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Application of computer software to determine water bodies assimilative capacity in effluent wastewater disposal

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Abstract

This paper presents the application of computer software to determine the assimilative capacity of water bodies, in relation to the disposal of domestic and industrial effluents. The software WASP - Water Simulation Program, CORMIX and QUALBAVI are used to determine the assimilative capacity of the Marinho estuary, Vitoria Bay and Camburi Canal considering the parameters BOD, DO, fecal Coliform, Nitrogen and Phosphorous. The assimilative capacity knowledge of these water bodies helped to define the best location for sewage treatment plants to be built in the Great Vitoria Region.

1 Introduction

The concept of assimilative capacity had its origination in the aquatic environment to the disposal of domestic and industrial effluents. Cairns [1] was the first to utilize this concept defining it as the ability of the water body to accept certain levels of pollution, without suffering any significant adverse biological effect. In practice this means building cost reduction for the domestic and industrial wastewater treatment plants.

The effluent constituents when in the water presence suffer chemical, biological and physical transformations. This work considers the physical constituent dilution and decay.

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There is no defined methodology to determine the water bodies assimilative capacity. The aim of this work is to present computer software utilization as a possible methodology.

To illustrate the software application this work studied the assimilative capacity of the Marinho estuary, Vitoria Bay and Camburi Canal, shown in Figure 1. These water bodies are in the Great Vitoria Region having 1.200.000 people, located in the State of Espirito Santo in Brasil. All domestic and industrial effluents from this area are discharged in these water bodies contaminating their waters and putting in risk the people's health. To solve this problem the local government is building a complete sewage treatment system for the region through the program called " PRODESPOL" amounting three hundred million US dollars financed by the World Bank. A paramount problem in this program is the local choice for three sewage treatment plants to be built Figure 1.

This paper starts with this introduction. Next it considers a short description of the used software including the basic theory. In continuity, it is made the software application for Marinho estuary, Vitoria Bay and Camburi Canal. Finally, it is presented the main conclusions.

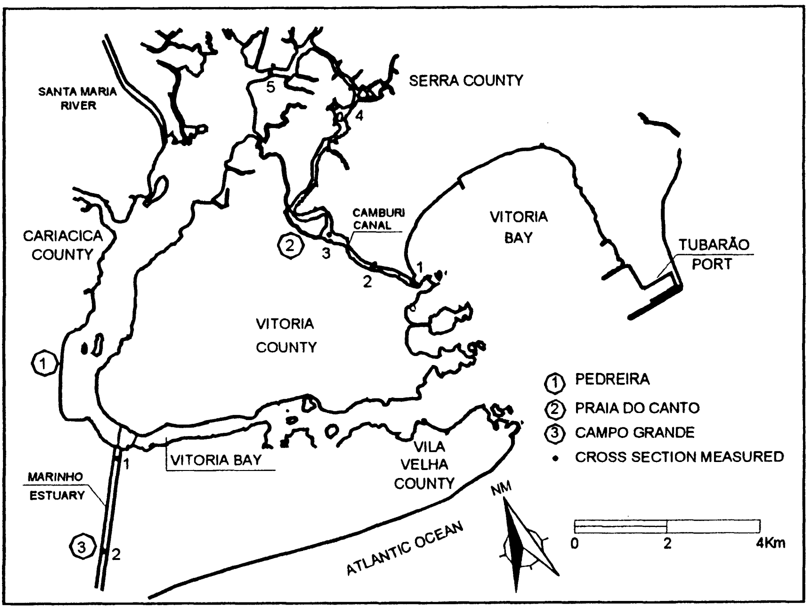

Figure 1: Marinho Estuary, Vitoria Bay, Camburi Canal and Wastewater Treatment Plants 1, 2 and 3.

2 The Software

2.1 WASP

The WASP - Water Quality Analysis Simulation Program was developed by Di Toro et al[2]., Connolly and Winfield[3], Ambrose, R. B. et al[4]. The model interprets and predicts water quality responses to natural phenomena and man - made pollution for several pollution management decisions. Also, WASP permits working with one, two, and three-dimensional models among others characteristics. The system consists of the software, DYNHYD, EUTRO and TOXI. The first one simulates the movement of water while the others simulate the movement and interaction of pollutants within the water. The mass balance equation for WASP, in one-dimensional form, is:

$$\vartheta(A.C)/\vartheta t = \vartheta\,(-U_x.A\,C)/\vartheta x + E_x.A.\vartheta C/\vartheta x)/\vartheta x) + A\,(S_L + S_B) + A.S_K \quad (1)$$

in which C = concentration of the water quality constituent; mg/l or g/m^3; t = time, days; U_x = longitudinal velocity, m/day; E_x = longitudinal diffusion coefficient obtained from Bella and Grenney[5] m^2/day; S_L = direct and diffusive loading rate, g/m^3 - day; S_B = boundary loading rate, g/m^3 - day; S_K = total kinetic transformation rate (source or sink), g/m^3 - day and A = cross - sectional area, m^2.

The model network is a set of expanded control volumes, or segments that together represent the physical configuration of the water body.

2.2 CORMIX

A series of models that uses length scales are the Cornell Mixing Zone Expert Systems[6], or CORMIX. The length scales describe the relative importance of discharge momentum flux, buoyancy flux, ambient cross flow and density stratification in controlling flow behavior. Examples of length scales are: jet to plume transition length scale = $M/J^{2/3}$; jet to cross flow length scale = M/u_a^2; jet/stratification length scale = $M^{1/3}/\varepsilon^{1/3}$; plume/stratification length scale = $J^{1/3}/\varepsilon^{1/2}$ and crossflow /stratification length scale = $u_a/\varepsilon^{1/2}$. In these relations M is the momentum flux, J is the buoyancy, u_a is the environment cross flow current and ε is the stratification.

CORMIX2, can computes the dilution and plume formation for three diffuser types. In this work it is used to study assimilative capacity of

Vitoria Bay considering the effluent from the wastewater treatment plant named Pedreira.
The software CORMIX does not allow obtain DO. To solve the problem it is considered the study of Mueller et al[7].

2.3 QUALBAVI

It is a computer interface software for data input/output and graphical data processing that utilizes Leendertse[4] computer program to simulate water quality for Vitoria Bay. The basic equation for two-dimensional transport of waste constituent in a well mixed estuary used by Leendertse[8] is given by:

$$\frac{\partial \rho_A}{\partial t} + \frac{\partial(\rho_A u)}{\partial x} + \frac{\partial(\rho_A v)}{\partial y} + \frac{\partial\left(e_x \frac{\partial \rho_A}{\partial x}\right)}{\partial x} + \frac{\partial\left(e_y \frac{\partial \rho_A}{\partial y}\right)}{\partial y} = S_A \quad (2)$$

in which: S_A = source function; ρ_A = mass density of substance A; e_x, e_y = coefficients turbulent diffusion.; u, v = velocity components; t = time.

3 Software application

3.1 Marinho estuary

The Marinho estuary has a watershed of 99 Km^2, length of 10 Km and it is a contributor of Vitoria Bay. It is intended to make the effluent final disposal of the Campo Grande wastewater treatment plant in this estuary. Campo Grande integrates Great Vitoria Region. This work makes use of WASP software to analyze its assimilative capacity in relation to this effluent. It was executed field work in order to calibrate WASP. Therefore, it was measured BOD, OD. N, P, fecal coliform and tide in three cross-sections of the estuary. In this cross-sections were collected water samples (in the middle of the cross section and the depth) for six hours intervals. The estuary bathymetry is known. The main parameters for the wastewater treatment plant are: effluent flow = 0.361 m^3/sec; plant performance: for BOD 89%; for SS 65% to 92% and 80% to 90% for fecal coliform. The raw sewage has the characteristics: OD = 2.60 mg/l; P = 2.35 mg/l; N = 18.76 mg/l and fecal coliform 1.0x 10^6 Coli/100ml. The

BOD design value for the treated effluent is 0.247 mg/l. The Marinho river flow is 0.925 m^3/sec, which was measured. These data are the initial and boundary conditions required running WASP. The calibration results are shown in the table 1.

Table 1: Concentrations and Tide after 12 hours

Parameter	Cross Section 1		Cross Section 2	
	me	ca	me	ca
DO*	0.00	0.05	0.00	0.03
BOD*	64.00	58.50	18.00	56.30
P*	2.79	2.91	1.29	2.78
N*	23.16	24.50	15.04	23.50
Fecal. Coliform+	$1.4x10^7$	$1.6x10^7$	$2.2x10^6$	$3.8x10^6$
TIDE**	0.52	0.48	0.88	0.79

* mg/l, ** m, + num/100ml,
me = measured; ca = calculated

After model calibration WASP was applied using the wastewater treated effluent flow design for the year 1999. The data input for this case are: a) effluent characteristics: BOD = 27.20 mg/l; DO = 1.5 mg/l; P = 6.0 mg/l, Bell[9]; N = 20.0 mg/l, Bell[9]; fecal cloakroom = $1.0x10^5$ um /100ml; b) constants : deoxygenation rate = 0.18 day $^{-1}$; reaeration rate = 0.001 dia^{-1}; temperature coefficient = 1.0, Martin[10]; mineralization dissolved organic phosphorous = 0.22 day^{-1}, Martin[10]; organic phosphorous temperature coefficient = 1.0, Martin[10]; mineralization organic nitrogen = 0.075 day^{-1}, Martin[10]; temperature coefficient for organic nitrogen = 1.0, Martin[10]; ammonia nitrogen nitrification rate = 0.11 day^{-1}, Martin[10]; fecal coliform decaying rate = 10.0 day^{-1}. The treated effluent flow is 0.361 m^3/sec. The results obtained are presented in table 2.

Table 2: Concentrations (mg/l) for year 1999 - Marinho Estuary

Cross Section	DO minimum	BOD maximum	P maximum	N maximum	num/100ml maximum
1	5,00	12,40	2,74	9,12	$3,75x10^5$
2	4,86	12,00	2,69	8,98	$1,60x10^5$

3.2 Vitoria Bay

Actually, Vitoria Bay receives all domestic and industrial effluents from the Great Vitoria Region without any treatment.
The assimilative capacity of Vitoria Bay was studied for the effluent disposal from the Pedreira wastewater treatment plant in the county of Cariacica. Vitoria Bay has 30 Km^2 of superficial area, and for the location of the plant its mean depth is 6 m and width 300 m. The main contributor for the Bay is Santa Maria River with $Q_{7,10}$ equal to 4.29 m^3/seg. The characteristics of the plant are: effluent flow 0.314 m^3/sec.; plant performance: 87% for BOD, 65 to 92% for SS and 80 to 90% for coliform. The design for the plant considers for the raw sewage BOD = 233.31 mg/l. The software CORMIX2[6] was utilized to study the assimilative capacity for the near field. The scenario simulated considered the tide amplitude of 2.07m the lowest for Vitoria Bay. The velocity current adopted was 1 m/sec., considered critical for this kind of study. For the wastewater treatment plant performance presented, the input effluent concentrations for CORMX2[6] are: BOD = 30.33 mg/l; fecal coliform = $1.0x10^5$ num/100ml; P = 6.0 mg/l (Bell, R. G. et al) and N = 20.0 mg/l (Bell, R.G. et al). The results given by CORMIX2 are BOD= 4.88 mg/l; DO= 8.0 mg/l; P= 0.97 mg/l and N= 3.22 mg/l.

3.3 Camburi Canal

The Camburi Canal links the west and east parts of Vitoria Bay and it is in the north side of Great Vitoria region. Its length is 10 Km, average width of 120 m, and its north bank has a mangrove having an area of 20 Km^2. Nowadays this Canal is the final untreated sewage disposal for about 60.000 people. Several cholera cases have been recorded in the inhabitants of the Canal neighborhood. The assimilative capacity was analyzed for the parameters DO, BOD and phosphorus through the Leendertse's computer program and the interface software QUALBAVI. To validate the software application it was considered five cross sections in the Canal in which were made water sampling (middle point of the cross section) and tide height recording for intervals of three hours during the tide period. Also, measured values of DO, BOD and P were utilized as initial conditions. The boundary conditions were:for the east side tide height and for the north side the flow. The input data required by Leendertse's computer program is: reaeration oxygen coefficient = 0.9144×10^{-5} m/sec; first order reaction coefficient for BOD = 0.3×10^{-5} sec^{-1}; phosphorus first order decaying rate = 0.411×10^{-5} sec^{-1}; oxygen

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saturated concentration = 7.2 mg/l. The future wastewater treatment plant effluent characteristics are: flow = 0.559 m^3/sec; DO = 5 mg/l; BOD = 20 mg/l and P = 5 mg/l. The calibration results for BOD, DO, and P, for 09 hours, is illustrated in Figures 2, 3 and 4 respectively.

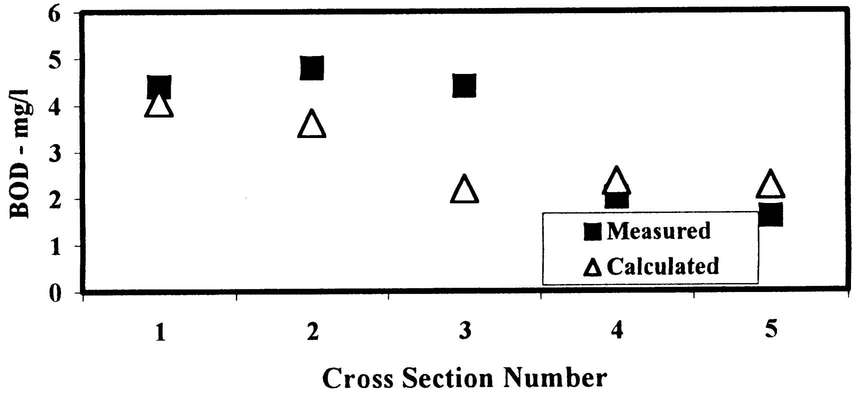

Figure 2: BOD after 09 hours

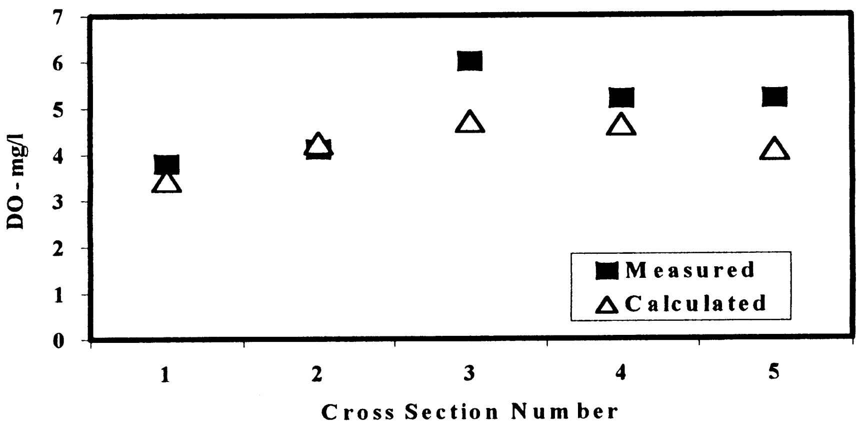

Figure 3: DO after 09 hours

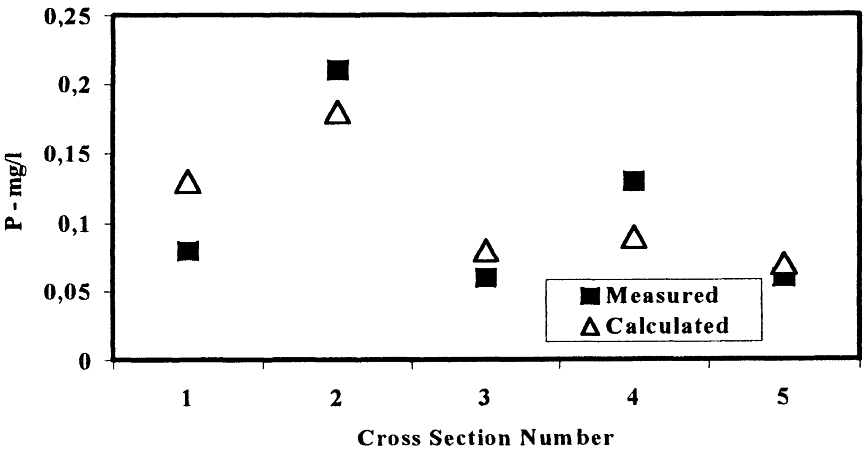

Figure 4: Phosphorus after 09 hours

For the year 2008, the results for the far field region are: $DO_{minimum}$= 6.47 mg/l; $BOD_{maximum}$= 0.41 mg/l and $P_{maximum}$= 0.10 mg/l. For the near field region (effluent discharge area) $DO_{minimum}$= 5.20 mg/l; $BOD_{maximum}$= 24.75 mg/l and $P_{maximum}$= 6.17 mg/l.

4 Conclusions

The assimilative capacity of the water bodies studied was analyzed according to the Resolution CONAMA 020/86 [11] which establishes the Brazilian constituents standards for the waters. For Class 2 (Marinho estuary): BOD ≤ 5 mg/l; DO ≥ 5 mg/l; fecal coliform ≤ 1000 num/100 ml (satisfactory water for bathing); total phosphorus = 0.025 mg/l P; no standard for nitrogen. For Class 5 (Vitoria Bay and Camburi Canal): BOD ≤ 5 mg/l; fecal coliform as Class 2; DO ≥ 6 mg/l; no standards for nitrogen and phosphorus.

From the results given by the WASP application to Marinho estuary it can be concluded that it has no assimilative capacity to receive the effluent from the Campo Grande sewage treatment plant because the CONAMA 020/86 will not be attended for the constituents BOD, P and fecal coliform. However, DO will satisfy it. Therefore, to keep this plant in the designed place it has to improve its treatment or to be moved to another area.

The CORMIX2[6] was applied to Vitoria Bay that. will receive the sewage effluent from the Pedreira treatment plant. In this case the CONAMA 020/86 will be satisfied for the constituents BOD and DO but not for fecal coliform. As for the Campo Grande plant, Pedreira plant has to be located in other place or improve its treatment technology. Considering that it was not possible to check CORMIX2[6] results against observed data due to the fact that the Bay has several effluent discharge points, which is not allowed in this software, the above conclusion can be used only to give a first insight into the problem for the near field effluent discharge area. Therefore, there is need for additional studies in this case.

For the Camburi Canal it was utilized QUALBAVI. The results show that for the near field region the constituents BOD and DO do not attend the standards. In the others regions of the Canal it was concluded that its water quality will have an improvement in comparison to its actual water quality. In this case, further studies indicated that the use of diffusers into the Canal would overcome the problem with BOD and DO problem. As conclusion the plant can stay in the designed local.

The application of computer software showed to be an important decision analysis instrument to decide about the best location to build the treatment plants studied, and to study the assimilative capacity.

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