MODELLING THE WATER QUALITY OF THE COASTAL WATERS ALONG THE AVEIRO REGION USING A MOHID-3D MODEL SETUP

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CHAPTER SYNOPSIS

Background
Since a proposal has been made to improve the level of treatment in three Waste Water Treatment Plants (WWTP) and a paper factory in the Aveiro region (Portugal), all of which are discharged through a submarine outfall into the ocean, about 3 km from the shore line, there is the need to build a model that can predict the influence of this proposal in the water quality in this coastal area. The model was, thus, applied to this region in order to estimate the importance of three different sources of nutrients and phytoplankton, the ocean, Ria de Aveiro, and a submarine outfall located 3 km away from the shore line.

Results
Three scenarios where built in a 3D-ecological model which includes: (1) no discharges; (2) discharge of Ria de Aveiro and (3) discharges of Ria de Aveiro and submarine outfall. The results show that of both discharges, only Ria de Aveiro has a significantly high influence in the hydrodynamics and nutrient fluxes near its mouth and a notable importance almost 40 km from its mouth, and the importance of the submarine outfall in nitrate and phytoplankton concentrations is never higher than 2% in all the time series implemented.

Conclusions
This work suggests that the implementation of a higher level of treatment in the WWTP and paper factory, in terms of nitrate and phytoplankton concentrations would have a very low impact on water quality in the Aveiro coastal region, as the ocean and the estuary are two much more important features.

1 INTRODUCTION

The Portuguese coastal area is a very complex region to study, not only from a hydrodynamic point of view but also from an ecological point of view, and especially because it is influenced by upwelling events during the spring/summer months [1]. These hydrodynamic events are caused by the combination of northerly winds and the Coriolis effect, pushing the surface water to the ocean and consequently bringing cold, saltier, nutrient-rich, to the surface. These events provide the primary producers enough food for a rapid growth during this time and are also responsible for an increase of the concentration of all the trophic levels above them, and a seasonal variation of the phytoplankton concentration.

This makes the Portuguese coast a very productive area, where fishing activities benefit. The Aveiro Coastal area is a particular case of the Portuguese coastal waters, where the hydrodynamics and primary production are difficult to model realistically [2], thus making the implementation of 3D ecological and hydrodynamic numerical models necessary to better understand and predict the influence of these upwelling events, variations of the discharges from the Vouga estuary (also called Ria de Aveiro) and the S. Jacinto submarine outfall in the primary production. In the case of coastal areas such as the Aveiro coast, the limiting factor is usually nitrogen, as is normally in the ocean, which explains the influence of the nutrients brought by upwelling events, river discharges and point sources such as submarine outfalls in the in primary production. The main focus of this work is the study of the contribution of these 3 sources of food for the primary producers in the coastal waters of Aveiro, in order to give a formal opinion on the need to implement a stronger treatment process to the water discharged by the S. Jacinto outfall.

2 THE STUDY AREA

The coastal waters of the Aveiro region studied in this paper are located between 40° N and 41° N (Figure 1), and its length extends until 66 km from the coast line at about 9° W with a low slope, at which point the slope of the continental shelf becomes very steep [3]. There are two sources of direct fresh water input to the area, the Ria de Aveiro and a submarine outfall which discharges treated wastewater from 3 WWTP and a paper factory. Regarding the climate, the study area is located in the northern part of the northern-hemisphere subtropical high pressure belt, and the location of the anti-cyclone determines the climate over the region [1]. Due to this anti-cyclone, winter is dominated by weak southerly and westerly winds, and in summer the atmospheric current changes, where strong northerly and north-westerly winds with mean velocity of 5 – 6 m s-1 are registered [4]. Throughout the winter when the wind blows northward, the currents, forced by the wind, and intensified by the density gradient and the water discharges along the Portuguese coast, flow northward with higher speed. During Spring/Summer months when the wind blows southward, the density gradient is not strong enough to maintain a superficial northward flow and its direction is inverted. The upwelling events occurring during these seasons push surface water to the open ocean and cool deep water is forced to emerge close to the coast, which generates a baroclinic jet flowing in the same direction as the wind [5].

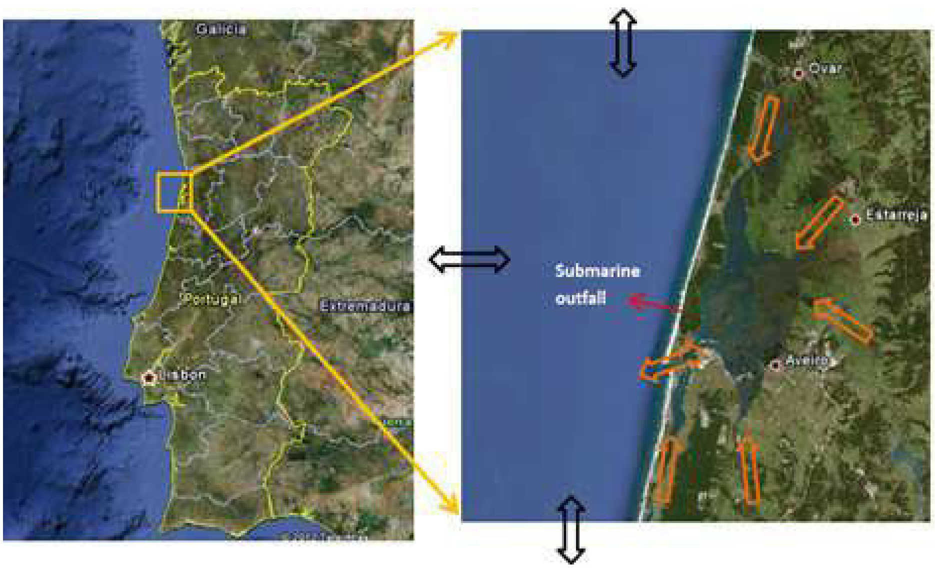

Figure 1. *Location of the study area.*

3 BATHYMETRY

There were two grids applied to the study area, one from the regional model – PCOMS-BIO model which is an external model to this work and the local one, built specifically for this work (Figure 2). The regional and local model cell's dimensions are 6×6 km and 2×2 km, covering an area of 11×16 and 30×42 cells, respectively. Throughout this study, several different bathymetries were used, due to hydrodynamic instability problems originated by them. The final bathymetries used were built using bathymetric points obtained from EMODnet (European Marine Observation and Data Network), which provides points in a 350 m grid.

4 WATER AND NUTRIENTS DISCHARGED

The discharges from Ria de Aveiro and the submarine outfall were provided by an external 2-dimension model implemented inside the Estuary and SIMRIA, respectively. The latter had to be estimated, since the results were relative to the WWTP entrance instead of the effluent. This estimate was made using efficiency data present in [6], and the concentration values for each of the nitrogen and phosphorus forms were obtained. Since these waters are later mixed before being discharged in the ocean, the final concentrations were calculated, using the Equation 1, were C_A(final) represents the concentration of property A in the month i, j is the index of the three WWTP and $M_A^{PORTUCEL}$ represents the mass average for each month being discharged by Portucel. In terms of nutrients, and due to lack of data, it is assumed that Portucel discharges the equivalent of 40% of all the three WWTP. The results obtained and used in the model are presented in and, and the average hourly flow for the outfall is 1 $m^3\ s^{-1}$.

$$C_A^i(final) = \frac{\sum_{j=1}^{3} (C_A^j \times V^j + M_A^{PORTUCEL})}{Vtotal} \tag{1}$$

As for the discharges from Ria de Aveiro, these were obtained using an integration box at the mouth of the Ria, and this box gives, as an output, mean hourly values for water (and all of its properties) flux coming in and out of the Ria. The concentrations of all nutrients considered in the discharge of the submarine outfall are presented in Table 1 where the most important nutrient discharge is the nitrate which also has the highest concentration due to oxidation of organic and inorganic matter in the WWTP. The average monthly flow of this discharge is 1 $m^3\ s^{-1}$.

5 ECOLOGICAL MODEL

In this project the following forms of nitrogen were simulated: ammonia (NH_4), nitrate (NO_3), nitrite (NO_2), dissolved refractory organic nitrogen (DONre), dissolved non-refractory organic nitrogen (DONnr) and particulate organic nitrogen (PON). As to the phosphorus compounds, the following are included in the model: Phosphate (PO_4), dissolved refractory organic phosphorus (DOPre), dissolved non-refractory organic phosphorus (DOPnr) and particulate organic phosphorus (POP). Regarding primary and secondary producers, phytoplankton and zooplankton were included.

Table 1. *Concentration of the various nutrients considered in the discharge of the outfall.*

	N-NH4	N-NO3	PON	DONre	P-PO4	POP	DOPre
Jan	1.95	10.67	4.68	8.46	1.27	0.13	0.46
Feb	3.00	16.42	7.21	13.03	1.91	0.20	0.70
Mar	2.32	12.67	5.56	10.05	1.52	0.16	0.55
Apr	2.83	15.47	6.79	12.28	1.69	0.18	0.62
May	3.65	19.98	8.77	15.85	2.00	0.21	0.73
Jun	3.78	20.66	9.07	16.4	1.59	0.17	0.58
Jul	3.67	20.06	8.81	15.92	2.35	0.25	0.86
Aug	3.87	21.21	9.31	16.83	2.74	0.29	1.00
Sep	1.70	9.33	4.10	7.40	1.53	0.16	0.56
Oct	2.18	11.94	5.24	9.47	1.70	0.18	0.62
Nov	2.15	11.78	5.17	9.35	1.96	0.21	0.72
Dec	2.94	16.08	7.06	12.76	2.01	0.21	0.74

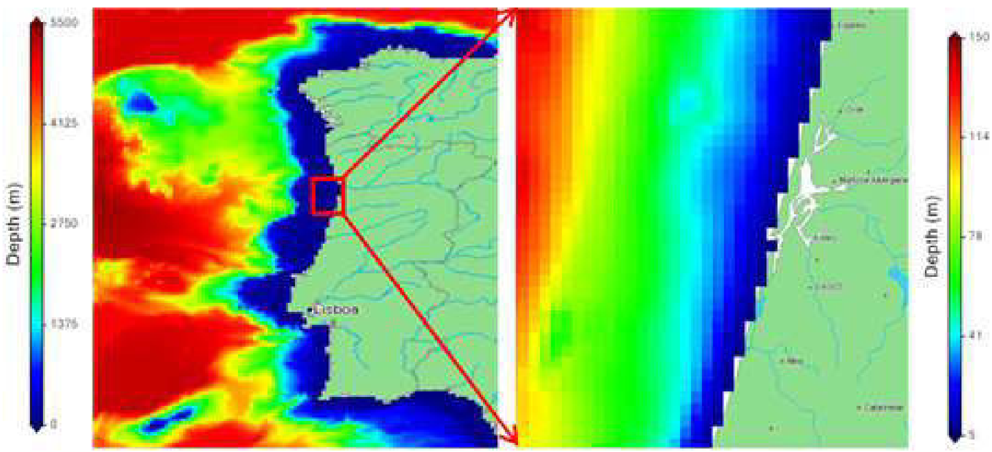

Figure 2. *Regional model (external) and local model (built for this project) bathymetries.*

For the maximum growth and mortality rates of phytoplankton, a value of 2 d^{-1} and 0.02 d^{-1} were assumed with nitrogen and phosphorus half-saturation concentrations of 0.014 mgN L^{-1} and 0.001 mgP L^{-1}, respectively.

6 RESULTS

In order to study the importance of each source near the mouth of the estuary, six integration boxes and four surface output time series were implemented, as shown in Figure 3. It was assumed that the number of time series would be enough to evaluate the influence of the submarine emissary far from its discharge point. The integration boxes were used to calculate the amount of nutrients and water flowing North, South and West, from the center cell near the mouth of the estuary.

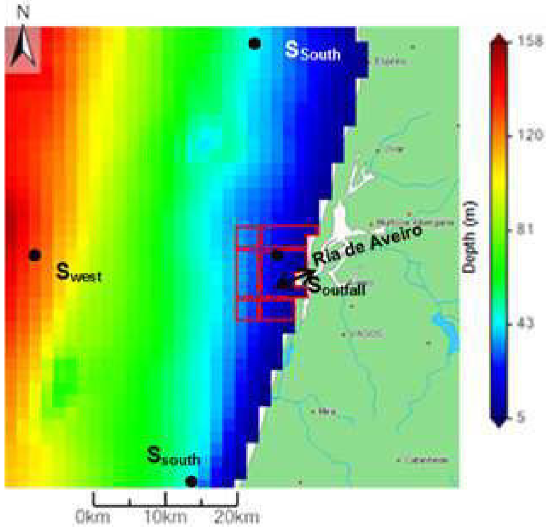

Figure 3. *Location of the time series (black, 2D integration boxes (red boxes), location of Ria de Aveiro and the submarine outfall' discharges (red dot and red double arrow).*

Furthermore, three different scenarios were created in order to determine the importance of each nutrient source. The first one considers the ocean to be the only contribution of water and nutrients to the coastal waters, the second includes Ria de Aveiro which enables to quantify its importance in comparison to the ocean, and the third considers all the sources (ocean, Ria de Aveiro and the S. Jacinto submarine outfall). The results provided by these integration boxes (Table 2) show a strong influence of Ria de Aveiro's discharge in the costal currents near its mouth, considerably changing the local hydrodynamics.

All fluxes considered were inverted when this discharge was included, with values changing from 1448×10^6 m^3 flowing North to 2332×10^6 m^3 flowing South for the scenario with no discharges and the scenario with the discharge of the estuary, respectively. The remaining fluxes have the same trend, with the discharge of the Ria changing the direction of the flow. This increase in the flux to the South is not expected as the fresh water discharge together with the Coriolis effect, tends to turn right (this case to the North). This is due to the angle of the discharge, which points southwest, forcing the water to move to the southern integration box.

There is a substantial difference in the amounts of nutrients and phytoplankton flowing through the boxes of scenario 1 and scenario 2, meaning that the water quality near the mouth of the Ria is determined almost exclusively by the net export of nutrients and phytoplankton generated inside it. The influence of the submarine outfall is barely noticed, except for the northern box, as the discharge cell is very close to it. For the remaining fluxes the influence of this outfall is less than 6%, which suggest the influence of this outfall in the concentration of nitrate and phytoplankton near the domain borders will be very small. This influence will be analyzed further ahead in this chapter.

Regarding phytoplanckton fluxes to the North, a diferent trend can be seen when comparing scenario 1 (no discharges) and scenario 2 (Ria de Aveiro) for the February period, where the flux for both scenarios have the same direction. This can be explained by the net export of phytoplanckton from the estuary. Since it's concentration is higher than in the ocean, whenever the water flows North, it takes the higher concentration of Phyhtoplancton, which makes up for the change in the flow direction from scenario 1 to scenario 2. The same thing happens with nitrate flux, although the diference between scenarios is smaller and almost inverted when the discharge of the Ria is implemented.

March results (Table 3) compared with February results (Table 2) show a significant increase of all fluxes to the North and a slight increase of phytoplankton flux to the South influenced by the discharges of Ria de Aveiro and the submarine outfall. As for the effect of the discharge, during these two months the estuary's discharge flows either south or north depending on wind, local hydrodynamics and discharge angle. Nitrate fluxes are dominated by the estuary's discharge, which accounts for an increase of 260 and 150 ton to the South in February and March, respectively, and the same happens to the phytoplankton fluxes.

As for the submarine outfall, results show a slight increase in all fluxes as was expected, but its influence is less than 10% in the primary production and nitrate concentration, which means that either the nitrate concentration is high enough already for maximum phytoplankton growth or there is not enough time for the nitrate discharge to have a higher effect before leaving the integration box, at least for the times when the water flows North and West.

Where the time series are concerned, these show that near the domain border, at a distance of about 40 km, the influence of both Ria de Aveiro and submarine outfall in the nitrate and phytoplankton concentrations is notable, even if the concentrations are very low (see Figure 4 and Figure 5). Furthermore, the time series located in the West and in the South show a significantly smaller importance of the discharges in the water quality with maximum differences of about 10% for Ria de Aveiro and 1% for the submarine outfall. The only case where the concentrations are truly affected by the discharges is the time series located in the location of the discharge of the submarine outfall, in which the concentrations of nitrate and phytoplankton are always higher for the discharge scenarios.

Table 2. *Fluxes through the integration boxes considered, for the period 08/02/2011 – 08/03/2011.*

	Scenario	Center to South	Center to West	Center to North
Water flow 10^6 m^3 month^{-1}	1	-1448	791	641
	2	2332	-1487	-612
	3	2389	-1524	-630
Nitrate ton month^{-1}	1	-17	4	-12
	2	250	5	-0.6
	3	269	16	15
Phytoplankton ton month^{-1}	1	-100	64	149
	2	113	-124	87
	3	121	-122	107

Table 3. *Fluxes through the integration boxes considered, for the period 08/03/2011 – 08/04/2011.*

	Scenario	Center to South	Center to West	Center to North
Water flow 10^6 m^3 $month^{-1}$	1	-232	-1393	1632
	2	1233	-2682	1700
	3	1282	-2672	1643
Nitrate ton $month^{-1}$	1	-0.07	-2.36	0.6
	2	152	62	157
	3	156	67	172
Phytoplankton ton $month^{-1}$	1	-15	-165	221
	2	159	-246	449
	3	189	-215	480

Figure 4. *Nitrate concentration in the Northern border of the domain.*

Figure 5. *Phytoplankton concentration in the Northern border of the domain.*

Figure 6 and Figure 7 also show tidal influence of Ria de Aveiro, with high concentrations in the low tide and low concentrations during the high tide. However the submarine outfall barely has any influence in the concentration of these water properties, even in its main area of influence, and when compared to that of Ria de Aveiro, its contribution is less than 0.5% for all borders considered, except for the area near its discharge, where the contribution reaches 1%. As for phytoplankton concentrations, the same trends are registered, with Ria de Aveiro playing the most important role near its mouth, and a low influence from the submarine outfall throughout the study area.

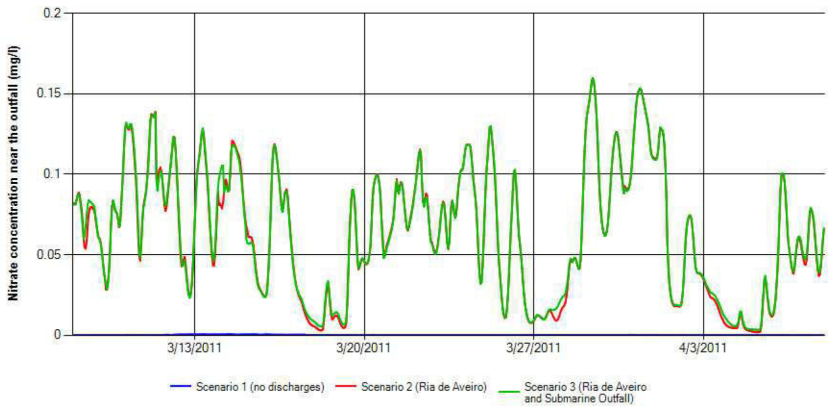

Figure 6. *Nitrate concentration in the surface cell of the location of the discharge of the submarine outfall.*

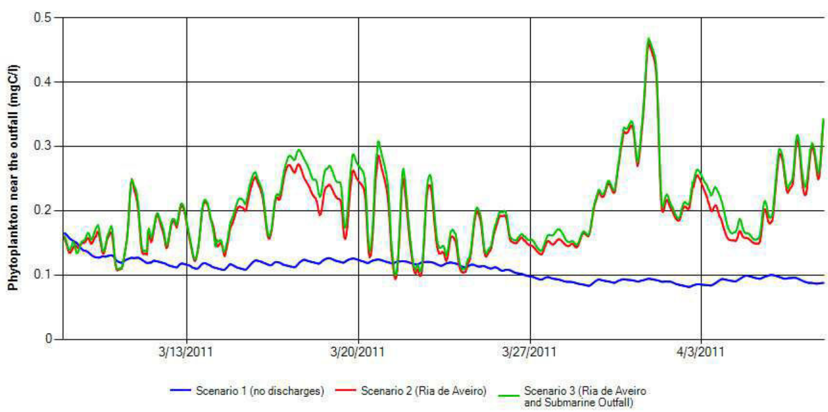

Figure 7. *Phytoplankton concentration in the surface cell of the location of the discharge of the submarine outfall.*

7 CONCLUSIONS

The main focus of this work was to study the contribution of the ocean, the Estuary of the Vouga river (or Ria de Aveiro), and of the S. Jacinto submarine outfall in the nutrient concentration (in this case only nitrate was presented) inside the study area and its effect on primary production. The MOHID 3-dimension ecological model proved its ability to represent hydrodynamic features such as the upwelling events, and nutrient and phytoplankton dynamics with accuracy, and it was able to show the influence of the submarine outfall, which, as results show, is less than 0.5%, when compared with the discharge of Ria de Aveiro, for all domain borders except for the area near its discharge). It was also concluded that the main hydrodynamic forcers close to land are the wind and the fresh water discharge (associated with the tide). It can also be concluded that the implementation of another level of treatment in the WWTP will have little impact on primary production and in nutrient concentration in the waters, as the dilution due to the ocean is very strong and capable of diminish its influence to only 1% near its discharge and almost undetected values at a distance of 40 km (Northern domain border). However, there is still work to be done in order to study the influence of this discharge in the water quality near Aveiro Coast, especially in terms of refractory organic matter. Another issue that should be addressed is the natural subterranean water discharge along the coast which was not considered but can also contribute to the nutrient dynamics near the coast where higher phytoplankton concentrations are found.

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