South Portugal Reservoirs – Status and major concerns

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Abstract
In southern Portugal, the dry summers together with low precipitations and high temperatures highlight the importance of reservoirs, built mainly for water storage and to smoothing the interannual precipitation variability, in one of the driest regions in the country.
According to the Water Framework Directive nº2000/60/CE, all states members are responsible for the classification of superficial water bodies using a system based on both ecological and chemical status. The Water Framework Directive set the aim of achieving the “Good” status for surface and groundwater by 2015.
There are two reservoirs typologies in the south of Portugal, the main course and the south typologies. Data from the current River Basin Management Plans were used to identify the quality status of 28 reservoirs, 26 from south typology and 2 main course typology. General physical and chemical elements (total phosphorus, dissolved oxygen, oxygen saturation rate, nitrates, pH), biological elements (chlorophyll *a*), specific pollutants and priority substances were used to classify the reservoirs status in “Good” and “Less than Good” quality classes.
Results showed that 20 reservoirs were rated as “Good” and only 8 reservoirs were below the “Good” status.

Key words: ecological potential; interannual variability; reservoirs; river basin management plans

INTRODUCTION

Technological development and population growth as well as climate change issues have brought new challenges to water resources management. Despite the major part of freshwater ecosystems being threatened by overexploitation and quality issues, this matter reaches major importance when associated with water scarcity areas in Arid, Semi-Arid and Mediterranean areas. In these areas it is essential not only to discuss priorities and prevention strategies but also to achieve sustainable management practices (Rosado & Morais, 2010), always keeping in mind that the combination of supply and demand management measures are needed (World Water Assessment Programme, 2009).

Portugal is located in the Mediterranean area characterized by an interannual climate variability with heavy rainfall events, flash floods, and no rain periods. This situation, affects mostly the southern part of the country, with hot dry summers and mil and wet winters (Lohmann *et al.*, 1993). The particular characteristic of climate promotes ecosystem vulnerability and temporality (Rosado & Morais, 2010). Due to the spatial and temporal variability of precipitation, public authorities invested in large storage, transport and water distribution structures, allowing an efficient water use and the sustainable exploitation of water resources. The dry and wet cycles have a major role in the structure and functioning of Mediterranean ecosystems. In the south part of the country, the disrupting of the superficial river runoff during the hottest months interferes in the variation of water levels in reservoirs, usually followed by a decrease in water quality. In the other hand, flash flood events increase the nutrient and organic matter loads that reach downstream reservoirs.

Reservoirs water quality relies on the relation between climate and its morphometry, morphology, geology, land uses (Walker, 1983) and its main use. Related to reservoirs uses are the seasonal water level variation, which directly interferes with physical, chemical and biological parameters (Wetzel, 1990; Geraldes and Boavida, 2004). According to Geraldes and Boavida (2004), intense water consumption and consequent water level fluctuations contribute to nutrient and organic matter increment, leading to high values of total phosphorus, nitrates and chlorophyll *a* in the water column. Portuguese reservoirs are the main source of freshwater for multiple uses, water supply, electricity, irrigation and recreation. According to the Water Framework Directive nº2000/60/CE (WFD), these important economic and social investments have the aim of achieving "Good" status till 2015. With the application of the WFD and the River Basin Management Plans implementation (not published), reservoirs are classified as High Modified Water Bodies and evaluated according to an integrated perspective which includes not only physico-chemical elements but also biological elements (chlorophyll *a*), specific pollutants and priority substances (INAG , 2009a). The worst status of chlorophyll *a*, general physical chemical elements and specific pollutants, rates the ecological potential which combined with chemical status (priority substances classification) determined the final status of a reservoir.

Using the WFD and River Basin Management Plans directives the main objective of this study was to assess the current status of 28 Portuguese reservoirs (26 in the south and 2 in main course typologies). Knowing ecological integrity of south Portugal reservoirs will be of great importance to identify the main problems and adapt water management systems to regional requirements.

STUDY AREA

Portugal extends for an area of 89 300 $km^{2,}$ 560 km long and 220 km wide. It is located between 6º W-10º W meridians and 37º N- 42º N parallels. The 28 reservoirs of this study are located in the south region of Portugal (Figure 1). Here, climate is characterized mostly by Mediterranean influence with most rainfall occurring seasonally between October and April, followed by five dry summer months, from May to September. In this region the interannual precipitation levels and its geographical distribution are highly variable. The land use is varied, usually dominated by Holm oak (*Quercus rotundifolia*) and Cork oak (*Quercus suber)* woodland, pastures, forest plantations, shrubs and agricultural areas.

In this study we evaluate reservoirs from south and main course typologies. The south reservoirs typology are located in lowland areas, with silicious basin substrate dominated by schist's and sedimentary rocks. Hardness is higher than 50 mg $CaCO_3$/L. Their main uses are irrigation and water supply, with more than 7 months of water residence time. Water levels are higher between January and June reaching the minimum in the summer (INAG, 2010). Main course reservoirs are characterized by a small water residence time (less than 10 days) and a drainage basin area higher than 20000 km^2 (INAG, 2010).

In the main course of Guadiana River is located the biggest artificial lake of the Iberian Peninsula, the Alqueva Reservoir. Alqueva together with Pedrógão reservoir form the Alqueva-Pedrógão system, an important multiple uses water supply system that stores up to 4500 million m^3 in Alqueva and 97 million m^3 in Pedrógão (Morais *et al.*, 2007).

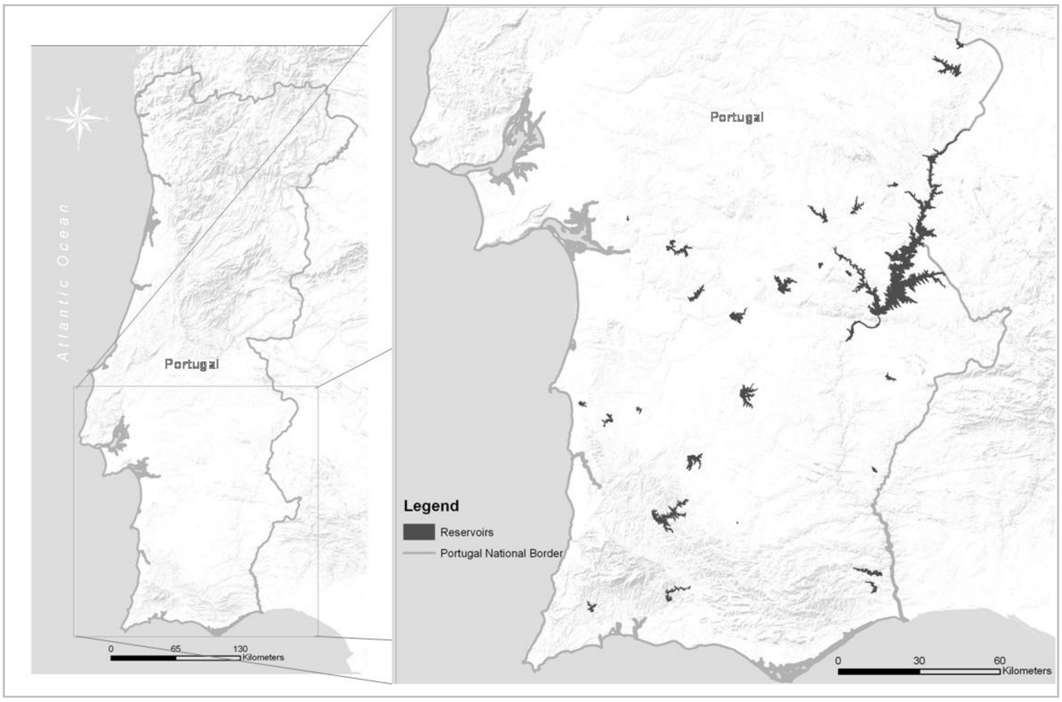

Figure 1. Map of Portugal, with the location of the 28 studied reservoirs in the south part of the country.

METHODS

Monitoring programmes carried out in 2009 evaluated 28 reservoirs (south and main course typologies) with a maximum storage level higher than 0.5 Km^2 and at least 5 or more year's age. Dissolved oxygen, oxygen saturation rate and pH were measured with a field probe (In situ Troll 9500 profiler XP) at surface. Vertical profiles were also measured (approximately from 2 in 2 meters). Water samples were taken to laboratory for the analysis of the physical-chemical elements described in V Annex of WFD, including total phosphorus, nitrates, specific pollutants and also priority substances. chlorophyll *a* was sampled according to INAG procedures (INAG, 2009b) and normalized into an Ecological Quality Ratio (EQR) by dividing the obtained values by a maximum potential reference value (1,6 mg/m^3) (INAG, 2009a). In each reservoir the aspects of the margin, water body pressures, and main observations were registered in a field form.

In the south reservoirs typology and because of the lack of enough historical data, it was only used the established boundaries (Good/Moderate) to some physical-chemical elements (dissolved oxygen, oxygen saturation rate, pH, total phosphorus, nitrates) and chlorophyll *a*. (INAG, 2009a). To specific pollutants the national boundaries were applied to the annual average concentrations (INAG, 2009a). Chemical status, and therefore priority substances were evaluated according to Decree nº103/2010. The chemical status was analyzed only in 19 reservoirs, 17 south typology and 2 main course typology. Reservoirs final quality status resulted from the combination of both Ecological potential (physical chemical, chlorophyll *a* and specific pollutants) and Chemical status (priority substances), from which the worst classification prevailed.

In order to understand the specific processes and reservoir conditions, a temporal evolution of the last six years was performed to phosphorus and chlorophyll *a*, using the software SPSS statistics 17.0.

RESULTS AND DISCUSSION

South reservoirs typology

In 2009, from the 26 evaluated south reservoirs typology, only 19 reached the "Good" status. High concentrations of total phosphorus and low chlorophyll *a* (EQR), as well as dissolved oxygen and oxygen saturation rates, defined the status of Monte Novo, Lucefécit, Enxoé, Pego do Altar, Vale de Gaio, Campilhas and Abrilongo reservoirs in "Less than Good" (Figure 2 and Figure 3). Pego do Altar presented in 2009, low oxygen values especially after summer, which could reflect the initial phase of Autumn water mixture, when the hypolimnetic water starts to mixture with surface water. Oxygen depletion interferes with water quality, promoting bad odors and taste as well as alterations in the biological communities. In other reservoirs such as Monte Novo, Lucefécit, Enxoé, Vale de Gaio, and Campilhas high values of dissolved oxygen together with slightly pH increase might reflect algal blooms and high primary production periods, as described by Chapman (1996).

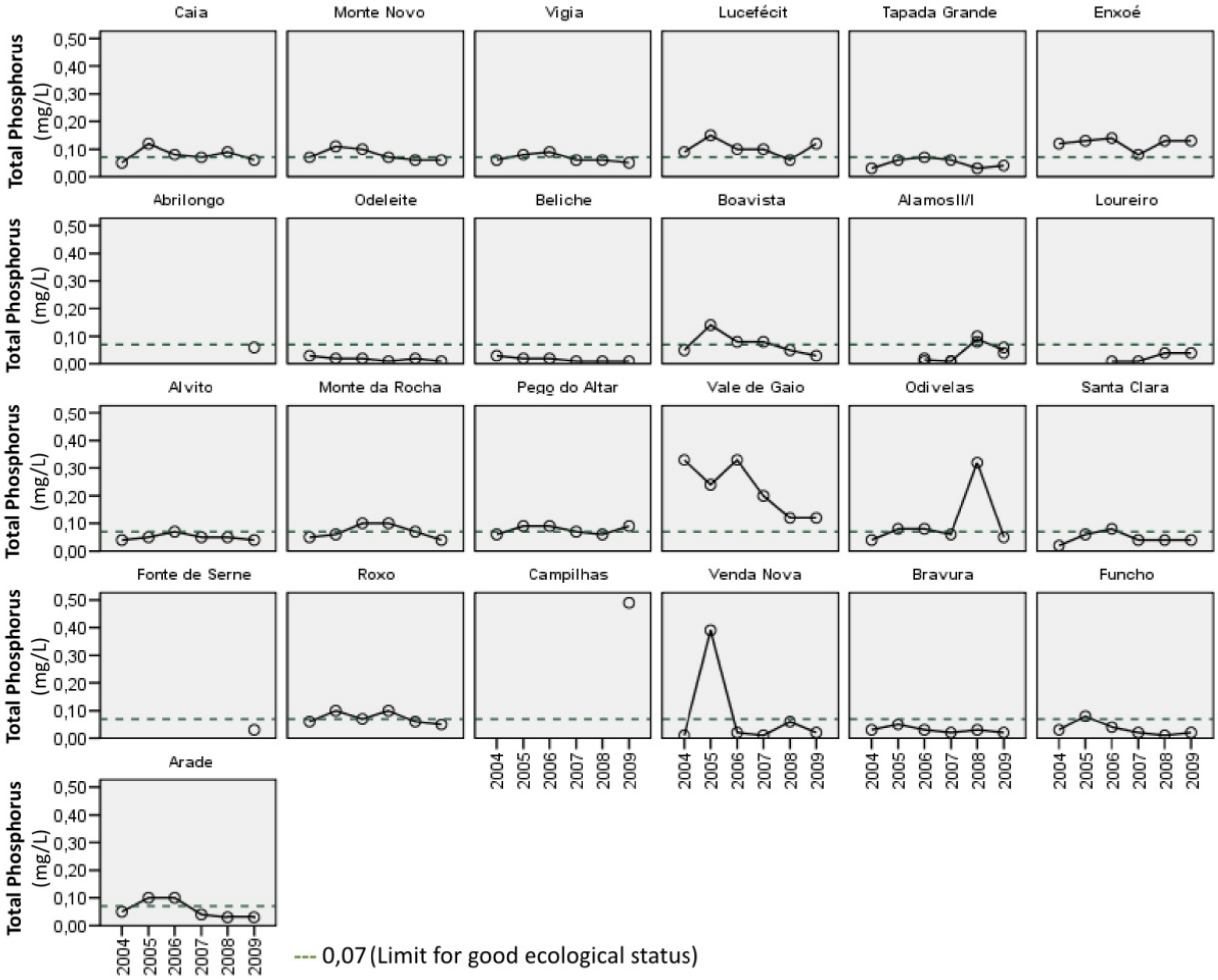

Figure 2. Temporal pattern of total phosphorus (annual average) from 2004 to 2009 in the south reservoirs typology.

The phosphorus values (Figure 2) in the last six years showed that, excluding Campilhas with only one value to 2009, there is a temporal pattern in Lucefécit, Enxoé, Pego do Altar and Vale de Gaio. Despite they are all relative mature reservoirs, with more than ten years, their continuous high values of phosphorus suggested exterior inputs and basin anthropogenic pressures. All four reservoirs are located in areas exposed to urban and livestock effluent discharges, and also agricultural runoff with high concentrations of fertilizers. Nutrient enrichment, especially high loads of phosphorus, can promote the rapid algal growth and affect the drinking water supply. Therefore in some of the reservoirs with “Less than Good” status, the high values of nutrients are followed by low chlorophyll *a* EQR (Figure 3).

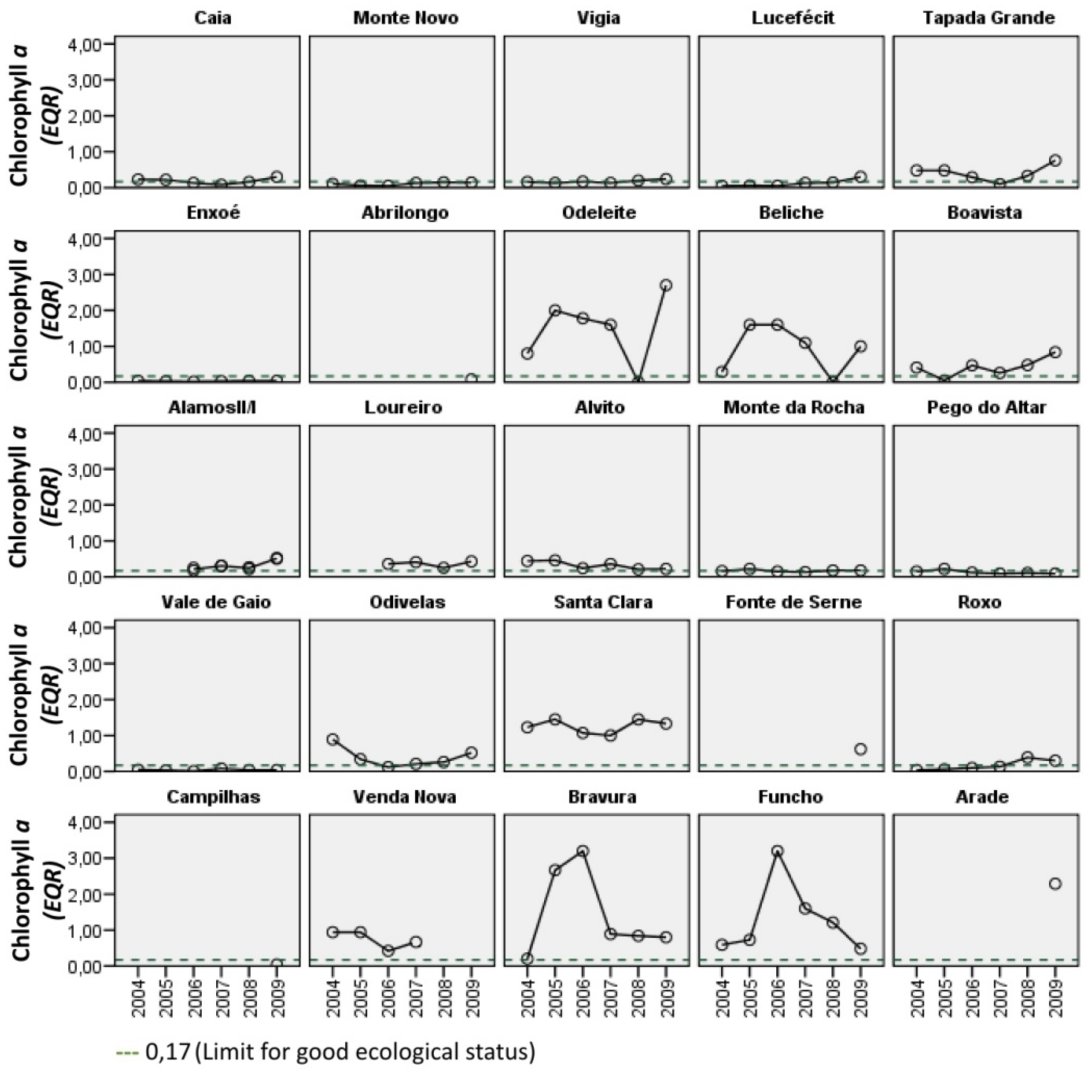

Figure 3. Temporal pattern of chorophyll *a* (annual average) from 2004 to 2009 in the south reservoirs typology.

Most of the reservoirs with “Less than Good” status serve to both water supplying and irrigation purposes. According to Moreno *et al*. (2004), in Mediterranean environments this type of reservoir use is related with the problem of water level seasonality. The water levels are directly connected to the river flow regime and the demand of large volumes of water for agricultural areas, especially during the growing season. The water level fluctuations increase the exposure and erosion of reservoir shoreline areas, interfering with biological communities habitats. Good structured margins also promote the recycling of organic material (Ferreira *et al*, 2009). During the summer of 2009 Campilhas, Vale do Gaio and Enxoé registered in the field form high variation of water level.

Although both phosphorus and chlorophyll *a* seem to be connected with the interannual precipitation levels, with chlorophyll *a* that relation was less evident. Phosphorus (Figure 2) and chlorophyll *a* (Figure 3) evolution in the last six years showed that besides the “Good” status of Caia, Boavista, Monte da Rocha, Odivelas, Vigia and Roxo reservoirs in 2009, they are in ecological boundary conditions, presenting in some cases, three consecutive years with values that transpose the guide boundaries (0.07 mg/LP and 0.17 EQR). “Good” status reservoirs like Tapada Grande, Odeleite, Beliche, Alvito, Loureiro, St.ª Clara and Bravura are under the 0.07 mg/L phosphorus value. Concerning chlorophyll *a*, Odeleite, Beliche, Alvito, St.ª Clara, Venda Nova, Funcho and Bravura reservoirs consistently present values above (0.17 EQR). Nitrates, pH and specific pollutants were all under the good ecological potential limits. Chemical status was also “Good” in all reservoirs.

Main course reservoir typology (Alqueva – Pedrógão System)

Alqueva status evaluation included the reservoir separation into five smaller water bodies, with available historic data. Therefore, the status evaluation of the two main course reservoirs included the classification of six individual water bodies (five from Alqueva reservoir and one from Pedrógão reservoir). According to the WFD, a water body should be homogeneous and have the same status, therefore the final classification of Alqueva results from the worst status of the five water bodies that includes it. The classification system used for the south reservoirs typology was also applied in the main course typology.

According to the 2009 River Basin Management Plans evaluation, four of the six water bodies that include the Alqueva-Pedrógão system are in “Good” ecological state. Only two water bodies presented oxygen, phosphorus and chlorophyll *a* values that classify them with a “Less than Good” status. High values occur mainly in the upstream area of Alqueva – Pedrógão system, near the entry of Guadiana River in Portuguese territory (Alqueva - montante rib. Mures and Alqueva - entrada rio Lucefécit). Therefore the importance of the basin in water quality issue is, according to Hwang (2003) and Morais *et al.* (2007) a basic step when studying reservoirs water quality. About 70 % of Alqueva reservoir catchment is occupied by agriculture, with only a small percentage of semi-natural areas (Morais *et al.*, 2007). The upstream area “Alqueva - entrada rio Lucefécit” receives anthropogenic nutrient inputs from 1) domestic wastewater from a treatment plant with an inefficient treatment, 2) agriculture runoff, 3) mining leaching and 4) inputs from the international part of the basin. In the other hand, “Alqueva - montante rib. Mures” receives domestic and industrial wastewater, agriculture and livestock runoff and also inputs from the international part of the basin.

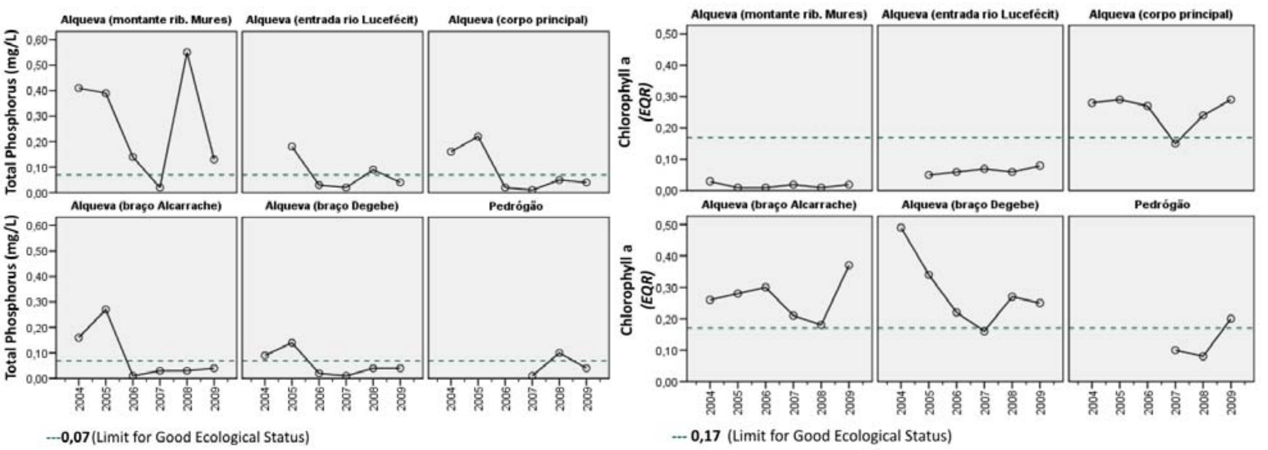

Figure 4. Temporal pattern of total phosphorus (on the left) and chlorophyll *a* (on the right) from 2004 to 2009 (annual average) in the six water bodies that form the two main course reservoirs typology.

The annual average values of total phosphorus temporal variation (Figure 4) showed an expected ecosystem instability in the early years. Phosphorus values above 0, 07 mg/L during 2004 and 2005 result from the beginning of the system´s operating life, in 2002. Total phosphorus registered noticeable interannual variation with values indicating "Good" potential in all the six water bodies during 2007 and also in the following years, depending on the water body.

Chlorophyll *a* pattern (Figure 4) discriminates mostly the nutrient gateways to the system in the upstream locations of "Alqueva - montante rib. Mures" and "Alqueva - entrada rio Lucefécit". Nitrates, pH and specific pollutants were all under the good ecological potential boundaries. Chemical status was also "Good" in all water bodies.

CONCLUSIONS

River Basin Management Plans provided updated information on quality status of the 28 reservoirs from south and main types, identifying a variety of factors that is influencing reservoirs water quality. Data indicate mainly phosphorus and chlorophyll *a* problems that combined with climate specific characteristics, water reservoir uses and catchment areas activities, could jeopardize reservoirs water quality.

In order to understand the specific processes and reservoir conditions, there is a need to improve and adjust monitoring strategies, which implies analysis concerning long term trends (Hoyos and Comin, 1999; Morais *et al*., 2007), as well as properly designed assessment programs focusing not only in parameters but also in reservoirs purposes and uses. It has become increasingly clear during the last couple of years that the combining of biotic and abiotic elements in assessment programs will fulfill the lack of information needed to establish and develop new evaluation methods and guide limits.

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