Verh. Internat. Verein. Limnol.	28	1–4	Stuttgart, December 2002

Limnology of mountain rivers and transport of phosphorus and nitrogen to an enriched reservoir (Cordoba, Argentina)

M. A. Bustamante, F. López, C. Bonetto and M. Granero

Introduction

The San Roque Reservoir is the principal water resource for drinking water in Córdoba City, Argentina. The basin is located in the central semi-arid region of the country, which has a mean annual precipitation of 650 mm, concentrated in spring and summer. It comprises a mountainous area formed by crystalline basement, igneous granitic rocks and gneiss. They include rocky soil (lithosols) and alluvial sediments. The landscape is mainly composed of two different environmental units, grassland and dry xerophytic bush, with some areas partially modified by rural activities. Tourism represents the main activity within the area, followed by extensive cattle breeding. Several cities are located within the basin. Carlos Paz, located at the lake shore, is the largest, with 50,000 permanent inhabitants, and increasing to 90,000 inhabitants in summer. None of theses cities have sewage treatment plants. Consequently, during the past few years, the reservoir has been showing strong signs of eutrophication. The purpose of the present study was to estimate the P and N loadings and to assess their relative importance in determining the trophic status of the lake.

Materials and methods

The San Roque Reservoir has a mean depth of 13.4 m, water residence time (tw) of 0.637 year, and a lake surface of 15.01 km^2. Its drainage system is formed by the basins of the San Antonio (505 km^2) and Cosquín River (820 km^2), and Las Mojarras (85 km^2) and Los Chorrillos (160 km^2) Creeks. Water samples and flow measurements were taken every 15 days from the last point of each tributary from June 1998 to August 2000. Within the San Antonio River basin, samples and flow measurements were taken at different sites, representative of different landscape units (grassland, bush, and rural) in order to compare the nutrient exportation from each of them (Fig. 1). Total phosphorus (TP, µg P L^{-1}) and soluble reactive phosphorus (SRP, µg P L^{-1}) were measured using the ascorbic acid method, nitrite ($N\text{-}NO_2^-$, µg N L^{-1}) by diazotation, nitrate ($N\text{-}NO_3^-$, µg N L^{-1}) by the cadmium reduction method (APHA 1992) and ammonium ($N\text{-}NH_4^+$, µg N L^{-1}) by the indo phenol blue method, modified from APHA (1992). Total inorganic nitrogen (TIN) was estimated by adding $N\text{-}NH_4^+ + N\text{-}NO_2^- + N\text{-}NO_3^-$. The fractions of nitrogen and SRP were determined after filtering the water through GF/C fiber filters (1.2-µm pore size) and bringing the filtrate in cold to the laboratory. Chlorophyll *a* (chl *a*, µg L^{-1}) was measured by spectrophotometry (APHA 1992). Together with water sampling, river flows ($m^3\ s^{-1}$) were calculated as the velocity (measured with current meter type c2 "10.150") times cross-section area (m). In some sites of the San Antonio River, the water level (H) provided by automatic sensor from the National Institute of Water was determined, and the flow was calculated using a calibrated H-Q curve. Because summer rains are often produced in discrete intense events, sudden floods occur. Samples were carefully taken during the floods and N and P concentrations were measured. Ten of these events could be successfully sampled only at the last sampling point of the San Antonio and Cosquín River. Three water samples were taken during each event, coinciding with the rising, maximum and decreasing phases of each flood. The duration was also measured. The nutrient load was calculated for each flood and the annual average load was estimated. The TP concentrations and chlorophyll *a* were also measured at the sub-surface (0.20 m) of the center of the reservoir every 15 days in summer and monthly throughout the rest of the year, in order to assess its trophic status. The Vollenweider model (Vollenweider 1976) was applied to determine the trophic state of the reservoir.

Results and discussion

Figures 2 and 3 show the weighted mean inflow phosphorus and nitrogen concentrations mea-

0368-0770/02/0028-1 $ 1.00

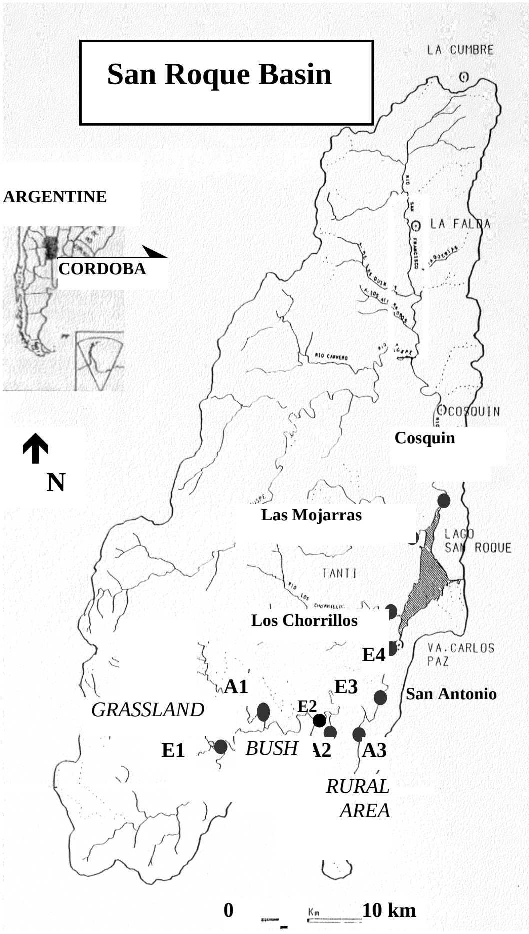

Fig. 1. San Roque Reservoir basin map. Labeled dots correspond to sampling stations, E_1, Icho-Cruz Malambo; E_2, Cuesta Blanca; E_3, National Institute of Water's station; E_4, El Fantasio; A_1, El Cajón; A_2, Las Tomitas; A_3, San Antonio.

sured at different points of the San Antonio Basin. Present figures show TP concentrations slightly higher than those reported for non-polluted rivers, 10–50 µg P L^{-1} (MARGALEF 1983). The concentrations were also comparatively modest when compared with other regional environments such as the Paraná River, which had concentrations from 84 to 703 µg TP L^{-1} (VILLAR & BONNETTO 1998). The SRP concentrations were lower than small rivers draining the loessic Pampa plain, which supports agricultural activities (0.01–11.54 mg L^{-1}, FEIJOÓ et al. 1996). SRP represented ca. 40% of the TP content of the San Antonio River and particulate P was the dominant fraction. The present results are consistent with those of CARPENTER et al. (1998), who reported higher P concentrations in water where the higher P content in soil was attained, and higher amounts of particulate than soluble P were being eroded from the soil. Nitrate represents more than 60% of the inorganic nitrogen concentration in the river. Lower exportation rates were estimated for the grassland, higher for the bush and even higher from the rural areas of the San Antonio basin (Table 1). Unlike N, P exportation from rural

Table 1. P and N loadings and exportation rates from different environmental units.

Reference	Environ. unit	P loading (kg P year^{-1})	P output (kg P year^{-1} ha^{-1})	N loading (kg N year^{-1})	N output (kg N year^{-1} ha^{-1})
E_1	grassland	1875	0.09	7454	0.36
A_1	grassland	678	0.06	5375	0.45
A_2	bush	310	0.12	1444	0.58
A_3	rural area	293	0.05	4770	0.87
E_4–E_3	urban area	1352		4343	

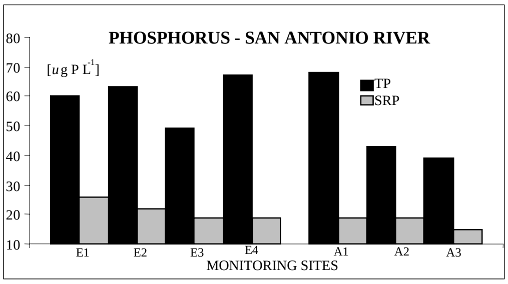

Fig. 2. Weighted mean inflow phosphorus concentrations measured at different points of the San Antonio Basin (TP, total phosphorus; SRP, soluble reactive phosphorus; Ei, main river stations; Ai, tributary stations).

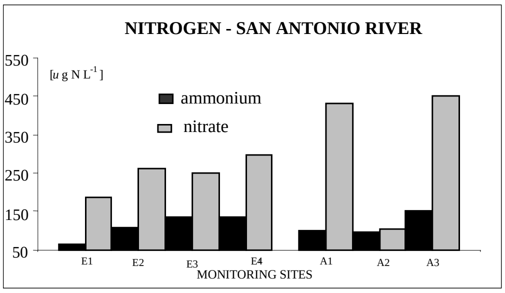

Fig. 3. Weighted mean inflow nitrogen concentrations measured at different points of the San Antonio Basin. (Ei, main river stations; Ai, tributary stations).

areas did not display any discernible increase over natural environments. The Cosquín River is influenced by several cities located in its basin and it supplies 73% of the total N contributed by the affluents and only 50% of the total P contribution from them. It appears likely that inorganic N is a more suitable indicator of human impact in these rivers than the P concentration.

However, the N-NH_4^+ and N-NO_3^- concentrations sampled were much lower than the reported levels draining the Pampa plain (0.11 mg L^{-1} and 5.82 mg L^{-1}, respectively, Feijoó et al. (1996)). The estimated P and N exportation rates in grassland and bush are similar to those reported by Ryding & Rast (1992). Table 2 shows the main P and N loadings to the San Roque Reservoir. The P loading provided by summer flood episodes represented 72% of the total P loading to the reservoir. The contribution of Carlos Paz City represented 16% of the total annual load. The Cosquín River, which provides the largest load from the affluents, receives untreated sewage from Cosquín City and several other tourist villages. If Cosquín City is added to the Carlos Paz contribution, the urban P loading would come close to 22%

Table 2. P and N loadings contributed to the San Roque Reservoir from different sources.

	P loading (kg P year^{-1})	N loading (kg N year^{-1})
1. Affluents, regular sampling	26,870	167,046
San Antonio	8332	24,341
Cosquín	13,516	123,508
Los Chorrillos	3384	12,494
Las Mojarras	1638	6703
2. Affluents during floods	180,000	
3. Carlos Paz City	41,600	270,400

of the total P loading. Rural activities and natural exportation rates from the dominant landscape units represent a minor contribution to the budget of the lake (10%). The permissible P loading estimated from the Vollenweider model amounted to 0.2 g P m^{-2} $year^{-1}$, corresponding to a mean P concentration of 15 µg P L^{-1} in the affluent. This value is smaller than the measured concentration at sites with minor human influence in San Antonio River (Table 1). It might be inferred that although an improvement in water quality is expected from sewage treatment, the reservoir might remain eutrophic. However, the Vollenweider model (VOLLENWEIDER 1976) failed to predict the main Chl *a* concentration (52 µg L^{-1}) from the annual average total P concentration (81 µg P L^{-1}) or the P loading to the reservoir. Summer floods produced by heavy showers in a hilly environment increase the total P loading because of the increased erosion within the basin. The availability of this material for phytoplankton growth is unknown. On the other hand, most of the urban P loading is available and it is provided in coincidence with the period of maximum phytoplankton growth. Dry winters, summer floods, small mean depth, short water residence time and the fact that the latter shows large variations throughout the year appears likely to prevent the application of Vollenweider's approach to the San Roque Reservoir. Furthermore, the mean summer Chl *a* concentration (100 µg L^{-1}) in the San Roque Reservoir was successfully predicted by the Lorenzen formulae (MILLS et al. 1985) based on the spring mean TP concentration (22 µg L^{-1}).

Acknowledgements

The authors acknowledge the financial support from the Public Services Cooperation Agency of Carlos Paz (COOPI), ILEC (International Lake Environmental Committee), the Aguas Cordobesas Company and the Catholic University of Córdoba.

References

APHA, 1992: *Standard Methods for the Examination of Water and Wastewater.* – American Public Health Association. Diaz de Santos S.A., España, 1604 pp.

CARPENTER, S., CARACO, N., CORRELL, D., HOWARTH, R. W., SHARPLEY, A. & SMITH, V., 1998: Nonpoint pollution of surface waters with phosphorus and nitrogen. – *Ecol. Appl.* **8:** 559–568.

FEIJOÓ, C., MOMO, F., BONETTO, C. & TUR, N., 1996: Factors influencing biomass and nutrient content in the submersed macrophyte *Egeria densa* Planch. in a pampasic stream. – *Hydrobiología* **341:** 21–26.

MARGALEF, R., 1983: *Limnología.* – Ediciones Omega S.A., España, 1010 pp.

MILLS, W., PORCELLA, D. B., UNGS, M. J., GHERINI, S. A., SUMMERS, K. V., MOK, L., RUPP, G. L., BOWIE, G. L. & HAITH, D. A., 1985: *Water Quality Assessment: a Screening Procedure for Toxic and Conventional Pollutants in Surface and Ground Water, Part II.* – Estados Unidos, 444 pp.

RYDING, S. & RAST, W., 1992: *El control de la Eutrofización en Lagos y Pantanos.* – Ediciones Pirámides, S.A., España, 375 pp.

VILLAR, C. & BONETTO, C., 1998: Estudio Limnológico del Río Paraná en la zona de Atucha. – *Aquatec* **5:** 1–13.

VOLLENWEIDER, R. A. 1976: Advances in defining critical loading levels for phosphorus in lake eutrophication. – *Mem. Ist. Ital. Idrobiol.* **33:** 53–83.

Authors' addresses:

M. A. BUSTAMANTE, F. LÓPEZ, M. GRANERO, CIRSA-Instituto Nacional del Agua, Av Ambrosio Olmos 1142, Córdoba, Argentina.

E-mail: abustama@com.uncor.edu

C. BONETTO, Inst. Limnol. Ringuelet, Av. Calchaquíe, Buenos Aires, Argentina.