Historical analysis of water flows in the Río Dulce catchment, Argentina

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Abstract

Debates on irrigation have recently integrated the concept of sustainable water use, involving qualitative and quantitative conceptualizations of flows of resources. The nature of unstable water availability during seasons and over years is a key issue. A storage facility is usually desirable. In the process of enlarging control through such facilities, water patterns in basins, in terms of flows, storage and use have changed. This paper discusses historical patterns of water flows in the Río Dulce basin in Argentina, in which the irrigation area known as the Proyecto Río Dulce has an immense influence on the catchment water balance.
Keywords: irrigation, river basin, water flows, catchment, Argentina.

1 Introduction

An important issue in water management is the nature of unstable water availability during seasons and over the years. Many rivers have an irregular flow pattern, with large fluctuations in and over seasons and very low flows in the dry season. In such a setting it is difficult to match water availability with actual water requirements. In many river basins, exploitation of the river through damming, channel manipulation, power generation and irrigation has become very intensive. Latin America is not an exception. The basin of Río de la Plata, fifth largest in the world with its area of 3.1 million km^2 counts a large number of dams, used for flood control, irrigation and industrial supply too. Petts [1] sketches the relationship between water, engineering and landscape as a three-phase development:

1) Management of perennial water sources for local agriculture and domestic supplies and the opportunistic use of seasonal floods and rains for agriculture;
2) Management of rivers for navigation and waterpower, informal regulation of seasonal floods for irrigation agriculture, and drainage of wetlands;
3) Regulation of rivers by large structures, often as part of a complex basin or inter-basin development, for power generation, water supply and flood control.

This development, referred to as 'centralization' by Petts [1], indicates two related processes. The water flows derived from rivers are concentrated through water infrastructure in certain areas, often at the expense of downstream use(r)s. Management of these flows has become centralized in larger institutions. This second aspect is not discussed in detail in this paper. Water patterns in basins, in terms of flows, storage and use have changed due to centralization; these issues will be discussed in this paper for a river basin in Argentina.

2 The Río Dulce basin

In the Río Dulce basin, Argentina, irrigation is a main water user and consequently providing water for irrigation has been one of the main goals for activities in the basin. The basin is small in relative terms (rough estimation: about 100,000 km^2). The importance of irrigation in the basin makes it an excellent case to discuss (some) possibilities of using historical studies to evaluate and appreciate the meaning of irrigation in a river basin. Within the Río Dulce basin, the irrigation area known as the Proyecto Río Dulce (PRD, irrigable area 122,000 hectares in a command area of around 350,000 hectares) has an immense influence on the catchment water balance in absolute and relative terms. About 50,000 were irrigated in the last two decades; but about 100,000 hectares were irrigated in recent years. Before 1968, the irrigation infrastructure provided two or three irrigation turns for each farmer in late spring and summer, when the water levels in the Río Dulce were sufficiently high. The building of a reservoir in 1968, the Embalse de Río Hondo, has shaped the potential for irrigation all year round. Salinization is a problem in the command area. In general terms, this is an indication of an inflow of water into the irrigated area too large to be drained out of the area. Entering history will show how sizes and directions of water flows have been changing by human intervention and how this has influenced system behavior at different scales.

Santiago del Estero province counts 150,000 square kilometers and is inhabited by just over 800,000 people (2001) (INDEC [2]). Its' climate is continental: winters are relatively cold and summers are hot. In winter, from June to August, the wind is south and night temperatures may drop below freezing. Day temperatures in winter may rise above twenty degrees Celsius. In summer, the wind blows from the north and is often very hot and dry. Temperatures may rise above 40 degrees during the day and stay above 25 degrees at night. Annual precipitation, mainly summer rains (November-April) ranges from 500 mm to 850 mm; mean annual precipitation in the PRD area equals 550 mm. Winters are dry; Santiago del Estero has about six dry months (April/May-September/October) (Torres Bruchmann [3]). In this dry and remote landscape two rivers are searching their way to the sea. Although small in comparison to Argentina's major river the Río Parana, these two rivers are the vital sources for life in Santiago del Estero. Along these rivers agricultural and pastoral activities have laid the foundation for the economy of Santiago. One of them, the Río Salado has succeeded in reaching the Río Parana. The other river, the Río Dulce flows into the salt-lake La Mar Chiquita. In the upper part of the Dulce catchment (Tucuman province), slopes are steep and rainfall high. This area can be characterized as a high erosion hazard region with low salinity problems; infiltrated rainwater leaches salts from the soil profile. The middle part of the basin, in which the PRD is located, has gentle slopes and less rain. As most soils in semi-arid areas, soluble salts are present in subsurface horizons, as percolated rain is not enough to leach the salts. When these soils are irrigated, a secondary salinization process may develop due to insufficient drainage capacity. In the lowest part of the watershed, the area is almost flat; water tables are generally shallow with high salt contents.

3 The Proyecto Río Dulce

In 1577, the Spanish built their first irrigation ditch (*acequia*) in Santiago del Estero. In 1583 this reached a length of 5 kilometers. In the modern city of Santiago del Estero, remains of an old irrigation ditch following the course of the original ditch can be found. The Río Dulce repeatedly destroyed the original ditch, until in 1650 a permanent canal was constructed. In 1680 an irrigator's register was established. Individual landowners, who dug a ditch until they reached their land, built the first acequias. This explains why the larger landowners (still) are situated in many tail end areas: they automatically became tail-enders, as their canals ended on their lands. In 1873, 73 acequias existed. These canals were not the small ditches one would perhaps expect: most were longer than 10 kilometers, some extending even up to 50 kilometers with a width of 6 meters. Officially about 8,000 hectares were irrigated by the acequias, but in practice this figure would have been higher (Michaud [4]). In 1878 canal *La Cuarteada* was built to pass floodwater from the Río Dulce to the Río Salado (Michaud [4]). However, instead of diverting access water, the canal inundated the land around it. Not before long individual agriculturists began to build their acequias from La Cuarteada, thus changing a canal basically built for flood control (drainage) into an irrigation canal.

In 1886 an intake structure was constructed for La Cuarteada (Michaud [4]). In addition, a program to develop the irrigated area by building more acequias in the command area of La Cuarteada was formulated. The intake structure did not hold long; the Dulce River washed it away. As the agricultural interests in the area had grown, plans were made to build a new structure. The new intake came in use in 1898 (HARZA [5]). In 1905 the existing irrigation infrastructure was further extended. From then on, the intake diverted water to a main canal, at the end of which (*La Darsena*) *Canal Norte*, *Canal Sud* and Canal La Cuarteada branched off (Michaud [4]): the first public irrigation system in Santiago del Estero, which became the basis for the infrastructure on the left bank of the modern Proyecto Río Dulce. It irrigated about 38,500 hectares; an extra 14,500 hectares were irrigated from private acequias (HARZA [5]). In 1913 a communal canal on the right bank was constructed: *Canal San Martin*, with a length of 64 kilometers (Michaud [4]).

4 Water availability

The canal systems on both banks derived water when flow and water level of the river was sufficiently high. The diversion dams in the river (*diques de ramas*) collapsed when discharges were very high. Water derivation could hardly be regulated, since no storage was available. Water was usually (sometimes too) abundantly available in the wet season, but scarce in the dry period (*estiaje*). Farmers had to make use of the start of the rainy season (November/December) to prepare their lands and sow their crops. During the rainy summer, one or two irrigation turns were usually available, but water availability and thus the number of turns changed from year to year (tables 1 and 2 show this tendency for the La Cuarteada area). Due to this insecurity of the water supply, farmers never could be completely sure of receiving sufficient water to grow their crops. Alfalfa (about 12,700 hectares) and maize (about 10,000 hectares) were important crops, together with cotton (about 9,000 hectares) (Michaud [4]). Most farms were relatively small: on the left bank, more than 1,000 farms (of nearly 2,000) were between 1 and 5 hectares, where only 9 were more than 100 hectares (Michaud [4]).

Table 1: Water availability in the La Cuarteada area (1926–1948) (Datos I [6]).

Year	*Mean annual flow in m3/s*	*Mean flow 'estiaje' in m3/s*	*Annual rainfall in mm*	*Hectares irrigated*	*River water available in l/s/ha*
1926	63	13	357	14,000	0.93
1927	103	12	487	15,000	0.80
1928	111	38	711	14,000	2.71
1929	72	16	384	15,000	1.07
1930	110	36	755	7,000	5.14
1931	176	44	372	17,000	2.59
1932	137	32	481	14,000	2.29
1933	192	22	312	13,000	1.69
1934	65	22	434	18,000	1.22
1935	80	11	530	18,000	0.61
1936	67	9	455	23,000	0.39
1937	10	2	200	26,000	0.08
1938	51	4	596	16,000	0.25
1939	68	10	621	24,000	0.42
1940	82	30	487	24,000	1.25
1941	74	15	388	23,000	0.65
1942	66	12	395	23,000	0.52
1943	73	17	611	38,000	0.45
1944	145	15	458	42,000	0.36
1945	54	10	361	47,000	0.21
1946	50	14	408	52,000	0.27
1947	44	14	261	52,000	0.27
1948	56	6	508	55,000	0.11

Around 1923, many European farmers arrived in Santiago, resulting in a sharp increase in the amount of irrigated hectares, with a clear decrease of available water per hectare as a result. According to normal irrigation practice in the area these farmers received water at the end of an irrigation turn. Soon they realized that irrigation water availability was not enough to sustain the needs; farmers representatives approached the Provincial Government and later the National Government to employ works to increase the amount of water (Prieto [7]). In 1947 the federal organization for water affairs *Agua y Energía Eléctrica* (AyEE) began to build a permanent diversion weir in the river, the *Dique Los Quiroga* (Michaud [4]).

Table 2: Detailed overview for La Cuarteada (1940-1947) (Datos II [8]).

Description		**1940**	**1941**	**1942**	**1943**	**1944**	**1945**	**1946**	**1947**
Mean river flow	m^3/s								
Year		82	74	66	73	145	54	50	44
'Estiaje' [1]		30	15	12	17	15	10	14	14
Number of acequias in use	-								
Year		31	30	26	29	31	30	36	37
'Estiaje' [1]		29	21	15	19	26	16	22	26
Total water volume derived	hm^3								
Year		440	426	379	412	440	426	521	535
'Estiaje' [1]		137	99	71	90	123	76	104	123
Irrigated area	ha	24,000	23,000	23,000	38,000	42,000	47,000	52,000	52,000
Water volume per hectare	m^3								
Year		11,405	11,517	9,980	6,739	6,517	5,636	6,113	6,283
'Estiaje' [1]		3,556	2,687	1,919	1,472	1,822	1,002	1,245	1,472
Water gift [2]	mm								
Year		1,141	1,152	998	674	652	564	611	628
'Estiaje' [1]		356	269	192	147	182	100	125	147
Rainfall	mm								
Year		487	388	395	611	458	361	408	261
'Estiaje' [1]		34	18	14	34	1	1	16	27
Water gift + rainfall	mm								
Year		1,628	1,540	1,393	1,285	1,110	925	1,019	889
'Estiaje' [1]		390	287	206	181	183	101	141	174

1 The 'estiaje' is the period of minimal water availability in a normal year, constituted by the months of July, August, September and October.
2 The water gift is the effectively available water volume per irrigated hectare.

At first, the main canal fed by Los Quiroga, *La Matriz*, only diverted water to the La Cuarteada system. San Martín continued to derive water directly from the river, as did the remaining private acequias. However, these canals downstream of Los Quiroga had difficulties getting water, in particular during periods of low flow, since almost the full flow was diverted to the La Cuarteada system on the left bank. Again, assistance from the National Government was looked for. As a solution, the San Martín system was connected to La Matriz through a siphon around 1954 (Prieto [7]). Some private acequias remained in the San Martin area, but they did not take water directly from the river any more; they were connected to the San Martín network. The main reason for the owners of the acequias to agree with this arrangement was that it secured their water delivery.

It has not been possible to determine in detail how Los Quiroga has influenced water availability, as data are not available. Although water availability would have increased (as the issues in the San Martín area indicate), it is highly unlikely that the increase has reversed the sharp decrease of water availability in l/s/ha sketched. Given the uneven distribution between left and right bank, it is possible that the left bank did have an increased water availability (the irrigated area increased relatively more in that area), where the right bank canals saw their water availability decrease (Prieto [7]). Overall water availability was to be improved by a reservoir in northwest Santiago, the *Embalse del Río Hondo*. AyEE presented plans in 1957 and the reservoir was completed in 1968. The reservoir has shaped the potential for irrigation all year round. However, its capacity is insufficient to provide more than annual regulation. Consequently, in a year with less than average rainfall or management problems, the reservoir cannot fully meet the diversion requirements for the total irrigable area. In 1966 the Proyecto Río Dulce was formulated. New canals were to be constructed, old canals rehabilitated and the acequia system was to be replaced by a tertiary unit system. Activities could not be extended to all the irrigated areas of the PRD. Two existing areas (parts of the former La Darsena and San Martin sub-systems) and one new area (Colonia Simbolar) can be considered modernized, with the remaining (larger) area virtually unchanged.

5 Water use in the PRD

Applying the phases of Petts [1] to Santiago del Estero gives figure 1. The first phase, management of perennial water sources for local agriculture and domestic supplies and the opportunistic use of seasonal floods and rains for agriculture, extends until about 1870 in Santiago del Estero. The second phase, involving the management of rivers for waterpower, informal regulation of seasonal floods for irrigation agriculture and drainage of wetlands can be defined between 1870 and 1968, with 1950 being a first step in the direction of the third phase, during which rivers have been regulated by large structures, often as part of a complex basin or inter-basin development, for power generation, water supply and flood control. In the Río Dulce basin, this period extends from 1968 onwards. Data show that PRD inflows per hectare are significantly higher in this period than before Los Quiroga was built and probably much higher too than when Los Quiroga was in use. These data from higher levels in the water system (respectively based on measurements at the main intake and on river water availability) seem to be not easily compatible with processes at lower levels (irrigation field practices). As field practices in the area are not the same in the command area, the issue is complex. In general, the larger farmers use more water than the small ones, before and in the PRD.

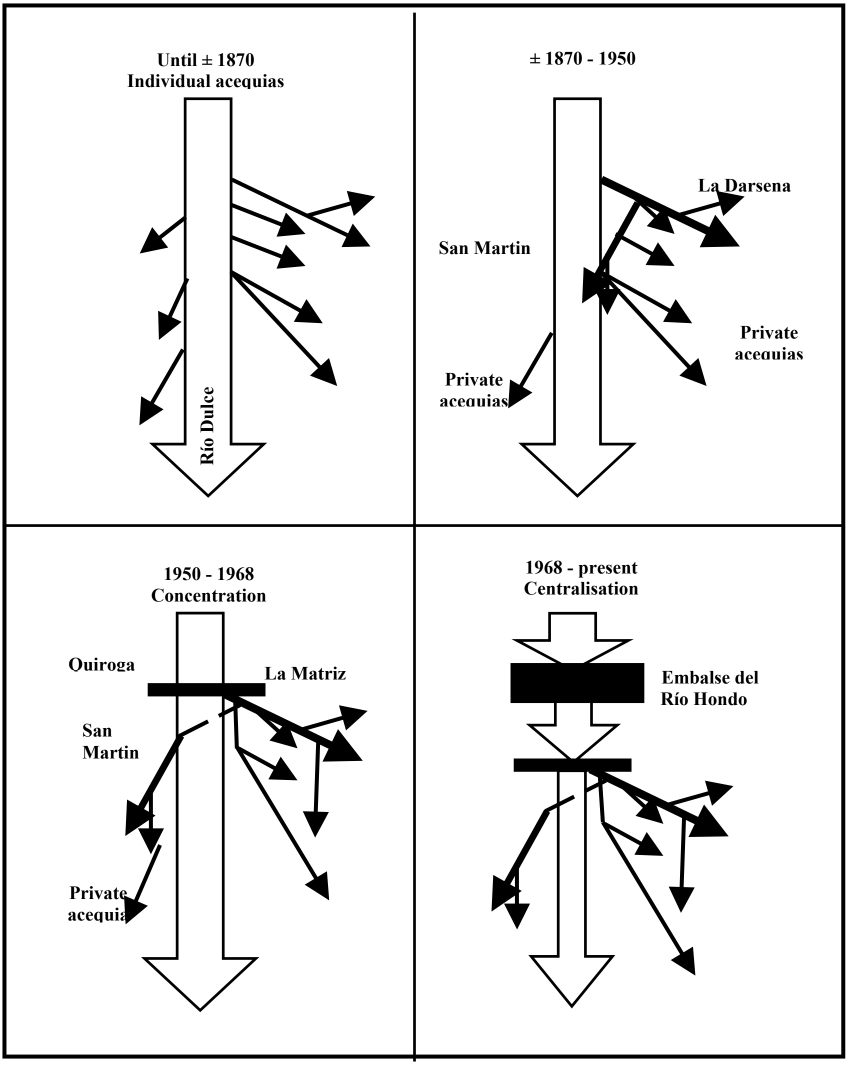

Figure 1: Schematic representation of water flow development in the PRD area.

In 1971 an irrigation distribution plan for the PRD was proposed (Romanella [9]). Irrigation water was to be distributed using a rotation schedule fixed in time, with a variable flow, and an interval of 30 days. The monthly interval was also taken, because it fitted in the already existing practice of larger intervals. The maximum irrigation flow was determined to be 300 l/s, required in December (the month of maximum irrigation needs). With these values from practice, the time needed to irrigate one hectare was calculated, resulting in an irrigation time per hectare of about 75 minutes. Using this time, irrigation flows required in other months were calculated. The proposed schedule has not been taken into use, but why is not clear yet. The distribution schedule designed by AyEE does apply monthly intervals, but with a fixed irrigation flow of 300 l/s. The permitted time per hectare is lower, namely 50 minutes per hectare per month. This results in a permitted irrigation volume of 900 m^3/ha per month (9,900 m^3/ha per year, a month maintenance excluded). To complicate matters, in actual practice farmers do not irrigate each month. Smaller farmers irrigating cotton or alfalfa on average irrigate two to three times per year, using about two and a half times more water per turn than allowed. The larger farmers take water during 8 to 9 turns; sometimes they irrigate a larger area than officially allowed. If 6 turns were an indicative average, annual water application would be around 1300 mm (Prieto et al. [10]). This actual water use pattern shows a continuation of traditional irrigation methods: when water in the unregulated river was available, it used to come in large flows, which had to be used in relatively short periods of time. Irrigators were used to handle such larger flows on their relatively large fields (Romanella [9]). Apparently, farmers reproduce the distribution schedule of the unregulated period. The stronger regulation of the available flows, however, allows better-secured starting conditions for the crops and a better regulated growing season. Second, the crops (like new types of cotton) grown nowadays respond less well to this distribution than the old types.

6 Water flow patterns in the Río Dulce basin

Looking at water flow in the Río Dulce basin, patterns of (re) distribution at different scales or levels (figure 2) can be distinguished. In relative terms, the canal system serves a larger area than the total irrigated area of 122,000 hectares would need, as the command area is three times as large as the irrigated area. Within the three core irrigation areas, not all the fields have irrigation rights; consequently not all fields are irrigated. Thus, both on scheme as on field level, pockets of irrigation can be found. This has impact on the water flows, for example capillary rise from groundwater to non-irrigated fields (with immediate impact for salinity problems). It seems safe to state that the increasing inflows in the PRD area can easily create and have already created problems like salinization, as system outflows do not have the same capacity and groundwater levels can rise. Most surface outflows of the canal system are known. Some secondary canals end into drinking water reservoirs, others directly drain into the river, and some drain into natural sinks. In terms of command area, defining borders is less straightforward. In general, the larger farmers have their farms in the downstream canal areas. These farms include irrigated and non-irrigated land and generally extend outside the borders of the command area. As a result, it is virtually impossible to define the boundaries of the command area of the PRD. It would be more suited to refer to a water use transition zone, both in terms of irrigated areas as in water flows. On catchment level, there is the issue of implications of water use in the PRD area for downstream use(r)s. The irrigation developments in the Río Dulce basin have enlarged the supply of irrigation water into the command area. With intake figures indicating that each hectare can be irrigated with 2000 mm, and field figures indicate that a mean of about 1300 mm are actually used, 35% of the inflow is not accounted for.

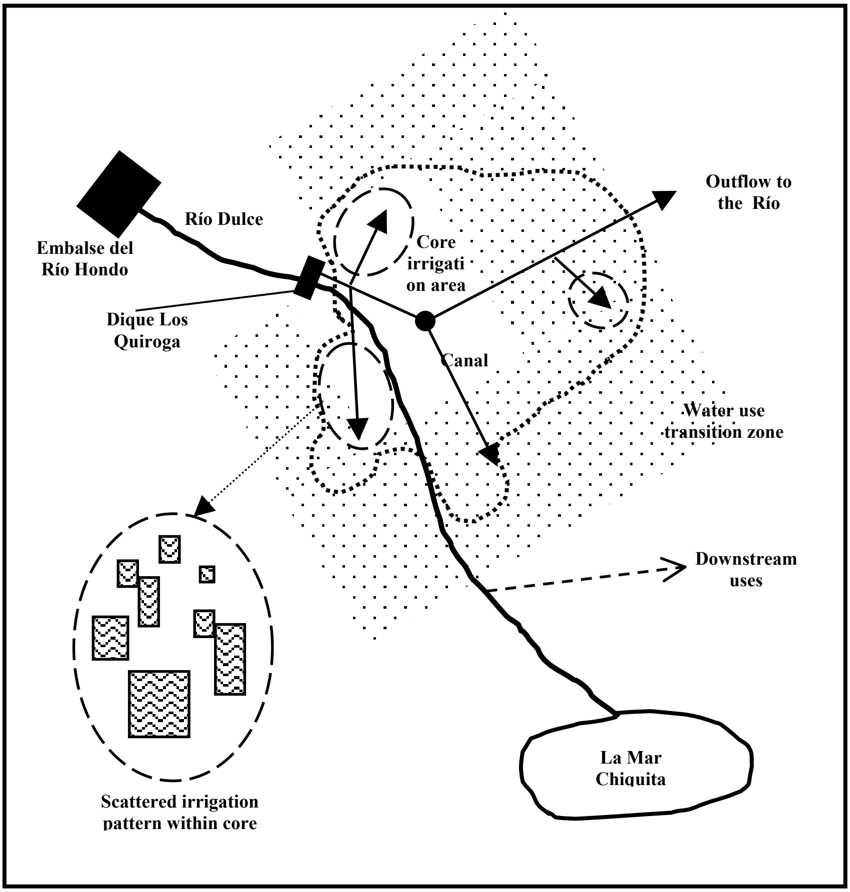

Figure 2: Water use and flow patterns in the Río Dulce basin.

It is perfectly possible, however, that this water ‘disappears’ at system level, but at catchment level it could perhaps be re-used downstream. It is equally possible, that most water remains in the command area. The salt content of two samples from the Rio Dulce water at low flow in and immediately downstream of the irrigated area was similar, indicating a low returning flow from the PRD (Prieto [7]). A hypothesis worthwhile to be studied is that non-irrigated areas within the command area are to be considered as “subsurface irrigated areas” with perennial vegetation. In this case, a large amount of water, perhaps larger than from cropped areas, would leave the system this way (Prieto [7]). Related to these issues of water use is the balance in the total catchment of different requirements for hydropower versus irrigation and the inflows needed to maintain La Mar Chiquita, an important area for birds.

7 Conclusive remarks

The case of the Proyecto Río Dulce irrigation area has shown that surface water flows into the PRD have increased as a result of growing water demands. The increase of the flows has been realized in a process of 'centralization' of both physical flows and management: dispersed flows in (private) acequias have been concentrated into the irrigation infrastructure of the PRD, including the Embalse del Río Hondo. As a result, the flow patterns of the basin will have changed, most probably at the expense of downstream use(r)s. The particular feature of the PRD to have an irrigated area dispersed within a much larger command area (and even beyond) probably increases the concentration of flows into the PRD area, as natural vegetation uses inflows too. The fraction of water used by natural vegetation in the "sub-surface" irrigated areas could be considered as a loss for use(r)s downstream; it does not have economic benefits. All together, ground en surface water outflows from the PRD area usable elsewhere could be quite low indeed. Further research to study these fractions is currently developed.

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