On the origin of cyanobacteria blooms in the Enxoé reservoir

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Abstract

In the framework of AquaStress (an EU funded integrated project), a small reservoir (Enxoé) located in the South of Portugal was studied. The reservoir was built to supply water for human consumption, but it shows several water quality problems namely cyanobacteria blooms. In the last years and as a consequence of these problems, it was not possible to use it to supply water during the entire summer. In order to try to understand the possible causes of the problems and, hopefully, find proper solutions to solve them, an integrated study involving the catchment, the data available concerning the nutrient loads, the meteorology and the water quality and mathematical models was set up. This approach allowed the suggestion of some possible actions that may lead to improve the conditions within the reservoir.

Some major conclusions of data analysis put in evidence that there was a sudden change after the winter 2000/2001 floods, namely a rapid phosphorous enrichment and a rapid decrease of N:P ratio, bottom anoxia and presumably phosphorous release from sediments and permanent cyanobacteria dominance since the 2001/2002 floods.

The first modelling results also put in evidence that the model was not reproducing accurately the behaviour of the reservoir. The main cause for this is probably due to errors in the methods of the loads quantification, although a standard approach based on OSPAR guidelines that showed to be successful in other applications made in the north of Portugal is being used. The cyanobacteria dominance started only after the winter of 2000/2001, indicating that the big floods that occurred on that year and associated erosion, may be responsible for a major source of P for the reservoir. This source is possibly misrepresented by any estimate of loads.

In order to try to clarify these aspects it was decided to find similar data from other reservoirs in the neighbourhood (e.g. Monte Novo and Roxo) to validate the thesis that floods might be a triggering mechanism for cyanobacteria dominance. Also to solve the problem of boundary conditions for the reservoir model, a simple inverse model that computes the loads as a function of measurements of Phosphorus in the reservoir and exchanges between the water column and the sediments was used.

Introduction

Enxoé reservoir is located on the left margin of Guadiana river, just to the south of Alqueva reservoir in Alentejo, Portugal – see Figure 1. This watershed has a Mediterranean climate that is characterized by hot, dry summers and cool, wet winters. According with the Köppen climate classification the south of Portugal is included in the class Csa. The letter *C* stands for Temperate/mesothermal and means that this climate has an average temperature above 10 °C in their warmest months, and a coldest month average between −3 °C and 18 °C. Letter *s* indicates the precipitation pattern which is characterized by dry summers (driest summer month less than 30 mm average precipitation and less than one-third wettest winter month precipitation). Letter *a* indicates degree of summer heat which in this case has the warmest month average temperature above 22 °C with at least 4 months averaging above 10 °C.

In terms of annual precipitation, Enxoé watershed includes isoyets of precipitation from 800mm to 600 mm. The nearest climatological station that have data for climatological caracterization is Mértola / Vale Formoso. Based on that data DSRNAH – DS (2003) applied the Thornthwaite method and concluded that the climate in the area was subhumid dry, mesothermic.

No data is available for the calculation of flow rates at rivers. The reservoir was projected for an average flow rate of 8.63 $hm^3\ yr^{-1}$. Simulations made with a model predicted 8.0 $hm^3\ yr^{-1}$ which is very close to the projected value.

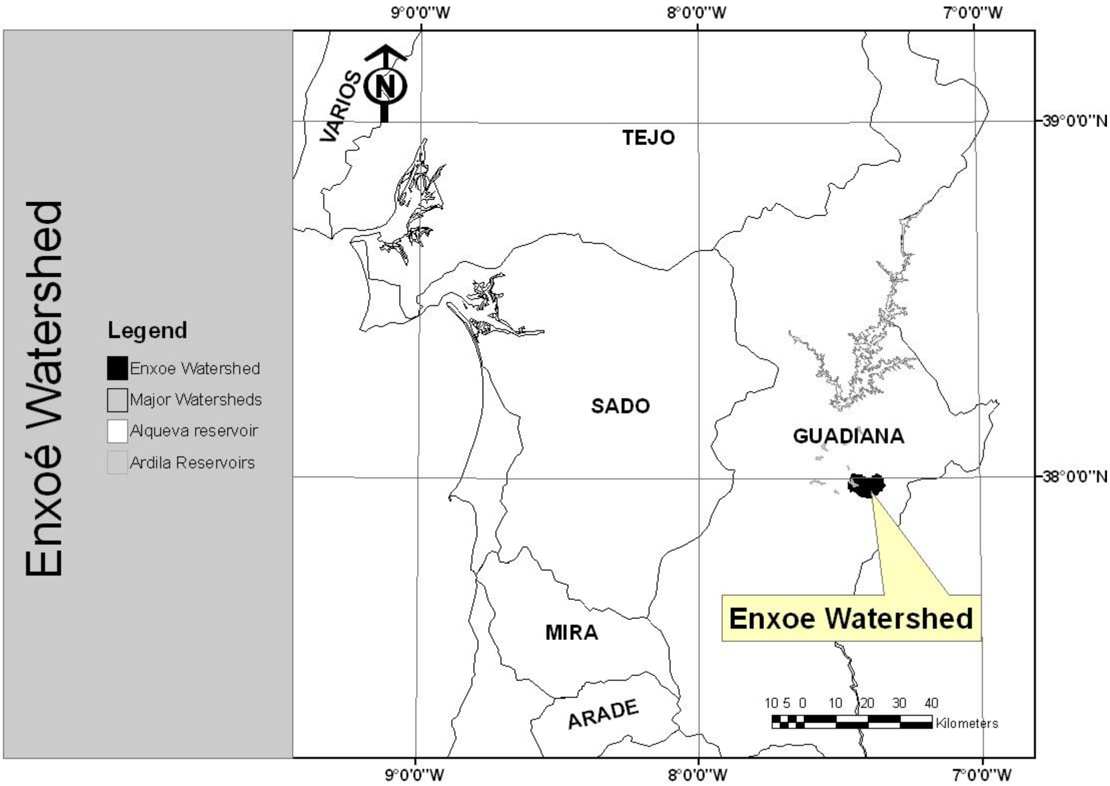

Figure 1 – Enxoé Watershed location in Alentejo, Portugal.

Data Available

Most of the data available for the reservoir was obtained from the National System of Information in Hydrological Resources (SNIRH) maintained by Instituto da Água. Some data concerning the qualitative phytoplantonic analysis was supplied by the municipality of Serpa. Finally temperature and dissolved oxygen profiles, a few measurements on the Enxoé River and on reservoir sediments were supplied by EDIA (The company that manages the Alqueva infra-structure).

The data obtained from SNIRH consists of time series, with a sampling interval of 1 month, of water quality parameters – nutrients, organic matter, chlorophyll-a – and hydrological parameters – reservoir level and volume stored. These data have been recorded continuously since 1998. Data from Serpa municipality consists of detailed analysis of phytoplankton using samples obtained at the Water Treatment Station since 2000.

Data Analysis

Let us start the data analysis by looking at the geometric averages of the nutrient parameters observed in Enxoé from 1998 to 2006. The first remarkable feature present in the data is the large increase observed in Phosphate and Total Phosphorous after the floods of December 2000. This increase is not clear in Nitrate concentration. Clearly there seems to be a relation between P concentration and precipitation (see Table 1) as it will be discussed later.

Table 1 –Yearly accumulated precipitation observed at Serpa meteorological station. The average accumulated precipitation at this station is 526 mm. Note that during 2000/01 the observed precipitation in December was 261 mm and the average for this month is 79 mm.

Hydrological Year	Precipitation (mm)
98/99	387
99/00	510
00/01	702 *
01/02	509
02/03	485
03/04	494
04/05	208
05/06	510

The fact that Nitrate concentration in the reservoir seems to be correlated to a minor extent with precipitation is reflected on the N:P ratios (by mass) calculated using the inorganic forms of N and P – that is, Nitrate, Nitrite, Ammonia and Phosphate. Actually, Figure 5 shows a substantial decrease in N:P ratio after the floods of December 2000. This decrease in N:P ratio, reflects the increase in P that was not accompanied by an increase in N.

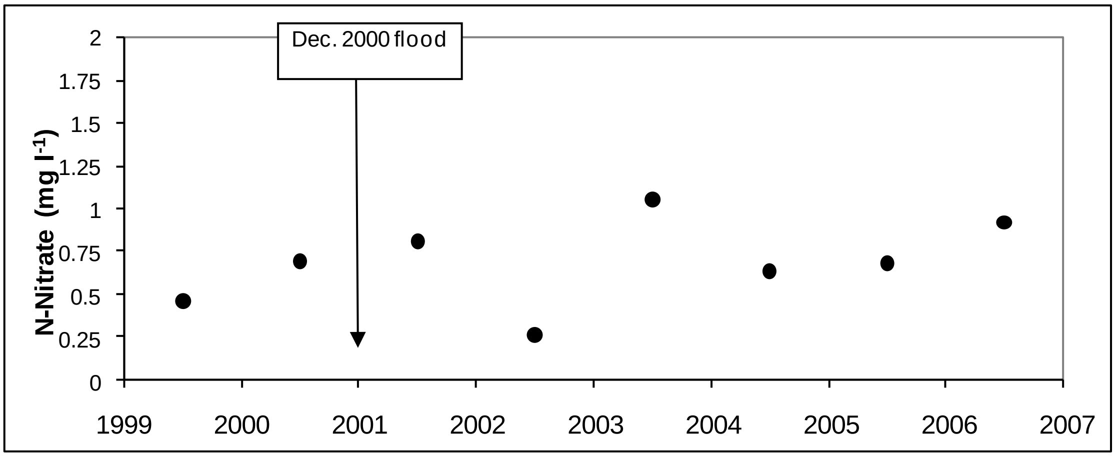

Figure 2 – Yearly geometric Average of N-Nitrate observed at Enxoé reservoir from 1998 to 2006.

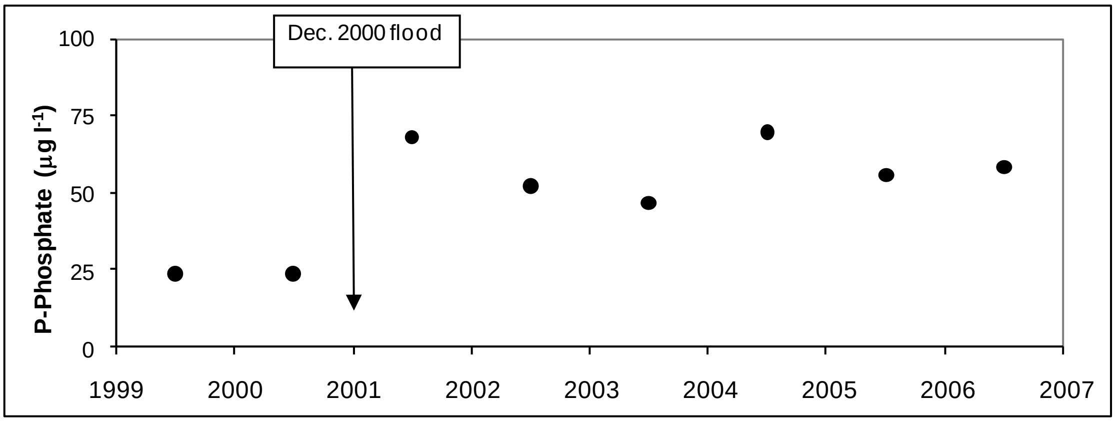

Figure 3 - Yearly geometric Average of P-Phosphate observed at Enxoé reservoir from 1998 to 2006.

Under these conditions, i. e. the reduction of the N:P ratio it is expected that cyanobacteria start to dominate the phytoplankton population at least in some periods of the year. Schindler (1977), referred that the phosphorous concentrations and the correspondent low N:P ratio, represent favourable conditions for the development of cyanobacteria blooms. Later, Smith (1983) using a large data set for temperate lakes, concluded that a TN:TP ratio of 29:1 makes the difference between lakes that are dominated by cyanobacteria and those that are not. The mechanism proposed by Smith (1983) to relate cyanobacteria with low TN:TP ratios, is the fact that cyanobacteria are better competitors for nitrogen under low concentrations of this component. Havens et al. (2003) using only inorganic forms of Nitrogen and Phosphorous established the N:P ratio for dominance of cyanobacteria as a value lower than 10:1.

Our data shows that the N:P ratio becomes very low after the floods of December 2000 and remains low for the next years, with the exception of 2003.

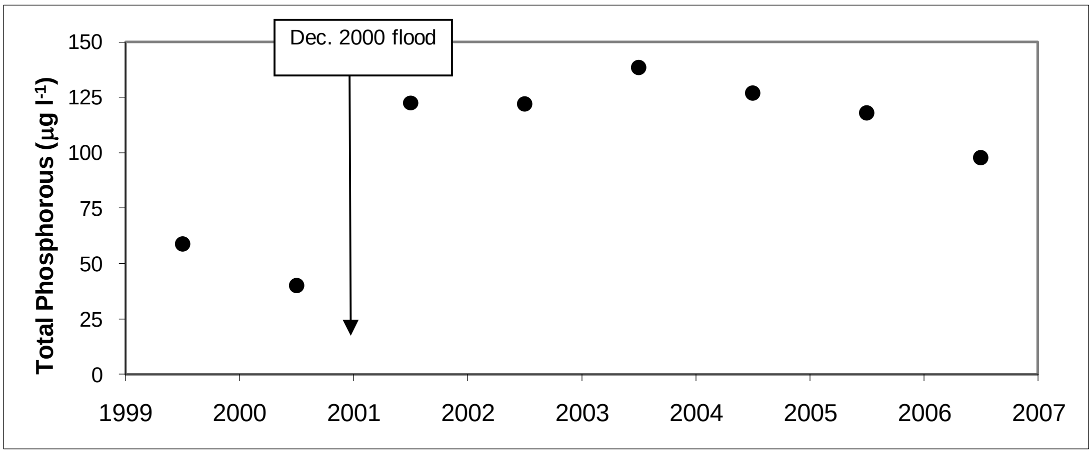

Figure 4 - Yearly geometric Average of Total Phosphorous observed at Enxoé reservoir from 1998 to 2006.

With these low N:P ratios, it is expectable that cyanobacteria blooms start to occur in Enxoé reservoir. On Figure 6 it is shown the relative abundance of cyanobacteria. Apparently a large increase in relative abundance occurred only in 2002 and not in 2001 when the Phosphorous concentration started to increase and the N:P ratio decreased. This might be a consequence of an increase in Nitrate also in 2001 that is not detectable in data because it has been consumed by diatoms and chlophytes. It is important to note that relative abundances of cyanobacteria close to 100% mean that, not only cyanobacteria is the dominant group of the phytoplanktonic population, but also, that they dominate during the entire year, which is far from a typical pattern of algae succession in a temperate lake.

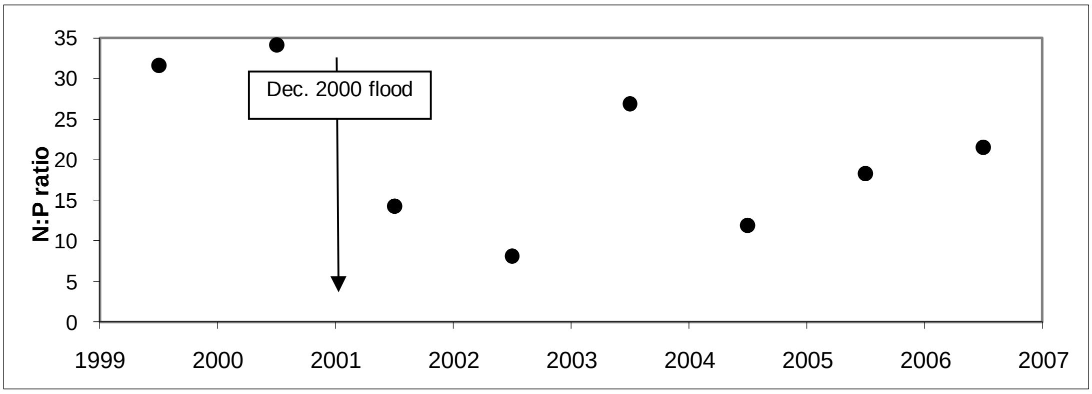

Figure 5 - Yearly geometric Average of N:P ratios (by mass) calculated using inorganic forms of N and P.

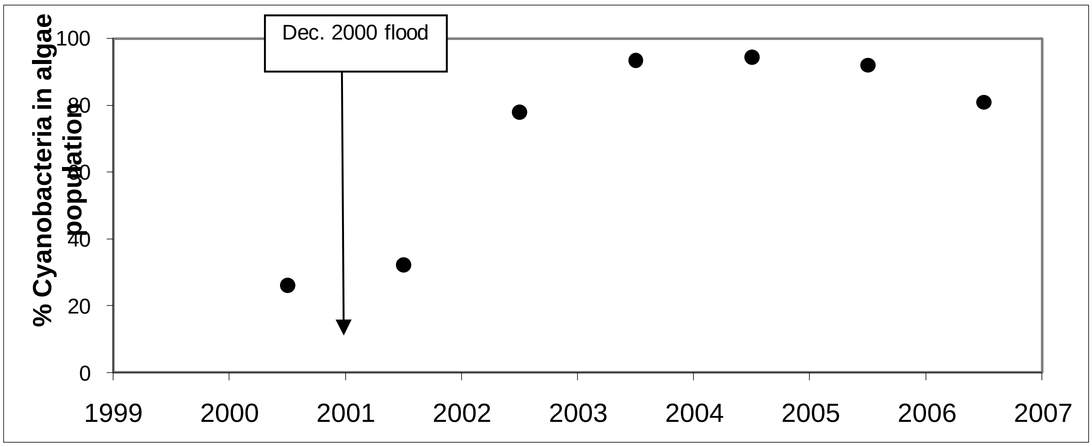

Figure 6 - Yearly geometric Average of relative cyanobacteria abundance.

Table 2 shows the correlations between a few water quality indicators. It is remarkable that cyanobacteria relative abundance is highly correlated with Total Phosphorous concentration but not with Nitrate. It was also found good correlation between cyanobacteria relative abundance and the minimum hipolimnium depth observed during one year. This minimum hipolimnium depth was determined from dissolved oxygen profiles as the depth at which the oxygen concentration falls bellow 1 mg l^{-1}.

Other important correlations are, the high values observed between minimum hipolimnium depth and N:P ratio, meaning that large N:P ratios are found when the water column is well oxygenated and the high negative correlation between cyanobacteria relative abundance and Chlorophyll concentration. This high negative correlation shows that high productivity is associated with relatively low chlorophyll concentrations in periods of cyanobacteria domination.

Table 2 – Correlations between a few water quality indicators measured at Enxoé reservoir between 1998 and 2006.

	Cyanobacteria relative abundance	*TP*	*P-Phosphate*	*N-Nitrate*	*Chlorophyl*	*Minimun Hipolimnium Depth*	*N:P*
Cyanobacteria relative abundance		***0.66***	***0.40***	*0.02*	***-0.88***	***0.61***	*0.28*
TP			***0.82***	*0.23*	*-0.50*	***-0.63***	***-0.56***
P-Phosphate				*0.22*	*0.32*	*0.10*	***-0.64***
N-Nitrate					*-0.06*	*0.10*	*-0.14*
Chlorophyl						*-0.33*	*-0.28*
Min. Hipo. Depth							***0.66***
N:P							

A first indication that the reservoirs in the southern part of Portugal have a different behaviour comes from the multivariate analysis of Trophic State Index defined by Carlsson (1977) using the available data for the reservoir. While for the reservoirs of the North of Portugal we clearly can distinguish between the summer period when the light decay is dominated by cyanobacteria or zooplankton, in the South light decay is dominated throughout the year by cyanobacteria – see Figure 7.

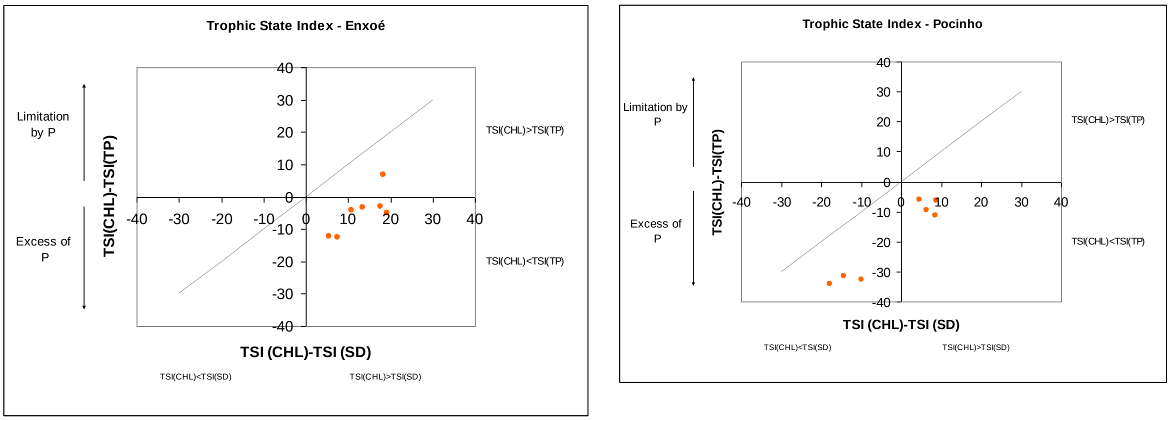

Figure 7: Multivariate plot of Trophic State Index for Pocinho (North of Portugal) and Enxoé (South of Portugal).

Discussion

The analysis of data obtained in the reservoir shows many important aspects of the behaviour of the reservoir. Let us try to provide an explanation for the data available. The reservoir is relatively young since the operations started in 1998. On the first years of operation it was observed a regular pattern with a typical algae succession and phosphorus levels in agreement with the neighbouring reservoirs. The winter of 2000/01 was particularly wet, with a large amount of precipitation falling during December 2000. The first response observed in the reservoir is the increase in phosphorus concentrations. However the change in phytoplankton population is not seen before 2002 which might be an indicator of an indirect consequence of the floods of December 2000. A possible explanation is that during the 2000/01 floods a large amount of organic material and nutrients adsorbed to sediments reach the reservoir. In the following months both phosphorus and nitrogen were consumed by primary producers. This increase in primary production was composed of successive peaks of cyanobacteria, clorophytes, dinofalgellates and diatoms, conveying the presence of phosphorus, nitrogen and silica in the reservoir. However at a certain time, both silica and nitrogen became the limiting factor in the reservoir. On the other the excess of phosphorous adsorbed to particulate material settled at the bottom and remained in the reservoir. Finally the oxidation of the large amounts of organic matter consumed the available oxygen available. The reservoir became anoxic, particularly in deeper layers, and the conditions for phosphorus remobilization were created. The dominance by cyanobacteria seen after March 2002 reflects essentially this excess of phosphorus.

This conceptual model could be confirmed by using a model of the reservoir. In the absence of flow rates and concentrations measured at inflowing rivers it is usual to use a model to estimate nutrient production in the catchment. This model can be simply an estimate following the OSPAR Guidelines or an implementation of a more complex scheme like SWAT. None of these approaches have produced reasonable results because clearly the upstream boundary condition is misrepresented. Presently an inverse model scheme that uses the data in the reservoir to estimate an upstream boundary condition for phosphorous that is used to calibrate the catchment model is being developed. The problem with the upstream boundary condition for the reservoir model is that the amounts of nutrients are overestimated in dry years and underestimated in wet years. This was confirmed in other reservoirs in the region where inflowing data exists. It seems reasonable to admit that in semi-arid regions like Alentejo with highly variable precipitation and runoff, a large amount of the organic material and nutrients produced in the watershed are not transported downstream. This is particularly evident in dry years but might be valid even in years with precipitation close to the average values. This means that a large proportion of this material accumulates in the watershed and only in very wet years with intense floods is removed and transported into downstream reservoirs. Often this occurs in a very short period of time. This could explain why the available catchment models (like SWAT) overestimate loads in dry years and underestimate them in wet years as the model misrepresent erosion processes. More important, this could explain what happened at Enxoé after the floods of December 2000.

Actually data shows a rapid increase of phosphate and total phosphorous after December 2000. This is accompanied by a rapid decrease in dissolved oxygen concentration and minimum hipolimnium depth. On the other hand, after 2002 cyanobacteria are basically the only group in phytoplankton population that is present in the reservoir. An analysis of the trophic state using the Carlsson index shows that the reservoir is eutrophic, with excess of phosphorous and light attenuation is dominated by cyanobacteria. Correlations also show that cyanobacteria relative abundance is very well correlated with total phosphorous and with minimum hipolimnium depth, confirming the conceptual model described above. The low correlation found between nitrate and both cyanobacteria relative abundance and chlorophyll-a also agrees with the hypothesis described.

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