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SANITARY SEWAGE OCEAN DISPOSAL: AN ALTERNATIVE TO SMALL COMMUNITIES

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Abstract: *More than 50% of the world population lives in coastal areas; a number which increases significantly in summer. It is common in these regions that the wastewater is disposed into the ocean, either through natural channels or directly on the beaches. Due to this, the preservation of coastal waters became a field of great relevance. Sanitary sewage ocean disposal by submarine outfalls with previous onshore sewage treatment is a good alternative that has been used for many years in many different countries with good results since the system is well designed and engineered to minimize the negative impact of effluent on the marine environment. Legislation to control water pollution, particularly to control wastewater discharge through outfalls normally is more restrictive in the developed countries. In Brazil the CONAMA resolution 274, and more recently 430 have been improved the legislation of water pollution including the topic of waste disposal through. This situation led to scientists to conduct studies to different combinations of ashore treatment and outfalls design that fulfills existing regulations. A choose of preliminary, primary or secondary treatment associated with ocean disposal through submarine outfalls, still remains as a controversial point of discussion and without common consensus. The availability of new materials and modern methods of outfalls construction, makes possible that small communities can have the option for the use of submarine outfalls. Many debates have occurred regarding on the benefit-cost of this alternative. Recent studies show that it is a competitive solution for small communities, even when considering the environmental cost. A study about how this issue is currently performing in the worldwide, in Brazil and, particularly, in the coast of São Paulo is carried out in this work.*

Keywords: *submarine outfall, sanitary treatment system, numerical model, CONAMA resolution*

1. INTRODUTION

More than 50% of the world population , which corresponds to three billions inhabitants, are actually concentrated at 60 km or less from the coast (Roberts et al, 2010), values which could oscillate according the season in countries like Brazil, where the coastal population in the summer increases significantly. The large human concentration in coastal regions could be observed through the satellite image illustrated in Fig. 1.

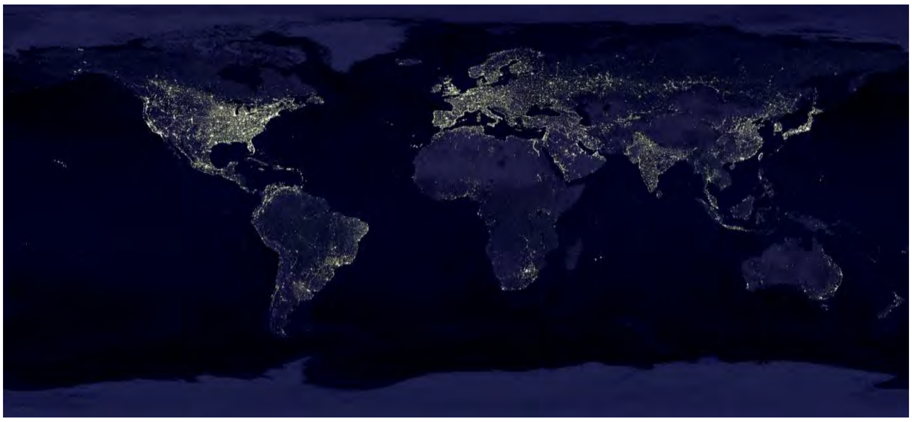

Figure 1: Satellite night image composition emphasizing the concentration of population in coastal regions (Font: NASA, 2009).

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With the social pressure for environmental protection, the water resources preservation is a topic which importance, is ever increasing. Pollution of water bodies by wastewater from sanitary sewage has been a common practice through history of humanity, bringing a concern related with the environmental protection and pressuring engineers and scientists to develop solutions to solve problems like: wastewater disposal, accidental pollutant discharges in water bodies, necessity of dredging works in water environmental, erosion and fluvial change morphology by sediment transportation in rivers etc.

The Brazilian coast water quality is strongly influenced by the basic sanitary conditions of its coastal cities. Brazil has nearly 8000 km of coast and many of its communities do not have enough sanitary infra-structure for the population, with the sewage disposal flowing through the coastal rivers and getting the beaches or disposing into the ocean through short submarine outfalls (Gunnerson, 1988).

Brazil as a BRIC´s member and in the route to be a developed country in the next decades, need to surpass its present condition of low Human Development Index – HDI. In this sense the improvement of the collection and treatment sanitary sewage systems is urgent which need a large amount of investments in infra-structure. The sanitary sewage must be collected, treated and must have an adequate final disposal. So, technical studies are important to choose the best alternative system taking into account the benefit-cost relationship, including the environmental impact of each possible alternative.

Considering the possible technological solutions for sanitary wastewater treatment in coastal zones, the use of submarine outfalls, as an integrant part of the treatment system, is a sustainable alternative to protect the water quality environmental (Echavarri-Erasun et al, 2010; Juanes et al, 2005) and could substantially reduce investment costs, operation and maintenance while reaching the same goals of environmental quality of treatments with high levels with an optimization at launch (Roberts et al., 2010). Although these benefits, under some environmental and launch conditions, the waste water submarine disposal can impact the water quality in the mixing zone nearby the point of discharge, if the system is not properly designed, when organic and inorganic matter of the effluent could enter in contact with the aquatic fauna and flora , causing a proliferation of aerobic bacteria, increasing the oxygen consumption dissolved in water, which causes environmental eutrophication and ecological disequilibrium in this region (Naval et al, 2001).

The management systems of wastewater in coastal regions nowadays offer a good possibility of combination between previous treatment in land and submarine outfalls disposal projects with the goal to avoid the negative impact of wastewater in the ecosystem and in the human health. However, many of these regions continue to suffer with environmental impacts, including impacts of submarine outfalls systems with design and operation not satisfactory.

In Brazil it was approved, recently, in 2011, a new legislation resolution (CONAMA 430), which define for the country, the minimum standards of land treatment, before to launch in the submarine outfalls. In developed countries like Spain and United States, the previous sewer treatment in land is more restrictive before to launch the effluent in the submarine outfall, but it is necessary a further discussion to understand the differences in the legislations.

1.1. USE OF SUBMARINE OUTFALLS AND PREVIOUS TREATMENT IN THE WORLD.

Wastewater ocean outfalls have been used in many countries and the designs are defined as function of: the discharge depth, the length and diameter of the outfall, the sewage volumetric discharge, the hydrodynamic of the field environment, the physical-chemical characteristics of effluent etc. However the level of land treatment to assume before to launch the effluent in the submarine outfalls is always a polemic point of discussion, with different opinions of the parts involved in the project. The reduction of the contaminants concentration in the near field of the water body is the result of the contaminants dilution in this region, which is function of the strong mixture induced by the diffuser system installed and of the position of discharge point of the effluent. Position of discharge point and diffuser system design must consider the minimum distance which is necessary to guarantee the decay of coliformes and the safety of the protected areas (beaches, areas for aquiculture etc). Also, a minimum depth of discharge is necessary to guarantee an efficient plume dispersion in the near field.

When the onshore treatment is preliminary it is necessary longer outfalls with deeper point of discharge from the diffuser systems. For shorter outfalls it is possible the necessity to improve the level of onshore treatment.

It is clear that, independently of the land treatment adopted, the presence of a submarine outfall reduce significantly the risks for public health and the damages for the environment from the effluent disposal. Therefore, sustainable systems must consider the benefit-cost relationship level of land treatment versus submarine outfall length.

Currently, there are nearly 150 submarine outfalls in Latin America and Caribe. In these regions there is a predominance of preliminary treatment condition or absence of land treatment and, in many cases, without an adequate study of the environmental effluent impact in the mixing zone of discharge and also in the water permit for bathing region.

In more developed countries like in the European Community, Spain for instance, a secondary treatment has been adopted and the technology of “Lodo Ativado de Alta Taxa” has been common with a reduction of 50 to 70% of DBO. In this case of treatment there is no removal of nutrients, and the main objective is the removal of the organic load. In these cases also, the great depth of discharge combined with strong currents help the complete mixture of the submerged plume (Echavarri-Erasum et al., 2010).

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In the same way, in Florida – USA, with six submarine outfalls, secondary treatment has been adopted (lodo ativado em batelada), and organic load is removed, including suspension solids and disinfection. In these cases, a small part of the volumetric effluent is applied in water reuse activities (Heaney et al., 2006).

Although some countries have been adopted secondary treatment with good results in the conservation and recovering of water bodies, the option of preliminary treatment accomplished with submarine outfalls has been proved a good solution, when a discerning system design is used. Good examples are Cartagena in Colômbia, La Puntilla, in Cuba and Guarujá, in Brasil.

Actually in Brazil the new CONAMA resolution 430 (2011) establishes preliminary treatment as a minimum to be adopted before to effluent launch in the submarine outfalls. Considering that submarine outfalls in Brazil have been designed and constructed by different companies, national or international, many times with a lack of systemic vision of the environmental impact process, and with an incomplete base of data for the design (Ortiz et. al, 2006) they must be improved in terms of project and construction to be in conformity with CONAMA 430.

São Paulo State coast suffer from basic sanitation problems and this situation must be worst considering that the population is increasing in this region for the next years. North coast of São Paulo State reaches four municipalities: Ubatuba (711 km2), Caraguatatuba 484 km2), Ilhabela (347 km2), Bertioga 491 km2, São Sebastião (401 km2). The regions has 41 islands, 16 islets, 14 flagged floor diffused in the coast region. The condition of basic sanitation of the region in 2011 is presented in the table 1 (CETESB - Relatório de Balneabilidade, 2011).

Table 1: North Coast Basic Sanitation of São Paulo State

Municipality	Maximum Population	Collecting Percent	Treated Sewage Percent	Polution Load (kg DBO/dia)			Receives Body
				Potential	Removed	Remaining	
Ubatuba	80.604	33%	100%	4.200	1.793	2.407	Rivers/sea
Caraguatatuba	104.150	51%	100%	5.347	2.454	2.893	Rivers/sea
Ilhabela	29.308	4%	10%	1.388	5	1.383	Rivers/sea
São Sebastião	76.344	43%	71%	4.013	961	3.052	Rivers/sea
Bertioga	47.645	33%	100%	2.604	773	1.831	Itapanhaú River

In São Paulo south coast the experience with wastewater disposal through submarine outfalls is concentrated in urban regions of large populations, like: Praia Grande, Santos e Guarujá. In the north coast there are some experiences with smaller population like in São Sebastião and Ilha Bela. Actually some of these outfalls are under reformulation.

Actually there are seven submarine outfalls for sanitary wastewater disposal in São Paulo State coast, operated by SABESP: two in Praia Grande (a third is under construction), one in Santos (under reformulation), one in Guarujá, two in São Sebastião and one in Ilhabela (see table 2).

In 2002, CETESB (Companhia de Tecnologia de Saneamento Ambiental) began a monitoring program of these systems taking samples of two outfalls which were complemented by the hydrodynamic modeling of the plume dispersion process in the mixing zone to have an evaluation of the environmental marine impact (Ortiz et al, 2006; Lamparelli, 2006).

Tabela 2: Some characteristics of the São Paulo coast submarine outfalls.

Outfall Location	Treatment Level	Output (m3/s)	Lenght (m)	Depth (m)	Population	Receives Body
Ilhabela, Saco da Capela	Preliminary	0,03	220	24	4.848	São Sebastião Channel
São Sebastião, Pta de Araçá	Preliminary	0,012	1.068	9	1.600	São Sebastião Channel
São Sebastião, Pta de Araçá	Preliminary	0,14	1.061	8	21.396	São Sebastião Channel
Guarujá, Enseada	Preliminary	1,447	4.500	14	445.858	Atlantic Ocean
Santos, José Menino	Preliminary	5,3	4.000	10	1.332.100	Santos Bay
Praia Grande I, Praia Forte	Preliminary	1,041	3.300	12,5	253.755	Atlantic Ocean
Praia Grande II, Vila Tupi	Preliminary	1,361	3.400	13	348.635	Atlantic Ocean

The results of the monitoring program evaluation showed that the system of Santos estuary is considered the most critic of São Paulo State coast in terms of degradation of marine water bodies. This situation is the result of the Petrochemical Pole of Cubatão, of the wastewater outfall disposal in the interior of Santos bay and, of the diffusion pollution from clandestine wastewater, which came from the irregular use and occupation of the Baixada Santista coast area (Subtil et al, 2013).

The preliminary treatment, combined with a short outfall length inside the Santos bay, with a mean volumetric discharge of 3 m3/s have caused an environmental degradation in the mixing zone of the bay with the eutrophication of this area, where large values of ammonia, nitrogen and phosphorus, together with low concentration of oxygen dissolved, have been occurred. Currently the wastewater submarine disposal system is passing through a remolded to fits according with CONAMA 430/2011 new resolution.

Maintenance and adequate operation of submarine outfall sanitary systems, together with proper location of wastewater discharge point and proper choose of combination land treatment level versus submarine outfall length are the receipt to get an advantageous benefit cost relationship for the decision solution using wastewater through submarine outfalls. A good environmental legislation could help in this decision.

1.2. ENVIRONMENTAL LEGISLATION

During a long time CONAMA resolution 20/86 was used for the quality control of coastal water in Brazil establishing the standard of saline waters bodies and the emission standards to be applied in the case of ocean disposal wastewater. In 2000 this resolution was complemented by CONAMA 274/00, which defines the proper bathing criteria of the beaches.

A revision of CONAMA 274, resulted in the CONAMA 357/05, both presenting a significant improving with the introduction of new parameters limits to be considered together with four classes of water for the water resources management. CONAMA 357 introduces, for the first time, the concept of mixing zone defines as “the region of the water body where the effluent initial dilution occurs”, and provide the regulation of the wastewater disposal by definition of conditions and standards of parameters concentrations in the point of effluent discharge. CONAMA 430/11 refines the previous resolution and incorporate the concept of ocean disposal through submarine outfalls.

1.3. OPTION FOR SMALL COMMUNITIES

Many debates have been occurred to compare the solution of waste disposal through submarine outfalls accomplished with a preliminary onshore treatment, with a solution of a traditional onshore treatment (primary, secondary or tertiary treatment station) in terms of benefit cost of each solution.

Publications of Ortiz et al (2006), Arasaki e Ortiz (2006), Souza et al (2007) and Freitas (2009) show that the option for submarine outfalls, in many cases, is more economic and is a competitive solution for Brazil and São Paulo coast, also considering the environmental impact coast.

Arasaki (2006) proposed some references per capita values for cost comparison between classical onshore treatment sanitary station using process of *Lodo Ativado em Batelada* - ETE/LAB and submarine outfalls with onshore preliminary treatment. Her results show that a value of order R$ 100.00 per capita could be assumed as a first approximation, but her results also show smaller values for the submarine outfalls solution system.

Although the option for submarine outfalls is more predominant for large communities (population larger than 200,000 inhabitants), it is increasing the interest for this solution in smaller communities, considering the new technologies of construction and materials available and considering the robotic technology application for monitoring oceanographic services. This solution could be a good alternative, in terms of benefit cost, instead to use standard onshore treatment station in each beach community.

1.4. COMPUTER MODELING APPLIED TO THE DESIGN AND MONITORING WASTEWATER SUBMARINE OUTFALLS DISPERSION PROCESS.

Nowadays, the use of computer models for the simulation of submarine outfall wastewater plume dispersion process is always necessary in the decision process take by environmental agencies and by companies which are responsible to sanitary waste treatment (Ortiz & Bessa, 2004). These models must solve the hydrodynamic plume dispersion field, which results are coupled with some kind of water quality model. In other words, they must give an answer in terms of pollutant concentration in the mixing zone and proper bathing condition near the coast line. The diffuser system (location and design) has a key importance in the success of this kind of solution. The diffuser system must be designed and constructed to maximize the initial dilution and to guarantee the coliform abatement in the mixing zone and to minimize the environmental and public health impact, considering the level of sanitary treatment previously defined in land.

According Ortiz et al. (2006) some questions are important and must be answered for the definition of the mixing zone:

- What is the waste plume dimension ?
- What is the plume distance from the beach ?
- Which parameters must be monitored ?

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- What is the real location of the diffuser system ?
- How many nozzle or risers are in operation ?
- How the diffuser operates during its operation life ?
- How is the subaquatic inspection frequency in the diffuser region ?

Answer to these questions are function of the major investments to get technological information which are supported by use of computer modeling, environmental monitoring campaign in the region and development of work routines which could permit to follow the performance of the submarine outfall.

Nowadays, there are several softwares which can be used to model wastewater plume dispersion process, like Visual Plume and CORMIX, which are used by the Environmental Protection Agency – USEPA, to simulate the efficiency of a diffuser in terms of the initial dilution in the near field. Other softwares are used to simulate the general hydrodynamic and the water quality, also in the far field, like DELFT 3D, MIKE 21, SIsBAHIA, AQUALAB etc.

The main objective of this work is the use of hydrodynamic numerical modeling in the coast region of Boracéia beach in the Bertioga municipality in São Paulo state to verify the technical and environmental viability of a submarine outfall implantation for domestic wastewater proceeding from this community, which has less than 30,000 inhabitants. It is searching in this study to establish a diagnosis of this system behavior based in the observation of the wastewater plume dispersion process and the possible exposure of water quality in the area limited by 300 m from the beach.

2. MATERIALS AND METHODS

According to Marcelino and Macedo (2006), during the preliminary study of the viability of a wastewater submarine ocean disposal it is necessary:

- Environmental evaluation of the region;
- Consulting to the nautical maps;
- Consulting to oceanography, geological and geotechnical studies available;
- Consulting to scientific publications available;
- Verification of legal impeditive according with the classification of the coastal zone;
- Consulting to the community.

Following these premises, computational modeling was applied and volumetric effluent discharge was estimated considering a population of 25,000 inhabitants with a consumption per capita of 200 L/dia, coefficients of consumption equal 1, resulting in 58 L/s. The nutrient parameter used for analysis was phosphorus, with a concentration of 5 mg/L in the point of discharge.

Delft3D was used for the hydrodynamic modeling of the coastal region, including the coastal rivers and the estuary. Delft3D is an integrated suite of software, which make possible to simulate flow, waves, advection, dispersion, sediment transportation, morphology changes, water quality control by using bidimensional or tridimensional models. In the study here presented it was used the module Delft3D-FLOW for bidimensional simulation considering the initial plume already in the surface after the discharge.

The bathimetry was reproduced in the model using data from nautical maps of the region. A grid with a bidimensional cells of nearly 100 x 100 m was generate (Fig. 2). For the tide entrance, in the east boundary of the model it was introduce the harmonic constants determined by the maregraph located in São Sebastião harbor and in the east of Ilhabela (Saco do Sombrio), which results are disposable by *Marinha do Brasil* in internet. Tidal data from Ilha do Montão de Trigo were also used for comparison and calibration. In the west boundary the data were obtained from the Oceanography Institute models using a temporal series for the period of 2004 to 2005, with intervals of 1 hour. The inferior boundary of the grid was considered for the effect of closed boundary.

The values adopted for the coastal rivers discharge affluent to the region were extracted from a report of *Agência Nacional da Água* (ANA) 2001, using mean annual flow. For the salinity and temperature entrance data it was applied constants values of 34.6 ppt (marine waters), 5 ppt. (rivers water) and constant temperature of 22.75°C, respectively.

The period of simulation was of 31 days (July 1, 2005 to July 31, 2005) and the analysis of the plume hydrodynamic behavior was done in some choose position considering two points of discharge per comparison: 1800 and 4000 m from the beach. The results of phosphorus concentration were compared with the standard value of CONAMA 357/2005 resolution, which establish for saline waters of class 1 a concentration of 0,062 mg/l of total phosphorus.

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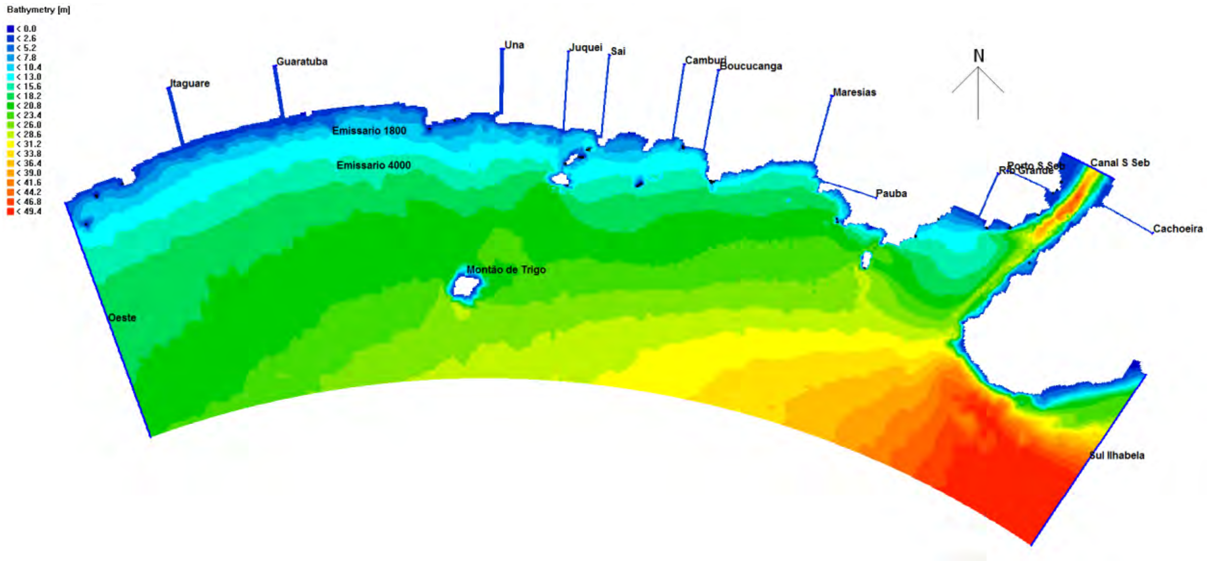

Figure 2. Bathimetry image of the modeling region between the small bay of São Lourenço and the São Sebastião island.

3. RESULTS AND DISCUSSION.

Figures 3 to 6 present the images of some phosphorus concentration results for some days of simulations, considering the outfall length from the beach with 1800 m (figures 3 and 4) and 4000 m (figures 5 and 6), respectively. Figures 7 and 8 present phosphorus concentration in the respective points of effluent discharge, as time function.

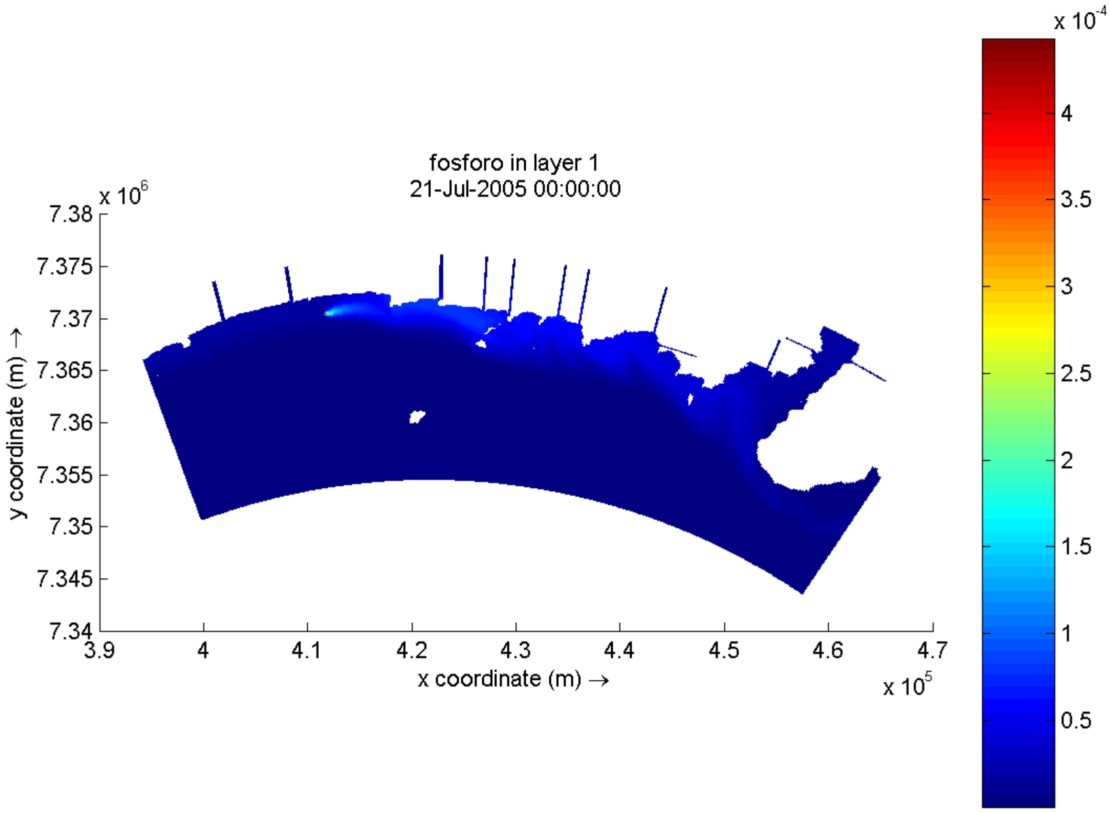

Figure 3. Phosphorus concentration distribution with effluent discharge point 1800 from the beach, after 21 days of simulation (values of concentration in mg/l)

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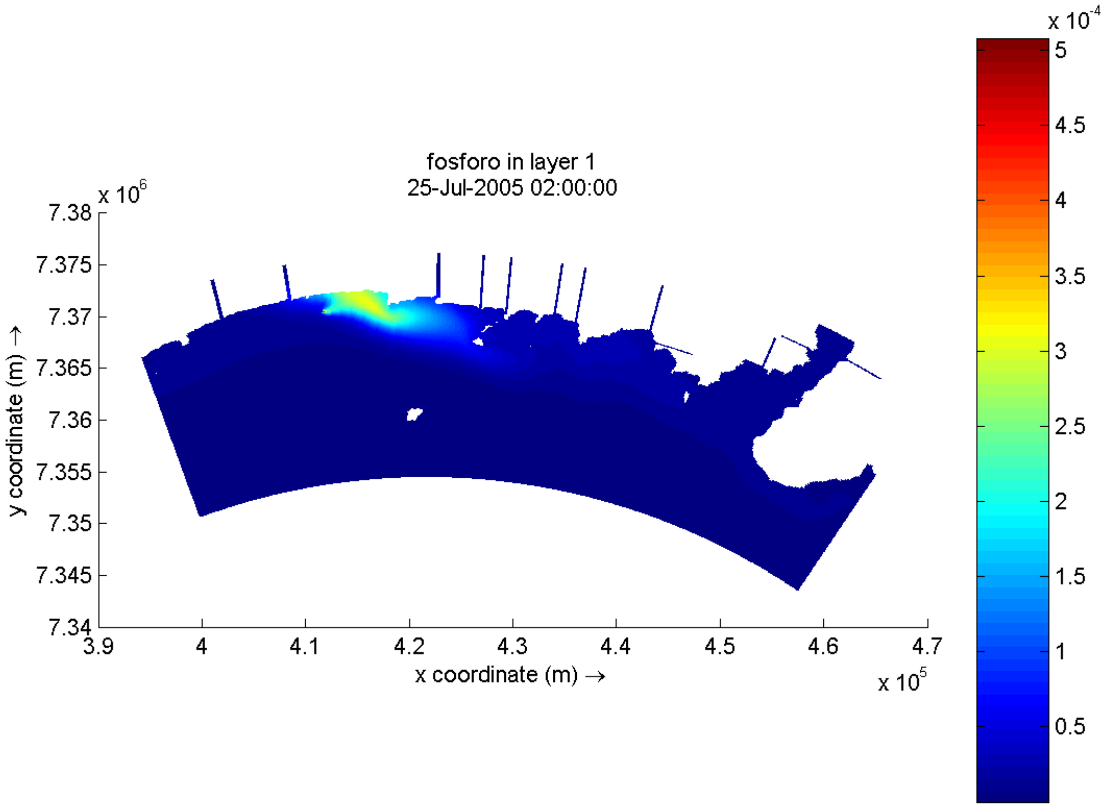

Figure 4. Phosphorus concentration distribution with effluent discharge point 1800 from the beach, after 25 days of simulation (values of concentration in mg/l)

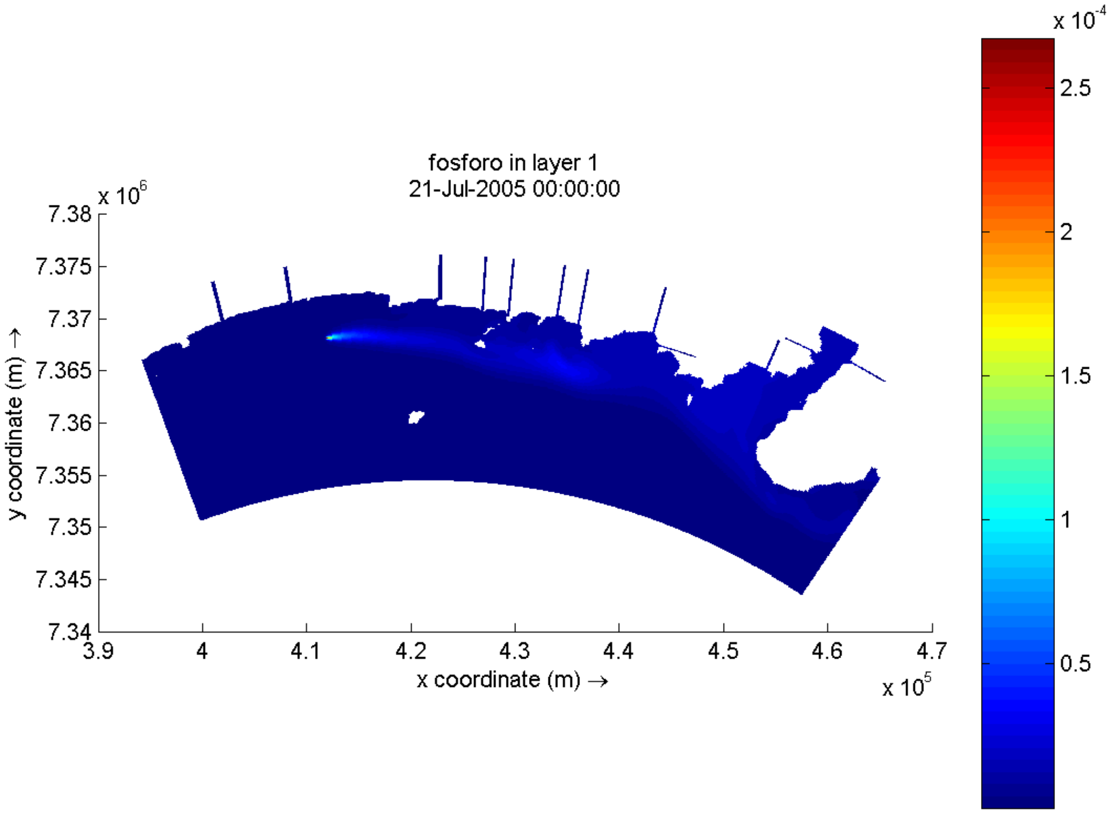

Figure 5. Phosphorus concentration distribution with effluent discharge point 4000 from the beach, after 21 days of simulation (values of concentration in mg/l)

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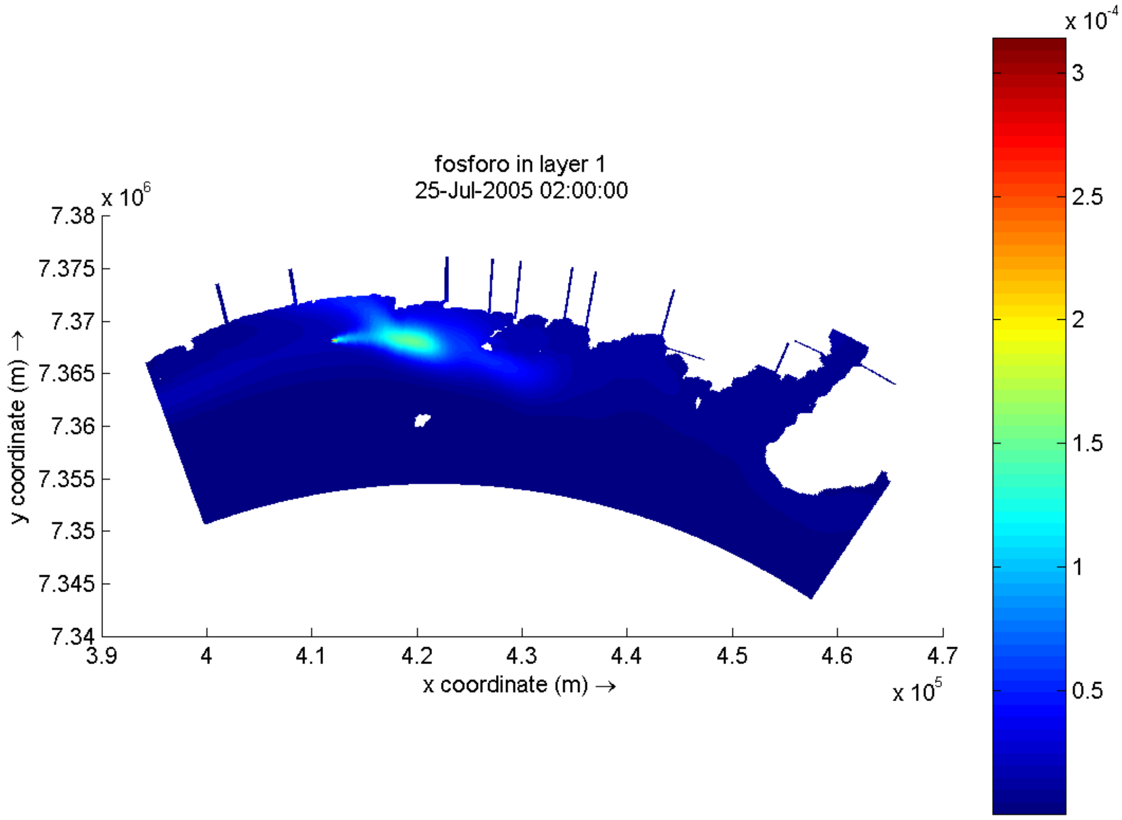

Figure 6. Phosphorus concentration distribution with effluent discharge point 4000 from the beach, after 25 days of simulation (values of concentration in mg/l)

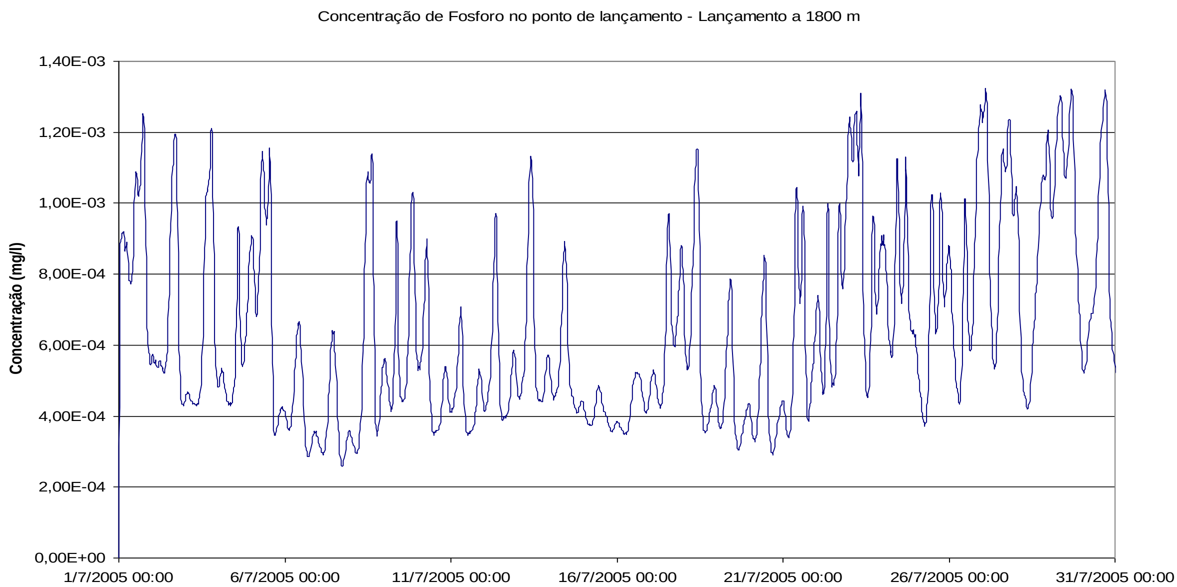

Figure 7. Phosphorus concentration in the discharge point for submarine outfall with 1800 m

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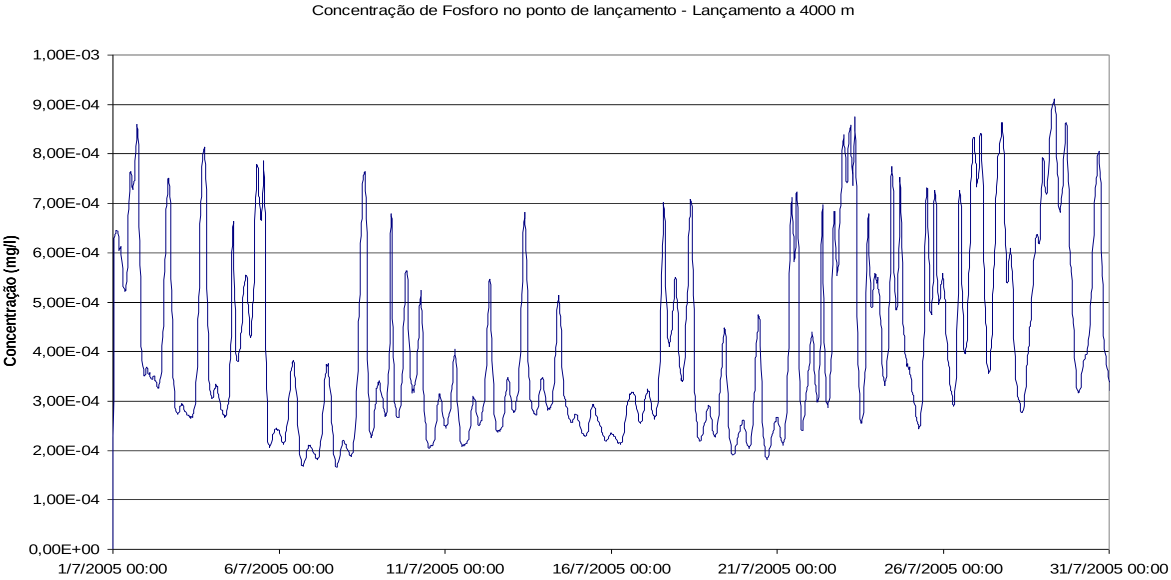

Figure 8. Phosphorus concentration in the discharge point for submarine outfall with 4000 m

The low value of effluent discharge combined with the high dilution permit that the concentration limit of phosphorus, according CONAMA 357/2005, for saline water of class 1 (0.062 mg/l), is already satisfied in the discharge point (see figures 7 and 8). These results suggest that the effluent discharge point could be near the coast line diminishing the cost and the complexity for the implantation of a submarine system in the local. However, it is important to note that the plume, following the preferential current, tends to maintain parallel and near the coast line, although, with 4000 m outfall length (figures 5 and 6) the interaction of plume with coastal line is much smaller when compared with 1800 outfall length (figures 3 and 4). It is necessary the simulation with 3D model to obtain the concentration field and the dilution process in the water column, particularly looking the possibility of vertical stratification in the column.

To improve the simulation modeling results it is necessary a campaign of field data to refine the east and west boundary entrance conditions and considering the inferior boundary as an open boundary. This improvement will permit to approach the boundaries for simulation and to refine the grid cells, optimizing the time of computer for simulations. New demographic studies are also necessary, considering the population growing in the region and bring to date the value of design discharge system.

4. CONCLUSION

The preliminary results here presented show the high technical and environmental potential for a sanitary treatment system using a submarine outfall for Boracéia beach in Bertioga municipality, considering the condition of open sea, high dilution and low discharge. However it is necessary to deepen the modeling research increasing the demographic, hydrologic, oceanography and environment data base in the region.

It is hope that this study could subsidized decision process for sanitary wastewater treatment system in coastal region with population to be served smaller than 50,000 inhabitants.

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