Victoria, as shown in **Figure 1** (ISAGEN, 2011). Part of the Guarinó River water volume is transferred into the La Miel River, specifically into the high part of the river, in the municipality Manzanares Caldas, upstream from the Amaní Reservoir, where the study took place.

**Figure 1.** Study area



Source. Own authorship

### 2.2. Sampling design

In order to determine the main nutrient changes in the La Miel River and the Amaní Reservoir, two moments are established. Moment 1 is from February 2009 to August 2010, and moment 2 is from October 2010 to April 2012, that is, before and after operation of the transfer. In order to determine the main temporal and seasonal changes in the nutrient loads of the La Miel River and the Amaní Reservoir, samples were taken at five stations located along the rivers with a direct influence on the transfer and the reservoir (see **Table 1**) during high and low water periods and their respective transitions in bi-monthly campaigns, two of which were conducted per climatic period between 2009 and 2012. One of the stations is located on the Guarinó River, and the other four on the La Miel River; of these stations, three are located in the lotic ecosystem and one in the lentic ecosystem. Different physicochemical properties are considered, including different forms of nitrogen and phosphorus, these being the variables on which the study is based, as well as some in situ variables, such as dissolved oxygen, temperature, pH, conductivity, and some checks for total suspended solids (TSS) and water flow. The study also makes use of a database provided by ISAGEN, and the analytical methods used by the Centro de Investigaciones Ambientales (Center for Environmental Research) laboratory at the Universidad de Antioquia were based on the Standard Methods for the Examination of Water and Wastewater, 20th edition, 1998.

The results obtained underwent descriptive and inferential analyses in which we determined statistics of central tendency and dispersion such as the arithmetic mean, the maximum and minimum values, and the coefficient of variation. Likewise, we developed non-parametric variance analyses (Kruskal-Wallis) in order to establish statistically significant differences between the variables and the systems, sampling sites, and hydrological moments. The information was processed using the statistics program STATGRAPHICS CENTURION XVI.

In order to reduce dimensionality and eliminate correlation between environmental variables with regards to the systems studied, we carried out a principal component analysis (PCA) that included the stations and sampling periods. The variables are standardized beforehand (x-min/max-min). This analysis was executed in the program CANOCO 4.5. For the station located on the tailwater, simple eutrophication models were used. The models selected were VbLacat 1.2 (Molina et al., 2004), and the trophic state index was taken from Aizaki (1981).

These procedures were carried out to determine the nutrient load evolution in these ecosystems before and after the transfer operation.

**Table 1** shows the sampling stations with their respective nomenclature and locations; **Table 2** shows the variables and factors of studies considered in these analyses.

**Figure 2.** Diagram of sampling station locations

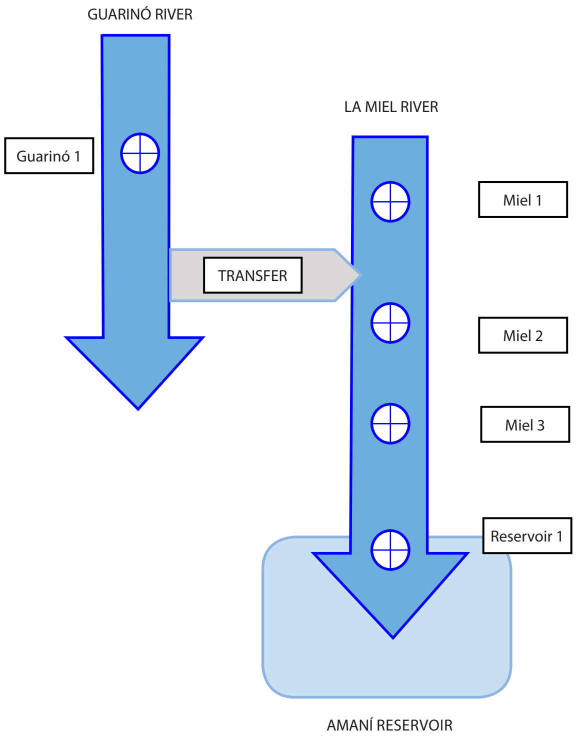


**Table 1.** Sampling stations

| Station | Name |
|---|---|
| Guarinó1 | Guarinó River 50m before Transfer and Canán Gully |
| Miel 1 | La Miel River before transfer |
| Miel 2 | La Miel River 50 m after transfer |
| Miel 3 | La Miel River before Amaní Reservoir |
| Reservoir 1 | La Miel River Amaní tailwater |

Source: Own authorship

**Table 2.** Parameters analyzed

| Variables | | | Study factors |
|---|---|---|---|
| TKN (mg/L) | TP (mg/L) | $O_2$ (mg/L) | Hydrological period |
| $NH_3$- (mg/L) | $PO_4^{-3}$ (mg/L) | T (ºC) | Moment |
| $NO_2$- (mg/L) | Water flow ($m^3$/s) | pH | Station |
| $NO_3$- (mg/L) | N load (kg/d) | Conductivity (uS/cm) | Month |
| TSN (mg/L) | P load (kg/d) | TSS (mg/L) | Year |

Source: Own authorship

## 3. RESULTS AND DISCUSSION

### 3.1. Spatial and temporal variation in water flow

The variation in water flow is strongly associated to the hydrological period and the moment, that is, before and after the transfer operation, as is shown in **Figure 3**.

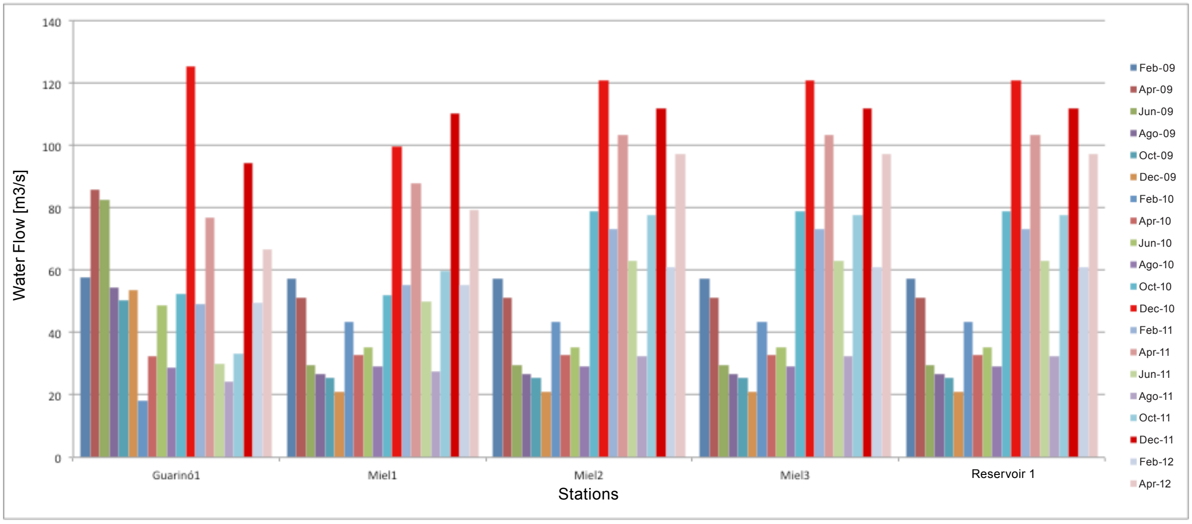
For Guarinó 1 during the year 2009, water flow varied between 50 and 85$m^3$/s; the minimum values correspond to the warm phase of ENSO (El Niño Southern Oscillation; this global cycle has two extremes: a warm phase known as El Niño and a cold phase, known as La Niña), but its effect was not as marked as in February and April 2010. In the month of February 2010, there was a minimum water flow of 18$m^3$/s. This period corresponds to the El Niño phenomenon. The maximum water level appeared in December 2010 at 125$m^3$/s. This period corresponds to the cold phase of ENSO. It is important to mention that for the Miel 1 station, water flow behavior is associated with the El Niño phenomenon until April 2010. The highest water flow appeared in December 2010 and December 2011, corresponding to the hydrological phenomenon of La Niña. The remaining months showed an average of 55$m^3$/s, except August 2011, which showed a water flow of 27.6$m^3$/s. At Miel 2, Miel 3, and Reservoir 1, the water flow decreased notably from June 2009 to June 2010, coinciding with the ENSO phenomenon in its warm phase. As of October 2010, water flow increased considerably with oscillations between 60$m^3$/s and 120$m^3$/s until April 2012, coinciding with the beginning of the transfer operation and the La Niña phenomenon. At the Miel 2, Miel 3, and Reservoir 1 stations, water flow behavior was the same due to the fact that we do not have measurements of water flow at each station, and we assume the same value as the Puente Samaná station located upstream from the transfer for the stations located on the La Miel River and the tailwater.

The highest value for the Total Soluble Nitrogen (TSN) load appears in December 2010 at the Miel 1 station. We can observe an increase in the TSN load at the stations located on the La Miel River with direct influence from the transfer. At Miel 2, Miel 3, and Reservoir 1, this increase appears between October and December 2010 (moment 2), as is shown in **Figure 5**. The average TSN load at moment 1 is of 1478.02 kg/day, and for moment 2, this load increases to 3176.04 Kg/day. Considering TSN as the assimilable fraction of the different forms of nitrogen, it is important to monitor and control more frequently, as it is known that excessive deposition of nutrients can have consequences on the trophic state and primary production of ecosystems (Moreno, Quintero & López, 2010).

At moment 1, the Miel 3 station showed the lowest values for total phosphorous load (TP). For moment 2 (October 2011 and December 2010 and 2011), higher TP values were found at the same station. In general, the station that showed the least variability in TP load was the Reservoir 1 station (see **Figure 5**).

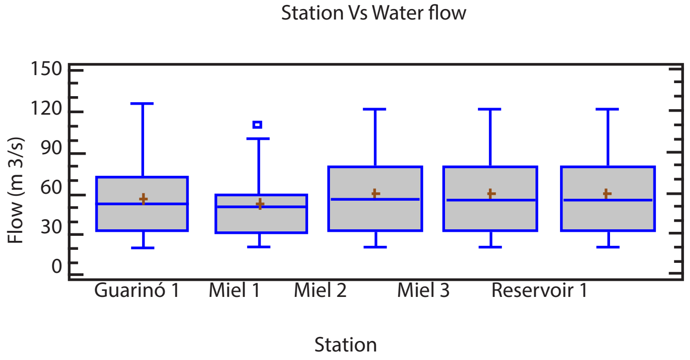
With regards to TSS load, the Guarinó 1 station showed the highest levels, as can be seen in **Figure 5**. Given the physical characteristics of the Guarinó 1 station, the river substrate, and the human activities carried out in its basin, we can see that they differ considerably from the characteristics of the La Miel River. It is presumed that the area associated with the Guarinó 1 station has been more heavily acted upon, which explains the higher concentration of nutrients at this station. Although the Guarinó River basin includes the zoning shown in **Figure 6**, it is important to emphasize the fact that within this basin, 4.22% of the total area is under mining titles (Corpocaldas, 2010). For its part, the high basin of the La Miel River, in contrast to the Guarinó River, has a much more stable cannel and a relatively low level of carrying material, which can be seen in the high levels of water transparency measured in previous studies (ISAGEN, 2011).

**Figure 3.** Temporal variation of water flow at sampling stations



Source: Own authorship

**Figure 4.** Dispersion of water flow data at sampling stations



Source: Own authorship

## 3.2. Physicochemical variables

These parameters reflect different changes between seasons and sampling periods where the behavior of the systems (lotic and lentic) is compared by moment, that is, before and after the transfer operation. Diverting water from one deposit to another represents a disturbance in the water quality of the receiving system, and this can greatly influence the concentrations of nutrients (Fornarelli & Antenucci, 2011).

The concentrations of ammoniacal nitrogen ($NH_3$-) vary between 0.112 and 0.896mg/l, with few values registered for the Guarinó 1, Miel 1, and Miel 2 stations during the sampling periods.

There were low values of nitrites ($NO_2$-) during the sampling period, which could be due to the fact that this is an unstable form that quickly and easily transforms in the nitrification process. For the Guarinó 1, Miel 1, and Miel 2 stations, we analyzed average values given the scarce information for some months during the study. This variable has a range between 0.0033 and 0.15mg/l with a general median of 0.035mg/l for the five stations during the entire sampling period.

**Figure 5.** Temporal variation of TSN, Total P, and TSS loads at sampling stations

Source: Own authorship

The concentrations of nitrates ($NO_3$-) were the greatest part of the different forms of nitrogen in the two basins (Guarinó and La Miel). This compound is the most representative fraction of the total nitrogen in the system. The nitrification process occurs in two stages: it begins with the oxidation of nitrites by ammonium, followed by the oxidation of nitrite by nitrate. This process can be affected by abiotic factors such as oxygen, temperature, and pH, as well as by biological processes of assimilation by associated organisms (Chlot et al., 2011). In Guarinó, $NO_3$- reached a higher value than in the remaining stations. This station is located in a basin with physical and chemical characteristics that differ from those in La Miel. The highest value was registered in February 2009 (9.1mg/l), and the lowest in April 2012 (0.3070mg/l). The Miel 3 station is characterized by a large number of values reported below the detection limit ($NO_3$-<0.112mg/l). Those values that could be quantified for moment 1 varied between 0.224mg/l and 0.56mg/l. With regards to moment 2, $NO_3$- showed a range of 0.357mg/l to 0.859mg/l. The station located in the tailwater had the lowest $NO_3$- values compared to the remaining stations.

The Total Kjeldahl Nitrogen (TKN) did not show a clear and marked trend during the study period. This fraction of nitrogen fluctuated between values below the method's detection limit (<0.112mg/l) and 15.10mg/l. This last value was registered in August 2009 at Guarinó 1 station, the station that showed the highest values during the sampling period. The overall average of TKN at all stations was of 1.218mg/l.

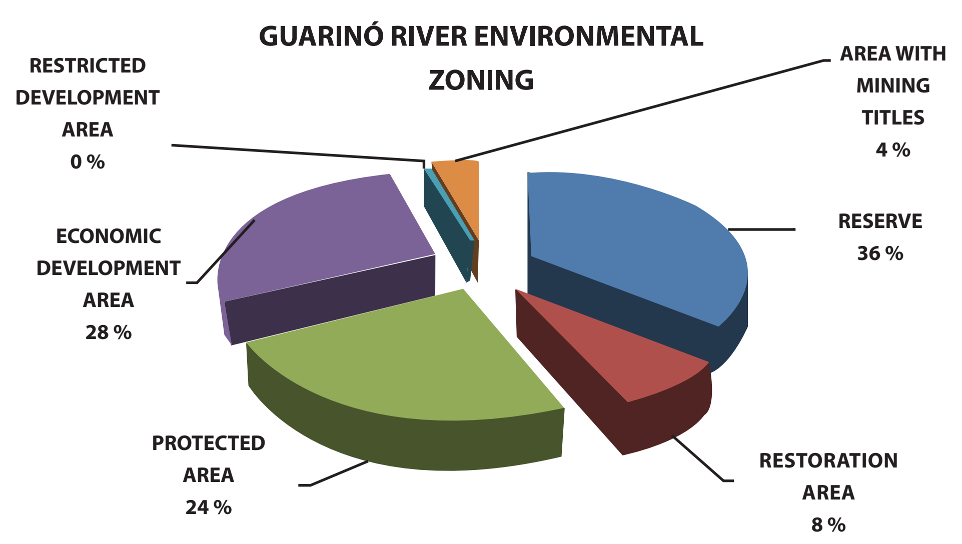
Total phosphorus showed little variability between the sampling stations with average measurements that varied between 0.12 and 0.19mg/l. This is in contrast to the Reservoir 1 station, where the average value was of 0.044mg/l.

The water temperature at the sampling stations is that of a warm climate, varying between 18.5 and 27.8°C. There are variations during the sampling period due to lower ambient temperatures and the inflow of colder waters as a result of rains during the heavy winter, mainly during the final months of 2010 and 2011.

The pH for all the sampling stations varied between 6.6 and 8.8, close to neutrality with a slight tendency toward alkalinity. There were no abrupt changes between stations or monitoring periods.

The concentration of dissolved oxygen is above 5.24mg/l at all stations and during all monitoring periods except August 2011, when at the Reservoir 1 station (tailwater), there was a concentration of 2.19mg/l of oxygen ($O_2$). In general, these values showed good water quality in terms of its capacity to support aquatic life.

**Figure 6.** Environmental zoning of the Guarinó River basin



Source: Corpocaldas, 2010

There was a substantial difference in electrical conductivity in the behavior of the station located on the Guarinó River and those located on the La Miel River. The average conductivity value at Guarinó 1 was 113.05µS/cm, while on the La Miel River, the average between the stations ranged from 37.36µS/cm and 54.87µS/cm.

The water flow values assumed for the stations located on the La Miel River correspond to those taken at the Puente Samaná station given that we do not have a registry for each of the sampling stations.

At the Miel 2, Miel 3, and Reservoir 1 stations, the transferred water flow is added, being why they show the same behavior; the water flow values for all the stations vary between $18.2m^3/s$ and $125.4m^3/s$.

**Figures 7** show the water flow, TSN, and TP diagrams for the five sampling stations. These diagrams show the general behavior of the variables and their dispersion during all the sampling periods. The stations Guarinó 1 and Miel 1 do not have a direct influence from the transfer, so their nutrient dynamics are associated with the area's natural conditions. The Miel 2 station is only 50m down from the output of the La Miel River transfer, and the parameters measure therefore do not reflect the direct effects of the project in terms of nutrients, since processes of resuspension, high turbulence, and oxygenation occur. The station that best shows the influence of the transfer is Miel 3, since at this station there has already been complete mix of the natural water flow of La Miel with the transferred water flow. In addition, the system is more homogenous in comparison with Miel 2, and the nutrient transformation processes are not affected by the physical characteristics of the outlet and strong fluctuations, given its proximity to the tailwater.

At Reservoir 1, the system shows greater stability due to nutrient assimilation processes carried out by aquatic organisms. This leads to lower variability given the importance of living organisms (bacteria, benthic algae, macrophytes, and benthic invertebrates) in the phosphorous cycle, as well as that of environmental factors such as temperature, pH, and oxygen (Ccopa, 2003).

The TSN and TP loads increased considerably at moment 2 as a consequence of the increased water flow. The average value at moment 1 for TSN load was 2157kg/day, and for TP load, it was 466.3kg/day. At moment 2, the average TSN load value increased to 3253kg/day, and for TP, it increased to 827.7kg/day. These changes in nutrient load can have profound effects on natural mitigation processes carried out by sediments that are considered contaminated (Koelmans et al., 2001).

Considering the stations, samples, and environmental variables, the two components shown in the graph make up 57.1%; the fourth component explains 83.1% of the total variance for the data.

According to the principal component analysis (PCA), water flow and temperature are not correlated variables. Temperature has an inverse relationship with TSS, $O_2$, TP, TSN, conductivity, and TKN. The magnitude of the temperature vector indicates greater importance or influence with regards to the data's variability. In addition, **Figure 9** diagrams the separation of the environmental gradient among the annual data (moment 1 and moment 2).

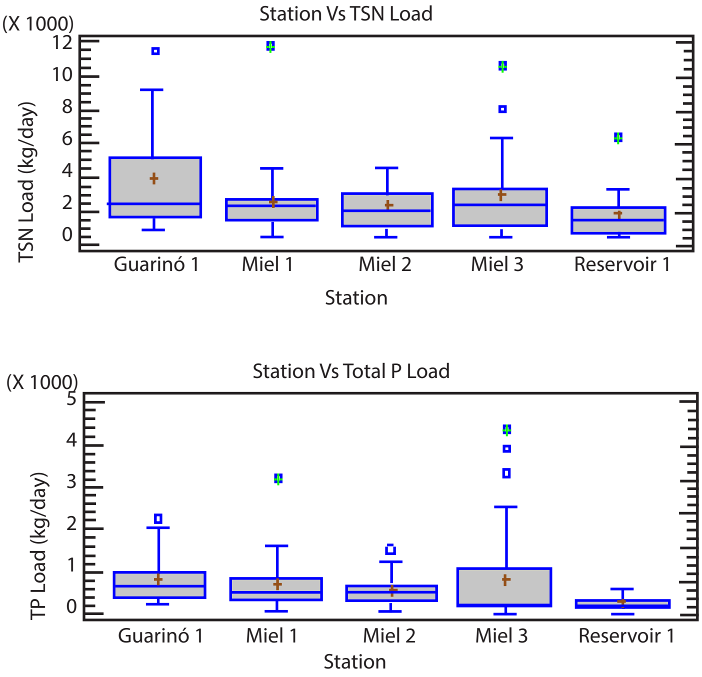
### 3.3. Correlations

Based on the principal component analysis graph, we determined the variables with the greatest correlation influence. As is described above, water flow and temperature show marked independence. Based on this characteristic, we propose some correlations.

We can see in **Figure 10** that water flow and TP show a direct relationship. This can be explained from the point of view of the nutrient dynamic since rivers transport a load of soluble and particulate matter that come from leachates and runoff from the basin they drain, and there is a strong correlation between the nitrogen and TP loads in rivers with land use, especially those with agricultural uses (Movellán, 2003). This can be seen in the strong relationship that exists between water flow and TP. If we bear in mind that the conditions between basins are different, Guarinó shows physicochemical and anthropogenic characteristics different from those of La Miel. There is also a direct response to water flow increase in terms of nutrients for Miel 3 station; if the water flow increases, the TP concentration increases for the sampling period between February 2009 and April 2012.

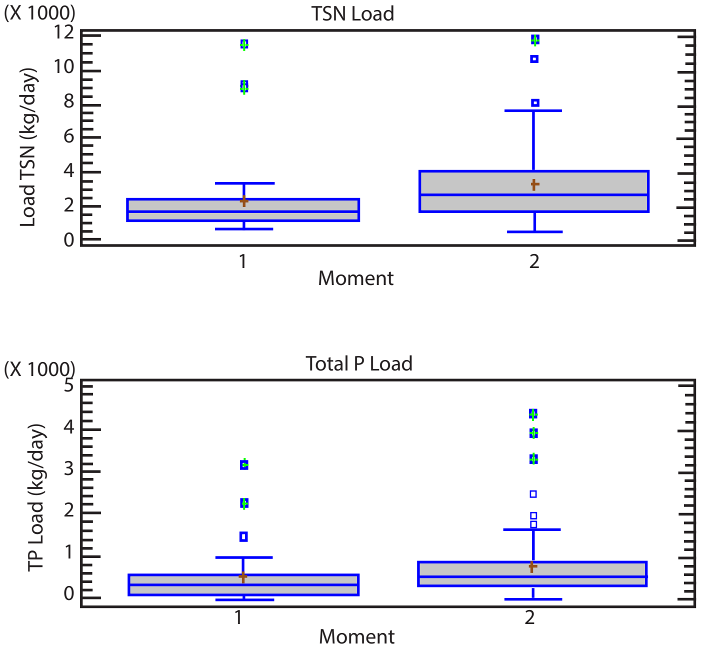
In **Figure 11**, we can see that temperature and TP have an inverse relationship. We can also see that the water temperature did not influence phosphorous transformation processes.

**Figure 7.** Dispersion of data for TSN and TP loads at sampling stations



Source: Own authorship

**Figure 8.** Data dispersion for TSN and PT loads by moment



Source: Own authorship

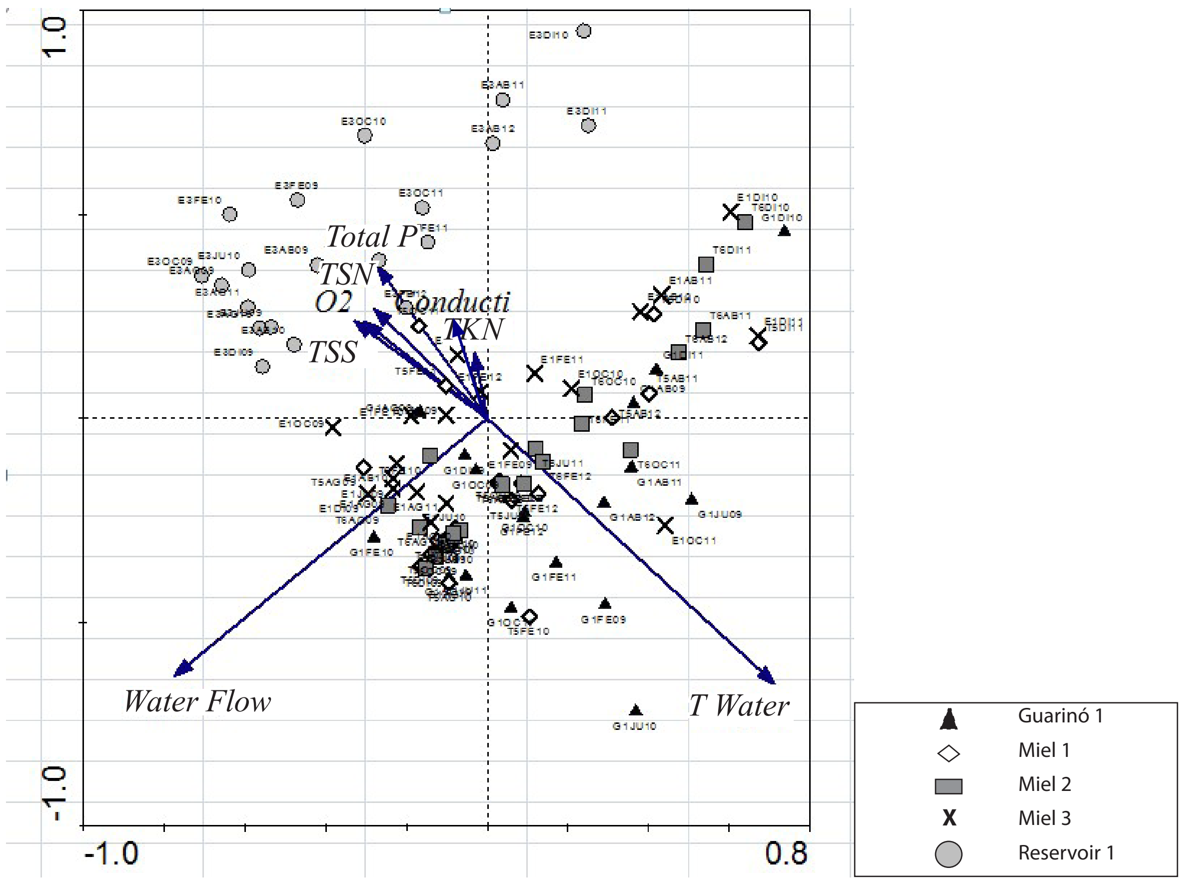
## 3.4. Simple eurotrophication models

A model can describe water quality on a very detailed level while identifying the processes that impact that quality and allowing us to insert data and predict the types of risks that bodies of water can be subject to, along with the chemical substances that cause those risks. The model also forecasts specific problems such as modifying the conditions of a specific body of water so that it complies with the quality regulations stipulated for the use that will be given to the water (Silva, 2008). The use of mathematical models allows us to predict the impacts a change in activity in the basin will have on water quality and thereby establish development priorities based on the desired uses for the water resource (Salas & Martino, 2001).

### *3.4.1 VbLacat*

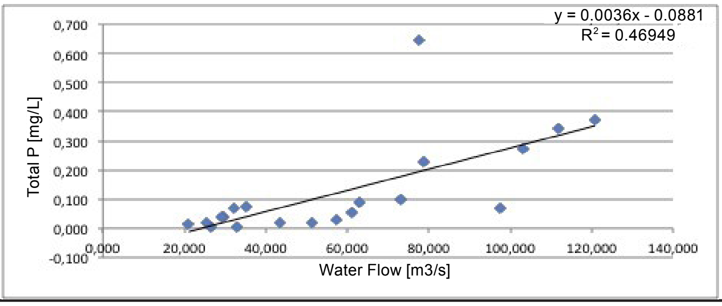
In order to evaluate the trophic state of reservoirs, which reflects the quality of the water they receive and especially the nutrient load, we used simplified methodologies for warm tropical reservoirs such as the VbLacat model (Molina et al., 2004) modified from the LACAT model of the Centro Panamericano de Ingeniería Sanitaria y Ciencias del Ambiente CEPIS (Pan-American Center for Sanitary Engineering and Environmental Sciences). Under this methodology, bodies of water can be classified as: oligotrophic (aquatic systems with a low nutrient content and minimal plant production), eurotrophic (with a high nutrient content and excessive plant production), and mesotrophic (with intermediate characteristics with regards to those described above) (Cuéllar, 2009).

**Figure 9.** Principal component analysis (PCA)



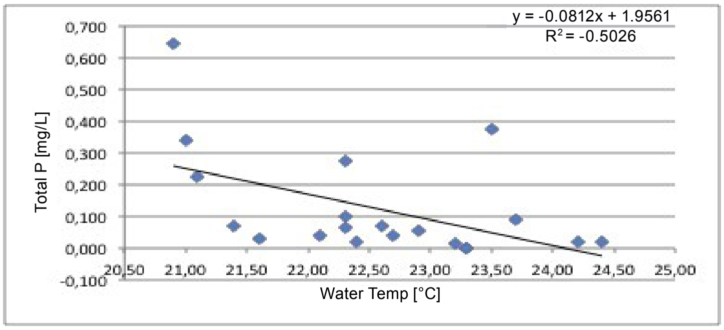
Source: Own authorship

**Figure 10.** Water flow and TP correlation at Miel 3 station



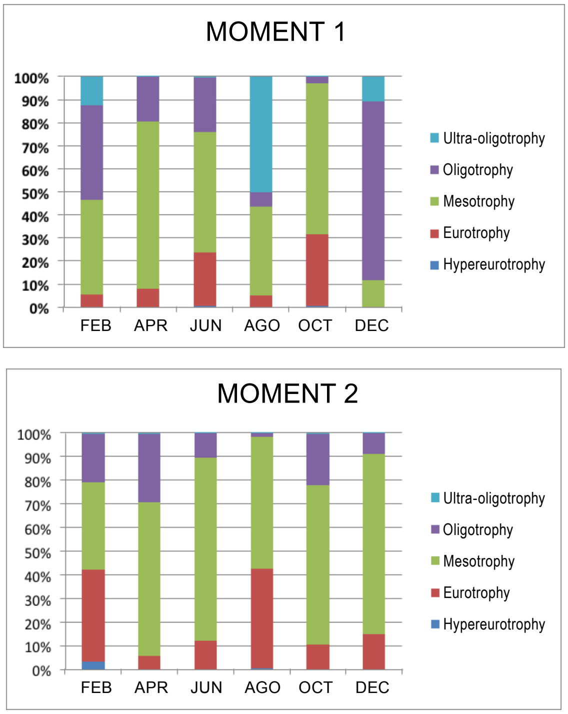
Source: Own authorship

**Figure 11.** Temperature and TP correlation at Miel 3 station



Source: Own authorship

**Figure 12.** VbLacat eutrophication model



Source: Own authorship

The simple VbLacat eurotrophication model uses TP as a response variable in the ecosystem and assumes that all changes in trophic state are caused by this parameter, considered a limiting nutrient for primary production. The concept of a limiting nutrient is based on the premise that, given a determined cellular stoichiometry for aquatic plants, the nutrient that controls the maximum quantity of plant biomass is the one that is consumed first or that reaches a minimum before the other nutrients relative to the stoichiometry (Salas & Martino, 2001). The increase in TP is due to a complex interaction between physical, chemical, and biological processes that occur both in the presence of oxygen and when it is absent (Fraile, Orive & Pozo, 1995).

This model is applicable to lentic systems, in this case the Reservoir 1 station, which corresponds to the Amaní tailwater. To more clearly show the effect of the transfer, we divided the sampling time into moment 1 and moment 2, that is, before and after the transfer operation. We also considered the hydrological period by averaging the values by months. For moment 1, the dominant trophic state in general terms was mesotrophic, with ultraoligotrophy and oligotrophy in August and December, respectively. During this period there was no hypereurotropia. In moment 2, there was hypereurotrophia in February and August, and in the same period, ultraoligotrohpy disappeared and oligortrophy decreased considerably, but mesotrophy remained the dominant trophic state (See **Figure 12**).

### *3.4.2 TSI (Aizaki* et al.*, 1981) Mesotrófico*

$$TSI\ (DiscoSecchi)$$

$$=10 * (2{,}46 + \frac{3{,}76\text{-}1{,}57\ \ln DS}{\ln 2{,}5})$$

$$TSI\ (Clorofila) = 10 * (2{,}46 + \frac{\ln Cl}{\ln 2{,}5})$$

$$TSI\ (Fósforo\ total)$$

$$=10 * (2{,}46 + \frac{6{,}68 + 1{,}15\ \ln PT}{\ln 2{,}5})$$

| **Estado de eutrofia** |
|---|
| Oligotrófico (TSI<30) |
| Mesotrófico (30<TSI<60) |
| Eutrófico (60<TSI<90) |
| Hipereutrófico (90<TSI<100) |

TSI is the trophic state index modified from Carlson (1977) which consists of determining the TSI for transparency measured with a Secchi disk, total P, and chlorophyll used as an indicator of the trophic level in aquatic environments (Mendoza et al., 2011). This index was applied for the entire sampling period. The results obtained after applying the equations for each variable indicate that the system is mesotrophic (TSI range between 30 and 60).

Eurotrophication is the process of underproduction of algae and macrophytes in bodies of water, which can cause problems for certain uses, such as: drinking water supply due to the alteration of its organoleptic qualities (smell, taste), corrosion of hydroelectric equipment and different disorders in drinking water treatment processes due to decreased oxygen content, or accumulation of ammonium in the water column and resuspension of certain metals (iron, manganese) from the sediment under anoxic conditions, among others. Although it is a process that, slowly, can have natural origins, today it is fundamentally cultural, accelerated by the continuous supply of nutrients due to human causes (Salas & Martino, 2001). The models described above establish the system's degree of eurotrophy, and based on this information, we can suggest management measures that will minimize the supply of nutrients to the ecosystem if we wish to maintain optimal conditions for energy creation.

## 4. CONCLUSIONS

1. In the sampling stations located on the Guarinó River (Guarinó 1), on the La Miel River, (Miel 1, Miel 2, Miel 3), and on the tailwater (Reservoir 1), the hydrological period influenced the increase and/or decrease of nutrient loads and water flows because rainfall generates a natural washing of the soils and a higher level of sediments being carried to the basins. Specifically at the Guarinó 1 and Miel 1 stations, the water flow is affected by the hydrological period. At Miel 2, Miel 3, and Reservoir 1, it is also influence by transferred water flow.

2. With regards to the spatial and temporal changes in nutrient concentrations and loads, Miel 3 is the station that most clearly showed these changes because there is already a complete mix of the natural water flow of the La Miel River and the transferred water flow, making the system more homogenous. Nutrient transformation processes are not affected by the physical characteristics of the outlet and strong fluctuations as at Miel 2, located only 50m from the outlet.

3. At the tailwater (Reservoir 1), the capacity for assimilation is high, due to the fact that the variation in trophic state between moments is not considerably significant; also, nutrient concentration decreases due to the processes of assimilation by aquatic organisms.

## REFERENCES

Ccopa, Elmer Alberto. *Modelo Sistêmico para Compreender o Processo de Eutrofização em um Reservatório de Água*. Faculdade de Engenharia de Alimentos da Universidade Estadual de Campinas, Campinas, São Paulo. 2003.

Chlot, Sara; Widerlund, Anders; Siergieiev, Dmytro; Ecke, Frauke; Husson, Eva; & Öhlander, Björn. *Modelling nitrogen transformations in waters receiving mine effluents*. Division of Geosciences and Environmental Engineering, Luleå University of Technology. Luleå, Sweden, 2011.

Cornare, Corantioquia, Área Metropolitana, & Universidad Nacional de Colombia. *Plan de Ordenación y Manejo de la Cuenca del río Aburrá*. Medellín, December, 2007.

Corpocaldas. *Plan de ordenación y manejo de la cuenca hidrográfica mayor del río Guarinó* – Caldas & Tolima. Capítulo I, zonificación ambiental, 2010.

Cuéllar, Winston. *Revista Empresas Públicas de Medellín* (EPM). No 1, Gestión Integral de embalses en EPM. Medellín. July - December 2009.

Fornarelli R. y Antenucci P. The impact of transfers on water quality and the disturbance regime in a reservoir. Centre for Water Research, University of Western Australia. Available at www.sciencedirect.co.m.2011.

Fraile, H; Orive, E. y Pozo, J. Evaluación del estado trófico y comparación de modelos relativos al fósforo en los embalses de Cernadilla y Valparaíso (río Tera, Zamora). Lab. Ecología, F. Ciencias, Universidad del País Vasco. Bilbao, España, 1995.

ISAGEN. Monitoreo y seguimiento hidrobiológico del proyecto Trasvase Guarinó. Universidad Católica de Oriente. Rionegro, Colombia, 2011.

ISAGEN, Central hidroeléctrica Miel I. Consulted December 10 2011. Available at http://www.isagen.com.co/metaInst.jsp?rsc=infoIn_centralMiel1.

Koelmans, A; Van Der, A; Knijff, L. y Aalderink, R. Integrated modelling of eutrophication and organic contaminant fate & effects in aquatic ecosystems. Aquatic Ecology and Water Quality Management Group, Department of Environmental Sciences. Wageningen University. Deventer, Netherlands, 2011.

Mendoza, M; Martínez, J; Moreira, P; Bonnet, M; Villar, R; Villagra, A; Abril, G, Patrick. Monitoreo espacial y temporal del estado trófico de los lagos de planicies de inundación en la Amazonía central mediante sensores remotos. Universidad Nacional de Tucumán UNT. San Miguel de Tucumán, Argentina, 2011.

Molina, R; Toro, A; Villegas, N; Aguirre, N. y Palacio, J. Recursos Hídricos, Control de Inundaciones y Embalses. Colombia, 2004.

Moreno, D; Quintero, J; López, A. Métodos para identificar, diagnosticar y evaluar el grado de eutrofia. Universidad Autónoma Metropolitana. Unidad Xochimilco. Departamento El Hombre y su Ambiente. Coyoacán D.F. México, 2010.

Movellán, E. Modelado de la cuña salina y del flujo de nutrientes en el tramo estuarino del río Ebro. Thesis. Universidad de Barcelona. España, 2003.

Román, R. Caracterización espacio temporal de la estructura térmica de un embalse tropical poco profundo, abastecido parcialmente por bombeo. Universidad Nacional de Colombia. Escuela de Geociencias y Medio Ambiente. Medellín, Colombia, 2011.

Salas, H. y Martino, P. Centro Panamericano de Ingeniería Sanitaria y Ciencias del Ambiente (CEPIS). Metodologías simplificadas para la evaluación de eutrofización en lagos cálidos tropicales, 2001.

Silva, S. Evaluación de la calidad del agua del futuro embalse Porce III por la influencia de la descarga del embalse Porce II. Revista Ingenierías Universidad de Medellín. July - December 2008.

Zhang, Q; Xu, Z; Cheng, X; Gu, S; Liu, W. and Li, S. Spatio-temporal dynamics of nutrients in the upper Han River basin, China. Center for Watershed Ecology, Wuhan Botanical Garden, The Chinese Academy of Sciences, Wuhan China, 2008.

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