

EU Water Framework Directive: will the nitrate load reduction from diffuse sources produce the same results in all estuaries?

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ABSTRACT: The impact of urban waste-water and non-point nitrate discharges in estuarine and near-shore coastal waters are analyzed. The study is focused on the effects of applying the European directives 91/271/EEC and 91/676/EEC to these systems. 4 Portuguese estuaries and two coastal lagoons with different characteristics are studied. A modelling system is applied and calibrated in each system. Three nitrate load scenarios are examined. It is shown that the morphologic and hydrodynamic characteristics of the domain largely control the ecological processes in these systems. The primary production limitation factors are split into “biologic” and “hydrodynamic” components. The physical limitation due to hydrodynamic and residence time is the most important factor. The combined limitation of “biologic” factors (temperature, light and nutrients availability) control productivity only in the systems where physical limitation is not important.

1 INTRODUCTION

The European directives 91/271/EEC and 91/676/EEC force the definition of sensible and vulnerable regions respectively. The first case address urban waste water disposal and the sensible regions are considered as “estuaries and coastal waters which are found to be eutrophic or which in the near future may become eutrophic if protective action is not taken”. The second case address nitrate loads from agriculture and a region is considered sensible if it presents a nitrate concentration over a defined lever or if are “found to be eutrophic or in the near future may become eutrophic” The legislation leaves thus the definition of the trophic state undefined. Several criteria can be used. Important references on this topic are the ERM and OSPAR reports (ERM 2001, OSPAR 2002). These criteria recognize that eutrophication is a process and not a state. The assessment must be performed based on substantial data collection. The data must span spatially through the area of study and also temporally during a time scale that enables the identification of eutrophication trends. In many cases such collection of data is not available. In this paper a modelling approach is used to overcome these problems. This work is part of a national project leaded by the Portuguese national water authority (INAG) to access the water quality in the main Portuguese estuaries, in view of the water directives. The modelling task, presented here, uses a hydrodynamic, ecological and water quality model to achieve this goal. The spatial requirements needed to apply any of the abovementioned criteria,

are naturally solved by the model since it can produce a complete picture of the systems based on localized data. The time span requirement can also be solved by looking into the processes of the systems and trying to understand if they are leading them to eutrophication. The results of this work have thus produced a set of information that can be used by the competent authorities to characterize the systems.

Four estuaries: Minho, Lima, Douro and Guadiana, and two coastal lagoons: Ria de Aveiro and Ria Formosa were analyzed (Figure 1).

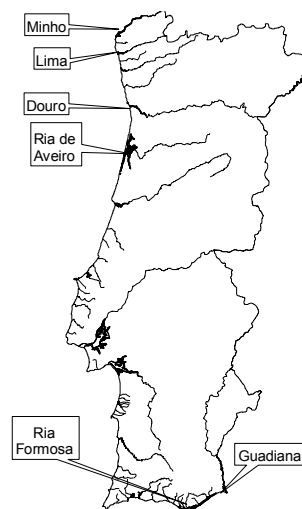


Figure 1. Site Identification

Morphologically and dynamically the Northern Portuguese estuaries are different from the southern estuaries. Estuaries in the northern part of Portugal are narrow and rivers have high discharge. In the South the flow is very irregular with long periods of very small flow interrupted by short and strong episodes of storm flow. The coastal lagoons also present significant differences: Ria de Aveiro receives significant amounts of fresh water from Vouga River and its connection to the ocean is narrow. Ria Formosa do not have permanent fresh water sources and have a easy connection to the ocean trough seven bars. These differences are critical for the control of the biologic processes taking place in each system.

2 METHODOLOGY

The MOHID modelling system was used to perform the simulations. It is driven by a 3D baroclinic hydrodynamic module including an eulerian and a lagrangian transport module. Parameters and processes involving non-conservative properties are object of specific modules (e.g. turbulence module, water quality, ecology and oil transformation). The hydrodynamic model solves the three-dimensional incompressible primitive equations (Martins et al., 2001). Hydrostatic equilibrium is assumed as well as Boussinesq approximation. The model uses a finite volume approach. This method makes the solution independent of the mesh geometry, allowing the use of a generic vertical mesh. The turbulence module uses the well known General Ocean Turbulence Model (GOTM). The model also solves a transport equation for salinity and temperature in order to compute the specific mass. The eulerian transport module used to transport these properties is based in the same finite volume method of the hydrodynamic model and is independent of the property transported. The lagrangian transport model tracks the trajectories of selected water masses using the transport fields from the hydrodynamic model in an explicit procedure. Dispersion is computed using the results from the turbulent model. The ecological model uses a zero-dimension formulation that enables the application of the same model with both the lagrangian and the eulerian transport models (Pina 2001). In this method the model equations are implemented in the form of source and sink terms of the transport models. Those terms are written in a generic form and can be applied both to eulerian cells and to lagrangian particles. The ecological model simulates the nitrogen cycle, the dissolved oxygen concentration, the BOD, the zooplankton and the phytoplankton population dynamics. The nitrogen species include the three main inorganic forms: ammonia, nitrate and nitrite and also three organic fractions: dissolved refractory fraction

(DRON), dissolved non-refractory fraction (DNRON) and particulate fraction (PON).

For each system a reference simulation representing the present conditions was run. Results obtained in this simulations aim to explain the functioning of the system. To evaluate the effects of reducing the discharge of nutrients from agriculture and nutrient removal by waste water treatment plants (WWTP) two reduction scenarios were simulated and compared with the reference situation. In the first case a 50% reduction of the nitrate river load was used maintaining all other parameters. This simulation is based on the assumption that agriculture is the major source of nitrate and in the fact that phosphorous is in excess in the estuaries. In the second reduction scenario the extreme situation of removing completely the discharge of all urban loads is considered. This will be useful to show the relative importance of this source of nitrogen.

3 RESULTS

Point time series are usually used, to characterize temporal variation of a property. This method raises two questions (i) which area is a point representing and (ii) which field data should be compared with a point time series computed by a model. On the other hand, interpretation of time series requires the knowledge of spatial distributions and associated transports. The association of time series to large boxes and the computation of fluxes across the boundaries of those boxes merge temporal and spatial variability simplifying the analysis of results.

In this work the estuaries were divided into boxes, each box including hundreds to thousands of model cells. The solution for each box was computed integrating spatially the results of cells inside the box and fluxes were obtained integrating the solution along box boundary. Both spatial average values inside the box and fluxes across box boundaries were used for building time series and computing annual net fluxes and average concentrations. Integration boxes as described in the above paragraph are similar to boxes used in traditional "box models" in the sense that the solution is presented in a few boxes, but are absolutely different in terms of how the result is generated. This integration boxes are a post-processing tool for simplifying the analysis of the detailed solution produced by the model. On the contrary "box-models" require residual water fluxes and corresponding diffusivities which have to be provided to the model as part of the input and are not usually known.

In figures 2 to 7 the annual average concentrations and total annual phytoplankton and nitrate transports between boxes are shown for the six systems.

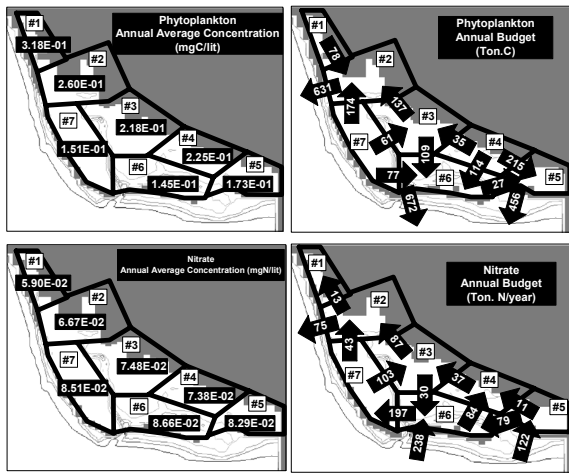


Figure 2. Ria Formosa, phytoplankton and nitrate average annual concentration and annual transport between boxes.

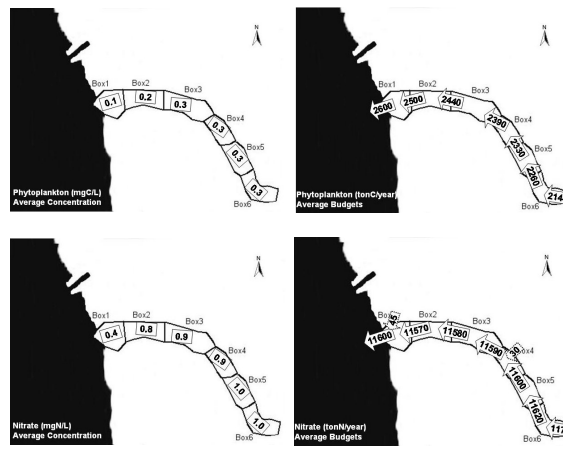


Figure 5. Douro River, phytoplankton and nitrate average annual concentration and annual transport between boxes.

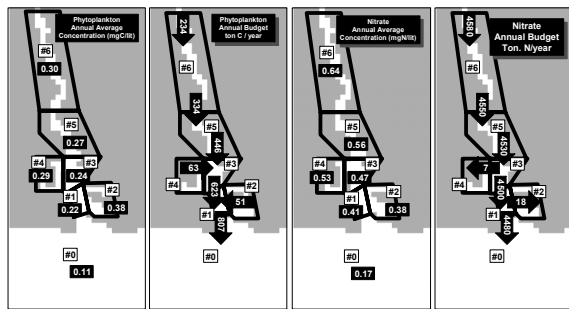


Figure 3. Guadiana River, phytoplankton and nitrate average annual concentration and annual transport between boxes.

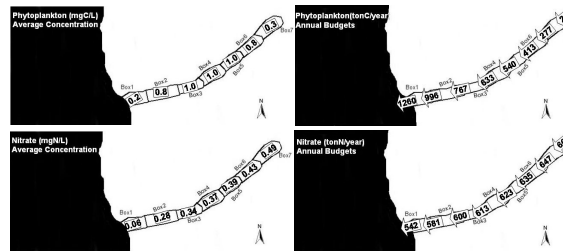


Figure 6. Lima River, phytoplankton and nitrate average annual concentration and annual transport between boxes.

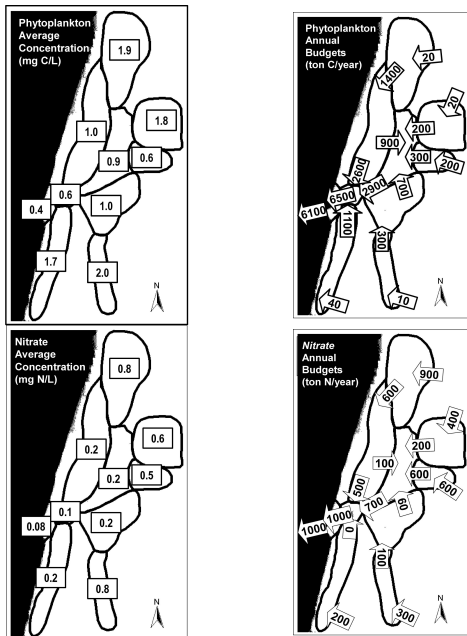


Figure 4. Ria de Aveiro, phytoplankton and nitrate average annual concentration and annual transport between boxes.

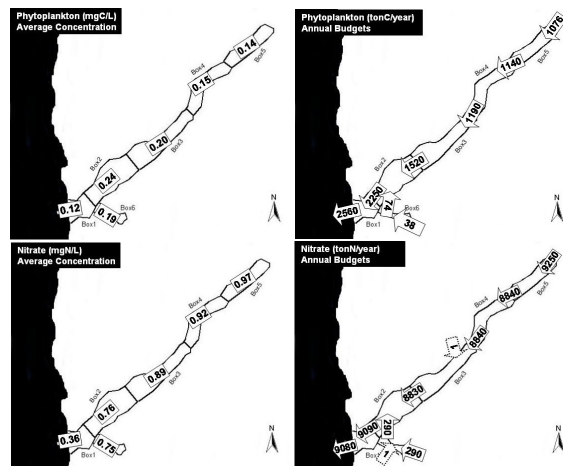


Figure 7. Minho River, phytoplankton and nitrate average annual concentration and annual transport between boxes.

The phytoplankton growth limitation coefficients due to nutrients, light and temperature were computed using the model. Each coefficient is a number from zero (total inhibition) to one (no limitation). The total limitation is the product of these three coefficients.

Table 1: Residence time and total growth limitation factor for the estuaries (0 => Total Limitation ; 1 => No Limitation ; w-Winter; s-Summer; nutr.-Nutrients; r.t.-Residence Time)

Domain	Residence Time (Days)	Limitation Factor	Main Limit. Process
Ria Aveiro	20	0.30	w-light s-nutr+r.t.
Lima Estuary	7	0.30	Nutrients
Guadiana Estuary	4	0.32	w-light s-nutr+r.t.
Ria Formosa	1.5	0.39	r.t.
Douro Estuary	1	0.2	r.t.
Minho Estuary	1	0.5	r.t.

In tables 1 and 2 information relative to each estuary is summarized. The annual budgets are positive when input plus production exceeds output plus consumption. The residence times were computed using a lagrangian transport model to trace the water parcels along the estuaries and applying the method described in (Braunschweig et al, 2003).

Table 2: Annual phytoplankton and nutrient budgets for the estuaries. (Positive => Inflow+Production>Outflow+Consumption)

Domain	Phytopl. (Ton C/y)	Ammonia (Ton N/y)	Nitrate (Ton N/y)
Ria Aveiro	+100	-250	-1400
Lima Estuary	+17	+68	-120
Guadiana Estuary	+10	-49	-100
Ria Formosa	+30	-90	-285
Douro Estuary	+8	+156	-201
Minho Estuary	+22	-20	-465

4 DISCUSSION

All systems behave as phytoplankton exporters to the coastal zone. To support this production all systems are net consumers of nitrate. The limitation to growth has different natures for each estuary: for the estuaries with high residence times such as Ria de Aveiro, Lima Estuary and, in some extent, Guadiana Estuary, the residence time is high enough to enable the biologic processes to take place inside the estuary. The limitation is thus due to lack of nutrients or shortage of light (temperature is usually not a problem in this latitudes). On the other hand in estuaries with low residence times such as Ria Formosa, Douro Estuary and Minho Estuary, the biologic processes do not have enough time to complete inside the estuary. In these systems cells are flushed out of the system before they can divide, inhibiting blooms. The nutrients are also flushed out and the uptaking and recycling occurs in the coastal zone.

In the first type of systems (high residence times) the scenarios with nutrients reduction produced significant reductions of phytoplankton concentration. For the systems with low residence times the simulations with reduced loads only show lower nutrient

fluxes to the platform but the phytoplankton concentration and the net production inside the system remains unchanged. This behavior is not constant along the year. Except for Ria Formosa and Ria de Aveiro all the other estuaries have much lower residence times during winter. This is particularly important in Guadiana River which shows a very irregular flow. In this case during high flow events residence time is the only process controlling production.

Due to the different nature of the systems, the effects expected from the application of nitrate and waste water directives will vary from system to system. In the systems with high residence time and when storm fresh water flows are not important a reduction in nutrients will produce a significant reduction in phytoplankton concentration and in primary production. In the systems with low residence time a reduction in load will only produce a decrease on the nutrient transit and will not affect the state of the estuary.

5 CONCLUSIONS

With this work it was shown that the effect of nutrient reduction can be very different from system to system. For the analyzed estuaries the major controlling parameter is the residence time. Systems with low residence time are not sensitive to nutrient reductions.

6 ACKNOWLEDGMENTS

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REFERENCES

- Braunschweig, F., Martins, F., Chambel, P. & Neves, R. 2003. A methodology to estimate renewal time scales in estuaries: the Tagus Estuary case. *Ocean Dynamics* 53(3): 137-145.
- ERM 2001. *Criteria used for the definition of Eutrophication in marine and coastal waters*. Environmental Resources Management report for the European Commission. DG-ENV.
- OSPAR 2002. *Common Assessment Criteria, their Assessment Levels and Area Classification within the Comprehensive Procedure of the Common Procedure*. OSPAR Agreement 2002-20.
- Martins, F., Neves, R., Leitão, P. & Silva, A. 2001. 3D modeling in the Sado estuary using a new generic coordinate approach. *Oceanologica Acta* 24:S51-S62
- Pina, P. 2001. An integrated approach to study the Tagus estuary water quality. M.Sc. thesis, Lisbon: I.S.T. Technical University of Lisbon.