SELF DEPURATION STUDY

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Data 19.10.2018

N° Referência

LD Celulose S.A.

Dissolving Pulp Mill in Indianópolis e Araguari – MG

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Distribution

LD CELULOSE	E
PÖYRY	-

Orig.	19/10/18 – msh	19/10/18 – bvv	19/10/18 – hfw	19/10/18 – hfw	Para informação
Rev.	Data/Autor	Data/Verificado	Data/Aprovado	Data/Autorizado	Observações

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1 INTRODUCTION

One of the most relevant issues for contemporary society is the preservation of water resources. In Brazil, the concern about this subject is evident, among others, in Federal Law Nº. 9.433/97 (that establishing the National Water Resources Policy), which discipline the use of water in the country. The CONAMA Resolution 357/2005 dispose about the categorization of water bodies and environmental guidelines for their classification, being complemented by the Resolution 430/2011, that establishes the conditions and standards for effluent discharge.

The Article 7º, paragraph 1 of CONAMA Resolution Nº. 430/2011 establishes that "... The competent environmental agency may require, in the licensing processes or in its renewal, the presentation of a study about the capacity support of the receptor body". And in the Article 7º, paragraph 2 states that "... The carrying capacity study shall consider at least the difference between the standards established by the class and the existing concentrations since the upstream, estimating the concentration after the mixing zone". Also in this Resolution (CONAMA Nº. 430/2011), the capacity of the receiving body to support the pollution released is defined in Article 4º, Section I, and states that "... Maximum value of a certain pollution that the water body can receive, without compromising the quality of the water and its uses determined by the class of framing".

In this particular, mathematical models that simulate water quality may be useful tools in assessing the receptor body's carrying capacity (self-purification ability). These models are composed by a set of equations that, solved, provide the spatial and temporal distribution of constituents that are transported in solution and in suspension by the hydric body. These equations, as a rule, are resolved numerically, generating so-called numerical simulation; and once the model is calibrated, allows future and past scenarios to be plotted according to the inputs that are prescribed. Thus, mixing zones, pollution feather behavior, dispersion and carrying capacity of the receiving body can be simulated.

There are many computational tools used to simulate water quality in rivers and reservoirs, whose choice depends on the level of complexity of the water system. The present study used an integrated management software of water resources in a basin scale denominated AQUATOOL. This tool was developed by the Institute of Water Engineering and Environment of the Valencia Polytechnic University.

The objective of this study was to know the self-purification capacity of the Araguari river, between the Miranda and Amador Aguiar I hydroelectric plants (also known as Capim Branco I), in a stretch of 46 km, due to the discharge point release point of treated effluent from the new pulp mill of LD Celulose.

The discharge point will take place on the right bank of the Araguari river, approximately 11 km upstream from the Amador Aguiar I hydroelectric plant (Capim Branco I). The water quality parameters analyzed were dissolved oxygen (DO), biochemical oxygen demand (BOD), total phosphorus, organic nitrogen, ammonia and nitrate. Were predicted scenarios for the self-purification capacity of the Araguari River at average flow and flow $Q_{7,10}$.

The inputs of the meteorological, hydraulic, water discharge and water quality datas required for the simulations were obtained from National Water Agency (ANA), Minas Gerais Water Management Institute (IGAM) and the National Institute of Meteorology (INMET).

This study is part of the Environmental Impact Study (EIA) of the industrial unit that will produce dissolving pulp in Minas Gerais State, aiming to obtaining the Previous License (LP) from the Superintendency of Priority Projects - SUPPRI.

2 PROJECT DESCRIPTION

2.1 Pulp Production Process

The main activity of the new industrial unit in the Minas Gerais State is the production of 540,000 t/year of dissolving pulp, using as basic raw material the eucalyptus logs, as well as various chemical inputs.

The production of pulp will begin with the preparation of the wood coming from the eucalyptus forests. The log will be transformed into small pieces of wood, called chips, with regular dimensions. Next, comes the cooking step, in which the structure of the wood will be modified until obtain the pulp of the cellulose, called brown pulp. To do this, a chemical process will be used, which happens in reactors called digesters. The next step is bleaching, in which the pulp will be bleached in a process composed of several stages that preserve to the maximum the strength characteristics of the pulp. And the last step is the drying, where the formation, pressing and drying of the pulp sheet will be carried out. At the end of the process, the baling takes place, in which the leaves removed from the dryer are cut, weighed and packaged in bales.

The kraft pulp process has a system that allows the recovery of the chemicals used to obtain the pulp. The recovery begins with the evaporation of the black liquor, raising the dry solids content. After the evaporation, the liquor is sent for incineration in the recovery boiler. In the boiler, the organic matter present in the liquor is incinerated, leaving a smelt formed by the inorganic compounds sent to the causticizing, where the clarification of the green liquor occurs, and subsequent obtaining of the white liquor.

2.2 Treatment and Disposal System of Liquid Effluent

The effluent treatment system generated in LD Celulose will essentially consist in the removal of solids and organic load.

The main steps of the effluent treatment process are: screening; primary clarifier; emergency lagoon; neutralization; cooling; activated sludge - aeration tank; secondary clarifier; primary sludge and secondary sludge dewatering systems; and emissary.

Untreated effluents will be gravity driven to a screening system to remove coarse materials. After passing through the screening system and flow measurement, the pre-treated effluent will be sent to the primary clarifiers to reduce the amount of suspended solids. These clarifiers will be equipped with a scraper to remove sedimented solids and accumulated scum on the surface of the same.

In addition to the leakage and spill collection and prevention systems planned in each department of the plant, there will be an emergency lagoon at the effluent treatment plant. The purpose of this lagoon will be to receive all effluents with characteristics out of the specification. Once diverted to the emergency lagoon, the contents of the lagoon will be dosed to the entrance of the neutralization tank so that no disturbance could be created in the biological treatment.

The clarified effluent in the primary clarifiers will be sent to a neutralization tank. The purpose of this step is to neutralize the combined effluent through the addition of caustic soda or sulfuric acid, aiming to maintain a pH between 6 and 8, making it suitable for biological treatment.

The high temperature that the neutralized effluent will present is too elevated for the biological treatment, so the effluent will be cooled to a temperature that does not detract the performance of the biological treatment.

The biological treatment system adopted in LD Celulose will be the aerobic type by activated sludge. The biological process requires nitrogen and phosphorus as sources of nutrients whose quantities will be related to the amount of biodegradable organic matter present in the untreated effluent.

After the dosage of nutrients, the effluent will be sent to the aeration tank, where they will be submitted to the degradation of the organic matter present in the soluble and colloidal form through the activity of the aerobic microorganisms. The air injection into the system will be performed by fine bubble diffusers installed at the bottom of the aeration tank.

In the process of activated sludge there will be the formation of a biological mass (sludge) that must be physically separated from the liquid mass (clarified effluent), which will occur through secondary clarifiers. The treated and clarified effluent shall be discharged into the river by means of an emissary.

The emissary will throw the treated effluents in the Araguari river in a controlled and safe way, through a underwater discharge and in conditions that prevent the formation of foams and promote the most efficient dispersion in the receiving body.

2.3 Treated effluent characteristics

Para realização do estudo da capacidade de autodepuração no baixo curso do rio Araguari, foi considerada a condição média mais desfavorável (crítica) no ano. As principais características do efluente tratado na indústria de celulose são apresentadas na Tabela a seguir.

For the study of the self-purification capacity in the Araguari River, the most unfavorable average condition (critical) was considered in the year. The main features of the effluent treated in the pulp mill are presented in **Table 1**.

Table 1 – Treated Effluent Characteristics

Parameters	Unit	Values
Flow	m³/h	2 200
	m³/s	0.61
pH	-	6 to 8
Temperature	ºC	< 40
BOD	kg/day	2 100

Parameters	Unit	Values
	mg/L	40
COD	kg/day	16 700
	mg/L	315
Total Suspended Solids	kg/day	3 200
	mg/L	60
Color	kg/day	52 800
	mg/L	1 000
Total Nitrogen	kg/day	800
	mg/L	15
Total Phosphorous	kg/day	80
	mg/L	1.5

Source: Pöyry Tecnologia (2018).

3 STUDY AREA

3.1 Overview of the Araguari river watershed

The Araguari River watershed has an area of 22 thousand km2, with approximately 1.2 million inhabitants distributed in 18 municipalities. It is located in the western region of Minas Gerais State, between 18°20' and 20°10' south latitude and 46°00' and 48°50' west longitude coordinates. The source is located in the Serra da Canastra National Park, in the municipality of São Roque de Minas, reaching 475 km to its mouth on the Paranaíba River (a tributary of Grande River, which is part of the Paraná River Transnational watershed) (SALLA et al., 2014). The altimetry heights in the watershed vary between 465 and 1350 m, rainfall is over 1600 mm/year and the climate is hot, with dry season between May and September and wet season between October and April (ROSA et al., 2004). The annual temperature averages are below 21 °C, however, in the cooler months (June/July) it maintains between 17 °C and 18 °C.

The watershed has four cascaded hydroelectric plants on the Araguari River, as shown in **Figure 1**. The first reservoir, located on the upper Araguari River, is a regularization with storage capacity of 12,8x106 m3 (Nova Ponte Hydroelectric Plant). The others three reservoirs, located on the lower Araguari River, are watercourse (in the sequence, Miranda, Amador Aguiar I and II hydroelectric plants- also known as Capim Branco I and II).

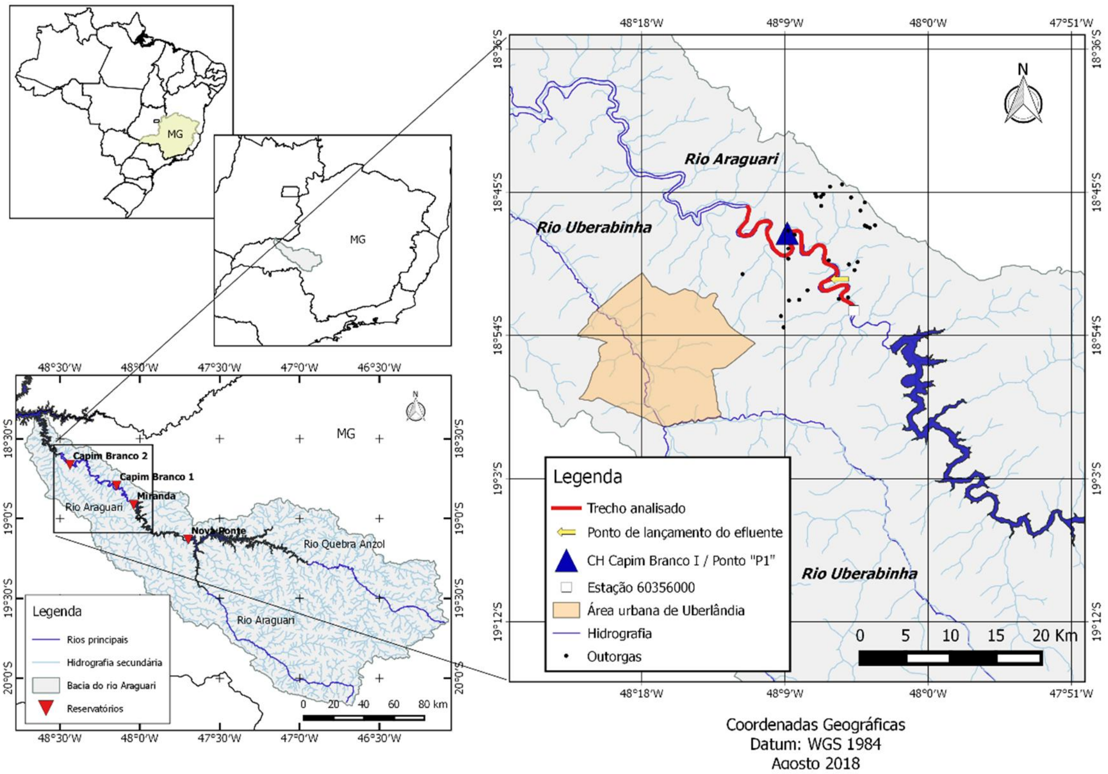


Figure 1 –Location of hydroelectric plants, section of studied river and point of release of the pollution load. Source: (Author, 2018).

The main economic activities in the watershed are agriculture, aquaculture, coffee cultivation, annual crop cultivation, horticultural cultivation, subsurface mining, dry surface layer mining, litter bed mining, power generation, processing industry, agroindustries and tourism. Thus, the main surface concessions were grouped in consumptive demands for irrigation and industrial consumption, besides the use with animal watering and public supply. The main non-consumptive demands are those related to leisure and landscaping, together with the flows used to generate energy (significant along the reservoirs mentioned above, with an average value of 376.41 ± 41.03 m³/s). **Figure 1** shows the location of the deferred grants in the studied section. The closest water intake point to the treated effluent discharge site is about 2.5 km downstream, referring to a superficial grant on the Araguari river for animal watering at latitude 18º49'16 ", longitude: 48º6'15" (JHUNIOR, 2017).

3.2 Stretch Studied

The study encompassed a stretch of approximately 46 km, including approximately 30 km from the fluviometric monitoring station of ANA - code 60356000 - located downstream of the Miranda reservoir (coordinates 18º52'25 "S and 48º04'35" W) to the Amador Aguiar I hydroelectric plant (coordinates 19º32'56"S and 44º07'00"W) and 16 km downstream from the Amador Aguiar I hydroelectric plant (see **Figure 1**).

The Amador Aguiar I hydroelectric plant, know as Capim Branco I hydroelectric plant, is located in the lower reaches of the Araguari river, between the Miranda reservoirs and the backwater of the Amador Aguiar II reservoir (Capim Branco II). According to De Paulo (2007), the drainage area of Amador Aguiar I in the Araguari River is 8,300 km^2, equivalent to approximately 83% of the drainage area in the entire watershed.

In the **Figure 1**, the discharge point of the treated effluent from the industrial enterprise is located approximately 11 km downstream from fluviometric monitoring station of ANA.

4 AQUATOOL

The Institute of Water and Environmental Engineering of the Universidad Politécnica de Valencia (IIAMA/UPV), Spain, has developed the software AQUATOOL, that acts as a Decision Support System in a watershed scale, widely used in water quantity modeling (SIMGES module) and water quality (GESCAL module) in streams, rivers and accumulation reservoirs.

According to Andreu et al. (1992), the water quantitative management module SIMGES is used in the simulation of flow in rivers, streams and reservoirs, based on the spatial and quantitative definition of discharges (specific withdrawals for irrigation, industries, human, among others), recharge (point and diffuse surface and underground tributaries) and in the environmental requirements defined by legislation of the Watershed Committees.

With the purpose of simulating water quality linked to the quantitative management in lentic and lotic environment, Paredes et al. (2007) developed the water quality model GESCAL, which allows simulating water quality in all water bodies within a river basin under different quantitative conditions.

The SIMGES and GESCAL modules are connected, sharing in graphic interface their quality and quantity water data, all georeferenced (PAREDES et al., 2010). Thus, hypothetically considering a multi-use and transient water basin, water quality can be simulated for any simulated discharge, recharge and ecological discharge scenarios.

The software AQUATOOL replaces the SIMWIN interface (Andreu et al., 1996), which was used only for the edition of the simulation of water quantity in watershed by SIMGES. In comparison, AQUATOOL has the following advantages: It uses a formatted database file to store the content of the simulation; For a quantity of n scenarios to be simulated it is not necessary to have n data files, where the database differentiates the data of each element by a single element code and a scenario code; Data editing interfaces for SIMGES and GESCAL fully differentiated; Has a tool that generates the relationships between elements of the GIS (Geographic Information System) of a hydrographic basin and elements of the simulation model.

In general, AQUATOOL is an interface for the edition, simulation, review and analysis of the simulation model of watershed management, including the simulation module of water quality in lentic and lotic environments, which integrate the following programs: Aquatooldma.exe: general program management and for editing data; simges.exe: simulation of watershed management in conjunction with other programs; gescal.exe: water quality simulation at watershed scale; grafdma.exe: manipulation of the graphical results of the simulations performed by SIMGES and

GESCAL and results generated by the inputs and outputs of water linked to the GIS; ges2dma.exe: updates projects developed in SIMWIN for AQUATOOL.

4.1 Application of the Aquatool

The IIAMA/UPV has partnerships with government agencies, public and private environmental agencies, consulting firms and universities worldwide for the use of the AQUATOOL. It acts directly in the hydrological plans throughout Spain, especially in the watersheds of the North, Douro, Ebro, Catalonia, Tajo, Júcar, Guadiana, Segura, Sur and Guadalquivir. It has partnerships with environmental agencies and universities in some Central and Latin American countries, such as Mexico (Lenma Chapala), Ecuador (Pauter river basin), Colombia (Apartado and Carepa, both in the Medellín region), Brazil (watershed the Araguari River and the Atibaia River - Cantareira system), Peru (La Molina University), Chile (Copiapó river basin) and Argentina (San Juan river watershed). It also operates in watersheds of other European countries (Italy and Cyprus) and Africa (Algeria and Morocco).

Following are some publications in qualified scientific journals, in order to show the potentiality of the AQUATOOL: Andreu et al. (1996); Arnold and Orlob (1989); Avezedo et al. (2000); Haro et al. (2014); Jhunior (2017); Monblanch (2015); Monzonis et al. (2016a); Monzonis et al. (2016b); Paredes and Lund (2006); Paredes et al. (2010a); Paredes et al. (2010b); Salla et al. (2014a); Salla et al. (2014b); Soliz (2010); Sulis and Sechi (2013).

4.2 SIMGES Module

The SIMGES module is a watershed management model that contains surface and underground elements to manage multiple uses, whose definitions of the elements considered is the user's task, where the model set to any type of scheme. The surface and subterranean elements considered are: Surface reservoirs; Channels and stretches of river; Intermediate entrances in river section, such as irrigation, urban and industrial demand; Recharges or returns (refers to the return to the watercourse of a previous capture); Demand without consumption (hydroelectric plants are considered); Artificial recharge (refers to the recharge of aquifers in the rainy season, defined by its physical characteristics); Extra extractions (collects water from an aquifer by pumping for any demand); Aquifers (defined by physical and operational parameters).

In general, the SIMGES module can then be used to:

- quantitatively simulate any watershed for hypothetical infrastructures, requested demands and management rules defined by local Hydrographic Basin Committee;
- define the most appropriate rules for a watershed management to ensure the minimum ecological flow and the minimum water quality to respect the watercourse classification (in Brazil, CONAMA Resolution 357: 2005);
- define the advantages and disadvantages of flow variations in relation to one or more priority uses;
- simulate pumping capacity for a given demand against minimum reserve requirements.

The main characteristics of the module for the estimation of flow variations in any region are:

- the inlet surface flows (tributary, point effluent releases, etc.) and output (human consumption, animal watering, irrigation, etc.) are calculated simply by the mass balance;
- with respect to the aquifers, the flow can be simulated by a simple or multicellular models and also by distributed linear models;
- the module also considers losses by evaporation and infiltration in accumulation reservoirs and river beds, in addition to the interactions between surface and groundwater;
- the management of the watershed in relation to the multiple uses is carried out aiming to maintain fixed liquid levels in the reservoirs, defined by the user, in order to guarantee a requested demand;
- the module also allows the user to define the minimum ecological flows and priority uses;
- the simulations are performed by means of a flow network optimization algorithm that controls the surface flow in the watershed, aiming to minimize the deficits and maximize the liquid levels in the reservoirs for demands such as irrigation, human consumption, production hydroelectric, etc.

4.3 GESCAL Module

The GESCAL module is a model for water quality simulation at watershed scale, initially proposed for the AQUATOOL Decision Support System (Andreu et al., 1996) and in the new AQUATOOLDMA (Solera et al., 2007). The version 1.1 of the GESCAL model was developed by Paredes et al. (2009). The advantage of this tool is that it simulates the quality of water in rivers and reservoirs over time and space in front of the different alternatives of management, purification, contamination and multiple uses of water within the watershed. In other words, it allows the development of water quality models on simulation models of water resources systems previously developed with the SIMGES module. Despite the complexity of the watershed scale model, it is possible to model reservoirs and watercourses in a single application and in an integrated way. It is also possible to study on a local scale, either for a stretch of natural water course or a individual tank.

The SIMGES module simulates the following constituents: temperature, dissolved oxygen, carbonaceous organic matter, nitrogen and fractions (organic, ammonia, nitrate), eutrophication (nitrogen and fractions, phytoplankton - chlorophyll a, organic phosphorus and inorganic), along with interference in dissolved oxygen. Such constituents are modeled on any scale in watershed.

The water quality model in reservoir (lentic enrironment) through the GESCAL module has the following characteristics:

- depending on the month that the modeling is performed, there is the possibility of modeling in two vertical regions, epilimnium and hypolimnium (see **Figure 2**) or as a single complete mixing element.

Epilimnium and hypolimnium refer to common thermal stratification in lakes and ponds (lentic environments), characterized by the formation of horizontal layers of water with different densities, stable, and ordered so that the less dense (epilimnium) float on the denser (hypolimnium), with a minimum degree of mixing between them. This stratification makes the behavior of the quality parameters different in each of the layers;

- establishes the quota of the thermocline and the quantity of entrances and exits between the layers, in a monthly variability. However, in an automatic way, the GESCAL module estimates whether or not the liquid volume is sufficient for the existence of a thermal stratification;
- the diffusion between the layers is considered when the thermal stratification occurs (depends on the time of year);
- the resurgence of bottom sludge are considered for the estimation of the demand for dissolved oxygen (organic matter and nutrients);
- as a function of the variation of the volume in the reservoirs over time, the GESCAL module performs an estimation of the water quality dynamically. **Figure 2** illustrates the reservoir modeling scheme by means of the GESCAL module.

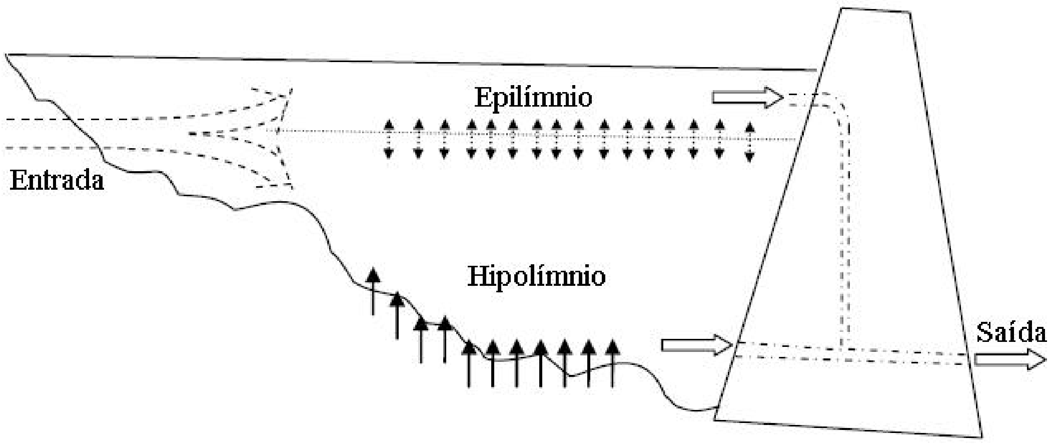


Figure 2 – Scheme of the modeling in reservoir through the module GESCAL. Source: (Paredes *et al.* 2009, adaptado).

For the case of the occurrence of a thermal stratification, the estimation of the concentration of any parameter studied passes through the resolution of a system of differential equations, defined in (1) and (2).

$$V_1.\frac{dC1}{dt} + C1.\frac{dV1}{dt} + \frac{C1}{2}.\frac{dV}{dt} = Q1e.Ce - Q1s.C1 + E'_{12}(C2 - C1) + \sum Wi1 \qquad \text{eq.(1)}$$

$$V_2.\frac{dC2}{dt} + C2.\frac{dV2}{dt} - \frac{C1}{2}.\frac{dV}{dt} = Q2e.Ce - Q2s.C2 + E'_{12}(C1 - C2) + Sed + \sum Wi2 \qquad \text{eq.(2)}$$

In which: sub-index 1 refers to the upper layer of epilimnium; sub-index 2 refers to the lower layer of hypolimnium; V_1 and V_2 are the volumes of the layers (m^3); V is the volume gain (if positive) and lost (if negative) of epilimnium on hypolimnium due to changes in the ambient temperature during the month (m^3); t is the time (T); C_1 and C_2 are the upper and lower layer concentrations (mg/L), respectively; $C_{1/2}$ is the concentration of the parameter in hypolimnium if the volume increment is negative and the concentration of the parameter in epilimnio if the increase is positive (mg/L); C_e is the concentration of the parameter at the reservoir inlet (mg/L); Q_{1e} and Q_{2e} are the inlet flows in the upper and lower layers (m^3/T), respectively; Q_{1s} and Q_{2s} are the output flows in the upper and lower layers (m^3/T), respectively; *Sed* is the resurgence of the studied parameter of the bottom load (M/T); E'_{12} is the dispersion coefficient between the layers of the thermal stratification (m^2/T); W_{i1} and W_{i2} represent the set of degradation or input processes of the studied parameter in mass balance.

Now, for the absence of thermal stratification or completely mixed volume, the estimate of the concentration of any parameter passes through the resolution of a single differential equation (equation 3). In this case, the epilimnium region is modeled, considering null the flow and concentration of the parameters for hypolimnium.

$$V1.\frac{dC1}{dt} + C1.\frac{dV1}{dt} = Q1e.Ce - Q1s.C1 + \sum Wi \qquad \text{eq.(3)}$$

The hydraulic reservoir process respects several criteria to define whether the modeling is performed in a fully mixed reservoir or in two layers, namely:

- for each month, when the thermocline dimension is zero, the reservoir will be modeled as a single fully mixed element;
- now, if the thermocline level is nonzero, it is initially verified whether the reservoir has enough volume for the production of a thermal stratification. When the volume is insufficient, the thermal stratification breaks due to the turbulences caused by the wind, the entrances and exits. To consider this factor into account, the GESCAL module has a parameter called the coefficient of thermocline in the constant file. In each monthly simulation, the coefficient is multiplied by depth of the reservoir. The existence of thermal stratification is not considered when the thermocline is below this value, and the reservoir will be modeled as completely mixed;
- if the thermocline coefficient multiplied by the depth of the reservoir is higher than the thermocline dimension, there is sufficient volume for the thermal stratification, being, from there, estimated the initial and final volumes of the layers of epilimnium and hypolimnium;
- it is then verified whether the final volumes are different from zero. If it is equal to zero, the reservoir will be modeled as completely mixed.

The summarized descriptions carried out here show the high potential of the GESCAL module in the diagnosis and prognosis of water quality in a lentic environment.

5 SCENARIOS

Two scenarios were analyzed: the first scenario referring to the normal regime in the Araguari river and a second scenario considering a critical situation $Q_{7,10}$ (minimum flow in 7 consecutive days with a 10 year recurrence time).

The topology of the water system was kept fixed for both scenarios, as shown in **Figure 3** In order to show the longitudinal profile of the water quality parameters along the stretch of 46 km in the Araguari River, a practical artifice was used in the AQUATOOL. Instead of modeling a single reservoir in complete mixing, a serial of hydraulics cell were used for each interval of 2500 m (one fictitious reduced reservoir per 2500 m). For this, eleven small reservoirs were considered between the Miranda and Capim Branco I dam and seven reservoirs downstream of the Capim Branco I dam (see **Figure 3**).

The interconnections between the reduced reservoirs were made by a stretch of fictitious river, whose self-purification processes were considered null in the passages through these stretches. The occasional inputs (from 8 sub-basins and the treated effluent generated by the pulp mill) and diffuse ones, as well as the specific outputs (consumptive demands of irrigation, water supply and public supply of the Uberlândia city, besides the non-consumptive demand for generation of electricity) were allocated in their respective reduced reservoirs (see **Figure 3**).

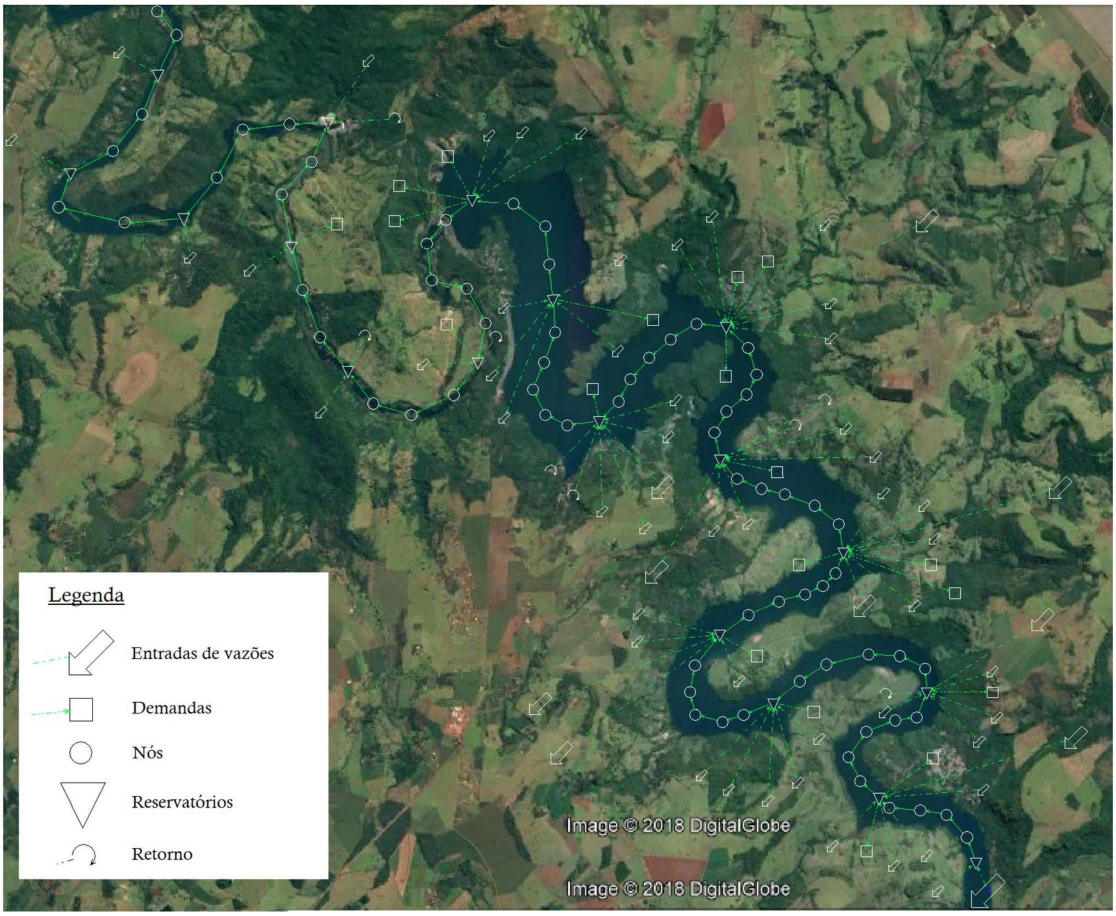


Figure 3 – Topology of water system. Source: (Author, 2018).

5.1 Input Data

5.1.1 Flow Rate

After defining the topology of the water system in AQUATOOL, it was necessary to feed the punctual and diffuse inputs, as well as the demands, all in m^3/s, to perform the water balance through a flow network algorithm (in SIMGES module). Considering extensive historical series with a minimum of failures, the period from October 1997 to September 2014 (17 years) was used for the calibration of the model and for the analysis of the scenarios. **Table 2** shows the values of the punctual flows, diffuse inputs and demands.

Table 2 – Punctual flows, diffuse inputs and demands (m^3/s)

Punctual entry on ANA station	$Q_{7,10}$ (Araguari river)	Demand generation electric power	Sub basin entries	Diffuse flows	Agricultural demand	Demand Public Supply	Punctual Entry Industry
*293,35 – 1174,11	*39,32 - 40,91	*286,56 – 420,38	*0,11 – 4,12	*0,002 – 0,47	*0,013 – 0,07	2,00	0,61
**430,10 ± 113,12	**39,98 ± 0,73	**376,41 ± 41,03	**0,71 ± 0,70	**0,05 ± 0,06	**0,035 ± 0,024		
*Mínimo – máximo **Média ± desvio padrão							

Source: PÖYRY (2018), ANA (2018) and Jhunior (2017)

Os dados referentes às demandas superficiais outorgadas para consumo humano, irrigação, indústria e dessedentação de animais foram obtidos junto à Agência de Bacia Hidrográfica do Rio Araguari, Secretaria de Estado de Meio Ambiente e Desenvolvimento Sustentável (SEMAD) e Jhunior (2017).

Datas about the surface demands granted for human consumption, irrigation, industry and animal dander were obtained from the Araguari River Watershed Agency, State Secretariat for Environment and Sustainable Development (SEMAD) and Jhunior (2017).

5.1.2 Water Quality

The qualitative modeling in the GESCAL module was developed after the quantitative simulations, maintaining the period from October 1997 until September 2014 for the calibration of the model and for the scenarios. The water quality input data are shown in **Table 3**. The polluting load released by the effluent from the industrial project was kept fixed throughout the 17 years of analysis. Water quality parameters for class 2 watercourse (according to CONAMA Resolution 357: 2005) were considered in the estimation of the quality at the input points of the sub-watershed and diffuse flows.

Table 3 – Water quality data

Parameter (mg/L)	Punctual entry on ANA station	Punctual entry industry	Sub basins entries	Diffuse flows
DO	*4,6 – 9,6 ** 6,7 ± 0,9	0	6,0	5,0
BOD	*0,2 – 7,7 **1,8 ± 0,8	40,00	3,0	5,0
Organic nitrogen	*0,0 – 0,4 **0,09 ± 0,06	6,00	*1,4 – 2,6 **1,7 ± 0,5	*1,4 – 2,6 **1,7 ± 0,5
Ammonia	*0,0 – 0,5 **0,1 ± 0,06	8,57	*2,0 – 3,7 **2,4 ± 0,7	*2,0 – 3,7 **2,4 ± 0,7
Nitrate	*0,0 – 0,7 **0,2 ± 0,1	0,43	10,0	10,0
Total phosphorous	*0,0 – 0,2 **0,03± 0,05	1,50	0,025	0,05
*Minimum - maximum **Average ± standard deviation				

Source: PÖYRY (2018), ANA (2018) e CONAMA 357/2005

5.1.3 Climatic data

The climatological data used in the modeling were obtained from INMET, specifically at the A507 meteorological station, located in the central region of Uberlândia. The data collected were: atmospheric pressure, temperature and relative humidity, precipitation, solar radiation, direction and wind speed. The monitored parameters are made available minute by minute, being converted to monthly values to be entered as input data in the tool.

5.2 Calibration of the water quality model

In the calibration process, the best fit was sought between the simulated profiles from October 1997 to September 2014 and the data monitored at a station located near the Amador Aguiar I dam (coordinates 18º47'12 "S and 48º08'42 "W) (see location in **Figure 1**, identified by "Point P1").

The calibration of the model was performed by means of trial and error adjustment of the main biochemical and sedimentation coefficients involved in the simulation of dissolved oxygen, biochemical oxygen demand, nitrogen and total phosphorus. The calibrated coefficients are shown in **Table 4**.

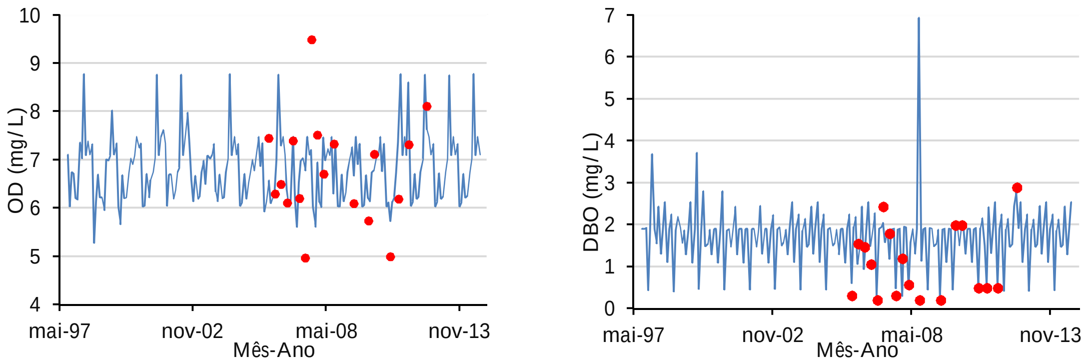
Table 4 – Calibrated coefficients

Turbulent diffusion coefficient	10 m²/s
Coefficient of biochemical reaction	
Reaeration	0,05 day^{-1}
Degradation of organic matter	0,01 day^{-1}
Degradation of organic nitrogen	0,01 day^{1}
Nitrification of ammonia	0,01 day^{-1}
Nitrate denitrification	0,001 day^{-1}
Degradation of organic phosphorus	0,01 day^{-1}
Sedimentation rate (m/dia)	
Organic matter	0,01 m/day
Organic nitrogen	0,001 m/day
Organic phosphorous	0,001 m/day

Source: Author (2018)

Water temperature interferes with biochemical reactions and sedimentation. An annual temperature profile of the water in each reduced reservoir is requested in GESCAL module. The mean monthly water temperatures considered in this study were obtained from ANA (mean value equal to 24.3 ºC ± 1.5 ºC).

Figure 4 shows a visual comparison of the simulated and monitored parameters at the station located near the Amador Aguiar I dam, for the period between October 1997 and September 2014.



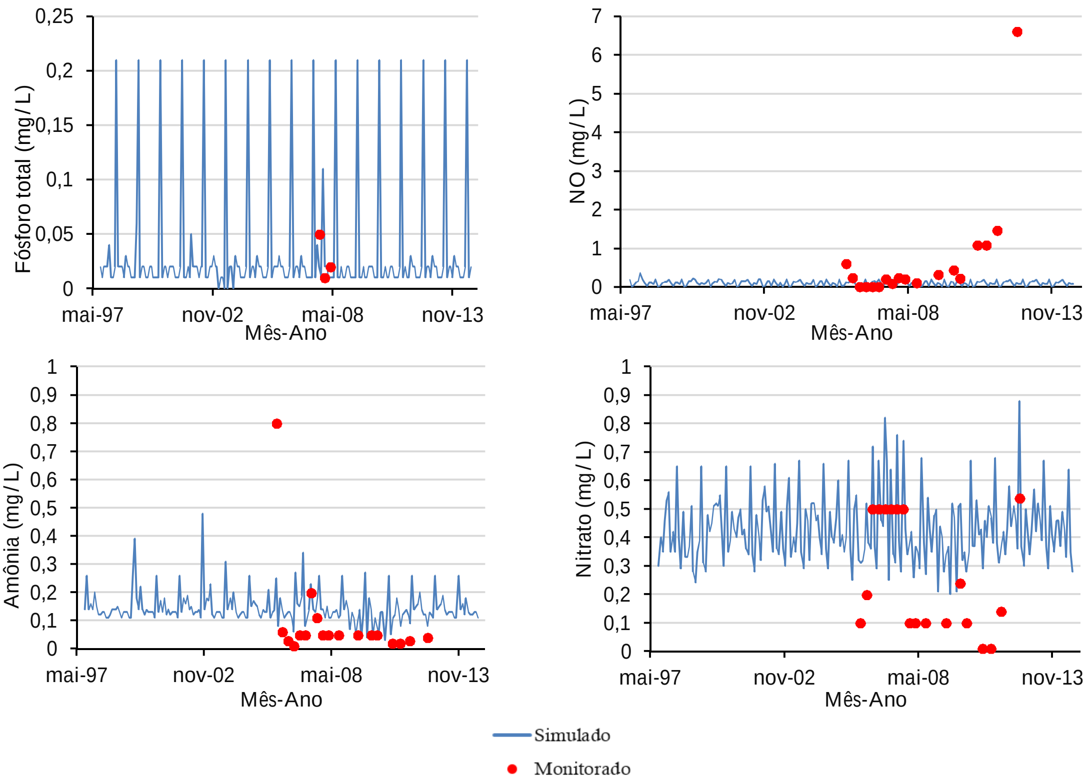
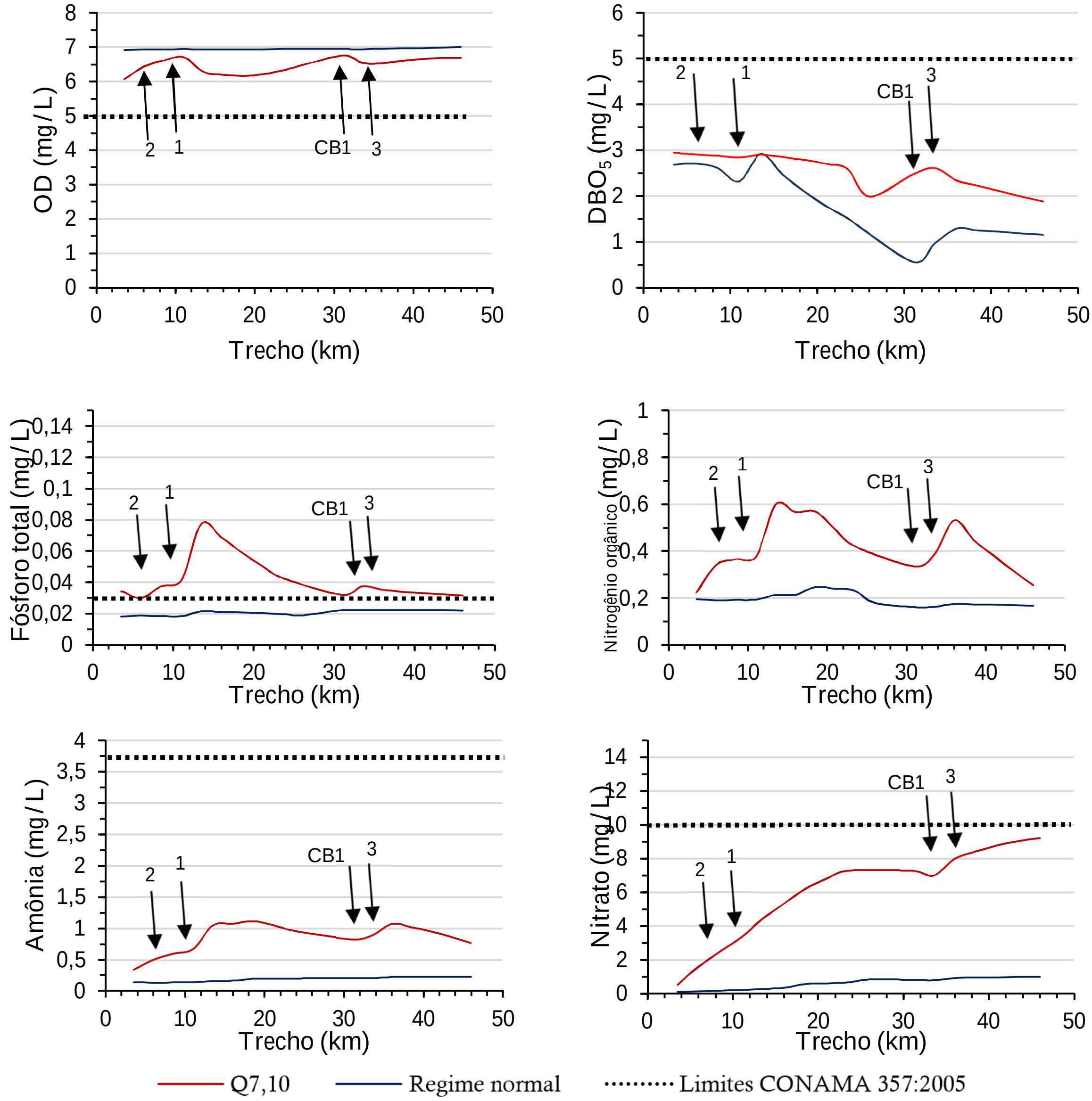


Figure 4 – Visual comparison of the simulated and monitored parameters at the station located near the Amador Aguiar I dam (so-called Capim Branco I). Source: (Author, 2018).

In general, despite the small amount of data monitored, it is visually observed that there was a satisfactory calibration of the biochemical reaction coefficients and sedimentation velocity. The relation between the simulated and observed values was between 0.98, 0.95 and 0.86 for dissolved oxygen (OD), biochemical oxygen demand (BOD) and total phosphorus, respectively. The reduced values for the nitrogen series prevented a better calibration of the organic nitrogen, ammonia and nitrate (ratio of 0.68, 0.77 and 0.53, respectively), which did not compromise the quality of the simulations of the scenarios.

6 SCENARIOS SIMULATIONS

Graphs were generated to relate the profiles of dissolved oxygen (OD), biochemical oxygen demand (BOD), organic nitrogen (NO), ammonia, nitrate and total phosphorus to the distance from the station monitored by ANA until approximately 16 km downstream of the Amador Aguiar I dam (so-called Capim Branco I). **Figure 5** shows the profiles for scenario 1 the results are represented by the lines "Normal regime", and for scenario 2 by the lines "$Q_{7,10}$". It is important to point out that the launch of the polluting load of the industrial enterprise was included in kilometer 11 of the simulated stretches.



Indications:
1 – discharge point of treated effluent;
2 e 3 – other existing demands (most significant, such as irrigation, max. 0.06 m³/s, and supply, 0.03 m³/s);
CBI – reservatório de Capim Branco I.

Figure 5 – Profiles of quality parameters for scenarios 1 and 2. Source: (Author, 2018)

6.1 Scenario 1 (average flow of Araguari river)

The classification of water bodies is defined by CONAMA Resolution 357/2005 and Deliberação Normativa COPAM/CERH nº 01/2008. The Araguari River is classified in Class 2, in which the following limits must be respected: dissolved oxygen ≥ 5.0 mg/L; BOD_5 ≤ 5.0 mg/L; ammonia ≤ 3.7 mg/L; nitrate ≤ 10.0 mg/L; phosphorus (lentic environment) ≤ 0.03 mg/L.

In view of a general analysis, for scenario 1, the longitudinal profiles of all the simulated quality parameters conform to the values defined in CONAMA Resolution 357/2005 and Deliberação Normativa COPAM/CERH nº 01/2008.

The discharge point of the treated effluent at kilometer 11 (indications 1 in **Figure 5**) interfere a little bit in the longitudinal profile of the studied parameters.

It can be verified the autodepuration of the Araguari river from the discharge of the treated effluent, because it is observed a constant drop of the parameters BOD_5, organic nitrogen, ammonia, nitrate and total phosphorus, and dissolved oxygen growth, resulting in a tendency to reach values prior to discharge.

The other demands present in the analyzed section of the Araguari river (indications 2 and 3 in **Figure 5**) also did not interfere in the longitudinal profile of the studied parameters. In indications 2 and 3, the volume intaked returns as sewage in a percentage that varies between 20% and 80%, referring to public supply and irrigation, respectively (ANA, 2013).

Approximately in the kilometer 33 a volume of water is withdrawn from the reservoir and returned just downstream of the dam (indication CB1, in **Figure 5**), which according to the results indicates an interference in the longitudinal profile of the parameter BOD.

6.2 Scenario 2 (Flow $Q_{7,10}$)

According to Figure 5, it is observed in the points 1, 2, 3 and CB1 the increase of the concentrations of BOD_5, organic nitrogen, ammonia, nitrate and total phosphorus and the decrease of oxygen dissolved.

However, in the whole studied stretch, the parameters: dissolved oxygen, BOD_5, ammonia and nitrate meet the values stipulated by CONAMA Resolution 357/2005 and COPAM/CERH Normative Resolution 01/2008 (dissolved oxygen $\geq$ 5.0 mg/L; $BOD_5 \leq$ 5.0 m /L, ammonia $\leq$ 3.7 mg/L, nitrate $\leq$ 10.0 mg/L). The exception is the total phosphorus parameter, whose effluent release treated by the pulp mill increased its concentration from 0.04 mg/L to 0.08 mg/L. It is important to note that the concentration upstream of the point of release of the treated effluent is already above the quality standard (which is 0.03 mg/L) for river class 2 in a lentic environment, according to CONAMA Resolution 357/2005 and Normative Resolution COPAM/CERH 01/2008.

As in scenario 1, scenario 2 also indicates the autodepuration of the Araguari river from the discharge of the treated effluent, since there is a constant drop in the parameters DBO_5, organic nitrogen, ammonia, nitrate and total phosphorus, and dissolved oxygen growth, resulting in a trend to reach pre-launch values.

7 CONCLUSIONS

According to the simulations carried out using the Aquatool and the respective results presented in scenarios 1 (average flow) and 2 (flow $Q_{7,10}$), it was verified that the Araguari river has a self-purification capacity of the treated effluent discharge by the pulp mill , since the DBO_5, organic nitrogen, ammonia, nitrate and total phosphorus parameters were observed to have a constant decrease, and OD growth was observed, resulting in reaching pre-launch values. For example, the parameters DBO, total phosphorus, organic nitrogen, OD return to their original conditions of 8 km up to 17 km away from the point upstream of the effluent discharge from the plant. The ammonia and nitrate parameters show a less pronounced fall curve, since the ammonia returns to the conditions after 37 km of distance, whereas the nitrate presents a curve less accentuated still.

It was also found that, for both scenarios, all quality parameters evaluated are within the limits established by CONAMA Resolution 357/2005 and COPAM/CERH Normative Resolution 01/2008. Exception of the total phosphorus parameter in scenario 2, whose concentration in the whole section was above the limit of 0.03 mg/L (valid for lentic environment) of CONAMA Resolution 357/2005 and COPAM/CERH Normative Resolution 01/2008. However, it is important to emphasize that the concentration upstream of the point of release of the treated effluent already has a value of 0.04 mg/L, that is, above the quality standard for river class 2 in a lentic environment.

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