Integrated Wastewater Management in Coastal Areas: Wastewater Treatment, Environmental Monitoring and Performance Optimisation of Costa do Estoril System.

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Abstract

A trunk sewer interceptor plus a treatment plant and a disposal system are the main components of most large wastewater management infrastructures. Wastewater processing starts in the sewer is continued in the treatment plant and generally ends after disposal of final products (sludge and treated effluent).
Long-sea outfalls can be the most efficient disposal systems in many coastal areas because they (i) promote dilution of the effluent into receiving waters during plume rising, (ii) transport wastewater off the coastline and (iii) can discharge the water in areas with low residence time.
In this paper Costa do Estoril Waste Water Management System is described. The impact of the discharge on the water column and sediments is very light and only detectable in the vicinity of the diffuser. Modeling has shown that the low impact in the water column is a consequence of the hydrodynamic and biogeochemical characteristics of the receiving waters. The small impact in sediments (e.g. the absence of the “piling effect”) is a consequence of the wave climate, which resuspends fine material, making it available to be transported by tidal and wind currents.
Monitoring results and model predictions have been used to demonstrate that a secondary treatment would mean no environmental benefit for the receiving waters, an essential condition to obtain a license for operating with a primary treatment out of the bathing period. This is the optimal exploitation configuration that complies with the European Directive on urban wastewater treatment. This paper presents a synthesis of the studies supporting the demand for operating with a primary treatment out of the bathing period.

Key words: Coastal areas, Long sea outfall, Monitoring, Wastewater

Introduction

Figure 1 representing a rectangle of about 120 km on horizontal times 80 km on vertical shows the region of Lisbon, Portugal. On the figure are indicated the Tagus Estuary with 300 km^2, the largest estuary in Western Europe, the Sado estuary further south with 100 km^2 and local streams and beaches.

Costa do Estoril beaches are those represented in the upper detail rectangle plus the three beaches westward of the rectangle. All together they correspond to the beaches on the drainage area of streams westward of Lisbon. The catchments areas of those streams start at Sintra mountain (600 m high) which is a major local geological feature individualizing Costa do Estoril drainage area.

Costa do Estoril is a residential and tourist area, with 720 thousand people equivalent, being one of the most attractive areas in Lisbon surroundings, due to its sandy beaches and appealing landscape. In the fifties Costa do Estoril population was less then 200 thousand inhabitants, living in small agglomerations located mainly along the coastline, with independent sewer systems, including sometimes short submarine outfalls. In the sixties, these agglomerations experienced a rapid growth and new cities were born further inland, contaminating local streams and through them the coastal waters. Then water quality started to deteriorate and, in the eighties, most of Costa do Estoril beaches had incompliant bathing water.

In the seventies, it was decided to build an intercepting system for transporting whole sewage to Guia, the rocky coast between the beaches located in the detail rectangle in Figure 1 and “Cresmina – Guincho - Abano”, the 3 beaches located westwards. There, a treatment plant should be built and the effluent should be disposed in the ocean through a submarine outfall 2750 meters long, terminated by a diffuser with two 400 meter long branches.

The construction of this system was very much affected by the political and economical instability lived in Portugal during the late 70’s and early 80’s and the first phase was concluded only in 1994. A special office of the National Water Institute (INAG) conducted the works. In 1996 a company – SANEST – was created for completing and managing the system.

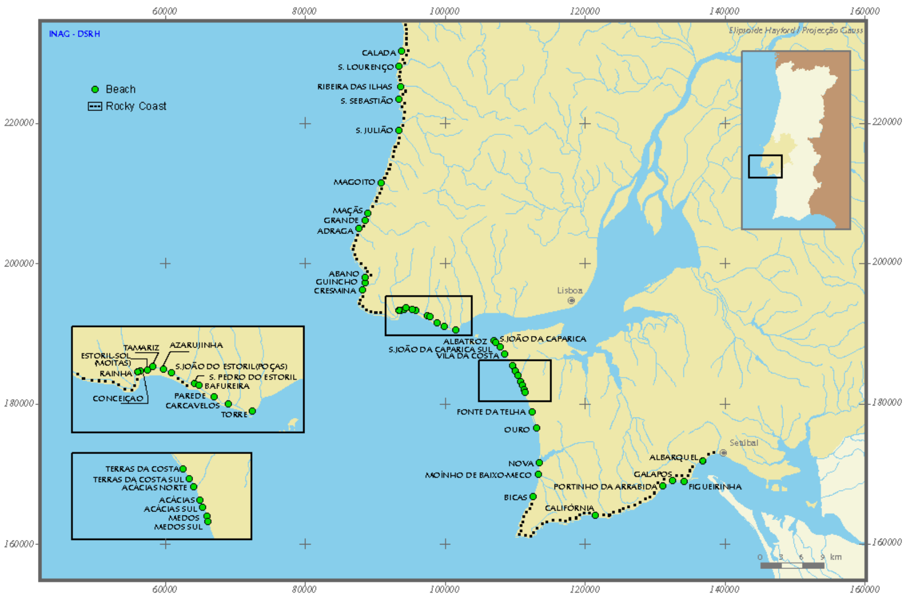

Figure 1: Map showing bathing areas, streams, the Tagus estuary and the Sado estuary (southward) in the region of Lisbon.

In meantime European Directive 91/271/CEE regulating the treatment of residual urban waters from December 2000 was published, which stipulates the secondary treatment as the most common level of treatment in normal zones. In sensitive zones the level of treatment has to be more developed and in less sensitive zones, a less exigent treatment can be used if it is demonstrated that a more exigent level has no benefit for the environment.

Guia region is a rocky coast with strong hydrodynamics and very energetic wave climate and with a short residence time and is classified as a less sensitive zone. Based on a monitoring program carried out between 1993 and 1998 (Santos *et al*, 2002), it was demonstrated that the discharge has no harmful consequences for the receiving environment. Based on a numerical model, it was demonstrated that a level of treatment higher then primary would have no environmental benefit for the receiving waters.

As a consequence of these studies the European Commission as accepted that a primary treatment out of the bathing season and a higher level of treatment, including disinfection during the bathing season would be the most adequate to Costa do Estoril sewage system (EEC, 2001). This paper describes the system of Costa do Estoril and summarizes the studies that supported the derogation demand.

Costa do Estoril Sewer System

Costa do Estoril wastewater system is represented in Figure 2 It is composed by a gravity trunk sewer 25 km long, parallel to the coast, ending at the treatment plant which is followed by a submarine outfall 2750 m long, with two diffusers of 400 meters each. The diffusers are in a region of 35 to 40 meters deep, laying on a sandy bottom. The flow rate affluent to the treatment station is typically 2 m^3/s and can reach 5 m^3/s during rainy periods.

Figure 2: Schematic representation of "Costa do Estoril" sewage system. The gravity trunk sewer, ends at the treatment plant, which is followed by a 2750 m long submarine outfall.

Sewage that is generated in the region between the trunk sewer and the sea is pumped back to the sewer by a set of elevation stations. Along the streams a set of sewers has been built to separate domestic from pluvial discharge. The treatment plant was conceived to perform a preliminary treatment and has been upgraded with a set of step screens in 1999. Work will start soon to build a new treatment plant according the decision of the European Commission of accepting the derogation proposal.

The long trunk sewer must be seen as a physico-chemical and biological reactor, where the hydraulic retention time is similar to that of typical aeration tanks of activated sludge treatment plants. Chemical Oxygen Demand (COD) is reduced adding oxygen and hydrogen peroxide along the trunk sewer. As a result, at the inlet of the wastewater treatment plant, the easily biodegradable fraction of COD is about zero and an important part of the dissolved COD is converted into particulate COD, easier to remove at primary settling tanks.

The receiving waters

The submarine outfall is located in front of a rocky coast (Figure 2) in a region with intense hydrodynamics and energetic wave climate and where nutrient levels are mostly determined by the river discharge in winter and by upwelling in summer.

HYDRODYNAMICS OF THE RECEIVING WATERS

Figure 3 shows a distribution of velocity in winter forced by the tide, the density distribution and a northern wind. In this simulation a river discharge of 1000 m^3/s was considered, which is ½ of typical maximum winter discharge. The figure shows that the flow in the vicinity of the estuary is mostly determined by the tide, being the estuary ebb jet deflected northward by the Coriolis Effect. The transient velocity in the in the region of Guia is of the order of 30 cm/s.

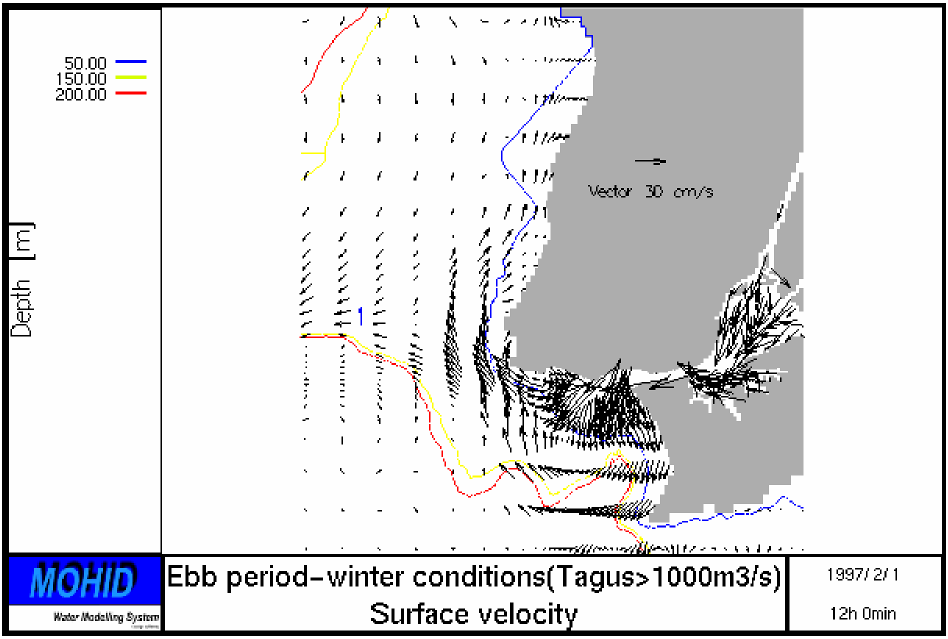

Figure 3: Instantaneous distribution of velocity at surface generated by the tide, river discharge density and northern wind.

Figure 4 shows the residual flux per unit of length generated by the tide alone. The figure shows a set of complex eddies in the estuary discharge channel and a set of two eddies adjacent to a residual jet, typical of tidal inlets. The jet is deflected northward by Coriolis

Effect. The consideration of baroclinic effects in the ocean and of the wind forcing would modify the values of the residual velocity, but wouldn't modify the flow pattern, showing residual velocities of the order of 5 to 10 cm/s, according to the direction of the wind (maximum for southern wind conditions), Leitão, 2002. Measurements carried out with an ADCP measuring velocities at 8 depths between the surface and the bottom, have shown velocities of the same order of magnitude.

The very intense values of transient velocity and the high depth of the diffusers, suggest that strong initial diffusion has to be expected. The model CORMIX[1], shows that for a velocity of 10 cm/s and a discharge of $2m^3/s$ an initial dilution of 1:700 must be expected when the pycnocline lays 15 meters deep (a typical summer condition). Measurements carried out in the field have shown values of the same order of magnitude (Matos et al, 1998)

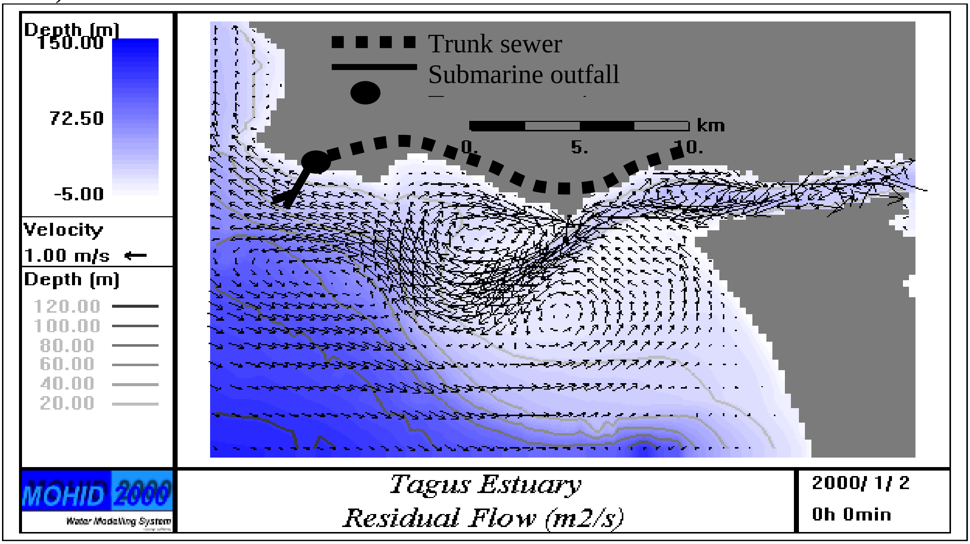

Figure 4: Residual flux (velocity times depth) at and off the mouth the Tagus Estuary. Location of Costa do Estoril trunk sewer, treatment station and submarine outfall are also indicated.

[1] Cornell Mixing Zone Expert System, http://www.epa.gov/ceampubl/swater/cormix/index.htm

WAVE CLIMATE

Figure 5 and Figure 6 give the distributions of frequencies of waves in the vicinity the diffuser computed using data from 2 standard buoys, one located northward of Guia (Figueira da Foz) and the other located southward (Sines), Consulmar (1996). The figures show that the most probable waves propagate from W and NW and that 60% of the time waves with a significant height of 1.5 m must be expected. The figure also shows that 10% of the time waves of 2.5 m have to be expected and that every year waves of 4.5 m have to be expected as well. Figure 7 shows the velocities generated 20 cm above the bottom by waves of different periods and heights. The figure shows that waves with periods of 10 s and heights of 3.5 m generate currents of 40 cm/s and 60 cm/s in case of 14 s. These figures show that wave climate makes difficult the deposition of fine matter close to the diffuser and that even if it settles for a certain time, it will be re-suspended latter.

In fact the wave climate explains the existence of a sandy bottom in this region although fine material exported by the estuary flows mostly through it. This material is effectively buried only after reaching the continental shelf edge, in regions deeper then 200 meter. The wave climate has been identified as the main cause of the small environmental impact of the discharge on the benthic system.

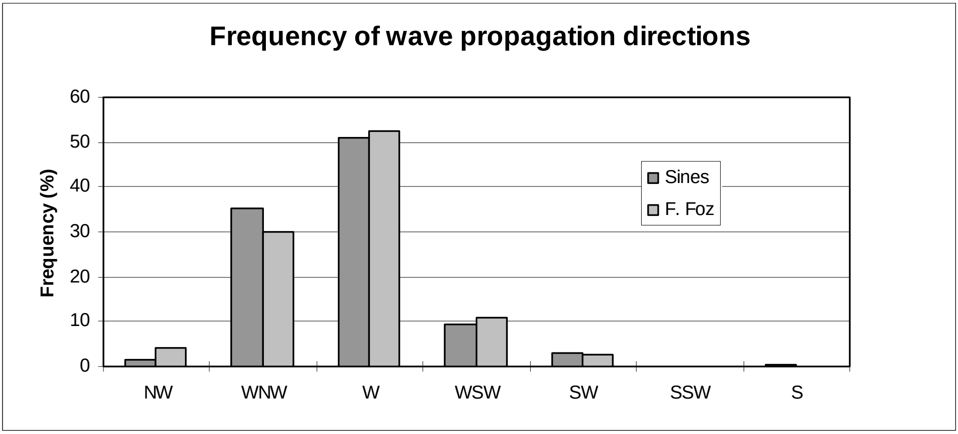

Figure 5: Distribution of wave propagation frequencies at the location of the diffuser computed using data measured at Figueira da Foz and Sines(Consulmar, 1996).

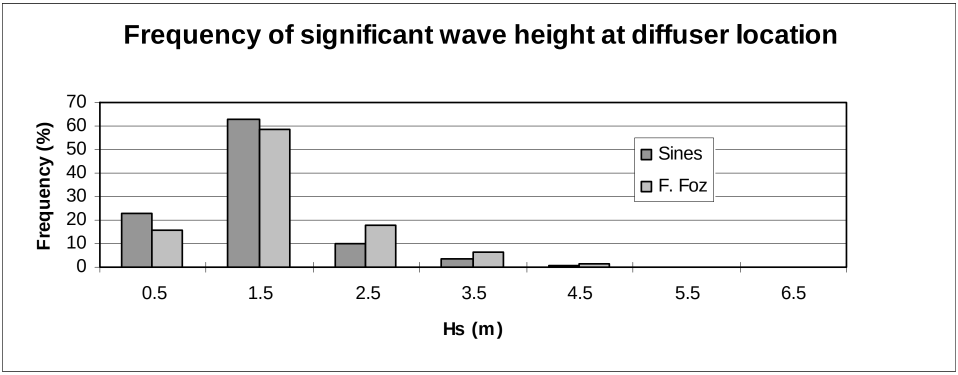

Figure 6: Frequency of wave height at the location of the diffuser, computed using data measured at Figueira da Foz and Sines (Consulmar, 1996).

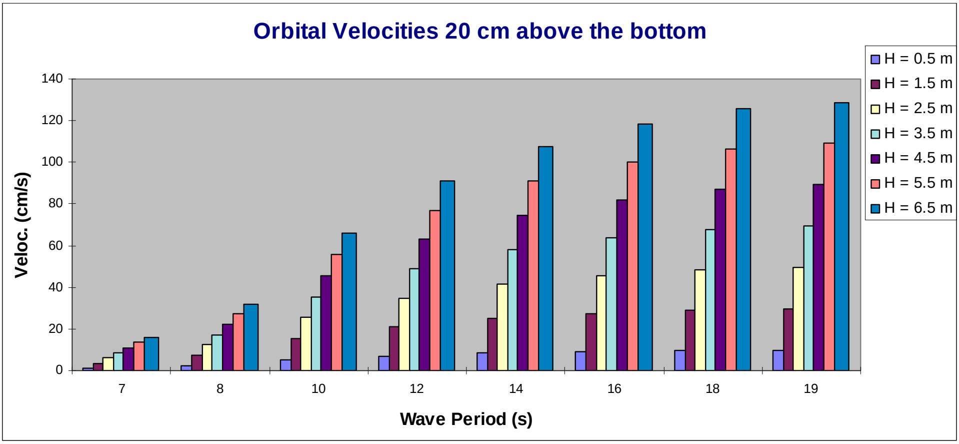

Figure 7: Orbital velocities generated by the waves 20 cm above the bottom, as a function of their period and height (Consulmar, 1996).

THE BENTHIC SYSTEM

Figure 8 shows distributions of fine material in April and October 2001, after 7 years of operation. The figure shows that the concentration increases towards the estuary and southward, to the deeper areas. The figure also shows a seasonal evolution, with concentrations higher after summer (October) and lower at the end of the winter. The maximum concentration in the vicinity of the diffuser is 3% of fine material in April and 5% in October.

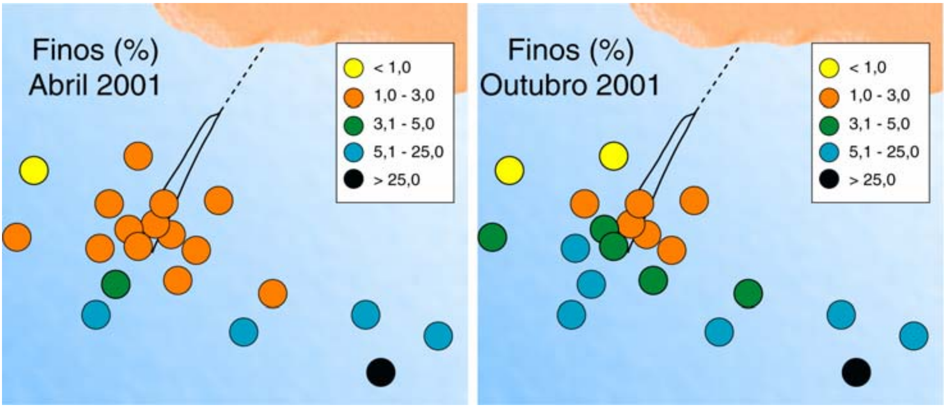

Figure 8: Distribution of fine material in April (left) and in October 2001, after 7 years of operation (Quintino *et al* 2001).

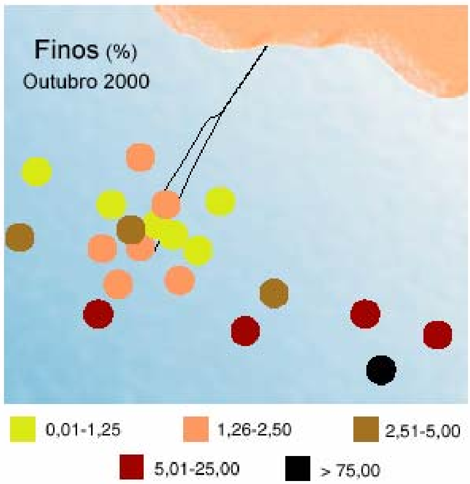

Figure 9: Distribution of fine material in October 2000, after 6 years of operation (Quintino *et al* 2000). Note that the scale is not exactly as in Figure 8.

Figure 9 shows the same information in October 2000. Comparison of corresponding periods shows that there is no inter-annual accumulation. This result should be expected, as a consequence of the characteristics of the wave climate in the vicinity of the diffuser.

THE PELAGIC SYSTEM

The distributions of properties in the pelagic system are also a consequence of the hydrodynamic properties of the region. The residual velocity displayed in Figure 4 shows that residence time is small and that local properties must be influenced by estuary exports. During winter the consumption of nutrients is small and nutrients exported by the estuary increase the concentration in this area. During summer consumption increases and estuary export is low. Then, concentration in this area is mainly influenced by upwelling of deep water reach on nutrients.
Figure 10 shows a 3 years nitrate time series and Figure 11 the corresponding chlorophyll time series. The figure shows that nitrate is usually below 0.1 mgN/L. Exceptions are January 1998 and 2001 same years' springs. During winter there is a vertical gradient with higher surface values, while in spring the vertical profile is homogeneous or it displays higher values in deeper layers. Figure 12 displays the corresponding salinity values and it shows that winter values must be related to fresh water discharge and that vertical gradient of nitrate is correlated to the vertical salinity gradient, at this time of the year. Middle and bottom water are oceanic water (salinity is 36 ‰). Higher nitrate values close to the bottom show that the oceanic water is the major source of nitrate, except during strong rainy events.
The evolution of chlorophyll displays two annual peaks, one at the end of winter period and another in spring. The correlation of these peaks with nitrate and salinity shows that inland nitrate drives the first peak, while the second is driven by ocean upwelling. The time series of chlorophyll also shows that there is no symptom of eutrophication, most values being below 2 μg (cha)/L.

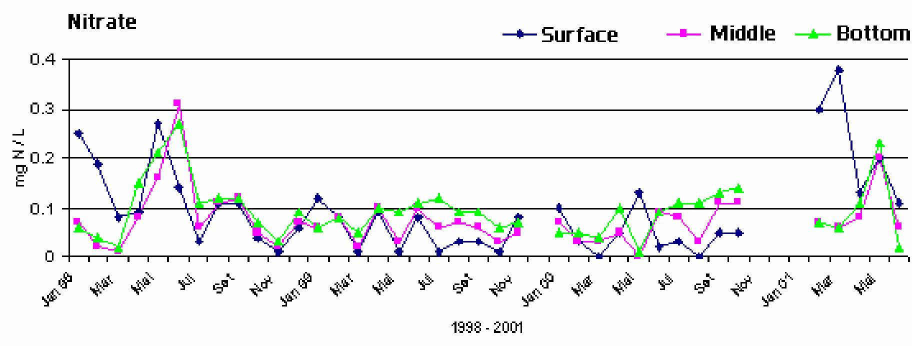

Figure 10: Time series of nitrate between 1998 and 2001.

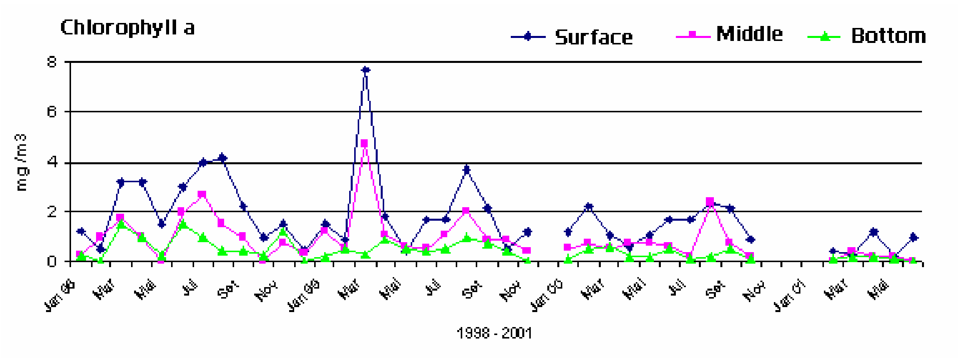

Figure 11: Time series of Chlorophyll a between 1998 and 2001.

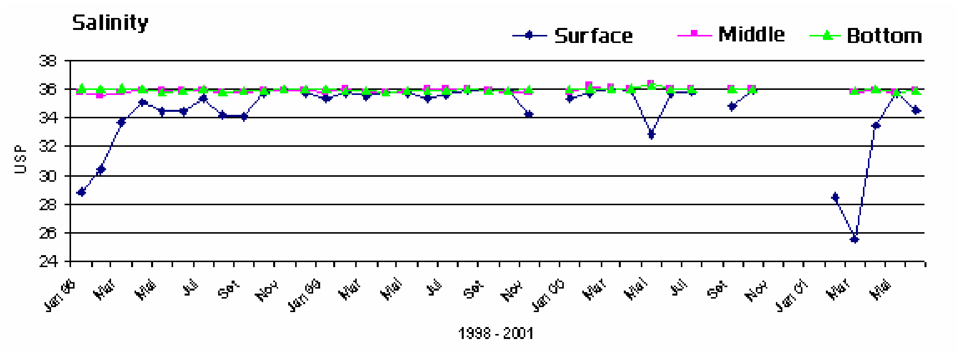

Figure 12: Time series of salinity between 1998 and 2001.

Optimized treatment

In this paper, optimizing wastewater management means to set up the most economic, yet environmentally safe system. This is achieved by distributing the treatment among its three components (interceptor, treatment plant and receiving waters), according to the local environmental characteristics.

This paper is concerned mainly with the fate of materials discharged in the ocean. The monitoring program has shown that there is no visible impact on the biology of the water

column and that the impact on the sediments is limited to a very restricted area close to the diffuser, although there is no inter-annual accumulation of fine material.
The results of the monitoring program show that there is no impact of the discharge on the trophic conditions of the receiving waters and that there is no reduction of dissolved oxygen concentration. As a consequence no significant environmental differences are expected if a secondary treatment instead of a primary treatment was performed. For quantifying those differences a primary production model (MOHID[2]) was implemented, to study the fate of the materials discharged by the submarine outfall. The hydrodynamic module was forced by the tide alone in order to have typical conditions. A detailed description of the water quality module is given in Pina, 2001.
The lagrangian model follows the methodology developed by Leitão, 1997. The outfall load is transferred to the water masses passing by diffuser region. These water masses are acted by small scale turbulence and increase their volume, incorporating water from the receiving environment and also by large scale turbulence, getting spread in the neighboring water. While they are moving, the products discharged by the outfall are submitted to biochemical processes and are transformed.
Differences between the results computed considering primary and secondary treatment are represented in Figure 13, Figure 14 and Figure 15, respectively for ammonia, BOD and chlorophyll a. The figures show very small differences, as was expected. Differences on ammonia concentration are of the order of 0.01 mgN/L and are restricted to the vicinity of the diffusers. Differences on BOD are smaller than 0.3 mg O2/L and differences of chlorophyll concentrations are smaller than 1%. Nitrate would display also negligible differences.
Monitoring and model results show that a secondary treatment instead of a primary treatment would have no environment benefit in terms of eutrophication. A treatment higher then primary can only be justified on the basis of fecal microbiological contamination. For this reason it was decided to perform disinfection during the bathing season (from June to September). During that period the effluent will be submitted to a removal of suspended matter and color sufficient for UV performing disinfection.

[2] MOHID (http://www.mohid.com) is an integrated model which development was initiated by Neves (1985) and continued in the framework of subsequent M.Sc and Ph.D thesis.

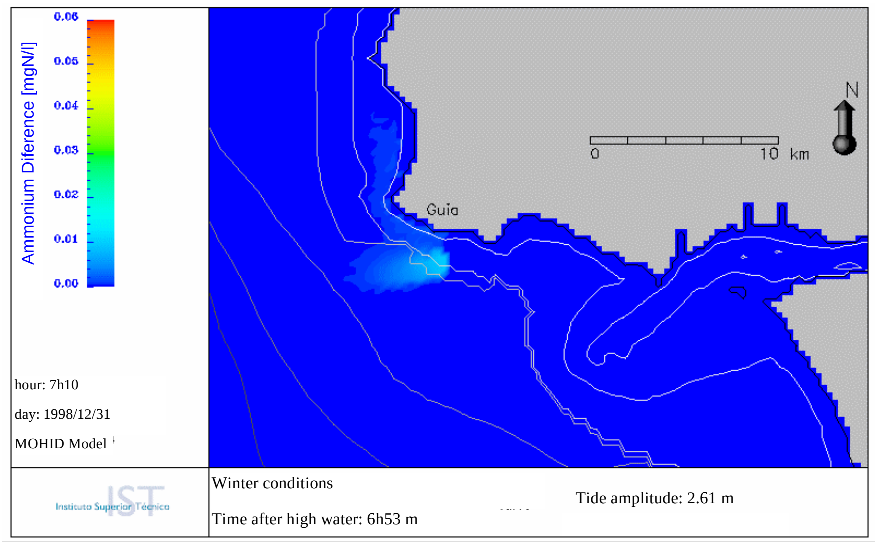

Figure 13: Differences between of ammonia concentrations in the water column, considering secondary and primary treatment.

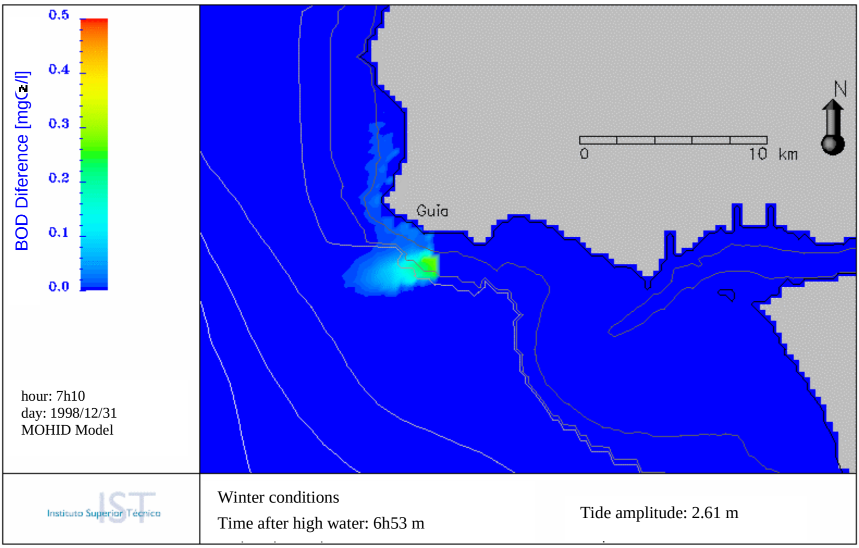

Figure **14**: Differences between BOD concentrations in the water column, considering secondary and primary treatment.

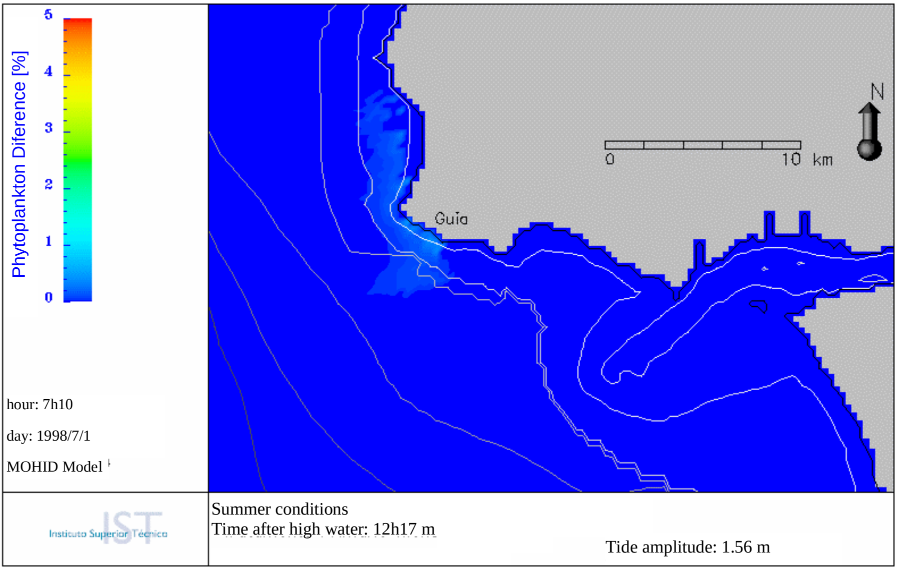

Figure 15: Differences between Chlorophyll concentrations in the water column, considering secondary and primary treatment.

Conclusions

This paper gives an overview of Costa do Estoril Sewage System and of the processes that determine the environmental impact of the discharge. It was shown that the local circulation and the wave climate in diffusers region are responsible for the small environmental impact both in pelagic and in benthic compartments.

Nitrate concentration is typically below 0.1 mgN/L and chlorophyll concentration is typically below 3 µg/L. It is also shown that the nutrients discharged by the estuary are unnoticeable except in winter, at surface, during periods of strong river discharge. During those periods they are accompanied of a reduction of surface salinity. During spring the concentration of nutrients tend to increase again, but without any modification of salinity and displaying the maximum concentration close to the bottom, showing that the deep water are the source of nutrients, which rise by coastal upwelling.

Fine material concentration in the sediments is very small and increases towards the estuary mouth (main source of fine matter) and to the deep waters since wave action decreases as depth increases.

A mathematical model has been used for quantifying eventual benefits of performing a secondary treatment instead of a primary treatment prior to the discharge through the submarine outfall. The results of the model have shown that the differences would be of the order of 1% and consequently much smaller than the natural variability of the system.

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