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Evaluation of Biological and Sedimentological Issues Regarding a Bottom Discharge in the Paciência Small Hydro Power Plant - Brazil

Vinícius V. M. Ferreira[1]✎, Lécio H. Salim[1], Jefferson V. Bandeira[1], Marília V. Junqueira[2], Marcela D. Carvalho[3], Helen R. Mota[3], Guilherme H. S. P. C. Barbosa[4]

[1]CDTN – Centro de Desenvolvimento da Tecnologia Nuclear, Av. Antônio Carlos 6627, Campus UFMG, Belo Horizonte – MG – Brazil. CEP 31270-901 - vvmf@cdtn.br, salimlh@cdtn.br, jvb@cdtn.br
[2]CETEC – Fundação Centro Tecnológico de Minas Gerais. Av. José Cândido da Silveira, 2000, Horto. Belo Horizonte – MG – Brazil. CEP 31035-536 - marilia.junqueira@cetec.mg.gov.br,
[3]CEMIG – Companhia Energética de Minas Gerais. Av. Barbacena 1200, Santo Agostinho. Belo Horizonte - MG – Brazil. CEP 30190-131marcela.david@cemig.com.br, helen.mota@cemig.com.br
[4]UFOP - Universidade Federal de Ouro Preto. Instituto de Ciências Exatas e Biológicas. Programa de Pós-Graduação em Ecologia de Biomas Tropicais. Morro do Cruzeiro – Campus UFOP. Ouro Preto – MG – Brazil, CEP: 35400-000 guilherme_hermano@yahoo.com.br

Abstract: The Paciência hydro power plant, located near the city of Juiz de Fora, Minas Gerais State - Brazil, was the scenario of many studies done in 2011-2012. These surveys were carried out in the scope of a project supported by CEMIG - electric utility responsible for the operation of the plant. The objective of this work is to present the results of the some studies conducted on the site, in particular those related to water quality and the existent benthic macroinvertebrate community, and the correlation of these parameters with the bottom discharge. The assessment of water quality showed the presence of critical levels of organic load in monitoring stations. The macrozoobenthic community found in the stations of the biomonitoring network reflected the conditions of water quality in this stretch of the Paraibuna River. The place was fairly poor in taxonomic variety and with excessive densities of a few taxonomic groups that are very resistant, characteristic of aquatic environments with high levels of organic load. The transport of fine sediment in suspension was quantitatively studied by labeling it with the radioactive tracer technetium 99, broadly used in nuclear medicine, in two campaigns, together with the application of a mathematical model. It was possible to verify that simulation of propagation of the suspended sediment concentration originating from bottom discharge in dry season, the most critical, showed that it decreased to a value of about 18% of the initial value of the bottom discharge

Keywords: Dams, impacts, macroinvertebrates, water quality, tracers, sediments.

Introduction

The increase of the environmental demands for dredging works in coastal and inland environments, including bottom discharges or reservoirs dredging with transposition of sediments downstream, began to be established in Brazil since the publication of the CONAMA (Environmental National Council) Resolutions 344/2004 and 421/2010. Considering that in a SHP – Small Hydro Power Plant, the effects of accretion can arise in medium or short term, the CEMIG (Minas Gerais State Energetic Company), under the scope of its Research and Development Program CEMIG GT (Generation and Transmission), developed a research project named "GT 198 - Environmental Assessment of the Paraibuna River Downstream the Reservoir of the Paciência SHP, after the bottom discharge". The project was executed by the CDTN (Center for Development of Nuclear Technology) and by the CETEC (Technological Center of Minas Gerais). Due to a greater sensitivity to sedimentation issues, a reservoir of a SHP will

✎ Vinícius V. M. Ferreira (Correspondence)
✉ vvmf@cdtn.br

tend to present a significant loss of volume in a relatively short time.

The main goals of the project GT 198 were:

• to develop applied research to evaluate, using tracers and related techniques, the physical environmental impact through measurements of advection, dispersion and settling of dumped material in watercourses downstream, of the sediment periodic pulses derived by bottom discharges and/or dredging of the Paciência reservoir in the Paraibuna River - Hydrographic Basin of the Paraíba do Sul River;

• to assess the environmental impact of its biological aspects, using the zoobenthic aquatic community as a bioindicator present in the studied river stretch downstream the Paciência SHP dam;

• to perform the ecotoxicological characterization of sediments deposited in the reservoir and that are regularly withdrawn from it as well as of the bottom sediment of the studied river stretch downstream the dam;

• to consider the requirements presented in the CONAMA Resolution 344/2004 [1], that establishes the general guidelines and minimal procedures for the assessment of the material to be dredged (the bottom discharge is a form of dredging) in order to manage its disposal in Brazilian waters;

• to establish a basic methodology to be applied, adapted to each case, to the numberless existing SHPs and other dams in Brazil contemplating, simultaneously and realistically, the physical and biological aspects of the impact of the dump in watercourses downstream, of dredged material in reservoirs.

The project is an opportunity to answer some needs of the electric sector and makes possible the evaluation of the environmental impact of the periodic pulses of sediment (bottom discharge), in the morphology of the river downstream the dam as also in its biological and ecotoxicological aspects. Previous results already published showed the granulometry of the sediments before and after the bottom discharge, and its chemical characterization [2]. Among other conclusions, it was possible to verify that the bottom discharge increased the volume of the river section between the dam and a bridge 1.6 km upstream in an amount of 24,400 m^3 (Fig. 1). This value can be considered as the sedimentation rate of the dam in a six month period. It was estimated that 6.4 tons of muddy sediment and 20.8 tons of sand were carried downstream the dam due to the bottom discharge. Also, the level of muddy sediment (smaller than 0.063 mm) fell drastically after the bottom discharge, especially in the samples collected upstream the Paciência SHP, showing that the bottom discharge is the mainly process that carries the muddy sediments. Regarding to the heavy metal content, the bottom sediments collected upstream and downstream the dam presented, in several samples, values higher than the threshold above which a probable adverse effect on the biota is expected, in particular for cadmium, chromium and zinc [3].

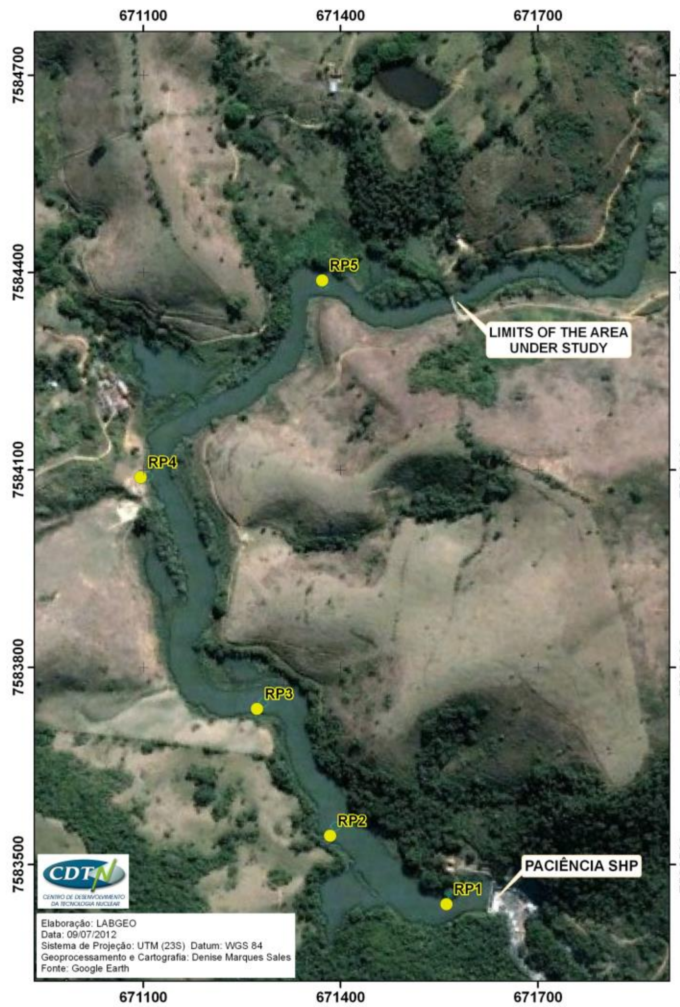

Figure 1 – River section where the bathymetric studies took place and location of the five sampling points upstream the dam (Source: Google Earth)

The objective of this paper is to present the results regarding the environmental impacts associated with the operation of the Paciência SHP, in particular those related to biological and sedimentological aspects. The bioindicator to be evaluated is the zoobenthic aquatic community present downstream the dam of the SHP in 2011. Five sampling stations were installed in order to study the biota in the Paraibuna River through the use of artificial substrates and a dredge. An assessment of water quality at the site was also done. Also, with the help of radioactive tracers, the dynamics of the sediments released after the bottom discharge was evaluated at the site.

It is valid to emphasize that tracers and mathematical models are complementary tools when complex environmental systems are studied. Tracer data are based on direct observations, but limited to the labeled component of the system and to a restricted domain in space and time. Mathematical models can theoretically perform simulations of new important situations of the system, but are limited by the underlying assumptions. Separately, these tools have their limitations, but together, synergy occurs and they constitute a powerful method for studying complex environments [4].

Characterization of the studied region

The Paraibuna River (Figure 2) rises in the "Serra da Mantiqueira", Minas Gerais State, about 1,200 meters above sea level, and flows into the Paraíba do Sul River, in the City of Três Rios - Rio de Janeiro State, which is 250 meters above the sea level. The Paraibuna River runs approximately 166 km from its source to its mouth. Its average flow, at the mouth region, is 200 m^3/s. The average slope of Paraibuna River varies a lot, reaching maximum values of about 70 m/km in its initials 4 km. In the urban stretch of Juiz de Fora (main city in the region with 510,000 inhabitants), the average slope is approximately 1.0 m/km and downstream the town of Matias Barbosa, until it reaches the Paraíba do Sul River, is approximately 5.0 m/km [5].

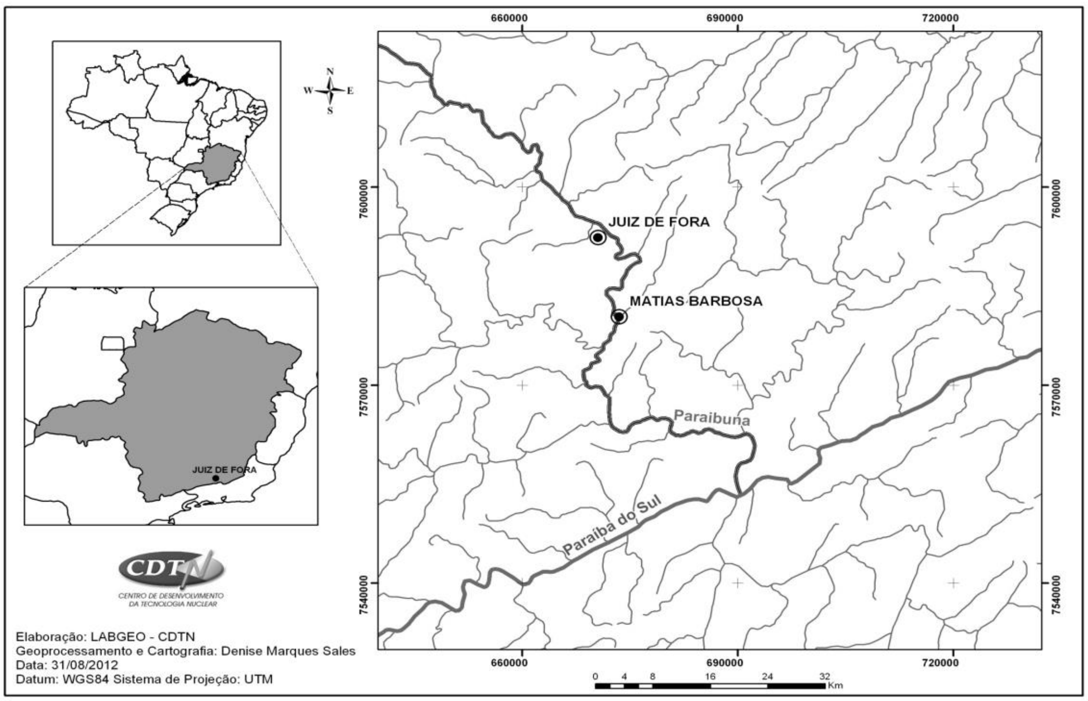

Figure 2 – Location of the Paraibuna River and Matias Barbosa and Juiz de Fora municipalities

The Paraibuna River has multiple uses such as power generation, industrial supply, irrigation, recreation and animal consumption. It receives a large volume of domestic sewage without any treatment, besides industrial sewage with high concentration and toxicity, being considered a dead river between Juiz de Fora and dam of Joasal at downstream. The volumes of sewage and industrial effluents treated today are negligible compared to the total that is launched into the river. Another impacting factor and of great importance is the accretion of the Paraibuna River and its main tributaries, caused by erosion found in several areas of Juiz de Fora due to the removal of existing natural vegetation, without the required technical skills to proper soil management. The SHPs of Marmelo, Joasal and Paciência were installed in the Paraibuna River since 1889, respectively from upstream to downstream, and are responsible for about 12.5% of the energy supply of Juiz de Fora [6].

The Paciência SHP started to operate in 1930 and is currently controlled by CEMIG. It has three generating units with a total installed capacity of 4.08 MW and its dam is 9 m tall. The SHP is located in the town of Matias Barbosa. The studied area covers an extension of 11.6 km of the Paraibuna River, being 1.6 km upstream and 10 km downstream the Paciência SHP, until the biological monitoring station EMB 5 (Figure 3).

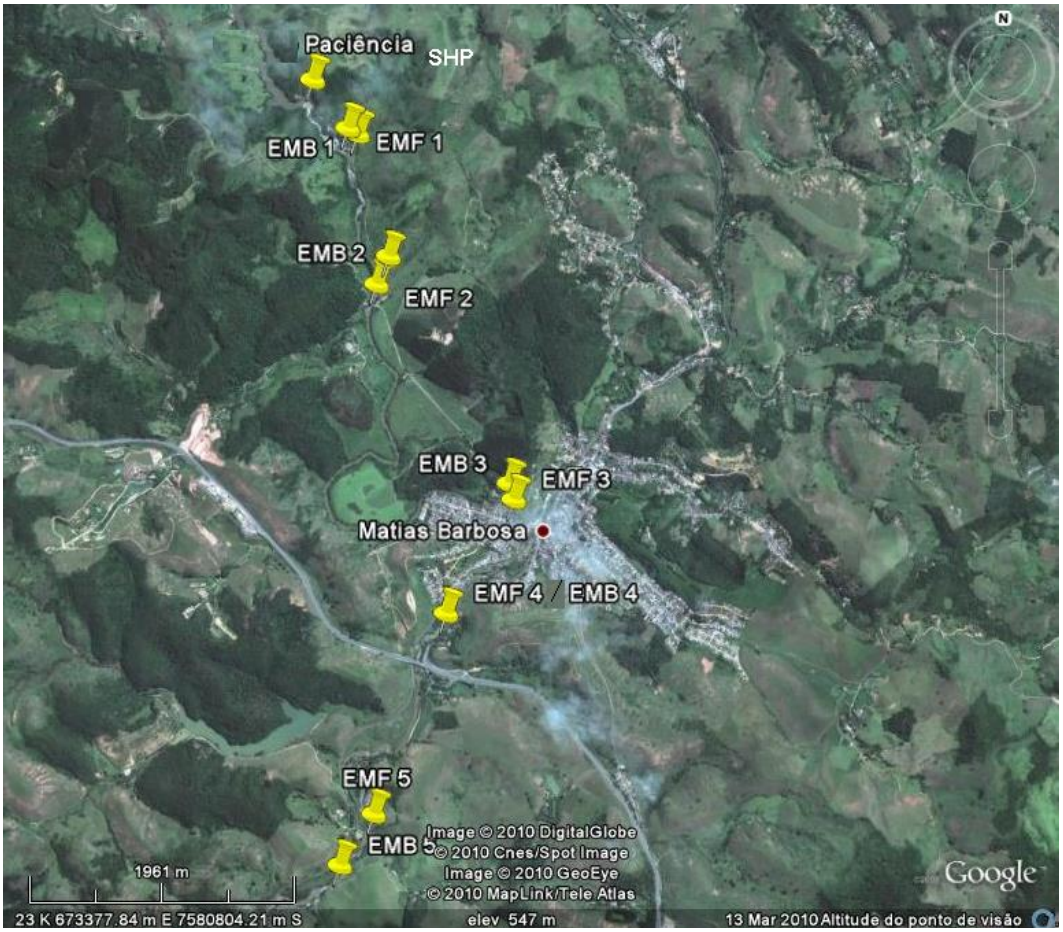

Figure 3 – Area under study and sampling stations

Table 1 shows info about the location of the sampling stations, where EMF are the physical monitoring stations, and EMB the biological ones.

Table 1 – UTM coordinates of the stations

Station	E	N
EMF 1	671890	7583125
EMB 1	671963	7583084
EMB 2	672218	7582180
EMF 2	672133	7581968
EMB 3	673167	7580506
EMF 3	673206	7580388
EMF 4 and EMB 4	672720	7579527
EMF 5	672211	7578014
EMB 5	671974	7577619

Datum: WGS-84

Materials and Method

Biological and chemical studies - the methodology adopted to assess the aquatic biota in the five network stations in the section of the Paraibuna River downstream the Paciência SHP (stations EMB1 to EMB5) included the study of the macro invertebrates of the benthic epifauna through the use of commercial bricks and nylon gauze as artificial substrates [7], which were exposed in five periods for five weeks covering the two bottom discharges performed in 2011. Sediment sampling was conducted for the study of benthic infauna with the aid of an Ekman-Birge dredger according to ISO 9391 [8], and three sample units were taken at each station in the same biomonitoring network.

The laboratory analysis consisted primarily of sieving the material through a sieve of 0.3 mm mesh followed by a screening of the material through a stereomicroscope which was prepared and fixed with alcohol 70°. For a qualitative and quantitative analysis, a taxonomic identification and enumeration of all organisms present in the samples was performed with the aid of dichotomous keys and usual techniques of optical microscopy. A systematic identification was made for most individuals in taxonomic level of family and gender and, when possible, of species level.

Concurrently to the zoobenthic sampling, water samples were collected for physicochemical analyzes. In parallel with the study of the conditions of the macro zoobenthic community and of the physicochemical characterization of the water, an evaluation of the amount of mineral and organic sediments deposited on artificial substrates exposed on the study stations, quantifying the material by volumetric measurements (ml), was performed.

To complement the studies on the biomonitoring network operated in the downstream stretch of the Paciência SHP, an assessment of the ecomorphological quality of the five sampling stations was held, based on a German methodology, adapted to the site under study [9,10], in order to characterize the ecophysical conditions of the studied stretch.

Hydrosedimentological studies – the first step of the hydrosedimentological studies included activities just before and just after the bottom discharge of June 2011, to evaluate its influence in the fluvial system, through the comparison of the obtained results. The activities performed included the sampling of bottom sediment in ten points, being five upstream and five downstream the dam followed by a grain size analysis. To attend the CONAMA legislation [1], a chemical characterization of the pollutants present in the sediments was done, in order to determine the levels of heavy metals, total organic carbon, nutrients and organic compounds: organochlorine pesticides and polycyclic aromatic hydrocarbons. Also, two bathymetric surveys were performed in the backwater region of the dam [3].

The transport of fine sediment in suspension downstream the dam was quantitatively studied in two field campaigns, in August an October of 2012, both during the dry season, being the first under normal operation and the second in a situation of bottom discharge of the SHP. The sediments were labeled with the radioactive tracer technetium-99 metastable (^{99m}Tc) that emits a gamma radiation whose energy is 140 keV. Its half-life is 6.02 h, and it is widely used in nuclear medicine. The methodology to apply this tracer in hydro sedimentological studies was developed by Bandeira [11].

Just after the dam, about 40 liters of sediment (previously collected at the same site) labeled with ^{99m}Tc were launched by gravity for approximately one minute, with a concentration below 200 g/L. The transit of the tracer cloud was detected at fixed sections downstream (from EMB1 to EMB4 – Fig. 3) with the help of scintillometers. Based on the results of the response curves recorded by the probes it was possible to determine the speed of advection (ν) and to evaluate, through integration of the areas under the curves, which represents the amount of labeled material that crosses each section, the settling of sediment between sections. With the application of a mathematical model [12] it was possible to determine the longitudinal dispersion coefficient (D) for several stretches between sections by adjusting the model to the experimental transit curves of each section.

The mathematical model of Singh and Beck [12] uses the one-dimensional dispersion equation:

$$\frac{\partial c}{\partial t} = D\frac{\partial^2 c}{\partial x^2} - \nu\frac{\partial c}{\partial x} \quad (1)$$

where: c = average concentration of the tracer in the measurements section;
D or DL = longitudinal dispersion coefficient (m^2/s);
ν = average velocity of the flow in the section under study (m/s)
x = distance measured along the channel from the injection section (m);
t = time (s).

Equation (1) cannot model the variation of tracer concentration within the section of measurements, being it considered uniform. The dispersion coefficient includes the combined effects of molecular diffusion, turbulent mixing and mixing caused by vertical and transversal shear, function of velocity gradients in the borders of the channels (along the width and depth of the flow). Thus, the value of D depends on the hydraulic properties of flow, which determine the turbulent mixing and the shear due to velocity gradients. Delays or stores in dead zones can also affect the dispersion coefficient.

Considering v and D as constants, and assuming that the specific masses of water and of the component being transported (solute or tracer) are the same, a solution for equation 1, that satisfies the initial and the boundary conditions:

$$c(0,t) = c_0 \qquad (2a)$$

$$\partial c(\infty,t) / \partial x = 0 \text{ for } t > 0 \qquad (2b)$$

was obtained by Ogata (1958) and Bear (1972), and used by Singh and Beck [12]:

$$\frac{c}{c_0} = \frac{1}{2}\left[erfc\left(\frac{x - vt}{2\sqrt{Dt}}\right) + \exp\left(\frac{vx}{D}\right) erfc\left(\frac{x + vt}{2\sqrt{Dt}}\right)\right] \qquad (3)$$

where: erfc (.) = complementary error function, being expressed by:

$$\text{erfc}(y) = 1 - \text{erf}(y) = 1 - \frac{2}{\sqrt{\pi}} \int_0^x \exp\left(-z^2\right) dz \qquad (4)$$

Equation (3) satisfies the boundary conditions (2a) and (2b), assuming that erf (0) = 0; erf (∞) = 1 [12].

To implement the model it is necessary that the measurements of the concentration time profiles have been performed in at least two stations downstream the release point. Being x the distance between these two stations, the concentration time profile in the upstream station can be decomposed into a series of concentration pulses of infinitesimal duration. The concentration profile at the downstream station is then the sum of the responses of pulses concentration measured at the upstream station.

Simultaneously to the injection of sediment labeled with ^{99m}Tc, Rodhamine WT (Water Tracer) was also injected to allow the measuring of the river water flow along the experimental stretch. The determination of liquid flow rates can be made using the integration method based on instantaneous injection of a tracer [13].

At one determined river point, a known mass M of tracer is released. Downstream this point, in a site located at a sufficiently distance from the previous, in order to fulfill the requirement of good mixing process, the transit curve of tracer is obtained, given by the variation of the concentration versus time. The area under this curve is the value of expression $\int C(t)\,dt$, which provides the river flow (Q) according to the equation number 5:

$$Q = \frac{M}{\int_0^\infty C(t)\,dt} \left[\frac{g}{\frac{g}{l}\,s} = \frac{l}{s}\right] \qquad (5)$$

Figures 4 and 5 shows the launching and detection points of the sediments marked with technetium 99 in the experiments done in August and October - 2012. The power house is situated about 430 m below the SHP dam.

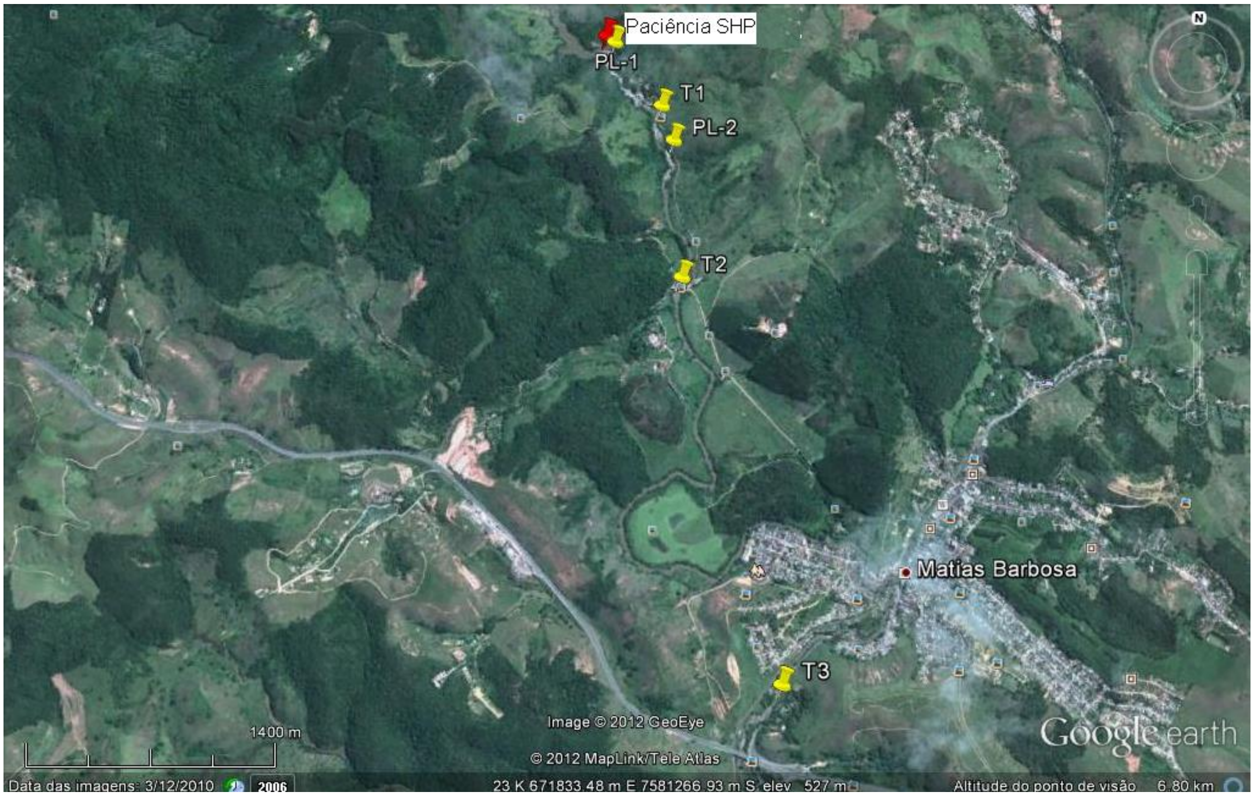

Figure 4 – Launching points (PL-1 and PL2) of the sediment marked with tracer and detection points (T1, T2 and T3) in the experiments done in August and October – 2012.

Figure 5 – Release point (PL-1) of the sediment marked with tracer and detection stations (T0 e T1A) in the experiments done in October 2012

Results and Discussion

The results of the physical-chemical analyses of water collected in the five sampling stations of the biomonitoring network implanted in the Paraibuna River downstream the Paciência SHP are shown in Tables 2 to 6. The found values indicate a possible decrease of the DO (Dissolved Oxygen) values that in the studied case is minimized due to the great waterfall located after the spillway of the dam, what causes the oxygenation in the water and reduces the BOD (Biochemical Oxygen Demand) and the damage effect of the AN (Ammonia Nitrogen).

Table 2 - Results of the physical-chemical analyses of water (station EMB1), June to November 2011

Station			**EMB1**		
Date of collection (day/month)	19/06	25/07	01/09	04/10	07/11
Water temperature (in situ) / °C	18.1	-	19.9	22.0	22.6
Electrical conductivity, μS/cm (in situ)	112.6	-	117.5	-	116.6
Electrical conductivity, 25°C / S/cm	117.4	105.7	116.3	126.9	120.4
Biochemical Oxygen Demand / mg/L	4.2	3.7	4.8	6.6	6.0
Total ammonia nitrogen / mg/L	2.2	1.8	2.4	2.7	2.5
Total dissolved solids, 103 – 105°C / mg/L	88.9	63.5	69.8	81.4	75.1
Total suspended solids, 103 – 105°C / mg/L	13.0	6.5	15.2	13.0	19.4
Turbidity / NTU	10.5	9.1	10.4	13.3	47.9
Dissolved oxygen, laboratory / mg/L	7.5	7.5	7.4	7.1	7.0
pH (laboratory)	7.0	7.0	7.3	7.3	7.7
pH (in situ)	7.85	-	7.6	-	7.6

Table 3 - Results of the physical-chemical analyses of water (station EMB2), June to November 2011

Station			**EMB2**		
Date of collection (day/month)	19/06	25/07	01/09	04/10	07/11
Water temperature (in situ) / °C	17.9	-	20.3	21.5	22.8
Electrical conductivity, μS/cm (in situ)	113.8	-	118.3	-	117.3
Electrical conductivity, 25°C / S/cm	118.0	106.8	121.6	136.4	123.0
Biochemical Oxygen Demand / mg/L	4.8	4.3	4.5	4.1	4.8
Total ammonia nitrogen / mg/L	1.5	2.6	2.6	3.1	2.5
Total dissolved solids, 103 – 105°C / mg/L	77.2	65.6	76.2	81.5	70.9
Total suspended solids, 103 – 105°C / mg/L	27.0	3.2	21.6	15.1	31.3
Turbidity / NTU	12.2	9.1	10.6	13.0	10.4
Dissolved oxygen, laboratory / mg/L	8.0	9.4	6.9	7.2	7.3
pH (laboratory)	7.4	7.0	7.2	7.4	8.0
pH (in situ)	8.13	-	7.7	-	7.55

Table 4 - Results of the physical-chemical analyses of water (station EMB3), June to November 2011

Station	EMB3				
Date of collection (day/month)	19/06	25/07	01/09	04/10	07/11
Water temperature (in situ) / °C	17.9	-	20.4	22.0	21.5
Electrical conductivity, μ S/cm (in situ)	109.8	-	119.8	-	104.0
Electrical conductivity, 25°C / S/cm	114.8	106.8	119.5	132.2	110.5
Biochemical Oxygen Demand / mg/L	5.3	2.9	3.2	7.7	4.7
Total ammonia nitrogen / mg/L	2.0	1.5	2.7	4.3	1.7
Total dissolved solids, 103 – 105°C / mg/L	77.2	64.5	75.1	74.0	62.4
Total suspended solids, 103 – 105°C / mg/L	32.4	6.5	23.8	24.8	8.6
Turbidity / NTU	25.6	7.9	12.6	23.6	13.1
Dissolved oxygen, laboratory / mg/L	7.7	7.8	6.3	6.1	9.7
pH (laboratory)	7.3	7.0	7.2	7.3	7.8
pH (in situ)	8.15	-	8.2	-	7.8

Table 5 - Results of the physical-chemical analyses of water (station EMB 4), June to November 2011

Station	EMB4				
Date of collection (day/month)	19/06	25/07	01/09	04/10	07/11
Water temperature (in situ) / °C	18.1	-	20.4	22.0	22.7
Electrical conductivity, μ S/cm (in situ)	105.4	-	117.1	-	113.5
Electrical conductivity, 25°C / S/cm	110.8	103.8	119.5	130.0	121.0
Biochemical Oxygen Demand / mg/L	4.0	4.7	4.6	5.5	5.2
Total ammonia nitrogen / mg/L	2.0	1.4	2.5	3.6	2.5
Total dissolved solids, 103 – 105°C / mg/L	63.5	63.5	81.4	67.7	59.2
Total suspended solids, 103 – 105°C / mg/L	48.6	13.0	37.8	38.9	17.3
Turbidity / NTU	20.6	10.5	28.1	22.9	17.5
Dissolved oxygen, laboratory / mg/L	7.7	7.3	6.7	6.5	6.4
pH (laboratory)	7.3	6.9	7.0	7.3	7.8
pH (in situ)	7.83	-	7.8	-	7.5

Table 6 - Results of the physical-chemical analyses of water (station EMB5), June to November 2011

Station	EMB5				
Date of collection (day/month)	19/06	25/07	01/09	04/10	07/11
Water temperature (in situ) / °C	18.1	-	20.7	21.0	21.8
Electrical conductivity, μ S/cm (in situ)	93.6	-	115.2	-	99.6
Electrical conductivity, 25°C / S/cm	99.2	101.6	119.5	126.9	107.0
Biochemical Oxygen Demand / mg/L	3.1	3.8	5.2	5.4	5.0
Total ammonia nitrogen / mg/L	2.1	1.4	2.4	3.8	1.3
Total dissolved solids, 103 – 105°C / mg/L	64.5	65.6	77.2	63.5	62.4
Total suspended solids, 103 – 105°C / mg/L	35.7	7.6	23.8	40.0	41.1
Turbidity / NTU	19.6	10.8	16.9	19.3	10.9
Dissolved oxygen, laboratory / mg/L	7.9	8.1	6.8	6.4	9.3
pH (laboratory)	7.3	7.0	7.1	7.3	7.7
pH (in situ)	7.9	-	7.7	-	7.7

The evaluation of water quality performed by the saprobic index ISMR [14] confirms that the biomonitoring stations downstream the Paciência SHP presents critical contents of organic load in the stations EMB1 to EMB4, with saprobic index very near to the ones found in EMB5, with high content of organic pollution. These data corroborate the physicochemical results found for water that also indicate a pronounced organic pollution in the studied stretch [15].

The results obtained for the benthic macro invertebrates of the stations EMB1 to EMB5 of the Paraibuna River show a community with much modified characteristics and a low taxonomic variety (Table 7). This situation is quite different from the characteristics normally found in pristine lotic environments, rich in taxons. In this way, the total abundance of the macro invertebrates in the stations was very high and varied between 1,276 (station EMB5) to 4,344 organism/m^2 in station EMB2. The dominant groups in the macro zoobenthic community were the chironomids, oligochaeta and hirundinea, in decreasing order of abundance.

Previous studies also done in the Paraibuna River, applying the same methodology, upstream Juiz de Fora – in a place called Chapéu D'Uvas (N7610636 - E654498) present different results when the composition of the macro invertebrates is analyzed [16]. Statistical results obtained with the density data of macro zoobenthic community found in the monitoring net show that there is a significant decrease [t (29) = - 1,89; P < 0,05] between the density average of the organisms in the Paraibuna River stations downstream the Paciência SHP caused by the bottom discharges (Figure 6). Two hypotheses were considered to explain this finding. The first is that the organisms were dragged downstream with the increase of the water velocity during the bottom discharge. The second is that with the increase in the quantity of solids flowing downstream due to bottom discharge the organisms could be missed, momentarily, their habitats. In face of this adverse condition, they buried themselves, how often can happen with the macroinvertebrates benthic fauna [17].

Table 8 presents the main groups found, whose composition is very different from those one expected in that scenario [14, 18].

Regarding the sediments deposited on artificial substrates, the results pointed to a high sedimentation considering all the studied period, mainly in the periods after bottom discharge: June/July and November (average values above 500 ml), when compared with results obtained by other measurements performed in different stretches of the Paraibuna River, where the same methodology was applied (Table 9).

Table 7 – Results of the benthic macro invertebrates analyses (organisms/m^2), from June to November - 2011.

Taxon	EMB1	EMB2	EMB3	EMB4	EMB5
Turbellaria	21.9	432.4	264.9	85.6	-
Dugesia tigrina	561.4	4131.3	853.2	1137.3	35.9
Nematoda	13.5	9.1	26.3	15.5	33.5
Hirudinea	155.9	322.5	187.5	650.3	256.3
Glossiphonidae	198.3	254.1	160.4	417.1	382.9
Placobdella sp.	50.0	1145.0	218.0	194.7	13.1
Helobdella stagnalis	60.7	40.0	61.1	178.1	749.8
Helobdella papilata	3.6	4.5	9.0	115.3	50.5
Helobdella triserialis	13.6	1.8	5.8	26.3	16.8
Helobdella maculata	0.9	2.7	2.7	1.8	-
Helobdella elongata	61.9	205.3	133.3	334.3	156.8
Helobdella lineata	25.1	165.9	39.6	235.2	252.2
Erpobdella punctata	1.8	12.6	0.9	31.6	0.9
Oligochaeta	2574.8	3169.2	1670.4	3995.7	3275.2
Tubificinae (juvenil)	17.6	10.3	11.0	34.2	6.7
Allonais chelata	1.8	-	-	3.6	-
Alonais inaequalis	6.3	-	-	4.5	-

Bothrioneurum sp.	4.6	1.0	-	2.8	1.0
Limnodrilus hoffmeisteri	11.0	5.6	7.3	16.4	5.7
Dero raviensis	0.9	-	-	-	-
Branchiura sowerby	-	-	-	0.9	-
Pristina americana	-	-	-	1.9	2.9
Physidae	0.9	0.9	0.9		
Physa sp.	276.5	3574.6	374.0	603.2	65.2
Sphaeriidae	-	0.9	-	9.3	-
Melanoides sp.	-	-	-	0.9	-
Chironomidae	3241.8	6613.4	4194.8	4385.2	1069.2
Ceratopogonidae	0.9	-	0.9	-	-
Syrphidae	-	5.4	1.8	-	-
Empidoidea	-	0.9	-	-	0.9
Smicridea sp.	89.4	1606.3	291.7	324.7	3.6
Zumatrichia sp.	0.9	-	-	-	-
Libellulidae		-	-	0.9	0.9
Elasmothemis sp.	1.8	-	-	-	-
Gomphidae	-	-		-	-
Progomphus sp.	-	-	1.0	-	-
Coleoptera		-	-		-
Elmidae	1.0	-	-	-	-
Gyrinidae	-	-	-	0.9	-
Megaloptera	-		-	-	-
Corydalidae	-		-	-	-
Corydalus sp.	-	0.9	-	-	-
Total - organisms/m²	7398.9	21716.6	8516.4	12808.1	6380.0

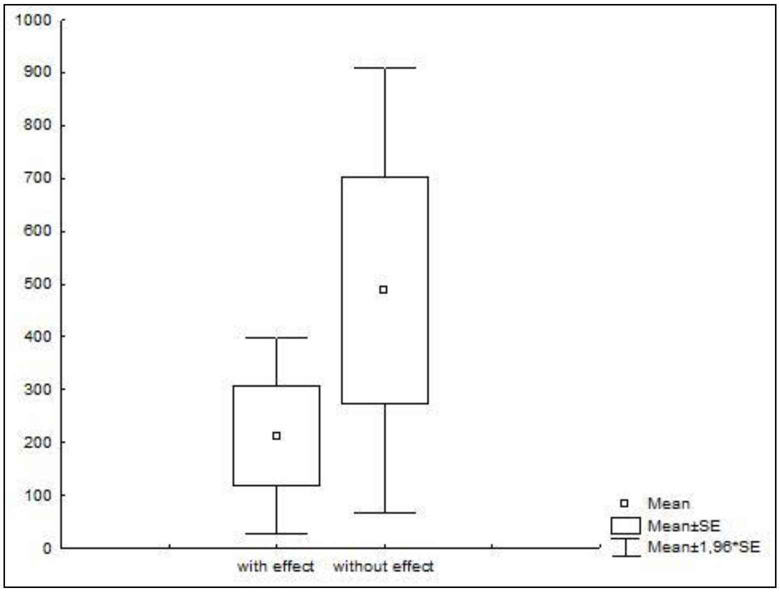

Figure 6 - Result of the test t of student ($t_{(29)} = -1.89$; $P < 0.05$) for comparison of density averages of macroinvertebrates with and without effect of bottom discharge

Table 8 – Composition of the macroinvertebrates found in the stations studied in the Paraibuna River downstream (2011) and upstream (2006) Juiz de Fora municipality.

Macroinvertebrates	2006 percentual composition (%) Chapéu D`Uvas	2011 percentual composition (%) Paciência SHP
Diptera	17	31.70
Ephemeroptera	13	-
Gastropoda	13	8.10
Trichoptera	9	3.40
Odonata	9	-
Hirudinea	9	14.30
Oligochaeta	1.3	28.20
Turbellaria	4.3	12.40
Coleoptera	4.3	-
Megaloptera	4.3	-
Plecoptera	4.3	-
Heteroptera	4.3	-
Hidracarina	4.2	-
Others	-	1.90

Analyzing the ecomorphological quality of the sampling stations, and considering the five sampling stations, the results indicated good quality for four stations, and regular for only one station, what means that the ecophysical conditions of the majority of the aquatic environments studied are still preserved.

Table 9 – Amount of mineral and organic sediment (ml) deposited in the artificial substrates in the stations of the biomonitoring net of the Paraibuna River – June to November (2011).

Date	**June**		**July**		**September**		**October**		**November**		Total average
Duration (days)	505		38		38		34		35		
Sampling unit	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	
EMB1	310	106	339	206	66	86	138	48	414	379	253
EMB2	611	119	158	106	359	126	193	126	*	*	330
EMB3	816	345	539	287	386	48	414	83	828	298	597
EMB4	321	321	910	83	579	166	745	143	359	48	583
EMB5	*	*	735	225	386	96	828	82	524	291	618
Total	515	89	536	71	355	18	463	34	605	251	

*Loss of sampler
SD = Standard Deviation

The results of the transport of fine sediment in suspension downstream the dam obtained in August and October of 2012 - the first under normal operation and the second in situation of bottom discharge of the SHP gave similar results. This is explained by the fact that the hydraulic conditions of the Paraibuna River have remained stable over the period. Table 10 shows the flow values measured with the fluorescent tracer Rhodamine WT, released during the experiments, using the methodology of Zuber [13]. These techniques have been used by the authors in other experiments with good results [19-22].

Table 10 - Paraibuna River flow rate Q (m^3/s) downstream Paciência SHP

Section/Day	08/21/2012	08/22/2012	10/24/2012	10/25/2012
EMB1	x	X	6.6	x
EMB2	6.7	6.1	X	6.1
EMB4	7.6	7.0	7.3	6.2

Figures 7 and 8 are examples of the results obtained in the field campaigns. It presents the data measured in two sections and the modeled results for the section downstream.

Tables 11 and 12 present the results for v and D for all the experiments performed in the field works.
Comparing the areas under the transit curves of the sediment clouds between successive stations, it was possible to calculate the amount of sediment that was trapped between the stations, either by sedimentation/decantation or for becoming temporarily trapped in the dead zones of the river. For the hydrodynamic conditions of the experiments conducted in August and October 2012 this retention varied between 8.7 and 35.2%. It was observed a tendency of higher retention for lower river flow rates.

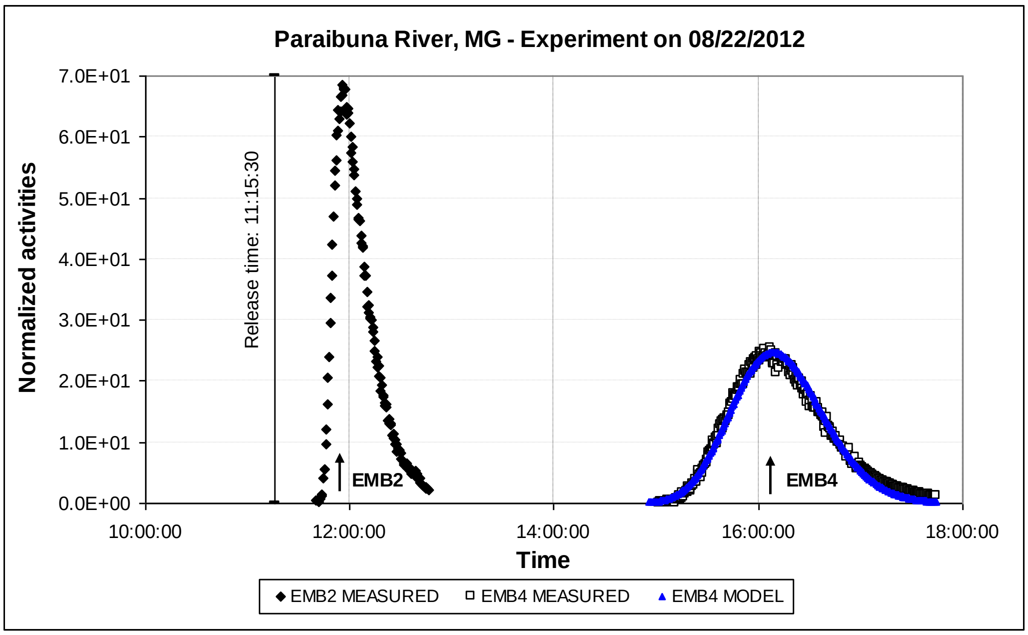

Figure 7- Transit curves (measured and modelled) of the sediment labelled with ^{99m}Tc in the stations EMB2 and EMB4, in the Paraibuna River, on 08/22/2012

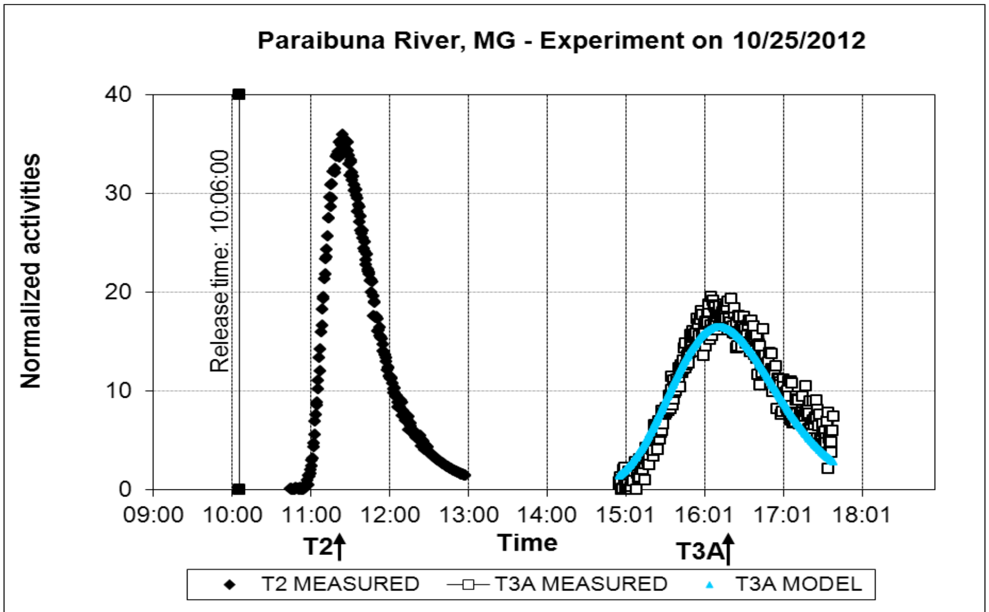

Figure 8- Transit curves (measured and modelled) of the sediment labelled with ^{99m}Tc in the stations EMB2 and EMB3, in the Paraibuna River, on 10/25/2012

Table 11 - Values of advection velocity (v) and dispersion coefficient (D) Experiments of August 2012

Stretch/Day	08/21/2012	08/22/2012	08/23/2012
EMB2 – EMB4	v = 0.39 m/s D = 9.40 m^2/s	v = 0.38 m/s D = 9.85 m^2/s	v = 0.38 m/s D = 9.00 m^2/s

Table 12 - Values of advection velocity (v) and dispersion coefficient (D) Experiments of October 2012

Stretch/Day	10/24/2012	10/25/2012
Power house – EMB1	v = 0.21 m/s D = 5.7 m^2/s	--
EMB1 – EMB4	v = 0.36 m/s D = 13.3 m^2/s	--
Power house – EMB2	--	v = 0.33 m/s D = 5.7 m^2/s
EMB2 – EMB4	--	v = 0.33 m/s D = 13.0 m^2/s

The same mathematical model, calibrated with the results of the tracer experiments, was applied to simulate the propagation of a bottom discharge and to estimate the attenuation of the concentration of fine sediment in suspension, originated from it, in a stretch of 34 km downstream the Paciência SHP, taking into account the dilution promoted in the Paraibuna River waters by some tributaries (Peixe River and Preto River). The simulation was performed for a period of 6 days, comprising 4.5 days of the bottom discharge (Fig. 9). It is done slowly since the dissolved oxygen of water, downstream the SHP, should not become smaller than 3, which could compromise the aquatic biota. Minimum measured values of advection velocity, dispersion coefficient, flow rate and dilution were used in this simulation, maximizing the environmental impact of the bottom discharge. This implies in the permanence of a higher concentration of sediment in suspension and a higher residence time of the sediment cloud in the considered stretch.

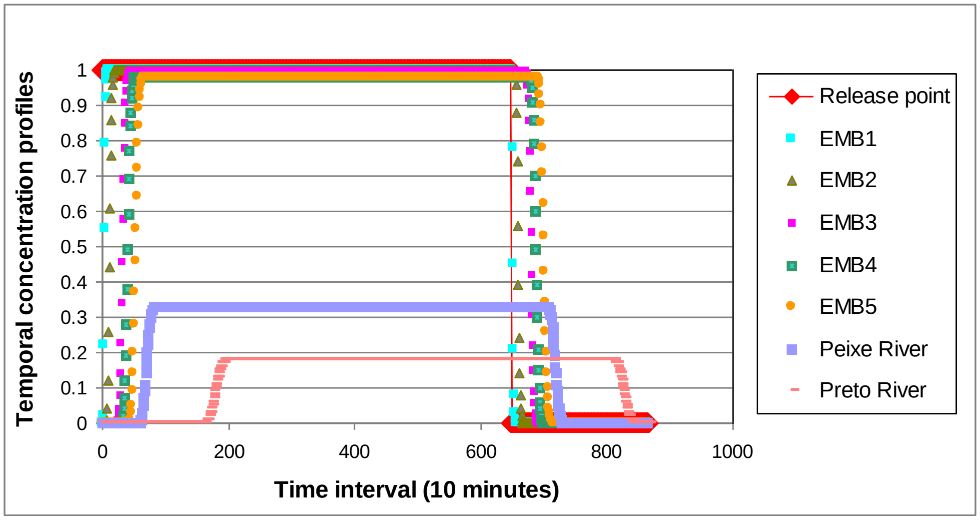

Figure 9 - Temporal representation of the concentration of sediment in suspension due to bottom discharge lasting 4.5 days, considering a unitary concentration in the release point

Conclusions

The experiments performed, labeling the fine sediment with technetium (^{99m}Tc), radioactive tracer widely used in nuclear medicine, allowed to quantify its transport in suspension along the studied stretch of about 7 km, from Paciência SHP to the station EMB4 (Fig. 2). This was done by determining the parameters of advection, longitudinal dispersion coefficient, sedimentation rate and river flow rate. With these results and using the minimum flow rates observed in the tributaries of the Paraibuna River, downstream of the studied stretch, it was possible to simulate, employing a mathematical model calibrated with tracer studies, the attenuation of the concentration of fine sediment in suspension, arising from a bottom discharge, in the Paciência SHP, up to the mouth of Preto river, about 34 km downstream of the SHP. The simulation of propagation of the suspended sediment concentration originating from bottom discharge in dry season, the most critical, showed that it decreased to a value of about 18% of the initial value of the bottom discharge, near the mouth of Preto River. This information can be used by CEMIG as a tool in the management of bottom discharge, associated with the currently employed controls, based on the level of DO, which must be smaller than three.

The macrozoobenthic community found in biomonitoring network stations reflected the conditions of water quality in this stretch of Paraibuna River: very poor in taxonomic variety and having excessive densities of very few resistant taxonomic groups, that is characteristic of aquatic environments with high levels of organic load.

It was observed a large sediment deposition on artificial substrates of the studied stretch of Paraibuna River, during the entire period studied, regardless of bottom discharge.

The bottom discharge of the Paciência SHP led to a significant reduction in density of macroinvertebrates found, but this fauna is recovered during periods of normal operation of the plant.

The results obtained with this research project are a contribution for the set-up of a basic methodology for bottom discharges of SHP to be applied, with adaptations for each studied case. They meet to answer the procedures established by CONAMA Resolution 344/2004 regarding the characterization of the material to be dredged and dumped in Brazilian waters. Furthermore, the methodology investigated in this project encompassed, simultaneously and realistically, the physical and biological aspects of the environmental impact of the sediment dredged inside reservoirs and dumped in the watercourses downstream, and could contribute to the improvement of national legislation.

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