ASSESSING THE IMPACT OF SEVERAL DEVELOPMENT SCENARIOS ON THE WATER QUALITY IN SANTOS ESTUARY

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1 INTRODUCTION

Growing human populations and associated infrastructures in coastal areas have been gradually destroying the balance between terrestrial and marine environments. Among these human pressures, the impact of sewage inputs and urban runoff has been highlighted as a major global problem requiring urgent action. Faecal pollution is a consequence with serious implications for human health. Eutrophication is another symptom with direct consequences for the ecosystem. Eutrophication is usually recognized as an undesirable effect, a fact that explains the numerous recommendations regarding reduction of nutrient inputs from wastewater treatment issued over the past decades (e.g., Helsinki Comission - HELCOM).

The Santos area faces the same basic problems experienced by many developing countries, such as shortage of adequate housing and lack of sewerage system (Garreta-Harkot 2003). There is growing anthropogenic pressure on the coastal zone resulting from the main socio-economic Drivers that include the rapid increase in the coastal population, industrial development, etc. Input of domestic sewage and estuarine discharge has been pointed out as the main source of eutrophication in this system (Moser et al. 2004), and studies have established a link between the contribution of Santos and São Vicente estuaries as the major cause of eutrophication of Santos bay (Moser et al. 2005).

The development of management policies for the Santos estuary has to deal with faecal pollution and eutrophication-related problems. An informed management for a sustainable use of estuarine services requires the capacity to assess their state, and to predict future states in the face of different development perspectives and choices. The definition of development strategies must consider that the existing Pressures can be mitigated or additional ones can appear. In addition, the overall Impact on the environment must be forecast. Part of this effort can be achieved by testing the result of different development scenarios with numerical model simulations. Models are increasingly becoming indispensable tools in environmental studies and management decisions. In the DPSIR framework models are commonly used to elucidate each component and the relation between different the different components (e.g., the pressures with the state). Combining the DPSIR with numerical models allows the generation of predictions on the potential levels of selected impacts, allowing policy makers to promote responsive remedial or mitigating actions before the predicted impacts manifest themselves in the environment.

This chapter describes such a modelling study, made to assess and forecast the result of four different management scenarios for wastewater disposal in the Santos Estuary. The study aimed to characterize the extension and degree of microbiological contamination and changes in the eutrophic state in the estuarine waters of Santos under different input scenarios of urban discharges and temporal and spatial evolution. This study does not address the feedback implications that each development scenario has on the socioeconomic activities in the Santos area.

2 DEVELOPMENT SCENARIOS

The simulated scenarios include a number of possible scenarios within the field of probable. The conditions that range from the "business as usual" scenario, i.e., no changes to the actual conditions, meaning that no actions are taken or management policies implemented to improve the sewage treatment and disposal, to an "optimum case" scenario (hypothetical). In this last scenario the population growth and its impact is minimized by adequate management procedures that significantly reduce untreated domestic sewage discharges into the estuary. The "business as usual" scenario is used as the reference condition.

Two intermediate scenarios have been projected having in mind the changes that are expected to occur in the estuary as a result of projected improvements in the sewage drainage system, such as the implementation of drainage systems in some slum quarters already urbanized, the construction and extension of the actual system in other areas, and the treatment of sewage effluent prior to disposal inside the estuary. These scenarios result from a prospective analysis that was made considering the main Drivers in the system. Finally, the fourth scenario, the "optimum case", is based on hypothesized desirable conditions.

The sewage input for all scenarios was estimated according to current sanitary conditions, future projects in basic sanitation foreseen for the region and one hypothetic scenario. A qualitative and quantitative secondary data survey on urban discharges was carried out on the model's land boundary, that is, all over the estuary's drainage basin, in order to characterize and estimate the pressures resulting from current urban occupation. This estimate was based on the data survey of a group of socioeconomic components related to the homes' sanitary characteristics described by Sampaio and Ferreira (this volume). Their data were obtained from the last demographic census (IBGE 2000) and from internal data from the Companhia de Saneamento Básico do Estado de São Paulo (São Paulo State Basic Sanitation Company - SABESP). By cross-checking these sources of information, it was possible to estimate quantitatively and more accurately the volumes drained to the estuary without treatment from the homes without a connection to the sewage drainage network and the loads of domestic effluents from the sewage treatment stations and the submarine outfall.

The discharge points defined in the simulations (Figure 1) were set based on current information on the sanitary conditions of the basin, so that a numerical reference scenario for the current situation could be established. Once this stage - consisting of the implementation, calibration and validation of a water quality model - had been accomplished, it was possible to prospect future development conditions. Thus, the aspects that involve the lack of coverage of urban sanitary services were also analyzed in a projection towards 2010 and 2015, to assess the impact of population growth and the possible advancements of public policies foreseen in this temporal window. Besides, the simulation of a hypothetical scenario - where all the loads that were not addressed by sanitary projects until 2015 were directed to treatment stations or to the existing outfall - was included in order to verify what the results achieved were.

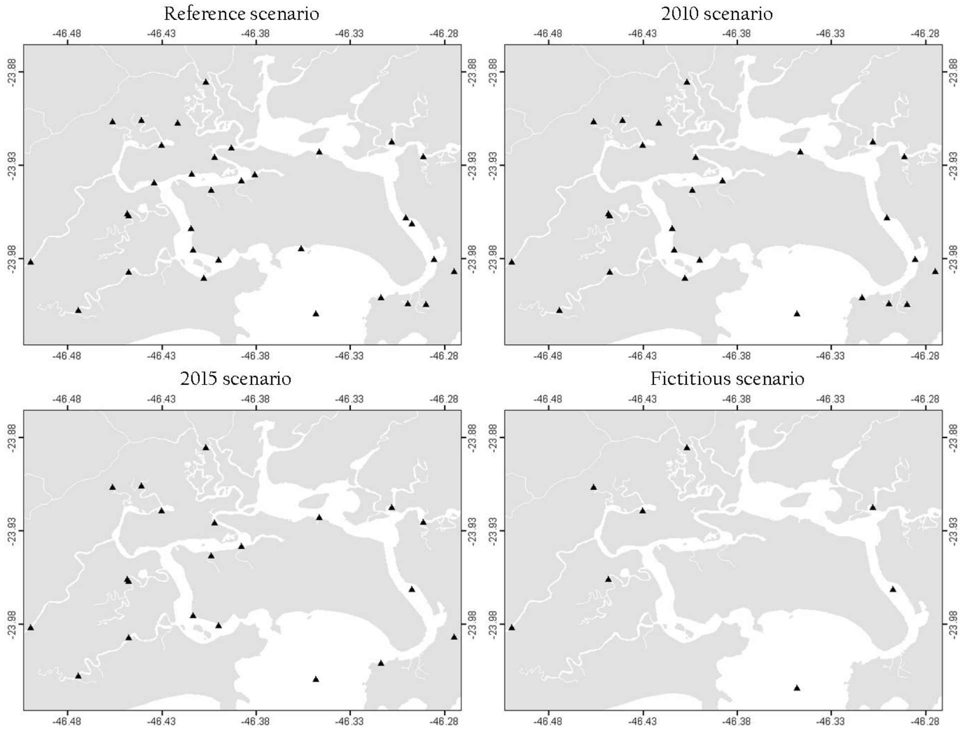

FIGURE 1: *Sewage discharge points for each scenario.*

2.1 Scenario 1: "business as usual"

This scenario can be seen as the "worst case scenario" since it implies that the actual situation is not improved by remedial actions. This scenario considers 31 sewage discharge points, three sewage treatment plants (STP) and the submarine outfall. This is considered as the reference scenario and has been addresses by Sampaio et al. (this volume) for the faecal pollution and by Mateus et al. (this volume) for the ecology.

2.2 Scenario 2

This scenario (2010 scenario) considers 27 sewage discharge points that include the improvements in the sewage drainage systems provided by the works announced for the region by the federal government and also an increase in sewage generation incurred by the estimated populational growth. Among the major changes from the reference scenario (Scenario 1) is the diversion of some sewage discharges from Piaçabuçu River to the Praia Grande outfall, part of the sewage diverted to the Santos outfall in the bay, the increase in the loads at Site 8 as a result of urban development in the surrounding area, and an increase in the discharges at Pompeba area.

2.3 Scenario 3

This scenario is based on predictions for the year 2015 for population growth and the sewage system improvement work that will be developed from 2010 to 2015. It considers 21 sewage discharge points. Compared to the reference situation, in this scenario the water treatment plan (WTP) flow at Cubatão is over three times higher, there is a new WTP at Santos channel, the diversion of some sewage discharges from Santos channel to the Guarujá outfall. Also, the sewage outfall flow in the bay was increased by 0.5 $m^3\ s^{-1}$ and its point of disposal moved 400 meters seawards. Improvements from ”Onda Limpa”, a great sanitary project (Diário do Senado Federal 2004) were included in addition to the previous works already foreseen in the 2010 scenario. Scenarios 2 and 3 were designed according to data provided by stakeholders, and existing chronograms being that analysis based upon the dates predicted for the end of the works.

2.4 Scenario 4: ”optimum case”

This is a fictitious scenario where all but three of the remaining slum quarters are connected to the sewage drainage network and directed to the submarine outfall or to sewage treatment plants. The loads have been calculated for the expected population in 2015.

3 MODEL SIMULATIONS

The water quality model used here to simulate the ecological dynamics and faecal pollution have been previously calibrated and validated (see Mateus et al., Sampaio et al., this volume) and the results presented in these previous modelling studies used to characterize the reference state. As such, the modelling settings used in the present study (forcing functions, initial conditions, assumptions, etc.) are the same as defined in these chapters. The only differences between scenarios are the discharge points inside the estuary and the loads.

Unlike the majority of water quality indicators, faecal contamination is a bioindicator. This means that it’s persistence time in aquatic systems is short, usually ranging from less than an hour to a day, and occasionally up to a few days days. Thus, even in intense hydrodynamic regimes, the range of their spreading is limited. The short life span of these organisms means that modelling fecal decay in aquatic systems can be done with small-scale applications and short-time runs. As such, the simulations to assess faecal pollution were made for a period of one month to comprise a full spring-neap cycle. The period of simulation for the ecological model, on the other hand, was set to 10 years to allow the system to stabilize under the new forcing conditions imposed in each scenario. The nutrient loads for each scenario were calculated based on the population growth estimate and according to the methodology previously described by Mateus et al. (this volume). In Table 1 are the sewage inputs of faecal coliforms concentration for the Submarine outfall, sewage treatment plant (STP), slum quarters and quarters out of sewage drainage (not treated) and the respective effluent flow for the sewage discharge, both used for all scenarios.

TABLE 1: *Sewage discharge points, the fecal coliform concentration and the respective effluent flow ($m^3\ s^{-1}$) for all scenarios. Discharges include the outfall, sewage treatment plants (STP), slum quarters and quarters beyond sewage drainage (Not treated). (*) Estimated value for new STP.*

Sewage discharge points	MPN/100ml	Reference	2010	2015	Fictitious
Not treated	1.00×10^8	0.436	0.361	0.134	0.012
STP Cubatão	3.72×10^5	0.200	0.210	0.322	0.347
STP Humaitá	5.30×10^5	0.040	0.042	0.049	0.061
STP Samaritá	2.30×10^5	0.040	0.046	0.049	0.094
Santos submarine outfall	7.48×10^6	2.500	2.674	3.003	3.271
STP Vicente de Carvalho	5.00×10^5*	---	---	0.267	0.273
	Total	**3.216**	**3.333**	**3.824**	**4.058**

4 MODEL RESULTS FOR THE DEVELOPMENT SCENARIOS

4.1 Faecal pollution

Regarding scenario 2 (2010 scenario), although some changes were made compared to the reference scenario, such as reducing the *in-natura* sewer contribution in the estuary, the model showed that there was an increase in faecal contamination in many places (Figure 2), mainly in the areas previously described as critical, like point 6. This was due to population growth, resulting in an increase of the discharges (flows and loads). Therefore, in general, the alterations attributed to this scenario showed that there was no significant improvement in the quality of the water of the estuary, as a consequence of population growth.

Results for scenario 3 (2015 scenario) show a significant reduction on *E. coli* concentrations when compared to the previous scenarios (Figure 1 and 2). The main reduction was observed in the Santos channel (P1 and P2), with the sewage treatment from Vicente de Carvalho quarters through the implementation of a new STP and the removal of three discharge sources associated to irregular dwellings in Guarujá to the outside of the basin. In São Vicente, the Jockey Club quarter link in the sewer line only caused a small improvement of water quality at Largo da Pompeba area (P6), probably due to the significant number of slum quarters in this area. *E. coli* concentrations are still close to 10^3 MPN/100ml. Concentrations at São Vicente channel are still high, more likely due to Mexico 70 slum quarter contribution (a densely populated slum quarter). This sewage input has a great impact on the water quality of the place.

However, the influence of São Vicente channel at Santos - São Vicente bay has been greatly reduced (Figure 3), compared to the reference scenario.

Finally, for scenario 4 (fictional) it is obvious that the connection of untreated sewage areas with the sewer line (thus assuming that the whole population has basic sanitation) causes a great improvement in water quality at the Santos estuarine system, as the model results for this scenario clearly corroborate. (Figure 2 and 3).

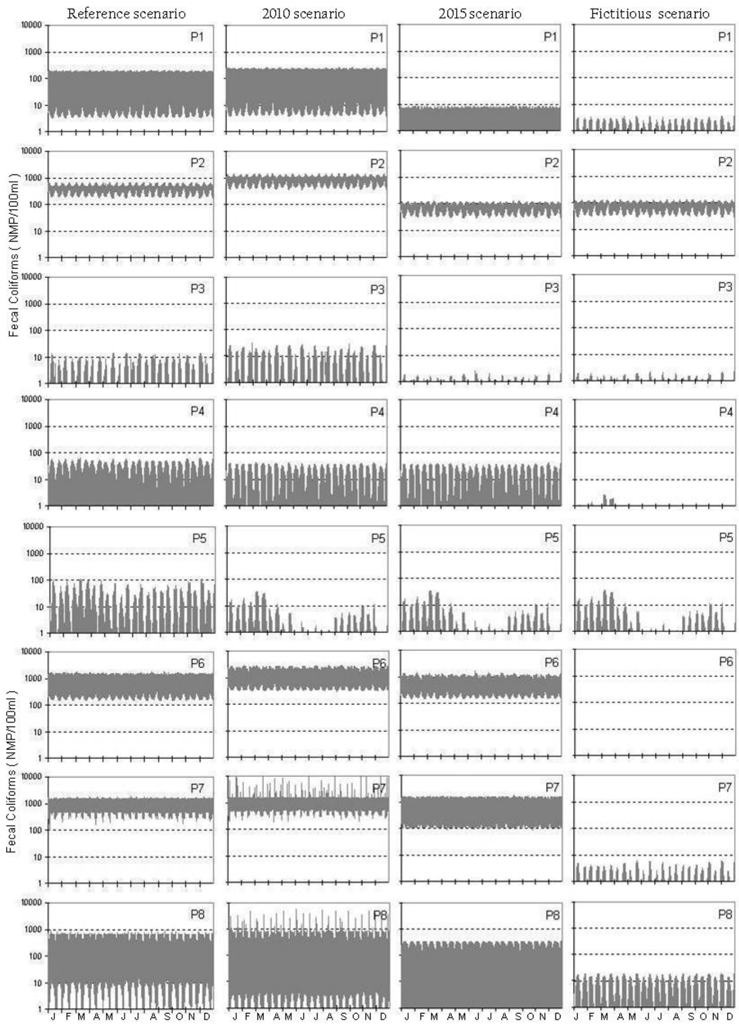

FIGURE 2: *Model results for E. coli concentration (MPN/100ml) at the monitored points for each scenario.*

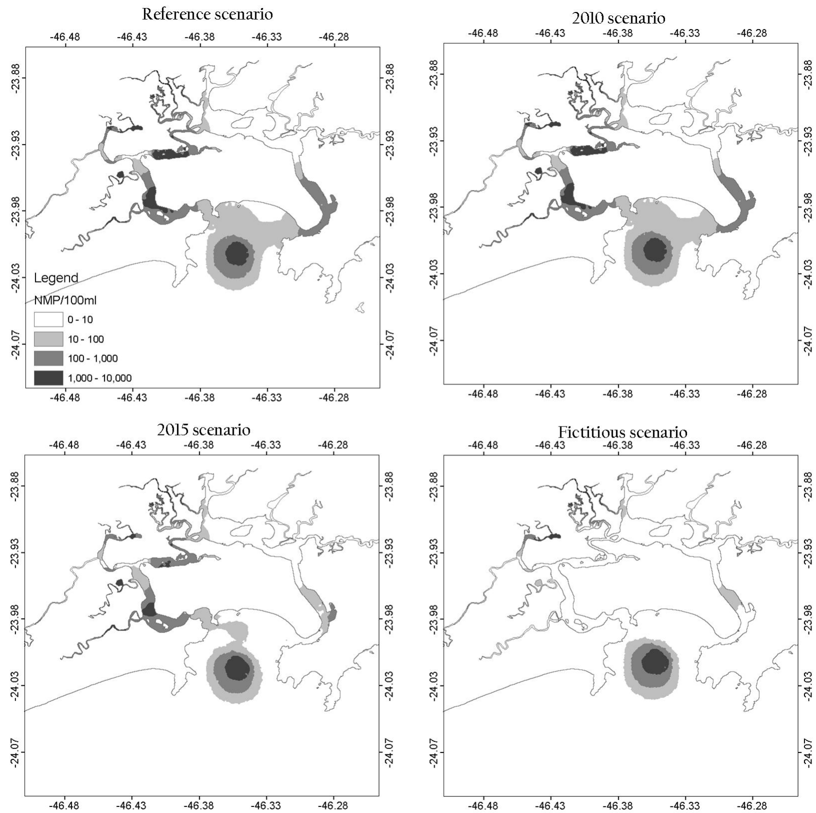

FIGURE 3: *Model results for fecal E. coli (MPN/100ml) for each sceanrio (same tidal conditions).*

4.2 Ecological status

The results obtained by the modification of the forcing conditions in the model (in terms of nutrient loads and input locations in the system) to generate a range of ”development scenarios”, generally conformed to expectations. Because nutrient inputs did not decrease from scenario 1 to scenario 2, and only slightly decreased from scenario 1 to scenario 3, the concentration of nutrients in the system is not significantly affected, as seen in Figure 4 for ammonia at various locations in the estuary. The most significant change is found when comparing the reference scenario with scenario 4. This is an expected occurrence since a part of the sewage has been diverted to the submarine outfall.

The decrease in nutrient concentrations in the system is not reflected in a general decrease in phytoplankton biomass (Figure 5). This outcome is not surprising considering that the estuary is a light limited system. As such, the magnitude of the reduction in nutrients achieved by the changes in each scenario does not seem to affect phytoplankton. The most expressive change is seen in scenario 4 at Station 8, suggesting that in this part of the estuary the conditions of this scenario are more significant.

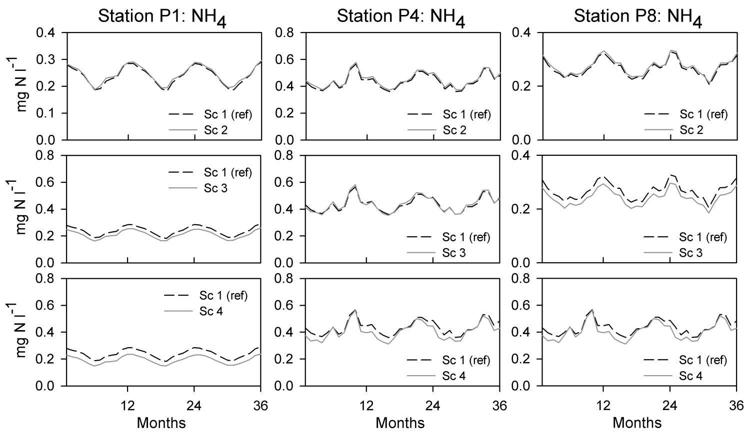

FIGURE 4: *Model results for ammonia at Stations P1, P4 and P8. Last three years of the 10-year simulation run.*

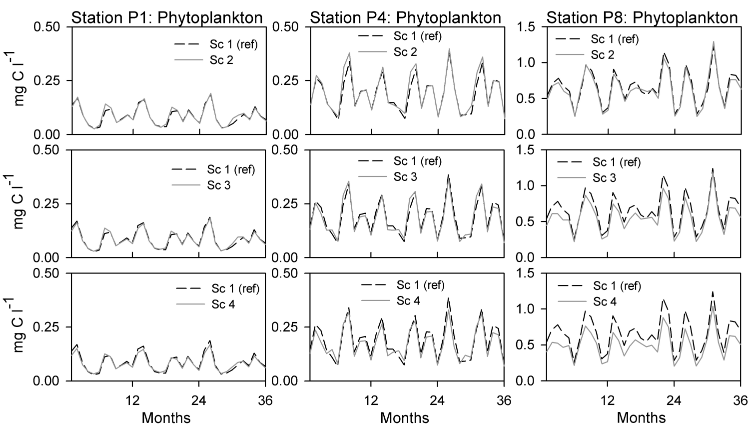

FIGURE 5: *Model results for phytoplankton at Stations P1, P4 and P8. Last three years of the 10-year simulation run.*

Dissolved oxygen concentration is one of the most important water quality parameters given the role of oxygen in the dynamics of aquatic systems. So, the health of a system can be assessed by looking at oxygen saturation in the water. The scenarios 3 and 4 tested in this study imply a reduction of nutrient loads to the system. Since a fraction of that nutrient load corresponds to particulate material, reductions in these inputs mean less bacterial activity, thus lower oxygen demand. The result of reducing organic matter inputs to the system is clearly seen in the results for dissolved oxygen concentrations (Figure 6). There are no apparent changes between scenario 1 and 2 but, as the reduction becomes more relevant in the other scenarios, the increase in oxygen levels becomes more significant. Hence, the largest changes are found when comparing the reference scenario with the fictitious scenario.

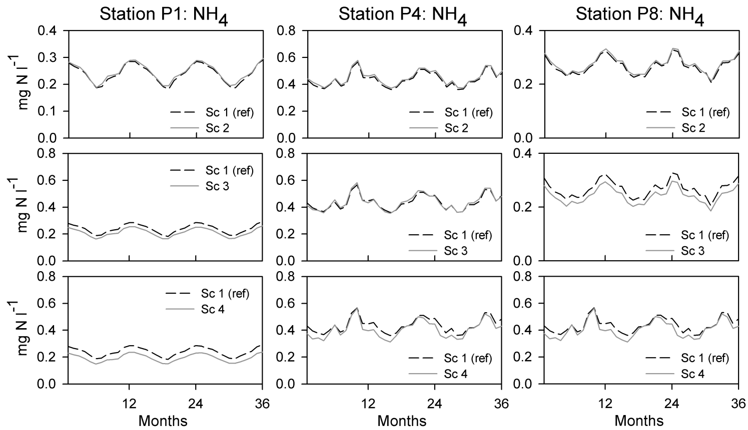

FIGURE 6: *Model results for dissolved oxygen at Stations P1, P4 and P8. Last three years of the 10-year simulation run.*

5 DEVELOPMENT SCENARIOS AND THEIR IMPLICATIONS

Results of future scenario analysis have suggested, as expected, that the treatment of domestic sewage effluents in the basin for the 2015 and fictitious scenarios reflected significant improvements in water quality, except for some points where critical zones remain due to the permanence of effluent discharges from the housing nuclei not included in these projects. The current and 2010 scenario analysis showed how the disorderly occupation of territorial space along with insufficient proper sanitary infrastructure can pose great threats for the riverside communities and other populations that use these waters for recreation, leisure and food. *E. coli* concentrations were some orders of magnitude above the level allowed for water bodies of Class 1, according to Resolution 357/05 from CONAMA (2005) which sets a mandatory maximum limit of 10^3 MPN/100 ml for brackish water. These values were estimated by the model under different tidal conditions and also obtained in laboratory analysis. Higher values imply human health risks in use of these waters by the population.

The estuary is subjected to intense anthropogenic impact from urban activities, manifested mainly in high loads of organic matter and nutrients discharged in the system. These pressures not only affect the (eu)trophic state of some parts of the estuary, but may also contribute to alter the ecologic dynamics of the system as a whole. The increase of both organic matter and nutrients in the system above background levels, as a result of eutrophication, poses serious threats. Oxygen depletion is one of the most serious threats that coastal systems such as estuaries can face (NRC 2000). If the enrichment occurs via the addition of organic material, then an increase in bacterial activity may be expected, leading to potential oxygen depletion, both in the water column and in the sediment. So, while not significantly changing the nutrient concentrations in the estuary, the decrease in nutrient loads from human occupation contributes to the increase in the oxygen concentration, as seen in the scenarios that have been tested. This is particularly relevant in a system like Santos estuary where the physical and biological characteristics can lead to anoxic conditions in the inner areas and in places where the water column may become stratified, or to less extreme conditions such as oxygen sags in places where residence time is long.

6 FINAL CONSIDERATIONS AND FUTURE WORK

Models are increasingly becoming indispensable tools in environmental studies and management decisions. This work shows the relevance of water quality modelling in the important and difficult task of integrated analysis of components responsible for the alteration of state in a dynamic environment under strong anthropogenic influence, such as densely populated estuaries. This study shows that even mild improvement of sanitary conditions (e.g. scenario 2) can already lead to situations where people, especially children, have free access to the water and may use it safely as a playground. From an ecological perspective, the results suggest that inappropriate management practices which result in an increase in nutrient inputs to the system, especially in the form of organic matter, inevitably contribute to its degradation.

This work represents the first step in the development of a water quality forecast system for the region, which can be used to improve the quality of future decision-making. Also, this study points to the benefit for the human and system's health if proper management practices are implemented with regard to the nutrient loads that reach the system in sewage. The results will provide relevant information to stakeholders for an effective management of issues related to the region's environmental sanitation, and to public health problems and further ecosystem degradation that might occur if appropriate management practices are not adopted.

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