The Water Delivery Performance within the Chivilcoy Tertiary Unit

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ABSTRACT

The 4th Chivilcoy tertiary unit (1630 ha) receives irrigation water from the Montecaseros canal. This canal and its 16 tertiary units is managed by the Montecaseros Users Association (8531 ha), being one of the 13 UA's in the Rio Tunuyan Medio irrigation system (81200 ha). The 4th Chivilcoy unit was selected for performance research because it is representative for a major part of the Tunuyan system; it contains (near abandoned) fields with water logging and salinity problems and fields with top yields. This paper reports on performance indicators quantifying the water delivery to the 12 quaternary units. Also the delivery of water to the 19 farms in the Los Sauces quaternary unit (109 ha) is quantified. All flow data were measured with broad-crested weirs fitted with pressure loggers measuring the head at 15 minutes intervals. Because of this short interval, the timing of water delivery could be monitored and compared with the intended delivery schedule.

Key words: water management, efficiency, seepage, delivery, farmer, rotation, Argentina

Introduction

The Rio Tunuyan Medio command area, Mendoza, Argentina covers an irrigable area of about 81200 ha of which 63401 ha has legal right to surface water. Surface water is released from Carizal Dam as a function of the water availability and the overall irrigation demand. Water is released from the Carizal Reservoir and supplied to 13 Users Associations (UA's) in proportion to the water rights in the related association (Chambouleyron 1992, Morabito et al 1998). The aquifer is recharged by the non-consumed fraction of the irrigation water and by part of the annual rainfall (190 mm/year). This groundwater is pumped by 6080 wells with a total capacity of about 50 m^3/s. The main canals plus related division structures, up to the structure where water is supplied to the Users Associations, are managed by the Sub-Delegado de Agua (Irrigation District Office) of DGI.

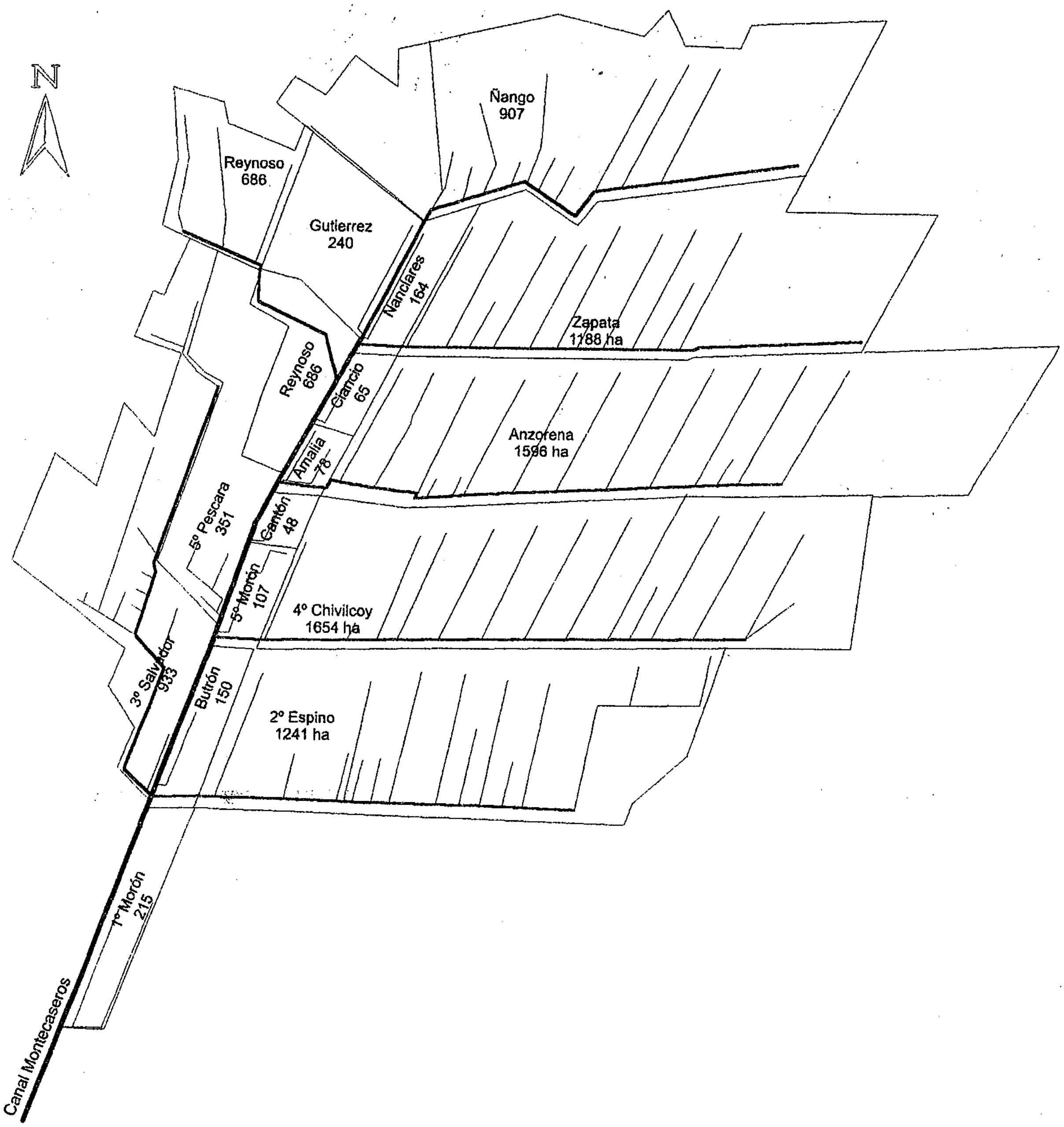

Figure 1 Lay-out of theMontecaseros canal system and related tertiary units.

Water users in the Montecaseros UA have water rights for 8531 ha (Figure 1). Since water is supplied in proportion to the water rights, the Irrigation District intends to supply 10.97 % of the flow released from Carrizal Dam to this UA at the Perrupato gauging station (Bos et al 1998). The User Association manages, operates and maintains the Montecaseros (secondary) canal and its tertiary and quaternary canals up to the farm inlet (Agradano de Llanos and Bos 1997; Chambouleyron 1994). The water delivery schedule to the tertiary units served by the Montecaseros Canal shows that five of the larger units, amongst which the 4th Chivilcoy, receive water continuously; the other 11 rotate as described by Bos e.a. (1998). Hence, the 4th Chivilcoy canal receives water continuously, however, at a variable rate. Figure 2 shows a characteristic flow histogram.

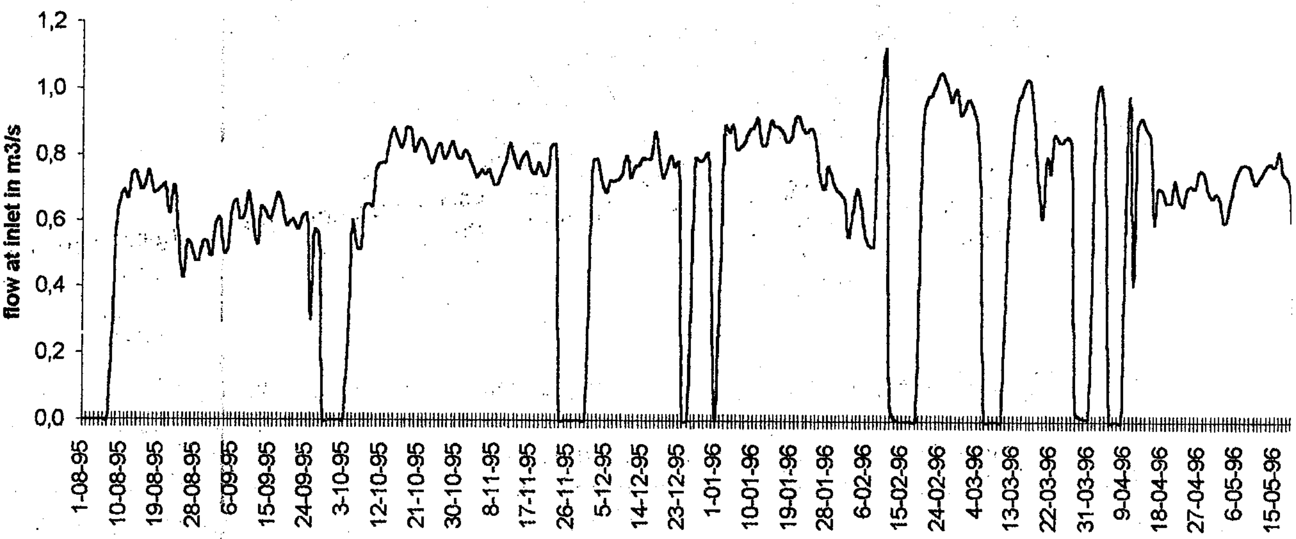

Figure 2 Flow rate delivered to theChivilcoy tertiary canal for the 1995-96 irrigation season.

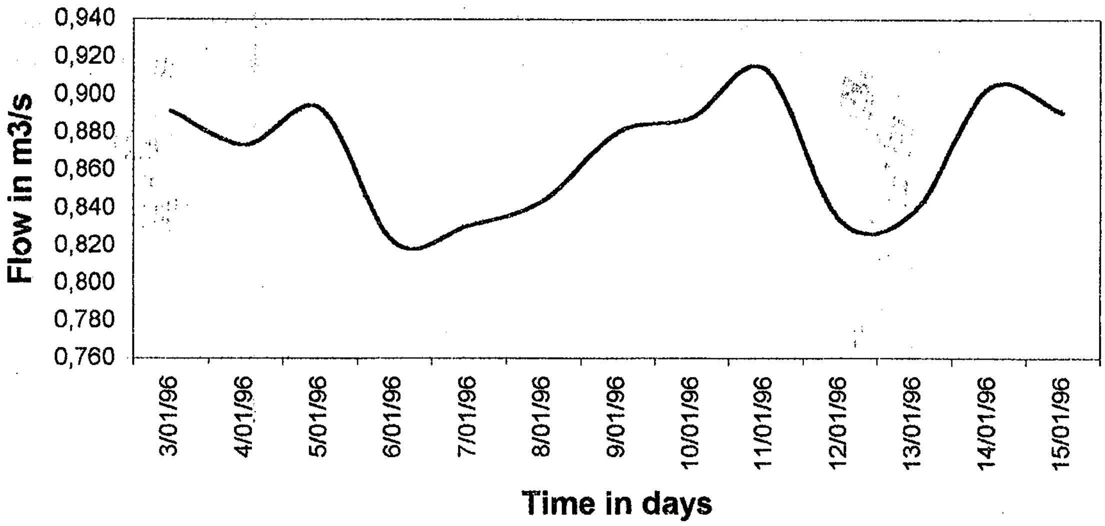

Figure 3 Detailed flow data for one rotation cycle of somewhat more than 13 days (3 - 15 January 1996, see also Table 4)

Water Delivery from the Tertiary Canal

The 4th Chivilcoy tertiary unit was selected as a pilot study area because it is centrally located within the total Montecaseros command area, the canal is accessible along one road, and serves a representative agricultural area of 1630 ha (Figure 4). Furthermore, the groundwater table varies from less than 0.5 m in the west to over 3 m in the east. Because of the related salinity, yields of the major crop (D'Agen grapes) vary from zero (abandoned fields) to more than 30000 kg/ha.

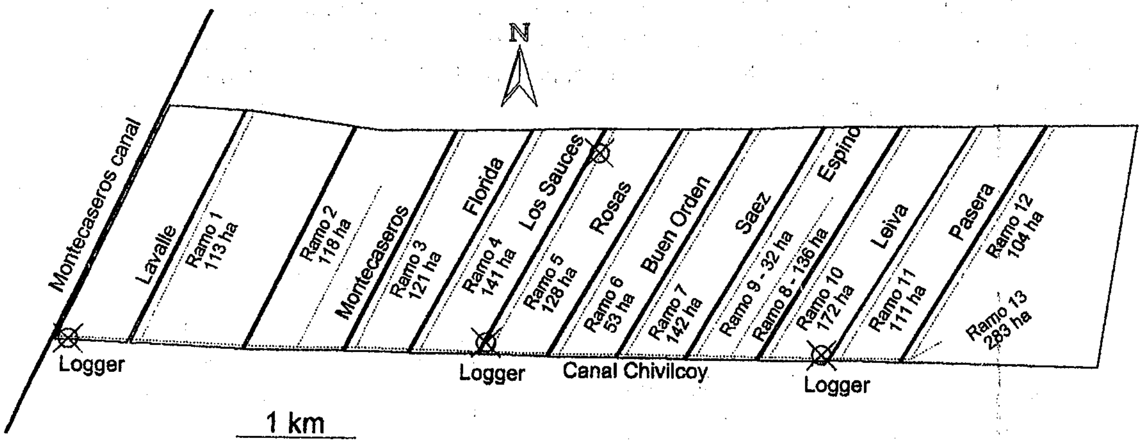

Figure 4 The 4th Chivilcoy Tertiary Unit

As mentioned above, the 4th Chivilcoy canal receives a continuous flow of which the rate varies as a function of the season as shown in Figure 2. Flow is measured with a broad-crested weir equipped with a (water) pressure logger in a stilling well. The intended operational practice (gate operation calendar) starts by delivering the undivided flow to the most upstream farm of the first quaternary canal. If this farm has received water for the pre-set duration (12 minutes per ha), the gate in the quaternary canal will be opened, the farm gate is closed, and water travels to the second farm, etc. (The next time that water is delivered to this quaternary unit, the rotation is started at the most downstream farm). If all farms within one quaternary unit have received water, the gate in the Chivilcoy canal will be opened and the gate to the quaternary canal is closed. Subsequently, the second quaternary canal receives all water, etc. All gates at canal bifurcation's and farm inlets are operated (and locked) by the gate-man of the UA. The intended schedule of water delivery to the quaternary units is shown in Figure 5. Interruptions are foreseen if flow at Carizal dam is cut on purpose because of significant rain on the irrigated area and major holidays like Christmas.

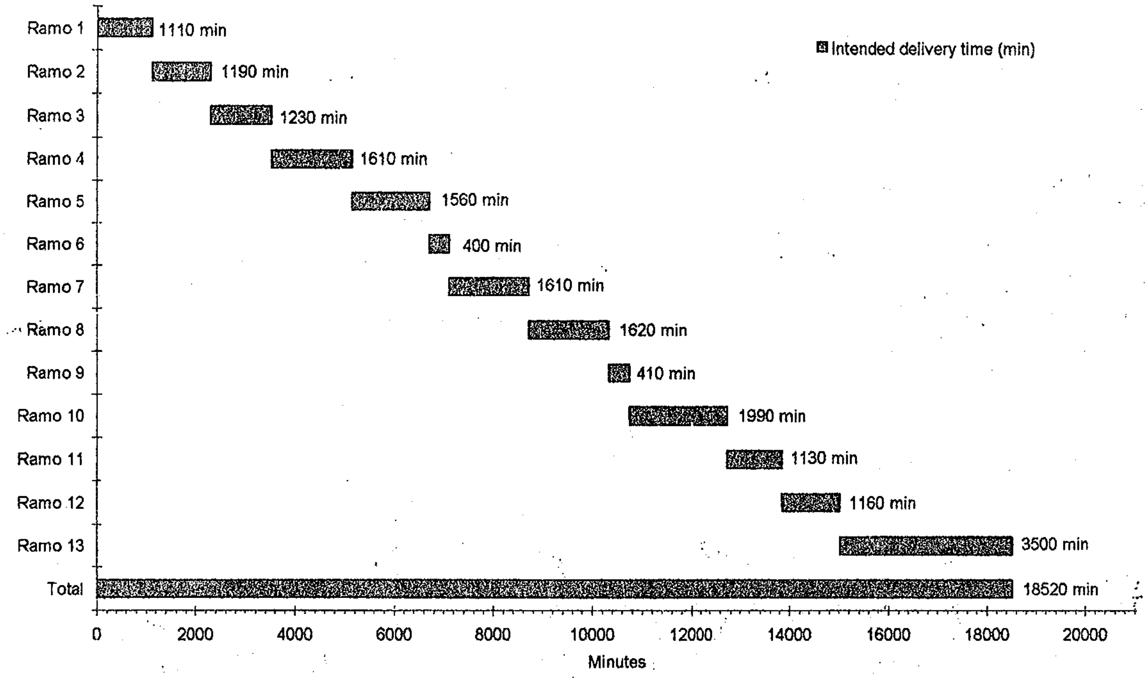

Figure 5 Intended flow delivery schedule from theChivilcoy Canal

As shown in Figure 5, a rotation to all quaternary units is completed in almost 13 days (18 520 minutes). Because only one farm receives water at the same time, and because the total area with water rights is A_{red} = 1536 ha, the intended water delivery time per hectare approximates 18520/1536 = 12 min/ha.

The actual water delivery to the 13 quaternary units is monitored by 6 weirs and flumes. All structures have a flow rating error of less than 2% (Bos 1976, Clemmens et al (1994). Heads are measured at 15 minutes intervals by pressure loggers. Their location (Figure 4) was selected to suit various purposes:

1 At the head of the 4th Chivilcoy Canal measuring the total inflow. Flow data also is used to calibrate the water delivery model for theMontecaseros canal (Bos et al 1997).
2 At the end of the concrete lined reach of the 4th Chivilcoy. The main purpose of this weir is to evaluate canal seepage. It also measures the flow into the first quaternary canal.
3 At the head of the Los Sauces quaternary canal. This weir is also used to measure seepage downstream of weir N° 2.
4 The weir at Leiva measures flow to the two most downstream quaternary units, and is used to calculate upstream canal seepage.
5 The flume at Fontana measures monthly water delivery to the last quaternary unit from the Cañada Moyano drain.
6 This weir measures the flow delivered to the Blanco farm. It also is used to measure seepage along the unlined Los Sauces quaternary canal (Ramo 5).

The intended level of service of the Montecaseros UA to each group of farmers within the 13 quaternary units is to deliver water according to the time schedule of Figure 5. Hence, the primary indicators for use in measuring predictability of water deliveries are concerned with the duration of water delivery compared to the plan, and the time between deliveries compared to the plan. They are (Bos et al 1993; Bos 1997):

$$Dependability\ of\ Duration = \frac{Actual\ Duration\ of\ Water\ Delivery}{Intended\ Duration\ of\ Water\ Delivery}$$

and

$$Dependability of Irrigation Interval = \frac{Actual Irrigation Interval}{Intended Irrigation Interval}$$

The actual time when a gate is opened and closed is written (in minutes) in the log book of the gate-man of the UA. For several locations the resulting flow rates are monitored by the water level loggers (one reading every 15 min). Comparison of these sources of data show a near 100% accuracy of the handwritten observations. Values of the dependability of the duration of water delivery for three irrigation seasons are shown in Figure 6.

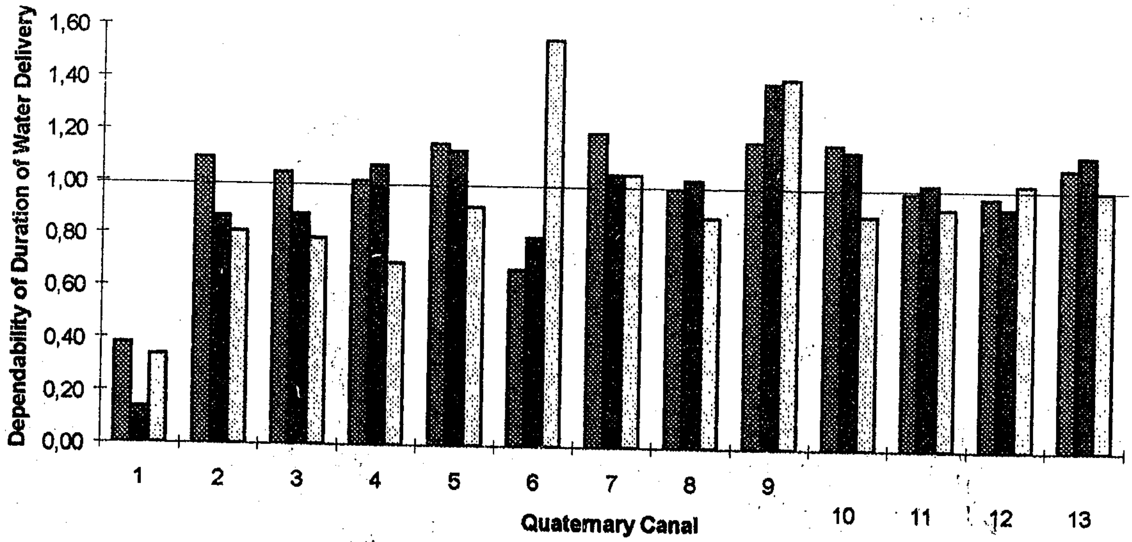

Figure 6 Dependability of water delivery during the 1994 through 1997 irrigation seasons along the 4th Chivilcoy canal.

Figure 6 is based on an intended duration of water delivery being equal to the area with water rights times 12 min/ha. In reality, however, the UA does not (and has not the intention to) deliver water to users who have not paid their water charges. This particularly is the case in the 1st quaternary units where a major area is abandoned due to water-logging and salinity. Since the lining of the Montecaseros Canal (1995 and 1997 canal closure periods), the groundwater table drops and this land can be reclaimed (Bos et al 1998).

In setting the intended rotation schedule, the UA tentatively assumes that flow in the 4th Chivilcoy canal is constant; both in terms of time and along the canal. As shown in Figure 2, however, the flow rate does vary in time. Also there is seepage from the canal (see Figure 3 for the location of flow measuring flumes). Hence, downstream users receive a lower flow. Measured seepage along the Chivilcoy canal is rather constant and thus predictable. It adds up to about 4% of the total flow at the head of the canal, being about 33000 m^3 per cycle of 13 days. As will be shown later (Table 4), additional water seeps from the unlined quaternary canals. Hence, downstream quaternary units receive up to 7% less flow.

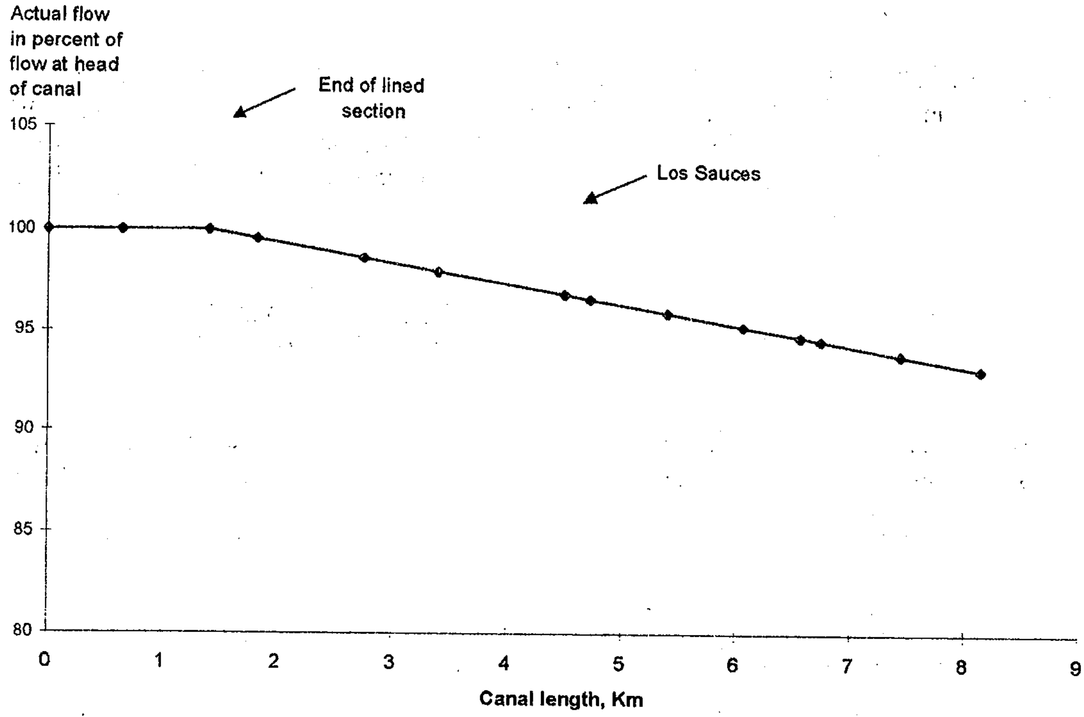

Figure 7 Influence of measured seepage on flow rate into quaternary canals

The dependability of the interval between irrigation water delivery is larger than 1.0 because DGI shuts down the water supply during public holidays, following rain event of more than 50 mm (as in the service agreement) and in case of emergency repairs of canals and related structures. Because the sequence of water delivery is not changed following such a closure period, the interval between water delivery is increased with the period that the related canal was closed. Hence, the actual interval will be longer than 18520 minutes as intended along the Chivilcoy canal (Figure 5). Figure 7 shows the dependability ratio for the 1995-96 irrigation season. A comparison of Figure 2 and 7 shows that all relatively high ratios can be explained by rain events (11-10. 2-1, 26-2, 11-3, and 9-4) or by damage to the canal system (4-12). Hence, the actual canal operation is better than suggested by the average dependability (1.15) and its standard deviation ($s = 0.26$).

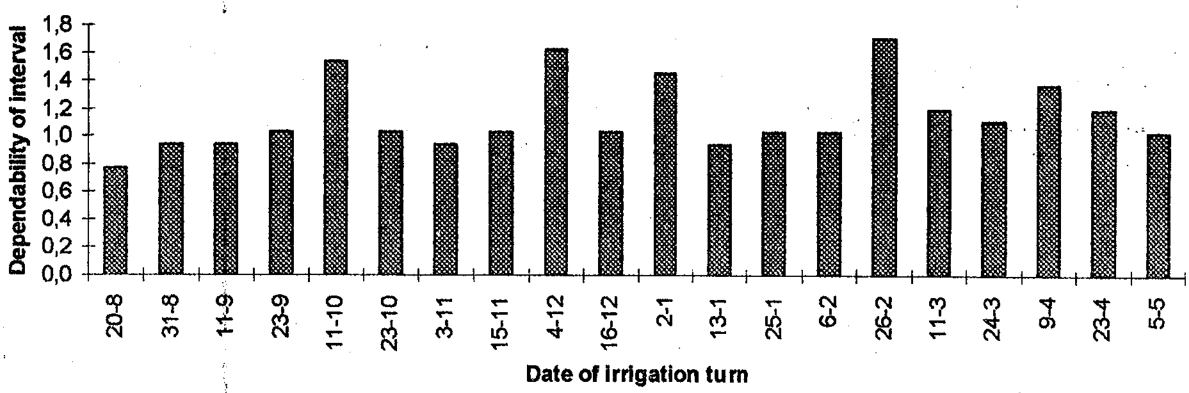

Figure 8 Dependability of the irrigation interval for the 1995-96 irrigation season

In addition to the dependability of water delivery in terms of timing, it is strongly recommended that the predictability of the volume of water delivered per irrigation turn (and per season) be included in this part of the assessment. To assess the performance of the UA in delivering an equal level of service to (a group of) farmers we use the concept of water delivery performance. It is defined as (Clemmens and Bos 1990; Bos et al 1991; Bos et al 1993; Bos 1997):

$$\text{Water Delivery Performance} = \frac{\text{Actually Delivered Volume of Water}}{\text{Intended Volume of Delivered Water}}$$

This indicator enables a manager to determine the extent to which water is delivered as *intended* during a selected period and at considered locations. Figure 8 shows average WDP values for the 1994/95 through 1996/97 seasons.

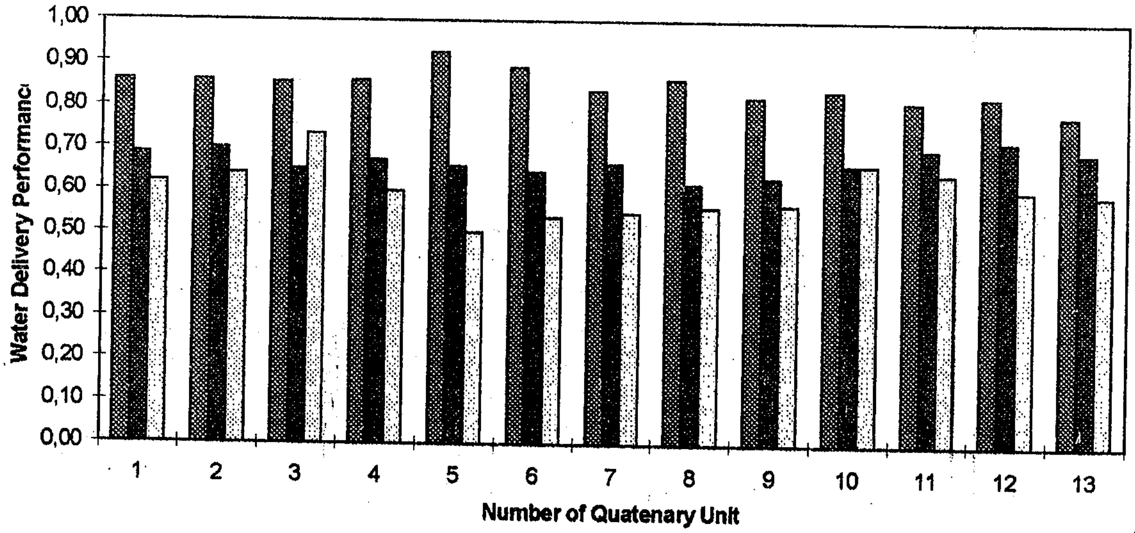

Figure 8 Water Delivery Performance along the 4th Chivilcoy canal for the 1994 through 1997 irrigation seasons

The Water Delivery Performance of Figure 8 gives a more accurate indication on variation in 'service delivered' (water received by the water user) than the dependability indicators of Table 2. Obviously. flow data must be available to calculate the WDP. Based on the systematic difference between the WDR for various quaternary units. the UA is reviewing the water delivery schedule for the 1997-98 season.

Water Delivery to Farmers

The Los Sauces quaternary canal serves 18 farms with a total area (with water rights) of 107.4 ha (Figure 6). The unlined canal distributes water with the on-off system. In other words; all water entering the canal is delivered during a pre-set period to one farm. As mentioned before. the period of water delivery is related to the 'paid water rights'. For the 4th Chivilcoy tertiary unit this equals 12 minutes per hectare per turn. For example. the farmer Escudero pays water rights for 5 ha (always rounded-off to whole hectares).

He thus receives water during 60 minutes. Also. farmers with water rights for less than 2 ha. receive water during 24 minutes. The rounding-off practice provides relatively more water to small farms. The intended water delivery time is shown in Table 3.

Random measurements have shown that the actual duration of flow into the farm inlets is close to the intended delivery period. Gate opening & closure always is closely attended by two or three persons; the gate-man of the UA. the irrigator going to receive water. and (commonly) the irrigator who is going to end his turn. Because of this high dependability of water delivery we may use the intended delivery time to calculate actual volumes of delivered water.

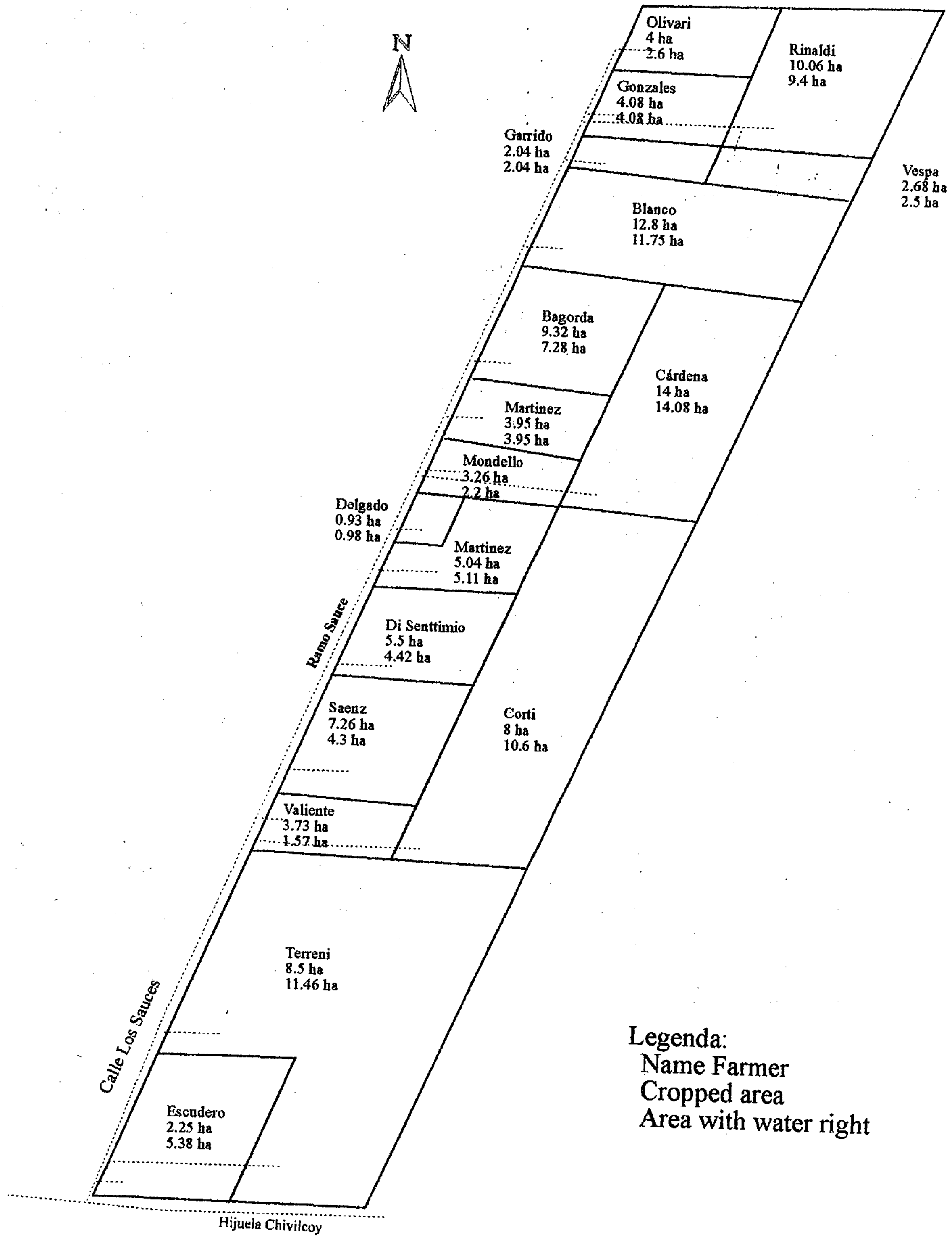

Figure 9 Location of farms and related farm inlets along the Los Sauces quaternary canal

The sequence of water delivery to farmers differs per turn: one time the most upstream farmer (Escudero) receives water first. the next time the most downstream farmer (Olivari) receives water first. To deliver water to the most downstream farmer. the entire quaternary canal needs to be filled first. This filling takes about 120 minutes ($v \cong 0.4$ m/s). When the upstream farmer receives water first this filling period is added to the intended delivery time of 12 min/ha. Hence. water delivery is switched after 13 min/ha (see Table 3).

The intended water delivery in Table 3 is based on the measured flow at the head of the Montecaseros Canal. which the UA intends to deliver in equal shares to all water users. The actual delivered flow is based on measured flow at the head of Los Sauces canal minus seepage in between this weir and the farm inlet. Average seepage is measured by subtracting the measured flow into the Blanco farm from the flow at the head of the canal. Seepage averages 1.25% per km of the quaternary inflow or about 1500 m^3/turn. Similar data are available for other irrigation turns during the 1994/95 and 1995/96 irrigation seasons.

Table 3 Example of Water Delivery along the Los Sauces quaternary canal for an irrigation turn starting at the downstream farm (starting 3 January1996)

Name of Water User	Area with Water Rights. ha.	Irrigated Area per Turn. ha	Distance from head of Canal km	Time of Gate Opening h:min	Intended Water Delivery Period. minutes	Actual Water Delivery Period. minutes	Measured Flow at Loss Sauces m3/s	canal seepage 1.25% per km	Corrected Flow at farm Inlet. m3/s	Intended Flow According to UA. m3/s	Actually Delivered Volume. m3/turn	Actually Delivered Depth. mm/ha	Intended Volume Delivered. m3/turn	Intended Depth delivered mm/ha	Wat Deliv Perf man
Escudero	6	2.00	0.03	19:45	72	78	0.67	0.00	0.67	0.94	3 135	157	4 394	220	0.7
Terreni	12	4.00	0.65	21:03	144	156	0.77	0.00	0.77	0.94	7 169	179	8 789	220	0.8
Corti	12	4.00	1.10	23:39	144	156	0.65	0.01	0.64	0.94	5 992	150	8 789	220	0.6
Valiente	2	0.67	0.75	2:15	24	26	0.81	0.01	0.80	0.91	1 249	187	1 427	214	0.8
Saez	5	1.67	0.90	2:41	60	65	0.86	0.01	0.85	0.91	3 306	198	3 568	214	0.9
Disentimio	5	1.67	1.15	3:46	60	65	0.86	0.01	0.85	0.91	3 297	198	3 568	214	0.9
Martinez	7	2.33	1.35	4.51	84	91	0.84	0.02	0.82	0.91	4 496	193	4 996	214	0.9
Cardenas	18	6.00	1.85	6:22	216	234	0.79	0.02	0.77	0.91	10 795	180	12 846	214	0.8
Delgado	1	0.33	1.45	10:16	12	13	0.74	0.02	0.72	0.91	565	169	714	214	0.7
Mondello	4	1.33	1.55	10:29	48	52	0.74	0.02	0.72	0.91	2 256	169	2 855	214	0.7
Martinez	5	1.67	1.85	11:21	60	65	0.72	0.02	0.70	0.91	2 740	164	3 568	214	0.7
Bagorda	8	2.67	1.80	12:26	96	104	0.74	0.02	0.72	0.91	4 498	169	5 709	214	0.7
Blanco	14	4.67	2.05	14:10	168	182	0.72	0.02	0.70	0.91	7 631	164	9 991	214	0.7
Garrido	2	0.67	2.25	17:12	24	26	0.74	0.02	0.72	0.91	1 116	167	1 427	214	0.7
Vespa	3	1.00	2.75	17:38	36	39	0.72	0.03	0.69	0.91	1 616	162	2 141	214	0.7
Rinaldi	12	4.00	2.80	18:17	144	156	0.77	0.03	0.74	0.91	6 924	173	8 564	214	0.81
Gonzales	6	2.00	2.35	20:53	72	78	0.79	0.03	0.76	0.91	3 572	179	4 282	214	0.8
Olivari	5	1.67	2.43	22:11	60	65	0.79	0.03	0.76	0.91	2 971	178	3 568	214	0.8
Total	127				1524	1651					73 328		91 198		
														Average:	0.81
														Standard Deviation:	0.07

As mentioned above. either the upstream or downstream farmer along the quaternary canal receives water first during alternate irrigation turns. Table 4 gives the average of the Water Delivery Performance (WDP) to each farm for the two delivery sequences. The shown values are averages of measured values during the 1995-96 irrigation season. No significant difference is shown between the two WDP for the two delivery sequences

Table 4 Water Delivery Performance along the Los Sauces quaternary canal for upstream and downstream start of water delivery.

Farmer along Quaternary Canal	Turns Starting Upstream		Turns Starting Downstream	
	Average	Standard Deviation	Average	Standard Deviation
Escudero	0.69	0.13	0.58	0.16
Terreni	0.71	0.12	0.71	0.18
Corti	0.71	0.14	0.78	0.20
Valiente	0.84	0.17	0.80	0.20
Saez	1.79	0.37	1.13	0.24
Disentimio	0.84	0.15	0.84	0.18
Martinez	0.99	0.16	1.15	0.24
Cardenas	0.76	0.14	0.76	0.15
Delgado	0.64	0.11	0.65	0.13
Mondello	1.42	0.27	1.39	0.28
Martinez	0.71	0.14	0.69	0.14
Bagorda	0.85	0.15	0.81	0.16
Blanco	0.70	0.12	0.69	0.14
Garrido	1.40	0.25	1.23	0.25
Vespa	0.46	0.08	0.80	0.17
Rinaldi	0.68	0.13	0.64	0.14
Gonzales	0.57	0.10	0.58	0.13
Olivari	0.51	0.08	0.60	0.14
Grand Average:	0.85		0.82	
Standard Deviation:	0.35		0.24	

Conveyance Ratios

Over a sufficiently long time frame (e.g. a month. or over three or four rotational time periods). it can be assumed that; if the Water Delivery Performance (*WDP*) is close to unity, then the water management inputs must be effective. The related water balance ratio can then be high without causing any water shortage to some of the farmers. The effectiveness (uniformity) of water delivery can be quantified by the standard deviation of the *WDP;* hence, by the standard deviation of the measured $V_{f.actual}/V_{f.intended}$ values to outlets in the considered command area (irrigation unit).

A target volume of water per selected period (e.g. m^3/turn) that should be delivered to a group of water users in one irrigation unit depends on:

- The value of the above standard deviation (s) of the WDP.
- The interpretation of the concept "level of service" between the UA and the farmers. In this context this boils down to the volume of water that is intended to be delivery by the UA to the farmers along a canal. In other words. which part (F in %) of the farms may receive less water than they need to meet all water requirements. It further depends on:
- The seepage from the considered water distribution system $V_{d.seepage}$.

Taking the above points into account, the summed target flow (or volume of flow over a considered period) serving a group of field off-takes equals

$$V_{d.target} = (1 + s\ T_p)\ x \sum V_{f.i.intended} + V_{d.seepage}$$

The standard deviation. s, and the intended flow to be delivered to the i-th off-take, $V_{d.i.intended}$. were defined above. Values of T_p versus F are listed in Table 6. For example, if we assume that 25% of the farmers receive less water than intended, the T_p-value is 0.67. Substituting the values of Table 3 into this equation yields for the considered irrigation turn

$$V_{d,target} = (1 + 0.07 \times 0.67) \times 91198 + 1747 = 97299\, m^3$$

This volume of water exceeds the actual delivered volume for two reasons; because different farmers receive less water each turn, a percentage of 50% is accepted by the farmers so that a T_p-value of 0 can be used. Secondly, the UA ignores seepage in between Perupato and the farm inlet and assumes that there is no mislocation of water along theMontecaseros canal.

Table 6 Values of T_p versus F

F *(in %)*	T_p *(dimensionless)*
50	0
25	0.67
10	1.28
5	1.64
2.5	1.96
1.0	2.33

For the irrigation turn starting 3 January 1996. the average Water Delivery Performance (*WDP*) was 0.81. Hence. farmers receive 19% less water than the UA intends to deliver on the basis of the inflow at Peropato. being the head of the canal system managed by the UA. The difference is due to misallocation of water (Bos et al 1998), seepage and leakage upstream of the Los Sauces intake, and because of seepage along Los Sauces. The effectiveness (uniformity) of water delivery can be quantified by the standard deviation of the *WDP* within the (tertiary) irrigation unit; hence, by the standard deviation of the measured $V_{f.actual}/V_{f.intended}$-values within the unit, which is $s = 0.07$. Values of $s < 0.1$ indicate a very uniform water delivery. The timing of the flow into the farm inlets is very accurate. Gate opening and closure is always closely attended to by two (or three) persons; the gate operator. the irrigator who is going to receive water. and (commonly) the irrigator who is about to end his turn. Thus, to reduce the standard deviation the inflow at the head of the canal should become as constant as practical.

With respect to the conveyance ratio,. let us consider the measured water delivery during the turn of Table 4. The distribution ratio quantifies. in this example. the water balance of the quaternary system. For the Los Sauces Canal. this ratio equals

$$R_{d,Sauces} = \frac{\Sigma V_{fi}}{V_d}$$

The volumes can be taken from Table 3. The measured inflow at the Los Sauces Canal equaled 75075 m^3 during the duration of the turn (1651 min). The total delivered flow was 73328 m^3. Hence. the conveyance ratio of this 3.3 km long quaternary equals

$$R_{d,Sauces} = \frac{73328}{75075} = 0.98$$

Due to the accurate timing of the on-off method of water delivery there is negligible misallocation of water along the canal (Table 3). Hence, the only water losses are due to seepage (about 1750 m^3 per turn). In fact, this seepage only causes a problem in the upstream part of Chivilcoy where the groundwater table is shallow and salinity causes yield reductions. More downstream, however, this water can be reused again.

Discussion

As shown in Table 1, the average value of the dependability of the irrigation interval remains rather constant from year to year. However, the standard deviation increased too much. The standard deviation depends on the level of technology available to apply water uniformly and on the quality of management and operation by the UA. The latter particularly because water shortage became more serious from year to year. In this context '*too much*' is determined by the relationship

$$\left| Indicator_{average\ value} - Indicator_{target\ value} \right| = s\ T_p$$

The target value for the dependability of the irrigation interval equals 1.0. while the average value and standard deviation s is given in Table 1. For the 1996-97 irrigation season. the above equation yields a T_p value of 0.57. Hence, about 30% of the water users receive water at longer intervals than intended. The percentage of the area (F in %) where an indicator value below its target value is acceptable, depends on local conditions. For example, if $F = 25\%$ is acceptable, the T_p value equals 0.67. Along the Chivilcoy canal, and along its quaternary canals, water delivery is managed in such a way that it does not systematically favor one group of users with respect to others. Farmers know that if they received a bit less water during one turn, they probably receive more next time. Hence, the UA works with $F = 50\%$ without complaints of the farmers.

Conclusions and Recommendations

Water delivery by the Montecaseros UA to the farmers within the Chivilcoy tertiary unit is according to water rights. The total flow supplied to the Chivilcoy canal (varies around 0.8 m^3/s) is rotated according to a predetermined rotational schedule. The timing of each rotation is determined by the UA on the basis of the users ledger. Each users receives a written notification on the next water delivery.

The dependability of water delivery and the water delivery performance show a high degree of uniformity of water delivery to all users. For example, downstream farmers receive an equal share (except seepage) of the available water. If less water is available, the burden is equally shared by all users.
The system of gate opening and closure, and the related social control by the farmers, has resulted to very accurate timing of flow duration to each farm inlet. If the flow rate would be constant, this also would result to a very accurate distribution of the available water to all farms. The water delivery performance can be improved by making the inflow at the head of the Chivilcoy canal as constant as practical and by correcting allocation times by upstream seepage.

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