1 INTRODUCTION

San Roque Reservoir is located in a semi-arid region where water resource is limited. It provides drinking water for the City of Cordoba and is used 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 studying physical, chemical, and biological parameters in order to quantify external and internal factors associated with the eutrophic process and define the optimum 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 km², and four rivers (Cosquín and San Antonio river, Las Mojarras and Los Chorrillos stream). The reservoir has one outlet, Suquía River, and its surface, volume, and maximum depth are 15 km², 190 hm³ 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 classified 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 (m³ s⁻¹), velocity (m s⁻¹) and chemical parameters. Dissolved oxygen (DO) mg l⁻¹, temperature (T) °C, 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-NH₄⁺ µg l⁻¹ by phenol reaction, N-NO₂⁻ µg l⁻¹ by diazotation and N-NO₃⁻ 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 Mul-
tiparametric Horiba U-23 Probe. Chlorophyll a
µg l⁻¹ was measured by spectrophotometry and the
alkalinity (mg CaCO₃ l⁻¹) by titrimetric method. The
ions Mn²⁺ and Fe²⁺ mg l⁻¹ were determined by flame
atomic absorption, Ca²⁺, Na⁺, Mg²⁺, K⁺, SO₄²⁻ y Cl⁻
mg l⁻¹ by exchange ionic chromatography and the
major components were used to estimate total salini-
ty. The study included also the physical and chemi-
cal composition of bottom sediments got from the
same two stations.

Phytoplankton diversity and abundance were ana-
yzed by syringe filtration technique (WHO, 1999)
and zooplankton by sedimentation in Sedgewick-
Rafters counting chamber (APHA, 1992): Microcys-
tins were identified by LC-MC and their concentra-
tions were measured using ELISA

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

4 RESULTS AND DISCUSSION

The lake water is bicarbonated calcic sodic deter-
mined by the geochemical characteristics of the ba-
sin 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 differ-
ces 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 concen-
trations are affected also by the typical rain distribu-
tion therefore, in rainy days some ionic concentra-
tions decreased due to an increased water volume
(Fig. 2).

In summer, surface temperatures measured in
both stations oscillated from 20 to 24 °C and in win-
ter from 8 to 14 °C. Since September until Novem-
ber a thermal stratification is developed and water
temperature displays a pronounced thermal gradient
around 5 meters depth which defines the metalim-
nium zone. The oxicline sets a month later in coin-
cide 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 hi-
polimnium 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. Mn²⁺, Fe²⁺ and the as-
associated PO₄³⁻ are released (Fig. 3).

Figure 2. Salinity and water surface level variations.

Granero et al, (2002) estimated a SRP release of
1,33 mg m⁻²day⁻¹, which demonstrates a high sapro-
pel 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-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.

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 algae 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.

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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6 REFERENCES


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