Nutrient balance in the continental shelf along the Aveiro region

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Abstract

The coastal area of Portugal is very productive, especially owing to the coastal upwelling during the spring/summer months, which causes a significant increase in nutrients on the continental platform. This increase, which occurs in spring and summer, linked to the greater sun exposure registered in the same period, is responsible for the increase of primary producers near the coast.

This work examines the importance of three sources of nutrients for the concentration of nitrates and phytoplankton on the continental shelf off the region of Aveiro, which are the ocean, the Ria de Aveiro, and the São Jacinto submarine outfall, the latter discharging water from the three WWTPs (North, South and S. Jacinto), and from Portucel, which currently undergo a secondary treatment about 2 km from the coast.

A 3D ecological and hydrodynamic model (MOHID) was built for this process, embedded in a regional model for the Portuguese coast (PCOMS-BIO), which simulated the biogeochemical cycles of nitrogen and phosphorus, a group of primary producers, phytoplankton, and a group of primary consumers, zooplankton. The results obtained suggest that the discharge from the Ria de Aveiro represents between 0.25 and 900% (the latter near the mouth of the river) of the nitrate concentration, and between 2.5 and 43% of the phytoplankton concentration. On the other hand, the contribution of the submarine outfall, in the case of the Ria de Aveiro discharge, is only 1% higher in the area in which the discharge takes place.
Introduction

The Portuguese coastal area is a very complex region to study, not only from a hydrodynamic view but also from an ecological view, and especially because it is influenced by upwelling events during the spring/summer months (Lopes, et al., 2009). These hydrodynamic events are caused by the joint efforts of northerly winds and the coriolis force, pushing the surface water to the ocean and consequently bringing cold, saltier water full of nutrients to the surface (see Figure 1). 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 the fishing activities have the most 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 (Stevens, 2000), 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 will be 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.

The study area

The coastal waters of the Aveiro region studied in this paper are located between 40North and 41North and its length extends until 66 km from the coast line at about 9°20W with a low slope, at which point the slope of the continental shelf becomes very steep (Peliz, et al., 2002). 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 WWTPs 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 (Lopes, et al., 2009). Due to this anti-cyclone, in winter time it is dominated by weak southerly and westerly winds, and in the summer the atmospheric current changes, where strong northerly and north-westerly winds with mean velocity of 5-6 m/s are registered. (Silva, 2001) 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 the Ekman 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 (Moita, 2001).

![Figure 2: Location of the study area and main sources of water and nutrients.](image)

**Water and nutrient discharges**

As was mentioned before, there are three sources of nutrients to the study area, which are the ocean, Ria de Aveiro and the S. Jacinto submarine outfall. The data regarding fluxes of water and its properties through the ocean boundary are provided by a regional model. For the Ria de Aveiro, all properties are provided by a 2-dimension model implemented for the inside of the Ria, and finally the discharge from the submarine outfall is provided by SIMRIA, and include the flows from WWTPs Norte, Sul, and S.Jacinto, whose flow and nutrient input are presented in Table 1: Incoming water flow to the submarine outfall. Table 1 and Table 2, respectively.

In terms of contributions to the submarine outfall WWTP Norte is clearly the most important with 42% of the water flow, 66% of total N and 58% of total P. Since the discharge from the Ria de Aveiro is not linear, as it discharges not only water from the rivers but also water that enters the Ria with the high tide and then leaves with the low tide. Thus, a study of the available information regarding the nutrient input to the Ria de Aveiro was made, and the results differ from source to source even if the values are of the same magnitude. According to INAG (INAG, 2003) the total nitrogen input from fresh water is 3600 ton of nitrogen per year with no information as to the phosphorus input, while (Silva, et al., 2002) estimated an average of 6118 ton/year of nitrogen and 779 ton/year of phosphorus.

**Materials and methods**

In this chapter, a description of the hydrodynamic and ecological model is made, which includes the boundary conditions, the bathymetry used and the water discharges implemented in the model.

**Physical model**

The numerical model applied to the study area is a 3D ecological and hydrodynamic model (MOHID - Water Modelling System) with vast applications and validated for both coastal areas and inland water bodies (Trancoso, et al., 2005), (Coelho, et al., 1998), (Vaz, et al., 2005) developed by the research group MARETEC - Marine and Environmental Technology Center, IST, Lisbon. This model has been programed
with fortran95 using an object oriented philosophy, and includes several modules interconnected between them, one of them being the ecological model which uses de data calculated by the physical modules to simulate the dynamics of nutrient and living organisms. It uses an Arakawa-C grid (Arawaka, et al., 1977) to perform the computations, and in this approach the discrete form of the governing equations is applied macroscopically to the cell control volume, and uses an ADI (alternating direction implicit) scheme to solve the equations. The equations that represent this hydrodynamic model are:

\[
\begin{align*}
\partial_t, u &= -\partial_x(\rho u) - \partial_y(\rho v) - \partial_z(\rho w) + \\frac{f v}{\rho} - \partial_z(p + \partial_x((\rho u + v) \partial_x u) + \partial_y((\rho v + v) \partial_y u) + \partial_z((\rho w + v) \partial_z u) + \frac{1}{\rho} \partial_z(p + \partial_x((\rho u + v) \partial_x v) + \partial_y((\rho v + v) \partial_y v) + \partial_z((\rho w + v) \partial_z v) \tag{1} \\
\partial_t, v &= -\partial_x(\rho u) - \partial_y(\rho v) - \partial_z(\rho w) - \frac{f u}{\rho} + \partial_z(p + \partial_x((\rho u + v) \partial_x v) + \partial_y((\rho v + v) \partial_y v) + \partial_z((\rho w + v) \partial_z v) \tag{2} \\
\partial_t, w &= -\partial_x(\rho u) - \partial_y(\rho v) - \partial_z(\rho w) - \frac{f w}{\rho} + \partial_z(p + \partial_x((\rho u + v) \partial_x w) + \partial_y((\rho v + v) \partial_y w) + \partial_z((\rho w + v) \partial_z w) \tag{3}
\end{align*}
\]

Where \( u, v, \) and \( w \) are the x, y and z velocity components, \( f \) the coriolis parameter, \( V_h \) and \( V_v \) the horizontal and vertical turbulent viscosities, \( v \) the kinematic viscosity \((1.3 \times 10^6 \text{ m}^2\text{s}^{-1}) \) and \( p \) the pressure. As shown in this equation, the velocity is the balance of the advective terms, the coriolis force, the pressure gradient and the turbulent diffusion. The vertical velocity is then calculated from the incompressible continuity equation, and by integrating between bottom and the depth \( z \):

\[
\partial_t, u + \partial_x, v + \partial_z, w = 0 \tag{3}
\]

The free surface elevation is then calculated by integrating the continuity equation over the entire water column:

\[
\partial_t, \eta = -\partial_z, \int_{-h}^{h} u dz - \partial_x, \int_{-h}^{h} v dz \tag{4}
\]

Where \( \eta(x,y) \) represents the free surface elevation and \( h \) the depth. The pressure is calculated assuming a hydrostatic approximation:

\[
\partial_z p + g\rho = 0 \tag{5}
\]

Where \( g \) and \( \rho \) are the gravity and the water density, respectively. The integration of this equation from the surface to the depth \( z \) results leads to:

\[
p(z) = p_{atm} + g\rho_0(\eta - z) + g \int_{z}^{\eta} \rho' dz \tag{6}
\]

This passage is done by subtracting the atmospheric pressure \( (p_{atm}) \) from \( p \) and dividing \( p \) into a constant reference density \( \rho_0 \) and a density deviation dependent of the depth \( (\rho') \). The transport equation for the water properties due to advection and diffusion is:

\[
\frac{d A}{d t} = \partial_x, \partial (uA) + \partial_y, \partial (vA) + \partial_z, \partial (wA) - \partial_x, (\partial u, \partial A) + \partial_y, (\partial v, \partial A) + \partial_z, (\partial w, \partial A) \tag{7}
\]

Where \( A \) stands for the property being calculated. However, by default, the model uses an eulerian formulation rather than a lagrangian one, shown in this equation. Thus, the equation becomes:

\[
\frac{d A}{d t} = -\partial_x, (uA) - \partial_y, (vA) - \partial_z, (wA) + \partial_x, (\partial u, \partial A) + \partial_y, (\partial v, \partial A) + \partial_z, (\partial w, \partial A) \tag{8}
\]

Where the first three terms of the right hand side of the equation represent the advection transport, and the remaining terms, the turbulent diffusion transport.

**Boundary conditions**

The boundary conditions applied to the study area were: lateral closed boundary with the coastline; free surface boundary; bottom boundary, and a lateral open boundary with the ocean. The lateral closed boundary is a free slip condition imposed by specifying a zero normal component of mass and null momentum diffusive
fluxes at cell faces in contact with land. Water level and all properties simulated are provided by a regional model called PCOMS-BIO – Portuguese Coast Operational Modeling System, which are then interpolated for all boundary cells. At the surface, heat and mass transfer of $O_2$, $CO_2$, and $N_2$ is considered as well as mass transfer of all properties in the bottom.

**Bathymetry**

There were two grids applied to the study area, one from the regional model – PCOMS-BIO model and the local one, built specifically for this work. The regional and local model cell's dimensions are 6x6 km and 2x2 km, covering an area of 11x16 and 30x42 cells, respectively. Throughout this dissertation, 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 meters grid, and are presented in Figure 3.

**Water and nutrients discharged**

As mentioned before, the discharges from Ria de Aveiro and the submarine outfall were provided by a 2-dimension model implemented inside the Ria and SIMRIA, respectively. Though, the latter had to be estimated, since the results were relative to the WWTPs entrance instead of exit. This estimate was made using efficiency data present in (Metcalfe & Eddy, 2003), 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 9, were $C_{A(final)}$ represents the concentration of property $A$ in the month $i$, $j$ is the index of the three WWTPs and $M^PORTUCEL_A$ 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 WWTPs. The results obtained and used in the model are presented in Table 1 and Table 2, and the average hourly flow for the outfall is 1 m$^3$/s.

$$C_{A(final)} = \frac{\sum V_{portal} \times C_{A(i)} + M^PORTUCEL_A}{V_{total}}$$

Equation 9

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.

![Figure 3: PCOMS-BIO bathymetry (left) and local model bathymetry (right), built with EMODnet data.](image)
Table 1: Incoming water flow to the submarine outfall.

<table>
<thead>
<tr>
<th>Month</th>
<th>WWTP Norte (10^6 m³)</th>
<th>WWTP Sul (10^6 m³)</th>
<th>Total (10^6 m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>1.819</td>
<td>0.924</td>
<td>2.743</td>
</tr>
<tr>
<td>Feb</td>
<td>2.252</td>
<td>1.698</td>
<td>3.950</td>
</tr>
<tr>
<td>Mar</td>
<td>3.467</td>
<td>2.533</td>
<td>5.999</td>
</tr>
<tr>
<td>Apr</td>
<td>4.782</td>
<td>3.457</td>
<td>8.239</td>
</tr>
<tr>
<td>May</td>
<td>6.104</td>
<td>4.035</td>
<td>10.139</td>
</tr>
<tr>
<td>Jun</td>
<td>7.314</td>
<td>4.968</td>
<td>12.282</td>
</tr>
<tr>
<td>Jul</td>
<td>8.613</td>
<td>5.477</td>
<td>14.089</td>
</tr>
<tr>
<td>Aug</td>
<td>9.822</td>
<td>6.058</td>
<td>15.880</td>
</tr>
<tr>
<td>Sep</td>
<td>11.022</td>
<td>6.877</td>
<td>17.899</td>
</tr>
<tr>
<td>Oct</td>
<td>12.221</td>
<td>7.796</td>
<td>19.917</td>
</tr>
<tr>
<td>Nov</td>
<td>13.420</td>
<td>8.715</td>
<td>22.135</td>
</tr>
<tr>
<td>Dec</td>
<td>14.620</td>
<td>9.634</td>
<td>24.254</td>
</tr>
<tr>
<td>Total</td>
<td>13.171</td>
<td>10.766</td>
<td>33.937</td>
</tr>
</tbody>
</table>

Table 2: Concentrations in the diffuser of the submarine outfall.

<table>
<thead>
<tr>
<th>Month</th>
<th>N NH₄</th>
<th>N NO₃</th>
<th>PO₄</th>
<th>DONre</th>
<th>DONnr</th>
<th>POP</th>
<th>DOPnr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>1.95</td>
<td>0.67</td>
<td>0.46</td>
<td>1.27</td>
<td>0.13</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>Feb</td>
<td>3.00</td>
<td>1.62</td>
<td>2.13</td>
<td>3.03</td>
<td>1.91</td>
<td>0.20</td>
<td>0.70</td>
</tr>
<tr>
<td>Mar</td>
<td>2.32</td>
<td>1.27</td>
<td>3.06</td>
<td>1.52</td>
<td>0.16</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td>Apr</td>
<td>2.83</td>
<td>1.57</td>
<td>6.79</td>
<td>1.69</td>
<td>0.18</td>
<td>0.62</td>
<td></td>
</tr>
<tr>
<td>May</td>
<td>3.65</td>
<td>1.99</td>
<td>8.77</td>
<td>2.00</td>
<td>0.21</td>
<td>0.73</td>
<td></td>
</tr>
<tr>
<td>Jun</td>
<td>3.78</td>
<td>2.06</td>
<td>9.07</td>
<td>1.59</td>
<td>0.17</td>
<td>0.58</td>
<td></td>
</tr>
<tr>
<td>Jul</td>
<td>3.67</td>
<td>2.00</td>
<td>8.81</td>
<td>2.35</td>
<td>0.25</td>
<td>0.86</td>
<td></td>
</tr>
<tr>
<td>Aug</td>
<td>3.87</td>
<td>2.12</td>
<td>9.31</td>
<td>2.74</td>
<td>0.29</td>
<td>1.60</td>
<td></td>
</tr>
<tr>
<td>Sep</td>
<td>1.70</td>
<td>9.33</td>
<td>4.19</td>
<td>7.40</td>
<td>1.53</td>
<td>0.16</td>
<td>0.56</td>
</tr>
<tr>
<td>Oct</td>
<td>2.18</td>
<td>11.94</td>
<td>5.24</td>
<td>9.47</td>
<td>1.70</td>
<td>0.18</td>
<td>0.62</td>
</tr>
<tr>
<td>Nov</td>
<td>2.15</td>
<td>11.78</td>
<td>5.17</td>
<td>9.35</td>
<td>1.96</td>
<td>0.21</td>
<td>0.72</td>
</tr>
<tr>
<td>Dec</td>
<td>2.94</td>
<td>16.08</td>
<td>7.06</td>
<td>12.76</td>
<td>2.01</td>
<td>0.21</td>
<td>0.74</td>
</tr>
</tbody>
</table>

The validation of the hydrodynamic model was not possible to lack of data, except for the surface temperature, which was compared with satellite images. Furthermore, in order to determine the influence of the fresh water discharges in the study area, six integration boxes and four time series (Figure 4) were implemented in the model. Thus, the model returns, as an output, the flow of water, nitrate and phytoplankton between each box. The flow through the boxes in the left corner was not considered, as they do not provide more useful information to this work.

**Ecological model**

The ecological model is coupled with the hydrodynamic model through the transport equation and it is capable of simulating the nitrogen and phosphorous cycles as well as the oxygen cycle, which are interconnected, the primary producers and secondary producers. In this project the following forms of nitrogen are simulated: ammonia (NH₄), nitrate (NO₃), nitrite (NO₂), 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 (PO₄), 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. All these properties are interconnected and the relations between then are shown in Erro! A origem da referência não foi encontrada.

Even though the bacteria group is included in this figure, it was not included in the model, as it is not included in the regional PCOMS-BIO model that provides initial conditions for the current local model. Another particularity in Erro! A origem da referência não foi encontrada. refers to the oxygen box outside the main circle.
The process shown in the upper right corner represents the oxygen transformation and absorption into dissolved matter.

Figure 5: schematics of the dynamics of nutrient and living organisms.

The temporal evolution of these properties is calculated using a sources and sinks for every control volume, in which there are transformations associated with each of the simulated properties. This formulation is described in the equation:

$$\frac{dP}{dt} = \frac{\partial P}{\partial t} + u \frac{\partial P}{\partial x_j} = \frac{\partial}{\partial x_j} \left( k \frac{\partial P}{\partial x_j} \right)$$  \hspace{1cm} \text{Equation 10}

(SOURCES – SINKS)

Where $P$ is the concentration (mg/l), $j$ is the index for the correspondent Cartesian axis ($x,y,z$) and $K\Theta$ is the turbulent mass diffusion coefficient. All the equations regarding the properties dynamics can be consulted in the MOHID water quality manual, present at (http://www.mohid.com/). The main parameters associated with the internal processes occurring inside the control volumes are shown in Table 3. The validation of the ecological model was done by comparing the results for phytoplankton concentrations with satellite images for chlorofill-a concentrations.

Results and Discussion

The results obtained by the 3-dimension model regarding the fluxes of water, nitrate and phytoplankton, which are considered the most important properties associated with primary production, are presented in

. These results are a product of the integration boxes implemented near the mouth of the Ria, which also includes the discharge from the submarine outfall. As shown in the table, the discharge of Ria de Aveiro considerably changes the costal currents near its mouth, increasing the southward volume of water to almost the triple of the obtained without any fresh water discharges.

Table 3: Main phytoplankton parameters.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu_{\text{max}}$</td>
<td>Maximum growth rate</td>
<td>$d^{-1}$</td>
<td>1.5</td>
</tr>
<tr>
<td>$m_{\text{max}}$</td>
<td>Maximum Mortality Rate</td>
<td>$d^{-1}$</td>
<td>0.02</td>
</tr>
<tr>
<td>$K_{N}^{\text{phys}}$</td>
<td>Nitrogen half-saturation constant</td>
<td>mgN $l^{-1}$</td>
<td>0.04</td>
</tr>
<tr>
<td>$K_{P}^{\text{phys}}$</td>
<td>Phosphorus half-saturation constant</td>
<td>mgP $l^{-1}$</td>
<td>0.001</td>
</tr>
<tr>
<td>$I_{\text{opt}}^{\text{phys}}$</td>
<td>Optimum light intensity for photosynthesis</td>
<td>W$m^{-2}$</td>
<td>121</td>
</tr>
</tbody>
</table>
### Table 4: Fluxes through the three boxes closest to land. **Scenario1:** no discharges; **scenario2:** Ria de Aveiro; **scenario3:** Ria de Aveiro and submarine outfall.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Center-&gt;South</th>
<th>Center-&gt;West</th>
<th>Center-&gt;North</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water flow (10^6 m^3/month)</strong></td>
<td>1: 2482</td>
<td>2: 7279</td>
<td>3: 7302</td>
</tr>
<tr>
<td></td>
<td>2: -545</td>
<td>3: -572</td>
<td>1: -3483</td>
</tr>
<tr>
<td><strong>Nitrate (ton/month)</strong></td>
<td>1: 23</td>
<td>2: 446</td>
<td>3: 468</td>
</tr>
<tr>
<td></td>
<td>2: -9</td>
<td>3: 17</td>
<td>1: -31</td>
</tr>
<tr>
<td><strong>Phytoplankton (ton/month)</strong></td>
<td>1: 210</td>
<td>2: 837</td>
<td>3: 848</td>
</tr>
<tr>
<td></td>
<td>2: 109</td>
<td>3: 107</td>
<td>1: -257</td>
</tr>
</tbody>
</table>

Figure 6: Nitrate (left) and phytoplankton (right) concentrations in the Northern border. **Scenario1:** no discharges; **scenario2:** Ria de Aveiro; **scenario3:** all discharges.

Figure 7: Nitrate (left) and phytoplankton (right) concentrations near the outfall discharge. **Scenario1:** no discharges; **scenario2:** Ria de Aveiro; **scenario3:** all discharges.

The results also indicate an average contribution of 6% from Ria the Aveiro, regarding nitrate and phytoplankton concentrations in all domain borders with the ocean, and 900% near the mouth of the Estuary. Furthermore, the time series show that the submarine outfall’s contribution, when compared to that of Ria de Aveiro, is less than 1% for all borders considered, except for the area near its discharge, where the contribution reaches 6%. 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. However, there is a difference in trends between the times series located in the borders and the one located in the outfall discharge area (see Figure 7), where the phytoplankton only starts to
increase its concentration in the middle of the simulated period. This is probably because of the light intensity, which, as time passes, grows increasingly higher and up to a point where light stops being a growth inhibitor, and the phytoplankton inside the estuary begins to grow rapidly, increasing its mass transport to the ocean. Finally, and if a longer simulation period were to be simulated, the influence of Ria de Aveiro could reach the Northern and Southern borders, as the currents are stronger for those directions, and because only in the end of the simulated period is there a rapid increase in phytoplankton concentrations near its mouth.

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 1%, 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 WWTPs 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 6% 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. This influence will be studied after the delivery of this work.

Bibliography


