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Limnological study and ecological modelling of San Roque Reservoir, Argentina

M.A. Bustamante, M. I. Rodríguez, M. Granero, S. Morillo, A. L. Ruibal & I. Zito Freyer
National Institute for Water, Semi Arid Region Center, Córdoba, Argentina

ABSTRACT: San Roque Reservoir is located in a semi-arid region where the water resource is limited. It provides drinkingwater for the City of Cordoba and simultaneously is used for irrigation and hydroelectric energy generation. A monitoring program of physical, chemical and biological variables of reservoir and tributaries has being carried out since 1996 in order to obtain a greater knowledge of its limnologic and hydrological characteristics. These results indicate eutrophic characteristics caused by the contribution of nutrients coming from the drainage basin. Model DYRESM-CAEDYM (CWR, University of Western Australia) was preliminarly applied satisfactorily to represent not only the temporary evolution of the water temperature but also the studied chemical variables.

1 INTRODUCTION

San Roque Reservoir is located in a semi-arid region where water resource is limited. It provides drinking water for the Cordoba City and is used also for irrigation, hydroelectric energy generation, flood control, and recreational activities.

The basin is characterized by a high urban development without any efficient sewage treatment system moreover it is receiving the contribution of nutrients and contaminants from the whole drainage basin and showing strong signs of eutrophication Bustamante et al. (2002). As a result of this process it is common to detect strong scent in tap water, low DO concentrations and transparency and fishes mortality, Phytoplankton studies are being reported since 1948 (Guarrera, 1948) and summer blooms have been dominated by blue green algae over 20 years. However, in 1998-1999 and 2001-2002 summertime, the growth of these was replaced by *Ceratium hirundinella* (Ruibal et al, 1999).

Since June 1996, the National Institute for Water is studing physical, chemical and biological parameters in order to quantify external and internal factors associated with the eutrofication process and define the optimun nutrient load to the reservoir. This study shows the main water quality characteristics observed between 1999 and 2002 and the preliminary application of one-dimensional hydrodynamic model and aquatic ecological model (DYRESM-CAEDYM, Centre for Water Research at University of Western Australia). The purpose is to get a predictable tool to determine water quality impact related to sanitation works into the basin.

2 STUDY AREA

It is characterized by an annual mean temperature of 14º C, annual mean rainfall of 700 mm, although the precipitation can vary from 400 to 1100 mm.

The surface basin comprises 1750 km^2, and four river (Cosquín and San Antonio river, Las Mojarras and Los Chorrillos stream). The reservoir has one outlet, Suquía River, and its surface, volume and maximun depth are 15 km^2, 190 hm^3 and 35,3 m, respectively. Its mean depth is 13 m and level annual fluctuation is 6 m with a water residence time of 0,6 year (average). Accord to its mixing regime it is clasificated as monomictic (DPH, 1982 and Helmbrecht & López, 2000).

3 MONITORING PROGRAM

Sampling activities were carried out in the lake and tributaries weekly, bi-weekly and monthly in the center and water intake of the lake.Variables taken in the rivers included discharge (m^3 s^{-1}), velocity (m s^{-1}) and chemical parameters. Dissolved oxygen (DO) mg l^{-1}, temperature (T) ºC, conductivity (µS cm^{-1}) and pH were recorded with Multiparametric Horiba U-10 Probe. Water samples were extracted in order to determine total phosphorus (TP) µg l^{-1} by persulfate digestion method, soluble reactive phosphorus (SRP) µg l^{-1} by ascorbic acid, $N\text{-}NH_4^+$ µg l^{-1} by phenol reaction, $N\text{-}NO_2^-$ µg l^{-1} by diazotation and $N\text{-}NO_3^-$ µg l^{-1} by reduction with cadmium column. Total inorganic nitrogen (TIN) µg l^{-1} was considered as the sum of nitrite, nitrate and ammonium.

Two stations were monitored into the reservoir in the vertical column (Fig. 1) each meter and water samples were extracted with Van Dorn bottle type at four depths from surface to bottom layer. Vertical profiles of DO, T, pH, conductivity and oxi-reduction potential (ORP) mV, were recorded with Multiparametric Horiba U-23 Probe. Chlorophyll *a* μg l^{-1} was measured by spectrophotometry and the alkalinity (mg $CaCO_3$ l^{-1}) by titrimetric method. The ions Mn^{2+} and Fe^{2+} mg l^{-1} were determined by flame atomic absorption, Ca^{2+}, Na^{+}, Mg^{2+}, K^{+}, SO_4^{2-} y Cl^{-} mg l^{-1} by exchange ionic chromatography and the major components were used to estimate total salinity. The study included also the physical and chemical composition of bottom sediments got from the same two stations.

Phytoplankton diversity and abundance were analyzed by syringe filtration technique (WHO, 1999) and zooplankton by sedimentation in Sedgewick-Rafter counting chamber (APHA, 1992): Microcystins were identified by LC-MC and their concentrations were measured using ELISA

Fishes were collected using a throw net of mesh size 7,5 mm.

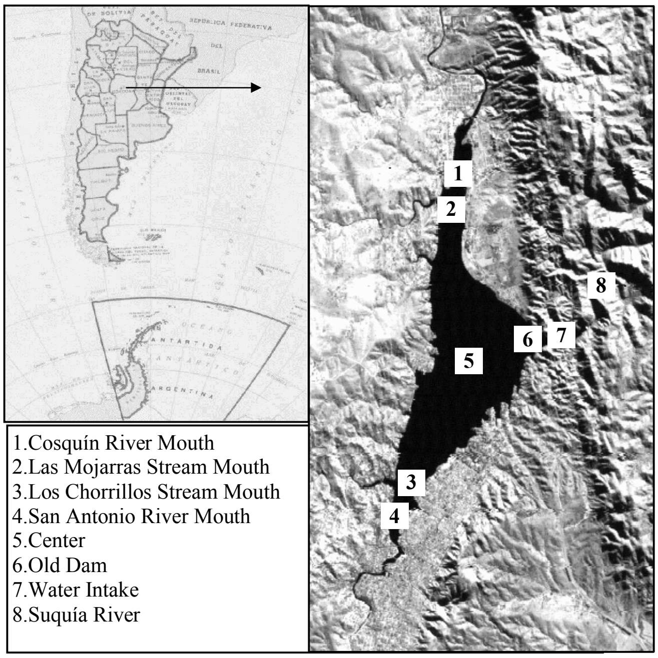

Figure 1. Location of San Roque Reservoir and monitoring stations.

The hydrometereological information related to the lake and rivers was provided by the CIRSA´s telemetric net such as air temperature, solar irradiation, wind speed and direction, relative humidity, precipitation and river water level. Reservoir water level was supplied by DiPAS (Work Agency).

4 RESULTS AND DISCUSSION

The lake water is bicarbonated calcic sodic determined by the geochemical characteristics of the basin and the lake metabolism. In the Center the mean values are pH: 8,2, conductivity (μS cm^{-1}): 268,5; salinity (mg l^{-1}): 126,8 with non-significant differences among points. It was studied previously that surface and bottom ions concentrations are vertically controlled by the stratification regime with some particularities depending on every ion, (Rodriguez et al 2002). In the same period the temporary concentrations are affected also by the typical rain distribution therefore, in rainy days some ionic concentrations decreased due to an increased water volume (Fig. 2).

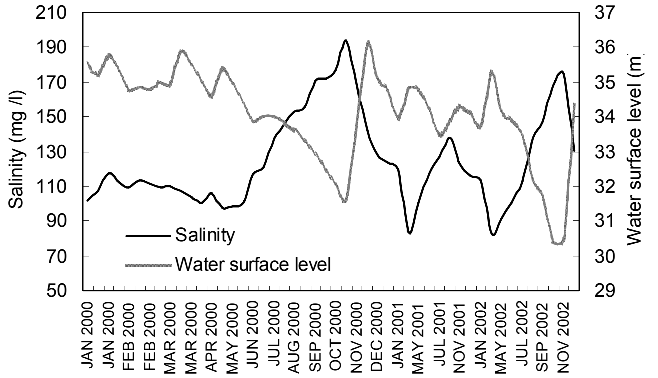

Figure 2. Salinity and water surface level variations.

In summer, surface temperatures measured in both stations oscillated from 20 to 24 ºC and in winter from 8 to 14 ºC. Since September until November a thermal stratification is developed and water temperature displays a pronounced thermal gradient around 5 meters depth which defines the metalimnium zone. The oxicline sets a month later in coincide with the maximum temperature gradient and the smaller vertical mixture induced by wind. Surface DO concentrations vary from 5 to 11 mg l^{-1} rising up to 16 mg l-1 in summer. DO depletion was observed in December and January since 14 m depth at the center station and 20 m at the intake point.

This situation generates a modification in the hipolimnium in the first layers of sediment. The ORP variation responds directly to the lack of oxygen and therefore the chemical bounds of certain sediment components become unstable. Mn^{2+}, Fe^{2+} and the associated PO_4^{2-} are released (Fig. 3).

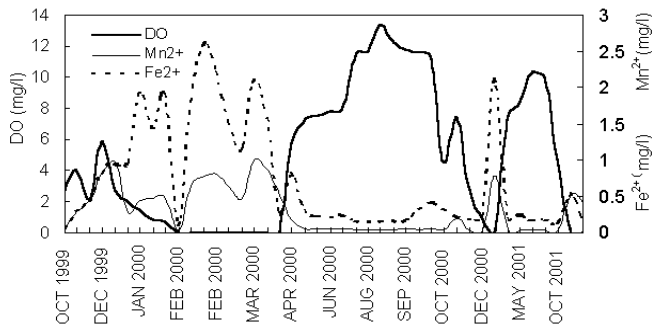

Figure 3. DO, Mn2+ and Fe2+ temporal distribution in hipolimnium.

Granero et al, (2002) estimated a SRP release of 1,33 mg $m^{-2}day^{-1}$, which demonstrates a high sapropel activity during the summer stagnation.

During mixing period, nutrients distributed uniformly in the water column not exceeding 100 µg P l^{-1} and 800 TIN l^{-1}. Greater TIN concentrations are observed at the bottom when the reservoir was stratified in concordance with hypoxia and anoxia conditions due to $N\text{-}NH_4^+$ and PRS concentrations. *Microcystis aeruginosa*, *Anabaena spiroides*, *Cyclotella sp* and *C. hirundinella* were dominant components of algae biomass (Fig. 4). It was observed that *C. hirundinella* develops to greater depth when higher abundance of cyanobacteria is detected at surface.

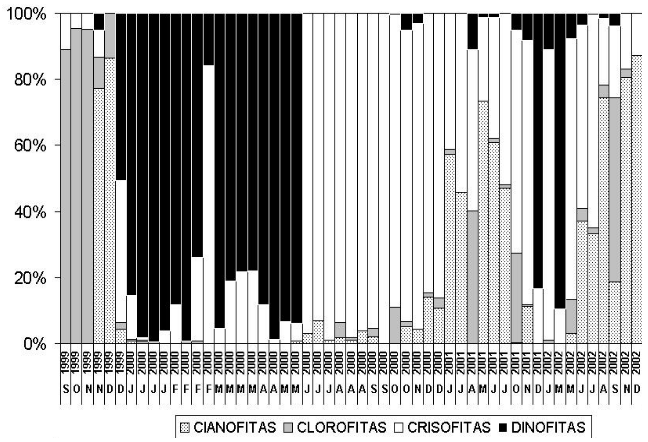

Figure 4. Temporal distribution of algae composition.

But in critical climate conditions like excessive precipitations, one group dominated on the other. This situation could be observed in 1999-2000 in which the average annual rainfall was 1049 mm and *C. hirundinella* dominated the summer. It has been expressed by (UNEP-IETC, 1999) that decrease in N:P relation suggests short periods where the just N would be limiting of phytoplankton growth, encouraging the dominance of fixing N species like *A. spiroides*. On the contrary it was observed that dinoflagellate can develop into fluctuated N and P environment.

Concentration of microcystins were higher and blooms samples were toxic during the whole period analyzed. Maximum concentrations were detected in summer and autumn from very low <0,050 to 923 µg l^{-1} and the water intake samples were higher than the Center ones. This may be explained because of the water intake point is located near the dam, protected from winds and consequently these characteristics make the area calm and appropriate for a good development of cyanobacteria bloom.

No relationship was found between concentration of microcystins and limnological data. However, two important conclusions could be inferred: the ratio between microcystin concentrations and cyanobacteria abundance demonstrated that these alga seems to contain higher toxic strains and that high concentrations of microcystins were detected bellow the threshold for cyanobacteria cell concentration proposed by WHO (1999).

Odontesthes bonariensis is the dominant and more important sport fishing specie in this reservoir. Its extraction by fishing can exceed 1000 kg $month^{-1}$ in winter, being almost 80 times smaller in spring and null in autumn and summer. In adverse situations like winter it accepts the fisherman bait, increasing the resentment. In summer this specie would feed of natural zooplankton. The results suggest that zooplankton would not exert a significant roll in the regulation of the phytoplankton community. More studies should be conducted in order to consider top-down biomanipulation strategies.

Certainly when *C. hirundinella* dominates it hasn’t a natural predator and others characteristics as the water level and nutrients load would seem to be the most important factors.

Figures 6, 7, 8 and 9 show the modelling estimations of water quality variables in a short period in order to calibrate the model. The water temperature responds well to the environmental parameters variations as solar radiation and wind intensity. The most satisfactory results were obtained with the short wave radiation data got from CIRSA transformed by a coefficient equal to 1,1. It is emphasized the importance of the energy given by the wind in the evaporation calculation.

The differences obtained between observed and estimated data (N and P) are explained by our subestimation of N and P loading coming from the urban uses in winter and spring as well as the over estimation of the total SRP loading transported by flash flood to the reservoir in fall. In this semiarid region the watershed hydrology and its variability shows a great influence to final water quality. As result of these we are encouraged to make progress with the two-dimension model for the reservoir.

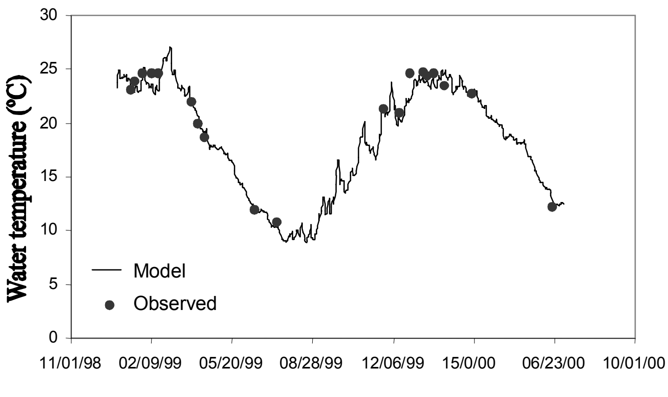

Figure 5. Observed and simulated water surface temperature at the center.

The limnological characteristics show a high complexity. The evaluation of these system requires the simultaneous integration of meteorological, hydrological, chemical and biological factors. It is necessary not only to know and integrate current data but also to consider the evolution occurred in the meteorological conditions and land uses, whether an appropriate manage of nutrients loads is wanted in order to predict phytoplankton biomass in San Roque Reservoir.

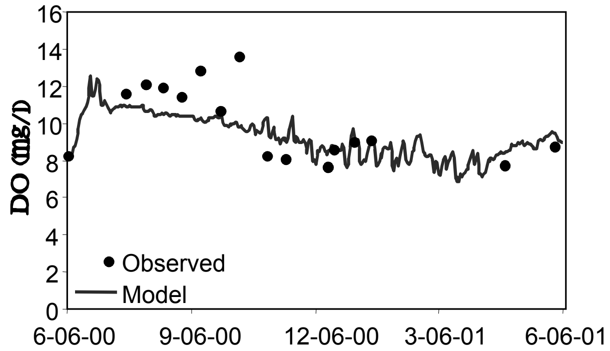

Figure 6 Observed and simulated DO surface concentrations at the center.

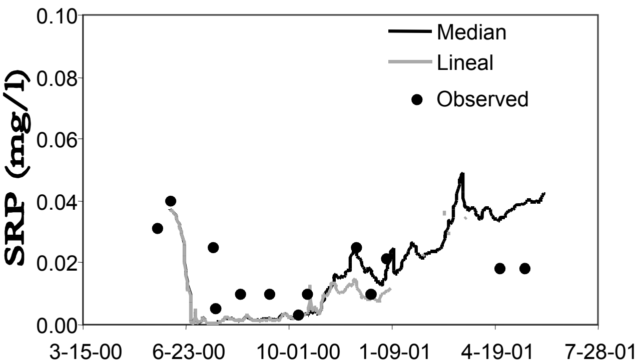

Figure 7. Observed and simulated SRP surface concentrations at the center.

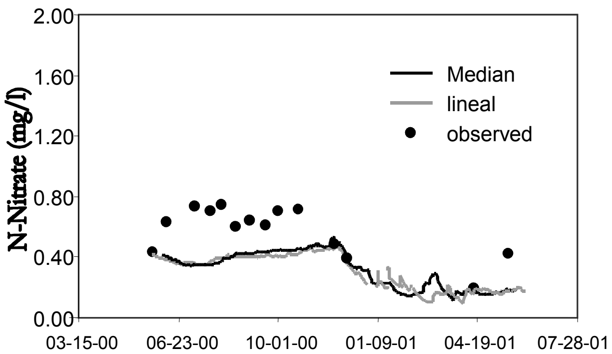

Figure 8. Observed and simulated N-NO3- surface concentrations at the center

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