STUDY OF THE INFLUENCE OF CHEMICALLY ENHANCED PRIMARY TREATMENT (CEPT) IN THE WATER QUALITY OF SANTOS SUBMARINE OUTFALL USING AN EUTROPHICATION NUMERICAL MODEL

E. L. Subtil, E.L*, J. C. Mierzwa*, J. P. Ortiz**, R. S. Robinson***, A. García**** and J. G. Alba, J.G.****

* Hydraulic and Sanitary Engineering Department, Polytechnic School, University of São Paulo, 120 av. Prof. Lucio Martins Rodrigues, São Paulo – BR
(E-mail: *eduardo.subtil@usp.br; mierzwa@usp.br)*
** Mechanical Engineering Department, Polytechnic School, University of São Paulo, 2231, Av. Prof. Mello Moraes, São Paulo – BR
(E-mail: *jportiz@usp.br*)
**Mauá Institute of Technology, School of Engineering, São Caetano do Sul, SP, Brasil
*** Mechanical Engineering Department, Polytechnic School, University of São Paulo, 2231, Av. Prof. Mello Moraes, São Paulo – BR
(E-mail: *robinson@uol.com.br*)
****Submarine Outfall and Environmental Hydraulics Group, Institute of Environmental Hydraulics, University of Cantabria, Av. de los Castros s/n, 39005, Santander – Spain
(E-mail: *garciagan@unican.es; garciajav@unican.es*)

Abstract
The present study aimed to evaluate the environmental benefit to use Chemically Enhanced Primary Treatment (CEPT) system to reduce the organic load and soluble phosphorus, as treatment for the wastewater discharged through the Santos Submarine Outfall (SSO). For this evaluation it was applied an eutrophication numerical model for two different scenarios: wastewater discharge with preliminary and wastewater discharge with CEPT treatment. The model results indicated that the phytoplankton growth in Santos Bay is influenced by river discharge and the SSO. However, SSO appears to be a significant source of nutrients that may also contribute to the development of eutrophic conditions in Santos Bay. Furthermore, the model results suggest that only the removal of phosphorus does not appear to be sufficient to control the phytoplankton growth. Maybe is also necessary to remove ammonia before the discharge.

Keywords
Submarine outfall; chemically enhanced primary treatment; eutrophication numerical model

INTRODUCTION

Nowadays the Santos Estuarine System is considered one of the most critical areas in São Paulo State concerning the degradation level of different environmental compartments encompassing the aquatic system and Seven Conservation Units. This condition has resulted from the presence of the Cubatão Petrochemical Pole, the Santos Harbor, the Santos Submarine Outfall (SSO), and also because of irregular land use and occupation, favouring the dissemination of diffuse pollution (Gasparro *et al*, 2008).

The SSO has been operating since 1978 and is the oldest submarine outfall along the São Paulo shore. 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. Nowadays, this system receives contributions from approximately 99% of Santos and 40% of São Vicente residences (Abessa et al., 2005), which results in a mean flow of 3.0 $m^3.s^{-1}$.

The current condition of SSO discharge is considered a significant source of contamination to the Santos Bay, as it discharges untreated sewage into the sea combined with an inefficient diffuser system that in some periods of the year barely reaches an initial dilution factor of 30. As a result nutrients concentration in water samples from the region under influence of SSO are much higher than those obtained in water samples from other regions , mainly to total phosphorus, with concentrations for these regions of 0.2±0.1 mgP/ L and 0.043±0.015 mg P/ L respectively (CETESB, 2006).

Significant increases in nutrient concentrations can result in increases of phytoplankton biomass indicated by high values of chlorophyll-a (Chla). Several studies performed through the last 30 years (Gianesella-Galvão, 1982; Moser, 2002, CETESB, 2005) have demonstrated an increase in Chla concentration in Santos Bay. CETESB (2005) reported values of 10 µg $Chla.L^{-1}$ next to the SSO discharge. Moser et al. (2005) recorded a maximum of 97.4 µg $Chla.L^{-1}$.

Besides nutrients concentration, phytoplankton growth is limited by others environmental factors, including light and temperature (García et al., 2010). However, among these factors, only nutrients can be controlled, so they have been the focus of most efforts to control algae blooms responsible for water quality deterioration (Na and Park, 2006).

Nitrogen controls primary production and eutrophication in most temperate estuaries and coastal waters, although phosphorus can be of concern in many tropical waters (bays and semi-enclosed waterbodies) and perhaps in some temperate estuaries (NRC, 1993). As a consequence significant environmental differences are expected if a Chemically Enhanced Primary Treatment (CEPT) with phosphorus removal instead of a preliminary treatment is performed.

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 introduced substances in their natural cycles. Within this context, the present study aimed to evaluate the environmental benefit to use CEPT system to reduce the organic load and soluble phosphorus, as treatment for the wastewater discharged through the Santos/SãoVicente submarine outfall.

MATERIALS AND METHODS

Santos Submarine Outfall

Santos wastewater ocean disposal system consists of a preliminary treatment system and a sewage outfall responsible for releasing a mean discharge of 3.0 m^3/s of effluent to a distance of 4,000 meters from the shore (Fig. 1) at nearly 11 meters depth, throughout a diffuser system with 40 risers. More details about the geometric characteristics of this outfall are presented in Marcellino and Ortiz (2001). In the currently operating preconditioning unit, sewage pass through a preliminary treatment, where coarse solids is removed and also a portion of settled sediments through railing and inclined rotating screens with openings of 1.5 mm (CETESB, 2006a). After this stage the effluent is chlorinated and discharged into the sea. The discharge occurs in the middle of the bay and the impact is characterized by the plume recirculation in the mixing zone region inside the bay (Ortiz *et al*, 2007).

In this study the SSO was considered as a point source of wastewater. The mean flow (3.0 m^3/s) was inserted into the model taking into account the sensing variables in the hourly flow of sewage. The coefficients of greatest and lower hour consumption were respectively 1.5 and 0.5.

Table 1 presents the mean concentrations of Biochemical Oxygen Demand (BOD), Ammonia and Phosphate in a wastewater after preliminary treatment (current situation) and CEPT. For the primary treatment it was assumed the obtained values from a monitoring program reported by SABESP (2006) while for the effluent from CPET it was assumed a removal efficiency of 85% to phosphate, 60% to BOD and 30% to ammonia.

Table 1: Mean values of BOD, ammonia and phosphate in the effluent discharge through SSO.

	BOD (mg O_2/L)	**Ammonia (mg N/L)**	**Phosphate (mg P/L)**
Preliminary Treatment*	240	23.2	2.8
CEPT	96	16.2	0.56

*Current situation

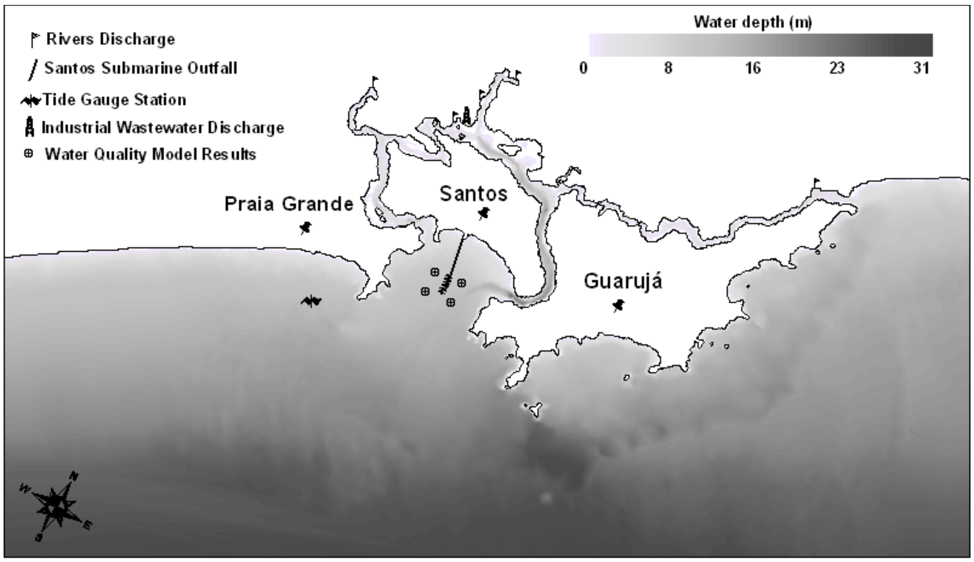


Figure 1: Study area whit the batimetry used in the models.

Water Quality Model

The water quality model applied for this study was developed by Submarine Outfall and Environmental Hydraulics Group from University of Cantabria. The model solves the system of differential equation that describes the main chemical and biological interaction related of eutrophication phenomenon and it includes the following variables: ammonia; nitrate, phosphate, phytoplankton biomass, dissolved BOD, suspended BOD, sediment BOD and dissolved oxygen. More details about the eutrophication model are presented in García et al. (2010).

The water quality model is coupled with the hydrodynamic model through the transport equation, which integrates the advection and the diffusion properties of the flow (Eq. 1). For model application it was necessary to make some assumptions about receiving water some physical features: (1) the water-column is homogeneous, i.e., non-stratified over the modelled domain (2D); (2) the hydrodynamic in the region is controlled by the tide and water flow from main tributary channels, i.e., there are no shelf water current; (3) the model domain is the same as for the hydrodynamic application with a total of 451827 grid cells (horizontal spacing of 90x90 m).

$$\frac{\partial(HC_i)}{\partial t} + \frac{\partial(UHC_i)}{\partial x} + \frac{\partial(VHC_i)}{\partial y} = \frac{\partial}{\partial x}\left(HD_x\frac{\partial C_i}{\partial x}\right) + \frac{\partial}{\partial y}\left(HD_y\frac{\partial C_i}{\partial y}\right) + R_iH \tag{1}$$

where H is the total water depth (m), C_i is the depth-average concentration for water quality (i), U and V (ms^{-1}) are the vertical integrated velocities, D_x and D_y are the diffusivities in x and y directions and R_i describes the chemical reaction terms, corresponding to the interaction equation

for state variables (García et al., 2010). In order to assure stable conditions a time interval of 5.0 s and 20.0 s as time step for the hydrodynamic and water quality model respectively were choosen.
At the open sea boundary (west) it was prescribed tidal elevation while in the open boundary (north) it was prescribed freshwater flow from the main rivers that results in addition of 61.5 $m^3.s^{-1}$. The model simulated a period of 3 month between December 2005 until March 2006.

RESULTS

Hydrodynamic Model Calibration

The hydrodynamic model has been calibrated with available data measured in July 2005 during a time period 18 days (SABESP, 2006). The collected data included only surface elevation measured in the tide gauge station showed in Fig. 1. Due to the scarcity of available data, the calibration process focused on reproducing the major tide features on the region. On Fig. 2 it can be observed a good correlation between measured and modelled surface elevation. Figure 2-A shows a semi-diurnal tide with daily inequalities the same results were reported by Harari et al. (2008). The velocity field during spring tides in two different periods are showed in Figure 3. In this period the currents reached high value of 0.21 $m.s^{-1}$ in the region of Santos Submarine Outfall discharge. This value is quite similar for those report by SABESB (2006) where were found to the same period in this region currents values between 0.06 until 0.20 $m.s^{-1}$.

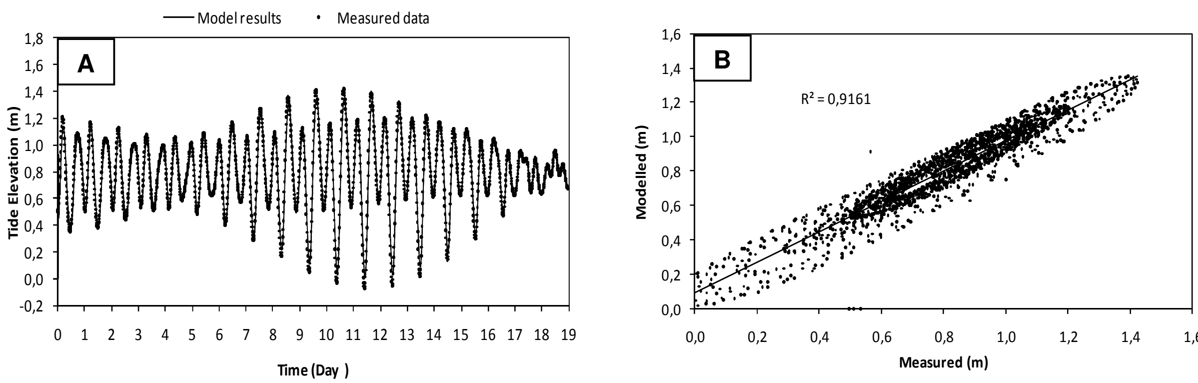


Figure 2: Sea surface elevation (A) and correlation (B) from model results and from the tide gauge located at Praia Grande.

Water Quality Results

The results obtained by the water quality model for the two simulated scenarios (discharge with preliminary treatment and CEPT treatment) on the region of influence by SSO discharge are presented in Fig. 4. When the effluent was discharge with a preliminary treatment (current situation) the phytoplankton reached values of 2.3 mg C/L while ammonia and phosphate reached values of 0.8 mg N/L and 0.22 mg P/L respectively. CETESB (2006b) reported similar values of ammonia and phosphate in the same region and period (February, 2006) of 0.9±0.7 mg N/L and 0.1±0.09 mg P/L.

The decrease in the nutrient concentrations in the effluent by addition of CEPT in ocean disposal system reflect in the decrease of phosphate and ammonia in water. As a result, the phytoplankton biomass decreases until values between 1.1 - 1.6 mg C/L. However, their concentration still remains high indicating eutrophication condition. This outcome is not surprising if it is observed the Fig. 5 where high levels of nutrients are transported from the Santos estuary to Santos bay. The contribution of rivers and the industrial effluent discharge in the estuary, which was considered in the model, has an important role in the phytoplankton growth. As such, the magnitude of the reduction in nutrients achieved by only the change in the treatment levels does not seen to reduce the biomass phytoplankton to low levels.

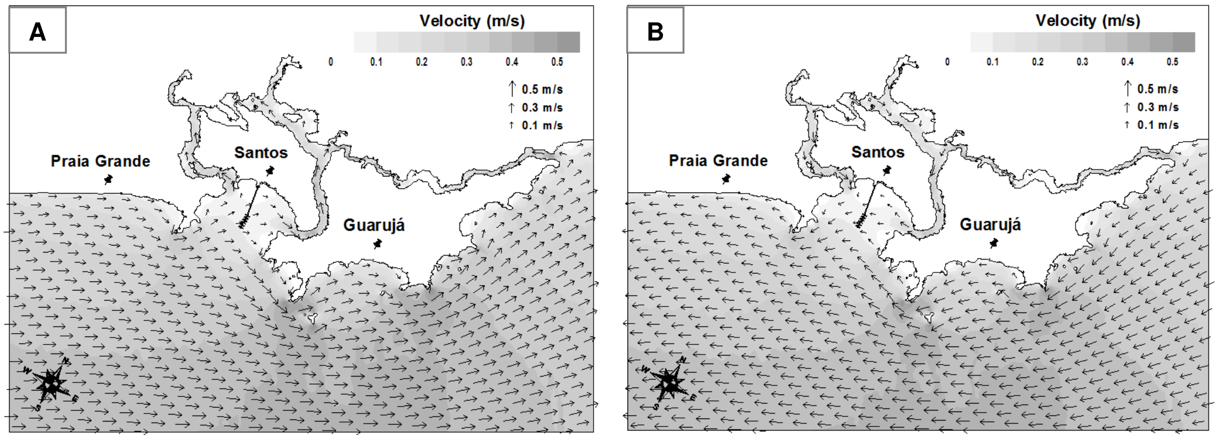


Figure 3: Modelled **v**elocity field during spring tides.

However, due the environmental characteristics of Santos Bay in respect with non-stratified ambient in the most of the year and the condition of SSO discharge in terms of depth, the effluent plume reach the surface before the complete mixing. In other words, the constituents of the effluent (nitrogen and phosphorus) will be available in high concentration on surface water. This situation in combination with some environmental condition like intense radiation, low tide and high temperature, can lead a very favourable condition to algae proliferation, i.e., even with the high contribution of the estuarine system in respect of nutrients, the SSO appears to be a significant source of nutrients that may also contribute to the development of eutrophic conditions in Santos Bay. It indicates that the removal of nutrients before the wastewater discharge should be taken in account. Furthermore, the application of CEPT with only significant removal of phosphorus does not appear to be sufficient to control the phytoplankton growth. Maybe it is also necessary to remove ammonia before the discharge.

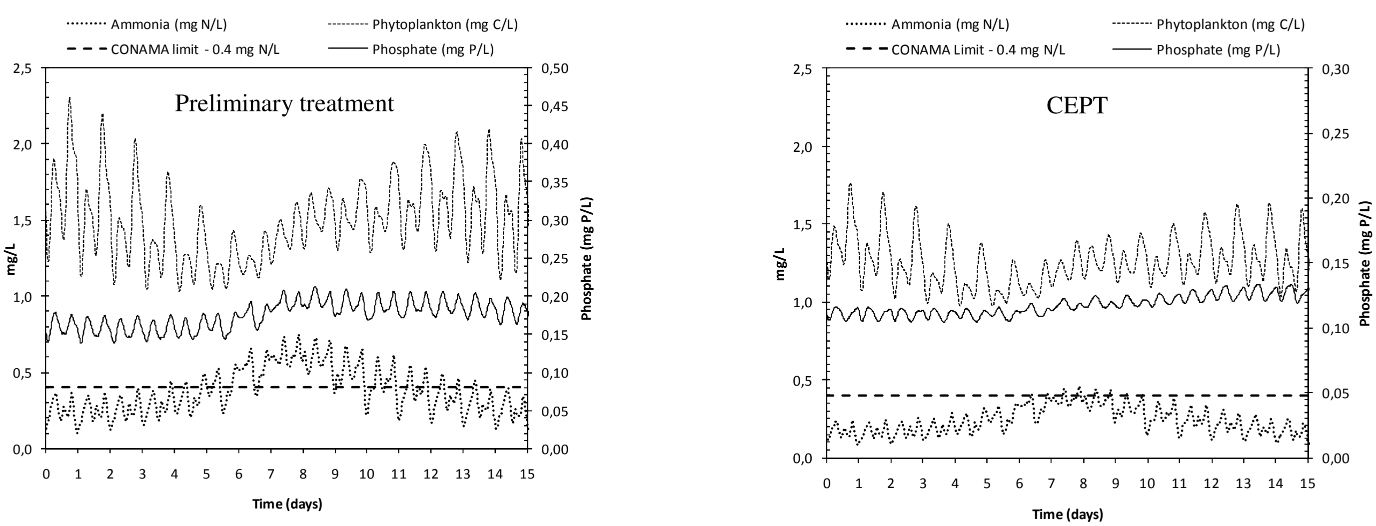
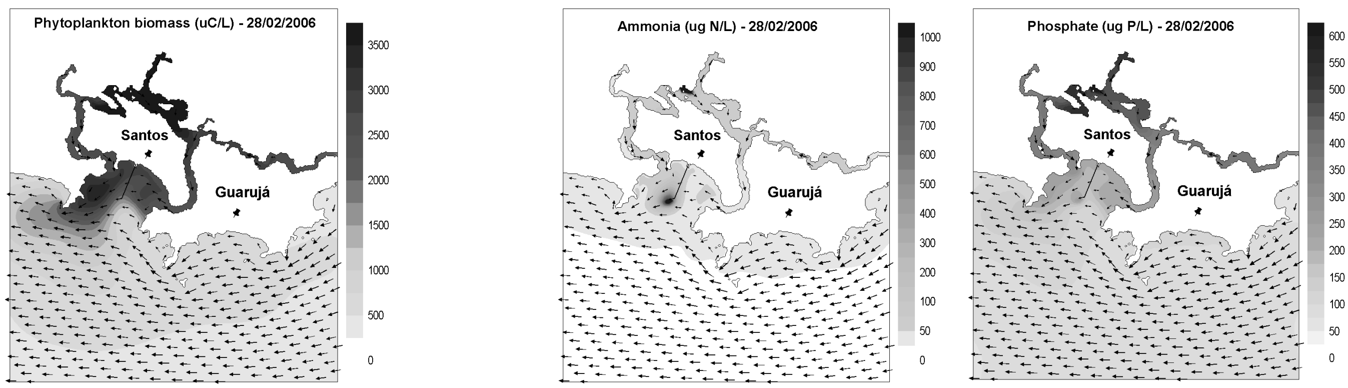


Figure 4: Model results for ammonia, phytoplankton and phosphate in the region of SSO discharge for the last fifteen days of the 3 month simulation run.

Discharge with preliminary treatment level



Discharge with Chemically Enhanced Primary Treatment

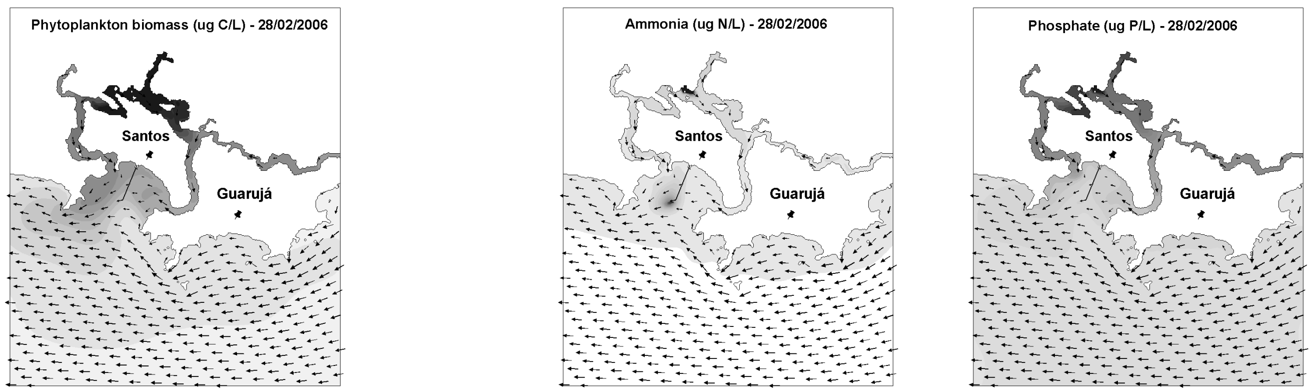


Figure 5: Model results for phytoplankton, ammonia and phosphate in the water column.

CONCLUSION

This works represents the first evaluation in the development of a water quality forecast by eutrophication models to different scenarios of wastewater ocean disposal system for this region, which can be used to improve the water quality of future decision-making. The eutrophication model showed to be an important tool to evaluated the environmental response of different wastewater discharge configuration. The results indicated that the phytoplankton growth in Santos Bay is influenced by river discharge and the SSO. However, SSO appears to be a significant source of nutrients that may also contribute to the development of eutrophic conditions in Santos Bay. Furthermore, the model results suggest that only the removal of phosphorus does not appear to be sufficient to control the phytoplankton growth. Maybe it is also necessary to remove ammonia before the discharge.

ACKNOWLEDGMENT

The authors would like to thank doctorate scholarship of E.L. Subtil supported by *Fundação de Amparo à Pesquisa do Estado de Paulo - FAPESP*, and undergraduate scholarship of R.S. Garcia supported by *Associação dos Engenheiros Politécnicos*.

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