

The water quality modelling and environmental impact of an azud (little dam) construction in Cuarto river (Argentina)

M.A. Bustamante, S. Morillo, S. Zito Freyer, M. Ruiz, C. Angelaccio & M.I. Rodríguez
Instituto Nacional del Agua (INA)-Centro de la Región Semiárida, Córdoba

ABSTRACT: Cuarto River, located in the south of Cordoba, has gradually lost its sediments due to a sand extraction made upstream, which represented a problem for the bridges foundations situated in the urban area. The construction of two little dams for sediments retention was presented as a feasible solution for this problem. However, they could cause an interruption to migratory fishes living in the region as well as change some water quality aspects needed for recreational activities. In this study we show the monitoring design, applied methodology, and the measurements of different ecological characteristics: water chemical properties, phytoplankton, zooplankton, fish communities. The impact was simulated and predicted and some suggestions could be given.

1 INTRODUCTION

The Cuarto river called “Chocancharava” is situated in the south of Cordoba, and cross de city from up to finalize in a lagoon system. High transparency, sandy bed and margins of muddy texture are its main characteristics. The accelerated lost of bed material due to human activities left exposed 3 m of bridge foundation in two cases, “Carretero and Ferroviario bridge” located in the town. The construction of two little dams could be the best solution which would retain the inorganic materials transported by the flash flood of summer. It is known that works can alter the composition and biological abundance since changes in the water and thermal regime. The river is important for recreational activities and it is used by migratory fishes as well. The rains induce them to overcome the river towards feeding and reproduction areas. This study shows the monitoring design, applied methodology, and the measurements of different ecological characteristics such as water chemical properties, phytoplankton, zooplankton and fish communities. Complementarily the ecological impact was predicted using numerical algorithms.

2 STUDY SITES AND METHODS

Samples and flow measurement were taken at seven points (Fig. 1).

Based on historical data and climate conditions three samplings were carried out in January 2003 (warm and rainy month) according to fish movements. In situ variables such as pH, water temperature (T),

conductivity, total dissolved solids (TDS) and dissolved oxygen (DO) were measured with Horiba multiparametric probe and samples were collected in homogenous mixing conditions. Biochemical oxygen demand (CBOD) was determined by 5 days incubation at 20 °C, total phosphorous (TP) and total dissolved phosphorous (TSP) were analyzed by digestion with persulfate, soluble reactive phosphorous (SRP) by method of ascorbic acid. Dissolved organic phosphorous (P-org) was considered as difference between TSP and SRP. Concentrations of ammonium ($N-NH_4^+$) were analyzed by spectrophotometry, nitrite ($N-NO_2^-$) by diazotation, nitrate ($N-NO_3^-$) by cadmium column, organic matter as carbon (TOC, POC and DOC) by Combustion/IR non-disperse (APHA, 1992). Ions Ca^{+2} , Mg^{+2} , Na^+ , K^+ , Cl^- and SO_4^{-2} were determined by chromatography.

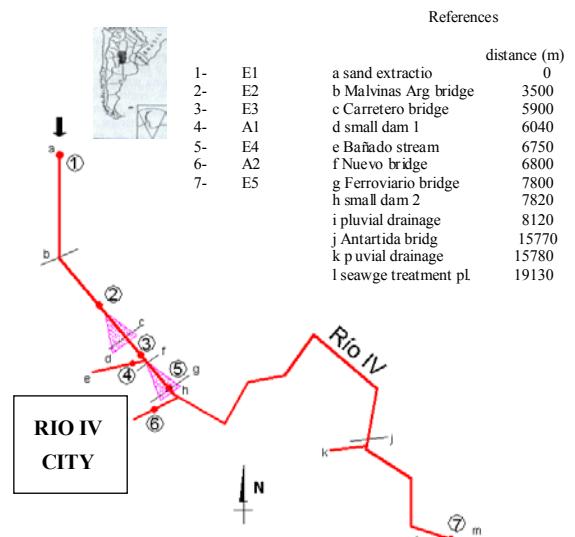


Figure 1. Locations of sampling stations in Rio Cuarto city.

Water samples for phytoplankton diversity and counts were collected at the same points, conserved in lugol solution 0.3 ml 100^{-1} ml $^{-1}$ in dark and analyzed after sedimentation (48 h) (Bourrelly, 1972). Density was assessed by cell counting in an Zeizz fotomicroscope III on Fuchs-Rosenthal camera with 32 fields (0.2 mm x 1 mm 2) conformed by 16 cells every one. Fishes were captured by netting (length: 20 m, mesh size: 10 mm), weighed, identified to species and extra information complemented by censuses to the villagers. River flows were calculated as the velocity using current meter A-OTT Kempten times cross-section area (m) according to ISO 748 - 1979.

The change in concentration of water quality variables (CBOD-DO, N and P) were described by a series of adjusted numerical and exponential functions (equations) and dam effects analyzed with different water velocity and reservoir characteristics.

Vertical mixing time was calculated as (1)

$$T = \alpha d^2 / \varepsilon_v \quad (1)$$

where

ε_v = vertical mixing coefficient, \bar{u} = average velocity, f = friction factor of Darcy-Weisbach and d = hydraulic depth ($\varepsilon_v \approx 0.07du^*$ and $u^* = \bar{u}\sqrt{f/8}$). The factor $\sqrt{8/f} = 15$, $\alpha > 0.35$ so $T \approx 75d/u$ being for the river $d = 0.12$ m, $u = 0.9$ m s $^{-1}$ and $T = 10$ s. The distance of vertical turbulent mixing is 9 m.

Streeter and Phelps's formulation (O'Connor & Dobbins 1958) was used to evaluate BOD-DO balance variation (2). The time for getting maximum oxygen deficit could be obtained (3) and the concentration using equation (4). Dynamics of non conservative substances as N-ammonium and P-org were described as a first-order decay model (5). It was applied to the river and balance mass made downstream of every tributaries mouth .

$$\frac{dDO}{dt} = KnL_i - KaDO = KnL_o e^{-Kat} - \widehat{DO} \quad (2)$$

$$t_c = \frac{1}{Ka - Kn} \ln \left\{ \frac{Ka}{Kn} \left[1 - \frac{\widehat{DO}_o (Ka - Kn)}{KnL_o} \right] \right\} \quad (3)$$

$$\widehat{DO}_c = \frac{Kn}{Ka} L_o e^{-Kn t_c} \quad (4)$$

$$s = s_o e^{-kst} \quad (5)$$

where,

\widehat{DO} = DO deficit (mg l $^{-1}$), L_i = CBOD, Kn = de-oxygenation rate (d $^{-1}$), Ka = aeration rate (d $^{-1}$), s = solute concentration (mg l $^{-1}$), A = area (m 2), Q = discharge (m 3 s $^{-1}$), $s = s_o$ in $x = 0$ and Ks = decay rate.

Usually Kn can vary between 0.004 and 1.4 (days $^{-1}$). $Ka = a\bar{U} / y^c$ was estimated using the model of DO renovation proposed by O'Connor and Dobbins (1956) fit with experimental tests. Therefore Kn was approximately zero. The presence of cascades was characterized according to the expression (6) in which r is deficit up and down of dam (Butts & Evans, 1983).

$$r = 1 + 0.38abH(1 - 0.11H)(1 + 0.046T) \quad (6)$$

$H = 3$ m is jump height, $a = 1.6$ and $b = 0.45$ Both are corrective coefficients for water quality and dock type (Chapra, 1997). Thus, using a water temperature of 25°C $r = 2.18$.

3 RESULTS AND DISCUSSION

The waters are well oxygenated, alkaline, with range pH of 7.02-7.70 and TDS of 110 – 150 mg l $^{-1}$. Calcium, sodium and bicarbonate were the predominant ions in the pH and greater chloride concentrations are caused by the city. TOC oscillated between 1 and 2.5 mg l $^{-1}$, and very low DOC concentrations (1 mg l $^{-1}$) were detected, which suggests a good decomposition rate. POC (1-2 mg l $^{-1}$) represents all material of a reasonable size up to 1 mm. The most important increase was observed between E3 and E5 and particularly the A2 contribution is more significant than the A1. It has been suggested by Allan (1995) that DOC greater than 10 mg l $^{-1}$ are associated to great rivers and human disturbances. The measured POC concords with those detected for forest basin and not disturbed river with an annual average smaller than 1 mg/l.

Discharges of 6 and 13.5 m 3 s $^{-1}$ were measured in E1, increasing to 10 % in the town and 20% in E7. Currently, vegetation just ranges as upland vegetation and macrophytas, which distributes along the river margin (sandy bottom diminishes its survival). Diatom (crysophytas) is the mayor dominant group of phytoplankton with a bigger number of saprobe in E7 (close to sewage treatment plant). The crysophytas 80 %, chlorophytas 11%, cyanophytas 1.5 % were comparatively observed in E1 and A1. Euglenophytas group 1 % of total biomass was sampling in E2 and A1. Diversity and abundance do not show significant differences along stations. Temporary variation of community, both composition and structure don't vary significantly to water level fluctuations. Zooplankton, benthos micro and macro-invertebrates are low in the main channel and increase in the marginal channels in moments of low volume.

Eight species of fishes were captured, seven of which (*Astyanax eigenmanniorum*, *Cheirodon interruptus*, *Hypostomus commersoni*, *Jenynsia lineata*, *Pimelodus albicans*, *Cyprinus carpio* and *Rhineloricaria catamarcensis*) are mentioned for this river and one, *Prochilodus lineatus* for the lagoons area (Haro et al., 1991). However, this last was seen in E7 overcoming the river at minimum depth (25 cm). Diversity correlated (Sperman correlation) with pH ($r = 0.693$ $p = 0.1$), water hardness ($r = -0.693$ $p = 0.1$) and turbidity ($r = 0.684$ $p = 0.1$) which is used by the fishes to protect themselves. Ringuelet et al. (1967) suggested that not only factors like temperature, feeding, reproduction would stimulate the migration but also exist populations with opposed movements to up and downstream.

In low flows super-saturation of DO was observed. The decay of DO is sensible to temperatures so the consumption due to organic matter degradation is quickly restored. The tributary A1 will reach the second little reservoir (figure 1) but it will not cause important water quality changes when the new lower velocities. For example it would be need a CBOD of 170 mg l^{-1} in A1 or $Q > 14$ and $\text{BOD} > 1.5 \text{ mg l}^{-1}$ to produce negative effects.

Different combinations were done with different K_a , K_n , volumes, flow velocities, at 25°C .

The presence of the little dam will modify the hydraulic characteristics, velocity is reduced (approximately 0.05 m s^{-1} with $Q: 4 \text{ m}^3 \text{ s}^{-1}$, maximum depth: 3 m) inducing a smaller K_a (final: 0.19 d^{-1}). The results (with dam), guarantee a lower DO deficit 2.18 times smaller than that produced upstream.

In this river the DO concentrations are very high because of turbulence. It favors the diffusion and any component as photosynthesis breathing or consumption in aerobic degradation, would be important in relation to diffusion.

The presence of N-NO_3^- in the water gives an idea of the account of contaminant coming from the city or formed since ammonium. Figures 2-3-4,5 shows the observed and simulated values obtained with ammonium and P-org decay model at different K_s . Both were well estimated using the greater coefficient approximately k_s between 2 and 2.5. Nitrogen would seem more sensible to any change in water quality and hydrodynamics than phosphorous. It is observed that both soluble nutrients increase their concentrations after the dams influence. Conveniently a nitrate and SRP curves were plotted including N and P formation plus previous concentration. In the reservoirs a nutrients accumulation was observed.

A prey height bigger than 0.5 m is considered important for the migratory movements. The migratory species, particularly *P. lineatus* have displacements until of 600 and 700 km doing 21.5 up to 8.7 km day^{-1} respectively.

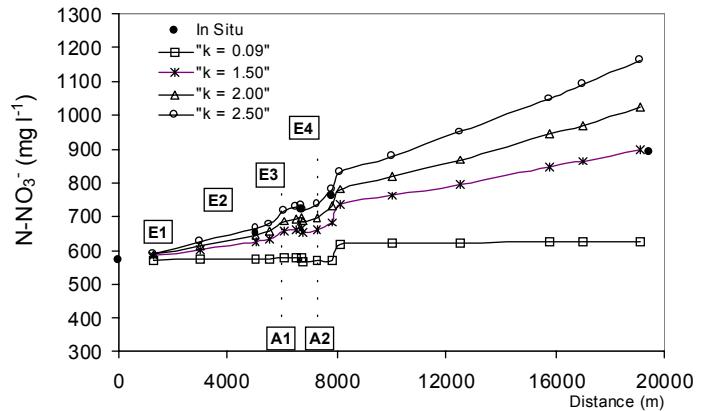


Figure 2. Observed and simulated nitrate concentrations in Cuarto river (town) using different solute decay rate. E1=station upstream with sand extract and E2-E3 &E4 are located in relation to the two little dams. A1-A2 are tributaries.

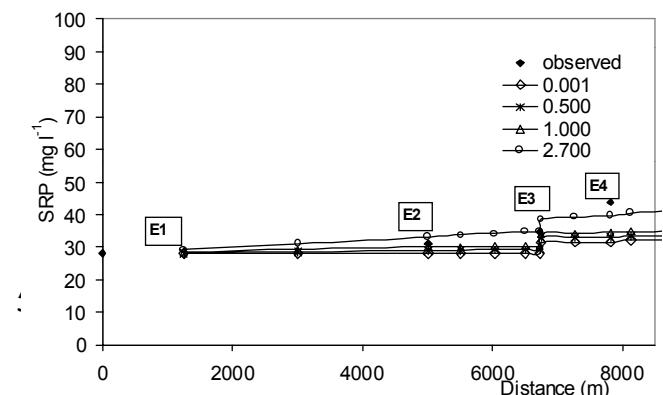


Figure 3. Observed and simulated soluble phosphorous concentrations in Cuarto river (town) using different solute decay rate. E1=station upstream with sand extract and E2-E3 &E4 are located in relation to the two little dams. A1-A2 are tributaries.

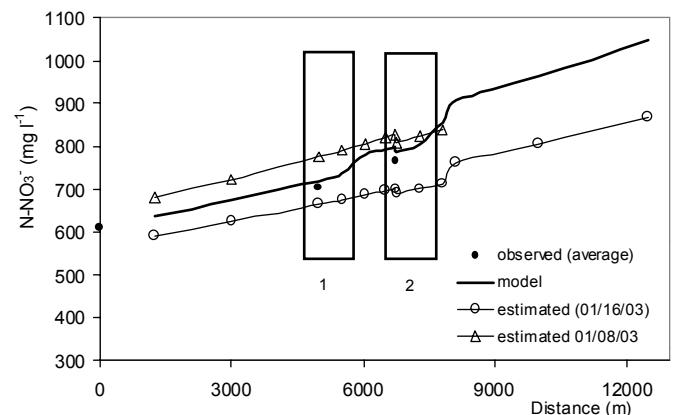


Figure 4. Nitrate concentrations estimated for Cuarto river (town) in which the effect due to dams is showed by the curve lines after both position (1 and 2).

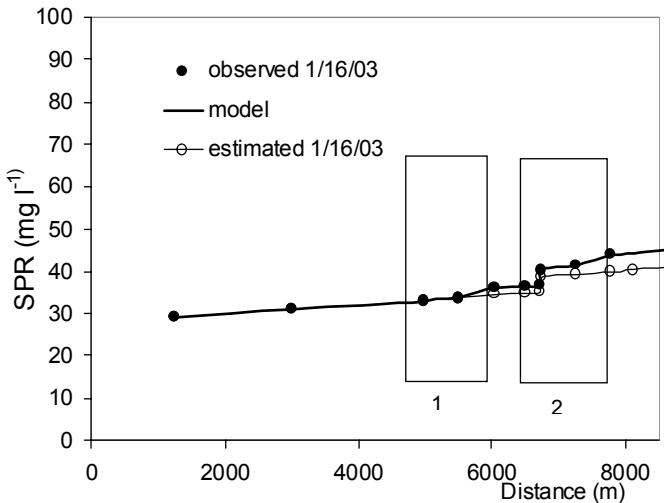


Figure 5. Soluble P concentrations estimated for Cuarto river (town) in which the effect (minimum) due to dams (1&2) is showed by the curve line produced after them.

According to the project, a “rampa” with moderate slope (1m of height each 4 m of length) would not present in itself an insurmountable barrier since these migratory fishes overcome the river just during the flooding and with runoff of $161 \text{ m}^3 \text{ s}^{-1}$ (maximum runoff estimated) the waterfall is represented by a wave sufficient to be crossed by *P. lineatus* (average body, 300 mm).

The formation of little reservoirs could cause erosion in the margins causing the loss of habitat and growing zones. A solution could be to built lateral channel with floodgate.

The current primary production due to macrophytes, and phytoplankton is not an important native source, on the contrary allochthonous material is entering into the system as detritus and this is the production source. Now there are not conditions that favor a high primary production in the river. The little dams will not cause a negative effect, despite of greater N concentrations estimated. The water residence time is short and it diminishes the chance for cyanophytes.

6. REFERENCES

- Allan, J. D. 1995. *Stream Ecology*, Ed. Chapman and Hall, London.
- APHA 1992. *Standard Methods for the Examination of Water and Wastewater*, American Water Works Association, Water Environment Federation.
- Bourrelly, P 1972. *Les Algues d'eau douce, Initiation à la Systématique*, Tomo I, II y III, Ed. Boubée & Cie Collection Faunes et Flores Actuelles, Francia.
- Haro, J.G.; Bistoni M.A. & M. Gutiérrez. 1991. Ictiofauna del Río Cuarto (Chocancharagua), Córdoba, Argentina. *Bol. Acad. Nac. Cs. Cba*, 59: 249-257
- Ringuet, R. A. ; Arámburu R. H. & Aramburu A.A. , 1967. *Los peces argentinos de agua dulce*. CIC, 601p.
- Butts, T. A. & Evans, R. L. (1983) "Effects of Channel Dams on Dissolved Oxygen Concentrations in Northeastern Illinois Streams", Circular 132, State of Illinois, Dept. of Reg. and Educ., Illinois Water Survey, Urbana, ILINOIS.
- Chapra, S. C. 1997. *Surface Water-Quality Modeling*, McGraw Hill.
- O'Connor, D. J. & Dobbins 1958. Mechanism of Reaeration in Natural Streams, *Trans. Am. Association Civil Engin.* 123: 641-666.