The impact of man-made hydrology on the lower stream bed of the Salado River drainage basin (Argentina)

V. Conzonno · P. Miretzky · A. Fernández Cirelli

Abstract Studies on the impact of channels constructed to prevent catastrophes during flooding periods on the hydrology of the lower bed of the Salado River drainage basin (Argentina) were performed as related to total dissolved solids (TDS) and ionic composition. Results indicated that most Salado River discharge (TDS 1.5–7.0 g/l, sodium chloride bicarbonate type) goes into artificial Channel 15. This situation leads to the decrease in Salado River discharge between the beginning of Channel 15 and the river's mouth at Samborombón Bay. Before it reaches Samborombón Bay the river receives the surplus of freshwater coming from a rock shell aquifer, and this makes TDS decrease to 5–6 g/l. The presence of Channel 15 has had a large influence on the ecological and socioeconomic conditions in the region.

Keywords Salinity · Ionic composition · Hydrology · Channels · Salado River drainage basin, Argentina

Introduction

The lower stream bed of the Salado River is in the geomorphic unit called Pampa Deprimida (34°20′ to 35°40′S and 57°40′ to 61°10′W) in the center east of the Buenos Aires Province (Fig. 1a, b).

The Salado basin contains Cretaceous, Tertiary (Lower and Upper), Plio-Pleistocene, and Pleistocene (Middle and Upper) sediments superimposed over the Precambrian crystalline basement. The Plio-Pleistocene sediments of the Pampean Formation are a succession of siltstones and fine sandstones with a relatively homogeneous mineralogical composition, consisting primarily of plagioclase, quartz, and volcanic glass. Amphiboles and pyroxenes dominate the heavy mineral fractions, with smectite and illite comprising the main clay minerals. Such sediments have generally been regarded as aeolian in origin, being derived from volcaniclastic deposits outcropping in the Andes over 1,000 km to the west, although localized fluvial and mass-movement processes probably redistributed the material to a large extent once it accumulated in the Pampas (Kemp and Zárate 2000).

The sedimentary sequence in the Samborombón Bay region continues with Post Pampean deposits of the recent Holocene age, mainly of marine origin [Formación Destacamento Río Salado (Entidad Querandino) and Formación Las Escobas (Entidad Platense)], and of aeolic origin (Formación La Postrera, Fidalgo and others 1973). The actual age of Formación Destacamento Río Salado sediments is estimated as 3,530 years and that of Formación Las Escobas sediments as 2,990 years. The former consists of 60–70 cm of sandy or silty sand sediments. Formación Las Escobas (2–6 m) lies over them, in erosion discordance and parallel to the coastal line. It consists of sandy to silty gray sediments with abundant shells in 10–30 cm beds, totally or partially cemented with calcium carbonate from shell dissolution. These sequences of sediments constitute the littoral rock shell chain which is restricted to coastal boundaries. Its thick granulometry and mineralogical composition facilitates infiltration, producing the displacement of high salinity water of marine origin retained in sediment pores, by low salinity rainwater, constituting an aquifer of good quality water.

Pampa Deprimida has a wet climate and a mean temperature between 13 and 16 °C. Mean annual precipitation is between 850 and 950 mm. Although precipitation is higher in summer, the precipitation–evaporation balance is negative in this season. Infiltration and evapotranspiration are the principal hydrological cycle components.

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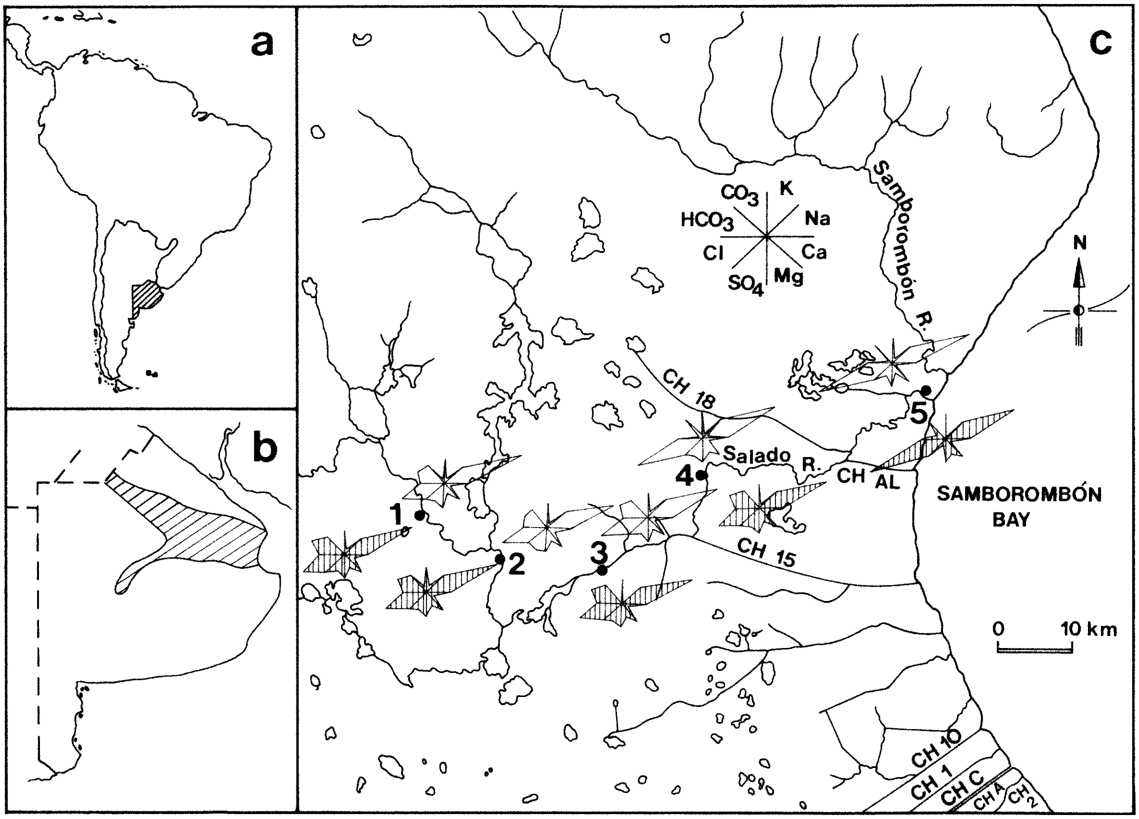

Fig. 1
a South America, Argentina, Buenos Aires Province; **b** Buenos Aires Province and the Salado River drainage basin; **c** lower stream bed of the Salado River drainage basin and sample stations in the first approach. Maucha's diagrams are *blank* and *shaded* for summer and winter, respectively (*CH* channel)

The Salado River flows along a NW–SE axis, meanders through a floodplain covered with shallow lakes and marshes that supply water to the river or receive water from it depending on their respective hydrological levels (Soldano 1947), and joins the River Plate estuary in the Samborombón Bay, which has a marine environment, TDS 10–25 g/l (Urien 1972).

The length of the river is 690 km, its catchment area is about 80,000 km^2 (Ringuelet 1972), and its annual runoff 3.5 km^3/year (Sala 1975). It is a typical plain area river, with a slope of 0.1–0.3 m/km (Sala 1975), a calm regime and variable stream flow, and a discharge rate of 15 m^3/s (Gómez and Toresani 1998). It presents a meandering character, especially in the lowest stream bed and in tributaries on the left bank. The Salado River shows high salinity values in its headwaters (El Chañar, Provincia de Santa Fe) probably because of: (1) the principal hydrological process being infiltration through sandy sediments, (2) lack of regional slope, (3) long water-sediment (rich in soluble salts) residence time, and (4) supply of high salinity groundwater during flooded periods (Vega and others 1995).

The area of investigation (Fig. 1c) is on the left side of the lower stream bed of the Salado River and between the east of a line that represents the union of the interconnected ponds called "Sistema de Las Encadenadas de Chascomús", connected with the Salado River through La Horqueta stream, and the Samborombón Bay (Miretzky and others 2000). Limnological and hydrochemical studies in these ponds, commonly known as pampasic ponds, have been previously reported (Conzonno and Fernández Cirelli 1988; Conzonno and Fernández Cirelli 1995).

The main characteristic of this littoral region is the absence of definite stream courses. It is a floodplain covered with shallow lakes and marshes and the morphological energy content of this region is characterized by the difference in height between the highest point and the outflow section. This difference is very small, and surface runoff is poorly developed. Precipitation reaching the surface is stored in the depressions, forming shallow lakes and marshes. The water exceeding the storage capacity of the depressions moves very slowly as surface sheet flow. Apart from evaporation, infiltration is also very high, and the water table is near the surface at most places. This results in high evapotranspiration from the soil moisture zone, as the decreasing moisture content due to evaporation is replenished from the groundwater by capillary rise. This process, important in summer, when the hydrological balance is negative, initiates the migration of salts and their accumulation in the top soil (Natraqualfs and Natraquols).

To the east of La Horqueta stream, the flooded area becomes larger. The Salado River does not receive tributaries, presents a much more meandering character, and in its course to Samborombón Bay it must go through a littoral rock shell chain (ca. 4 m high), which it does with great difficulty.

An aspect that must be taken into consideration is the negligible slope of the region and the low energy governing the flow of both surface and groundwater under natural conditions. Human activities can easily create gradients many times higher in artificial systems. The flow direction of man-made channels may be directed against the natural slopes without requiring the construction of large hydraulic structures (Kovacs 1983).

Several channels were constructed (Channel 15, Channel 18, Aliviador) to prevent catastrophes during flooding periods, but there are doubts about their function in operating water control. Channel 15 was made wider and deeper in 1997 and nowadays the channel carries water not only in flooded periods but also in normal conditions. This promotes loss of freshwater in the Salado River and, in summer periods, near the mouth in the Samborombón Bay, the river is almost dry.

This paper presents chemical data indicating the environmental impact of these channels, which have changed the hydrological characteristics of the area, and consequently the socioeconomic conditions of the local population.

Materials and methods

Samples were taken during summer 1997, winter 1998, and winter and summer 1999. The samples were filtered using 0.45 µm acetate cellulose membrane Micro Separations Inc. (MSI), and were stored in polyethylene bottles.

Temperature and pH were determined in the field by means of a portable pH meter Hanna HI 9025. Major ions were determined by conventional methods: carbonates and bicarbonates by acid titration, chloride by $AgNO_3$ titration, sulfate by precipitation titration with $BaCl_2$ and sodium rodizonate as an indicator in water–acetone medium; Na, K, Ca, and Mg were determined by atomic absorption (Varian Techtron Model AA275).

Total dissolved solids (TDS) were calculated as the sum of the above ion concentrations.

Results and discussions

The study began with a preliminary sampling in two periods (summer 1997 and winter 1998), in five sampling stations to analyze TDS and ionic composition of the surface waters. The results obtained during a second survey proved that the Salado River loses its identity when it joins Channel 15. A third survey provided hydrological characteristics of the Salado River from Channel 15 to its mouth in the Samborombón Bay.

First approach

Samples were taken during summer 1997 and winter 1998 at the sampling stations shown in Fig. 1c. TDS and ionic composition values (Table 1; Fig. 1) indicated a clear difference between stations 1, 2, and 3 and station 4 and also in comparison to station 5. From stations 1 to 3 TDS shows a slight increase, probably due to the evaporation process. TDS values are between 1.5 and 2.0 g/l in summer and

Table 1

Chemical parameters. *S* Summer, *W* winter, *asterisk* mean values obtained during one-day sampling

Station	pH	TDS g/l	Na meq/l	K meq/l	Ca meq/l	Mg meq/l	Cl meq/l	CO_3 meq/l	HCO_3 meq/l	SO_4 meq/l
First approach										
1 S	8.40	1.5	18.09	0.43	1.50	2.55	10.74	0.44	6.60	4.80
1 W	7.12	1.7	18.52	0.60	2.25	3.16	11.21	0.00	9.06	4.60
2 S	8.43	1.9	20.61	0.85	2.27	3.91	13.69	0.00	7.04	7.20
2 W	8.58	2.0	22.60	0.60	1.75	3.95	13.27	0.23	9.74	6.00
3 S	7.87	1.8	20.96	0.72	1.80	3.37	13.84	0.00	8.28	4.80
3 W	8.14	2.0	22.82	0.60	1.78	4.05	13.5	0.00	10.19	6.00
4 S	8.25	10.8	135.38	2.52	8.48	26.98	126.99	1.77	7.48	37.12
4 W	8.13	1.8	20.00	0.68	2.07	3.75	12.43	0.00	8.82	5.60
5 S	7.50	5.3	73.78	1.61	3.58	7.10	71.41	0.00	3.08	12.17
5 W	8.00	5.1	66.87	1.32	4.35	14.70	73.41	0.00	7.92	4.00
Second approach										
3	9.12	3.0	40.32	1.01	1.84	3.74	26.94	2.00	10.10	7.24
4	8.56	8.0	123.40	2.00	3.49	19.90	118.57	1.50	8.00	23.97
5*	9.07	10.0	143.08	3.06	5.11	18.02	151.50	0.50	3.20	15.08
6	9.21	3.3	41.33	1.33	2.79	4.80	27.54	2.00	10.10	9.89
7	8.94	3.1	40.25	0.89	2.14	4.05	27.54	2.00	10.10	8.89
8	8.41	11.0	158.00	3.49	5.39	18.50	166.69	0.50	2.60	16.98
Third approach										
5	8.54	11.8	169.80	3.54	5.08	20.65	177.55	0.50	3.54	18.38
6	8.70	6.8	100.90	1.46	3.04	9.57	82.62	2.00	10.72	12.79
9	8.84	7.2	104.20	1.69	3.32	11.21	86.32	2.00	11.72	15.38
10	8.20	20.4	275.00	4.68	14.46	54.39	292.40	0.50	9.87	40.96
11	8.34	11.0	161.30	2.76	4.99	19.50	159.80	0.50	6.98	16.08
12	8.79	11.9	182.30	2.48	6.18	22.40	164.13	0.00	10.47	16.39
13	9.30	5.9	83.40	1.79	3.09	10.95	86.32	3.00	2.24	8.49

winter. Ionic composition is similar in all samples, being mainly of sodium chloride type with significant proportions of bicarbonate, sulfate and magnesium as indicated by Maucha's diagrams (Fig. 1c).

A drastic change is observed in station 4 during summer when TDS increases to 10.8 g/l, whereas in winter the value resembles the one obtained for stations 1–3. Ionic composition in winter is that of a sodium chloride type, with presence of bicarbonate, but in summer is essentially a sodium chloride type, revealing the influence of an evaporation–crystallization process (Gibbs 1970) with the consequence of calcium carbonate precipitation. At the mouth of the Salado River (sampling station 5) TDS in both seasons is almost the same, about 5 g/l. The difference in the ionic composition is associated again with the evaporation–crystallization process during summer (Fig. 1c).

Second approach

A second survey was undertaken during winter 1999 at the sample stations shown in Fig. 2a. Results (Table 1) indicate that the river TDS and ionic composition before it joins Channel 15 at sample station 3 are the same as TDS and ionic composition of Channel 15 (sampling stations 6 and 7): TDS about 3 g/l and sodium chloride type with a significant proportion of bicarbonate and sulfate. At sampling station 4, a winter TDS value of 8 g/l and ionic composition of sodium chloride type with a significant proportion of sulfate and magnesium were found, similar to values found in the first summer survey.

TDS at the river's mouth (sampling station 5) was about 10 g/l and the ionic composition was slightly different from that of the preliminary sampling, although of a sodium chloride type too. At this station, samples were taken from the morning to the afternoon to determine the influence of tidal events on TDS and ionic composition. Significant differences were not observed, indicating that tidal currents move the same mass of water in and out of the bay (negative and positive flux, respectively; Fig. 3). At the mouth of the Aliviador (station 8) TDS and ionic composition were similar to that at station 5.

On the basis of chemical data and considering the values obtained at sampling station 4, this second approach confirmed that most of the water of the Salado River goes through Channel 15 to the Samborombón Bay and the Salado River loses its identity.

Third approach

To study the hydrological characteristics of the Salado River section between Channel 15 and the Samborombón Bay (57 km length), a third survey during the summer of 1999 included samples at stations shown in Fig. 2b. The Salado River near Channel 15 (station 9) and Channel 15 (station 6) has similar TDS values (7 g/l) and ionic composition (sodium chloride type; Table 1).

Near station 9, due to evaporation, the Salado River is interrupted and an isolated section was found at sampling station 10. In this interval, the Salado River behaves as a lentic environment in which TDS increases up to 20 g/l and the ionic composition is of sodium chloride type but with a lesser proportion of bicarbonate than at station 9. Stations 11 and 12 presented TDS about 11 g/l and ionic composition of sodium chloride type. Station 13, between stations 12 and 5, relatively near both (3.5 and 6 km, respectively), presented, at first sight, an anomalous value of TDS of about 6 g/l. This value is significantly lower than TDS at station 12 and also at station 5, where the TDS value obtained was 11.8 g/l, similar to that registered in the second survey.

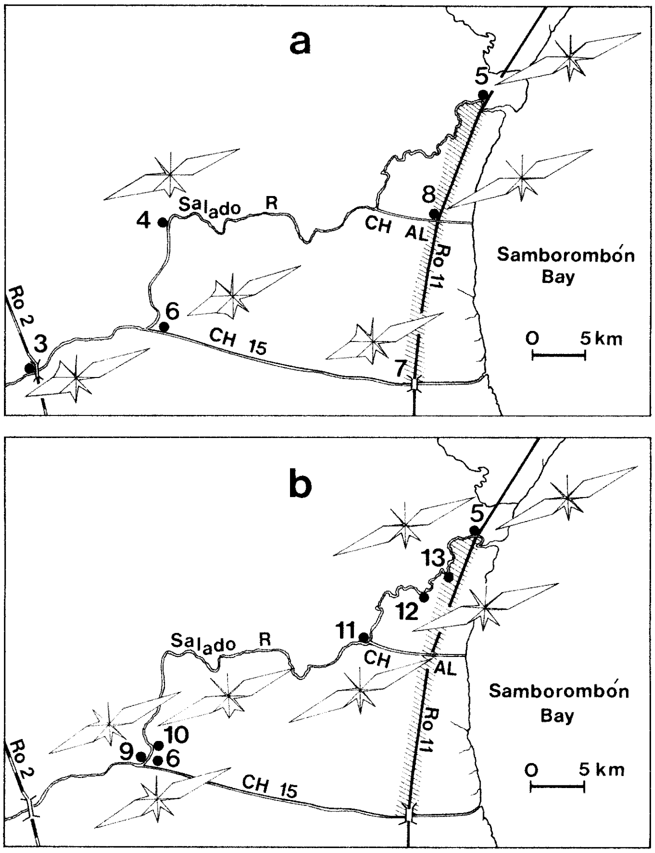

Fig. 2
a Sample stations and Maucha's diagrams in the second approach. *Shaded area* indicates the location of the rock shell chain. **b** Same as **a** but in the third approach (*CH* channel; *Ro* route)

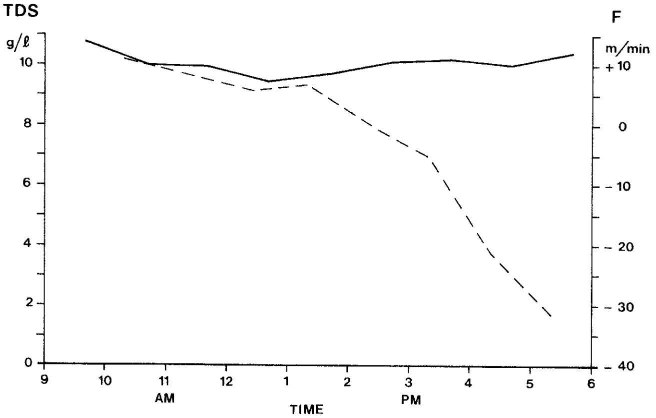

Fig. 3
Total dissolved solids (TDS–) and flux (F– – –) as a function of time of day

The explanation for the diluted TDS value obtained at station 13 may be the existence of the littoral rock shell chain (Formación Las Escobas), 2–6 m high, over which route number 11 was built (Fig. 2b). As mentioned earlier, Formación Las Escobas has a sandy thick granulometry and mineralogical composition, which facilitates infiltration, producing the displacement of high salinity water of marine origin retained in sediment pores, by low salinity rainwater (average local rainwater TDS value: 8.0 ppm; sodium chloride type), constituting an aquifer of good quality water. In dry periods, groundwater is able to dilute the Salado River waters in this region. This fact may explain the TDS values at station 5 (mouth of Salado River) of ca. 5 g/l, obtained during the first survey, since TDS at Samborombón Bay is between 10 and 25 g/l.

Conclusions

Under normal conditions, except extreme flooding periods, most of the Salado River water goes into Channel 15 and reaches the Samborombón Bay. This has occurred since 1997 when the channel was made wider and deeper. The decreases in the Salado River discharge between the beginning of Channel 15 and Samborombón Bay promote isolation of certain sections of the river and, as a consequence, the river acquires characteristics of a lentic environment and evaporation increases the TDS. In the region near the Samborombón Bay, the river receives the surplus of freshwater from the littoral rock shell chain aquifer and the TDS decreases. Eventually this water may reach the Samborombón Bay.

In the section between Channel 15 and its mouth, the Salado River loses its identity. A lesser supply of water from the Salado River causes a change in the ecological conditions such as the formation of swamps, the modification of aquatic habitats with consequences in the fish community, and the diminution of water availability for the farmers who must search for alternative sources of fresh water. The hydrological characteristics of the area have changed, and consequently the socioeconomic conditions of the local population.

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