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Distribution Factor Technique for Water Allocation in Rotational Irrigation

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Abstract: With irrigation water getting increasingly scarce in arid or semi-arid areas many techniques and methods have been implemented and tested to improve the use of irrigation water. The most commonly adopted solution consists of either reducing the quantity of water applied at each irrigation event in proportion to the ratio of available water and crop water requirement or extending time interval between irrigations. Rotational irrigation system has been identified as a practical tool to mitigate the effects of water shortage; however the question often comes up of how to modify a rotational water supply during shortage condition so that crop yield reduction can be kept to the minimum. The ratio demand/supply is a dynamic parameter that must match both crop water stress and physical structures in the irrigation scheme. Farm size, canal length and capacity are the main factors influencing water distribution. Distribution factor (DF) is a double-weighting technique based on the dynamic character of water supply and able to categorize distribution within the limit of channel capacity in order to satisfy crop water requirement. In this study DF technique was applied in the irrigation season 2006 to 2191 ha of paddy field in Chianan Irrigation Association. The results show that if uniform reduction of water supply can be applied in moderate water shortage condition, adjustments can be made using the distribution factor allowing to distribute rationally water among rotational groups in case of severe shortages.

Key words: Rotational irrigation . farm water demand . irrigation requirement . water shortage . distribution factor

INTRODUCTION

Irrigation water becomes increasingly scarce not only in arid and drought prone areas but also in regions where rainfall is abundant [1]. In addition to climate vagaries leading to water shortage, competition with other sectors may prove to be as hard as irrigation cannot sometimes be provided with enough water necessary for proper growth of crops. In these areas, water shortage is a major problem and a limiting factor for irrigation development. Water distribution hence, became a bottleneck for both water supply system and farmers. Farmers are under pressure to grow more “crop per water drop”; so there is an urgent need to find ways to grow more with less water [2]. Therefore, adjustments are required in management practices in order to ensure not only a minimum equity in water allocation and preserve farmers’ reliability but also to cope with the severity of the water shortage. Many improvements have been made to increase water delivery system. These improvements include improved irrigation conveyance and distribution systems that can provide increased flexibility of deliveries and reduced system water wastages, enhanced operation and maintenance, development of new sources of water supplies etc. Since opportunities for large-scale water-supply development are limited, additional water demands must be met largely through conservation and reallocation of existing irrigation supplies [3-6]. Water savings methods become essential for meeting future water needs. Some irrigation managers adopted the method of hedging that consists of applying a sequence of smaller shortages before the impending drought to avoid one severe shortage. In this condition the hard is to quantify the triggering mechanism of hedging rules, including onset, termination and percentage of water reduction [7]. Lund and Reed [8] mentioned that in the Western United States water rationing was a demand management approach frequently used. However, this management practice has not been studied widely. The

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most commonly adopted solution is to reduce the irrigation dose in proportion to the ratio of available water and crop water requirement or enlarge time interval between irrigations in proportion to the inverse of this ratio. The fact is that reducing the amount of irrigation water or extending the irrigation interval sometimes is not in harmony with the physiological development of the plant [9]. The rotational irrigation method has been introduced in many irrigation systems as an alternative water distribution to manage the shortage of water. However rotational irrigation is more complex compared to continuous irrigation as it requires additional managerial inputs in terms of number of gate operations, monitoring points and travel distance of gate operator. For reasonable water distribution in large areas, Kan and Shu [10] proposed an adjusted irrigation plan by lengthening the rotational irrigation periods in no water shortage conditions. This plan allowed good water distribution but it was much limited when under large stresses water supplies considerably decreased. Pasandaran *et al.* [11] used K factor method to cope with minor water shortages. The method becomes less competitive in the case of large water shortage. In addition, water losses considered in this procedure takes into account the total conveyance in the entire command area while occurring losses vary in respect to the water supply during the crop growth stages and the conveyance channels conditions and that the whole area is not irrigated at the same time. Shanti and Pundarikanthan [12] formulated a multi-criteria mathematical model for irrigation canal scheduling with rotational distribution which includes the objectives of achieving minimization of gate operations, equity, adequacy and timeliness. These multi-objectives of water distribution were expressed in terms of measurable criteria on a weight basis and they in turn form the basis for design of the scheduling model. The force of the model was well observed when the distribution canals were sufficiently larger in number and varied in discharge capacity. The objective of the current study is to suggest a technique that can improve water use by categorizing the distribution under changing water supply within the canal capacity as to satisfy crop water requirement. The technique is constructed based on a double-criteria technique namely farm size and canal length. The technique is based on the dynamic character of water supply, taking into account the actual availability of the resources subject to temporal depletions.

MATERIALS AND METHODS

Site description

Location, climate and soil: Located at 23°13’SZS’, 120°11'E, Chianan Irrigation Association (CIA) is the largest of the 17 irrigation associations in Taiwan. In 2007 its total irrigated area was about 64066 ha. The area belongs to a subtropical climate and has an annual average temperature ranging between 21 and 24 degrees Celsius with an evaporation of 3.5 mm/day. The composition of soil (Table 1) based on the classification from textural triangle is loam soil with 34.94% sand, 47.95% silt and 17.11% clay.

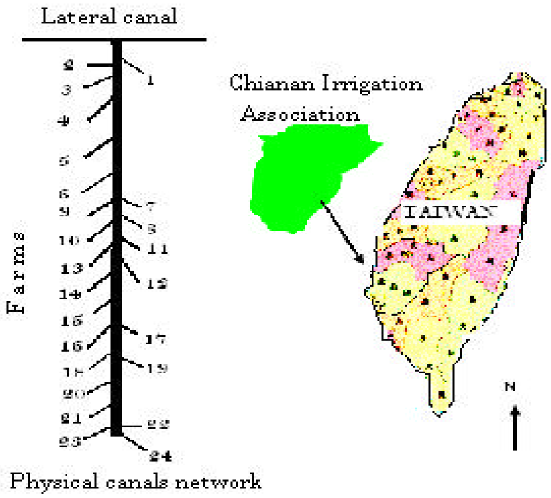

Fig. 1: Location of Chianan irrigation association and physical canal network

Chianan Irrigation Association witnesses an average annual rainfall of 2500 mm, of which 80% is concentrated in the wet season from May to October. In general farmers had two growing season of paddy rice of which the first season is from mid-December to the end of April and the second season from June to October. The site under consideration consists of a set of rice farms supplied by one lateral canal that belongs to the southern main canal of Wushantou reservoir.

Data collection and computation: Data related to crops were obtained from Irrigation works stations. Climatic data were provided by the Regional Weather Services. Reference evapotranspiration (ET_O) was calculated on a monthly basis using the Penman-Monteith method [13]. Rice coefficients (Kc) developed using FAO guidelines were in use for long time in Chianan Irrigation Association. Monthly net crop water requirements were calculated using CROPWAT FAO, 1992. Net crop irrigation requirement was computed as the difference between crop evapotranspiration (*ET*c) and effective rainfall (ER).

Chianan irrigation practice: Generally the association prepares irrigation schedule for the different irrigation districts based on integrated consideration of crops,

Table 1: Soil texture and soil physical characteristics at the Chianan experimental station

	Soil depth (cm)					
	0-10	10-20	20-30	30-40	40-60	
Soil texture	Silt-loam	Silt-loam	Silt-loam	Silt-loam	Loam	Average
Parameters						
Bulk density (g/cm^3)	1.37	1.54	1.60	1.56	1.52	1.52
Saturation content (% of dry weight)	31.40	31.90	33.05	32.80	31.70	32.17
Field capacity (% of dry weight)	24.80	20.20	20.40	21.90	19.50	21.40
Wilting point (% of dry weight)	5.98	6.31	6.37	5.90	5.84	6.08

soil, climates and hydrologic conditions. The schedules are subject to adjustments depending on the local conditions in growing seasons of each year. Both upland crops and paddy crops are grown in the region. Rice, sugar cane, sweet potato, peanut, soybean, corn and sorghum are the main crops grown in the area. As the Association is a water shortage area, rice cropping pattern includes double-rice cropped cultivation, single rice-cropped cultivation, three years-two rice cultivation, rice rotation with other crops and cane crop.

Irrigation and drainage systems: The irrigation water is released from Wushantou reservoir and conveyed in leading canal, the laterals, sub-lateral, down to the farm level ditches and finally delivered to farmland. The drainage water is collected from farmlands in farm drains, discharged into the drains at various levels and eventually into the natural streams. In order to facilitate irrigation management the Association land was divided into 673 irrigation groups of about 150 ha each group based on the categories of systems, topography etc. Each group was divided into three sub-groups of which each is further divided into several blocks.

Distribution factor technique for irrigation water allocation: As in any irrigation system water distribution through canals system consists of canals network that include water resources system, conveyance system, distribution system and drainage system. Conveyance system consists of main and secondary canals that may be or not lined while distribution network including sub-lateral canals and ditches is in the major case earthen canals. Regardless the weather conditions and owing to the losses occurring during the transit the amount of water diverted from the source becomes smaller and smaller till it reaches the farm unit. The model is constructed based on a double-weighting criterion related to farm size and the length of canal serving this unit farm.

Determination of the double-weighting factor and water loss coefficients: Unlike the pressurized systems of which water losses are more or less mitigated, canals irrigation systems record a significant loss of water due to the nature of the flow from the canal to the underlying aquifer system [14]. In addition, losses occur due to evapotranspiration from water surfaces and the effect of trees and other vegetation along canals and seepage due to hydraulics structures condition. Even the application of water to the field plot is likely to lead to losses unless if it is controlled very carefully. As losses vary from farm to farm and in relation to the distance from the water supply intake, evaluation of water losses in the farm plot requires to take into account coefficients losses related to farm size and distance of transport. Two weighting factors are defined to characterize water losses at farm unit and irrigation canals. The weighting factors Ka and K_L are assigned to each farm unit considering farm size and channel length, respectively. Water loss measurement is based on the variation of water entering the canal Q_{in} and water exiting the canal Q_{out}. By measuring these two discharges on a given portion of canal length with an adequate device such as a flow-meter or propeller-meter we can get the water loss and the ratio of water loss in this portion of length. The conveyance loss factor is defined as the ratio of the water loss in the canal to the discharge entering the canal.

$$S = \frac{Q_{in} - Q_{out}}{Q_{in}} \qquad (1)$$

Where Q_{in} is entering discharge, Q_{out} the exiting discharge. The difference (Q_{in}-Q_{out}) represents the water loss Q_{loss} in at the intake structure or at the farm ditch level. The ratio of the factor S to the area under the entering discharge Q_{in} is termed the percentage of the experimental field ditch water loss per hectare of irrigated area and is designed by So.

$$S_o = \frac{S}{A} \qquad (2)$$

where A is the area under the entering discharge and S as previously defined. The magnitude of S_o depends on the standard tertiary unit that is decided by each Irrigation agency according to the local conditions. The coefficient obtained by dividing the factor S by the portion length of channel on which measurements are conducted is defined as the percentage of experimental water loss of the conveyance system and designed by C_o.

$$C_o = \frac{S}{L} \qquad (3)$$

where L is the segment of channel under consideration and S previously defined. The values of C_o were experimentally obtained and range between 0.1 and 0.4

Land weighting factor: The land weighting factor K_a is defined as:

$$K_a = \sum_{i=1}^{n} A_i \frac{(\sum_{1=1}^{n} S_i)/n}{\sum_{i=1}^{n} A_i S_i} \qquad (4)$$

and

$$Si = S_o A_i \qquad (5)$$

where *i* is the index of farm unit; S_i is the loss factor in the i^{th} farm unit in respect to the size, *Ai*, the i^{th} farm area; S_o, the percentage of experimental field ditch water loss per hectare of irrigation area, n is the number of the farms units. The coefficient of loss related to the i^{th} farm unit is expressed as:

$$CL_{fi} = S_i Ka \qquad (6)$$

Channel weighting factor: The Channel weighting factor K_L is linked to the average canal lengths in the irrigation service area by the relation:

$$K_L L_m = 1 \qquad (7)$$

Where L_m is the average channel length in the field.

The conveyance loss coefficient from the channel intake (main, lateral or sub-lateral canal) to the i^{th} farm unit is defined as the product of the factor K_L and channel intake water loss.

$$CL_{ci} = C_i K_L \qquad (8)$$

and

$$C_i = C_o L_i \qquad (9)$$

Where CL_{ci} is the coefficient of conveyance loss from the channel intake to the i^{th} farm unit, C_i the coefficient of channel intake water loss to the farm unit, C_o the experimental channel loss coefficient and L_i the length of channel serving the farm.

Field irrigation requirement: The field irrigation requirement is the crop water requirement less the effective rainfall, if any. Moreover, additional irrigation water is needed to compensate the continuous percolation losses in the paddy field.

$$Q_{FIRj} = Q_{CWRj} + Q_P - Q_{Erj} \qquad (10)$$

Where Q_{FIRj} is farm irrigation requirement at the growth stage j, Q_{CWRj}, the crop water requirement at the growth j stage. Q_P is the water losses through deep percolation and Q_{ER} is the effective rainfall at the growth stage j.

Determination of farm water demand: Water demand/supply is the core activity of any irrigation distribution system management. Farm water demand depends on prevailing weather conditions, biological characteristics of the crop, its growth stage and the physical and biological properties of the soil. The farm water demand is the sum of field irrigation requirement and the conveyance losses.

$$Qf_{ij} = A_i Q_{FIRij} + A_i CL_{fi} Q_{FIRij} = Q_{FIRij} A_i (1+CL_{fi}) \qquad (11)$$

Where Qf_{ij} is the water demand for the farm i in the growth stage j, j is the index of growth stage, Q_{FIRj} is the field irrigation requirement at the growth stage j and Ai is the area of the farm i.

The total water demand for the whole irrigation service area at the growth stage j is the sum of the farm demands during this growth stage

$$Qf_j = \sum_{i=1}^{n} Qf_{ij} \qquad (12)$$

Determination of Water demand for the system: During the supply process losses generally occur in conveyance, distribution and application of water. The conveyance loss from channel intake to the i^{th} unit at the j^{th} growth stage is:

$$Ql_{ij} = Qf_{ij} CL_{ci} \qquad (13)$$

Where Ql_{ij} is the conveyance loss from channel intake to the unit i at the growth stage j, Qf_{ij} and CL_{ci} as previously defined. The system water demand for the farm i at growth stage j is the sum of farm water demand and the conveyance losses in the system intake.

$$Q_{Dij} = Qf_{ij} + Ql_{ij} = Qf_{ij}\,(1+ CL_{ci}) \qquad (14)$$

Where Q_{Dij} is total water demand for the farm i at growth stage j, Qf_{ij}, Ql_{ij} and CL_{ci} as previously defined. The conveyance water loss in system intake at the growth stage j is as the summation of conveyance loss from channel intake to the unit at this growth stage

$$Ql_j = \sum_{i=1}^{n} Ql_{ij} \qquad (15)$$

The water demand at the growth stage j for the whole irrigation area is the sum of the total water demand for all farm units.

$$Q_{Dj} = Qf_j + Ql_j = \sum_{i=1}^{n} QD_{ij} \qquad (16)$$

Definition and utility of the distribution factor in irrigation water management: The possibility of supplying as much water to the farm as required during each stage of the growing period depends on the availability of water at the source. This availability varies over the growing season and the quantity of the supply depends on the capacity of the canal that conveys water. In case of severe water shortage this availability might not be beneficial for crop growing if it was to be used for the whole cropped land.

The water distribution factor allows identifying the actual available water to be delivered to the farm and serves to allocate water demand proportionally to the existing supply. It also serves to identify the condition of water availability at each farm. For a given growth stage j, DF is expressed as the ratio of the quantity of the actual available water at the farm gate and the farm water requirement.

$$DF_j = \frac{Q_{aj}}{Q_{fj}} \qquad (17)$$

Where DF_j is the distribution factor for the growth stage j; Qa_j is the actual available quantity of water and is defined as the water supply less the water loss at growth stage j. The water supply is in general decided by the irrigation water delivery office and is dictated by the flow rate of the diverted river or the level of water depth in the reservoir. DF value with respect to the water supplies is of paramount importance. The best conditions could be when DF>1 indicating that supplies are greater than the demands. A good distribution system must work to balance supply and demand maintaining DF=1. Water shortages occur when DF<1. The determination of factor DF for each growth stage allows calculating the quantity of water that can be allocated to the farm unit at the growth stage j with according to supply status. This quantity is computed as:

$$\overline{Q}f_{ij} = DF_j\, Qf_{ij} \qquad (18)$$

Where $\overline{Q}f_{ij}$ is the actual amount of water that can be applied to the farm and DF_j, the distribution factor for the growth stage j. The use of the distribution factor does not allow to irrigate the whole field in case of water scarcity but gives a precious indication of the field fraction to be put watered. The number of rotational groups likely to be irrigated at the same time is visibly expressed when the distribution factor is put into the fraction format. For example the value DF = 0.25 means that the available water can only meet ¼ of the farm water demand. Under this condition the irrigator is required to irrigate only one of the four rotational groups. The method divides the irrigation area into several groups and each group contains several farms. Water is then delivered only to certain groups at once. However, the number of irrigation groups depends on the soil condition particularly the available moisture content and the allowable drought tolerance of crops. Table 2 shows the number of rotational groups to be irrigated at the same time with respect to DF.

The use of DF procedure becomes meaningful as it indicates measures to take under specific water shortage conditions. However, there is a threshold beyond which the technique cannot be applied. The distribution factor limit DF_{lim} defines the value under which the irrigation

Table 2: Number of rotational groups to be irrigated with respect to DF

Shortage state	K value	Rotational groups and distribution procedure
Normal	≥ 0.84	The whole field can be irrigated
Mild	0.79-0.83	4 rotational groups only 3 could be irrigated
moderate	0.56-0.78	3 rotational groups only 2 could be irrigated
Severe	0.43-0.55	2 rotational groups only 1 could be irrigated
Emergency	0.38-0.42	5 rotational groups only 2 could be irrigated

cannot be possible due to the lack of water in the canal and the distribution factor critic DF_{cr} is the value of DF at which the rotation distribution may be launched. The determination of DF_{lim} and DF_{cr} depends on the type of crop, its sensitivity to drought and the soil water content. They might be defined by Irrigation technicians having good knowledge of the relation soil-plant-water. In the case of no limitation of water resource (DF>1), continuous irrigation can be done uniformly with respect to the canal capacity. However, to prevent the probable water shortage improvement of the storage facilities should be done to store the excess water.

RESULTS AND DISCUSSION

The distribution factor is implemented to cope with the frequent water shortages the farmers face in their irrigation conduct. The year 2006 witnessed a big rainfall deficit compared to 2005. The monthly average recorded in 2006 is 160 mm against 277 in 2005 representing a decrease of 42%. Average evapotranspiration ET_O is around 3.6 mm/day.

Fig. 2 shows the monthly variability of precipitation of year 2005 and 2006

Apart from April and November 2006 which exhibited a precipitation increase of 83% and 88%, respectively compared to those in 2005, most quantities of rainfall recorded in 2006 were smaller than those in year 2005.

Irrigation water requirement

Loss coefficients and crop water requirement: Crop water requirement is defined as the total water needed for evapotranspiration, from planting to harvest for a given crop in a specific climate regime, when adequate soil water is maintained by rainfall and/or irrigation so that it does not limit plant growth and crop yield. Crop water requirement depends on the reference evapotranspiration ET_O and crop coefficients. Crop coefficient (Kc) was estimated for each growth stage. Crop water requirement is the product of ET_O by Kc.

$$CWR = K_C ET_O \tag{19}$$

The USDA soil conservation service formula for effective rainfall was used to compute the effective rainfall during year 2006.

$$Q_{ER} = \begin{cases} R\dfrac{125-0.2R}{125} & \text{if} \quad R<250\text{mm} \\ 125+0.1R & \text{if} \quad R>250\text{mm} \end{cases} \tag{20}$$

The field irrigation requirement was computed using equation (10). As soaking for maintaining water level in the field and soil saturation require more water than plant transpiration 1.5l/s/ha of water was added at the stage of land preparation. For deep percolation 4mm/day was maintained during the whole growing period. Table 3 displays the farm irrigation requirement for each crop growth stage.

The different farm areas A_i and the length of canals serving L_i in Table 4 were used to compute loss coefficients CL_{ci} and CL_{fi} based on the experimental farm ditch loss and conveyance coefficients S_o and C_o for which values were 0.005 and 0.1, respectively. The land weighting factor Ka= 0.282 was computed using the formula (4) and equation (7) served to calculate the channel weighting factor $K_L=1.65 \times 10^{-4}$. Farm water demand for each growth period is determined by the equation (11).

System water requirement: The system water requirement at each stage of the growing period consists of water lost during transport and the farm water demand. Equations (13) and (14) were used to compute the conveyance losses and total water demand for each farm unit. Results of computation are presented in Table 5.

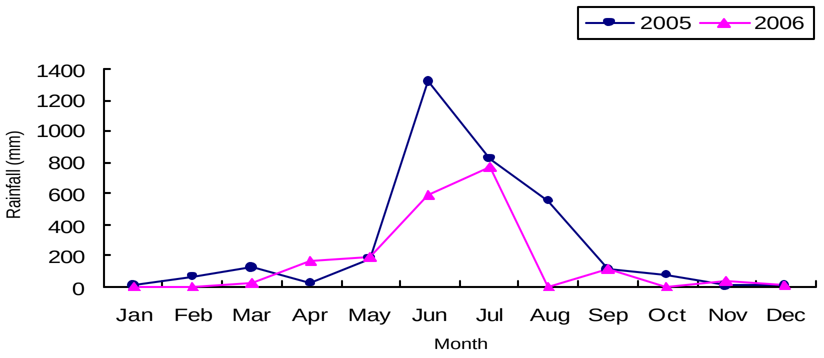

Fig. 2: Monthly variability of rainfall in year 2005 and 2006

Table 3: Paddy field irrigation requirement with respect to growth stage

Growth period	Kc	ETo (mm/day)	CWR (mm/day)	ER (mm/day)	FIR (mm/day)	FIR (l/s/ha)
Land prep.	0.5	2.2	1.10	0.00	5.10	1.74
Tillage1	0.8	2.2	1.76	0.29	5.47	0.63
Tillage2	1.2	2.0	2.40	0.13	6.27	0.73
Flowering 1	1.3	2.0	2.60	0.13	6.47	0.75
Flowering 2	1.3	2.5	3.25	0.14	7.11	0.82
Ripening 1	1.2	2.5	3.00	0.14	6.86	0.79
Ripening 2	1.0	3.1	3.10	0.71	6.39	0.74
Ripening3	0.7	3.4	2.38	0.71	5.67	0.66

Table 4: Determination of coefficients of losses and farm growth stage water requirements

Farm characteristics			Loss coefficients		Farm water requirement (cms)							
No	Length (m)	Area (ha)	[1]CLfi	[2]CLci	[3]GS1	GS2	GS3	GS4	GS5	GS6	GS7	GS8
1	1058	496.1	0.6995	0.0174	1467.27	533.78	611.90	631.37	693.82	669.43	623.56	553.30
2	1843	1.9	0.0027	0.0303	3.32	1.21	1.38	1.43	1.57	1.51	1.41	1.25
3	1851	15.1	0.0213	0.0304	26.84	9.76	11.19	11.55	12.69	12.24	11.41	10.12
4	2655	19.2	0.0271	0.0437	34.32	12.48	14.31	14.77	16.23	15.66	14.58	12.94
5	2733	21.5	0.0303	0.0450	38.55	14.02	16.08	16.59	18.23	17.59	16.38	14.54
6	3288	5.2	0.0073	0.0541	9.12	3.32	3.80	3.92	4.31	4.16	3.87	3.44
7	3651	71.5	0.1008	0.0601	136.97	49.83	57.12	58.94	64.77	62.49	58.21	51.65
8	3655	97.1	0.1369	0.0601	192.12	69.89	80.11	82.67	90.85	87.65	81.65	72.45
9	3638	43.4	0.0612	0.0598	80.15	29.16	33.42	34.49	37.90	36.57	34.06	30.22
10	4098	39.7	0.0560	0.0674	72.96	26.54	30.42	31.39	34.50	33.29	31.01	27.51
11	5050	53.3	0.0752	0.0831	99.73	36.28	41.59	42.91	47.16	45.50	42.38	37.61
12	6010	116.8	0.1647	0.0989	236.74	86.12	98.72	101.87	111.95	108.01	100.61	89.27
13	6301	20.3	0.0286	0.1036	36.34	13.22	15.15	15.64	17.18	16.58	15.44	13.70
14	7077	6.2	0.0087	0.1164	10.88	3.96	4.54	4.68	5.15	4.97	4.63	4.10
15	7078	39.6	0.0558	0.1164	72.76	26.47	30.34	31.31	34.41	33.20	30.92	27.44
16	7730	46.8	0.0660	0.1272	86.82	31.58	36.20	37.36	41.05	39.61	36.90	32.74
17	7730	44.8	0.0632	0.1272	82.89	30.15	34.56	35.67	39.20	37.82	35.23	31.26
18	8447	34.3	0.0484	0.1389	62.58	22.77	26.10	26.93	29.59	28.55	26.59	23.60
19	8447	41.3	0.0582	0.1389	76.06	27.67	31.72	32.73	35.97	34.70	32.32	28.68
20	10240	26.3	0.0371	0.1684	47.47	17.27	19.79	20.42	22.45	21.66	20.17	17.90
21	10645	5.33	0.0075	0.1751	9.35	3.40	3.90	4.02	4.42	4.26	3.97	3.52
22	10893	402.1	0.5670	0.1792	1096.51	398.9	457.20	471.83	518.50	500.27	465.99	413.49
23	10893	38.6	0.0544	0.1792	70.83	25.77	29.54	30.48	33.49	32.32	30.10	26.71
24	10893	504.6	0.7115	0.1792	1502.94	546.76	626.70	646.72	710.69	685.70	638.72	566.75
Total	145904	2191.0			5553.50	2020.30	2316.00	2389.70	2626.10	2533.70	2360.13	2094.20

[1]Coefficient of loss at farm level; [2]Coefficient of conveyance loss from the channel intake to the farm unit; [3]Growth stage

Distribution factor and water allocation strategy: Table 6 summarizes the overall farm demand, system demand and water losses during crop growing stage. The available water provided by the irrigation agency and the distribution factor DF also are shown in last two rows in the table. This available water varies from land preparation to harvest (third ripening) with value of 6250 cms to 1500 cms, respectively. DF was computed using equation (17). For example in the third growth stage DF= (2000-2647)/2316 = 0.75. The distribution factor identifies the available water, indicates areas that must be irrigated all together and distributes the resource in accordance with the request of the farm in these areas. When the supply meets the system water demands there is no need to use the distribution factor and water can be distributed in normal continuous

Table 5: Conveyance loss and system water demand

	GS1		GS2		GS3		GS4	
Farm	conv. loss	syst. dem	conv. loss	syst. dem	conv. loss	syst. dem	conv. loss	syst. dem
1	25.54	1492.81	9.29	543.07	10.99	622.84	10.99	562.93
2	0.10	3.42	0.04	1.24	0.04	1.43	0.04	1.29
3	0.82	27.65	0.30	10.06	0.35	11.54	0.35	10.43
4	1.50	35.82	0.55	13.03	0.64	14.96	0.64	13.51
5	1.73	40.28	0.63	14.65	0.75	16.82	0.75	15.19
6	0.49	9.61	0.18	3.50	0.21	4.01	0.21	3.62
7	8.23	145.20	2.99	52.82	3.54	60.66	3.54	54.75
8	11.55	203.67	4.20	74.09	4.97	85.08	4.97	76.80
9	4.80	84.95	1.74	30.90	2.06	35.49	2.06	32.03
10	4.92	77.87	1.79	28.33	2.12	32.54	2.12	29.37
11	8.28	108.01	3.01	39.29	3.56	45.15	3.56	40.73
12	23.40	260.14	8.51	94.64	10.07	108.79	10.07	98.10
13	3.77	40.11	1.37	14.59	1.62	16.77	1.62	15.12
14	1.27	12.15	0.46	4.42	0.55	5.08	0.55	4.58
15	8.47	81.23	3.08	29.55	3.65	33.99	3.65	30.63
16	11.04	97.86	4.02	35.60	4.75	40.95	4.75	36.90
17	10.54	93.43	3.83	33.99	4.54	39.10	4.54	35.23
18	8.70	71.27	3.16	25.93	3.74	29.84	3.74	26.88
19	10.57	86.63	3.84	31.51	4.55	36.26	4.55	32.67
20	8.00	55.46	2.91	20.18	3.44	23.23	3.44	20.91
21	1.64	10.98	0.60	4.00	0.70	4.60	0.70	4.14
22	196.47	1292.98	71.48	470.38	84.54	541.79	84.54	487.58
23	12.69	83.52	4.62	30.38	5.46	35.00	5.46	31.50
24	269.30	1772.24	97.97	644.73	115.88	742.60	115.88	668.30
Total	634.00	6187.00	231.00	2251.00	273.00	2589.00	273.00	2333.00

	GS5		GS6		GS7		GS8	
Farm	conv. loss	syst. dem	conv. loss	syst. dem	conv. loss	syst. dem	conv. loss	syst. dem
1	12.07	705.90	11.65	681.08	10.85	634.41	9.63	562.93
2	0.05	1.62	0.05	1.56	0.04	1.45	0.04	1.29
3	0.39	13.08	0.37	12.62	0.35	11.75	0.31	10.43
4	0.71	16.94	0.68	16.34	0.64	15.22	0.57	13.51
5	0.82	19.05	0.79	18.38	0.74	17.12	0.65	15.19
6	0.23	4.54	0.22	4.38	0.21	4.08	0.19	3.62
7	3.89	68.66	3.75	66.25	3.50	61.71	3.10	54.75
8	5.46	96.31	5.27	92.92	4.91	86.55	4.36	76.80
9	2.27	40.17	2.19	38.76	2.04	36.10	1.81	32.03
10	2.33	36.82	2.24	35.53	2.09	33.10	1.85	29.37
11	3.92	51.08	3.78	49.28	3.52	45.90	3.12	40.73
12	11.07	123.01	10.68	118.69	9.95	110.56	8.83	98.10
13	1.78	18.96	1.72	18.30	1.60	17.04	1.42	15.12
14	0.60	5.75	0.58	5.54	0.54	5.16	0.48	4.58
15	4.01	38.41	3.87	37.06	3.60	34.52	3.19	30.63
16	5.22	46.27	5.04	44.65	4.69	41.59	4.16	36.90
17	4.98	44.18	4.81	42.63	4.48	39.71	3.97	35.23
18	4.11	33.70	3.97	32.52	3.70	30.29	3.28	26.88
19	5.00	40.96	4.82	39.52	4.49	36.81	3.99	32.67
20	3.78	26.23	3.65	25.30	3.40	23.57	3.01	20.91
21	0.77	5.19	0.75	5.01	0.70	4.67	0.62	4.14
22	92.91	611.41	89.64	589.91	83.50	549.49	74.09	487.58
23	6.00	39.49	5.79	38.11	5.39	35.50	4.79	31.50
24	127.34	838.03	122.86	808.56	114.45	753.17	101.55	668.30
Total	300.00	2926.00	289.00	2823.00	269.00	2629.00	239.00	2333.00

irrigation scheme as long as the canal capacity allows it. This is the case for the growth stage 1 and 2 for which DF equals 1.011 and 1.371, respectively. For the other growth stages, farm water needs cannot be satisfied because supplies are smaller. However, in the condition of mild water shortage (DF= 0.79~0.83) for which theoretically three of the four rotational groups can be simultaneously irrigated, some improvements in the farm unit management and in the irrigation canals network might be done allowing continuous irrigation.

All growth stages except GS1 and GS2 are deficient in terms of water supply. The related values of DF varying from 0.750 to 0.522 give an indication for the action to be taken to cope with the water shortage. They help determine the number of rotational groups to set up and the number of those that can be irrigated at the same time. Accordingly, the area is divided into rotational groups based on the sensitivity of crops (in case of multi-cropping system) and the location of the farms for easier irrigation practice. Based on Table 2,

Table 6: System water demand for the whole growing period

Growth stage	GS1	GS2	GS3	GS4	GS5	GS6	GS7	GS8
System demand	6187	2251	2580	2662	2926	2823	2629	2333
Farm demand	5554	2020	2316	2390	2626	2534	2360	2094
Loss	634	231	264	273	300	289	269	239
Supply	6250	3000	2000	2000	2000	2000	1500	1500
DF	1.01	1.37	0.75	0.72	0.65	0.68	0.52	0.60

Table 7: Farm water allocation using technique of distribution factor DF for all rice growth stages

			GS3			GS4			GS5		
Farm	GS1	GS2	I+II	II+III	I+III	I+II	I+III	II+III	II+III	I+III	I+II
F1	1483.8	731.7	681.6	0.0	868.2	983.8	615.0	0.0	0.0	608.9	980.4
F2	3.4	1.7	1.5	0.0	2.0	2.2	1.4	0.0	0.0	1.4	2.2
F3	27.1	13.4	12.5	0.0	15.9	18.0	11.2	0.0	0.0	11.1	17.9
F4	34.7	17.1	15.9	0.0	20.3	23.0	14.4	0.0	0.0	14.2	22.9
F5	39.0	19.2	17.9	0.0	22.8	25.8	16.2	0.0	0.0	16.0	25.8
F6	9.2	4.5	4.2	0.0	5.4	6.1	3.8	0.0	3.9	0.0	6.1
F7	138.5	68.3	63.6	60.0	0.0	91.8	0.0	60.0	59.0	0.0	91.5
F8	194.3	95.8	89.2	84.1	0.0	128.8	0.0	84.1	82.7	0.0	128.4
F9	81.1	40.0	37.2	35.1	0.0	53.7	0.0	35.1	34.5	0.0	53.6
F10	73.8	36.4	33.9	31.9	0.0	48.9	0.0	31.9	31.4	0.0	48.7
F11	100.9	49.7	46.3	43.7	0.0	66.9	0.0	43.7	42.9	0.0	66.6
F12	239.4	118.1	110.0	103.7	0.0	158.7	0.0	103.7	101.9	0.0	158.2
F13	36.7	18.1	16.9	15.9	0.0	24.4	0.0	15.9	15.6	0.0	24.3
F14	11.0	5.4	5.1	4.8	0.0	7.3	0.0	4.8	4.7	0.0	7.3
F15	73.6	36.3	33.8	31.9	0.0	48.8	0.0	31.9	31.3	0.0	48.6
F16	87.8	43.3	40.3	38.0	0.0	58.2	0.0	38.0	37.4	0.0	58.0
F17	83.8	41.3	38.5	36.3	0.0	55.6	0.0	36.3	35.7	0.0	55.4
F18	63.3	31.2	29.1	27.4	0.0	42.0	0.0	27.4	26.9	0.0	41.8
F19	76.9	37.9	35.3	33.3	0.0	51.0	0.0	33.3	32.7	0.0	50.8
F20	48.0	23.7	22.0	20.8	0.0	31.8	0.0	20.8	20.4	0.0	31.7
F21	9.5	4.7	4.3	4.1	0.0	6.3	0.0	4.1	4.0	0.0	6.2
F22	1108.9	546.8	509.3	480.2	0.0	0.0	459.6	480.2	471.9	455.0	0.0
F23	71.6	35.3	0.0	31.0	41.9	0.0	29.7	31.0	30.5	29.4	0.0
F24	1519.9	749.5	0.0	658.1	889.3	0.0	629.9	658.1	646.9	623.7	0.0
Total	5616.0	2769.0	1849.0	1740.0	1866.0	1933.0	1781.0	1740.0	1714.0	1760.0	1927.0
Loss	5616.0	231.0	151.0	260.0	134.0	67.0	219.0	260.0	286.0	240.0	73.0
Supply	6250.0	3000.0		2000.0			200.0			2000.0	
DF	1.01	1.37	1.11	1.05	1.42	1.56	0.97	1.02	0.91	0.88	1.41

Table 7: Continued

			GS6			GS7		GS8		
Farm	GS1	GS2	II+III	I+III	I+II	I	II	II+III	I+III	I+II
F1	1483.8	731.7	0.0	760.5	678.2	1036.3	0.0	0.0	457.1	733.5
F2	3.4	1.7	0.0	1.7	1.5	2.3	0.0	0.0	1.0	1.7
F3	27.1	13.4	0.0	13.9	12.4	19.0	0.0	0.0	8.4	13.4
F4	34.7	17.1	0.0	17.8	15.9	24.2	0.0	0.0	10.7	17.2
F5	39.0	19.2	0.0	20.0	17.8	27.2	0.0	12.2	0.0	19.3
F6	9.2	4.5	0.0	4.7	4.2	6.4	0.0	2.9	0.0	4.6
F7	138.5	68.3	0.0	71.0	63.3	96.7	0.0	43.3	0.0	68.5
F8	194.3	95.8	0.0	99.6	88.8	135.7	0.0	60.7	0.0	96.0
F9	81.1	40.0	0.0	41.5	37.0	56.6	0.0	25.3	0.0	40.1
F10	73.8	36.4	35.5	0.0	33.7	51.5	0.0	23.1	0.0	36.5
F11	100.9	49.7	48.6	0.0	46.1	70.4	0.0	31.5	0.0	49.9
F12	239.4	118.1	115.3	0.0	109.4	167.2	0.0	74.8	0.0	118.4
F13	36.7	18.1	17.7	0.0	16.8	25.7	0.0	11.5	0.0	18.2
F14	11.0	5.4	5.3	0.0	5.0	7.7	0.0	3.4	0.0	5.4
F15	73.6	36.3	35.4	0.0	33.6	51.4	0.0	23.0	0.0	36.4
F16	87.8	43.3	42.3	0.0	40.1	61.3	0.0	27.4	0.0	43.4
F17	83.8	41.3	40.4	0.0	38.3	58.5	0.0	26.2	0.0	41.4
F18	63.3	31.2	30.5	0.0	28.9	44.2	0.0	19.8	0.0	31.3
F19	76.9	37.9	37.0	0.0	35.2	0.0	48.5	24.0	0.0	38.0
F20	48.0	23.7	23.1	0.0	21.9	0.0	30.3	15.0	0.0	23.7
F21	9.5	4.7	4.6	0.0	4.3	0.0	6.0	3.0	0.0	4.7
F22	1108.9	546.8	533.9	0.0	506.8	0.0	699.4	346.7	341.6	0.0
F23	71.6	35.3	34.5	36.7	0.0	0.0	45.2	22.4	22.1	0.0
F24	1519.9	749.5	731.8	779.0	0.0	0.0	958.7	475.2	468.2	0.0
Total	5616.0	2769.0	1736.0	1846.0	1839.0	1943.0	1788.0	1272.0	1309.0	1441.0
Loss	5616.0	231.0	264.0	154.0	161.0	57.0	212.0	228.0	191.0	59.0
Supply	6250.0	3000.0		2000.0		2000.0			1500.0	
DF	1.01	1.37	1.07	1.14	1.01	1.66	1.50	0.84	0.83	1.33

growth stages GS3, GS4, GS5, GS6 and GS8 fall in the category of moderate water shortage condition requiring three rotational groups of which only two must be irrigated all together while GS7 belongs to the severe water shortage requiring splitting the farm into two rotational groups that can be supplied with water alternatively. When the division into rotation groups is achieved, the related water needs and the system loss are subsequently deducted. A new distribution factor DF is then computed for the projected area to be irrigated permitting to rationalize farm water demands. Table 7 displays the water allocation procedure for each growth stage. For example in GS8 the total quantity of water required by the farm is 2094cms and DF=0.602 indicated that two of three rotational groups should be irrigated at once.

If the divisions are such as the last two groups (II+III) may be irrigated all together (i.e. F5-F24) water loss and DF values are 228 and 0.84, respectively. In the case where the first and the third groups must be irrigated at the same time water loss in the farm and DF are 191 and 0.83, respectively. The grouping for which the first two groups must be supplied together water loss and value of DF are 59 and 1.33, respectively. It can be seen that for the first two grouping patterns i.e. (II+III) and (I+III) the supplies are closer to but still smaller than the demands. Some management improvements and reinforcement of the hydraulics maintenance might help to satisfy farm water demand.

The last division that consists of irrigating the first two groups of farms together and alternatively with the third group shows DF= 1.33 and water loss = 59. The total water need for two groups are 1087.25 but DF yields 1441.42 of water. So a surplus of 354cms or 32.5% of water required by the two groups can be used in the next irrigation turn for the last group. This technique if it is well implemented allows rationalizing the use of water in case of resource scarcity. For the growth stage GS6 three options of groupings for rotational irrigation (II+III), (I+III) and (I+II) shown in Table 7 have DF>1 implies that under this option all the projected water supplies meet farm water demands. Additional water of 7%, 14% and 1% are obtained with option (II+III), (I+III) and (I+II) that can be used in the next irrigation for group I, II and III, respectively.

CONCLUSIONS

Most of irrigation systems face water shortages. Consequently, the allocation and distribution of water become the most important activity. To achieve the goal of rational water delivery, some improvements are essential in water use and irrigation hydraulic infrastructures management. This requires a sound understanding of the complex interaction between the irrigation infrastructures and the management practice that affect the system. Distribution Factor is a useful tool that can be used at the limit of canal capacity and helps address the water shortage problems since it is able to categorize the distribution under changing water supply. According to the results obtained in this case study it was found that even in case of severe water shortage DF helped to distribute rationally the existing resource among the rotation irrigation groups.

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