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

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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

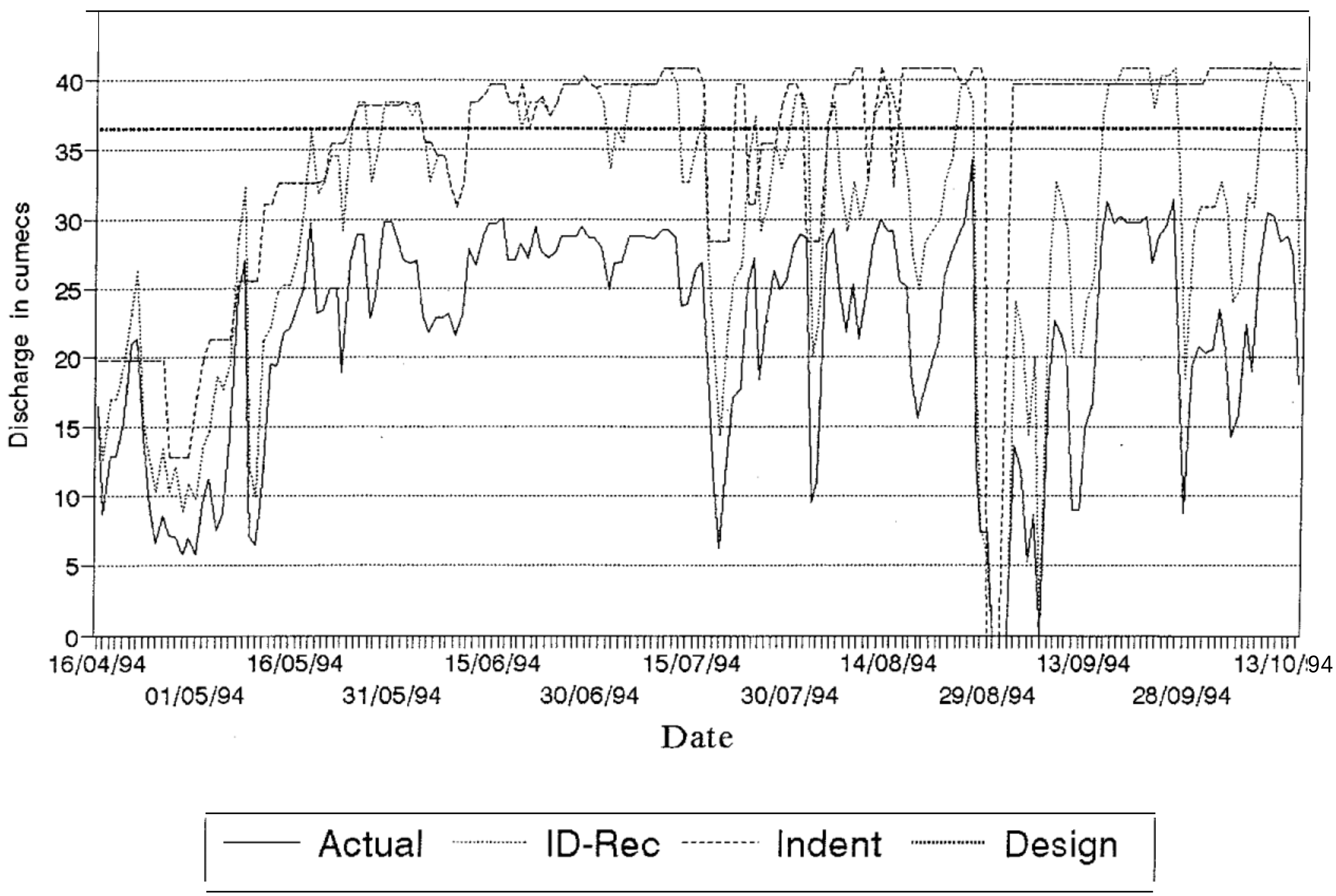
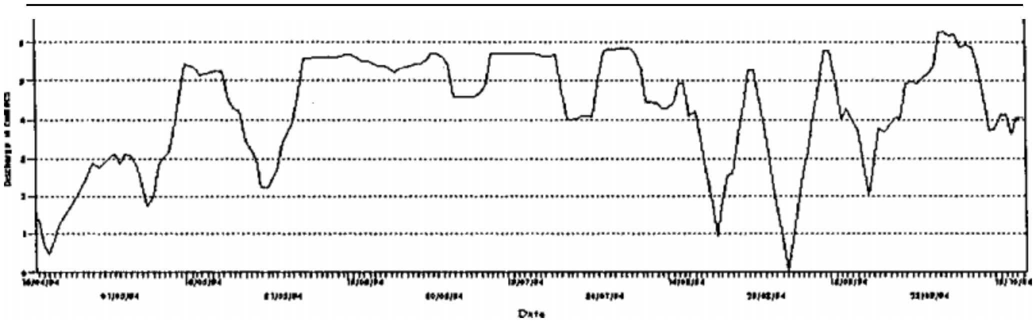
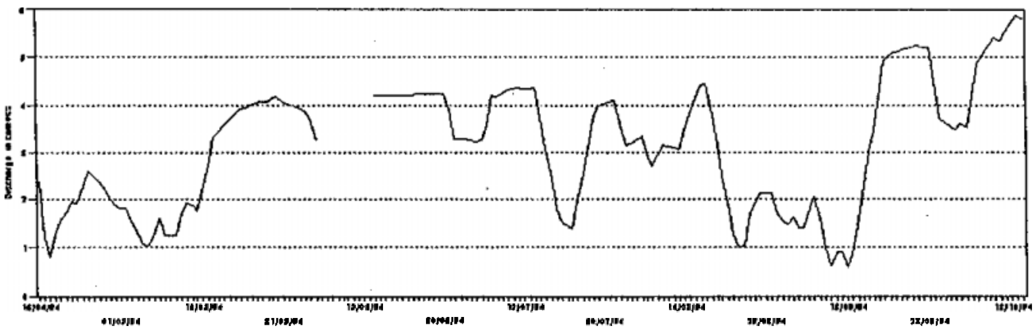


Figure **2**

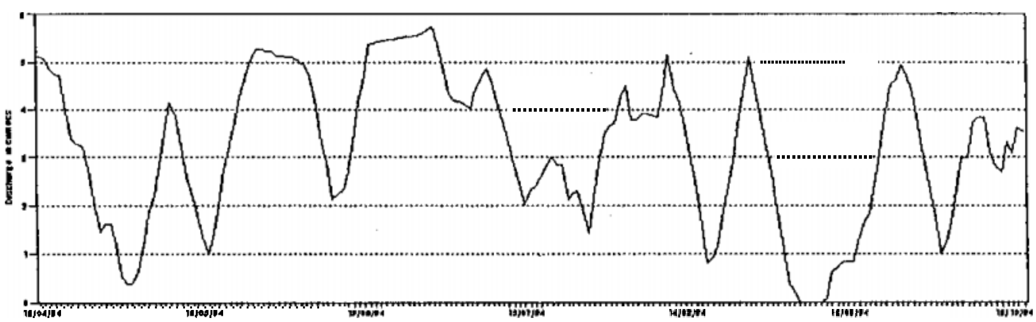
Actual Discharge of Daulat located in
First reach of Fordwah Branch: Kharif 94



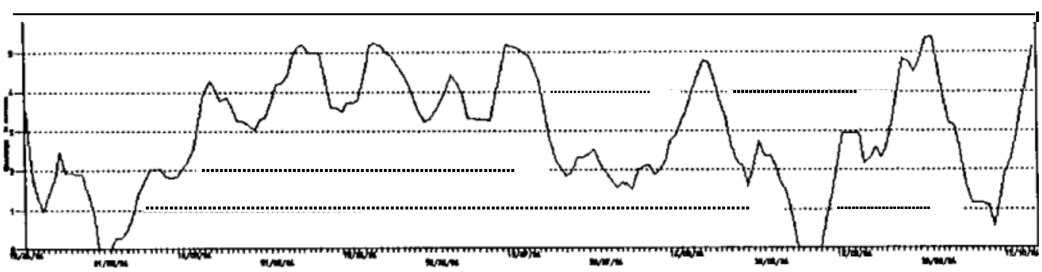
Actual Discharge of ShahrFarid located
2nd reach of Fordwah Branch: Kharif **94**



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

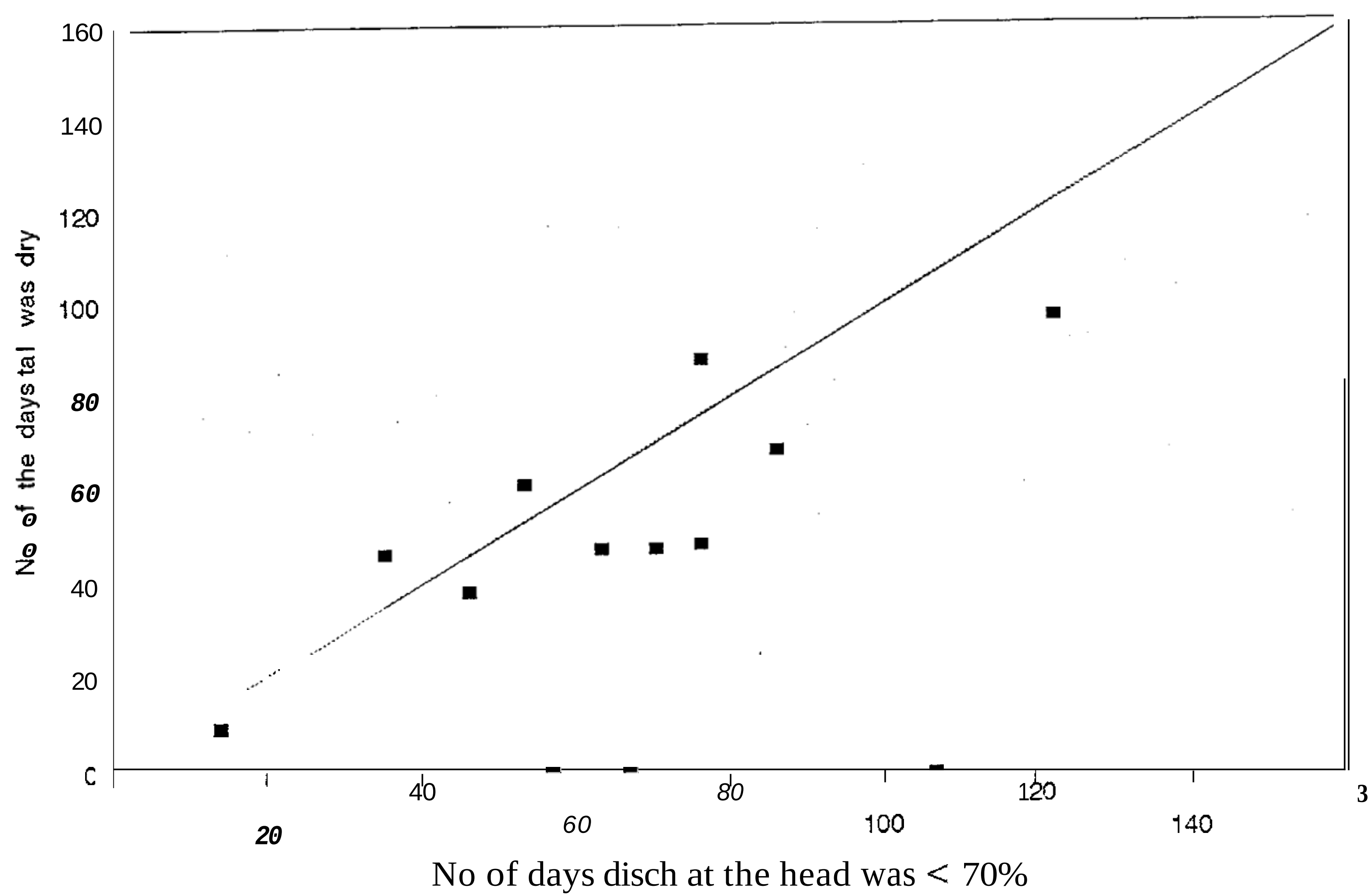


Figure 4

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

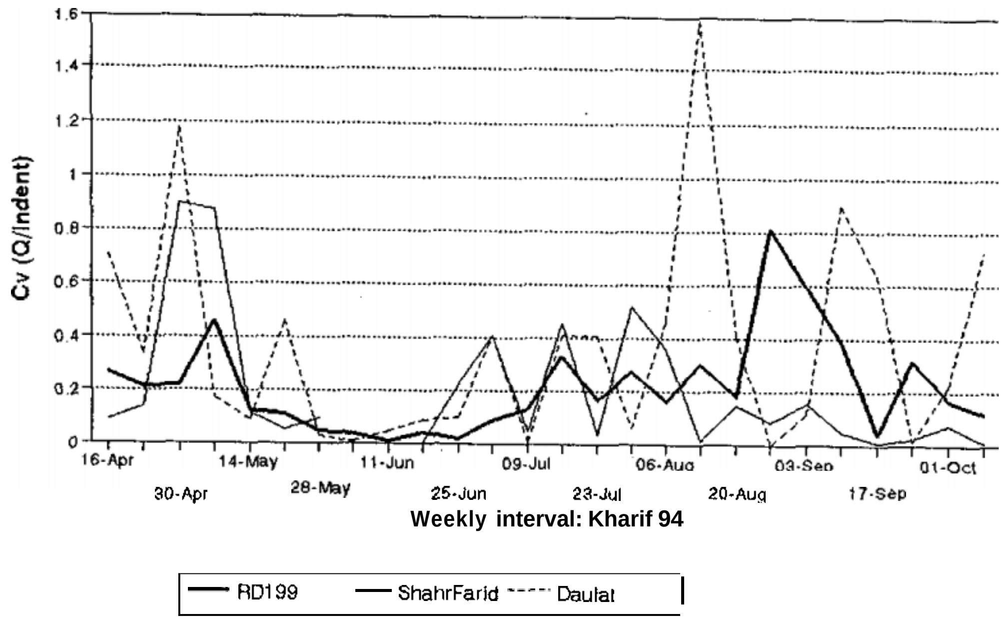
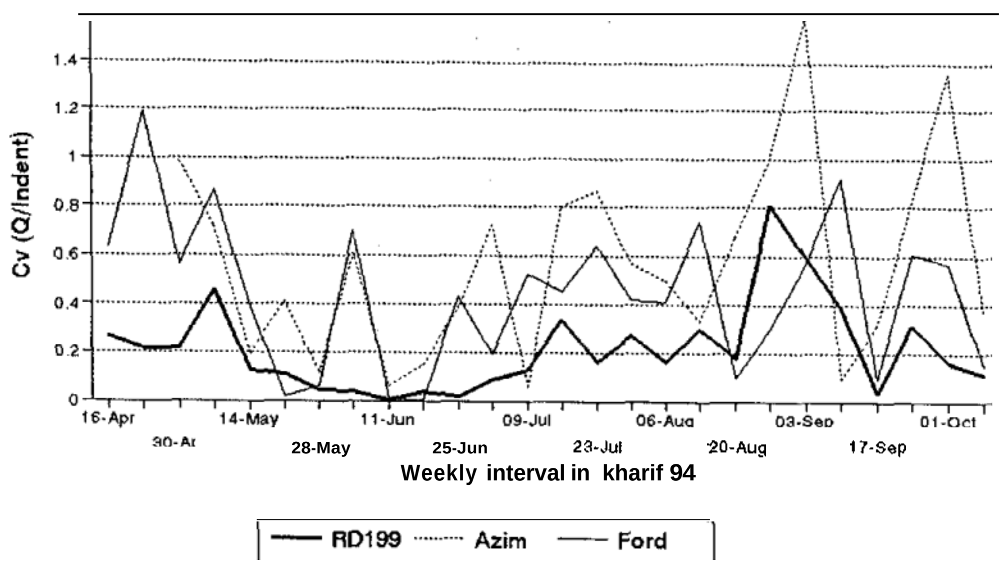


Figure 5

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)

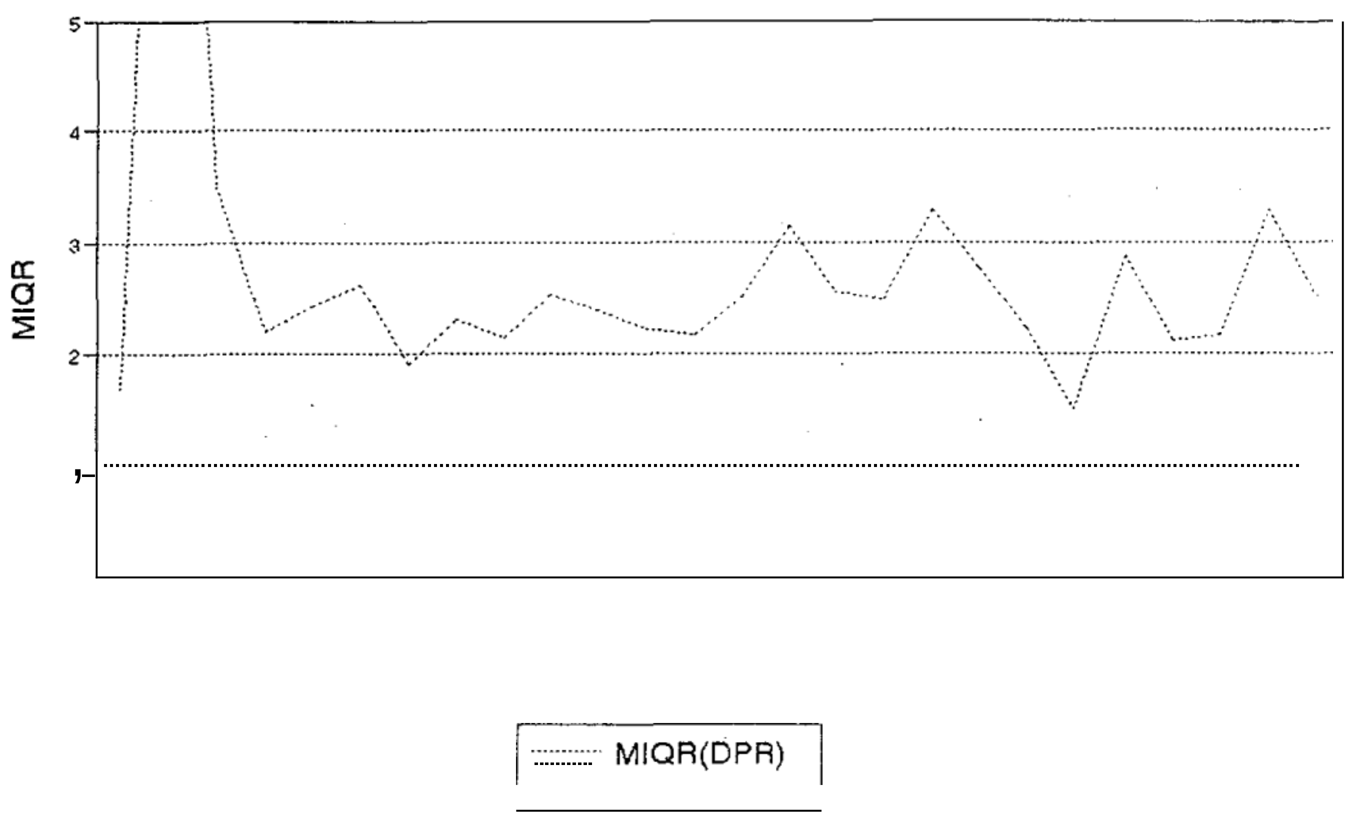
MIQR was proposed by Abernathy (1986) and has been recommended by many researchers due to its simple and quantitative nature. It is originally defined as a ratio of average depth of water received by all, land in the best quarter to the average depth of water received by the poorest quarter. The equal 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):

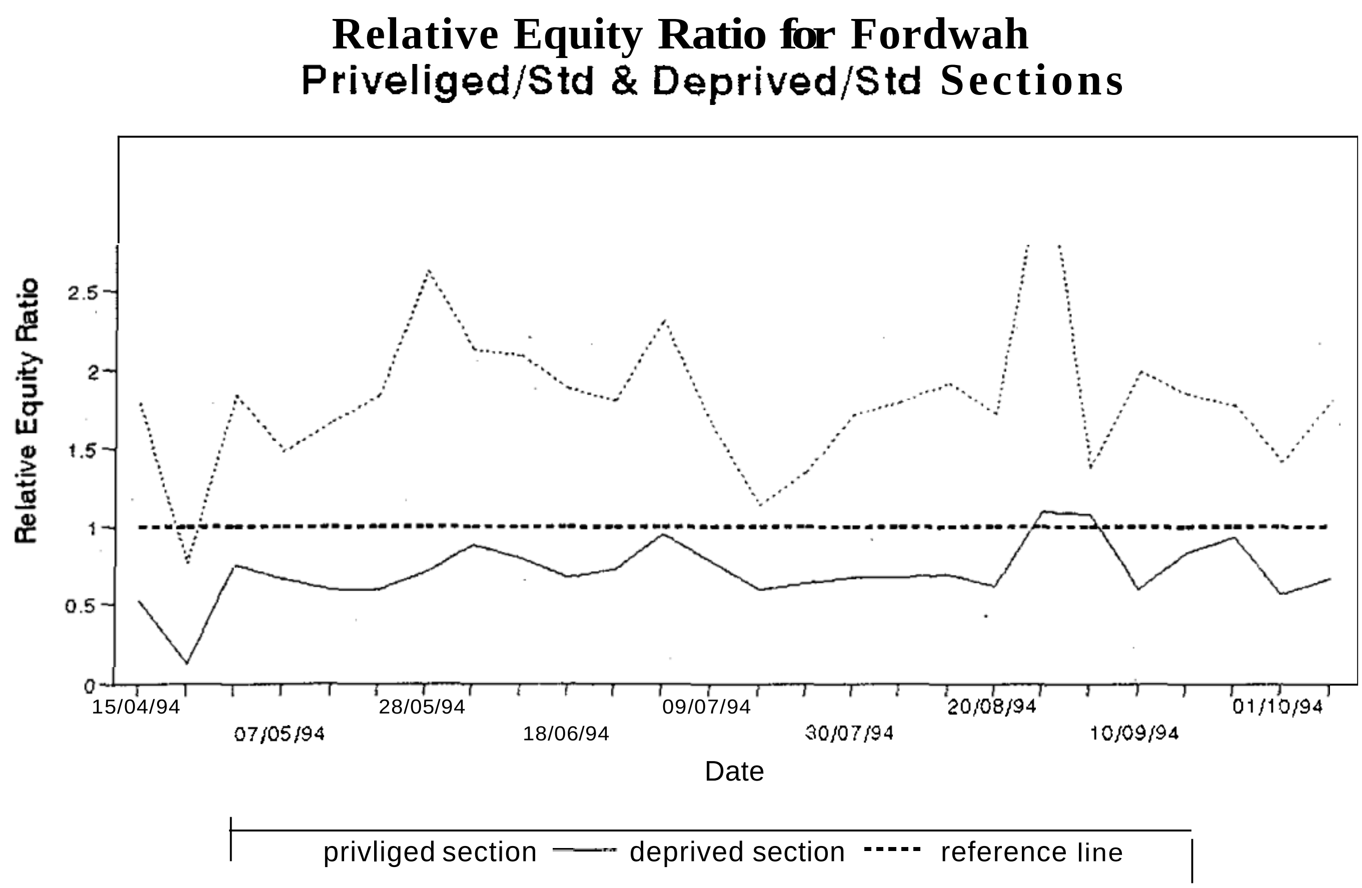
Christiansen coefficient of variation (UCC) is originally defined as;

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

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
Relative Equity Ratio
0
0.5
1
1.5
2
2.5
15/04/94
07/05/94
28/05/94
18/06/94
09/07/94
30/07/94
20/08/94
10/09/94
01/10/94
Date
privliged section
deprived section
reference line

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

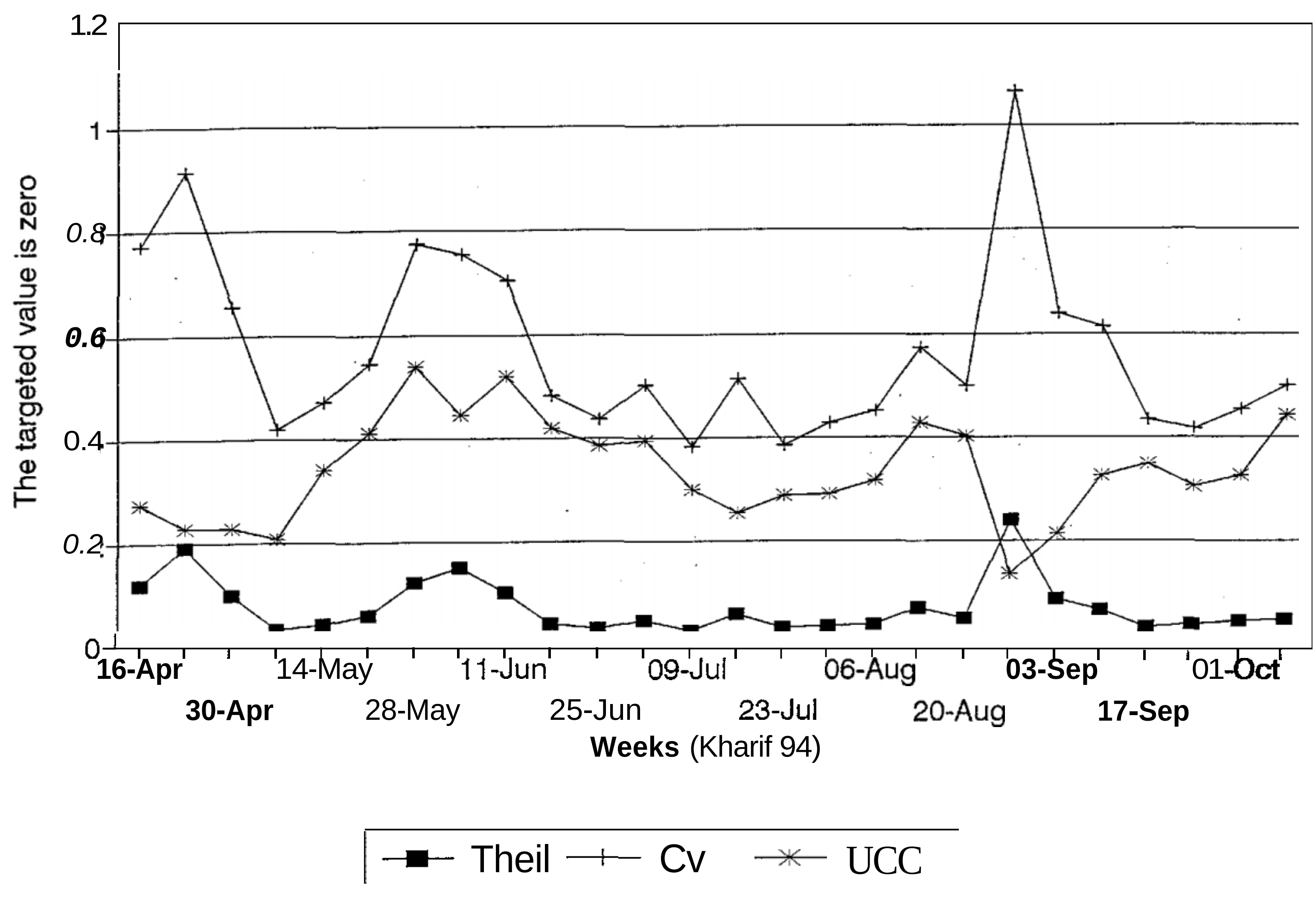
The Coefficient of Variation, Cv, is the most used statistical measure of a distribution function. It is defined as:

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

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.

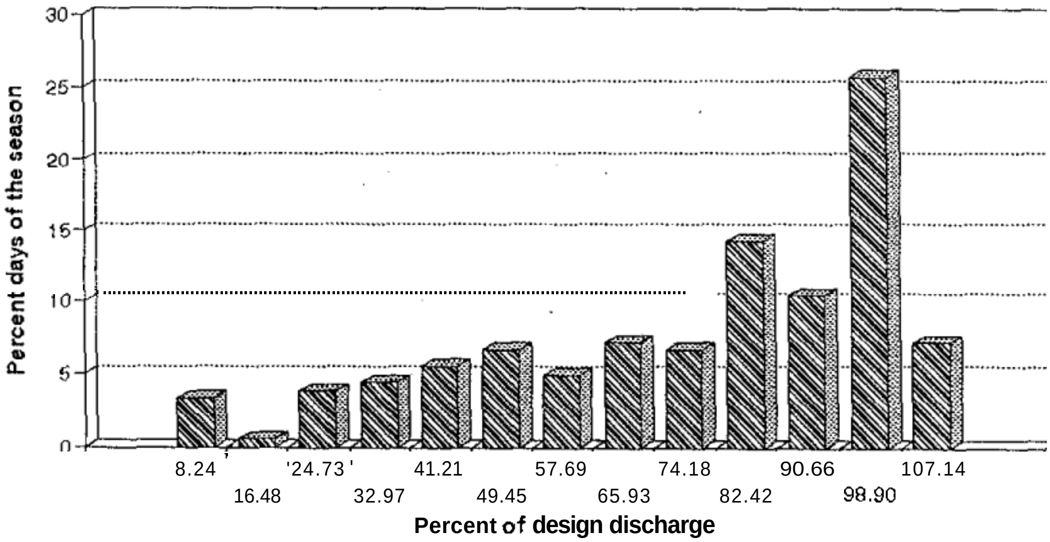
Figures 9 and 10 show the cluster analysis for RD199 (inflow) and two head and tail distributaries of the system. Figure 9 shows that about 12% of the time, the discharge at RD199 is less than 33%, about 22% of the time in the range of 33% to 74%, and about 55% of the time in the range of 74% to 107%. 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

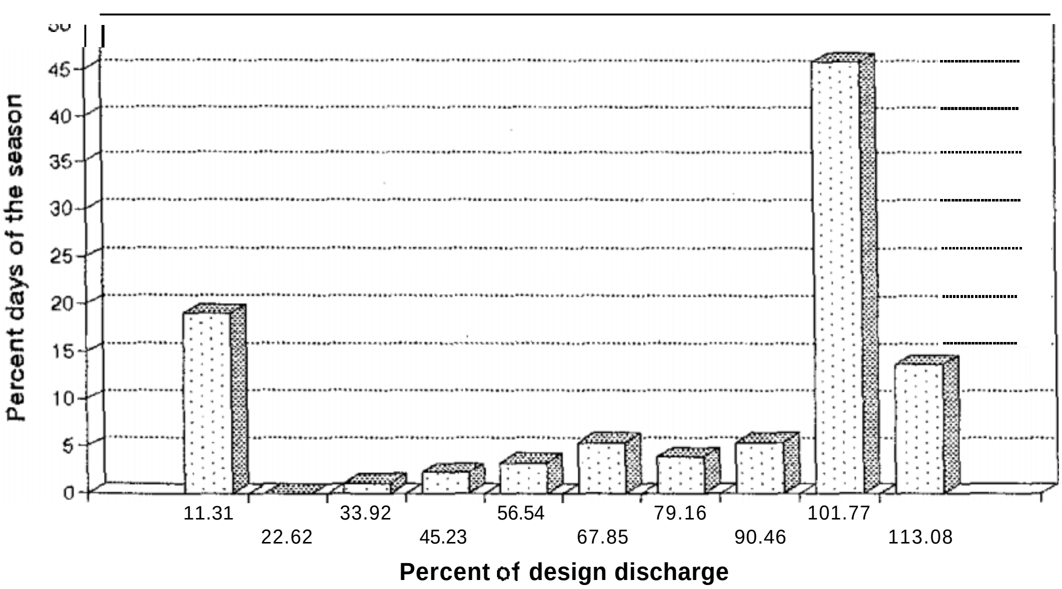
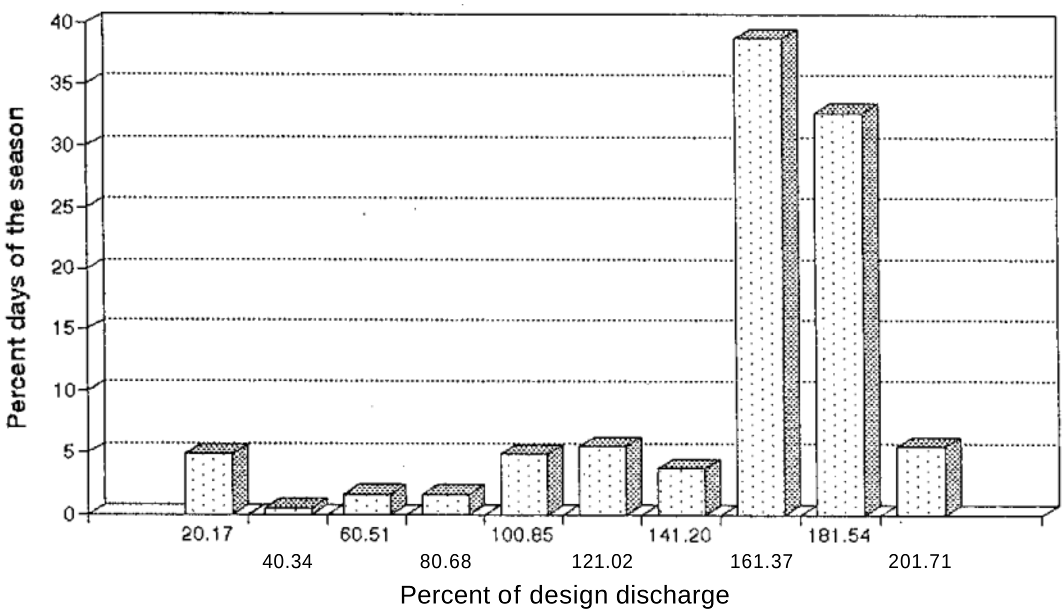
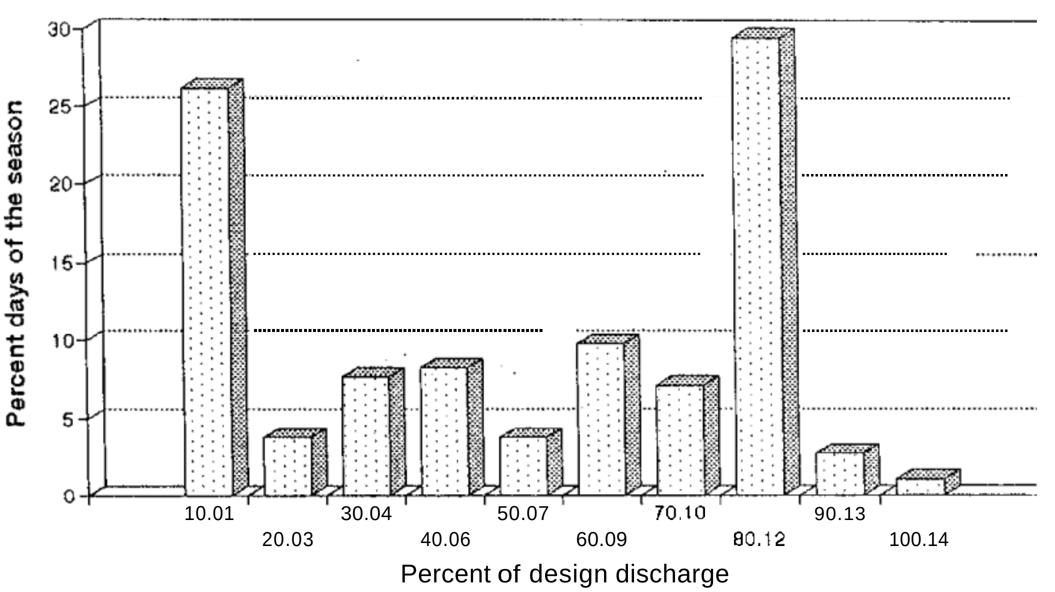


Figure 10

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.

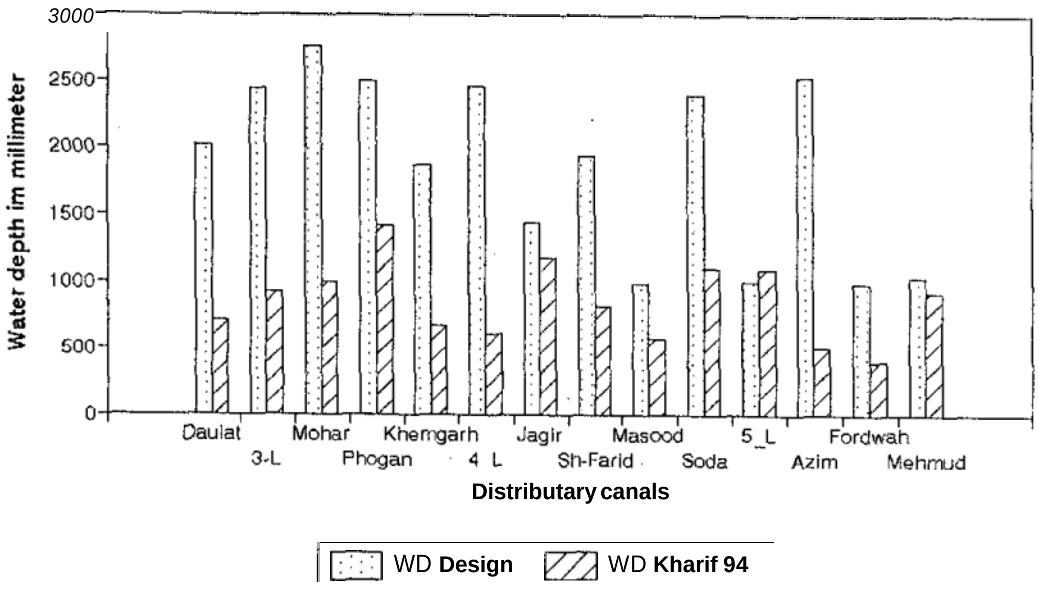
Crop water requirements for the command area are estimated using FAO's package CROPWAT. The relative water supply index for Azim and Fordwah distributaries is 0.53 and 0.47, respectively, which indicates a severe water shortage during the kharif season.

5.2 Mao-Zhi's Composite set of Indicators

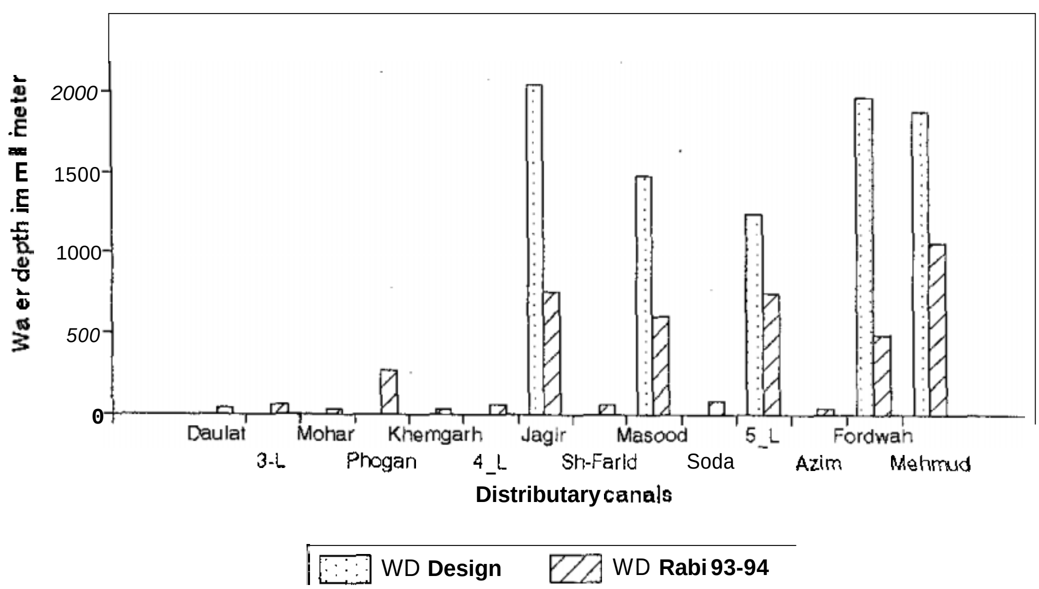
In 1989, Mao Zhi presented a set of twelve techno-economic indices to assess the gross performance of a rehabilitated scheme in South China. Six of these indices address the relative conditions of the land and water utilization; these six indicators are applied here for Kharif 1994.

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 = WIA

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
Jaqii	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.

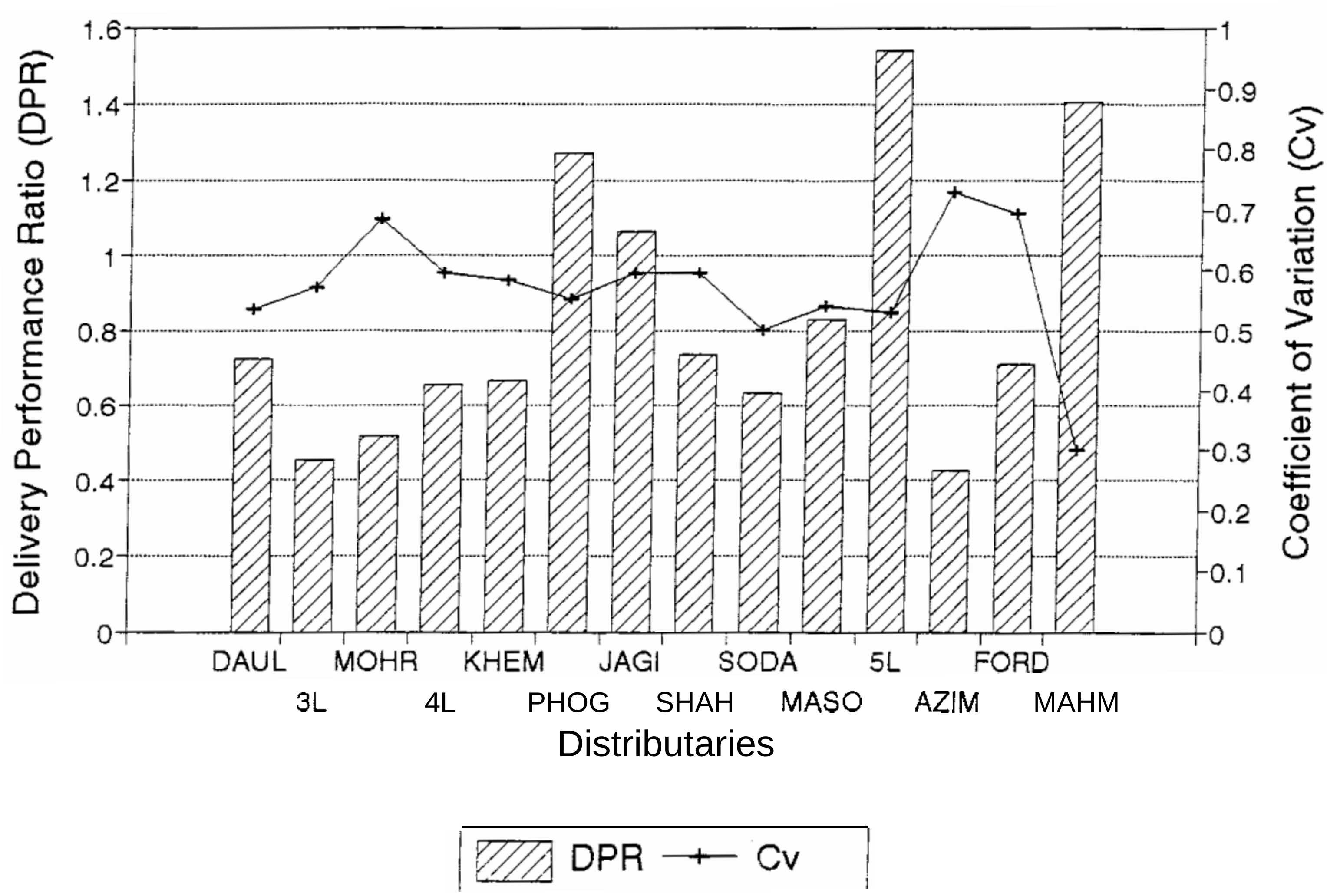
6. DISCUSSION OF THE RESULTS

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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