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Water delivery performance in the Doroodzan Irrigation Scheme, Iran

SAMAD SANAEE-JAHROMI[1], HERMAN DEPEWEG[2] & JAN FEYEN[1]
[1]*Institute for Land and Water Management (ILWM), Katholieke Universiteit Leuven, Leuven, Belgium (E-mail: samad.sanaee@agr.kuleuven.ac.be),* [2]*Section Land and Water Development, International Institute for Infrastructural, Hydraulic and Environmental Engineering (IHE), Delft, The Netherlands*

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Abstract. Delivery performance ratio was used to assess the water delivery performance in an irrigation district in the Doroodzan Irrigation System in Iran. The measurements were applied to three selected irrigation canals and their tertiary outlets during five consecutive irrigation cycles. The canals were located at the head, middle and tail end of the irrigation district.

Performance indicators reveal that the physical system and the management could respond to the delivery of the intended supply. The indicators show a better reliability performance than the equity performance in water delivery at the tertiary outlets. The results from the Doroodzan Irrigation System reveal that the system could not deliver water according to the real crop water requirements. The actual overall efficiency was used to quantify the water delivery performance in terms of deficit and excess water. The equity and reliability performance was illustrated by using the spatial and temporal variation of the expected overall efficiency at the district level.

Key words: Iran, irrigation performance assessment, delivery performance

Introduction

There has been an increasing concern about the performance of irrigation systems in recent years. This is due to the fact that many projects have failed to deliver the level of performance expected (Lenton 1988). This demands for the evaluation of the water delivery performance in irrigation systems. According to Small & Svendsen (1992), the assessment of irrigation performance is clearly important to managers of irrigation projects, but it has been seriously neglected by those who allocate public funds for irrigation, and by researchers.

The delivery system's ability of the Doroodzan Irrigation System in Iran was assessed by the delivery performance ratio during the agricultural year 1997–98. Additional indicators provided information on the spatial and temporal variability performance. The actual and the expected overall efficiencies were used to demonstrate the water delivery performance at the main level.

Methods

Water delivery performance

Water delivery performance is generally defined as the amount of actual water delivered by the system compared to the target amount (Lenton 1984). This concept serves as an indicator of the performance of an irrigation system to monitor productivity and equity. Clemmens (1990) describes a method for evaluating the water delivery performance of a system before rehabilitation. Molden & Gates (1990) describe a number of performance measures for use in the evaluation and design of new or rehabilitated irrigation water delivery systems. Clemmens & Bos (1990) use the statistical relations to express equity, adequacy and reliability by the measurement of actual to intended flows or intended to required flows. Bos et al. (1991) provide the use of the average seasonal values of the ratio of intended and actual volumes of water delivered to the tertiary units in a performance evaluation of a secondary canal of an irrigation scheme. In this study, the operation performance was assessed by the delivery performance ratio while the delivery schedule performance was assessed by the expected overall efficiency.

Delivery performance indicators

The ratio of the amount of water actually delivered to the intended amount of water to be delivered is defined as the delivery performance ratio. The delivery performance ratio is the simplest and yet probably the most important hydraulic performance indicator (Clemmens & Bos 1990; Bos et al. 1991). The relationship between the actual and intended as the major state variables defined in terms of an amount of water Q, can be written as:

$$d = Q_a/Q_I \qquad (1)$$

Where d is the delivery performance ratio (fraction); Q_a is actual discharge and Q_i is the intended discharge. These variables may refer to rate, volume, frequency or duration of water delivery (Molden & Gates 1990).

Delivery system's ability indicator

Adequacy of the supply can be defined as the ability of an irrigation system to meet the required amount of water. Clemmens & Bos (1990) defined the ratio of the actual amount of water delivered to the amount intended as a measure of the delivery system's ability to supply water according to their schedule. They also define the adequacy of delivery in a lateral canal as the portion of outlets (or area) that receive at least the intended amount.

The average delivery performance ratio can be used to indicate how adequate the system could deliver the intended water.

$$a = \overline{X}(d) \quad (2)$$

Where a is a measure of the system's ability and $\overline{X}(d)$ is the average delivery performance ratio along a course over different time periods. A value equal to unity means that on the average, the system is able to deliver the intended amount. Values less than one reveal inadequate portion of the intended for the direct users (insufficient water delivered according to the schedule). But a value greater than one means that extra water than scheduled is being delivered to the area under assessment. This is the water that could have been used productively elsewhere in the system resulting in water shortages in those other areas.

Equity performance indicator

The spatial variability performance indicator reflects the uniformity aspect of water delivery. It measures the equity performance. The spatial variability performance indicator defines the variability in the delivery performance ratio over the time period of interest. The coefficient of variation (*CV*) is used to indicate the degree of this variability.

$$e = CV(\overline{d}_t) \quad (3)$$

Where e is the spatial variability of delivery performance ratio over the time period of interest and $\overline{d}_t$ is the temporal average value of the delivery performance ratio at the tertiary outlet. The value of e, as an equity performance indicator reveals the degree of spatial variability of d. As the value of the indicator comes close to zero, the degree of equity (spatial uniformity) in water delivery is higher.

Reliability performance indicator

Reliability of water delivery in an irrigation system refers to temporal variability. The variation in the delivery performance ratio at any location of the delivery system and over time periods is in fact the temporal variability performance indicator. The coefficient of variation is used to evaluate the temporal variability performance.

$$r = CV(\overline{d}_s) \quad (4)$$

Where r is the temporal variability of delivery performance ratio over a course (reliability performance indicator) and $\overline{d}_s$ is the spatial average value of the delivery performance ratio during the irrigation period. The indicator r is a reliability performance measure and the closer the value of this indicator comes to zero, the more reliable the water delivery becomes over time.

Expected overall efficiency

Calculation of the "actual" efficiency requires the estimation of the actual amount of water being delivered to the crop root zone. If the efficiency of an existing irrigation system is determined on basis of the crop water requirement, and not on the water actually delivered to the root zone, which is consumed by the crop, the expression "expected" should be used for the efficiency (Sanaee-Jahromi & Feyen 1997a). To quantify the expected overall efficiency Sanaee-Jahromi & Feyen (1999a) analyzed different equations relating the in- and outgoing terms of the water balance. Among these equations, the standard form of the overall irrigation efficiency defined by Bos & Nugteren (1983), was used to evaluate the delivery performance in the Doroodzan Irrigation Scheme.

$$Ee_o = (ET_c - R_e(a))/SUPW \tag{5}$$

$$ETc = \sum_{i=1}^{n}(Ai\,ETci) \tag{6}$$

Where SUPW is the amount of water supplied to the whole project in m^3; ET_c is the water required for the consumption of the crops in the whole project in m^3; Ai is the cultivated area by crop i in ha; ETci is the volume of water required for the consumption of crop i in m^3 ha^{-1}; n is the number of crops; R_e(a) is the effective rainfall in the whole project, in m^3 and derived from the actual rainfall; and Ee_o is the expected overall efficiency based on actual rainfall. Instead of actual rainfall, the dependable forecast of rainfall could be used in the calculation of the Ee_o. The expected overall efficiency can be used to assess the adequacy performance.

Materials

The Doroodzan irrigation system

The Doroodzan Reservoir with a capacity of 990 million m^3 feeds the Doroodzan irrigation system, which is located in the north part of the Fars

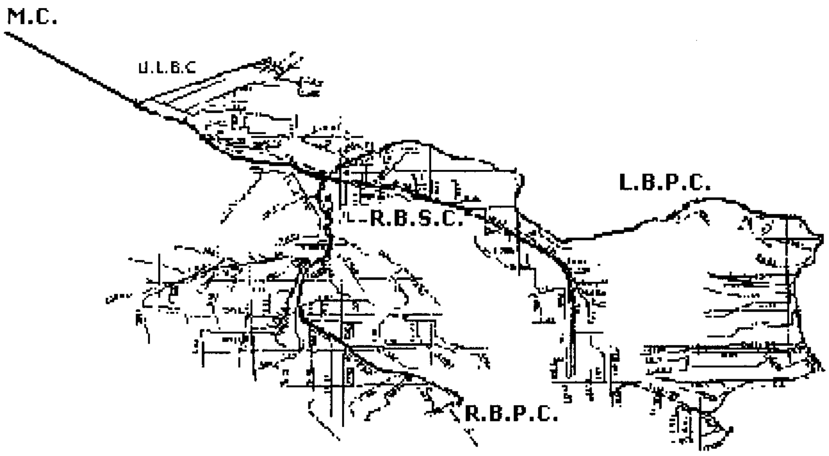

Figure 1. The network of canals in the Doroodzan Irrigation System.

Table 1. Planted area of various crops in the command area in 1997–1998.

Crops	Area in ha	Percentage
Wheat	26539	62.6
Rice	5170	12.2
Corn	5198	12.3
Sugar beet	4110	9.7
Sunflower	591	1.4
Alfalfa	321	0.8
Miscellaneous	493	1.2
Total	42422	100

Province in Iran. The irrigated command area of this modern network is about 42,000 ha with a diversification of winter and summer crops (Table 1). The system consists of four irrigation districts: Main Canal (M.C.), Ordibehesht (R.B.S.C.), Hamoon (R.B.P.C.), and Left Canal (L.B.P.C), with an average cultivated area of 15.5, 15.5, 39 and 30% of the total project area, respectively (Figure 1). Two control structures are used in the system. Radial gates are constructed at the main level to control the water level in the upstream and to regulate the flow in the downstream. The number of 2315 constant head orifices with slide gates is used at the tertiary level to regulate the discharge.

Performance assessment

The operation performance indicators presented in the previous section were used in this study to demonstrate the delivery performance in the Hammon Irrigation District (R.B.P.C.) of the Doroodzan Irrigation System. The decision-makers and the system's management can use the result as a measure of the ability of the system and its management at water delivery with existing facilities. The delivery performance values were calculated on the basis of observations. The expected overall efficiency was used for the overall assessment of the whole system during the agricultural year 1997–1998. Three canals: T25, T27 and T29 were selected to evaluate the operation performance based on the application of the indicators presented before. The canals are located at the head, middle and tail end of the Hamoon Irrigation District, respectively. The delivery performance ratios were computed for nine tertiary outlets of each canal over five irrigation periods during the months of May and June, which are the most important months with respect to the growing stage of the crops and the peak demand. The actual discharge Q_a was measured with current meters. The intended supply Q_i is derived from the delivery schedule for the growing season 1997–1998, which was prepared in advance by the irrigation management of the Doroodzan Irrigation System. The schedule is traditionally prepared according to the contract with the farmers and the area of the cultivation. The water delivery schedule of the project is arranged on a monthly basis. The supply flow is continuos in the main system and is rotational at the tertiary level.

To evaluate the overall performance of the whole system and at the district level the monthly water balance components were used to calculate the values of the expected overall efficiency. Monthly water balance data were derived from Sanaee-Jahromi and Feyen (1999b). Evapotranspiration was estimated using real time climatic data from the meteorological stations in the project area. The data were processed using the CROPWAT program. Data about the cropping pattern were obtained from land surveys. Effective rainfall was estimated from the actual precipitation. The method of USDA (1967) was used to estimate the effective fraction of the rainfall.

The actual overall efficiency (e_o) was used to demonstrate the effect of irregular delivery of water in terms of deficit and excess water. The amount of water received by the crop (RCW) was compared to the crop water requirement (CWR).

$$CWR = ET_c - R_e(a) \tag{7}$$

$$RCW = e_o \cdot SUPW \tag{8}$$

The neutron probe meter was used to determine the soil moisture content for the calculation of the efficiency. Conveyance efficiency in the main system and in the consecutive parts of the conveyance system was determined using the inflow-outflow method. The relationship between the overall efficiency of the scheme, e_o(Sch), and the districts overall efficiency, e_o(Dis), was based on the following equation:

$$e_o(Sch) = e_o(Dis) \cdot e_c(Main) \tag{9}$$

Where e_c(Main) is the conveyance efficiency in the main system.

Results and discussions

Tertiary level

The specific delivery ratios vary per tertiary outlet and per irrigation turn for each canal. A distinct correlation, either spatial or temporal, between these values could not be obtained. Therefore the average values and the spatial and temporal variables of the delivery ratios are used to assess the performance of the scheme.

Figure 2 shows the spatial average value of the delivery performance ratio during five irrigation periods in the three canals. For the overall assessment, the average values depict an adequate delivery of the scheduled water. During the last two irrigation periods the delivery ratio d for canal T25 is more than 1.10, meaning that this canal received at least 10 percent more than the intended discharge. Just in the last three irrigation periods in the canal T29 the average value of the delivery performance ratios is less than 0.90 with a minimum of 0.80. This means that all other cases received more than 90 percentage of the intended amount of water. For the first three irrigation periods the average value of the delivery performance ratios are close to each other in all canals. The management of the irrigation system has to compare the average values and their variations to assess whether the water delivery corresponds with their objectives.

Figure 3 indicates the temporal average value of the delivery performance ratio at the tertiary outlets. This figure reveals the equity performance in the water delivery system at the tertiary turnout level.

The average values of the delivery performance ratios reveal that the water was delivered relatively less than the intended to the last tertiary outlets in all canals. It is also interesting that the delivery performance ratios had the same trend along the three irrigation canals. The average of the delivery ratios for canal T25 and T27 is more than 1, meaning that the canals received more than

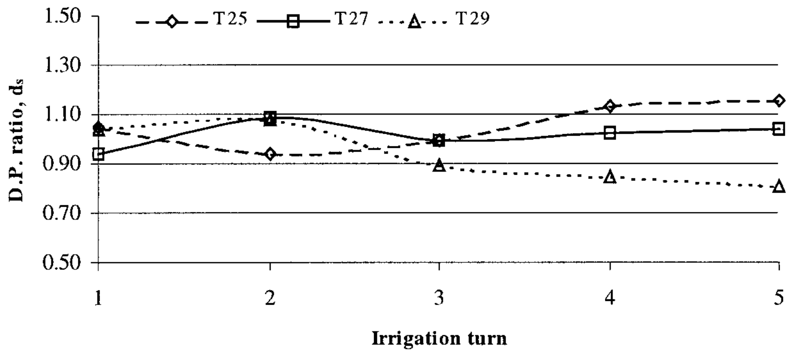

Figure 2. Plot of spatial average value of the delivery performance ratio during the irrigation turns.

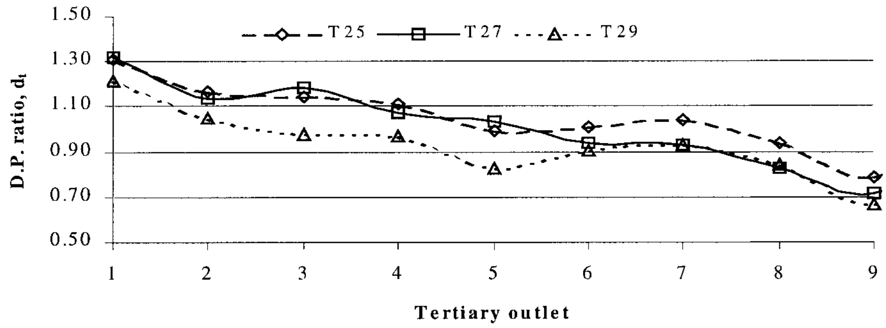

Figure 3. Temporal average value of the delivery performance ratio at the tertiary outlets.

the intended discharge. Canal T29 received less than the intended discharge during the five irrigation periods. Along canal T25 six (out of nine) turnouts received more than the intended supply. In canal T27 this number was five out of nine and in T29 only the two most upstream outlets received more than intended supply. In this canal three outlets received only 0.85 or less from the intended canal supply. In canal T25 the most downstream and in canal T27 the two most downstream outlets received less than 0.85 of the intended supply. This could affect the yield productivity of the farmers.

Figures 2 and 3 reveal the ability of the delivery system not only along the tertiary outlets but also over the canals. This depicts the delivery system's ability at tertiary turnout level and also at tertiary canal level.

The summarized values of the indicators (Table 2) together with Figures 4a & 4b) give a clear picture of the delivery system's ability, equity and reliability performance at tertiary turnout level in the Hamoon Irrigation District. The average value of the spatial variability indicator was calculated as r = 0.08 and the average value of the temporal variability was equal to e =

Table 2. The values of the delivery performance indicators at tertiary outlets

Parameter	Indicator	T25	T27	T29	Average
Ability	**"a"**	1.05	1.02	0.93	1.00
Reliability	**"r"**	0.08	0.05	0.11	0.08
Equity	**"e"**	0.14	0.17	0.16	0.16

a = delivery system's ability indicator = $\overline{X}$(d)
r = reliability performance indicator = temporal variability of delivery performance ratio over a course = $CV\,(\overline{d}_S)$
e = equity performance indicator = spatial variability of delivery performance ratio over the time period of interest = $CV\,(\overline{d}_t)$

0.16. This means that the water was generally delivered more reliable rather than equitable in the irrigation canals.

The values of the indicator (a) depict the common problem of inadequate delivery at the tail end of the system in the Hamoon Irrigation District (Table 2 & Figure 4a). The most adequate delivery of water according to the schedule was in T25 (a = 1.05) comparing to the value of this indicator in canal T29, which is equal to 0.93. Figure 4b reflects the reliability and equity performance in the three canals. The values of "r" show that the water was delivered reliable in the irrigation canals. The best delivery was in the T27, with respect to the reliability performance (r = 0.05). The values of the equity performance indicator presented in the Table 2 reveal that the most equitable delivery was in canal T25 (e = 0.14).

Main level

The monthly water balance components are shown in Figure 5. Figure 5 shows that the most important months for the water delivery are April to September. The values of the expected overall efficiency were computed for the performance assessment at the scheme level. Figure 6 presents the values in the months of April to September during different seasons. The figure can be used as a tool to evaluate the water delivery performance in the total system. High values of the expected overall efficiency reveal water shortage, while low values refer to loss of water. The high values of the expected efficiency in the months of April and Jun imply shortage of water during these months. To avoid water shortage during periods with high values, it is recommended to reduce the outflow of the reservoir during the off-peak months. The value of the expected overall efficiency for the studied agricultural year, is equal to 0.50. The actual overall efficiency of the total system was determined as 0.33 during the growing season 1997–1998 (The official record was 0.36). Comparing the actual overall efficiency and the expected ratio (0.50) suggests

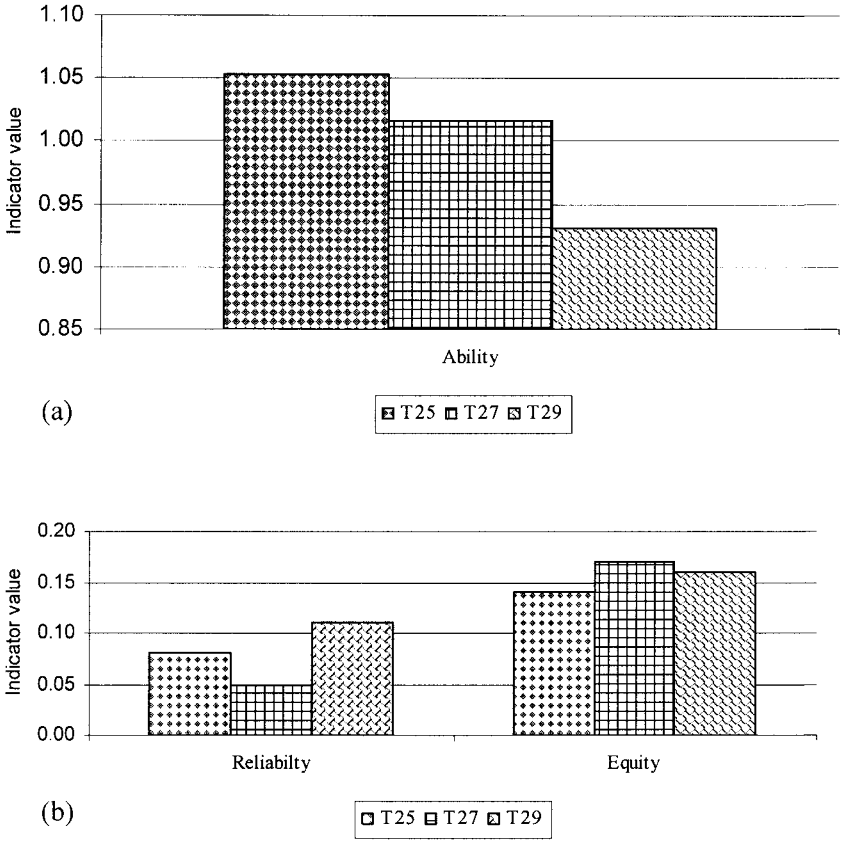

Figure 4. Performance assessment for the canals T25, T27 and T29.

an inadequate supply of water in the Doroodzan Irrigation System during this year. Figure 6 reveals the largest deficiency in water delivery during the month of April. The actual overall efficiency quantifies the amount of deficiency in this month as 35.58 mm. The most adequate delivery of water was in the months of August and September.

The expected overall efficiency, which in fact reflects the adequacy performance, was used in this study to compare the monthly water balance terms in the irrigation districts during the growing season 1997–1998 (Figure 7). This figure illustrates a spatial uniformity of the management performance with respect to the water delivery (CV = 0.15). It gives an indication of the equity performance at district level. The relatively high temporal variation in the expected overall efficiency reflects unreliable performance (CV = 0.77). But the delivery performance was more reliable than equitable at the tertiary

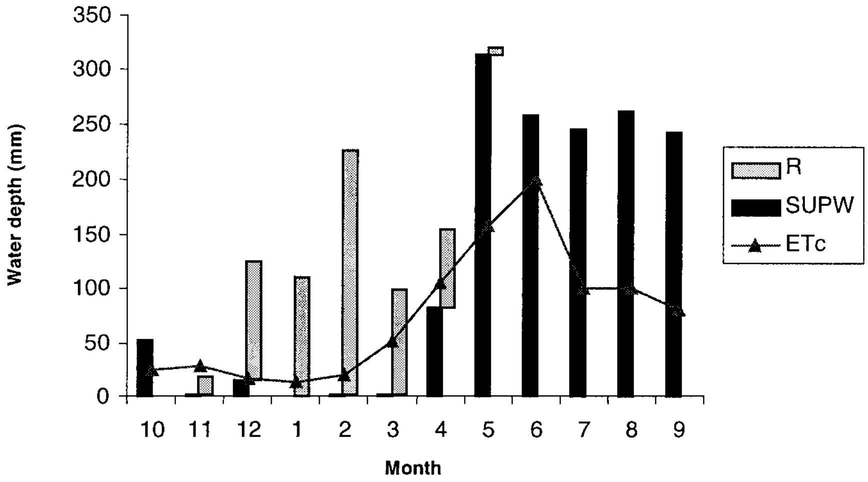

Figure 5. Monthly components of the water balance in the Doroodzan Irrigation System during the hydrological year 1997–1998.

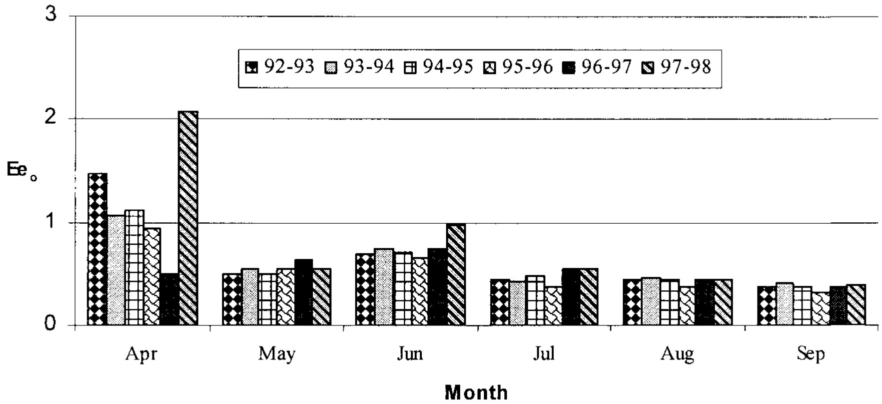

Figure 6. The monthly variability of the expected overall efficiency based on actual rainfall, in the Doroodzan Irrigation System during different seasons.

level in the Hamoon Irrigation District. This means that the results of the reliability and equity performance at the tertiary level can not necessarily give information about the main level. The reasons of better equity performance at the main level and better reliability performance at the tertiary level are related to the spatial and temporal control of the water delivery. The total activity in the main system is under the direct responsibility of the system management. The management can control the allocation of the existing water to the different districts. The poor reliability performance is due to the pre-scheduled delivery and the storage variation in the reservoir that is not

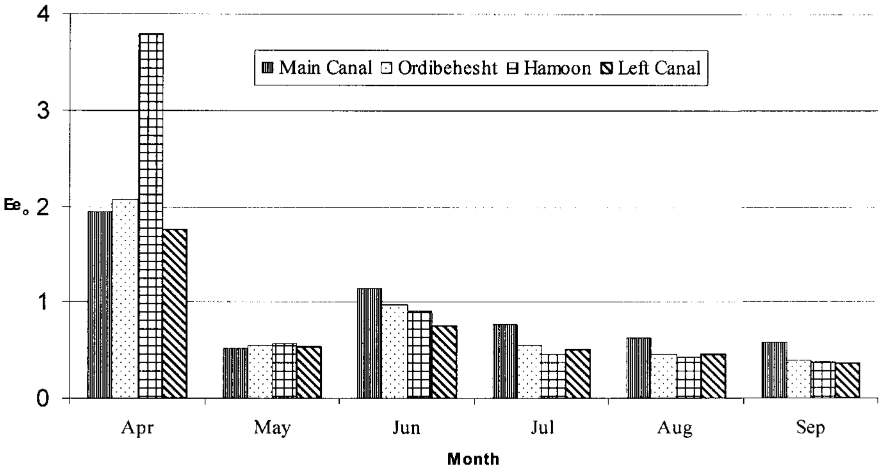

Figure 7. Monthly variation of the expected overall efficiency in the different irrigation districts during April to September in 1998.

under the control of the irrigation system management. This results in a better equity performance at the main level. Moreover, when the water arrived in the irrigation canals the temporal delivery is under the control of the system management. The farmers' interference in the irrigation canals without having enough facilities for the maintenance of the canals affects the spatial delivery. This results in a better reliability performance at the tertiary level. Poor maintenance of the irrigation canals was observed during the measurements of this study.

The effect of irregular delivery of water is demonstrated in Figure 8 in terms of the actual amount of water being delivered as excess and the deficiency of water with respect to the requirement. Figure 8 was constructed using the Equations 7 and 8, applied to the actual overall efficiency in the agricultural year of 1997–1998. The area between the two curves (CWR and RCW) and above the curve CWR is excess water, which means wastage. On the other hand, the area between the curves and below the CWR is deficit that is in fact an indication of depression of yield due to the deficiency of water. The total area should be generally considered as loss due to the irregular delivery of water. Table 3 shows the calculated amounts of deficit and excess water in the total system and in different irrigation districts during this agricultural year.

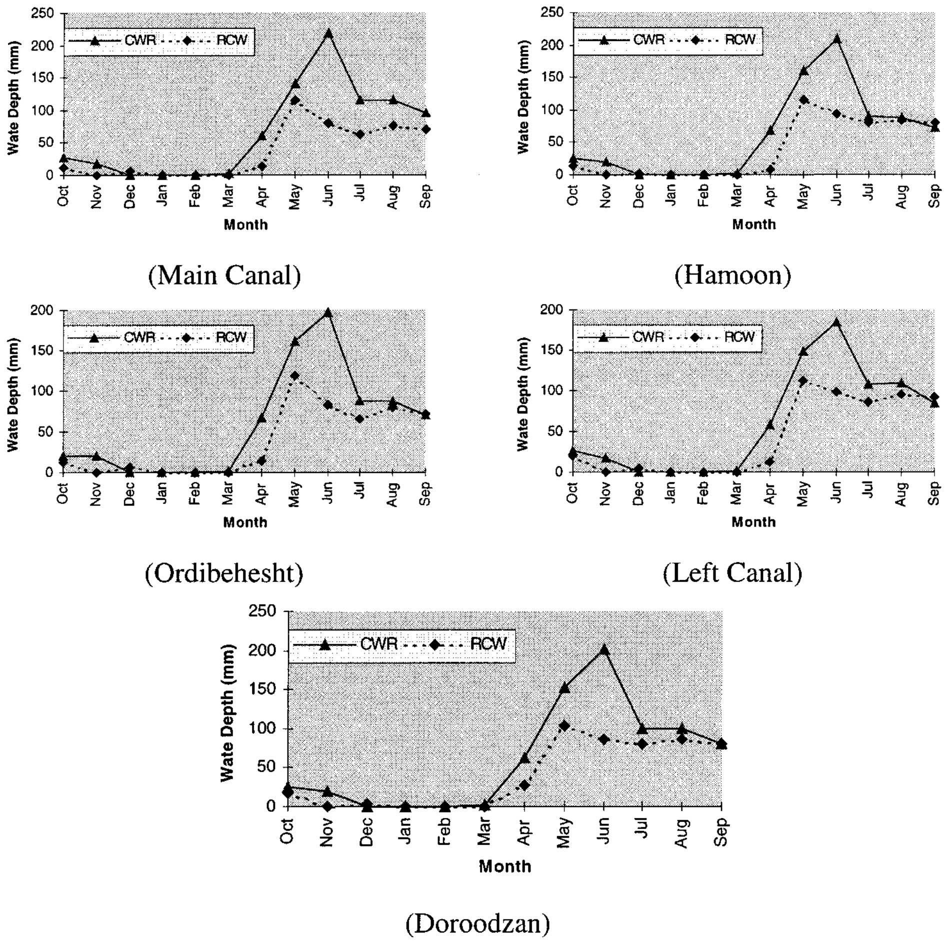

Figure 8. Delivery of water based on the actual overall efficiency in the growing season 1997–1998.

Table 3. The amounts of deficit and excess water in mm during the year 1997–1998

Water loss	Doroodzan System	Main Canal	Hamoon District	Ordibehesht District	Left Canal District
Deficit	260.53	365.55	264.55	270.84	228.26
Excess	4.92	5.63	9.05	7.77	13.34

Conclusions and recommendations

The ability of the irrigation system to supply water according to the intended supply has been evaluated using the delivery performance ratios. This was done at the tertiary level. The overall ability of the system in supplying water according to the crop water requirement was considered by the expected overall efficiency at the total system level and at the district level. The results obtained for the Doroodzan Irrigation System reveal the ability of the system to supply the water with respect to the amount of intended water, but shows the inability of the system to deliver according to the downstream crop water requirement.

The values of the indicators reveal that the physical system and the management performance could relatively well respond to the delivery of intended water. The average values of the delivery performance ratios at tertiary turnout level in the Hamoon Irrigation District show the adequacy in the water delivery performance according to the scheduled amount.

Analysis of the results expresses a better reliability performance than equity performance of the water delivery at the tertiary turnout level in 1997–1998. The recommendation here is to check and improve the operational management or maintenance that sometimes could be a main problem, at the tertiary turnout level. Moreover it is necessary to consider the problem of inadequate delivery at the tail part of the system. The values of the averaged delivery performance ratios for the five irrigation periods in the three canals reveal uniformity in the water delivery at tertiary outlet level and at canal level as well. Without considering the uniformity of spatial and temporal variation of the water delivery at different levels, it is not possible to illustrate a proper assessment of the delivery performance (Sanaee-Jahromi & Feyen 1997b). However, the study depicts the common problem of inadequate delivery at the tail end of the system at both levels.

Both expected and actual overall efficiency can be used to illustrate an overall assessment of the water delivery performance at main level. But, the actual overall efficiency quantifies the amounts of deficit and excess water. The monthly values of the expected overall efficiency show that the system management was not able to prepare a proper water delivery schedule in the growing season 1997-1998. This, might be not only due to an improper scheduling of the water, but also due to the irregularly in the availability of water at the source or operational problems with the multipurpose Doroodzan Reservoir. The recommendation for this problem is to reduce the flow from the Doroodzan Reservoir relatively during the off-peak months. It is also recommended to improve the delivery schedule for the whole system on the basis of the real crop water requirements.

The water was delivered more equitable than reliable at the district level in the year 1997–1998. The different performance of reliability and equity at the tertiary and district levels indicates that the individual results at one level can not necessarily give the same information about the other level.

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References

Bos M.G. & Nugteren J. 1983. On irrigation efficiencies. Wageningen, The Netherlands: International Institute for Land Reclamation and Improvement (ILRI), publication 19.

Bos M.G., Wolters W., Drovandi A. & Morbito J.A. 1991. The Viejo Retamo secondary canal-performance evaluation, case study: Mendoza, Argentina. Irrigation and Drainage Systems 5: 77–88.

Clemmens A.J. 1990. Understanding delivery performance before rehabilitation, irrigation, and drainage. In Proceedings of the 1990 National Conference, Steven C. Harris (ed). American Society of Civil Engineering.

Clemmens A.J. & Bos M.G. 1990. Statistical methods for irrigation system water delivery performance evaluation. Irrigation and Drainage Systems 4: 345–365.

Lenton R.L. 1984. A note on monitoring productivity and equity in irrigation system. In productivity and equity in irrigation systems; Niranjan pant(ed). Ashish publishing house.

Lenton R.L. 1988. IIMI's new Director General: Looking ahead. International Irrigation Management Institute (IIMI) Review 2(1).

Molden D.J. & Gates T.K. 1990. Performance measures for evaluation of irrigation water delivery systems. Journal of Irrigation and Drainage Engineering, ASCE 116(6): 804–823.

Sanaee-Jahromi S. & Feyen J. 1997a. Approach to the evaluation of undependable delivery of water in irrigation schemes. Institute for Land and Water Management, K.U. Leuven, Belgium, Dep. Note ssj/tp/97/101, 25 pp.

Sanaee-Jahromi S. & Feyen J. 1997b. Spatial and temporal variability performance of the water delivery in irrigation schemes. Institute for Land and Water Management, K.U. Leuven, Belgium, Dep. Note ssj/tp/97/102, 23 pp.

Sanaee-Jahromi S. & Feyen J. 1999a. Use of the water balance approach as a tool to evaluate the delivery performance in irrigation schemes. Proceedings of the Conference on Benchmarking Irrigation System Performance Using Water Measurement and Water Balances, San Luis Obispo, CA, USA, March 10–13.

Sanaee-Jahromi S. & Feyen J. 1999b. Assessment of efficiency and dependability performance in irrigation schemes. Proceedings of the 1999 International Water Resources Engineering Conference, ASCE, Seattle, Washington, USA, August 8–12.

Small L.E. & Svendsen M. 1992. A framework for assessing irrigation performance. Working paper on irrigation performance 1. Washington, D.C. International Food Policy Rsearch Institute.

Smith M. 1993. CROPWAT. A computer program for irrigation planning and management. Irrigation and Drainage Paper No. 46. FAO. Rome, Italy.

Smith M., Allen R. & Pereira L.S. 1996. Revised FAO methodology of crop water requirements. Proceeding of the International Conference on Evapotranspiration and Irrigation Scheduling, San Antoni, Texas, U.S.A.

U.S.D.A. Soil conservation service. 1967. Irrigation water requirement. Tech. Release No 21, Engl. Div. SCS. 83 pp.