NEW DESIGN OF SANTOS SUBMARINE OUTFALL: HYDRODYNAMIC MODELING SIMULATION AT THE SANTOS BAY

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Abstract
In the São Paulo coast, where it is located the majority of wastewater ocean disposal systems of Brazil, the Santos-São Vicente, operated by *SABESP* (São Paulo Basic Sanitary Company), is the oldest system. The former diffuser was designed and constructed with 200 m length, 40 circular exits with 300 mm of diameter each, considering a design discharge of 7.3 m^3/s. Most of the orifices were out of service in the last years. More recently, a new diffuser was designed with 425 m length, 79 vertical flexible rubber risers with 2 nozzles of 110 mm in each riser. The new design discharge was considered 5.3 m^3/s. The new diffuser was implanted recently connected to the end of the former, closing the former orifices. With this solution the original 4 km outfall length and 11 m discharge depth were increased to at least 425 m and 12 m, respectively. A new land primary treatment to be coupled to the submarine outfall is under construction (SABESP, 2009). The study here presented is focused in the hydrodynamic computer simulation of the near field of Santos ocean discharge system, considering the two options of submarine outfall length (4 and 5 km). It was used the hydrodynamic module of MIKE 21. The numerical model was calibrated considering correlation coefficient of 0.86 when comparing numerical data with field measurement. The results confirm previous physical model results of plume recirculation inside the Santos bay (Ortiz et al, 2007 and FEHIDRO, 2008) and the influence of the outfall length and of the rivers estuary discharge in the plume recirculation behavior.

Keywords
Santos submarine outfall; numerical simulation; CONAMA resolution, outfall length, diffuser system.

INTRODUCTION

Wastewater treatment and the disposal of its residuals is one of the most important features of coastal management. The scenario turns out to be more complex if social and environmental contexts are considered. The Brazilian federal constitution declares the coastal zone as national heritage. It has a fragile ecosystem, a dense urban and tourist population due to its natural environmental attributes.

Adequate decision making for this problem must be based not only on environmental studies but also on technical capabilities, including regionally developed solutions with local public participation. Therefore, governmental agencies have to become aware of these problems and provide information for the sustainable development and management of maritime and coastal areas (Lamparelli and Ortiz 2006).

In São Paulo State, the most populous and developed, located in southeastern Brazil, the predominant treatment process is through activated sludge. Marine disposal although representing only 2% of all SABESP (São Paulo Basic Sanitation Company) installations, accounts for 22% of total waste disposal for treatment, occupying the second place in terms of installed capacity.
Nowadays, the Santos Estuarine System is considered one of most critical areas in São Paulo State, concerning the degradation level of different compartments which integrate the aquatic system and the Seven Conservation Units due to the presence of the petrochemical industry pole in Cubatão

city, the Santos Harbor, the Santos Submarine Outfall (SSO), and also due to irregular use and occupation of the lands favouring the dissemination of diffuse sources of contamination (Gasparro *et al*, 2008).

Santos is the oldest sea outfall system in operation along the São Paulo coast serving both Santos itself and the neighboring São Vicente. According to Marcellino and Ortiz (2001) and Rachid (2002) the system was designed to accommodate a maximum population of 1.322 million people with a maximum project flow of 7.267 m^3/s. Original planning of the system dates from 1969, but SSO has been operating since 1979. From additional studies of the SBS – Baixada Santista Sanitation Company, as coordinated by Professor Garcia Occhipinti (Hidroconsult 1975 apud CETESB 2006) more precise design and construction criteria for this system were defined, this including the preliminary treatment at José Menino Beach, and a submarine outfall of steal, covered by concrete, starting on the beach with a length of 4 km. On considering the lack of an adequate waste collection network system in the region, with clandestine wastewater flowing into the numerous channels of both towns, these were connected to the oceanic interceptor thereby making it possible, within a certain flood limit, to direct the channel flows to the preliminary treatment plant. For the new diffuser system recently installed, the value of maximum discharge was corrected for Q_{max} = 5.3 m^3/s (SABESP, 2009). Figure 1 shows a general view of São Paulo coast submarine outfalls.

The combination of wastewater treatment plant with a submarine outfall has been considered a sustainable system in many coastal cities (Juanes, et al, 2005). The key is related with the capacity of receiving waters to assimilate the introduced substances in their natural cycles. Within this context, the present study aimed to evaluate the hydrodynamic circulation at the Santos bay due the effluent discharge considering, respectively, the old outfall design in operation and the new design under construction, which increase the outfall length.

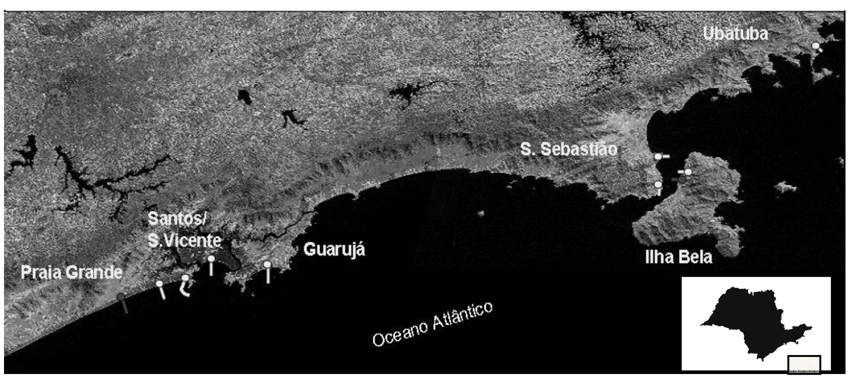

Figure 1: Location of SABESP sea outfalls in operation and under construction.

MATERIALS AND METHODS

Conama Resolution

The main purpose of sea outfalls is wastewater disposal, as a form of protecting the coastal region, in compliance with bathing water quality limits as stipulated by the CONAMA 274 resolution (2000), as well as minimizing launch impact through quick and high dilution using conveniently projected diffusers in compliance to Class 1 (saline waters - Article 18) and in accordance with CONAMA resolution 357 (2005). CONAMA is the *Conselho Nacional de Meio Ambiente – Brasil,* which establishes the environmental resolutions applied to water quality resources.

CONAMA resolution 357 (2005) in the Article 33 gives rise to the possible use of the concept "mixing zone", whereat concentration parameters could be in disagreement with that was established for water classes, and as presented in that resolution. However in the article 34, it is established the launching standards for the effluent discharge parameters to attend these standards, which means a minimum level of inland treatment to be imposed.

A revision of these Articles is under discussion by a CONAMA workgroup, in an attempt at improving this resolution and adequating legislation to sea disposal through outfalls.

To date, the option for sea disposal with preliminary inland treatment for sanitary discharge has been the rule, for the SABESP submarine outfalls. In this case, the standard oceanic disposal system is comprised of a preconditioning plant and its respective sewage outfall. The pre-conditioning consists of a process in which the effluent is chlorinated, double screened, and sieved (1.5 mm rotation sieve), before being carried into the pipeline. (Rachid, 2002; CETESB, 2006). To the new project of Santos outfall CETESB - São Paulo State Environmental Company, which is responsible for licensing the operation of these plants, enforced advanced primary inland treatment, following the proposal revision of CONAMA 357.

The Santos Outfall – current operation

As mentioned previously the maximum project discharge of 7.267 m^3/s, was adjusted to a more realistic project discharge of 5.3 m^3/s and a mean operation volumetric discharge of 3.34 m^3/s.

The submarine outfall was originally designed and constructed with a 1.75 m diameter and an extension of nearly 4 km, discharging to a depth of 11 m. The original diffuser system was designed and constructed with a 200 m length, and with 40 circular openings of 30 cm each, spaced 5 m in between the openings orifices. More details about the geometric characteristics of this outfall are presented in Marcellino and Ortiz (2001). A new diffuser was designed as a step in reformulating the old diffuser of Santos outfall. This new diffuser was installed onto the end of the old diffuser, with 425 m of length, 79 vertical flexible rubber risers with two nozzles of 11 cm in the exit of each riser (Ortiz et al, 2010). The effluent discharge depths proposed here for comparisons are 11m and 12 m, for 4 and 5 km lengths, respectively.

Previous computer simulations

Although the new diffuser will represent an improvement on the dispersion process as a whole in the near-field, dilutions values will not exceed 100, when considering dispersion process limitations within the bay. Previous simulations running CORMIX 2 show dilution values of order of 60, according to Ortiz et al, 2011. For more details of software CORMIX – Cornell Mixing Zone Expert System, see Doneker and Jirka 1991; Jirka and Akar 1991. The application of CORMIX 2 permits evaluating the dilution efficiency of submerged multiport diffuser systems, comparing different designed diffusers alternatives.

Taking as a boundary conditions the effluent concentrations of phosphorus in the end of the near field obtained running CORMIX 2, Ortiz et al, 2011 simulated three scenarios for transition and far field conditions using FLUENT 6.1.22 – 2D (FLUENT tutorial - academic license), which is based on CFD finite volume technique. The mixture model was used to simulate the multiphase mixture: sea and effluent. In this case, the Santos bay geometry was represented in the neighbourhood of the submarine outfall using the available bathymetry. The first scenario was simulated for stagnated sea without wind effect; the second scenario was simulated for tidal variation without wind effect; the third scenario (worst situation) was simulated for tidal variation with wind effect, with velocity of 2 m/s towards estuary bay. In this case transient discharge was considered based on data variation in the access channel to Santos Harbor and to Mar pequeno channel (FEHIDRO, 2008).

The results of the third scenario presented in Ortiz et al, 2008 and Ortiz et al, 2011 show that the plume circulate and disperses in almost all Santos bay and close to the coast, with dilution values reaching 67.

Computer simulations – software MIKE 21

MIKE *21*

MIKE 21 is part of the new generation of DHI (Danish Hydraulic Laboratory) software used for flow simulation of water bodies, lakes, estuaries , bays and coastal regions . Although MIKE 21 is composed by several modules, this article presents the results of application of the hydrodynamic module (HD), which academic license is available at Mechanical Engineering Department of Polytechnic School – University of São Paulo. Together with HD it is available pre and pos processing modules (PP).

In the MIKE 21 (HD) the equations are solved using a finite difference technique, particularly the ADI (alternating direction implicit) technique, which consists of the integration in 2D, of continuity and momentum equations in time and spacing. The complete set of equations used in MIKE 21 HD can be seen in Souza, 2006 and Baptistelli, 2008.

For plume path circulation visualization it is used the particle track plot, a tool available in MIKE 21 (HD), which permits a lagrangian plot that follows the path of the effluent injected in the flow field.

Boundary Conditions

The computer simulations using MIKE 21 here presented are done assuming the maximum effluent discharge of 5.3 m^3/s for outfalls of 4 and 5 km, respectively. However, instead of use the transient discharge data in Santos Harbor and Mar Pequeno channels, as mentioned above, it was prescribed freshwater flow from the estuary main rivers, assuming mean volumetric flow based in the data measure in July 2005 (SABESP, 2006). At the open boundary (north) it was prescribed two conditions for simulation of freshwater flow from the main rivers: a critical condition of drought, with almost zero contribution (0.5 m^3/s) and a second condition of 61.5 m^3/s. At the open sea boundary (west) it was prescribed tidal variation. At the open sea boundary (south) it was not prescribed any flow. At the open sea (east) it was prescribed a mean elevation constant value. Figure 2 shows the general view of the geometry simulated using MIKE 21.

For the simulations it was assumed Courant number of 1.06, resulting in a time step of 5 s and grid spacing of 90 x 90 m. The total number of cells resulted in 451827 horizontal cells. To model application it was assumed some physical features that are: no-stratification and homogeneous water-column and hydrodynamic controlled by the tide and by water flow from the main channel, as mention above.

Wind velocity was assumed constant and equal 2 m/s blowing in the north direction toward to the coast.

For the turbulence model it was assume the Smagorinsky hypothesis, choosing the constant of Smagorinsky of 0.5. In this case only the large scales can be reproduced.

The simulations were done for 4 and 5 km of outfall extension, respectively, and it was assumed a single point effluent discharge at the exit of the outfall.

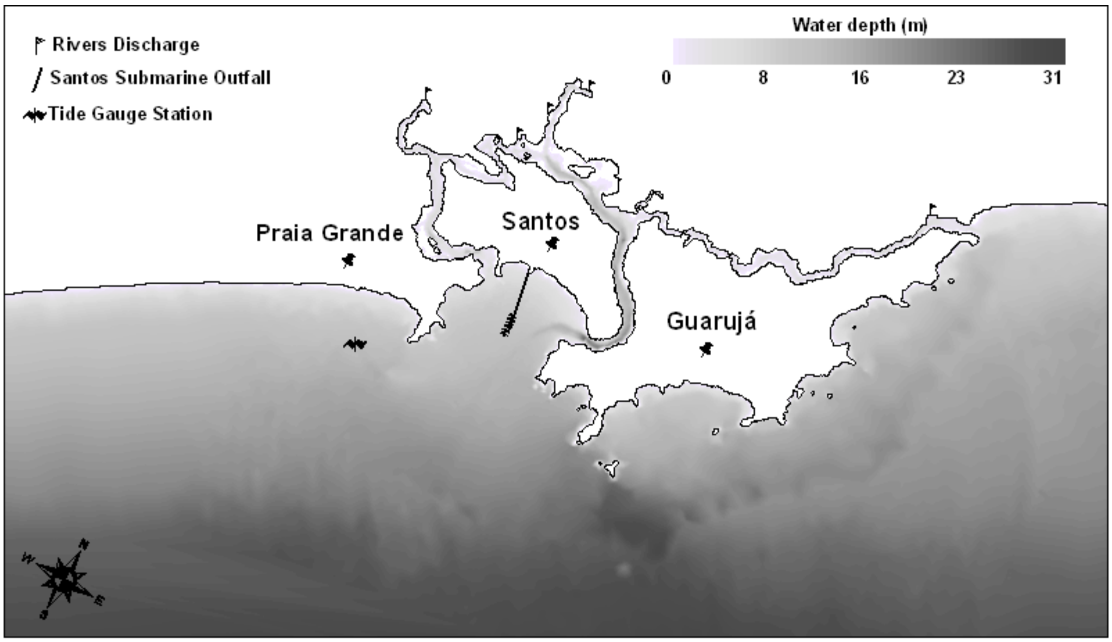

Figure 2 : Study area with the batimetry used in the models.

Model calibration

The hydrodynamic model has been calibrated with available data measured in July 2005 (SABESP, 2006) and the collected data include surface elevation measured in the tide gage station as showed in Figure 2.

Figure 3 shows a good correlation between measured and modeled surface elevation (0.86) and to get this correlation, the model simulated a period of 5 days.

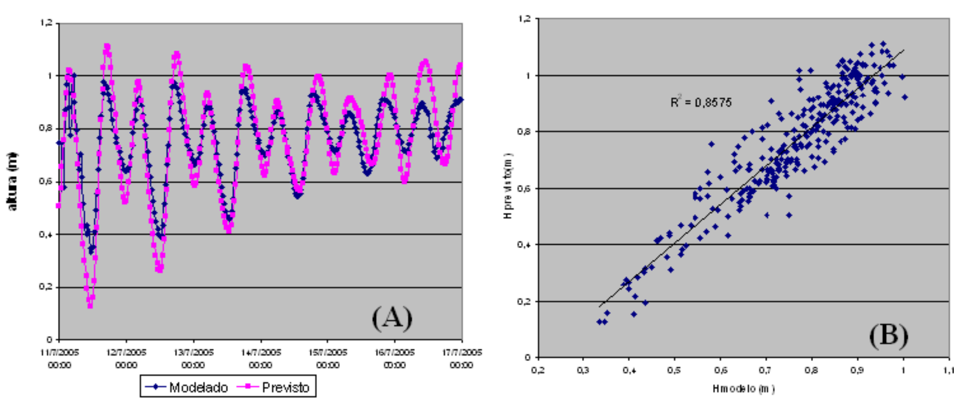

Figure 3: Sea surface elevation (A) and correlation (B) from model results and from the tide gauge located at Praia Grande.

RESULTS

The hydrodynamic results are presented in figure 4. Figures 4A and 4B present the simulations with 4 and 5 km outfall length, respectively, for condition of almost zero flow from the main rivers. Figures 4C and 4D present the simulation with 4 and 5 km outfall length, respectively, for condition of 61.5 m^3/s from the main rivers. Comparison of figures 4A and 4B shows that for low river discharge there is a strong recirculation inside the bay for 4 km, which is not happen for 5 km, with the plume flowing towards the open sea. The increase in the rivers volumetric discharge (61.5 m^3/s) interfere significantly in the result of the 4 km length outfall, with the plume escaping from the bay (figure 4C), with the predominance of tidal currents in the spreading action into the plume. For 5 km the results of plume recirculation in the bay are analogous to that showed for 4 km (see figures 4C and 4D), although in the last case the dilution should be more favourable

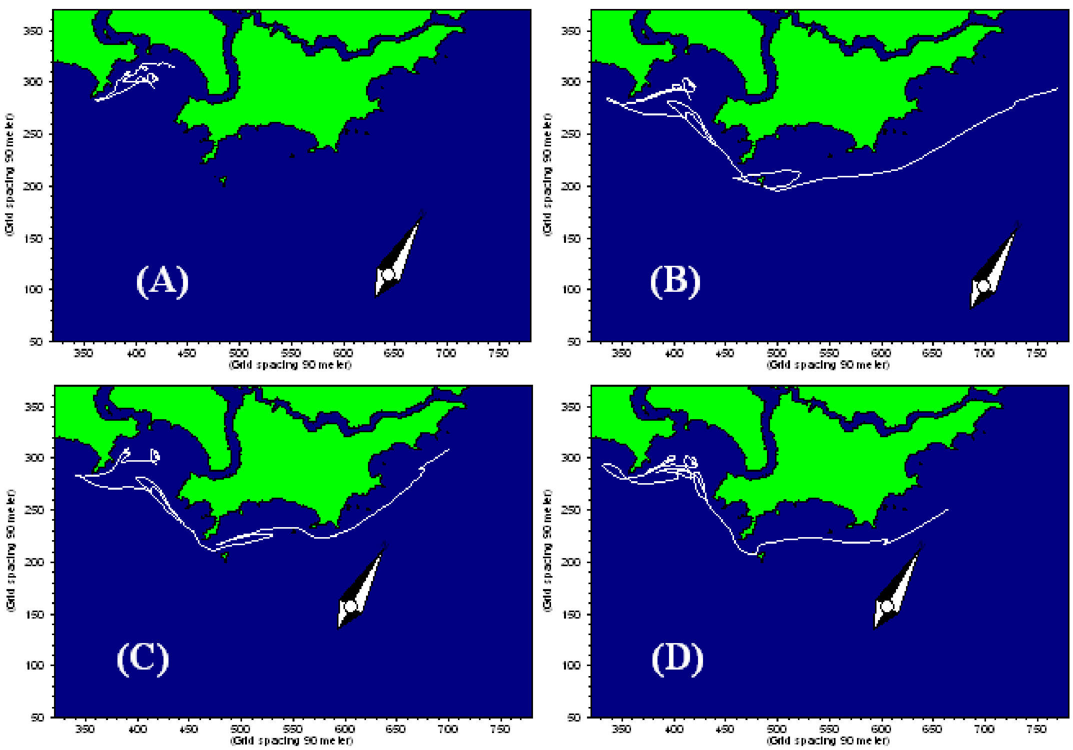

Figura 4: Particle track from the outfall effluent discharge exit. (A) outfall with 4 km and rivers contribution of 0.5m³/s; (B) outfall with 5 km and rivers contribution of 0.5m³/s; (C) outfall with 4 km and rivers contribution of 61.5 m³/s; (D) outfall with 5 km and rivers contribution of 61.5 m³/s.

CONCLUSION

The results of the computer simulation presented in figure 4 show that 1 km of outfall length extension diminished the bay recirculation, for the critical condition of low flow from the rivers estuary and wind blowing towards the sea, because there is a tendency of plume to leave the bay toward the open sea (figures 4A and 4B). These results confirm previous results obtained in a distorted physical model operated in the *Centro Tecnológico de Hidráulica – EPUSP* (see Ortiz et al, 2007 and FEHIDRO, 2008). The increase in the rivers flow (61.5 m³/s) is favourable to minimize recirculation inside the bay and to plume conduction outside the bay. In this case, the 1 km outfall increase is not relevant, comparatively (figures 4C and 4D).

Previous studies show that the new diffuser design will improve the dilution in the near field inside the bay, but not more than 100. In the other hand, the Santos outfall length extension will be less than 1 km. However, with the new treatment inland station (primary treatment) under construction, the water quality in the mixing zone of Santos bay will improve following the new trends of CONAMA resolution.

Further simulations studies are necessary, particularly in terms of rivers estuary flow contributions.

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