ANALYZING THE IMPACT OF ALTERNATIVE OPERATIONAL RULES ON WATER DISTRIBUTION

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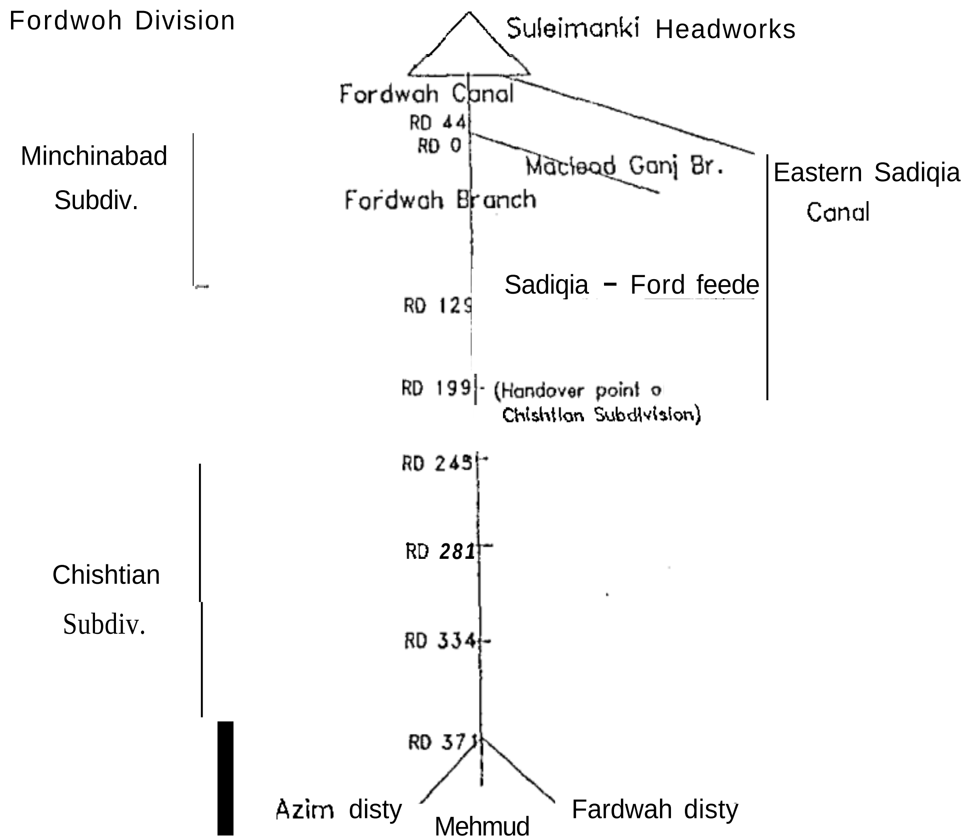
4 Kuper and Kijne (1992) show that the official allowances vary between 0.8 to 1.4 l/s/ha. Also, canal commands have been designated perennial and non-perennial, the latter receiving water only during the flood season (Kharif).

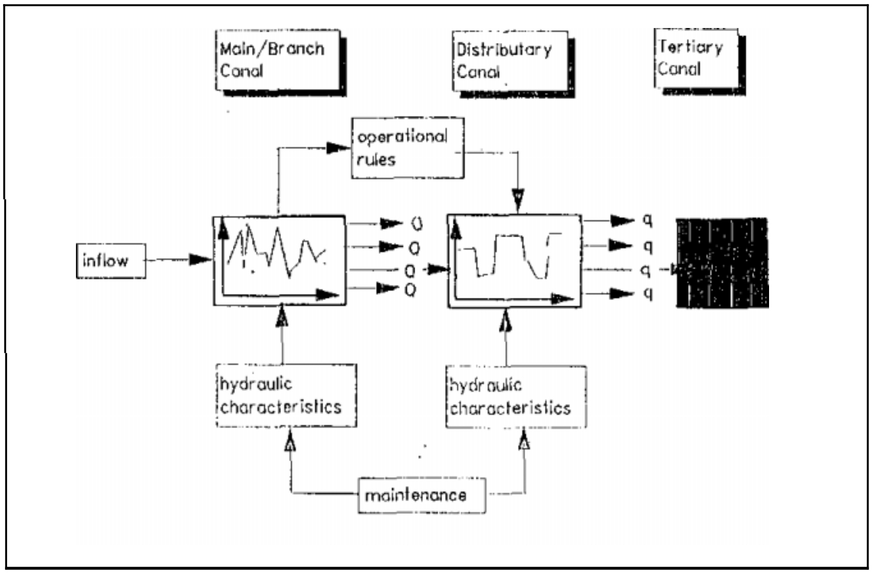


The description of the management set-up, as well as the physical system, allows us to define the scope for management interventions leading to .alternative water distribution patterns. Five types of interventions seem possible:

* 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.

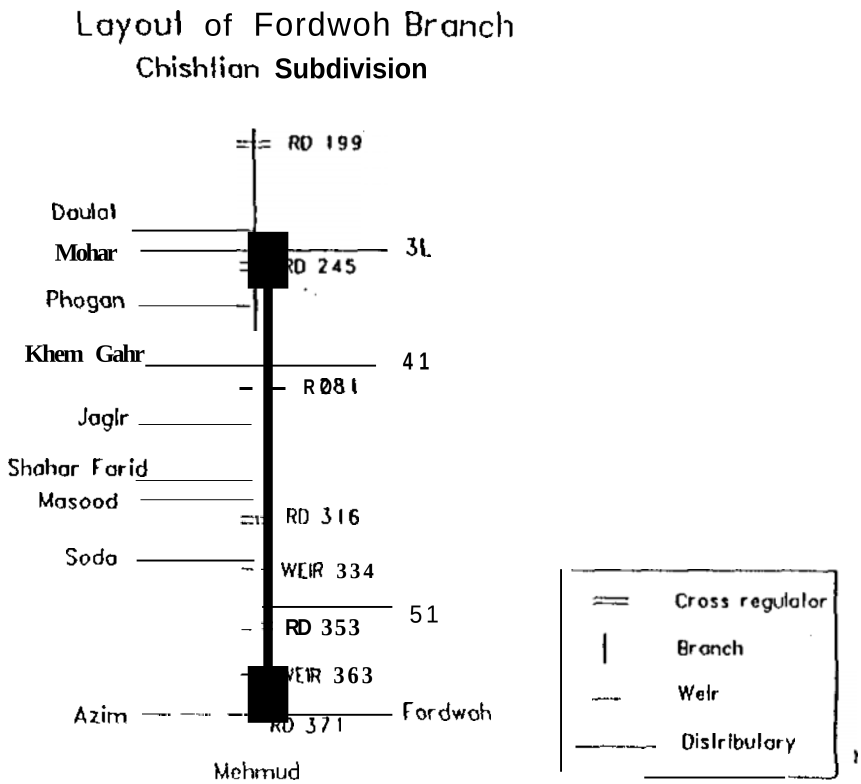


In this study, the inflow pattern and the water allowances will be accepted as given, which implies retaining water use efficiency and equitability as the main principles underlying irrigation management in the Indus Basin. The focus of this paper will be on redefining the operational rules at the main 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.

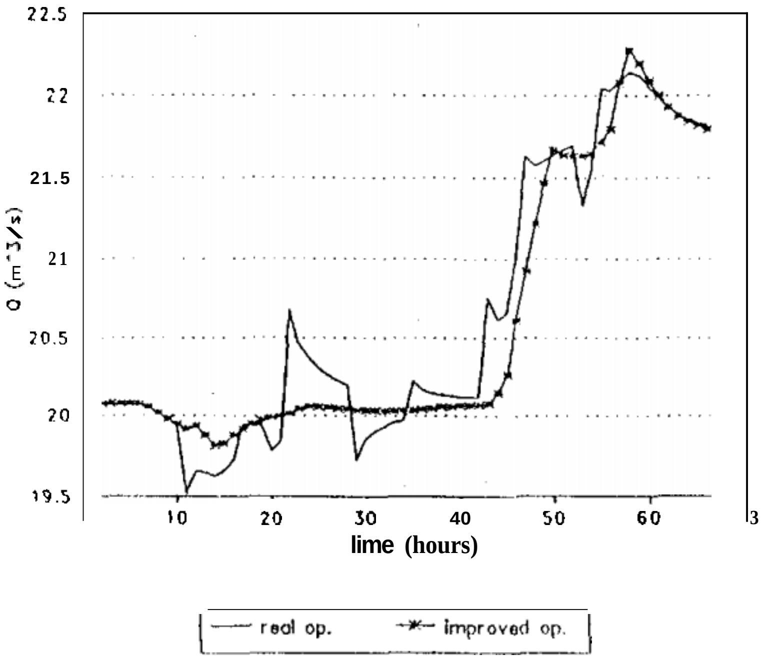
The regulation module generates an order of priority for the distributaries based on a set of rules (either official rules or a set of alternative operational rules). This order is valid for a fixed number of days, which can be selected in the module. Then, the module decides (based on this order and 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.

[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

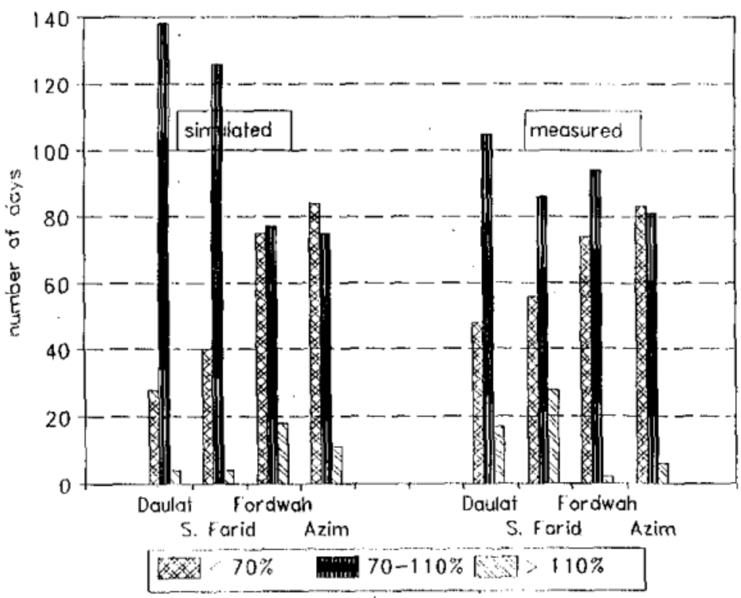
inflow pattern that may deviate, errors in levels and dimensions of structures, etc. **A** difference of 10 % in delivered volumes seems, therefore, allowable. Only in the case of Phogan Distributary, a **small** ungated channel that is not attended by a gate operator, the difference exceeds 15%. An 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.

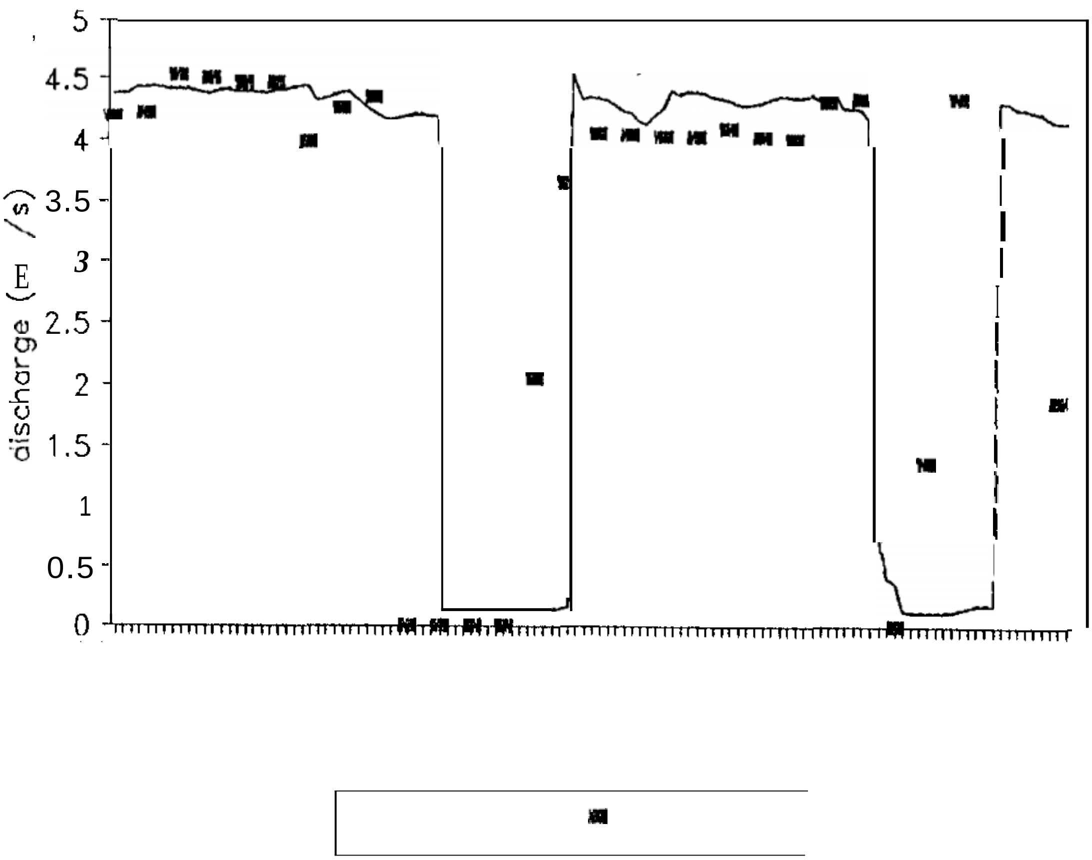
Particularly for Fordwah and Azim, the simulated values match very well the measured values. In the case of Daulat and Fordwah, the distribution is somewhat more skewed (more days of supply between 70 and 110%), because of the logic of the model which attempts either to deliver the targeted discharge 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.



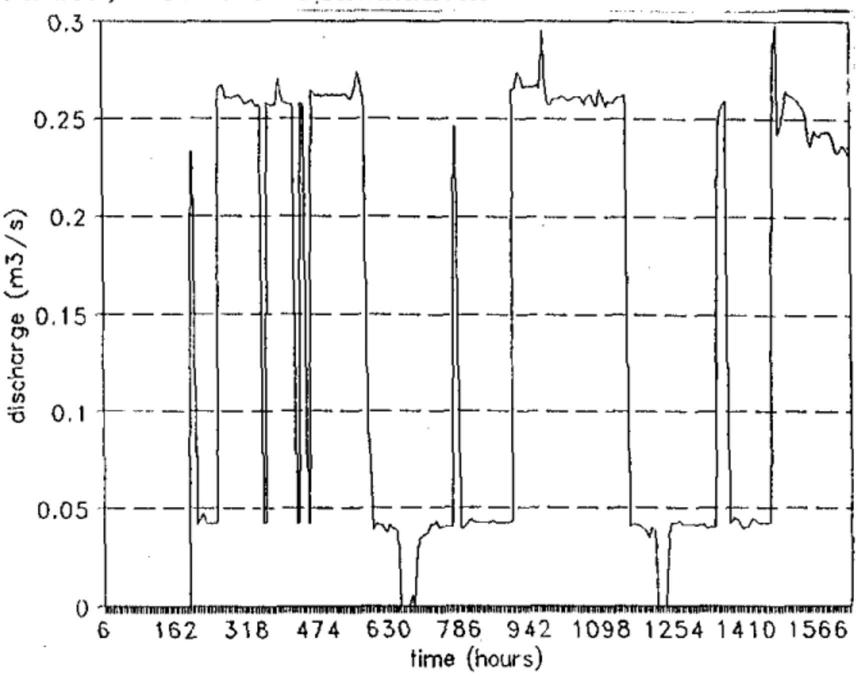
Management Interventions: Modifying the Operational Rules

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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