IMPACT OF CASALITO WASTE WATER TREATMENT PLANT DISCHARGE ON ÓBIDOS LAGOON WATER QUALITY

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EXTENDED ABSTRACT

Human activities can cause strong alterations in the environment. As physically sensitive areas, coastal lagoons are particularly vulnerable to water quality deterioration and eutrophication problems caused by population growth, urbanization and effluent disposal. Óbidos Lagoon is a small and shallow coastal lagoon subjected to different environmental pressures. One of these pressures is the effluent disposal of the Casalito Waste Water Treatment Plant. Presently, this urban discharge serves a population of 920 resident inhabitants but is expected to serve a population of 10000 in the near future.

This study reports the effect of the urban discharge upon primary production and fecal coliform contamination in Óbidos Lagoon. To study the impact of the discharge is very important; this ecosystem was considered vulnerable according to the national water authority (INAG-Instituto da Água) eutrophication criteria (Decree-Law nº149/2004, 22 June). The water quality in the lagoon must also respect the European Community Batching Water Directive (European Union Directive 76/160/EEC), which aims to protect surface water quality, as well as the national legislation referring to water quality (namely, Decree-Law nº236/98).

To achieve this goal a monitoring plan was developed; it includes field campaigns (with the determination of biological, physical-chemical and microbiological parameters) and a modeling approach. Field measurements were analyzed together with model predictions, to understand the feature of the discharge in the coastal lagoon. Fluctuations in the lagoon primary production and fecal coliform contamination, under distinct scenarios were analyzed: (i) reference situation; (ii) considering a system without the discharge; (iii) considering the inhabitants served in the near future (10.000); and (iv) considering that urban discharge serves 100.000 inhabitants (unreal scenario, preformed only for sensitive analyses of the ecosystem).

In general, it can be concluded that model results for the reference situation are in agreement with field measurements, demonstrating both that currently the impact of the urban discharge on lagoon water quality is very low. Predictions considering the inhabitants served in the near future (10.000) do not show significant differences in terms of nutrient concentrations and primary production (they are less than 1%). This result was already expected because the discharge presents a small contribution to the ecosystem in terms of nutrient (total nitrogen and total phosphorus) loads, when compared to river discharges. For the scenario with 100.000 inhabitants major differences occur in terms of nutrient concentrations with an increase of 50% for nitrate and 25% for ammonia. This is an unreal scenario, but very helpful to understand the lagoon response to nutrient loads.

Keywords: MOHID, Water Quality, Monitoring, Casalito WWTP, Óbidos Lagoon.
1. INTRODUCTION

Various factors may increase the supply of organic matter to coastal systems, but the most common is clearly nutrient enrichment (Nixon, 1995). The major causes of nutrient enrichment in coastal areas are associated directly or indirectly to human activities, which may cause strong alterations in the environment; population growth, urbanization, effluent disposal, intensive agriculture, aquaculture and coastal engineering place increasing demands in aquatic ecosystems. This can cause deterioration of water quality and eutrophication problems. Coastal lagoons are particularly vulnerable to these problems. They are regions of restricted exchange with the adjacent ocean and, thus, may accumulate nutrients supplied by the surrounding watershed. The European Environmental Agency calls such zones physically sensitive areas (Newton et al., 2003).

Located in the Portuguese west coast, Óbidos Lagoon has been for several years the main receptor of urban discharges coming from the western region of Portugal, although most of the WWTP discharges have nowadays been directed to the Foz do Arelho submarine outfall (operating since 2005; Malhadas, 2008). Currently the only urban discharge that is made directly into the lagoon is the Casalito WWTP discharge. It serves a population of approximately 920 resident and 2000 fluctuating inhabitants but is expected to serve a population of 10,000 inhabitants in the near future. In order to evaluate the impact of this urban discharge on the lagoon water quality, a monitoring program was developed; it includes the determination of biological, physico-chemical parameters and a modeling approach. Field data are useful to develop an understanding of the system and numerical model to evaluate the coastal system response in the future.

The main purpose of this study is to evaluate the impact of Casalito WWTP discharge in Óbidos Lagoon primary production and fecal contamination, considered a vulnerable ecosystem according to national water authority INAG (Instituto da Água) eutrophication criteria (Decree-Law n.º149/2004, 22 June). Also, the water quality in the lagoon must respect the European Community Batching Water Directive-EC WD (European Union Directive 76/160/EEC), which aims to protect surface water quality by controlling discharges that can compromise it, and other national legislation referring to water quality (namely, Decree-Law n°236/98). Fluctuations in the lagoon primary production and fecal contamination, under distinct scenarios were analyzed: (i) reference situation; (ii) considering a system without the discharge; (iii) considering the inhabitants served in the near future (10,000); and (iv) considering that urban discharge would serve 100,000 inhabitants.

This contribution is arranged as follows. Section 2 describes the study area, sampling sites and data measured in the lagoon and discharge; it introduces also the numerical model and its implementation. Section 3 presents an analysis of the observations and numerical simulations. Section 4 summarizes the major findings.

2. MATERIAL AND METHODS

2.1. Study site

Óbidos Lagoon (Fig. 1a) is a small and shallow coastal lagoon located in the west coast of Portugal (39º24´N, 9º17´W). With a surface area of about 7 km², the lagoon is 1.8 km long, 4.5 km wide and is connected to the sea through a shallow and narrow inlet. It is characterized by two distinct regions with different hydromorphological and sedimentary characteristics: the lower lagoon and the upper lagoon. The lower lagoon with several sand banks and channels is characterized by strong current velocities (~1.6 ms⁻¹) and low residence times (less than 3 days, Santos et al., 2004). The upper lagoon comprises a large shallow basin, two elongated bays (Barrosa and Bom Sucesso arm) and a small embayment (Poça das Ferrarias) on the southern margin (Oliveira et al., 2006). This part of the lagoon is characterized by low velocities, muddy bottom sediments (Freitas, 1989).
and high residence times in the arms (on the order of 3 weeks). Freshwater inputs come mainly from two rivers and one drainage stream: Arnóia river (3 m$^3$s$^{-1}$ average flow) and Cal river (0.14 m$^3$s$^{-1}$ average flow) and Vala do Ameal stream (0.08 m$^3$s$^{-1}$ average flow) (Vão, 1991). Arnóia River accounts for 90% of the freshwater input into the lagoon. Tides are semidiurnal with a tidal range varying between 0.5 to 4.0 m depending upon location and tidal phase (Malhadas et al., 2009). The influence of the tide extends to the entire lagoon, without pronounced longitudinal variation of salinity or stratification (Carvalho et al., 2006).

Casalito WWTP is located near the southern branch of the lagoon (Bom Sucesso) and presently discharges 4945 m$^3$month$^{-1}$ of water into the lagoon (urban discharge only).

![Figure 1](image)

**Figure 1:** (a). Geographical location of Óbidos Lagoon. Casalito WWTP and main freshwater tributaries are represented. Sampling stations in the lagoon (●) and in the tributary of WWTP discharge (●) are marked; (b). Bathymetry used in simulations. Depths are in meters (over the local datum).

### 2.2. Monitoring

Sampling was performed in four stations (Fig. 1a): one located in the tributary of the WWTP discharge (EC#1) and three in the lagoon (EC#2, EC#3 and EC#4). During 2008, four campaigns were carried out, in April, July, October and December in order to capture seasonal variability. Measured parameters include microbiological variables (total coliforms, fecal coliforms, *Escherichia coli* and Enterococos), total suspended solids (TSS), nutrients (phosphate, total phosphorus, nitrate, nitrite, ammonia and total nitrogen), and metals (nickel-Ni, copper-Cu, lead-Pb and cadmium-Cd). All determinations were performed using certified methods.

Temperature (°C), salinity (PSU), pH, saturated (%) and dissolved (mgL$^{-1}$) oxygen, turbidity (NTU) and chlorophyll (µgL$^{-1}$) were measured *in situ* using a multi-parametric sonde (YSI 6600-V2). The 6-series environmental monitoring systems are multi-parameter water quality measurement and data collection systems intended for use in research, assessment and regulatory compliance applications. Data accuracy is ± 0.15 °C for temperature, ±1% for salinity, ±0.2 unit for pH, ±2% oxygen and ±5% for turbidity. No information is available on the data accuracy of chlorophyll concentrations (YSI, 2006).
2.3. Modeling
The model used in this study is MOHID, a fully non-linear, three-dimensional and baroclinic water model. MOHID is developed in the Technical University of Lisbon (IST) and is under continuous development; the home page can be found at http://www.mohid.com. Some of the key features of the model are highlighted below and a complete description of the model can be found in Martins et al., (2001). The implemented modeling system is able to simulate the dynamics in the lagoon driven by tide and river flows; and also the ecological processes. It integrates hydrodynamic (Aires et al., 2005; Neves et al., 2000) and water quality models (Saraiva et al., 2007; Trancoso et al., 2005). The hydrodynamic model solves the 3D incompressible primitive equations and is prepared to simulate several properties (i.e. temperature, salinity and currents) in the marine environment. State variables, such as phytoplankton and macroalgae (primary producers), zooplankton (consumer), dissolved nutrients, dissolves oxygen, organic matter in the pelagic phase and organic matter in the benthic phase (particulate, refractory and non-refractory) are simulated in the water quality model.

The model applied in the Óbidos lagoon used a single layer-2D depth integrated model; it was assumed that the study area presents a homogeneous water column due to minor freshwater discharges and shallowness. Two different resolution grids were used: a finest for the hydrodynamic simulations (300 by 340 cells with a grid spacing of 25 by 25 m) and a coarser for the ecological processes. It is well known that ecological processes need longer simulations, at least 1 year; for that reason a coarser grid was used that results from the spatial integration of hydrodynamic bathymetry, merging 3x3 cells into one (Fig. 1b). The model was forced through prescribed surface elevations from FES95.2 global tidal solution (Le Provost et al., 1998) at the open boundary and rivers inputs at land boundary (flow rate and nutrients concentrations are provided by INAG). Casalito WWTP discharge was also used as a load in the land boundary (flow rate and concentrations measured in the discharge and, for the scenarios, estimated values based in the number of inhabitants served, were imposed). A more detailed description and hydrodynamic model validation of the 2D Óbidos Lagoon model can be found in Malhadas et al., (2009). Lagoon ecological model was also validated; the results can be found in unpublished work (IST, 2009).

3. RESULTS AND DISCUSSION
Analysis includes main physical-chemical parameters, nutrients and chlorophyll, microbiological parameters and metals. Numerical simulations are presented and analyzed in order to examine the current status of the ecosystem and its response in the future.

3.1. Monitoring
3.1.1. Physical-chemical parameters, nutrients and chlorophyll
These parameters were analysed distinctively for station EC#1 and stations EC#2, EC#3 and EC#4: the first station refers to freshwater (station in the tributary that receives the WWTP discharge before entering the lagoon) and the others to saltwater (stations within lagoon).

In station EC#1, temperature readings show variation according to the season, with minimum values in winter (15ºC) and maximum values in summer (25ºC). Salinity measurements always show freshwater typical values (0-1). Dissolved oxygen varies between 50-80% with no clear seasonal pattern. It is likely that oxygen concentrations are determined by temperature and organic matter, rather than season or primary production. pH values are around 7, as expected for freshwater. Turbidity and TSS show the same variation, as they are both measurements of suspended matter in the water, but no specific pattern. Values range from 0 to 30 for both parameters. Nitrate concentrations
range from 5 mgNL$^{-1}$ to 23 mgNL$^{-1}$, nitrite varies between 0.013 mgNL$^{-1}$ and 0.73 mgNL$^{-1}$, ammonia between 0.04 mgNL$^{-1}$ and 12 mgNL$^{-1}$ and total nitrogen ranges from 5 mgNL$^{-1}$ to 38 mgNL$^{-1}$. Phosphorus and total phosphorus range from 1-2 mgPL$^{-1}$ and 1-3 mgPL$^{-1}$, respectively. No seasonal pattern was found for any of the nutrients. All physico-chemical data values are in the ranges defined by applicable legislation, while nutrient concentrations are occasionally, higher than legislated (Decree-Law nº236/98).

In stations EC#2, EC#3 and EC#4, temperature readings also show seasonal variability. As expected, warmer waters correspond to warmer months. Salinity varies between 33 in winter months and 36 in summer months, probably due to freshwater discharges of the nearby rivers. Dissolved oxygen ranges from 90% in winter months to 140% in summer months, indicating a good oxygenation of the lagoon water and seasonal rise in primary production. These concentrations although high are not indicative of eutrophication problems. Pronounced variations in oxygen concentrations (30%-260%) are found in Barrosa arm (Pereira et al, 2008), a potentially eutrophic area. Again, turbidity and TSS show the same variation. Higher values (15 NTU or 10 mgL$^{-1}$) correspond to periods after rainfall events, when flow from rivers is higher. Therefore, lower values are found in summer months and higher values in winter or after rainfall as is the case of the April field campaign. Nutrient measurements show significant differences between freshwater station and lagoon stations, with higher values in the freshwater and values mostly below or near the quantification limits for the used determination method (2 mg NO$_3$L$^{-1}$ for nitrate; 0.01 mg NO$_2$L$^{-1}$ for nitrite; 0.05 mg NH$_4$L$^{-1}$ for ammonia; 0.5 mg NL$^{-1}$ for total nitrogen; 0.08 mg PL$^{-1}$ for total phosphorus) in the lagoon. Stations within lagoon (EC#2, EC#3 and EC#4) do not show significant differences between them, and no particular seasonal patterns were identified. Ammonia ranges from 0.04 to 0.26 mgNL$^{-1}$ and phosphate from 0.02 to 0.07 mgPL$^{-1}$, values much lower than that the ones found in station EC#1. Nitrite values were around 0.003 mgNL$^{-1}$. Other nutrients are below quantification limits. Chlorophyll values in the lagoon stations are very low (less than 6 µgL$^{-1}$). Higher values were found in April in station EC#2 (5.4 µgL$^{-1}$). During spring nutrient and light availability burst primary production. However, results show algal growth is not potential in this area.

### 3.1.2. Microbiological parameters

Microbiological results show total coliform concentrations in station EC#1 ranging from $1\times10^3$ to $1\times10^5$ CFU/100ml whilst in stations EC#2, EC#3 and EC#4 total coliform concentrations are below $1\times10^3$ CFU/100ml. Also for fecal coliforms, values decrease from $1\times10^2$-$1\times10^5$ CFU/100ml in station EC#1 to less than 100 CFU/100ml in the other stations. This result shows that the impact of the discharge is much localized and puts in evidence the high dilution and water renovation capability of the lagoon in this area.

Portuguese legislation for bathing use (Decree-Law nº236/98) allows a maximum admissible value of $10\times10^4$ CFU/100ml for total coliforms and $2\times10^3$ CFU/100ml for fecal coliforms and a maximum recommendable value of $2\times10^3$ CFU/100ml for total coliforms and $1\times10^2$ CFU/100ml for fecal coliforms. All values observed in stations EC#2, EC#3 and EC#4 are below admissible values and most are below maximum recommendable value.

### 3.1.3. Metals

As previously mentioned, metals were characterized through the determination of Cd, Pb, Cu and Ni. All Cd results are below the quantification limit of the used method (1µgL$^{-1}$), both for station EC#1 and stations EC#2, EC#3 and EC#4. For the other metals, results are also mostly below quantification limits, especially for the sampling stations within the lagoon. Higher values are found in the freshwater sampling point (EC#1), although
always below legislated admissible values (100 µgCuL⁻¹, 50 µgPbL⁻¹, 10µgCdL⁻¹ and 50 µgNiL⁻¹, Decree-Law nº236/98).

### 3.2. Modeling

#### 3.2.1. Influence on lagoon primary production

Fig. 3 depicts the simulations of nutrients (ammonia and nitrate) and chlorophyll at Station EC#3 (aligned with the discharge) for the period of seven months and four scenarios. Reference scenario consider the inhabitants served currently, scenario 1 represents the system without the discharge, scenario 2 includes the 10.000 inhabitants served in the future and scenario 3 refers to 100.000 inhabitants served. The last scenario is performed only to evaluate the sensibility of the ecosystem, since it is an unreal scenario. Only ammonia and nitrate are presented because it is nitrogen that limits the primary production in the lagoon, as determined along lagoon monitoring program (unpublished data that can be found in IST 2009).

![Figure 3](image)

**Figure 3**: Time-series of ammonia, nitrate and chlorophyll provided by model for all of the scenarios.

By observing the simulations for all the scenarios, it appears that major differences are observed in the scenario 3, with a significant increase in nutrient concentrations. These differences are more visible for nitrate concentrations with an increment of about 50% (~0.4 mgNL⁻¹), whereas only a 25% rise in the ammonia concentration was found. Dynamically, this could have two explanations; ammonia is most at all removed from the urban discharge (secondarily treated) whilst nitrate is not, and an increase in inhabitants (100.000) leads to an increase in the discharge (flow rate and concentrations). For reference situation, scenario 1 and scenario 2 were not observed substantially significant differences in nutrient concentrations. This kind of response reveals that the impact of the urban discharge upon nutrients is negligible. This result may be explained due to the fact that urban discharge represents a small contribution to the ecosystem in terms of nutrient (total nitrogen and total phosphorus) loads, when compared to the average freshwater fluxes from river discharges. River discharges are more important in defining the nutrient concentrations in the lagoon than the WWTP discharge. Small differences (less than 1%) were observed in terms of chlorophyll concentrations for all of the scenarios. Primary production in this part of the lagoon is limited by residence time (less than 3 days, Santos et al., 2004), which means, there is no time for phytoplankton growth, since nutrients are at most at all being transported and renewed due to currents advection. Hence, it is expected that primary production it will not enhanced when the Casalito WWTP serve more inhabitants.

Fig. 4 shows the spatial distribution of nitrate concentration provided by the model for the reference situation, scenario 2 and scenario 3. Here we present only the nitrate results because, as mentioned above, major differences were observed for this property. Reference and scenario 2 do not show significant differences in terms of concentration. In scenario 3, it is visible the effect of the WWTP discharge on the surrounding area and in the upper lagoon (both arms and Arnóia River delta), relative to the reference and scenario 2. In this case model predictions suggest an increase in nitrate concentration by
about ~40% near the WWTP discharge and 50% in the upper part (arms and Arnóia River delta). However, this scenario is totally unreal, and performed only for sensibility analysis of the ecosystem.

**Figure 4**: Spatial distribution of nitrate concentration provided by the model for the reference situation, scenario 2 and scenario 3.

### 3.2.2. Fecal coliform contamination

Fig. 5 shows the spatial distribution of fecal coliform concentration provided by the model for the reference situation scenario and scenarios 2 and 3. The major differences are observed in scenario 3, when compared with the others. Such an increase in the inhabitants served by the Casalito WWTP discharge, results in a major impact in terms of fecal contamination. However, this impact is minimized due to higher dilution promoted by currents advection – fecal coliforms concentration in the lagoon can be diluted by about five times more than that the values discharged in the WWTP.

**Figure 5**: Spatial distribution of fecal coliform concentration provided by the model for the reference situation scenario, scenario 2 and scenario 3.

It may be concluded that fecal coliform plume is located near the WWTP discharge, suggesting that contamination only occurs in the surrounding area and does not affect the water quality in the lagoon.

### 4. CONCLUSIONS

Field measurements show that WWTP discharge is in agreement with the Portuguese laws; surface microbiological concentrations in the lagoon are very low or null and metals are below quantification limits. Nutrient concentrations and chlorophyll are also mostly low or below limits. There is a marked difference between tributary and lagoon water quality which suggests little impact of the discharge in the lagoon. This is due mainly to good water renovation, but also because loads coming from the discharge are negligible when compared to river loads entering the lagoon. Model results for the reference situation are in agreement with field measurements, showing a very low impact in the
lagoon water quality. Model predictions (considering 10,000 inhabitants served) do not show significant differences in terms of nutrient concentrations. The contribution of the discharge is smaller than the rivers nutrient load inputs. Small fluctuations were observed in terms of primary production (less than 1%). For the scenario with 100,000 inhabitants major differences occur in terms of nutrients concentrations with an increase of 50% for nitrate and 25% for ammonia. However, this is an unreal scenario only used to understand the lagoon response to nutrient loads.

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REFERENCES
17. YSI, 2006. 6-Series Environmental Systems. YSI Incorporated.