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RIVER WATER QUALITY STUDIES BY USING RADIOACTIVE TRACERS. A PRACTICAL CASE

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This works presents an analysis of the self purification behavior of the High Middle Tietê river in relation to several effluents flows of the Rasgão Reservoir and several BOD and OD levels. The water transit time the flows measurement performed and the longitudinal dispersion coefficient are important parameters evaluated by the use of tracers technique. Between 1982 and 1984 five campaigns of transit time and water quality measurements of the river were made. In these campaigns, a radioactive tracer produced by IPEN was injected into the river by CETESB's technicians downstream of the Rasgão water reservoir. The works were performed in steady state conditions. The behaviour of the "radioactive cloud" was evaluated along a 266 km sector of the Middle High Tietê river. Flows varied from 1.1 to 350 m^3/s.

1. INTRODUCTION

The metropolitan region of São Paulo, including 38 cities, is one of the largest industrial centers in Latin America. The region is almost completely crossed by the Tietê river, the main receiver of liquid waste generated in the city. Most of such wastes are discharged into the river without treatment which results in serious pollution problems. An important part of the research of the pollution of water bodies receiring domestic and industrial effuents is related to the knowledge of pollution changes.

During the last years, the Environmental Sanitation Technology Company – CETESB, a governmental institution responsible for the pollution control and development of environmental technologies in the São Paulo state, has been developing and applying a technology using radioactive tracers for measuring some hydraulic parameters of rivers. The application of the "Interior Water Qualities Program" requires the measuring of flows, transit times and dispersion coefficients.

The radioactive tracer technique proved to be a reliable tool in such kinds of hydraulic measurements. Many water quality models could be checked with data obtained from measuring compaigns and the understanding of the system is improved when the selfpurification process of the river is followed step by step.

The radioactive material employed by CETESB was produced at the Nuclear Energy Research Institute, IPEN–CNEN/SP. This material was prepared for measurements at CETESB's laboratory.

Taking into consideration the importance of this river for the control of pollution within the São Paulo state, a further study will be necessary.

2. RADIOTRACER TECHNIQUES

The water transit time is the elapsed time from injection to passage of the gravity center of the tracer cloud through a chosen cross section of the river. The CETESB used the ^{82}Br tracer, in the chemical form of KBr, with a half–live of 35.4 h. The KBr was irradiated in the nuclear research reactor of IPEN–CNEN/SP and dissolved in an aqueous sodium–thiosulfate solution. The detection system was composed of two or more control stations. In each place there was a scintillation probe, with a 2" x 2" crystal, coupled to a scaler type BASC III.

The dispersion coefficient was determined using Godtrey & Frederick's formula [1]. The water flow was determined using the dilution method. The activity used in these applications was about 5–100 GBq and it was estimated using the empirical formula [1]:

$$A = \frac{K.Q.N}{\eta.\varepsilon}$$

where

Q – flow, L/s,

N – expected count rate,

η – detector efficiency,

ε – geometry factor,

A – activity, GBq,

K – constant

3. HYDRAULIC MEASURING OF THE "MIDDLE HIGH TIETÊ RIVER"

The "Middle High Tietê River" is known as the extension of the Tietê River located between the Metropolitan Region of São Paulo city and the Barra Bonita Reservoir. In fact, this study covers the Tietê River from the Rasgão Reservoir up to the Conchas/Anhumas road bridge, located at the upstream Barra Bonita Reservoir. This means 266 km fully checked in five campaigns of transit time measurement employing radioactive tracers. Figure 1 shows the transit time vs. to the distance covered from the Rasgão Reservoir onwards in the five compaigns accomplished.

Considering that the pollution of the Middle High Tietê River is mainly due to organic materials, only the data on dissolved oxygen and oxygen demand were analyzed. Dissolved oxygen curves obtained during the five campaigns

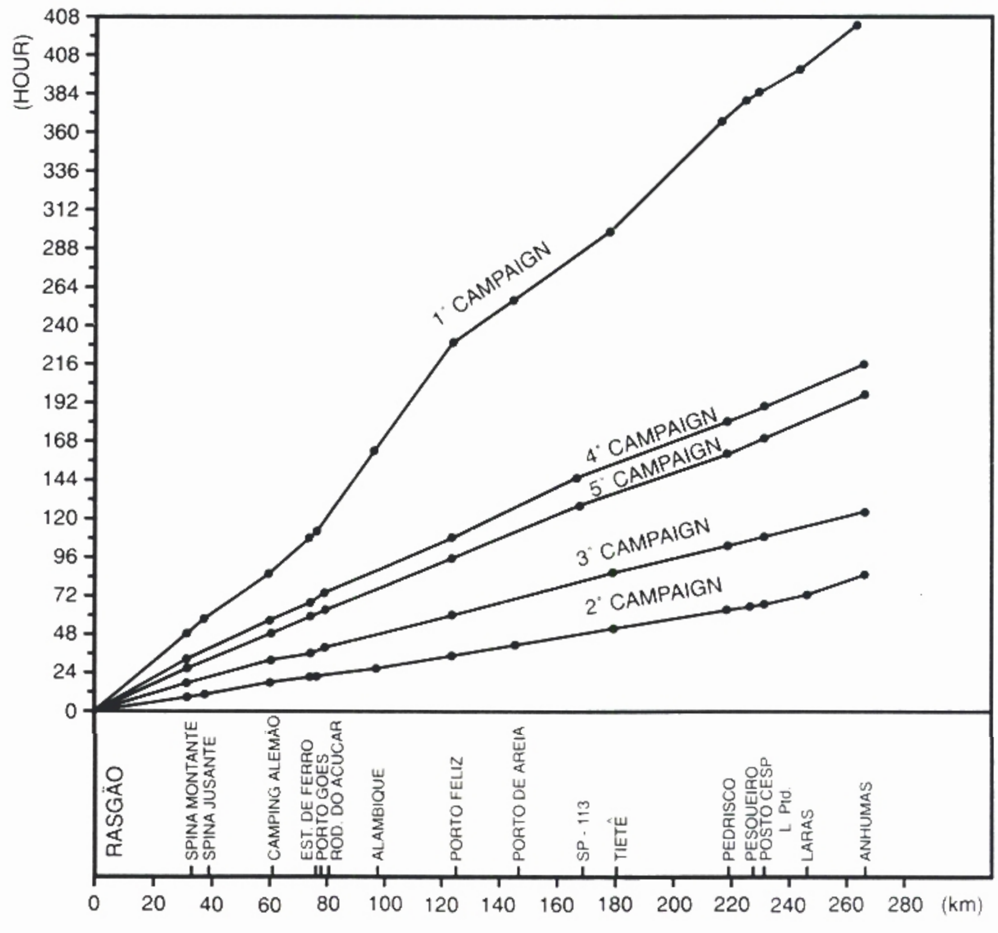

Fig. 1. Transit time vs distance covered in the campaigns

emploigns radioactive tracers are shown in Figure 2. Figure 3 shows BOD values along the Middle High Tietê River during the five campaigns.

Longitudinal dispersion coefficients between the origin and each detection point, as well as the flow at a determined cross section, may be estimated from the radiotracer concentration distribution at selected cross sections along the Middle High Tietê River. Such values will be presented further.

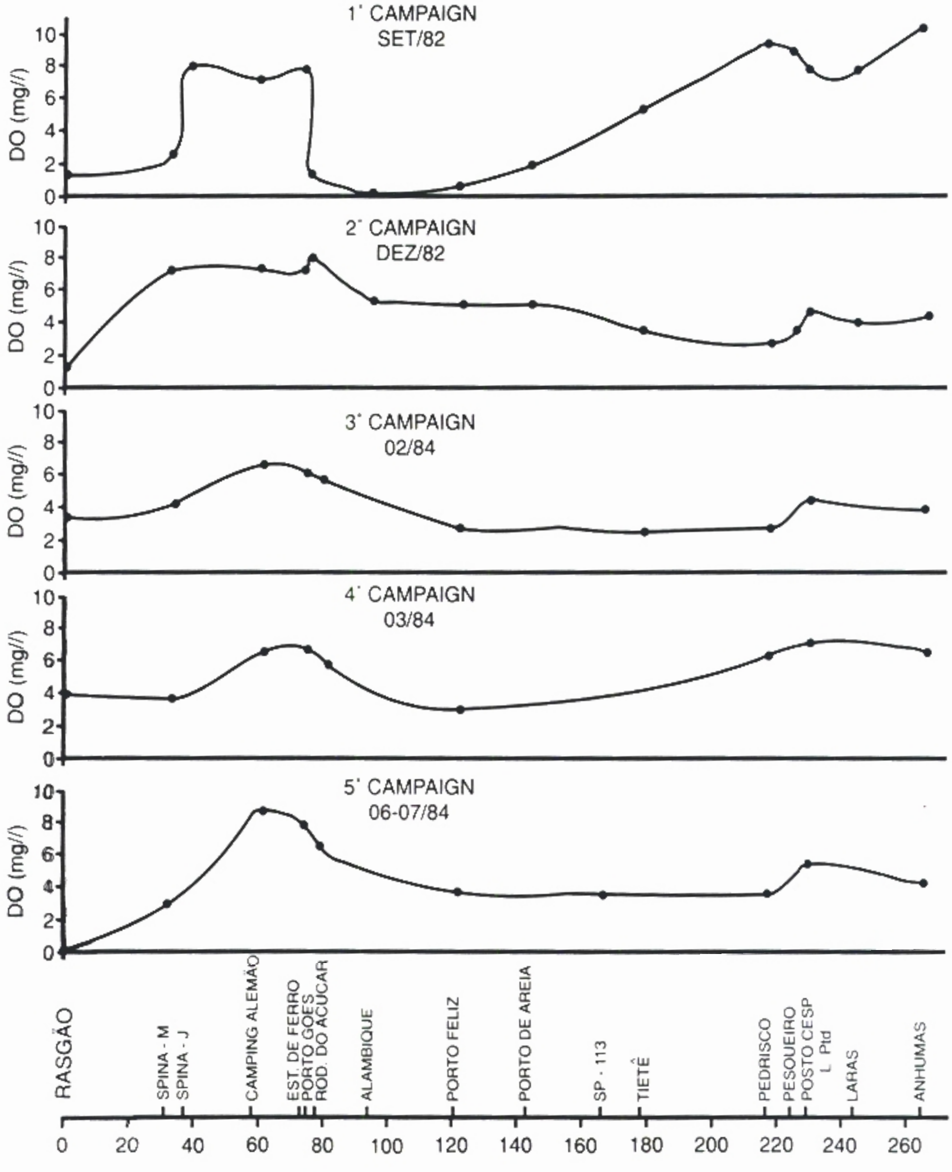

Fig. 2. DO in the Middle High Tieté river for the five campaigns

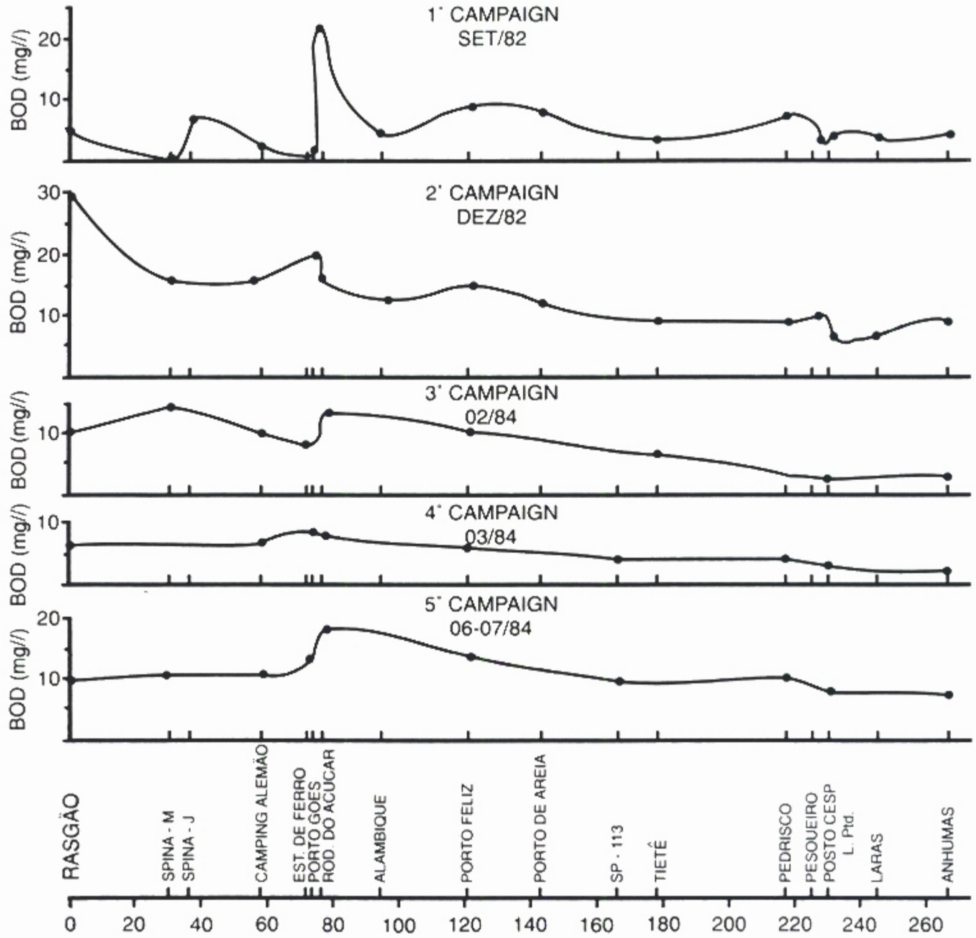

Fig. 3. BOD in the Middle High Tieté Médio river for the five campaigns

Bathymetry determination was also carried out in 133 cross sections. All the information obtained is very important for fitting a "Model". The knowledge of existent marshes, rapids and waterfalls will allow us to get some additional information not supplied by the sample analysis.

4. SURFACE AND RIVER–BED SIDE MORPHOLOGY

The use of a water quality model perfectly simulating the selfpurification conditions of a river, requires good knowledge of its hydraulic and hydrologic characteristics, as well as its morphology.

Morphological peculiarities such as waterfalls, rapids, high turbulence regions, swampy fields, islands, and so on, are to be taken into consideration.

In order to locate, photograph and evaluate the characteristics of each morphological peculiarity, some exploration journeys were made along the Middle High Tietê River.

Although it is a well known area, the first sector, which is between the Rasgão Reservoir and the Hydroelectric Power station of Porto Góes, was not studied.

The next sector from the Hydroelectic Power Station of Porto Góes to Tietê city, was studied on September 7, 1985. Along this sector, of approximately 105 km, 59 rapids were found. It also provided more than one hundred data about the river bed. Main references such as large rapids, bridges or islands were pictured. For flows of about 100 m^3/s, this sector works as an important aerator. For flows smaller than 40 m^3/s, the critical area of dissolved oxygen is in this area.

The following sector of about 100 km, extending from Tietê city to the Barra Bonita Reservoir, shows at the water level cluring the measurements only 16 rapids. Contrary to the previous, this sector works as a selfpurification reservoir.

The information obtained along the Middle High Tietê River refers to the conditions prevailing on the sampling days. A higher level could make some of the 65 rapids found between the Hydroelectric Power Station of Porto Góes and the Barra Bonita Reservoir disappear. On the other hand, a lower level should show a greater number of rapids, due to tens of the turbulent areas surveyed. Such areas are regions with stones emerging from the watercourse, reaching almost the water surface. Many places showed stones covered by only few centimeters of water.

Out of the 266 km of the Middle High Tietê River, about 200 km were already surveyed.

These two sectors were chosen for the first phase of observation since they allow to verify selfpuri phenomena, which are those less studies for the time being.

Information about rapids, waterfalls and other morphological accidents do not make part of this paper as its purpose is the development of water quality for 5 scenarios of flow.

5. ANALYSIS OF MEASURED PARAMETERS

First campaign (flow of 1.1 m^3/s, September 13 to October 2, 1982). The analysis of the first campaign curve, where the initial flow of the Rasgão dam was 1.1 m^3/s, allows us to observe that the dissolved oxygen increases considerably, reaching almost saturation level at the Camping do Alemão site. The sampling at the Spina Montante was carried out inadequately. Samples were taken on the left side of the river, near the Spina factory water intake, and consequently this value was low. The Camping do Alemão site value must be taken into consideration due to its high value, even though the sampling was made beyond the radioactive cloud. The Jundiai river entrance, with a flow equivalent to Tietê's, caused a decrease of DO to more than 1 mg/l. With BOD higher than 40 mg/l. The Jundial river causes that the Tietê river has a critical point in relation to oxygen between Destilaria and Porto Feliz city. After Porto Feliz, the Tietê river shows noticeable oxygenation due to small waterfalls and rapids in the sector. With the Capivari and Sorocaba river inlet, the Tietê river assumes values near to saturation as far as the Barra Bonita Reservoir [1].

Second Campaign (flow of 350 m^3/s, December 15 to 19, 1982). With an anitial flow of 350 m^3/s and a low level of dissolved oxygen, the Tietê river experiences high oxygenation until almost saturation at the Camping do Alemão site. The influence of the Jundiai river as a whole is very small. The BOD of the Rasgão Reservoir is still responsible for the DO reduction in the region between the Rasgão Reservoir and Tietê city. The Capivari and Sorocaba rivers junction into the Tietê, improves it a little, although that is immediately neutralized by the high BOD from the Rasgão Reservoir. For high values, around 350 m^3/s the critical point in relation to dissolved oxygen is between Tietê city and the Capivari river mouth. The Pedrisco's Sand Harbour has been rougly considered the critical point of this flow [2].

Third Campaign (flow of 86 m^3/s, February 14 to 18, 1984). As it happened in the last two campaigns, there is a complete oxygenation of the river between the Rasgão Reservoir Dam and the Camping do Alemão. For a flow value of 86 m^3s at Rasgão, the influence of the Jundiai river becomes very significant since its flow amounts to 20% of the total flow, even though the BOD is elevated. The transit time for such flow values is still quite short, therefore there exists high residual BOD, originated from the Rasgão Reservoir at Porto Gões. So the critical region in relation to the dissolved oxygen, was not well defined, with values approximately equivalent to those from Porto Feliz city to the Pedrisco's Sand Harbour. The Sorocaba and Capivari junctions into the Tietê, with high dissolved oxygen values, merely improved the Tietê river. A small reduction of DO was noticed, which still indicates high BOD values present at the Pedrisco's Sand Harbour [3].

Fourth Campaign (flow of 39 m^3/s, March 20 to 29, 1984). With initial values of dissolved oxygen of 4.3 mg/l and relatively low concentrations of BOD, the first sector was responsible for the increase of DO, keeping BOD almost stable. With a flow equivalent to that of the Tietê river, the Jundiai river added its flow, maintaining the BOD concentration almost constant. The sampling error of the transit time measurement during the campaign prevents us categorically from affirming that the critical point is between Porto Feliz city and the Tietê city, however this is what Fig. 2 shows. The high transit time indicates that water at Laranjal

Paulista was quite purified. By receiving DO rich waters from the Sorocaba river, and probably from the Capivari river, the Tieté river reaches Anhumas, at the beginning of the Barra Bonita Reservoir, with a high level of DO. Unfortunately, and contrary to other campaigns, this time no samples were collected from main effluents as done before [4].

Fifth Campaign (flow of 47 m^3/s, June 26 to July 4, 1984). Starting with anaerobic conditions at the Rasgão Reservoir Dam, the Tietê River water reached Camping do Alemão with 88% saturation. This campaign showed clearly that independently of DO and BOD starting conditions at Rasgão, the dissolved oxygen level at Camping do Alemão would be quite higher. From Salto, with calm waters, and with addition of the liquid mass of the Jundiai river, the resulting BOD diminished the dissolved oxygen considerably. In this case, observing the DO curve, it can be noticed that the critical region is downstream Tietê city. To determine a critical zone, it is recommended to take intermediate samples at Porto Feliz city, Tietê city and the Pedrico's Sand Harbour in the next campaigns with radioactive tracers. The larger concentrations of dissolved oxygen in the Capivari and Sorocaba rivers improved the sanitary conditions of the Tietê river, before its entrance to the Barra Bonita Reservoir [5].

6. CONCLUSIONS

The analysis of the first section between the Rasgão Reservoir dam and Spina factory allows us to conclude that there is a flow value of about 40 m^3/s that represents the limit to which the dissolved oxygen recovery is quite deficient. For lower values, there is a more accentuated recovery due to the high transit time, even with the high BOD originating from Rasgão. For higher values, the turbulence in the sector controls the dissolved oxygen recovery. The fourth campaign of transit time measuring, allowed us to prove such deficient recovery when Rasgão's flow reached 38 m^3/s and dissolved oxygen diminished from Rasgão to the Spina factory.

The 60 km sector from the Rasgão Reservoir to Camping do Alemão will be studied together with the first sector. The results of the five campaigns carried out with radioactive tracers are as follows.

Whatever may be the initial flow value, BOD or DO in the Rasgão Reservoir outlet, the dissolved oxygen grows, reaching almost saturation at Camping do Alemão. The flows during the five campaigns varied from 1 to 350 m^3/s while the DO varied from 0 to 4,3 mg/l and the BOD from 4 to 13 mg/l, showing an abnormal result of 74 mg/l. In short, no matter what may be the data of the exit at Rasgão, the DO practically reaches saturation at Camping do Alemão, attaining its minimal level at Spina factory whenever the flow is near the limit of 40 m^3/s.

After Camping do Alemão, there is a short sector to the Porto Góes Hydroelectric Power Station, wherein there are two small reservoirs as well as the Jundiai river inlet. This is quite a turbulent sector too. The initial conditions of this sector exit are strongly influenced by the Jundiai river, mainly for flows lower than 100 m^3/s.

The following sector, from the Porto Góes Hydroelectric Power Plant Reservoir dam to the CESP station, bridge at Laranjal Paulista, is the real Middle High Tietê River Reservoir of selfpurification.

What ever may be the flow of the river, the critical point for dissolved oxygen will be found between Porto Feliz city and Laranjal Paulista city.

At Rasgão, for flows of 350 m^3/s, the critical point practically coincides with the Capivari and Sorocaba river inlets. When the flow decreases, the critical point displaces toward the upstream. For a flow of 1,1 m^3/s at Rasgão, the critical point reaches Destilaria, at Porto Feliz city.

For very high flows, around 350 m^3/s, and a very short transit time, there is no great influence of the sector between Camping do Alemão and Porto Góes, although there are two small reservoirs and the inlet of the Jundiai river. The turbulence in this case is very high due to the rocky bed of almost all the Middle High Tietê river, keeping always the DO values high.

The presence of the Capivari and Sorocaba rivers at about 40 km from the Barra Bonita Reservoir inlet provides an additional oxygenation by dilution of at least 4 mg/l in each of the five campaigns.

Next campaigns for the transit time determination will require a better determination of the dissolved oxygen concentration in the critical area. This may be achieved by creating new sampling points between the Porto Góes dam and the CESP station bridge at Laranjal Paulista, an area which has not yet been examined.

Since celerity might lead us to misconsider studies of displacement the water mass the evaluation of transit time required the use of radioactive tracers, which proved to be useful and efficient tools for these hydraulic parameters.

Celerity is responsible for wave evolution, producing a level increase, without any correspondence with the flow or even the displacement of the gravity center of the radiotracer cloud.

The velocity measured by dicplacement of the radioactive cloud proved to be an interesting parameter for sanitary engineers as it defines the movement conditions in the selfpurification process of a river.

The difference between mass velocity and wave celerity has been distinctly shown in many studies. In some cases celerity was five times higher than mass velocity.

7. REFERENCE

1. Albuquerque A. M. & Radioisotopes Appl. Div. Technicians. Tempo de transito e qualidade das āguas dos sistemas Alto Tieté/Zona Metropolitana e Médio Tieté Superior em época de estiagem. Relatório CETESB. Setembro/Outubro 1982.
2. Albuquerque A. M. & Radioisotopes Appl. Div. Technicians. Tempo de Trânsito e qualidade das āguas do rio Tieté Médio Superior em periodo chuvoso – segunda campanha. Relatiorio CETESB. Dezembro. 1982.
3. Albuquerque A. M. & Radioisotopes Appl. Div. Technicians. Tempo de trânsito e qualidade das āguas do rio Tieté Médio Superior terceira campanha. Relatiorio CETESB. Fevereiro. 1984.
4. Albuquerque A. M. & Radioisotopes Appl. Div. Technicians. Tempo de trânsito e qualidade das āguas do rio Tieté Médio Superior quarta campanha. Relatorio CETESB. Março 1984.
5. Albuquerque A. M. & Radioisotopes Appl. Div. Technicians. Tempo de trânsito e qualidade das āguas do rio Tieté Médio Superior quinta campanha. Relatorio CETESB. Junho/julho 1984.

BADANIA JAKOŚCI WODY ZA POMOCĄ WSKAŹNIKÓW PROMIENIOTWÓRCZYCH

Streszczenie

W pracy przedstawiono analizę samooczyszczania rzeki Tiete w jej środkowo–górnym biegu w odniesieniu do kilku przepływów ścieków ze zbiornika Rasgao o różnych poziomach BZT i tlenu rozpuszczonego.

Wykonane pomiary czasu przejścia wody dla różnych przepływów i współczynniki wzdłużnej dyspersji stanowią ważne parametry uzyskane za pomocą techniki znaczników promieniotwórczych. W latach 1982–84 przeprowadzono pięć kampanii pomiarów czasu przejścia i jakości wody w rzece. W tych kampaniach użyto wskaźnik promieniotwórczy, wyprodukowany w IPEN, który technicy CETESB wprowadzili do rzeki poniżej zbiornika Rasgao. Prace wykonano w warunkach stacjonarnych. Badano zachowanie się „radioaktywnej chmury" wzdłuż 266 km odcinka środkowo–górnego biegu rzeki Tiete. Przepływy zmieniały się w granicach od 1.1 do 350 m^3/s.

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ИССЛЕДОВАНИЯ КАЧЕСТВА ВОДЫ С ПОМОЩЬЮ РАДИОАКТИВНЫХ ИНДИКАТОРОВ

Резюме

В работе представлен анализ процесса самоочищения реки Тете на отрезке ее средне-верхнего течения по отношению к нескольким течениям сточных вод из водного резервуара Расгао, имеющим различные уровни БПК и растворенного кислорода. Важными параметрами полученными в результате проведенных с помощью техники радиоактивных индикаторов измерений являются продолжительность прохождения воды для различных течений и коэффициенты продольной дисперсии. На протяжении 1982-84 годов было проведено пять кампаний по измерениям продолжительности течения и качества воды в реке. Для измерений применялся радиоактивный индикатор, разработанный в IPEN, который вводился сотрудниками CETESB в реку ниже водного резервуара Расгао. Работы проводились в стационарных условиях. Исследовалось поведение „радиоактивного облака" вдоль отрезка протяженностью 266 км в районе средне-верхнего течения реки Тете. Скорости течения менялись в пределах от 1.1 до 350 нм^3/сек.