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FOREWORD

This Volume contains the three papers on Managing Canal Operations that were presented at the National Confernece on Managing Irrigation for Environmentally Sustainable Agriculture in Pakistan held at Islamabad, November 5-7, 1996. These papers are authored by the researchers of IIMI-Pakistan jointly with professionals from collaborating organizations, CEMAGREF in France and the Irrigation and Power Department of the Punjab Province in Pakistan.

ANALYZING THE IMPACT OF ALTERNATIVE OPERATIONAL RULES ON WATER DISTRIBUTION

Marcel Kuper[1], Xavier Litrico[2] and Zaigham Habib[3]

ABSTRACT

The Indus Basin Irrigation System irrigates an area of about 16 million ha in Pakistan, Traditionally, the regulation of irrigation canals aims to distribute water according to the official targets, sharing any shortfall in inflow equitably among the canal commands. Since the demand for water has more than doubled over the years, the irrigation agencies are dealing with a permanent water shortage. On the one hand, farmers try to increase their share, infringing on the concept of equitability. On the other hand, farmers have augmented irrigation supplies by tapping the groundwater, which is increasingly leading to problems of sodification and soil degradation due to the poor quality groundwater.

This study quantifies the impact of the present pressure in the irrigation system on regulation and on water distribution, using a mathematical unsteady state hydraulic model (SIC). The present operational rules were programmed in a regulation module (Gateman) that is linked with SIC, which generates priority orders for the secondary canals. Based on this order and based on the inflow on a given day, decisions are taken which distributaries should be open, which closed and which distributary will absorb the fluctuations. The module further generates the gate settings that are necessary to achieve the target levels and discharges that have been defined, following the present practices of gate keepers. The effect of these gate operations on the water distribution is calculated in SIC. A calibration of the composite model showed an average accuracy of within 5%.

This methodology is applied to the Fordwah Branch Canal and 14 off-taking secondary. canals. The impact of an alternative set of Operational rules on the water distribution is then evaluated, using the combined SIC-Gateman tool. Operational rules relate mainly to the length and timing of rotational programmes, the definition of target discharges during the season, and the operational preferences for canal commands. It is shown that it is possible to better achieve equitability by modifying the operational rules. Redistributing canal water in order to allow farmers to better manage salinity is relatively easy to achieve. System constraints, such as the inflow and the physical condition of the canal system, impose limitations on this improvement.

There is much discussion in Pakistan about modifying irrigation management of the Indus Basin Irrigation System to better fit canal water deliveries with present objectives of a productive, sustainable irrigated agriculture. The methodology that has been developed can be used by system managers to assess a priori the impact of proposed management interventions and lhus contribute to matching ambitions and reality.

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INTRODUCTION

The contiguous Indus Basin Irrigation System irrigates an area of about 16 million ha, diverting annually about 128 billion m^3 of surface water to 43 canal systems. In addition to that, extensive development of groundwater resources for irrigation has taken place over the last 30 years through public and private tubewells. These tubewells are presently providing an estimated 30-40% of the irrigation water at the farm gate (Nespak/SGI, 1991). Cropping intensities originally envisaged to be about 70% have risen to about 130%, while farmers have changed to producing high yielding varieties (HW) since the Green Revolution, putting a lot of stress on the scarce surface water resources.

Traditionally, the regulation of irrigation canals aims to distribute water according to the official targets and sharing any shortfall in inflow equitably among the canal commands. Since the demand for water has more than doubled over the years, the irrigation agencies are dealing with a permanent water shortage in the system, which complicates the regulation and prompts farmers to ask for quantities of water that infringe on the concept of equitability. Another major problem of present day large scale irrigation in Pakistan is the threat of sodification, as farmers are forced to extensively use poor quality groundwater for irrigation.

This paper addresses two main issues. Firstly, a tool is developed to analyze the impact of operational rules on.water distribution with an aim to provide policy makers and irrigation managers with a means to quantify the effect of changes in irrigation policies and in operational rules on the water distribution. It is hoped that this will facilitate on-going discussions in Pakistan on modifying irrigation management. Secondly, the analysis shows that it is possible to achieve a redistribution of water with the existing system constraints, i.e. the absence of an escape, minimum freeboard and an inflow that is highly variable and not sufficient.

CANAL REGULATION: OLD RULES AND NEW PRACTICES

Large scale irrigation development took place in the Indus Basin from the second half of the 19th century onwards. The magnitude of issues such as food security, stability and economic gains, led the colonial government to maximize the area brought under irrigation, thereby supplying farmers with just enough water for crop protection, which in turn would lead to a greater **water use efficiency** (Bandaragoda and Rehman, 1995; Malhotra, 1982). Shortages in water supply in this run-of-the-river gravity irrigation system were to be shared **equitably** between users with reference to authorized discharges (Waterhouse, 1918; Varma, 1917). However, when authorized discharges are achieved (supply is equal to the water allowance) users do not have necessarily equal access to irrigation water in terms of a volume or irrigation depth[4].

The responsability of the irrigation agency,for regulation is restricted to the main and secondary levels up to the tertiary offtake, while farmers are to share the water amongst themselves in tertiary units through a roster of turns (*warabandi*), whereby a certain farmer is entitled to the entire discharge, entering a tertiary unit for a specified amount of time. The warabandi generally is defined for a 7-day period.

In order to achieve an efficient and. equitable water supply, certain operational rules have been defined to guide the irrigation manager in the regulation of canals. These rules are documented in the Manual of Irrigation Practice (PWD, 1961) and those pertaining to the study are summarized here:

- water supply to a distributary should be ensured *for* a full cycle of warabandi, i.e. 8 days including one day to stabilize the inflow

- target discharges are based on the official allowances; they can be adjusted downwards during the irrigation season if demand is less than the supply; these allowances vary over quite a large range

- a canal should not receive less than 70% of the official target discharge in order to avoid siltation

- at the secondary level water is distributed proportionally, whereby the inflow is delivered to fixed off-takes and changing the delivered discharge is only possible by modifying the dimensions of off-takes

- the discharge to a distributary should not exceed 110-120% in order not to surpass the carrying capacity of a distributary

Implementation of these rules is often delegated to the gate operators, who on the basis of instructions from the irrigation managers operate the gated cross-regulators in main canals as well as the gated head regulators of secondary canals. Gate keepers generally maintain water levels upstream of a cross-regulator at a pre-defined *full supply* level (FSL) in order to be able to stabilize the supply to off-taking distributaries or the on-going parent channel (e.g. see the sketch for Fordwah Division on the next page).

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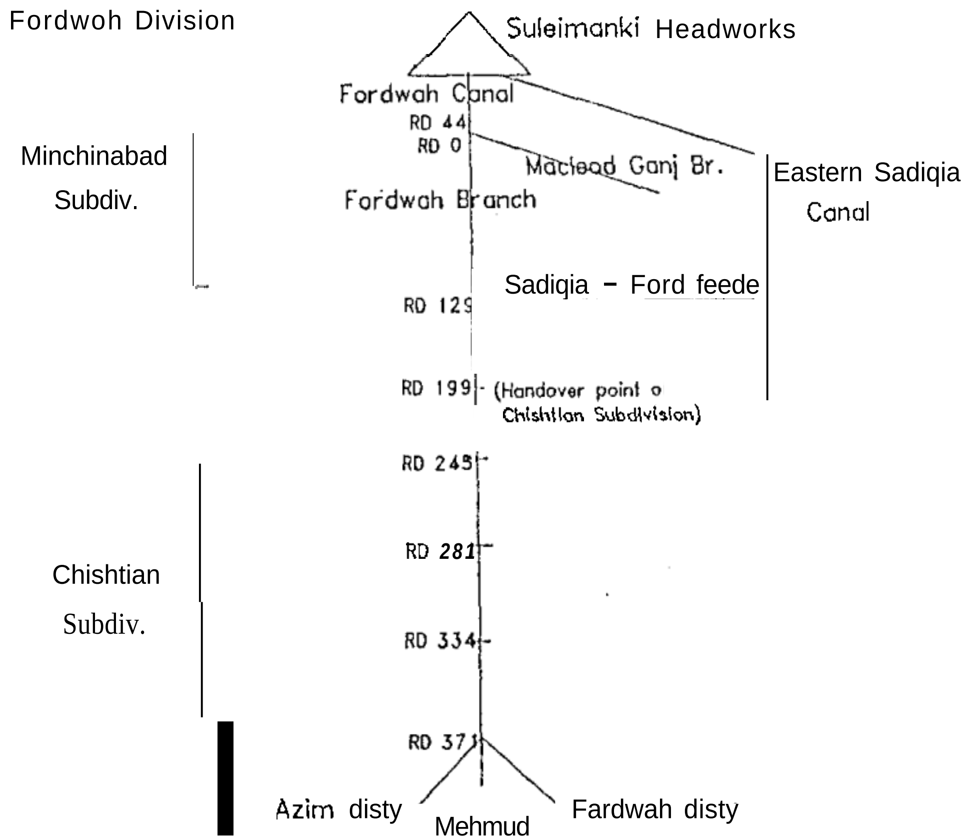
[4] Kuper and Kijne (1992) show that the official allowances vary between 0.8 to 1.4 l/s/ha. Also, canal commands have been designated perennial and non-perennial, the latter receiving water only during the flood season (Kharif).

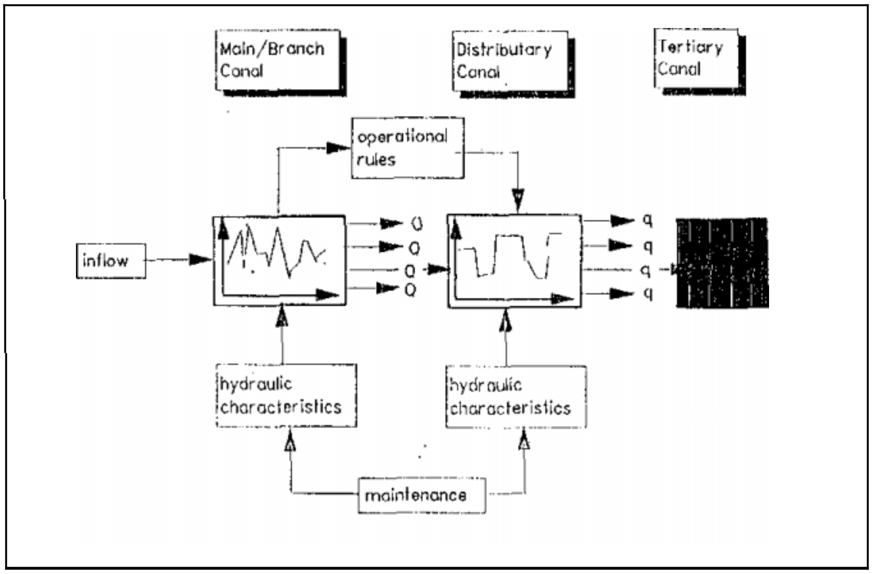


The description of the management set-up, as well as the physical system, allows us to define the scope for management interventions leading to .alternative water distribution patterns. Five types of interventions seem possible:

* modification of the inflow pattern
* redefinition of the water allowances
* redefinition of the operational rules at the main canal level
* redefinition of the implementation rules at the main canal level
* remodelling of the present physical infrastructure at the main and secondary levels

This is represented in Figure 1.

Figure **1.** Representation **of Irrigation** Management at the Main and Secondary Levels.

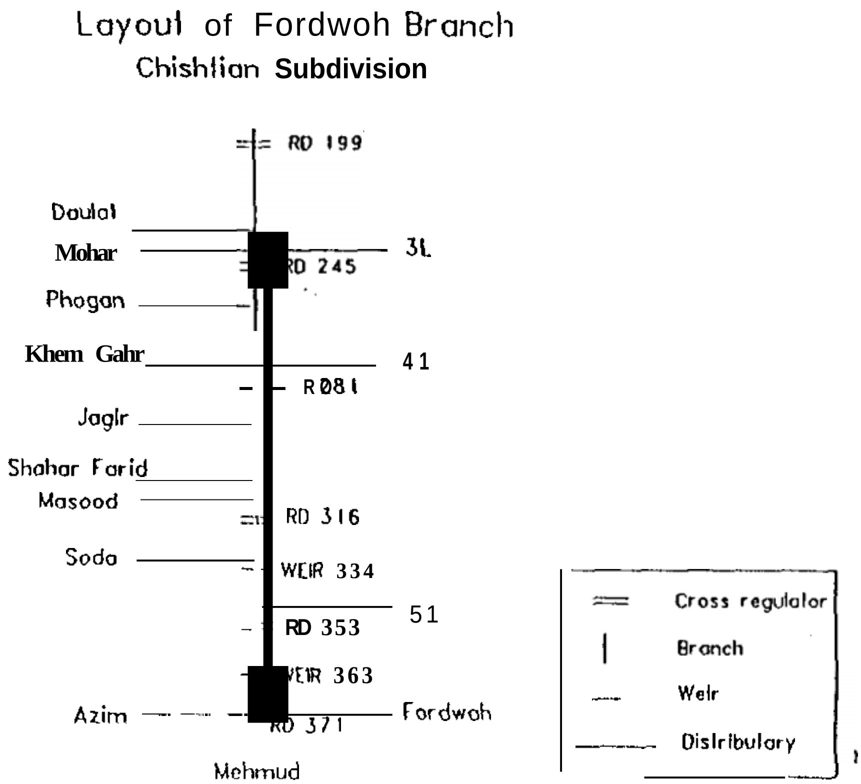


In this study, the inflow pattern and the water allowances will be accepted as given, which implies retaining water use efficiency and equitability as the main principles underlying irrigation management in the Indus Basin. The focus of this paper will be on redefining the operational rules at the main canal level. Alternative ways of implementing the operational rules by gate keepers has been reported previously by Litrico (1995) and Kuper et al. (1994), to which some reference will be made in the present study. The effect of changes in the physical infrastructure on the water distribution was studied by Litrico (1995) and Hart (1996) and will not be treated in this study.

METHODOLOGY

The study area is located in south-east Punjab, bounded by the Sutlej River on the north, the Indian border in the east and the Cholistan Desert in the south. The upper boundary of the study area was defined at km 61 of Fordwah Branch, going down to its tail at km 114. This coincides with the limits of a hydraulic sub-unit, the Chishtian Sub-division. The width of Fordwah Branch is 35 m at km 61 and 15 m at the tail with an average slope of 1:5000. There are a total of around 500 tertiary units served by 14 secondary or *distributary* canals and 8 minors. A few units are supplied directly from Fordwah Branch. The target discharge of Fordwah Branch at km 61 is 36.3 m^3/s in summer and 12.8 m^3/s in winter. From km 61 to the tail, there are a total of 6 cross-regulators, generally located just downstream of distributary off-takes to ensure a stable supply to secondary canals. A schematic map is given below.

Map **1.** The hydraulic network **of** the Chishtian **Sub-division**



Water flows at the main system level and deliveries to secondary off-takes were simulated using a mathematical unsteady state model SIC (Simulation of Irrigation Canals) developed by Cemagref. SIC was linked with a regulation module (Gateman) that was developed especially for this study.

SIC is organized around three units[5]. Unit I reads the canal geometry from a set of cross sections acquired by a physical survey and from the location of cross structures and offtakes. **A** topographic file is created defining the canal network. Unit II reads hydraulic data and computes water surface profiles under steady state conditions using the Manning-Strickler equation expressed as a differential equation of the water surface profile solved by Newton's method. Two sub-modules compute the gate openings for offtakes and cross-regulators for target discharges and target water levels, respectively. Unit III computes unsteady flow conditions by solving the Barre de Saint Venant equations, The initial water surface profile (steady state) is provided by Unit II. It computes offtake discharge openings under varying flow profiles or discharges for fixed openings. The Saint Venant equations are solved numerically by discretizing the equations through a four-point semi-implicit Preissman scheme.

[5] The information contained in this section on SIC is obtained from Baume et al. (1993), and **Cemagref** (1992).

The operational rules are captured in a regulation module, Gateman, that was developed especially for this study. It is based on earlier work of Malaterre (1989) and was initally developed by Litrico (1995) to simulate manual operations of gate keepers. The module is integrated in the unsteady state module of SIC. Basically, the module generates an action (open or close a gate) whenever the upstream water level (Hu) of a cross-regulator deviates more than 2 cm from a pre-defined Full Supply Level (FSL). This represents the decision-making process of a gate keeper whose responsability it is to maintain a constant water level (generally FSL) upstream of a cross-regulator. The discharge is then calculated based on the gate opening, G_o, and upstream and downstream water levels (H_u, H_d).

Gateman was further developed for this study in order to include operations of distributary head regulators, using the same parameters as for the cross-regulators. For regulation, the following implementation rules can be identified:

1. If a distributary is in priority, the gate keeper will try to keep the upstream water level constant by operating the cross-regulator. He will generally not move the distributary regulator.
2. If a distributary is not in priority but one or more other distributaries at this location are in priority, the gate keeper will operate the distributary gate in order to keep the upstream water level constant for the other distributaries and for the on-going discharge in the parent channel.
3. If a distributary is not in priority and neither are the other distributaries at this location, the gate keeper does not maintain the upstream FSL and allows the water level to drop. This happens usually only in the off-season.

Another important addition to the module was an extra "strategic" layer, intended to capture the global decision-making process regarding the regulation of the Chishtian Sub-division. The irrigation manager formulates at the beginning of the irrigation season a rotational plan, which is implemented based on the system inflow, the canal capacity, the target discharges of distributaries, operational preferences and interactions with farmers.

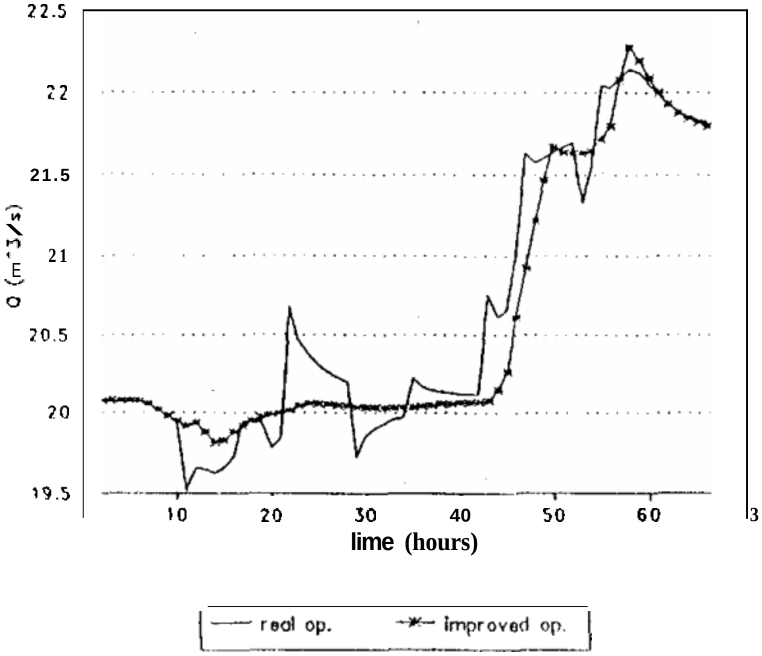
The regulation module generates an order of priority for the distributaries based on a set of rules (either official rules or a set of alternative operational rules). This order is valid for a fixed number of days, which can be selected in the module. Then, the module decides (based on this order and based on the inflow on a given day) which distributaries should be open, which closed and which distributary will absorb the fluctuations. This is done twice a day, as indeed is the official practice of the Irrigation Department. In a third step, the module will generate the gate settings that are necessary to achieve the targets that have been defined (H_u, Q of distributaries), following the present practice of operating cross-regulators or distributary head regulators. This is done in conjunction with SIC, every 10 minutes.

The impact of present operational rules is simulated using the composite Gateman-SIC model and compared with measured daily discharges at the distributary head regulators. Then alternative rules will be defined, which are then simulated with the help of the model.

RESULTS AND DISCUSSION

Calibration and validation of the composite model took place in different steps. Firstly, SIC was calibrated and validated for two different periods and at different discharges, which gave an accuracy within 10% for the discharges delivered to all off-taking distributaries (Litrico, 1995). The same periods were used to calibrate and validate the implementation rules of Gateman, related mainly to the amplitude of opening and closing gates as well as to the operational timing. The results were satisfactory for the operational conditions in Fordwah Branch. An example of the calibration output for Gateman is given in Figure **2.**

Figure 2. Observed and computed gate openings for the cross-regulator located at km 75 of Fordwah Branch Canal.



Understanding the Actual Operational Rules

The official operational rules that were defined above are not always followed for various reasons by the system manager and his staff. When looking at the observed values of deliveries to distributaries, the following **actual** operational rules can be identified:

- a reduction in the rotation time from 8 days to 4 days
- a change in target discharges of the distributaries
- a continued implementation of a rotation between the four major distributaries, Daulat, Shahar Farid, Fordwah and Azim; the other distributaries are not involved in this rotation
- a rotation between Azim and Fordwah distributaries[6]

These rules were programmed in Gateman **(scenario 1)**. **By** running the composite model, the discharges to the different distributaries could be compared with the actual measured data of Kharif 1994. The results of the simulations, presented in Table 1 (scenario 1), show that the definition of the operational rules yields a water distribution that on average resembles reality (in terms of volumes). However, there appears to be a need for further refinement of the operational rules. A number of adjustments were made and a new scenario **(scenario 2)** was defined incorporating the following changes:

1. The target discharges of Shahar Farid and Azim were too high. In the regulation module, they were adjusted downwards to 4.2 and 5.0 m^3/s (from 5.0 and 5.5 m^3/s), respectively. Fordwah was slightly adjusted downwards to 5.3 m^3/s (from 5.5 m^3/s).
2. A rotation of 16 days with 4 cycles of 4 days each was adopted:

	Cycle 1	Cycle 2	Cycle 3	Cycle 4
Daulat	4	2	1	1
Shahar Farid	1	1	4	2
Fordwah	2	3	3	4
Azim	3	4	2	3

3. The target discharge of some of the smaller distributaries is lower during the first few months of Kharif, because of the prominence of rice in their command areas. A widespread custom of transplanting the rice in the months of June/July reduces the water requirement of these distributaries. The target discharges for the gated distributaries were adjusted downwards (Mohar, Jagir and Masood), but not for the ungated distributaries (3-L, 4-L and 5-L), since their discharge depends solely on the upstream water level. In the field, gate keepers sometimes put bushes or karrees in the intake of these distributaries to reduce the intake.

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[6] This is due to physical limitations of the system, whereby it is quite dangerous to supply water sirnulataneously to both large distributaries at the tail. Any fluctuation in discharge would in this case lead to breaches..

4. The daily measured inflow discharges were interpolated on an hourly basis and an extra sub-routine was added in the regulation module in order to read this hourly inflow pattern. This served an additional purpose, as the input restrictions of **SIC** which limit the number of changes in inflow to 20, were circumvented, thus allowing simulations of up to 9 weeks. With an hourly change of discharge, this implies more than 1500 changes in inflow.

The results of the simulations of scenario 2 are presented in Table **1.** It is shown that the results match the observed values very well with an average difference of less than 5%.

	Volume measured in 100,000 m^3	Difference scenario 1 %	Difference scenario 2 %
Inflow	3674.2	+ 13.8	+ 2.2
Daulat	677.6	- 4.2	+ 3.5
Mohar	90.2	+ 35.6	+ 2.9
3-L	46.6	+ 36.6	+ 4.1
Khemaarh	89.9	+ 8.9	+ 4.6
4-L	47.4	+ 28.3	- 7.5
Jagir	102.9	+ 32.6	+ 6.5
Shahar Farid	488.5	+ 11.7	+ 1.6
Masood	138.3	+ 33.3	+ 4.8
Soda	216.9	- 0.4	- 0.7
5-L	27.5	+ 30.4	- 5.5
Mehmud	56.9	+ 12.9	+ 8.5
Azim	468.3	+ 18.0	- 3.9
Seepage and direct outlets	622.6	+ 12.8	+ 8.8

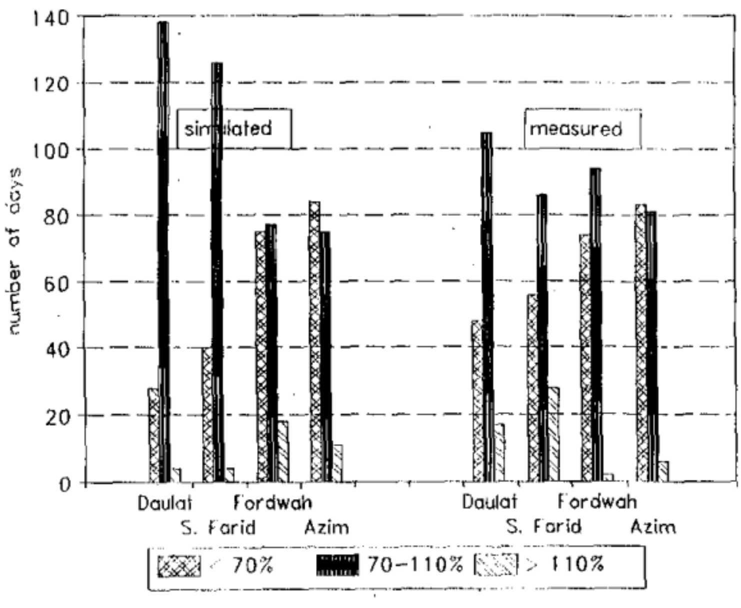
inflow pattern that may deviate, errors in levels and dimensions of structures, etc. A difference of 10 % in delivered volumes seems, therefore, allowable. Only in the case of Phogan Distributary, a small ungated channel that is not attended by a gate operator, the difference exceeds 15%. An error in the crest level cannot be excluded in this case, as farmers have tampered with this intake at various occasions.

A comparison in volumes does not say much about the quality of delivered discharge, such as the discharge level, the temporal variation in delivered discharge and timing of deliveries. For this analysis, four indicators will be used:

- a frequency distribution of the delivered discharge, indicative of the level of discharge. We have fixed the limits of the desired discharge between 70 and 110% of the target discharge.
- the temporal coefficient of variation (CV) of the delivered discharge[7] to represent the discharge variability.
- a correlation (R^2) of the simulated and measured values through a linear regression.
- a qualitative comparison of the hydrographs through a visual comparison.

The frequency distribution was undertaken using three classes, lower than 70%, 70-110% and higher than 110%. The results are presented in Figure 3.

Figure 3. Frequency distribution of daily delivered discharge to the four major distributaries, simulated versus measured.



[7] CV is calculated by dividing the standard deviation of the daily discharge by the mean of the daily delivered discharge.

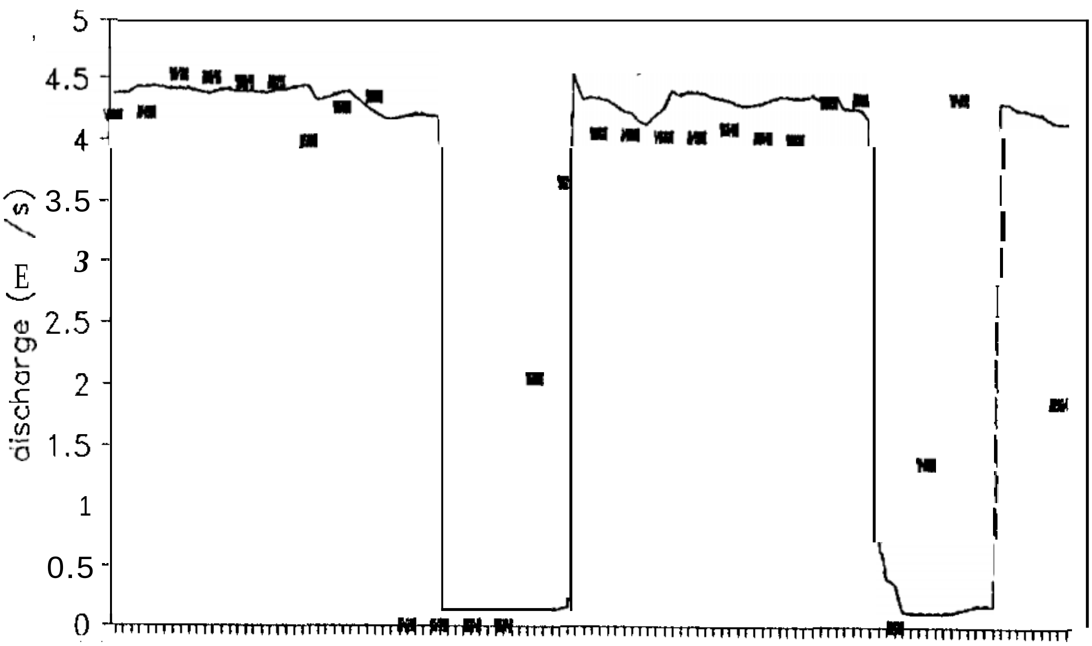
Particularly for Fordwah and Azim, the simulated values match very well the measured values. In the case of Daulat and Fordwah, the distribution is somewhat more skewed (more days of supply between 70 and 110%), because of the logic of the model which attempts either to deliver the targeted discharge to a distributary or is closed. In reality, gate keepers sometimes increase the discharge in case of great demand, while they release less in periods of slack demand.

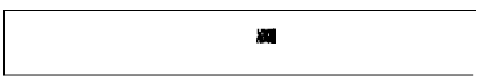
The values of the temporal CV, documented in Table 2, also demonstrate the extent to which the actual hydrographs have been reproduced.

Table 2. Temporal coefficient of variation (CV) for the daily delivered discharges at the head of the major distributaries, simulated versus measured.

	simulated			measured		
	STD	AVG	CV	STD	AVG	CV
Daulat	2.16	4.44	0.49	2.30	4.29	0.54
Shahar Farid	1.74	3.14	0.55	1.82	3.11	0.59
Fordwah	2.41	3.21	0.75	2.20	3.17	0.69
Azim	1.73	2.90	0.60	2.15	2.96	0.73

Figure **4.** Hydrographs **of** the daily discharge delivered to Shahar **Farid** Distributary during Kharif **1994,** simulated versus measured.





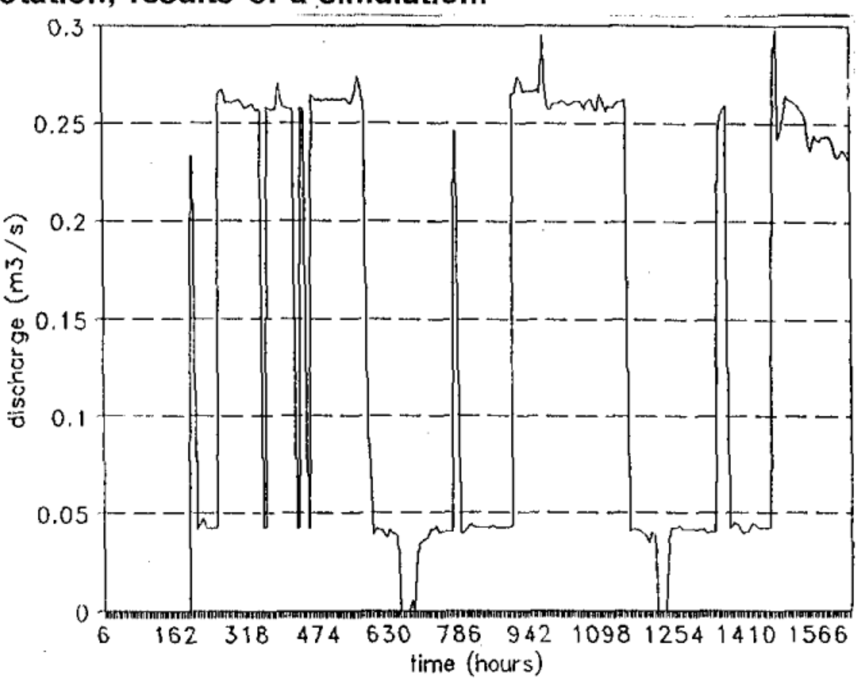
Management Interventions: Modifying the Operational Rules

To achieve the system objectives of efficiency and equitability, we can propose several interventions in the existing operational rules. Firstly, the probable impact of the official rules is evaluated, using the composite model. Then, alternative operational rules are captured in scenarios 3, 4 and 5 and simulated.

The official rules relate to the fact that an 8-day rotation exists between Chishtian Sub-division and the more upstream located Bahawalnagar Sub-division; when Chishtian is in first preference all its distributaries should run at their target discharge, when it is in second preference an internal rotation is implemented. The official rules further define the order of rotation, in which all. 14 distributaries in the Chishtian Sub-division participate. The target discharges are equal to the official discharges unless farmers require less water.

A close look at those rules reveals that it is impossible to implement them. Firstly, the inflow of Chishtian Sub-division is highly variable, even during times of first preference, and is generally not sufficient to supply all distributaries at the same time. Secondly, a rotation involving all distributaries is impractical given the large fluctuations of discharge at the inflow point. A discharge variation of 3 m^3/s during a day, which is not uncommon, that needs to be absorbed by distributaries with discharges lower than 1 m^3/s would lead to a great number of operations and further discharge fluctuations.

Figure 5. Discharge variability for Mehrnud Distributary when involved in a rotation, results of a simulation.



This is illustrated in Figure 4, where the results of a simulation involving all distributaries for a typical small distributary is shown. In times 'of third preference, the distributary is opened and closed several times during a day. Thirdly, it is physically very difficult to involve the ungated distributaries (3-L, Phogan, 4-L, Soda, 5-L) with a total off-taking discharge of 4.3 m^3/s in a rotation, even though some regulation is possible through wooden stop logs and bushes. Removal and insertion of these accessories is, however, time consuming and cumbersome.

This leads us to the formulation of alternative scenarios that try to approach the official rules as close as possible, while taking the system realities into account. An 8-day internal rotation is continued even when Chishtian is in first preference.

In scenario 3 only the four major distributaries are involved in this rotation. The order of rotation is presented in Table 3. The target discharges that were defined for the actual scenarios (e.g. scenario 2) are not changed.

In **scenario 4** the four major distributaries are involved in the rotation, while the small gated distributaries are open or closed following the major distributary close to which they are located, see Table 3. The target discharges remain unchanged.

In **scenario 5** the same rotation as in scenario **4** is adopted. The target discharges are reverted back to the official values, see Table 3.

Table 3. Proposed rotation of the four major and other gated distributaries for scenarios 3. **4** and 5.

	Cycle 1	Cycle 2	Cycle 3	Cycle **4**
Daulat	1	**4**	3	2
Mohar	open	closed	open	open
Khemgarh	open	closed	open	open
Shahar Farid	2	1	**4**	3
Jagir	open	open	closed	open
Masood	open	open	closed	open
Fordwah	4	3	2	1
Mehmud	closed	open	open	open
Azim	**3**	2	1	**4**

N.B. In scenario 3 only the four major distributaries are involved, while in scenarios **4** and 5 the other five smaller distributaries also participate.

The official target discharges are summarized and compared with the actual target discharges in Table **4** for those distributaries that show a large difference. Especially for the smaller distributaries, the difference is very high. The positive differences can be explained by the tremendous pressure on fresh canal water. The negative differences for some of the distributaries in the head reach is a result *of* the direct outlets that have enabled PID to curtail some of the distributaries (Masood. 3-L, Khemgarh). Shahar Farid and Azim distributaries have a substantial number of outlets towards the tail that do not receive any water.

Table 4. Official and actual target discharges of distributaries in the Chishtian Sub-division.

	Scenario 3, 4 Actual target m^3/s	Scenario 5 Official target m^3/s	Difference Y0
Mohar	0.80	1.08	-25.9
3-L	0.50	0.65	-23.1
Phogan	0.80	0.51	56.9
Khemgarh	0.64	0.85	-24.7
5-L	0.25	0.11	127.3
Fordwah	5.30	4.47	18.6
Mehmud	**0.42**	0.25	68.0
Azim	5.00	6.91	-27.6

Distributaries	Scenario 2 volumes	Scenario 3 difference	Scenario 4 difference	Scenario 5 difference
Daulat	70138656	-23.3	- 2.1	-26.4
Mohar	9279360	- 0.4	-24.2	+30.2
3 L	4847904	+16.1	+ 8.1	+14.8
Phogan	8308224	+11.8	+ 2.0	+13.3
4-L	4378752	+12.8	+ 4.5	+14.5
Jaair	10955520	+ 2.3	-25.5	-24.3
Shahar Farid	49620816	-13.5	- 6.0	-17.5
Masood	14485824	+ 4.2	-24.4	-28.3
Soda	21532608	+15.5	+11.2	+23.7
5-L	2595024	+21.5	+16.7	+31.8
Fordwah	51054624	+ 2.4	+ 1.1	+ 0.1
Mehmud	6168960	- 0.3	-25.9	-55.9
Azim	45022608	+34.6	+29.2	+63.2

Reverting the length of the rotation time back to the official rules has **a** big impact on the average period of constant water delivery to distributaries, defined as the time period during which the discharge does not go below 70%. This has been detailed as an example for scenarios 2 and 5 in Table 6. While the average constant delivery period for Daulat is markedly reduced and brought in line with the other major distributaries, these periods increase substantially in time for Azim Distributary. Shahar Farid and Fordwah distributaries are much less affected by the length of the rotation time.

Table 6. Simulated delivery pattern to four major distributaries in the Chishtian sub-division, comparison between the effect of actual and official rules.

	Scenario 2 Actual rules		Scenario 5 Official rules	
	length delivery period	number of periods	length delivery period	number of periods
Daulat	15.8	9	9.1	11
Shahar Farid	9.4	14	9.0	12
Fordwah	5.3	18	6.5	15
Azim	3.5	26	9.9	13

The results of the simulations of scenario 6 are presented in Table 7. It is shown that the interventions have had the desired effect on the water distribution in the sense that an increase of about 6% is achieved for Fordwah Distributary, while Masood gets 12.5% less. At the same time, the deliveries to other distributaries are only slightly affected, mainly around the targeted distributaries. Since the targeted reduction to Masood is smaller than the targeted increase to Fordwah, a certain quantity is taken from Azim Distributary. This reflects the locational disadvantage of Azim, which generally absorbs shortages as a result of overtapping of upstream distributaries. Since the quality of distribution in terms of duration or rate of delivery was not an objective of this scenario, no further indicators are calculated.

Table 7. Simulated deliveries to distributaries, comparison between the effect of actual and salinity targeted operational rules.

Distributaries	Scenario 2 volumes m^3	Scenario 6 Difference %
Daulat	70138656	+ 0.1
Mohar	9279360	- 0.4
3_L	4847904	- 0.3
Phogan	8308224	- 0.1
Khemqarh	9400320	- 0.3
4-L	4378752	- 0.1
Jagir	10955520	- 0.3
Shahar Farid	49620816	- 0.6
Masood	14485824	-12.6
Soda	21532608	+ 1.4
5-L	2595024	+ 2.5
Fordwah	51054624	+ 6.4
Mehmud	6168960	-0.3
Azim	45022608	- 2.5

CONCLUSIONS

1. It was shown that the actual operational rules could be accurately defined through the use of a regulation module in combination with a mathematical unsteady state model. Simulated deliveries deviated on average less than 5% from the observed values for an irrigation season.

2. It was demonstrated that a strict implementation of the official operational rules is impossible and impractical. However, the adoption of a modified set of rules was shown to contribute considerably to achieving the system objective of equitability.

3. At present there is much discussion in Pakistan about changing the system objectives from an equitability-based system towards a productive, sustainable irrigated agriculture. It is not clear, however, whether these changes are possible and how a redistribution of water could be achieved. The composite model that was developed in this study and applied to an irrigation system in Pakistan was shown to be useful in evaluating the impact of present and alternative operational rules on water distribution. These types of tools can be used by researchers and system managers to assess *a priori* the feasibility of proposed changes.

4. The outputs of the present study are quantities of canal water delivered *to* tertiary units. If the irrigation system is considered to be part of the larger context of irrigated agriculture, the effect *of* changes in water deliveries on crop production and on environmental parameters, such as salinity, need to be evaluated. This is the principal research axis of IIMI in Pakistan.

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INTRODUCTION OF AN INFORMATION SYSTEM FOR FACILITATING CANAL OPERATIONS

Mian Hafeezullah [1], Mushtaq A. Khan[2], Paul W. Vehmeyer [2]

ABSTRACT

Pakistan possesses one of the largest continuous irrigation systems in the world. Large command areas are supplied water through the operation of a single gate. An important factor in controlling degradation of irrigated lands by waterlogging and salinity is good irrigation management, ensuring every farmer an equitable and reliable irrigation supply. At present, fluctuations in the secondary system resulting from numerous gate operations endanger these objectives.

This paper discusses the collaborative efforts of the Punjab Irrigation and Power Department (PIPD) and the International Irrigation Management Institute (IIMI) to further improve existing irrigation management,' The aim is to provide the irrigation managers with fools and procedures to take better founded decisions on operation and maintenance. These tools and procedures are called a Decision Support System (DSS).

Pilot areas for implementation were identified within the Fordwah / Eastern Sadiqia area. In these areas, IIMI and PIPD strengthened tlie existing procedures concerned with the collection, conveyance and display of data for the irrigation managers. Furthermore, a computer tool by the name of irrigation Management Information System (IMIS), which allows monitoring of the actual water distribution and performance of the irrigation system was selected for supportive use to the irrigation manager.

Results show an iniproved insight of the irrigation manager in the actual water distribution within his system, allowing him to give the gate operators set targets and thus, improving equity in water distribution. Through the display of data in the irrigation manager's office, the visiting fanners and others who are interested, are easily informed, ensuring'their confidence in the working of the irrigation system. Both IIMI and PIPD field staff have received additional training in ensuring the collection of accurate data and have improved their system awareness /performance .

Within the pilot areas, training in the use of the computer tool IMIS was not always of lasting effect, due to changes in the PIPD staff. Some problems were caused by a troublesome communication system.

In future planning the computer tool IMIS will continue to be reviewed, so that it will be able to spread the implementation in the whole of Bahawalnagar Circle and further on into the Province of Punjab.

In the end, overall conclusions show a strengthening of existing departmental procedures and practices in monitoring the irrigation system, resulting in improved equity through reduced gate operations and more confidence of the beneficiaries in the system.

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1. BACKGROUND

Pakistan possesses one of the largest continuous irrigation systems in the world. It encompasses a large part of the Indus Basin. Construction of the irrigation system started in the early 20th century. The system is being operated as supply-oriented, spreading the available irrigation water over a large area of the Indus plains and distributing it equally among the farmers according *to* their farm size. The irrigation managers operate the system only through gates at the heads of canals and distributaries. Fixed outlets take their due share from a distributary, whenever the distributary is running at its design level. As a result, large command areas (15,000 - 50,000 acres) are supplied water by operation of a single gate.

During the years after construction of the irrigation system, the groundwater table rose, causing waterlogging and salinity and, as a result, forcing large parts of the command area out of agriculture. An important factor in controlling further degradation of irrigated lands will be good irrigation management, ensuring every farmer an equitable and reliable irrigation supply. Large fluctuations within the irrigation system have been observed, resulting from numerous gate operations, causing inequitable and unreliable irrigation supplies. Table I shows inequity in water distribution in a sample distributary by comparing the design and measured discharges for a number of outlets.

In 1989, the International Irrigation Management Institute (IIMI) started a project funded by the Government of the Netherlands, to identify possible improvements in the irrigation management that will prevent degrading of the land through waterlogging or salinity. Part of this project is carried out in collaboration with the Punjab Irrigation and Power Department (PIPD) and aims *to* develop tools and procedures to assist irrigation managers to take better founded decisions on operation and maintenance of the main system. These tools and procedures are also known as Decision Support Systems (DSS).

In order to manage an irrigation system properly, its manager needs accurate information. Information on the past, present and, if possible, on the future state of his system. Having easy access to all this information will enable him to make the best decisions on operation and maintenance.

Table 1. Outlets Discharge Comparison for Gujjiani Disty (2 September 1996).

OIL No	Location	Q Design (cusecs)	Q Measured (cusecs)	% Increase or decrease
1	900-R	1.50	1.69	13
2	6640-L	1.11	1.37	77
3	16550-L	2.13	2.45	15
4	24800-R	1.49	1.58	6
5	32120-R	0.90	1.32	47
6	41720-L	1.29	1.73	34
7	49640-L	1.94	3.45	78
8	54260-R	1.08	1.93	79
9	64545-L	1.11	1.36	23
10	74690-L	1.28	1.93	51
11	80040-R	0.66	2.08	215
12	87120-R	2.36	3.02	28
13	93080-L	1.58	2.22	41
14	98100-R	1.58	4.20	166
15	106060-L	2.26	2.68	19
16	110780-L	1.82	3.35	84
17	118130-R	1.16	1.44	24

Design discharge of Gujjiani Disty - 319 cusecs
Measured discharge of Gujjiani Disty = 427 cusecs
Design average cropping intensity - 80% (Kharif 32% and Rabi 48%)
Actual average cropping intensity = 125%

The time space with which certain information should be collected and presented to the manager varies. Some of the information should be collected on a monthly basis (e.g. bed levels), while other informntlon Is required by tho hour (e.g. upstream water levels).

Tools and procedures can assist in collecting, processing and presenting information at the right time and in the right way. At present, quite a number of tools have been developed for use in a DSS. Many of these tools are computer based.

At the start of the project, IIMI was asked by the Secretaries of Irrigation and Power and Agriculture of the Government of Punjab to commence work in the Fordwah/ Eastern Sadiqia area. Given the fact that this area was highly affected by shortages of irrigation water, waterlogging and salinity, a number of other projects would be initiated in the area. In May 1993 the joint implementation of DSS started in Chishtian subdivision (Fordwah division) Implementation in Malik Subdivision (Sadiqia Division) followed around August 1995.

2. PLAN

At the start of the implementation phase, initial observations were done on the situation in the pilot areas. From these observations, the following steps were anticipated to establish a Decision Support System (DSS) within the subdivisions:

* Installation of gauges
* Calibration of structures
* Preparing / revising discharge tables
* Ensuring regular collection and conveyance of data
* Storage and temporary display of collected data
* Identification of computer tools:
    - To improve operation of the system / sub-system
    - To improve insight into water distribution and performance of the irrigation system
    - To improve irrigation management

To ensure a sustainable implementation of the different steps, trainings were planned in the calibration of structures / preparing of discharge tables and the use of the identified computer tools.

3. IMPLEMENTATION

The planned implementation started in Chishtian Subdivision, located at the tail end of the Fordwah Branch Canal system. Within the subdivision both perennial and non-perennial channels are located, making it a difficult system to manage. Farmers have the tendancy to ensure a year round water supply, whenever they see water available nearby. The implementation procedure was followed and tested within these demanding circumstances. In this period, a computer tool was to be identified, which could support the existing irrigation management.

One of the available computer tools for use in a DSS, and implemented with help of IIMI in countries like Sri Lanka and Mexico, is called Irrigation Management Information System (IMIS). It consists of a database and a series of computational modules. In the database, data is stored on the configuration of the concerned irrigation system and the recorded actual water levels, while in the computational modules this data is processed into information on water distribution and performance of the irrigation system. The main advantage of this tool is its flexibility. Apart from using the predefined setup, the user has the possibility to define himself what kind of information he wants to receive and in which way it should be presented to hirn. IIMI and PIPD decided to use this tool as the primary computer tool to assist the irrigation managers in their tasks.

After the first experiences within Chishtian Subdivision, a middle reach subdivision with perennial channels was chosen as a second pilot area. This area was Malik Subdivision in the Eastern Sadiqia Canal command area. Before implementation in this second subdivision, the IMIS program was updated according to the findings within the Chishtian Subdivision. For example, in the discharge calculations, the structure formula was replaced by the PIPD procedure of using the KD-formula. With this, and other gained experiences, the implementation procedure went even better and clear achievements were seen.

4. ACHIEVEMENTS

Following are selected achievements in Malik Subdivision, which indicate an improved irrigation management:

- ★ After adopting the described procedure, the tail shortage has diminished.
- ★ The disty / minors gate / karries operation are minimized, which can be seen from the constant tail gauges of the minor and disties in the research area. Table 2 shows the tail gauges of several distributaries in Malik Subdivision for the years 1995 (PIPD record) and 1996 (PIPD data, verified by IIMI).

Table 2. Tail conditions of Gujjiani Distributary Minors for May 1995-1996.

DATE	BHUKAN		KOKNI		CHATALA	
	1995*	1996	1995*	1996	1995*	1996
	feet	feet	feet	feet	feet	feet
1	1.15	1.10	1.20	0.90	1.20	0.80
2	1.15	1.20	1.20	1.40	1.20	1.45
3	1.15	0.80	1.20	1.50	1.20	1.35
4	1.15	0.90	1.20	1.50	1.20	1.55
5	1.15	0.90	1.20	1.30	1.20	1.50
6	1.15	1.10	1.15	1.30	1.15	1.45
7	1.15	1.10	1.15	1.40	1.15	1.40
8	1.15	1.10	1.25	1.10	1.20	1.00
9	1.15	1.10	1.25	0.80	1.20	0.70
10	1.15	1.10	1.25	0.90	1.20	0.80
11	1.15	1.10	1.25	1.00	1.20	1.00
12	1.15	1.20	1.25	1.20	1.20	1.30
13	1.15	1.00	1.25	1.15	1.20	1.10
14	1.15	1.10	1.20	1.20	1.20	1.05
15	1.15	1.20	1.20	1.20	1.20	1.10
16	1.15	1.20	1.20	1.40	1.20	1.50
17	1.15	1.20	1.20	1.45	1.20	1.55
18	1.15	1.20	1.20	1.55	1.20	1.60
19	1.20	1.20	1.20	LKG	1.20	LKG
20	1.20	1.20	1.20	LKG	1.20	LKG
21	1.15	1.20	1.15	0.70	1.15	0.80
22	1.15	1.30	1.20	LKG	1.20	LKG
23	1.15	1.10	1.20	0.50	1.20	0.60
24	1.15	1.20	1.20	1.20	1.20	1.30
25	1.15	1.10	1.10	1.25	1.10	1.35
26	1.15	1.10	1.10	1.30	1.10	1.30
27	1.15	1.10	1.10	1.35	1.10	1.30
28	1.15	1.20	1.10	1.40	1.10	1.35
29	1.15	1.20	1.15	1.45	1.10	1.50
30	1.15	1.20	1.15	1.40	1.15	1.55
31	1.15	1.20	1.15	1.45	1.15	1.60

* According to PIPD records, not verified by IIMI

LKG Leakage (very small amount of water)

* Set targets have been defined for the gate operators in order to minimize gate operations. This has reduced both gate and supply fluctuations.

* Due to access to reliable and on time data,the irrigation manager is able to reduce his frequent visits to the field, leaving more time to pursue other assignments.

* The crests of some minors were adjusted after identifying that these minors were drawing more water than allocated, which was causing an excess of water at the tail.

* Due to accurate and timely arrival of data to the irrigation manager's office and by using a display white board, it is now easy for the irrigation manager to inform farmers, visitors and his superiors on the actual condition of the system, thus, improving users' confidence.

* Both IIMI and PIPD field staff have been trained in calibrating structures and have been improving their system awareness / performance.

5. ISSUES / DIFFICULTIES

The road to the implementation of a DSS for operation of the irrigation system is not always very easy. The communication system for transfer of data and other information between the gate operators and the office of the irrigation manager is oflen malfunctioning. Use of the computer for irrigation management is a new phenomena and many of the concerned irrigation managers have little prior computer knowledge Training of the managers should therefore be one of the key points in the implementation of the **DSS.** In both subdivisions in which trainings were given to the irrigation managers, personnel changes made it difficult to see the result of the training. In Chishtian Subdivision, eight people held the position of Subdivisional Officer in the period between 1994 and 1996.

6. FUTURE PLANS

In the near future, the communication system should be modernized, making it less vulnerable to breakdowns. The computer tool IMIS will be reviewed for its user friendliness and its applicability within the irrigation management in Pakistan. It is anticipated that IMIS will be updated with a new version in the coming year. The DSS implementation will continue to proceed, spreading the tools and procedures over the whole of the Bahawalnagar Circle. A planning will be made to introduce the DSS to the entire Punjab Province.

7. CONCLUSIONS

At the present stage of the on-going efforts, a few concluding remarks can be made:

* The procedural part of implementing the DSS strengthens the existing departmental procedures / practices ensuring its success.

* The irrigation system monitoring is enhanced, which helps the managers to identify any possible problems and diagnose their underlying causes.

* The implementation of a DSS ensures the confidence of the beneficiaries in the irrigation system.

* As the gate operators are given set targets, fluctuations in the irrigation channels are reduced.

* The communication problems in this huge irrigation system are largely underestimated. Unless an efficient data transmission network is in place, the data will not reach the decision making center in time and may prove of little use for the management.

PERFORMANCE ASSESSMENT OF AN IRRIGATION SYSTEM: APPLICATION TO THE FORDWAH BRANCH CANAL SYSTEM

Zaigham Habib[1] and Marcel Kuper[2]

ABSTRACT

This paper reports on a comprehensive performance analysis of the water allocation and distribution system at a sub-divisional level. The study discusses performance at the level of the irrigation system, after which an evaluation is carried out of the impact of water deliveries on irrigated agriculture. The analytical procedure can be divided into fhree steps.

1. *The performance of the irrigation system is estimated with reference to the existing targets of depaffment. The analysis is extended by evaluating the different functions of the system with an additional set of indicators. AN these indicators are called internal indicators as they address the behavior and operation of the irrigation system from inside.*

2. *The outputs of tlie irrigation system have been evaluated by puffing it in the larger context of the irrigated agriculture. This analysis provide a broader and comprehensive vision of the system.*

3. *A set of indicators is selected on the bases of the results of steps 1 and 2*

The background of the study is provided by giving a brief review of the evolution of the perfonnance concepts for the irrigation systems and the work done by IIMI in the past.

For the first part of the analysis, fhe parameters measured in routinely the Irrigation Department and the currant operational rules are considered as the official internal indicators. Their recommended values are considered as the official targets. To further evaluate the water allocation and distribution functions of the system, a set of more sophisticated indicators for equity, reliability, variability and adequacy has been applied. This part of the analysis provides more insight into fhe performance of the irrigation system and better defines its function to provide water for crop production.

The analysis indicates a substantial gap between the supply and the demand of the canal water. The uncertainty of the inflow posed a constraint for the scheduling of the water deliveries. The perennial and non-perennial wafer rights of the command area set a difference between the equitable water supply to the command area and the target of matching the design discharges. The management of ground water by the farmers introduces another dimension to the decision making.

Finally, some external performance indicators have been applied to judge the performance and productivity of the irrigation system as a part of the irrigated agriculture setup. The values of these indicators shows the strong and weak aspects at the gross level (i.e increase in cropping intensities, average productivity per unit water and per unit land, etc.).

The paper also provides an analysis and comparison of the indicators used to measure the certain target. For example, a couple of indicators suggested for measuring equity has been computed and compared. Based upon the results of the performance analysis and the comparison of the indicators, a set of internal and external indicators is recommended to be used at the main canal level. The scope for further analysis is menfioned.

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An important conclusion of the paper is the need to reconsider the irrigated agriculture system as a unit and to readjust the existing objectives and targets which could lead to beffer management of the resources and the beffer interaction of different actors.

1. INTRODUCTION

1.1 Background

In recent years, the performance of irrigation systems has become a growing concern of the researchers, irrigation policy makers and donor agencies. The issue has been addressed at different levels of the irrigated agriculture system by the professionals of different disciplines. In the beginning, studies were mostly focused on the irrigation water supply network. Afterwards, more comprehensive approaches considering the agricultural productivity and the sustainability of the water and land resources came in. In this context, comprehensive performance studies have been undertaken by the Global and the National programs of IIMI. The work done by IIMI on performance has addressed the methodological and practical issues:

- development of a performance framework (e.g. Murray-Rust and Snellen 1993; Svendsen and Small, 1992);

- defining the irrigation (or irrigated agriculture) system, processes occurring in it, different actors involved and their objectives, measurement techniques, etc. (Abernathy 1987 & 1990; Chambers 1992); and

- development and selection of internal and external performance indicators that allow a comparative analysis of irrigation systems around the world (Abernathy, Vender Velde. Kuper & Kijne, Chris Perry and others).

This paper evaluates the performance of a branch canal system which delivers water to fourteen distributaries. The existing official, as well as many other indicators, have been used to evaluate different objectives. The selection of indicators based upon the concepts *of* performance are discussed in the next section.

1.2 The **Concept of Performance Assessment for Large-scale Irrigation Systems and the Selection of Indicators**

Several definitions of performance have been proposed, highlighting the issues like; boundaries and levels of the systems, goals and targets of a particular activity or agency, relations between the system's Performance and management's achievements, readjusting the targets with reference to new situations, and relationships of different actors. A framework of nested hierarchy of the systems ranging from irrigation to irrigated agriculture and then to the national level has been proposed by Small and Svendsen (1992) and then further discussed by Murray-Rust and Snellen (1993). In the framework where the performance can be measured at different levels of the nested hierarchy, Abernathy's definition (1990) is used to measure the fulfillment of the objectives in terms of targets set at a specified level. Abernathy defined performance as:

> The *performance of* a system *is* represented *by its* measured levels *of* achievements in terms *of one,* or several, parameters which are chosen *as* indicators *of the* system's goals.

This definition requires a clear identification of the tasks (objectives) with reference to the activities and actors. In the case of irrigation activity, there is a difference between satisfying the demand (of farmers) and the efficient management of the resources. It is specially true for the water shortage systems, Hence, the criteria mentioned by Ansoff (1987) are used to separate two types of targets. Ansoff says that, from the viewpoint of society, the effectiveness of an organization's activities can be measured by two complementary criteria:

1. The degree to which organizational productslservices respond to the needs of the customers; and

2. The efficiency with which the organizations uses resources in supporting their needs.

A set of old (already used in the system) and new internal indicators have been selected in the abovementioned framework to assess the performance of different activities of the irrigation system. In addition to that, preliminary work on the gross performance of the system is presented.

2. METHODOLOGY

2.1 Objectives

* To evaluate the performance of the canal water distribution system in the Chishtian Sub-division with reference to the design water allocation and managerial planning,

* To investigate the gap between canal water supplies and the crop water requirements of the command area with reference to the inherited physical limitations and the existing cropping intensities of the system.

* To test and evaluate a set of traditional and modern performance indicators applicable to large supply based schemes.

2.2 Approach of the Study

This study undertake a comprehensive performance analysis of the water allocation and distribution system. The major steps of the study are:

* The information and data related to the canal supplies are collected by IIMI and ID staff under a collaborative activity: Implementation of Irrigation Management Information System (IMIS) in Chishtian Sub-division. The conveyance losses are measured by IIMI and the International Sedimentation Research Institute, Pakistan (ISRIP). The crop data collected by ID and the climatic data collected by WAPDA are used.

* The current status of the performance has been analyzed using the official internal indicators, such as the relation between head and tail conditions, and a comparison of design and existing water allocations.

* The scheduling and water distribution in kharif 94 has been analyzed using the most recommended internal indicators of equity, reliability and variability. These indicators represent the objectives which are valid at the sub-divisional level.

* The analysis is extended *to* indicate the gap between water requirements and canal supplies. A set of composite indicators is applied *to* measure the gross performance.

* The selection procedure of the indicators is shown by the comparison of equity indicators: A simple procedure is developed to evaluate the variability of flows at the head *of* secondary canals.

2.3. Introduction of the Study Area

The Fordwah Eastern Sadiqia area is located in the south-east of the Punjab and *is* confined by the Sutlej river in the north-west, the Indian border in the east and by the Cholistan desert in the south-east, The Chishtian Sub-division is a 67,000 ha hydraulic unit starting at 61 km of the Fordwah Branch (which off-takes from Fordwah Canal) and going down to its tail at 113 km, combining 5 perennial and 9 non-perennial[3] distributaries (see Table 1). The present irrigation network was designed in 1920 and has been operated since 1927.

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[3] Non-perennial distributaries are entitled to water from 15 April to 15 October (kharif). while they will receive three "walerings" during rabi if supplies are available. A watering is defined as a full warabandi cycle for a given distributary.

In kharif, the design discharge for the Chishtian Sub-division amounts to 36.4 m^3/s, while in rabi the design discharge is 12.7 m^3/s. An eight day rotation is implemented in kharif to share the available water between the three sub-divisions in the Fordwah Division. The upper sub-division (Minchinabad) is exempted from this rotation[4] and shortages are shared between the two lower sub-divisions (Bahawalnagar and Chishtian). The rotational plan further specifies which distributaries should be closed in case of water shortage during a period of second preference.

The climate is (semi-)arid with annual evaporation (2400 mm) far exceeding annual rainfall (around 200 mm). The area is part of the cotton-wheat agro-ecological zone of the Punjab, with cotton, rice and fodder crops dominating in kharif and wheat and fodder crops in rabi.

3. ANALYSIS OF CANAL WATER SUPPLY WITH REFERENCE TO THE OFFICIAL TARGETS OF THE SUPPLY AGENCY

3.1 Water Allocation and Canal Capacities (Evaluating the Constraints)

The original water allocations to different irrigation systems were based upon multiple factors such as the expected availability of water, soil type, ground water quality, cropping pattern and socio-political factors. The command area of Chishtian Sub-division has perennial and non-perennial water rights and the duties are in the order of 0.25 to 0.50 l/s per ha. If the irrigation intensities are taken into account, the water availability increases to about 0.7 to 1.4 l/s/ha. The water allowances and the canal capacities of the secondary channels of Fordwah are given in Table 1.

With time, small changes in the original water allocations have occurred, for example special allocations have been sanctioned for reclamation of salinity affected lands, for special food supply schemes ("grow more food"), for gardens and for fish ponds. These supplies can be seasonal, as in the case of reclamation supplies, or are permanent.

Water shortage were anticipated at the design stage of the system, which has been exhibited in the perennial and non-perennial setup. The **use** of ground water has also been encouraged by the Government. The existing canal water availability status of the sub-division is worse than the other sub-division of the area due *to* the following reasons:

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[4] **It is only since 1994 that the Minchinabad Sub-division has been exempted from the rotational plan of the Fordwah Division.**

(i) tail sub-division;
(ii) reduced capacity of the branch canal and distributaries; and
(iii) perennial and non-perennial setup of the system.

Table 1. Water rights and the physical capacities of distributaries in Chishtian Sub-division

Name of the distributary	CCA ha	Design Alloc. l/s/ha	Design Disch. cumecs	Avg Indent cumecs	Max Indent cumecs	Max Disch cumecs
Daulat	13570	0.38	5.9	5.77	6.46	6.67
Mohar	1446	0.49	1.1			1.29
3-L	1166	0.49	0.7			.54
Phogan	949	0.49	0.5			1.09
Khemgargh	2032	0.38	0.8			I.0a
4-L	877	0.49	0.5			.75
Jagir	1604	0.42	1.1	.65	.85	1.72
Sh-Farid	10255	0.38	4.3	3.21	4.96	5.76
Masood	3295	0.25	1.0	.76	.99	1.44
Soda	4093	0.49	2.2			2.5
5-L	357	0.25	0.1			.39
Azim	12199	0.49	6.9	5.2	6.9	6.91
Mehmud	813	0.25	0.2	.23	.25	.45
Fordwah	14941	0.25	4.5	3.65	4.81	6.08

3.2 Seasonal planning at the Sub-divisional Level

3.2.1 Procedures for the seasonal scheduling

For each crop season, an amount of water is sanctioned for all canal commands based on the forecast of river supplies, provincial water share for the Punjab and water requirements (indents) formulated by the irrigation officers located at the head works. Due to water shortage and high demand, a tremendous pressure is exerted on the system. **As** a result of this, a rotation between distributaries or even sub-divisions is required. The Executive Officer (XEN) and the Sub-Divisional Officer (SDO) are entitled to prepare the operation plans, which should be advertised throughout the command area.

There are clear operational rules to guide the SDO in the distribution of canal supplies. Firstly, supply to a distributary must be higher than 70 % of the design discharge in order to avoid siltation and should not exceed the capacity of the distributary, generally fixed at 120 %, except in times of emergency. Secondly, a continuous supply to a distributary should be ensured for at least one warabandi cycle (7 days) plus one day. Finally, the tail of the distributary should receive supply for 7 days to make sure that all watercourses in a distributary are served.

3.2.2 Seasonal Planning.in the context of Chishtian sub-division

The Chishtian Sub-division has a well specified intra-sub-divisional rotation and not very clearly defined internal rotation. Figure 1 shows the actual, design and indent pattern at the head of the sub-division. Indent is about 170 cusecs higher than the design discharge and is achieved for about 70 % of the time according to the ID register. **A** new rating curve has been prepared for the head regulator which gives 150 cusecs less discharge. If the difference of the rating curve is taken into account, the maximum indent and the design discharge are in the same range.

The weekly average supply pattern for four big distributaries are shown in Figure 2 . The following can be concluded from this information.

i All four big distributaries can obtain full supply when the discharge at the head is more than 32 m^3/s.

ii. At the sub-divisional level, water shortage is directed towards the four big distributaries. Only a few small distributaries share this shortage locally.

iii. When the discharge at RD 199+000 is in the range of 25-32 m^3/s, either one distributary was closed or the shortage was given to two distributaries. During June and July, there were short closure periods upto 1/2 day only.

Applying the operational rules that dictate a supply of more than 70 % when a canal is operated and;' an uninterrupted supply for an entire warabandi period (+ 1 day), it appears that the irrigation performance leaves much to be desired in the sub-division.

Figure 1. Indent, Design and Delivered Discharge to Chishtian Sub-Division in Kharif 94

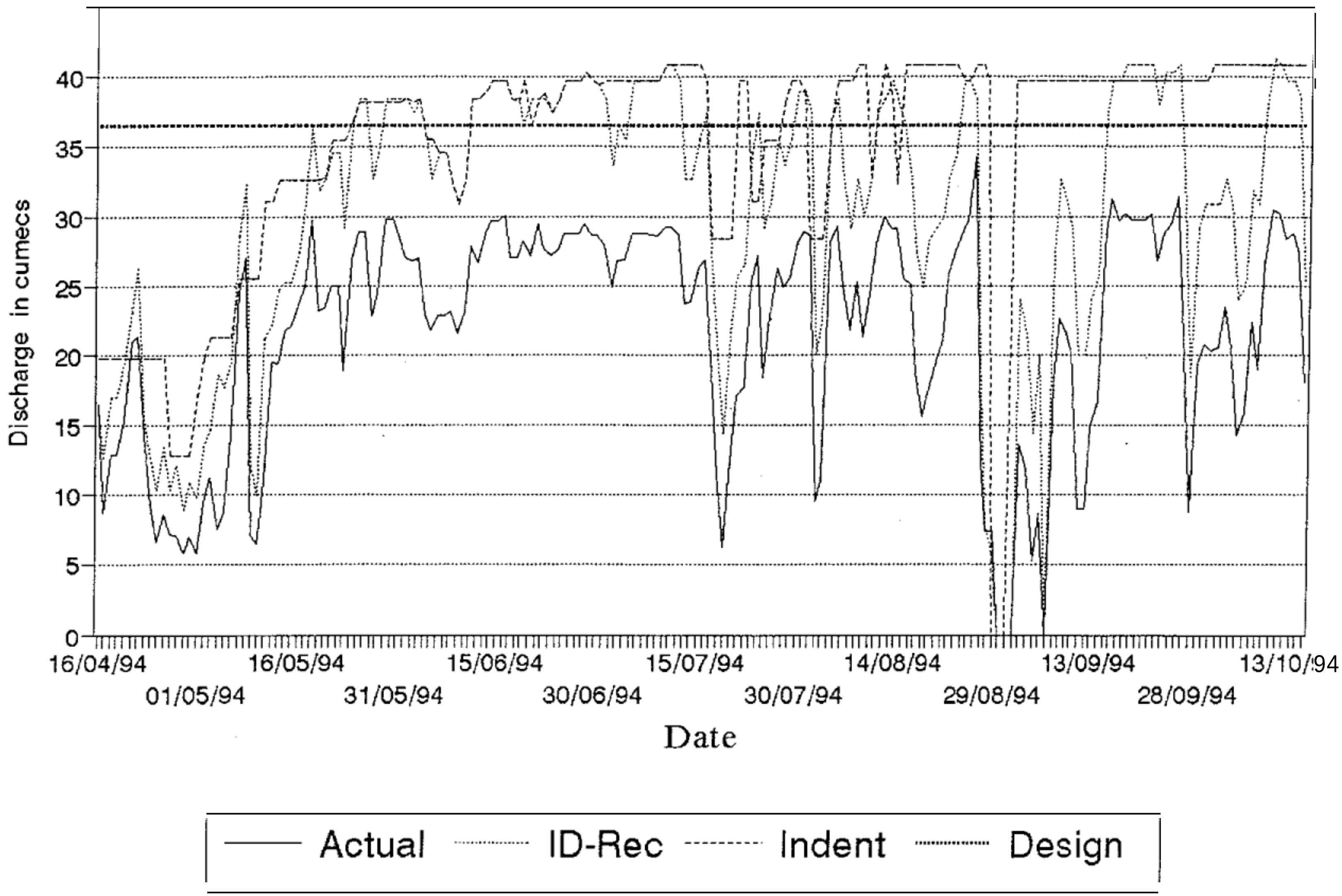
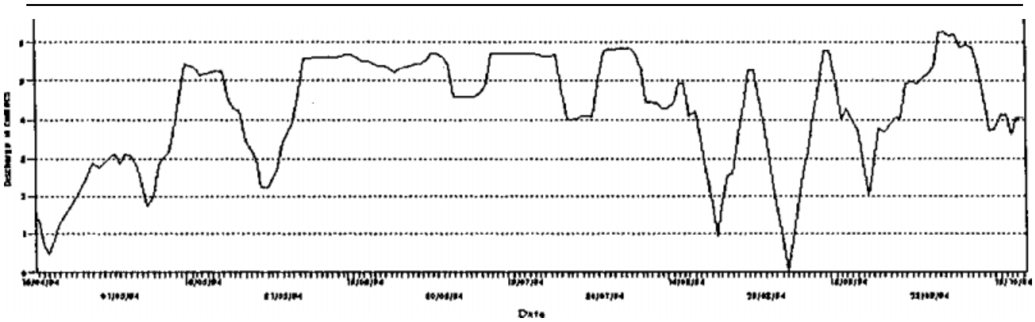
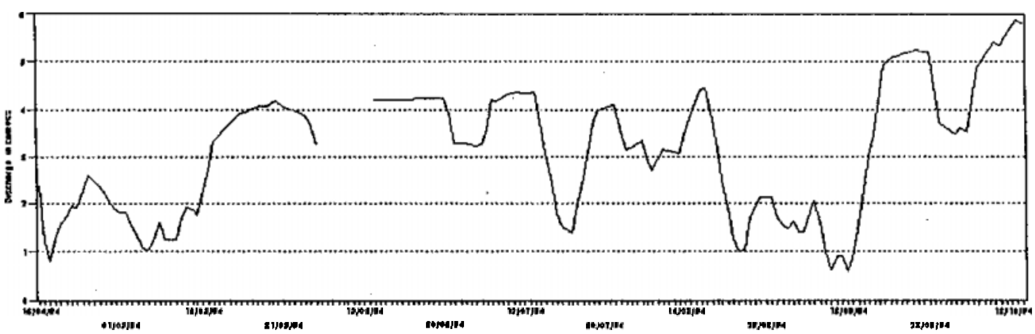


Figure **2**

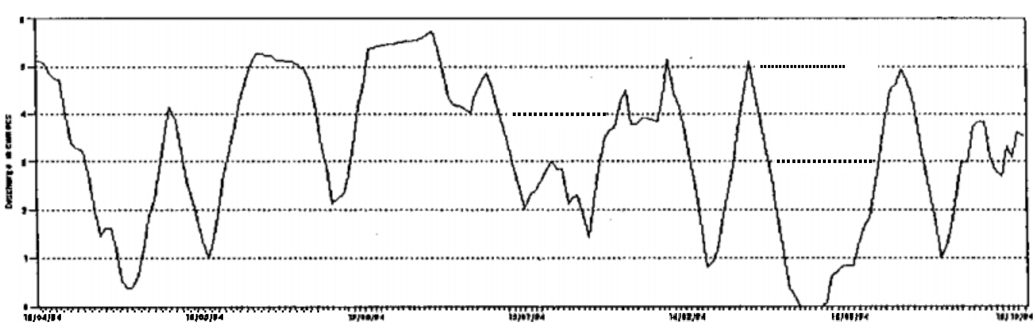
Actual Discharge of Daulat located in
First reach of Fordwah Branch: Kharif 94



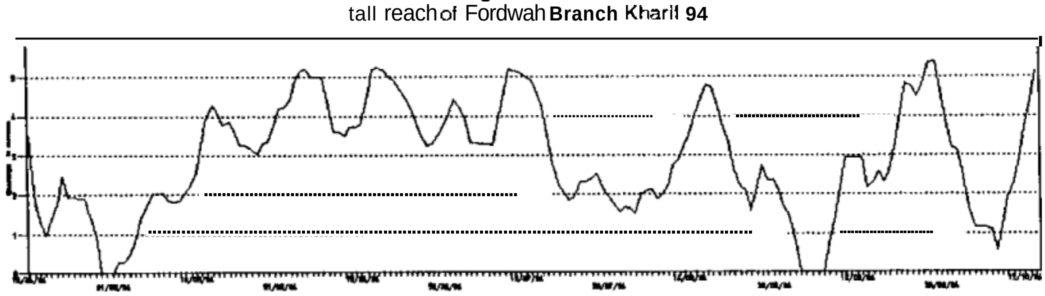
Actual Discharge of ShahrFarid located
2nd reach of Fordwah Branch: Kharif **94**



Actual Discharge of Fordwah Disty
tail reach of Fordwah Branch: Kharif 94



Actual Discharge of **Azim located** In **the**
tall reach of Fordwah **Branch** Kharif **94**



3.3 Tail Gauge

Tail conditions of Chishtian distributaries are shown in table 2

Table 2. Tail gauges (T) of distributaries (in feet) in the Chishtian sub-division for Rabi 1993/1994 and Kharif 1994.

	Kharif 1994				Rabi 93
Distributary	Dry tail	Dry Head	Tail > 1 ft	Head Q %Design	Dry Tail
	days	days	days	T = 1ft	days
Daulat	130	35	36	70	
3_L	81	36	102	45	
Mohar	32	50	117	85	
4_L	48	40	53	95	
Khemgarh	47	39	48	100	
Phogan	38	28	47	75	
Jagir	47	18	111	65	88.00
Shahar Farid	125	31	4		
Masood	68	36	16	100	83.00
Soda	61	26	92	100	
5_L	46	30	68	110	86.00
Fordwah	97	41	64	70	100.00
Mehmud	91	10	83	110	67.00
Azim	'88	41	168	100	

Table 2 shows that, in general, the tails are not getting water for 30% to 50% of the time. It also shows that the maximum tail gauge in kharif is much higher than the recommended value of one foot. Two factors can contribute to this behavior: 1) tails receive water when it is higher than the design discharge or surplus in the upstream reaches, and 2) physical conditions in the tail reaches have changed the canal cross-sections and the tail gauges.

The correlation between the head and the tail conditions are shown in Figure 3. This figure indicates that the relationship between dry tail and lower than 70 % of the design discharge at the head are generally linear; three channels are not included in this analysis because their functional tails continue shifting. Two of the distributaries, which are basically water short channels, show a better behavior, their tails get water when the head discharge is between 60 to 70 percent of the design discharge. It is clear from the above discussion that the major cause of the tail shortage is insufficient and variable supplies at the head.

4. ANALYZING THE WATER DISTRIBUTION WITH REFERENCE TO SYSTEM'S TARGETS

4.1 Reliability of the Water Supply

Reliability is defined here as a degree to which water deliveries accommodate the expectation of the users and match the planned schedules of the irrigation department. If the operational plans have been properly prepared and advertised, farmers can know about the timing of the supplies even if these are not timely for meeting crop requirements (reliable but not timely supplies).

To measure the reliability of the supplies, weekly coefficients of variation for the ratio *discharge/indent* has been computed. The weekly values of reliability for four big distributaries and RD199 are plotted in Figures 4 and 5. These plots indicate that the supplies at RD199 are reliable from the first week of the May to the third week of August, while for the distributaries reliability is quite poor. The two distributaries at the head (Daulat, Shahr Farid) perform relatively better than the two distributaries at the tail (Azim, Fordwah). However, the supply pattern, is quite undependable at the secondary channels and the flow to the tertiary levels will be even more unpredictable.

4.2 Equity Indicators

Equity or fairness of water distribution is the most discussed performance measure for large scale supply based irrigation systems. These systems have long and complex conveyance networks which carry a limited amount of water to a vast command area; hence, extra supply to one section of the canal can cause a water shortage in another section. Also, the deteriorated maintenance conditions can disturb the carrying capacity of a part of the system. According to the design documents, and O & M manuals, the design discharges at all levels of the system must be ensured. The measures suggested for this are:

Figure **3:** Head and Tail Supply Relationship
Fourteen distributaries in Kharif 94

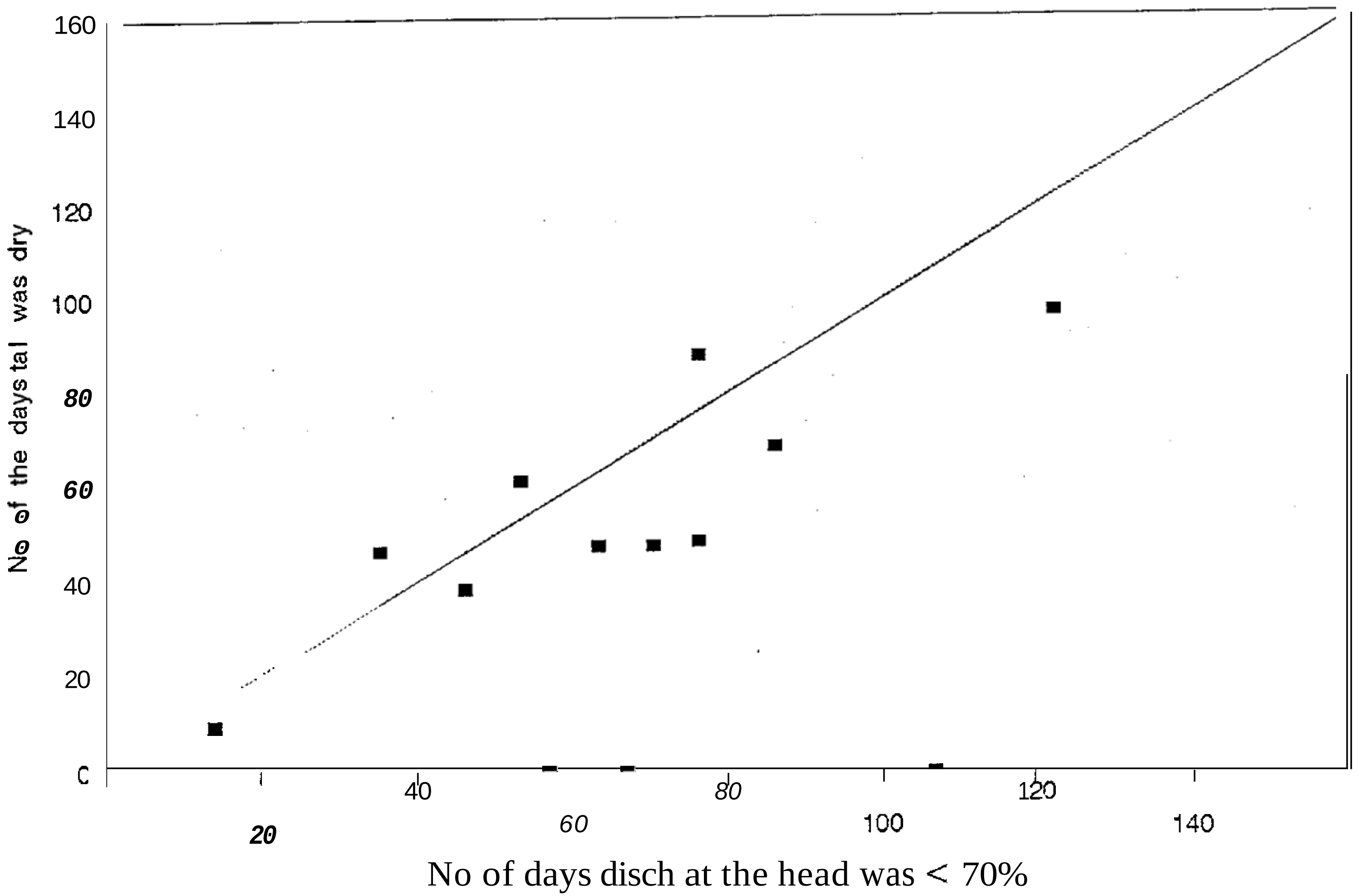


Figure 4

Reliability of supplies at the head of
of Sub-div & two Secondary Channels

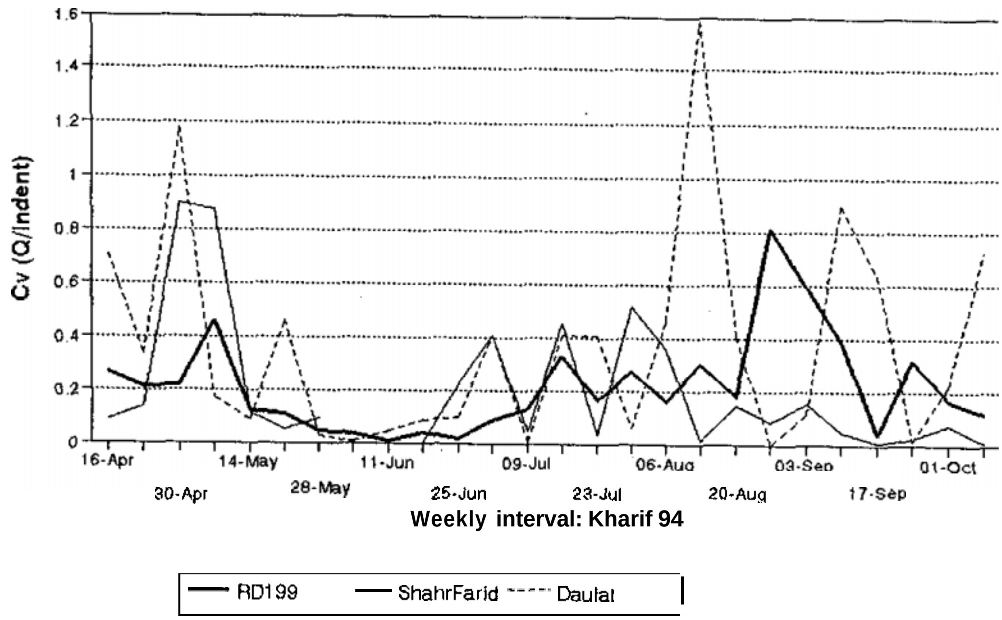
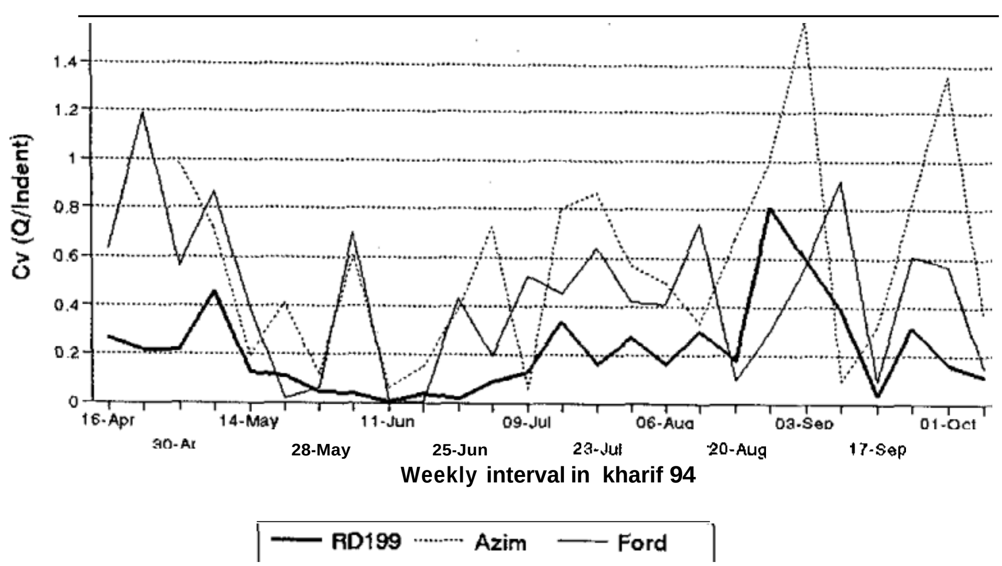


Figure 5

Reliability of supplies at the head of
Sub-div & two Secondary Channels



i. proper regulation of the water diverted at different nodes;
ii. maintenance of canal system; and
iii. water sharing at the farm level (Warabandi)

The importance of equity for Chishtian Sub-division is to distribute the water shortage and excess proportionally. Five equity indicators have been used to evaluated the spatial distribution of water over fourteen distributary head regulators:

i. Modified Inter Quartile Ratio;
ii. Relative Equity Ratio;
iii. The Relative Mean Deviation (UCC);
iv. Spatial Coefficient of variation; and
v. Theil's Coefficient.

4.2.1 Modified Inter Quartile ratio (MIQR)

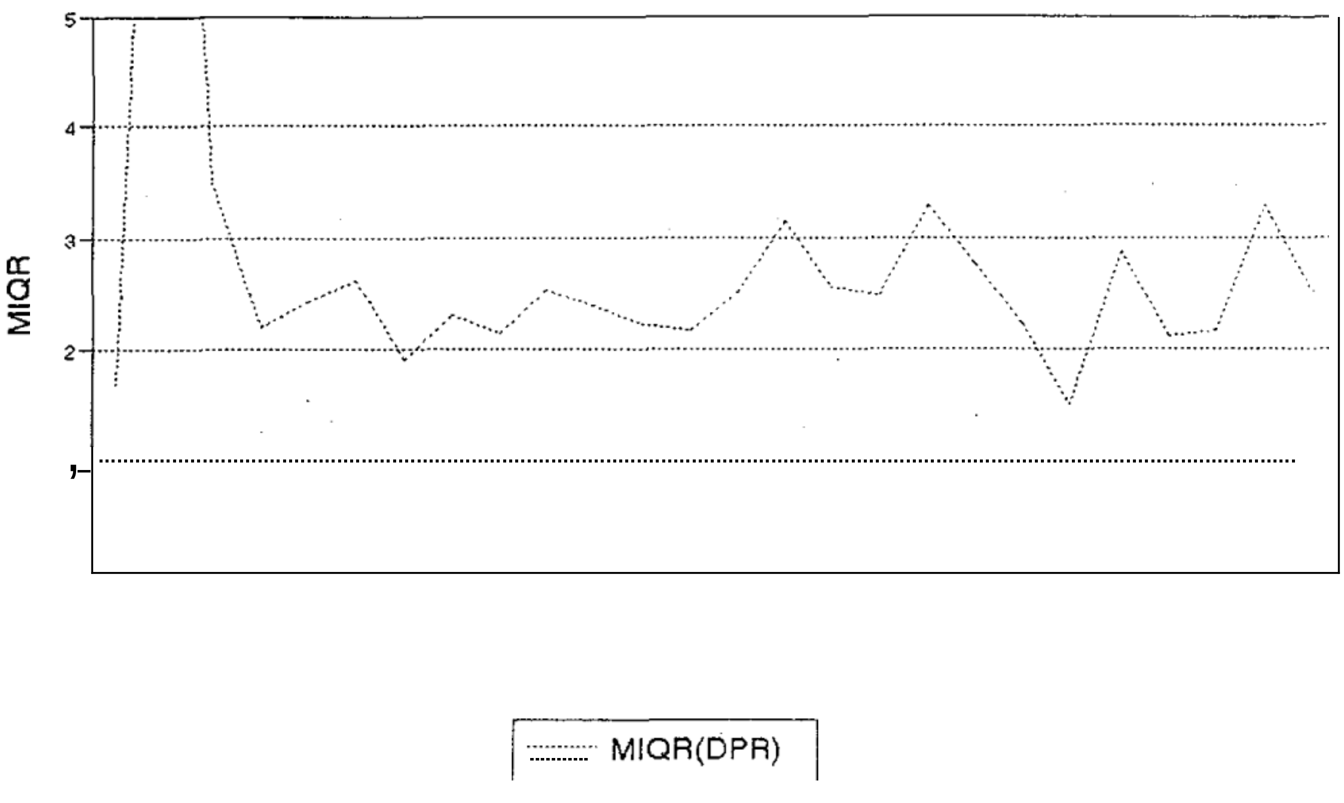
MIQR was proposed by Abernathy (1986) and has been recommended by many researchers due to its simple and quantitative nature. It is originally defined as a ratio of average depth of water received by all, land in the best quarter to the average depth of water received by the poorest quarter. The equal water depth over the command area is an equity target by definition. However, to address the target of the manager of Chishtian Sub-division, MIQR is evaluated here for the delivery performance ratio (actual/target discharge).

Figure 6 shows the Modified Inter Quartile Ratio for a six month period during Kharif 94. During this period, MIQR varies in the range of 2.05 to 2.8 (target is one) which is the level of inequitable distribution. The peaks occur during the period of disturbed .supply when some of the distributaries were closed due to rains. The values of 2.05 and 2.8 indicate that the supply to the best quarter is two to three times more than the supply to the worst quarter. In its computations, MIQR considers the best situation as its target, without taking care of the validity of this situation. The best quartile of MIQR can be a section receiving water more than its share (privileged one) and the ratio of the best to the worst though represent the level of inequality, but not the actual departure from the required fairness.

A slightly different comparative technique is used in the next section to more explicitly consider the fairness of distribution.

Figure *6*

Modified Inter-Quartile Ratio
Fordwah Branch Distributaries Khar f 94



4.2.2 Relative Equity Ratio (RER)

RER is again a ratio between the best-off and worst-off groups, where the middle group receives water within the 10% of the proportionately fair amount, and is called a standard group. The areas receiving water higher or lower than this range are put respectively in the privileged and deprived categories.

For the Relative Equity Ratio, the fourteen distributaries of Fordwah Branch Canal have been divided into three unequal sections. The standard section is the section which received water within the irrigation department recommended range of 70 to 110%. The privileged section gets more than 110% of design (target), while the deprived section receives less than 60%. The breakdown of command area, according to this criteria, is quite informative itself; only **4%** of the area is privileged, while about 30% of the area is deprived.

Figure 7 shows the ratios *of* the **DPR** of the privileged and the deprived sections to the DPR of the standard section. This figure indicates that during the maximum demand and stable period a small command area gets about double, the water as compared with 66% of the command area of the sub-division. The ratio for the deprived section indicates that this section gets almost 70% of the standard section during the maximum demand period. On the average, it gets 25% less water. The peaks shown in the figure occur during low demand or rainy periods.

In the context of Fordwah, this indicator seems quite informative. There ***is*** a need *to* further apply (and explore) it to the systems where part of *the* command area gets more than its fair share, while another part is deprived.

4.2.3 The relative mean deviation (UCC):

Christiansen coefficient of variation (UCC) is originally defined as;

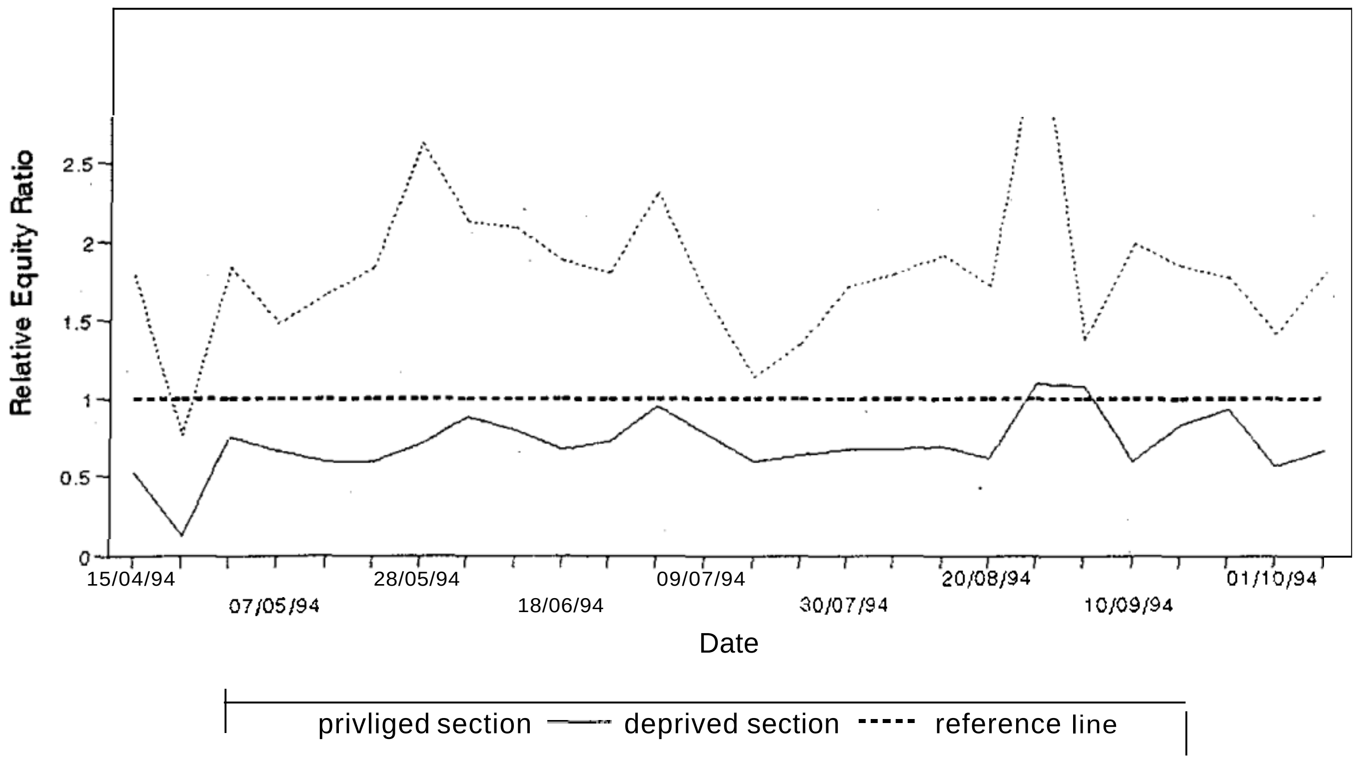
$$UCC = 1 - \sum_{i}^{n} (|X_i - \bar{X}| a_i) \; / \; (\sum_{i}^{n} a_i)\bar{X}$$

where

x_i ,is the value of a single unit (DPR of a distributary)
$\bar{x}$ is the average value (average DPR)
a_i is the number of units (number of distributaries)

Figure 7

Relative Equity Ratio for Fordwah
Priveliged/Std & Deprived/Std Sections



This coefficient is a relative mean deviation which compares the **DPR** for each unit with the gross mean **DPR** by taking the average of all absolute differences of the mean and the actual values. The average absolute difference is then subtracted from 1. The maximum value of UCC is 1 for complete equality where all individual values are same as the mean value. For this study, only the mean deviation term of the equation is used to make it comparable with other range variables (coefficient of variation, Theil's coefficient) which should have a value of zero for complete equality.

Figure 8 shows the Relative Mean Deviation for the fourteen distributaries. The low values of .13 and .205 occur during supply disturbed periods. While for the normal supply period, it varies between .22 to .53, which indicates a 22 to 53 percent deviation from equity according to this indicator.

UCC is not sensitive to a shift within the units lying on the same side of the mean share. The important characteristic of the UCC is that if all units are getting low supplies, the variation within the units will be less important because UCC will have a smaller value'for the same level of inequity. Hence, for this indicator, inequity is more important at higher supplies as compared to the lower supplies.

4.2.4 The Spatial Coefficient of Variation

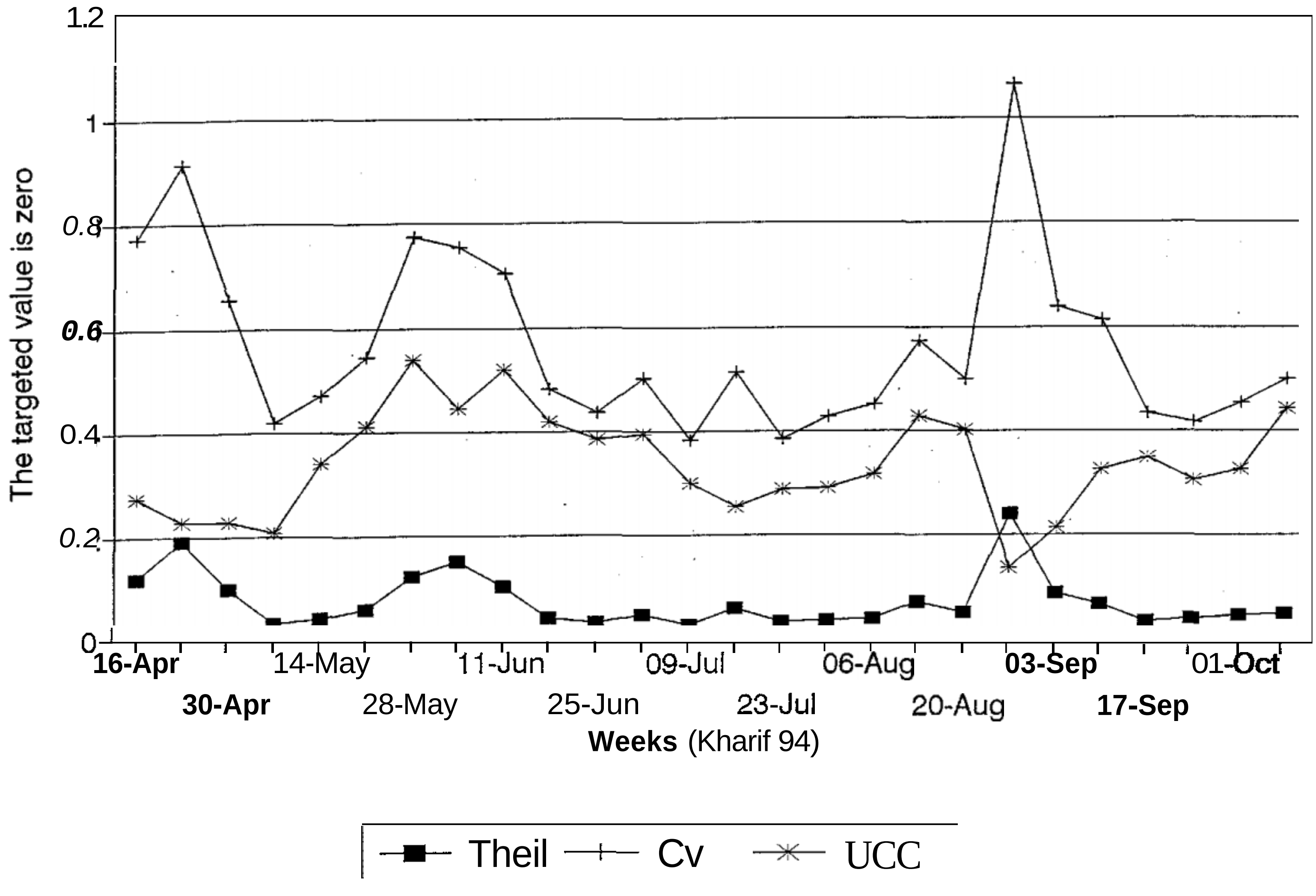
The Coefficient of Variation, Cv, is the most used statistical measure of a distribution function. It is defined as:

$$C_v = \frac{\sqrt{\sum_{i}^{n} (X_i - \bar{X})^2 / (n)}}{\sum_{i}^{n} (X_i) / n}$$

Where, x_i and xare as defined in the previous section and n is mumber of the units.

Cv takes care of inequality of a distribution irrespective of its average level. The important characteristic of the coefficient of variation is its sensitivity for extreme values.

Figure 8 Comparison of Spatial Indicators for the fourteen distributaries of Fordwah



For water scarce irrigation systems, where zero or low supplies could not be avoided, Cv can vary over a large range. This variation indicates the level of *non-uniformity* over time and its pattern characterizes the pattern of supply or scheduling. In itself, Cv is not a real measure of fairness, especially for those systems where supplies can fluctuate between extreme values.

Figure 8 shows that the spatial coefficient of variation (Cv) for Kharif 94 varies in a range of 0.4 to 1.05, its value is higher than 0.6 during the rains and low demand period (the most unstable period). Even during the most stable period, it varies between *0.4* and 0.5, which are quite high values.

The volatile nature of Cv can provide a good preliminary insight into those systems where a good knowledge base and comprehensive information are not already available. Its sharp peaks and valleys indicates that extreme variations or abnormal behavior is there, which can be further explored.

4.2.5 Theil's information measure:

Theil's measure for inequality is a logarithmic expression basically used to represent the entropy. Entropy is defined as a measure of disorder or disorganization in thermodynamics and as a rate of transfer of information in mathematics. Sampath (1989) proposed it for irrigation systems because of its ability to capture the contribution of different components of the system properly. It is defined as:

$$\log n\ H(y) = \sum_{i=1}^{n} y_i \log n\ y_i$$

where n is the number of units to be analyzed and y_i is the fractional share of the ith unit. The H(y) is a measure of the entropy, it is subtracted from its maximum value (log n) to have Theils' coefficient which varies between zero to log n. The value of Theil's coefficient is higher when the number of units *(n)* is higher.

Theil's coefficient is calculated for the Chishtian Sub-division by taking DPR as the unit value. As there are only fourteen distributaries, the coefficient varies in a small range of .04 to .203 (Figure 8). Although there are peaks during the unstable period; when the variations are big, the period from mid-June to mid-August seems very stable and equitable. Theil's coefficient shows the same trend as Cv, including the over-sensitivity to extreme values.

4.2.6 The comparison of equity indicators

The behavior of the three equity indicators; namely, Theil's coefficient, Cv and UCC is compared in Figure 8. The trends shown by Cv and Theils are similar for the whole range, while UCC also shows the same trend during normal conditions. The opposite trend of Cv and UCC during the low supply periods indicates UCC's insensitivity at the low supplies and Cv's over-sensitivity for the extreme cases. From the above discussion of each indicator, it can be concluded that Cv is good in indicating the stability, while UCC is good to estimate the quantitative value of equity.

4.3 A Simple Technique to indicate the Variability of Flows

A number of the indicators discussed above have shown the impact of variations in flow to different extents. In a rotational supply system, the essential and accepted fluctuations must be separated from the unexpected fluctuaticns. The head-tail relations, discussed above, indicate that 70% of the design disctiarye at the head is a threshold to feed the tails. This 70% is already an operational criteria of ID; hence, a manager should try to maximize the number of days when a distributary gets more than 70% of the design discharge. A simple statistical technique, cluster analysis of the actual discharge at the heads of the sub-division and distributaries is used here to indicate the range of fluctuations. The analysis counts the frequency of different discharge ranges.

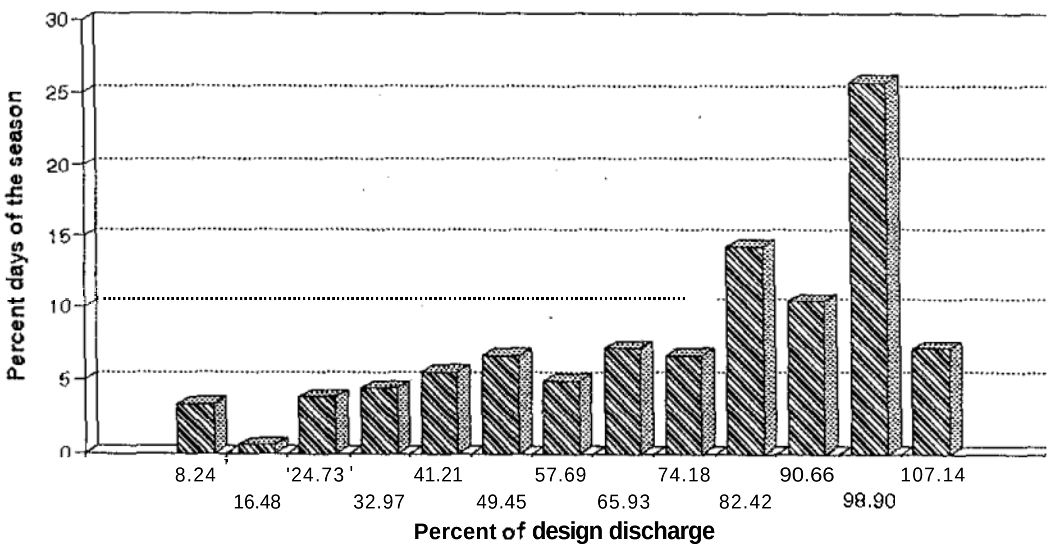
Figures 9 and 10 show the cluster analysis for RD199 (inflow) and two head and tail distributaries of the system. Figure 9 shows that about 12% of the time, the discharge at RD199 is less than 33%, about 22% of the time in the range of 33% to 74%, and about 55% of the time in the range of 74% to 107%. While the first gated distributary of the sub-division, Daualt, is an excellent example of operations. It receives higher than the design discharge for 58% of the time while for 20% of the time it gets lower than 34% of the design discharge. For the rest of the period, it fluctuates, mostly on the higher side. The overall variability of flows at the head of Daulat is much less than the head of the sub-division.

The cluster analysis of two other tail distributaries is shown in Figure 10. Mehmood is a small distributary, always operated at the maximum discharge, while Azim is the biggest distributary of the system and mostly has to acquire the tail shortage. The frequency pattern of Azim is quite arbitrary, only 40% of the time does it get water greater than 60% of the design discharge. From this graph, it can be easily concluded that the chances for the Mehmood tail to get water are 80%, while for the Azim tail these chances are less than 40%.

There is one limitation of the cluster analysis, the time variable is not included, but, from the plots discussed above, a manager can easily see what percent of time his objectives have been achieved and what is the range of the fluctuations.

Figure 9

Discharge Variability at RD 199
Cluster Analysis for Kharif 94



Flow Variability at the Head of Daulat
Cluster Analysis for Kharif 94

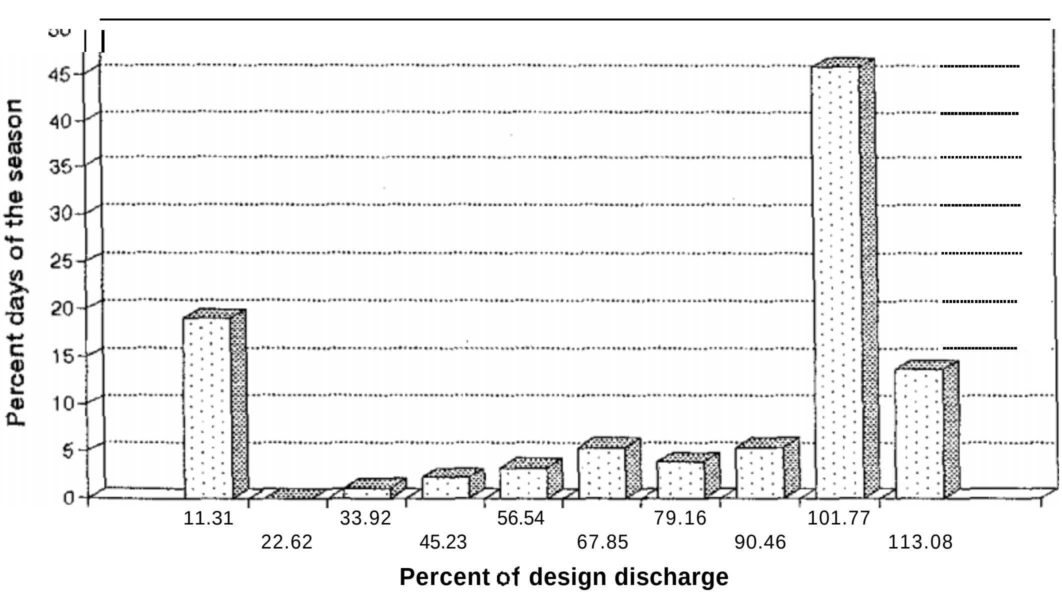
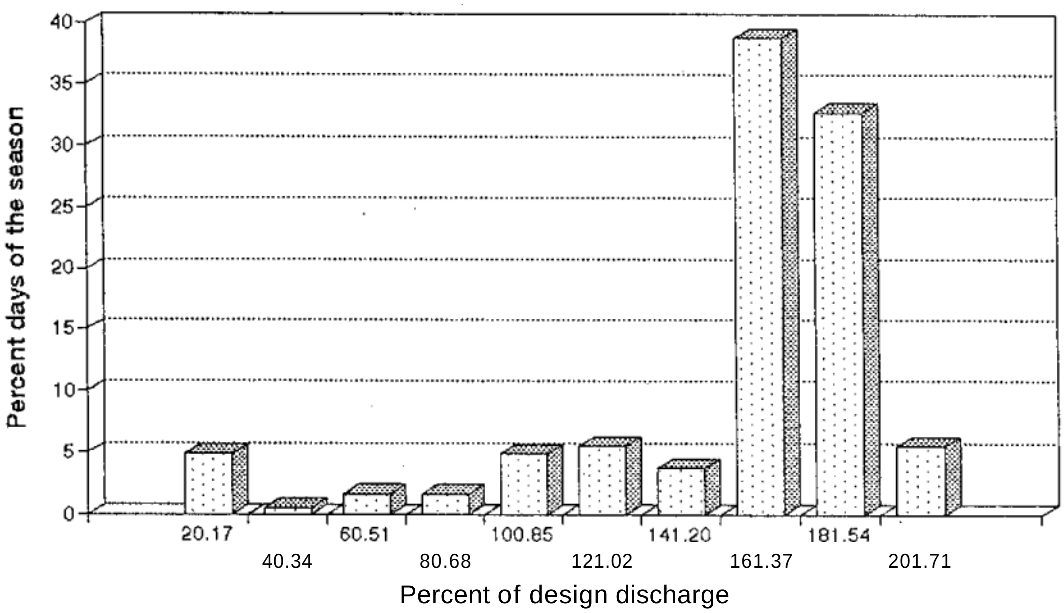
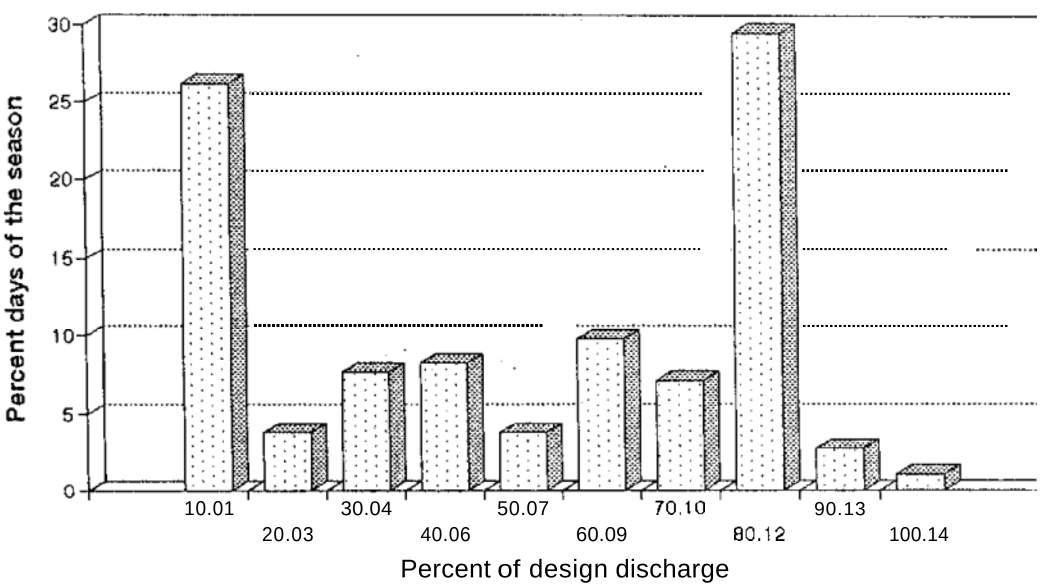


Figure 10

Flow Variability at the Head of Mehmud
Cluster Analysis for Kharif 94



Flow Variability at the Head of Azim
Cluster Analysis for Kharif 94



5 FROM THE PROSPECTS OF IRRIGATED AGRICULTURE

5.1 Adequacy *of* supplies

To meet the water requirements for the crops is a basic need of the farmers, In the Chishtian command area, the gap between the crop water requirements and the canal water supplies is partly satisfied with ground water use. The mismatch between canal supplies and crop demands has been magnified due to the increase (about 100%) in cropping intensities and the shortage of water at the node (more than *30%* of the design). To illustrate the impact of these two factors, the design and the actual water depths (for canal water only) for the Rabi 93-94 and for the Kharif 94 are shown in Figure 11

The two big distributaries are further analyzed by computing the Relative Water Supply (RWS) based upon the primary data of rainfall and ground water use for the sample watercourses. RWS is considered as a powerful adequacy indicator, which relates the process of irrigation with agriculture.

RWS = (Actual supply+ rain fall)/ (Crop Et + S and P)

where Et is evapotranspiration, S is the seepage and P is the percolation losses.

A reliable monitoring of the many processes is required to compute reasonable values far RWS:

a. actual irrigation water supply by all of the sources;
b. rain fall for all units of the command area;
c. cropping intensities and then crop water requirements; and
d. a good estimation of conveyance losses.

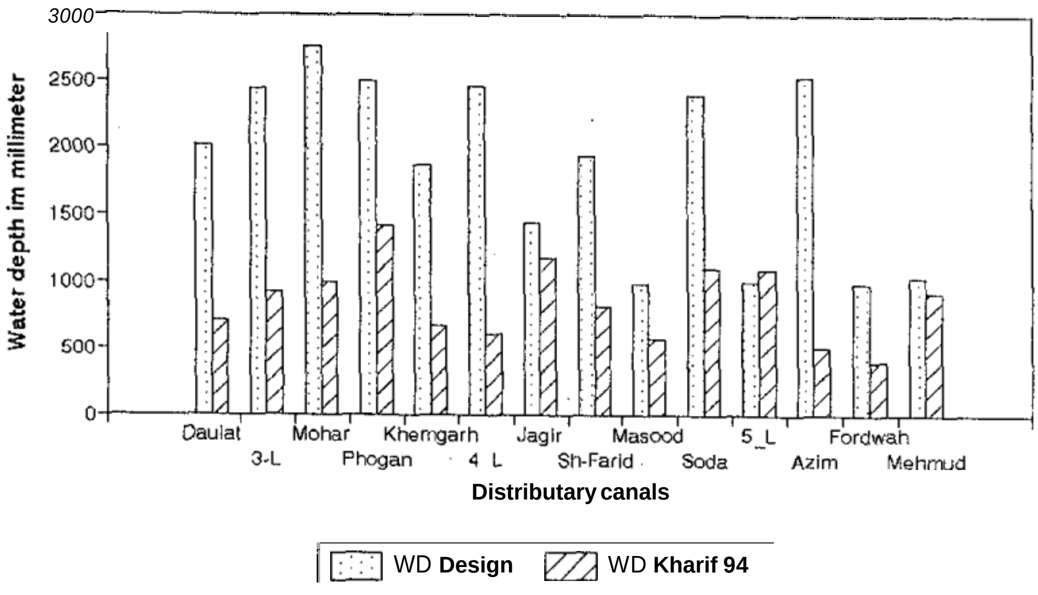
Crop water requirements for the command area are estimated using FAO's package CROPWAT. The relative water supply index for Azim and Fordwah distributaries is 0.53 and 0.47, respectively, which indicates a severe water shortage during the kharif season.

5.2 Mao-Zhi's Composite set of Indicators

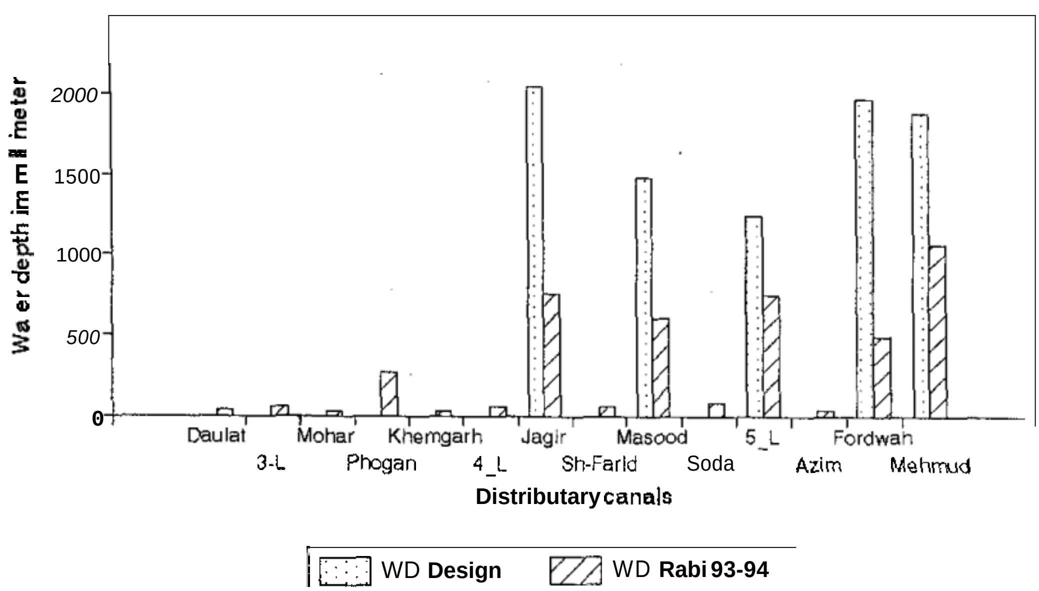
In 1989, Mao Zhi presented a set of twelve techno-economic indices to assess the gross performance of a rehabilitated scheme in South China. Six of these indices address the relative conditions of the land and water utilization; these six indicators are applied here for Kharif 1994.

Figure 11

Average Design and Actual Water Depths For Fourteen Distributaries: Kharif 94



Average Design and Actual Water Depths For Fourteen Distributaries: Rabi 93-94



(1). *Efficiency of* Utilizing *Irrigation* Water Resources, S

$S = Wp/Wd*100$

where Wd and Wp are the design and actual annual water quantities supplied to a system during the current season (m^3/season).

(2) Gross Seasonal Irrigation Water Quota, M **(m3/ha/season)**

$M = W/A$

Where W is the total canal water used for irrigation and A is the total area irrigated.

(3) Irrigation Application Efficiency, E

$E = W_f/W_h$

where, W_f is the total volume of water delivered to the points of use in the field by the irrigation canal system; and W_h is the total volume of water diverted *to* the head of the sub-division.

(4) Efficiency of Actual Irrigated Area, **F**

$F = A/A_d$

A is actual and A_d is design irrigated area.

(5) Percent of Area Provided with Field Irrigation and Drainage Sysfem, F

$D = A_{fa}/A_{fd} * 100$

where $A_,$ and $A_,$ are the design and actual area provided with the field irrigation and drainage facilities.

(6) Efficiency *of* facilities in a good condition, *G*

$G = Ng/N*100$

Where N is the total number of canal structures and Ng is the number of structures in good condition.

Table 3 below gives the computed and design values of these indicators for gross seasonal quantities at the sub-divisional level.

Table 3. Mao Zhi's Indices of irrigated area and water utilization

Distributary	Efficiency of resources	Irrigation Quota	Actual Area Efficiencv	% area with drainaae	Efficiency facilities	Irrigation efficiency
		m^3/ha/season				
Target value	1.56e+161	8000	35	0	100	50
RD199	61	9800	65	0	84	61
Daulat	72	6811	1.56e+161	0	69	57
3-L	45	9378	1.56e+161	0	83	58
Mohar	52	9650	0.74	0	77	59
Phoaan	128	13346	1.19	0	78	59
Khemgarh	67	6633	0.95	0	78	56
4_L	66	7441	1.09	0	71	60
Jaaii	63	9589	1.23	0	78	60
Sh-Farid	73	7924	0.90	0	66	54
Masood	89	6161	1.44	0	88	60
SODA	63	8447	0.90	0	88	56
5_L	154	11305	1.36	0	50	51
Azim	43	5078	1.56e+161		1.56e+161	1.56e+161
Fordwah	71	4265	1.65	(	1.56e+161	1.56e+161
Mehmood	153	11148	1.30	0	71	59

Mao Zhi's indices are quite powerful for indicating a gross seasonal picture of the water availability and the irrigated area. The efficiency index shows that 60% of the area got about 75% of the water. The most suffered distributary is at the tail (20% of area) which gets less than 50% of the design discharge. There are three small distributaries getting too much water. The pattern shown by index 'M' is slightly different from the efficiency indicator 'S'. 'M' is always higher for the distributaries getting too much water, but not always lower for the distributaries having severe water shortage. This strange behavior of the index 'M' can be explained by the efficiency of the actual irrigated area index 'F'. This index shows clearly that the actual irrigated areas are more than design for those distributaries where the availability of canal water has been ensured, while prominently low for the distributaries where less water is available. So, the farmers having a water shortage do not take the risk of cultivating all of their area. No drainage has been provided in the area; hence, the drainage index is zero. The irrigation efficiency has been calculated based upon the seepage and conveyance losses measured by IIMI in the field.

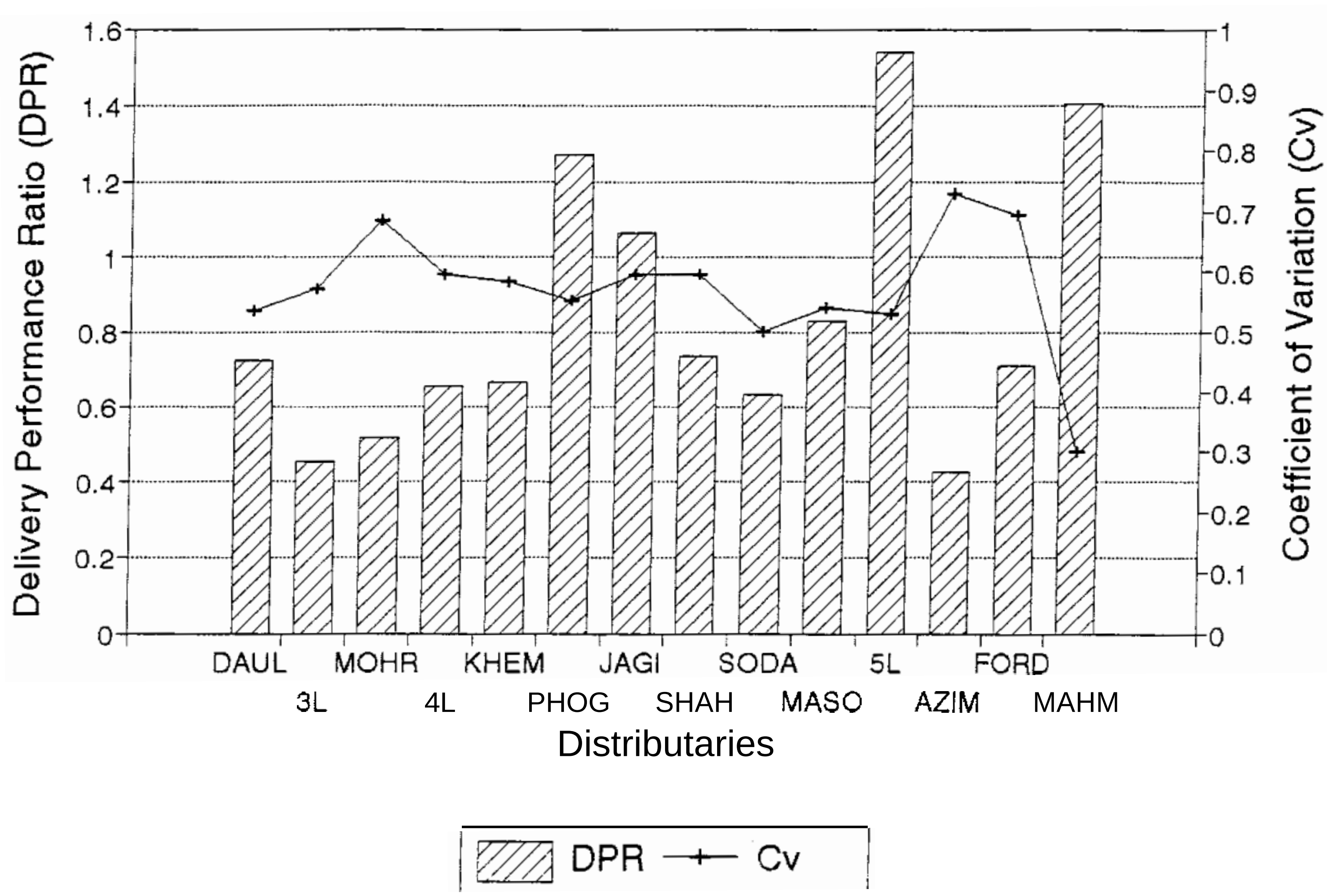
6. DISCUSSION OF THE RESULTS

The performance analysis indicates that the total supplies to the sub-division are not adequate to meet the crop water requirements, they are less than even the design and indent discharge. The ground water is used to compensate for the shortage to some extent. The distribution of ground water shortage is not equitable and the variability of flows at the head of the secondary canals is quite high. The overall picture of the sub-division is shown in Figure 12.

The first part of the analysis indicates that the traditional approach provides rules and indicators to a manager for the strengthening of the process of monitoring and evaluation for water scheduling and distribution. If all of the conditions are met, these indicators provide sufficient support to a manager at the sub-divisional level to address his targets. The prerequisite for this process is to keep the monitoring and the control tools in updated conditions. All head and tail gauges should be available and calibrated at least once in a season, discharge data must be recorded daily a communication system should be available and the secondary channels need to be operated in the flow range of 70 to 120 percent. These indicators, however, do not provide direct and quantitative values to assess the general objectives of an irrigation system.

The second section shows that the application of the internal indicators can be useful for having judgment of the performance of a water distribution system (consisting of many channels). The equity and the reliability of the water distribution can be measured by different statistical or mathematical indicators. The choice of indicators depends upon the level of the analysis and the user, sometimes simple variables can replace the complicated ones, These internal indicators can be used at the weekly, monthly or seasonal intervals depending upon the need of the user.

Figure 12: Delivery Performnace Ratio & Cv at the Head of Distributaries in Kharif 94



The application of the third set of indicators is not exhaustive in this paper. Two examples have been given to indicate the value of knowledge about the gross performance of the system from the perspectives of the irrigated agriculture. Without knowing the status of the total resources utilized and the output of the system, it is not possible to have a better understanding of the irrigation schemes. This type of knowledge can be useful for the policy maker and the managers sitting at higher levels, In the context of a main canal of the Indus Basin, it is required to improve the monitoring and evaluation procedures and to start using a few simple internal and external indicators to assess the performance of the water distribution system.

7. CONCLUSIONS

* Within the sub-division, the authorized or promised supplies are not being provided to 30% of the area for most of the time. The reasons for this are water shortage and the system's operations.

* The existing rotational procedures have not been able to distribute the shortage equitably.

* A big gap exists in the water demand of crops and canal supplies; this gap is partly compensated by ground water use which is managed by the farmers.

* The objectives and the targets of the irrigation system cannot be defined clearly without considering it a part of irrigated agriculture.

* There is a need to reconsider the management of water resources with reference to their productivity.

* For better operation of the sub-division, the communication system needs to be reinstalled completely or partly.

* The traditional set of indicators provides useful information to evaluate the recommended operations of the system. A regular implementation of these indicators would improve the water distribution and scheduling at the sub-divisional level.

* To better evaluate the objections of equity and reliability, there is a need to use a few more internal indicators like spatial and temporal coefficient of variation, relation equity ratio and cluster analysis.

* To evaluate the function of the canal irrigation system in the context of irrigated agriculture, an overall performance assessment is essential. The external indicators discussed in the last section provide information about the gap between supply and demand of water in development of the different aspects of the system.

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