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CHANGES IN WATER DUTIES

AND THEIR IMPACT ON AGRICULTURAL PRODUCTION

The Case of Girsal Minor

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Contents

Figures. Maps and Tables

Abstract

There is an increasing emphasis in Pakistan on improving the performance of its irrigation systems. As part of this strategy, the North-West Frontier Provincial Government has allocated increased water duties (from traditional levels) to the newly built Chashma Right Bank Canal (CRBC) Irrigation System. The Girsal Minor, which is part of the old Paharpur Irrigation System, and now integrated into the CRBC, has benefitted from these efforts.

The paper describes the impact of the changes in water duties on the agricultural production in the Girsal Minor Command Area. Results show that farmers have reacted to the new canal water environment in various ways: modifying their cropping pattern; applying larger quantities of water per unit area; and diminishing the use of the more expensive tubewell water.

A major impact has been an increase in the area under rice up to 25 percent of the Cultivable Command Area (CCA), far from the original design percentage of 2 percent reported in the various project planning documents. The area under sugarcane has also increased but these changes are found to be more related to the improved marketing conditions of the crop (installation of a new sugarmill in the area) than to the upgraded water availability of the system.

The increase in the quantity of water supplied per unit area has led to a significant increase in crop yields. However, a regression analysis for rice and wheat crops shows that only a percentage of the total increase in yields is attributable to changes in water duties.

While the changes observed in the area under rice and sugarcane are the result of farmers' rational behavior in their allocation of the water resource, if this pattern is to continue, the increasing demand for irrigation water could eventually impair both the availability and reliability of the water for those farmers further downstream in the system.

Finally, the paper suggests that if a better understanding of the relationship between water and agricultural production is to be obtained there is a need for further use of analysis techniques of farming systems in a more generalized and complete way.

Acknowledgements

This paper presents some of the research results of the International Irrigation Management Institute (IIMI) Crop-Based Irrigation Operation Project, funded by the Asian Development Bank. The authors would like to thank the staff of the Provincial Irrigation Department and Provincial Agriculture Department stationed in D.I.Khan who have made available the data used in the analysis. The efforts of the IIMI field team involved in the collection of water data and farmers' interviews in the Girsal Minor Command Area are acknowledged. The authors would like to thank also Dr. Don Parker (IIMI-Bangladesh), Mr. Marcel Kuper (IIMI-Pakistan) and Prof. Skogerboe (IIMI-Pakistan) for their comments and suggestions.

Introduction

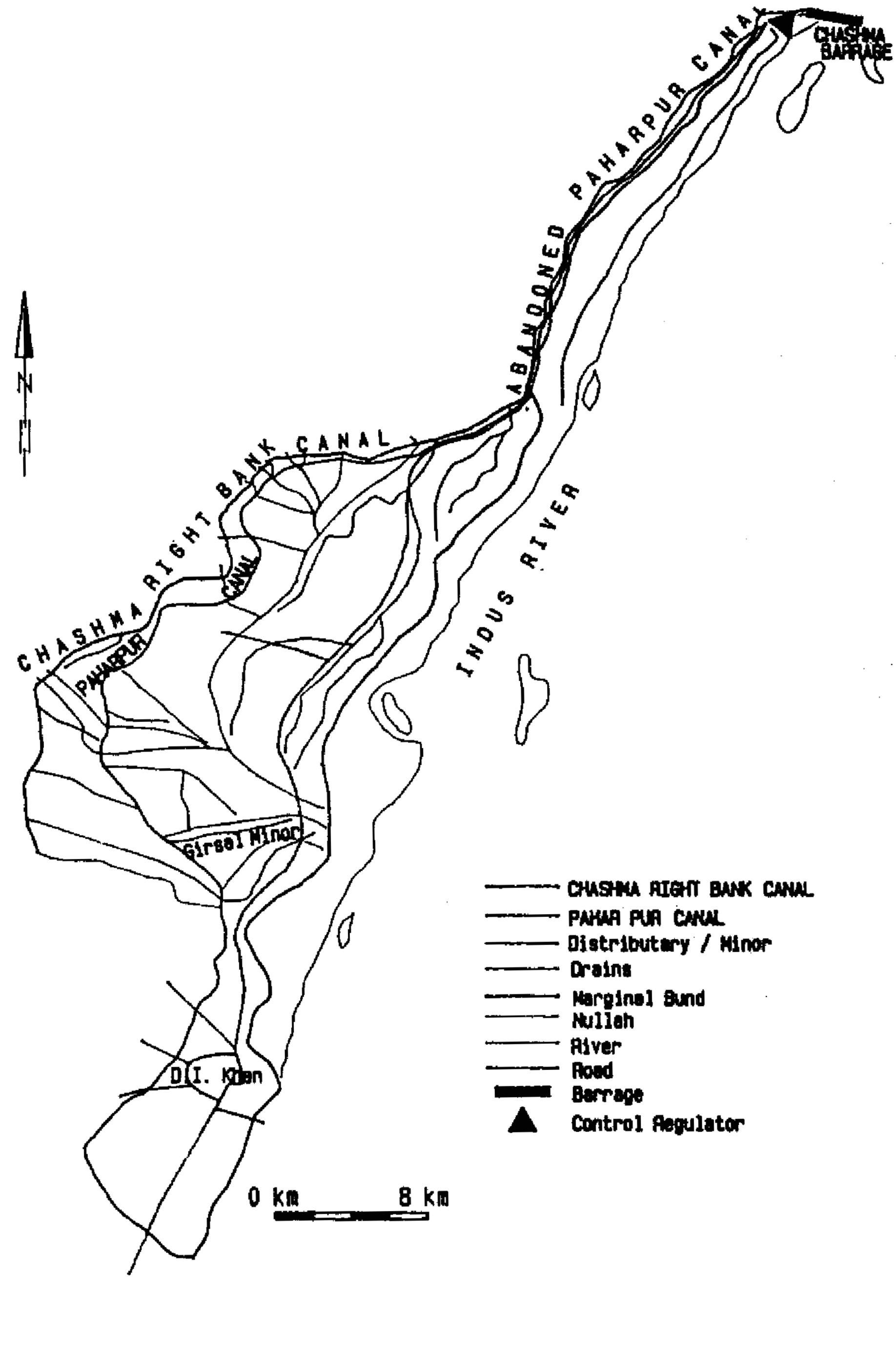
The Chashma Right Bank Canal (CRBC) System (Map 1) is the most recent irrigation system constructed in the North-West Frontier Province (NWFP) of Pakistan. Planned in three stages, this 285-kilometer (km) long canal offtakes from the Indus River at Chashma Barrage, with a design discharge of 138 cumecs to be supplied to a Cultivable Command Area (CCA) of 230,675 hectares (ha}. The first 32 km (Stage I) became operational in 1986; the rest of the system is still under construction. An important feature of the CRBC System has been the integration of the old Paharpur Canal Irrigation System into its command area. The Paharpur System was remodeled in 1983-1985 for it to provide the same water duties as designed for the CRBC System which was implemented in 1986.

The new average water allowance is equal to 0.6 liters per second (lps)/ha, more than twice the traditional design capacity of 0.28 lps/ha found in irrigation systems of the NWFP and other areas of the country. This upward shift in the water allocation was based on changes in the management philosophy of provincial officials; from an equitable distribution of the water between various canals, distributaries and individual outlets to a distribution based on crop water requirements. However, no specific infrastructure has been provided to run the system with variable discharges according to these requirements. Moreover, changes in the design have not been followed by the adoption of appropriate management procedures to achieve both a more suitable matching between supply and demand requirements and a better water use efficiency.

IIMI-Pakistan, started its work in the project area in August 1991 with the main objective of seeking to improve the overall productivity of water through enhanced system management in accordance with crop water requirements within the authorized system-level water allocations and available supplies. IIMI's main output will be the proposal of management innovation(s) and its implementation for field-testing and evaluation. Although IIMI's focus is primarily on the new CRBC Irrigation System, it was decided to monitor a portion of the Paharpur Canal Irrigation System. The objective was to analyze disparities in irrigation water management and irrigated agricultural production between the two areas: the CRBC newly developed, and Paharpur remodeled but with an old tradition in irrigated agriculture, so as to compare the situation of low water duties before the remodeling with the situation of high water duties after the remodeling.

Two different ways can be used to analyze the impact of different water duties in influencing farmers' decision-making process and agricultural production: the first is to compare two locations with different water duties; the second is to analyze the evolution, over time, of one location where water duties have been modified. Both approaches have their own limitations. In the first case, the problem is to ascertain that the environment (physical, social and economic) is the same for the two locations (which is rarely the case). In the second one, the problem is to make sure that the environment is the same before and after (which is rarely the case either), or to find some ways to estimate what would have been the evolution without the changes in water duties.

Map. I. Chashma Right Bank Canal Irrigation System (Stage I).



IIMI's work in the CRBC System provided a good opportunity to study the consequences of changes in the irrigation water supply on the farming systems and agricultural production, using a *Before* versus After type of analysis (Garces and Bandaragoda 1991). The recent remodeling of the Paharpur Irrigation System is of particular interest because an important feature of the remodeling has been the increase in the water duties from 0.21 l/s/ha to 0.60 l/s/ha after 1985.

Some of the expected changes in the Paharpur Area due to an increase in the irrigation water duties are: (i) an increase in the cropped area and the cropping intensity; (ii) a change in the cropping pattern, with a shift from crops with low water requirements to crops with high water requirements; (iii) an increase in yields; and (iv) a change in the use of different inputs, with an increase in the use of complementary inputs and a decrease in the use of inputs of substitution. The relative importance of these changes will vary from one farmer to another, according to the main constraints faced by individual farmers.

This paper is a first attempt to analyze the impact of changes in the irrigation environment on the agricultural production, and to gain a better understanding of the relationship between a specific input, water, and the agricultural output. It will also assess which (one or more) of the expected changes listed in the previous paragraph have indeed taken place as a result of the increase in water duties in the old Paharpur Irrigation System.

The present study focuses on a specific minor of the old Paharpur Irrigation System, Girsal Minor, that has been monitored by the IIMI field team since October 1991. Data collected through farmers' interviews during Rabi 1991-92 were complemented by those from the Provincial Irrigation Department (PID) and Provincial Agriculture Department (PAD). Farmers' interviews focused on the management of irrigation water at the farm and watercourse (tertiary canal) levels, farming practices, agricultural production and on different constraints faced by the farmers. Fifty farmers from four different watercourses served by the Girsal Minor were interviewed. Specific field observations on the watercourse itself were also collected at the time of the interviews. Irrigation water supply data were provided by the PID and were also collected by the IIMI field staff for the year 1992. Irrigated area, cropping intensity and cropping pattern at different levels of the irrigation system were provided by the PID for Paharpur Canal and Girsal Minor (from 1970 to 1991). Data on agricultural production and yields for the D.I.Khan District were provided by the PAD for the period 1980-1991.

Site Background

PHYSICAL CONTEXT

The Paharpur Canal was constructed in 1880. The system has been remodeled several times since then, the last one taking place in 1983, coupled with the construction activities of the Chashma Right Bank Canal Irrigation System as described above.

The Gross Command Area (GCA) of the system is about 47,000 ha and the CCA is 42,000 ha. As stated above, it has been completely integrated within the CRBC System from which the irrigation water supply is received. The Paharpur Canal itself has been split into several sections; hence, it is not continuous anymore, although the operation and maintenance (O&M) activities remain the task of a specific subdivision of the Irrigation Department. Separate reaches of the canal are fed by the CRBC System through 4 link canals, in order to supply the different distributaries and minors of the old system. These reaches, as well as all the distributaries and minors, have been remodeled to carry the increased and fluctuating (according to crop water requirements) discharges.

The Girsal Minor offtakes at RD 151+650 (original units in feet) at the middle reach of the Paharpur Canal. This 12.4-kin-long minor supplies 24 outlets with a GCA of 1,845 ha and a CCA of 1,660 ha. The main modifications resulting from the remodeling have been: (1) the lining of some 200 meters at different points along with the tail of the minor (from RD 19+000 to the tail); (2) the addition of 3 escapes in order to increase water management flexibility; (3) some changes in the sizes of the outlets; and (4) an increase in canal capacity to carry the increased water supply.

The maximum design discharge is now 1.1 cumecs, compared with 0.73 cumecs before the remodeling. At the same time, the CCA has been reduced by 20 percent, because part of the former area was transferred to the command area of Shah Kot Minor. As a result of the link set up between the new CRBC and the old Paharpur System, the Girsal Minor has now been made part of Distributary 3, offtaking at RD 237 + 320 of the CRBC. Distributary 3 has a maximum design discharge of 3.2 cumecs of which 1.1 cumecs are supplied at its tail to feed the Girsal Minor. Kech Minor, offtaking before the junction of Distributary 3, and Paharpur Canal, complement this part of the surface irrigation system (Map 2).

Two drains cross the command area of the Girsal Minor. They have an impact on the management of water since farmers return surplus water into the drains through the escapes of the minor or directly from the tail of the watercourses or the fields. Sometimes, the drain is used by downstream farmers as a source of irrigation during water-shortage periods.

Four watercourses were selected by IIMI, according to their location along the Girsal Minor, for monitoring and research work. The main characteristics of these watercourses are given in Table I.

Map 2. Chasma Right Bank Canal (Stage I).

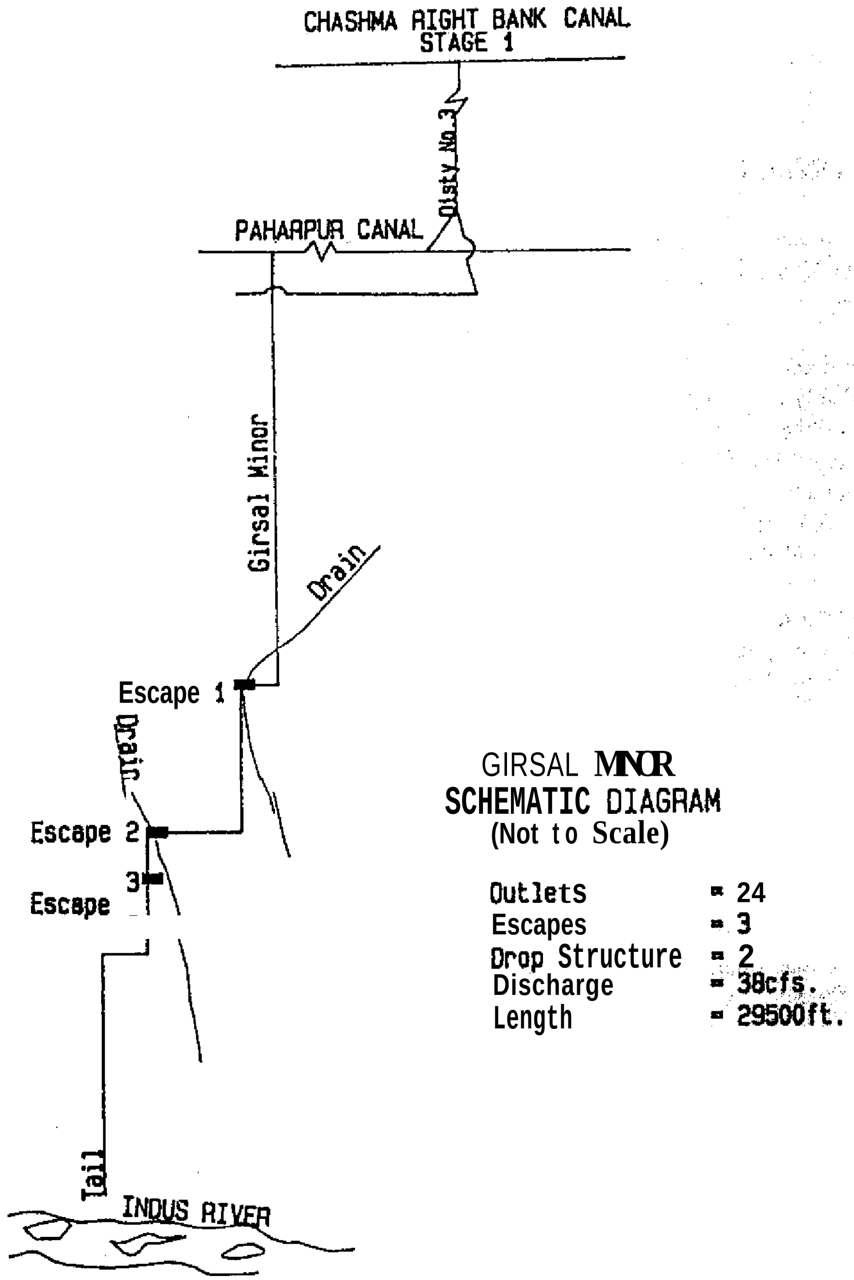


Table 1. Characteristics of the sample watercourses.

Watercourse number (RD)[1]	Design discharge (cumecs)	Length of watercourse (meters	Lined portion (meters)	GCA (ha)	CCA (ha)
5767-L	0.042	3,300	630	89	79
13526-R	0.063	3,920	784	123	117
21516-L	0.025	1,500	215	55	46
29650-TL	0.038	1,250	250	76	69

It has to be noted that the first outlet along the Girsal Minor is at RD 5767, with the area upstream of that receiving water from the Kech Minor, already mentioned. Lining of the watercourses has been done in different phases by the On-Farm Water Management (OFWM) project staff in collaboration with farmers. Watercourse 13526-R was included in a lining program started in 1982. However, in 1988, at the time that watercourses 21516-L and 29650-TL were lined, the lining of watercourse 13526-R was also extended to its total length. Watercourse 5767-L was lined in 1986.

IRRIGATED AGRICULTURE

Farmers in the Girsal Minor Area have had long experience with irrigated agriculture. The area itself is well-developed, with proper leveling of fields, which is an indication of a long tradition in agricultural and farming practices. Certain plots are large enough for easy mechanization such as plowing, but in some cases, modern mechanical harvesters are also used. In the past, some farmers have installed private tubewells to complement their canal water supply. Through direct control of the groundwater resource, the main role of private tubewells has been to increase the total quantity of irrigation water available for crops and to compensate for the unpredictable fluctuations of the surface water supply.

Farmers are mainly growing rice, sugarcane, fodder, wheat and gram. The average cropping pattern for the three more recent years (from 1988 to 1991) is given in Table 2. Crops are usually organized with the following specific sequence,

1.Rice -> 2.Gram -> 3.Fallow -> 4.Wheat -> 1.Rice -> etc,

with the position occupied by sugarcane and fodder in the sequence being less strictly defined. On some farms, sugarcane is intercropped with wheat, but it remains a rare practice. The importance of gram in the cropping pattern is rather interesting because gram is a crop which does not normally need supplemental irrigation during the season, as it can usually meet the crop water requirement from the high moisture content left in the soil after the harvesting of the rice crop.

[1]The suffixes L and R added to the RD number of the watercourses mean that the watercourses offtake from the left side (L) or from the right side (R), respectively, of the minor. The suffix TL is added to the RD number of the watercourse located at the very tail of the minor.

Table 2. Average cropping pattern in Girsal Minor (1988-1991).

Kharif Season		Rabi Season	
Crop	% of the CCA	Crop	% of the CCA
Rice	25.4	Wheat	28.5
Maize	1.4	Gram	11.0
Sugarcane	6.0	Sugarcane	6.0
Fodder and miscellaneous	4.5	Fodder and miscellaneous	13.4
Kharif cropping intensity	37.3	Rabi cropping intensity	58.9
Yearly cropping intensity	90.2%		

With the commissioning of the CRBC, fanners fear that waterlogging can become a major problem for the area. Already, some of them complain about a high watertable during the rabi season when water is in excess and cannot be drained completely by the poorly maintained surface drains crossing the area. For the tail farmers, the main problem is the Indus River itself, which slowly, but surely, erodes the culturable (and cultivated) land of the last five watercourses of the Girsal Minor (the last watercourse of our sample, 29650-TL, is in this very situation).

Changes in the Irrigation Water Supply

CHANGES IN WATER SUPPLY AT THE HEAD OF THE GIRSAL MINOR[1]

The canal water supply at the head of the Girsal Minor has been dramatically modified during the last decade. The average seasonal flows at the head of Girsal Minor from Kharif 1980 to Kharif 1992 are presented in Figure I.

The period 1980-1992 can be subdivided into three phases, each characterized by a specific canal water supply condition. The first phase (Kharif 1980 - Rabi 82/83) pertaining to a pre-remodeling condition has a traditional low water supply (0.52 cumecs per 1,000 ha and 0.35 cumecs per 1,000 ha, respectively, for the Kharif and the Rabi seasons). The available irrigation water supply is relatively constant from one year to another, which is supplied by the Paharpur Irrigation System still operating as an independent unit.

The second phase, from Kharif 1983 to Kharif 1988, corresponds to a transitional period; the seasonal average flow is greatly variable, especially among Kharif seasons. During this period, the remodeling activity taking place in the whole Paharpur Area -- including the Girsal Minor -- and the physical connection of the Paharpur System to the CRBC, had a negative impact on the canal water supply, not so much on the quantity delivered but on its variability and reliability.

The last (and third) phase starts in Rabi 1988-89, with the flows at the head of the Girsal Minor stabilized at the new high levels: 0.8 cumecs per 1,000 ha for the Kharif seasons and 0.45 cumecs per 1,000 ha for the Rabi seasons. Higher water duties are now allocated to the irrigation system in general, representing a shift from the traditional supply-based mode to a crop-bused approach. For each season, the average seasonal flows are expected to be more related to the prevailing cropping pattern than to purely system operational factors.

The comparison between the average flows of the first phase (low water duties) and the third phase (high water duties) highlights that the increase has been particularly important for the Kharif season, with an increase of 54 percent versus only 31 percent for the Rabi season. The increase of water duties has been accompanied by an increase in the variability of this supply (in terms of standard deviation of the flows), to match more closely the new crop-water requirements.

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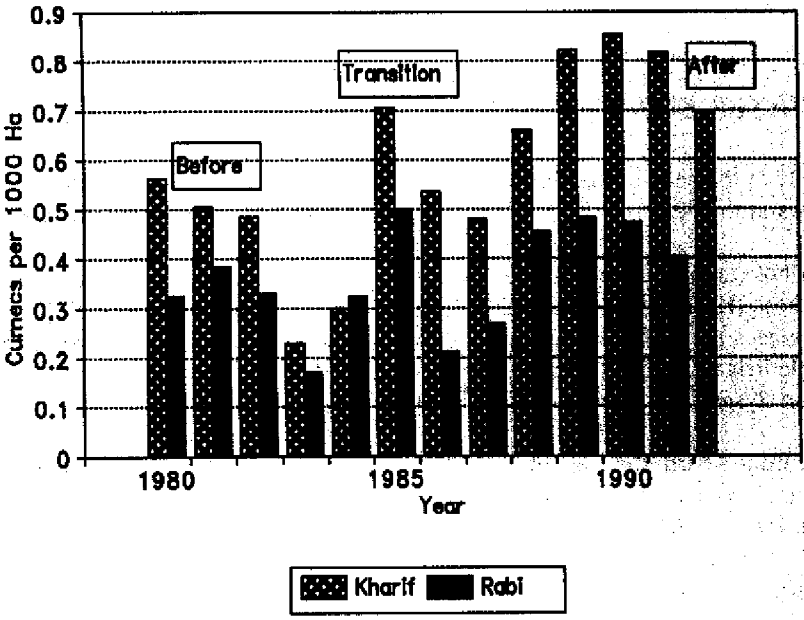
[1]Data provided by the Provincial Irrigation Department have been used to analyze changes in the canal water supply at the head of the Girsal Minor from the beginning of Kharif 1980 to the end of Kharif 1991. To estimate their accuracy, data collected in 1992 by IIMI (daily gauge reading) and the PID have been compared. showing that while the PID data follow exactly the same trend as the IIMI data, PID data slightly underestimate the discharge by a bit more than 10 percent on average. The cause of this constant underestimation could be the use by PID staff of a rating curve that has not been upgraded after the remodeling of the Girsal Minor.

Figure 1. Average seasonal flows at the head of Girsal Minor (Kharif 1980 -- Kharif 1992).

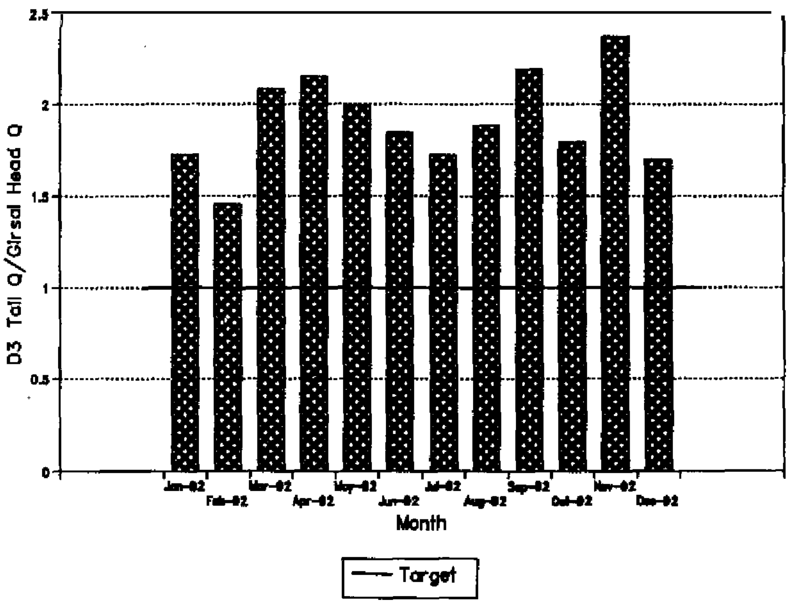


For the first and the third phases, the coefficient of variation of the Girsal Minor head discharge is relatively high for the Rabi season, due to specific peaks in irrigation water demand for the wheat crop (peaks for pre-planting irrigation and two seasonal irrigations). Because of the higher (although more constant) irrigation requirements of the rice crop, the coefficient of variations are lower in the Kharif months. However, the comparison of the monthly coefficient of variations between these two phases did not show any significant difference between the two periods, as one would have expected. The implication is that even before the remodeling took place there was already some degree of response by the system to the need of the crops (higher allocations in Kharif over Rabi, increases allocations during the rice land preparation stage, decreases at night, etc.)

CURRENT OPERATION OF THE SYSTEM BY THE PROVINCIAL IRRIGATION DEPARTMENT

Because of the configuration of the system, operation of the Girsal Minor is tied directly to whatever happens in Distributary No. 3 upstream. By design, the discharge at the tail of Distributary 3 should be "equal" to the discharge at the head of the Girsal Minor, although some drainage water finds its way into the feeder, thus accounting for some variation. After one year of monitoring, it appears that discharge largely exceeds the demand of the Girsal Minor. This situation is shown in Figure 2.

Figure 2. Monthly average discharge ratios of Distributary 3 tail versus Girsal Minor head.



The excess water at the tail of Distributary 3 can be partly explained by an excess of water supplied at the head of the distributary to cope with an actual cross section larger than designed (Strosser and Garces 1992). But also it can be related to a conservative canal operation on the part of both the PID, in charge of the operation of the distributaries and minors, and the Water and Power Development Authority (WAPDA), operating the main canal, that do not take into account the manipulation of outlets by farmers and its impact on the downstream portions of the system.

At the Girsal Minor itself, the problem of excess water is further compounded by the use of old – and not upgraded -- PID rating curves by the minor gatekeeper who ends up supplying water in excess to minimize risks and conflicts with farmers.

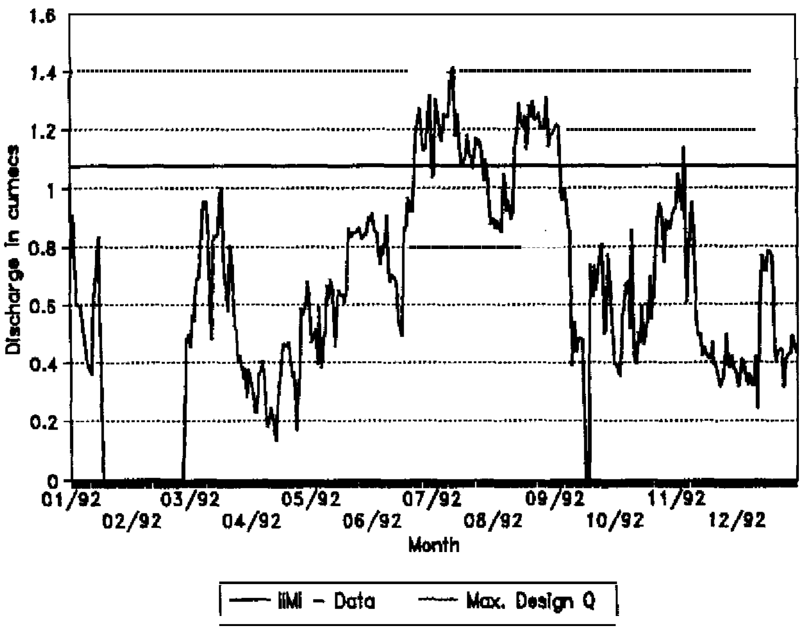
Figure 3 presents the daily water flows at the head of the Girsal Minor for the year 1992. The peaks observed during the Rabi season correspond to the different irrigations periods for wheat. The zero flows, from 15th January to the end of February, pertain to the period when the canal remained closed for its annual maintenance program. The analysis of the flows during the Kharif season shows that water bas been supplied during some periods at higher levels than the maximum design discharge.

The escape structures along the Girsal Minor allow farmers to get rid of their surplus water, if needed. In this case, the PID has, in fact, transferred part of the operation of the minor to the farmers[3] This excess water supplied to the system coupled with the poorly maintained drains of the area, can lead to waterlogging problems. This has already been reported by farmers, mainly at the head of the minor.

[3]The information on the opening and closure of outlets by farmers, reported in the *Water Management at Watercourse and Farm Levels* part of the present paper shows that fanners are involved in the operation of the canal water at the outlet level. Moreover, farmers report *that* they operate the escapes themselves.

A last, but important, point that needs to be made is that under the present PID institutional arrangement there is a change in operational responsibility at the tail of Distributary 3. Beyond this point, it is the Paharpur Irrigation Division that has control of the water, as opposed to the CRBC Remodeling Division. While it can be expected that coordination between the two PID units is a foregone conclusion, in reality there is quite a bit of independence in the day-to-day operation of the system.

Figure 3. Daily discharge at the head of Girsal Minor (IIMI data).



SUPPLY VERSUS DEMAND OF IRRIGATION WATER

In order to integrate the *supply* and *demand* sides of the irrigation equation, the Relative Water Supply (RWS)[4] has been calculated for the Girsal Minor Command Area. Average seasonal values for the three phases (low water duties, transition and high water duties) were calculated and are presented in Figure 4.[5]

[4]The RWS. as the *ratio* of the supply to the demand, was introduced by Levine (1982). It is an indicator of the adequacy of the irrigation water supply. It has been calculated for every 10-daily period with the following formula:

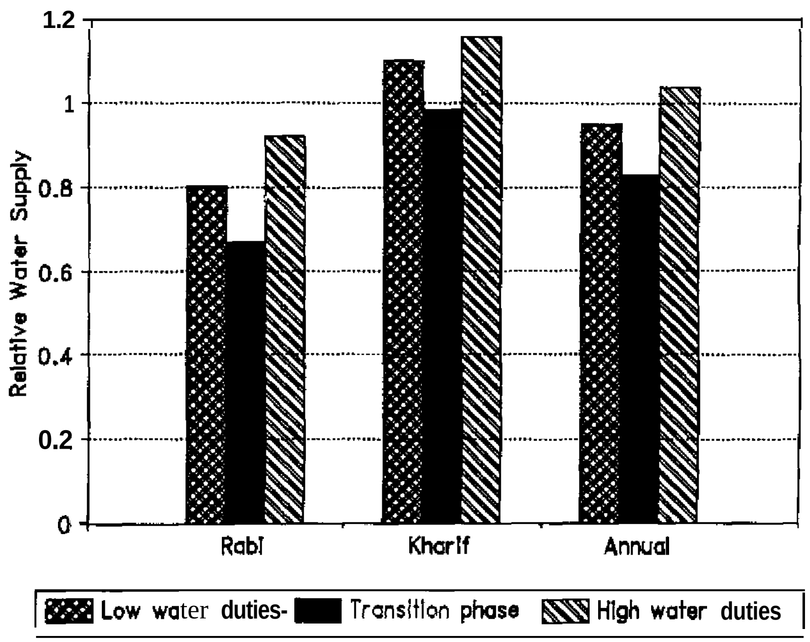
$$RWS = \frac{\text{Irrigation} + \text{Effective Rainfall}}{\text{Crop Water Requirements} + \text{Losses}}$$

[5]Rough estimates of the quantity of water supplied by private tubewells have been calculated. based on the number of private tubewells operated by farmers and the average utilization rate reported by farmers for the *Before* and *After* situations.

The figure shows a trend of increasing RWS along with the increase in water duties at the Girsal Minor head. During the period of low water duty the values were found to be 0.8 and 1.05 for Rabi and Kharif, respectively. However, during the remodeling, there was a negative impact on the RWS characterized by its variability, especially for the Rabi season. For example, the average RWS of 0.9 for the Kharif seasons during this phase is relatively satisfactory. However, this average value hides a large variability, from 0.6 in 1983 to 1.1 in 1984. Finally, after the remodeling, the RWS values increased to 0.9 and 1.15 for Rabi and Kharif, respectively.

An increase in RWS values indicates that farmers supply more water per unit of area cultivated now than before the remodeling. As a result, higher yields would be expected after the remodeling. Since there has been no significant increase in the cultivable area, and field conditions have remained essentially the same, the excess water supplied to the system should go either to an increase in the cropping intensities or to changes in the cropping pattern. When the farmer perceives that more water is being made available to him, he will begin to adapt his management practices towards more water-demanding crops. Whether this has been the case for the Girsal Minor will be addressed later in the present paper.

Figure 4. Average seasonal Relative Water Supply -- Low water duties, transition phase and high water duties.



However, the values obtained for RWS at this present stage are also useful because they show clearly that the Girsal Minor Area can no longer be thought of as water-deficient. In fact, the earlier indications are being confirmed that excess water is running through the system, a trend that should be discouraged as it will have both short- and long-term negative impacts. Of the former type, localized waterlogging and rising water tables have already been reported in the area. Of the latter type. over-deliveries could result in water shortages for new areas coming under the CRBC System Command (Stage II and later on Stage III).

Water Management at the Watercourse and Farm Levels

FARMERS' PERCEPTION OF THE CURRENT WATER SUPPLY

Although the canal water supply at the head of the minor has been significantly increased during the last 10 years, the magnitude of the changes at the watercourse and farm levels varies greatly, according to the position along the canal and along the watercourse. Table 3 shows the changes in irrigation water supply reported by the farmers of the four sample watercourses of the Girsal Minor.

Table 3. Farmers' perception of changes at the farm level for four sample Watercourses served by the Girsal Minor.

Watercourse number	No. of farmers reporting changes in irrigation water supply		
	Decrease	No change	Increase
57671	50%		50%
13526R	85%	-	15%
21516R		15%	85%
29650TL			100%
Total	35%	5%	60%

Sixty percent of the farmers interviewed report an increase in their canal water supply, against 35 percent reporting a decrease and 5 percent no change. Answers reported by farmers in each watercourse highlight the following results.

1. Farmers from the tail watercourses have benefited from the remodeling of the minor and the increase in water duties. The increased water supply has mitigated the negative impact of the illegal appropriation of water by head farmers.

2. For the two head watercourses, more than half of the farmers complain about the decrease in the water supply especially during the Kharif season. The modification of the outlet structure during the remodeling works (from Open Flumes to Adjustable Proportional Modules) is seen as the new constraint limiting the canal water supply[6]. Farmers would like to go back to the previous system with wider outlets.

[6]The impact on outlet discharge for a change in the water level in the minor is less with the new Adjustable Proportional Modules than with the former Open Flumes. The possibilities of large illegal water appropriations by farmers of the head watercourses by blocking the flows in the minor with wooden logs, or other means, and thus increasing its water level, have been reduced.

3. Farmers reporting an increase in the supply of water for watercourses 5767-L and 13526-R are all tail farmers. Lining of the watercourse, more than modification of the water supply. has been reported as the main cause of the positive changes.

Most of the farmers interviewed (except for the remaining tubewell owners) are exchanging canal water turns or even selling and buying turns, to increase the flexibility of their irrigation water supply. At the tail of the minor, exchanges take place essentially during the Kharif season while farmers at the head of the minor mainly exchange canal water turns between the Rabi and the Kharif seasons.

Farmers clean their watercourses twice or thrice a year except for Watercourse 5767-L which requires cleaning five to six times a year. Canal closure, before rice transplanting and after wheat sowing time, are the main periods when cleaning takes place. In Watercourse 5767-L, some additional cleaning is organized during the rice season as well.

Watercourses are cleaned jointly by farmers, either from the head to the tail of the watercourse with each farmer stopping at his own farm outlet, or by allocating specific reaches to each irrigator according to the size of his landholding (or the duration of his water turn). One farmer, selected by all the farmers of a specific watercourse, will be in charge of organizing the cleaning (to fix the date, to allocate the reaches to be cleaned, to call the farmers to work, etc.). Farmers have the choice of cleaning by themselves or of sending a laborer to do the required work. In some watercourses, the Provincial Irrigation Department is involved in the process as well, supervising the work and trying to resolve disputes among farmers. This situation is, however, rather rare.

Farmers do not report major changes in the cleaning of the watercourse as a result of the remodeling of the minor and the higher water duties. Their only complaint is about the new narrower outlet which has to be cleaned quite often. An important difference, however, is that farmers from the lined portions do not participate anymore in the collective effort of cleaning the watercourse, jeopardizing the formal or informal arrangements that existed before at the watercourse level.

WATER SUPPLY CONTROL AT THE OUTLET

Irrigation water is now supplied during the Rabi season in sufficient quantities or even in excess compared to the irrigation water requirements during certain periods of the season. Farmers close their outlets to control and manage their new canal water supplies at the head of the watercourse, mainly after a rainfall, when crops do not need water, or when no neighbor wants to use the water turn.

During the Kharif season, even though improvements have been made, the water supply is still reported to be inadequate to cover higher crop water requirements. However, watercourse off-takes are still found closed as well during that season. Figure 5 compares the percentage of time the outlets are open or partially open[1] with the crop water requirements for the Girsal Minor Command Area.

A strong correlation exists between the two sets of data. Months with high crop water requirements (like June, July or August) record open or partially open outlets almost 100 percent of the time. On the other hand, the time the outlets are open during the Rabi season is only around 60 percent. The high percentages of outlets opened for the Kharif months could imply that water is still scarce during this period of the year.[2]

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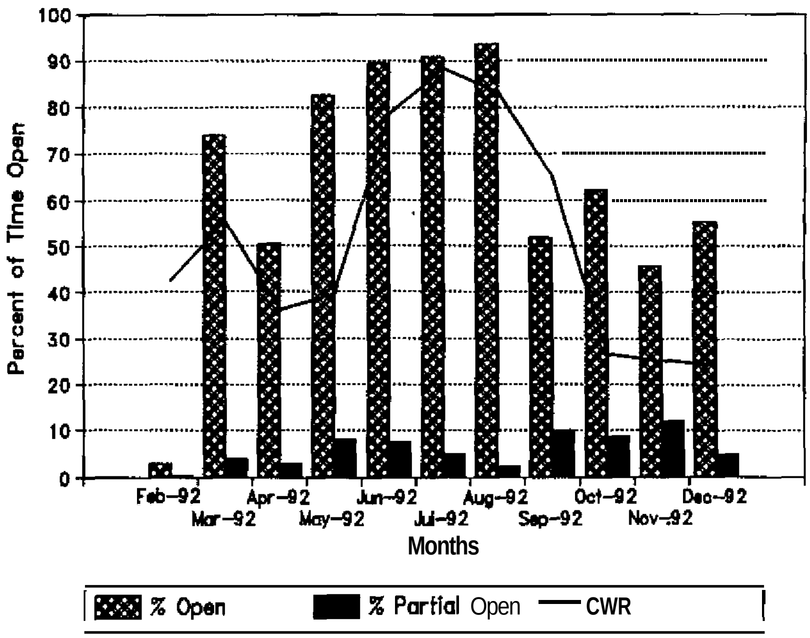
[1] Farmers sometimes partially close (or open) their outlets to manage their water flows taking into mount different parameters such as location and size of the field to be irrigated or time available for irrigation. Figure 3, however, shows that it accounts for less than 10 percent of the time.

[2] This has been confirmed by the operation of private tubewells limited to the Kharif months and by interviews with farmers.

Figure 5. Monthly open/closure of outlets versus Crop Water Requirements.



Results of the comparison between outlets are rather interesting. They show that outlets from the tail reach are less frequently open than outlets from the head and middle reaches. Important factors that could explain this trend are: the impact of the closure of the head outlets that causes excess water supply at the tail outlets; management of the Girsal Minor head by the Irrigation Department to minimize problems by supplying water in excess that reaches the tail; and the erosion of the culturable land, thereby limiting irrigation needs for the tail watercourses. Also, outlets from the right side of the minor are closed more often than outlets from the left side; in this case, it is for topographical reasons that benefit flows to the right side outlets.

As reported by farmers and highlighted by IIMI data presented in Figure 4, the closing of outlets is now a common practice performed by irrigators to manage the new canal water supply. Farmers were unanimous when interviewed: they close their outlets more often now than before the remodeling of the minor because of the increased irrigation water supply at the head of the Girsal Minor. The opening and closure of outlets has a serious impact on the operation of the system. It is made possible by the existence of escapes located at the tail reach of the minor, used by tail farmers to divert surplus waters into the surface drains.

CHANGES IN PRIVATE TUBEWELL OPERATION

The increase in the canal water supply has had an impact on the use of groundwater for irrigation by farmers in Girsal Minor watercourses. Mainly, two important changes have taken place.

The first noticeable aspect has been an important decrease in the total number of private tubewells operated by farmers in the area. While there were more than 40 private tubewells in the command area of Girsal Minor at the beginning of the 1980s, only 8 tubewells are still operated by their owners in 1992.[9]

The second aspect reported by the remaining tubewell owners has been a drastic decrease in tubewell operation. Tubewell operation during the Kharif season is lower than before the canal water supply increase but it has remained of some importance (300- 350 hours of operation per month on average) for the months of May, June, July, August, when most of the outlets are open almost the whole time.

During the Rabi season, however, five tubewell owners out of eight have completely stopped operating their tubewells. Higher canal water duties have had an indirect effect on tubewell operation via water sales as well. Tubewell owners report that with higher canal water supplies, the demand for tubewell water from non-tubewell owners has considerably decreased for the last five years.

Electric tubewell owners find themselves now in an economically unbalanced situation. With a constant electricity bill amounting Rs. 1,000 to Rs. 2,000 per month (Rs. 25 = US$1.00 at the time of the farmers' interviews), independent of the operation of their tubewells,[10] and with the decreasing number of hours of operation of their tubewells, the cost per hour of operation has been drastically increased. As a result, two tubewell owners have already disconnected their tubewells from the electric network and have installed a diesel engine, more economically justifiable for a low level of tubewell operation than electric tubewells with their flat rate tariff.

With the increased canal water supply, farmers have shifted their irrigation water use from tubewell water to the less-expensive canal water. The role of private tubewells in the area has changed as well. To mitigate unpredictable fluctuations in canal water supply has become more important in the current operation of private tubewells than in the past when the primary objective was to increase the quantity of irrigation water.

[9]One tubewell owner located at the head of Watercourse 13526-R installed his tubewell in 1988 after the increase in canal water supply ! With the new supply, tail farmers of this watercourse are now able to receive canal water during thew turns and do not sell them anymore to the head farmer, thus decreasing his *canal* water supply.

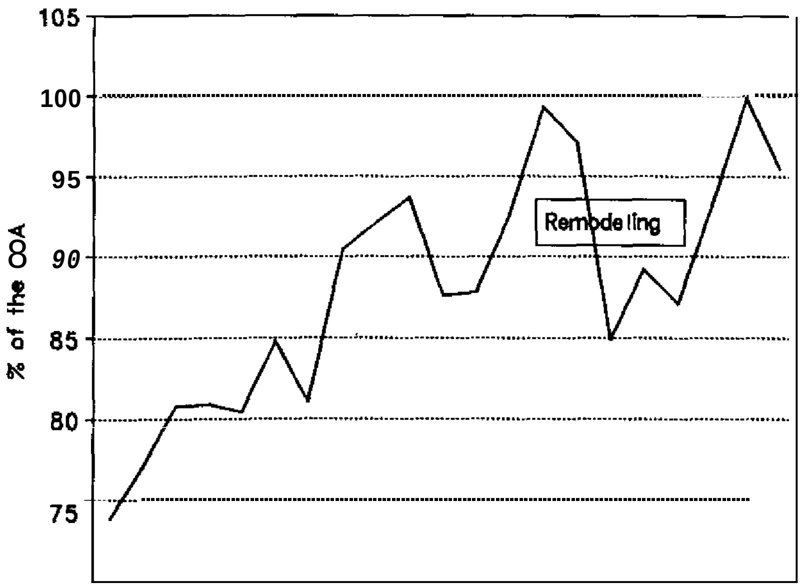
[10]A flat *rate* tariff for electricity consumption is the norm for tubewells in the area.

Impact on Agricultural Production

CROPPING INTENSITY IN THE GIRSAL MINOR COMMAND AREA"

The yearly cropping intensity of **the Girsal Minor has** changed **from 75 to 95 percent** from **1970-1991. The evolution, however, has not** been **constant as shown in** Figure *6*.

Figure 6. Changes in yearly cropping intensity in the Girsal Minor Command Area (1970- 1991).



"Cropping intensity and cropping pattern have been analyzed, using data collected by the Provincial Irrigation Department to assess the level of water *charges* to be paid by farmers. Discrepancies between the real cropping pattern and crop data collected by the Department have been documented in several studies (as, for example. ACE (1990). highlighting that crops with high water requirements and high *abiana* rates (like rice or sugarcane) are usually underestimated in the data recorded by the Department.

The cropping intensity of the Girsal Minor has increased rather regularly from 1970 to 1983 (with an average increase of 2% per year). For the following years, changes from one year to the next have been considerable, with a major decrease in the cropping intensity from 1983 (nearly 100% of the CCA) to 1985 (85%), followed by two years with a yearly cropping intensity close to 90 percent. These two years have already signalled the increase taking place from 1987 to 1989. Although the 1990 figure is lower than for 1989, data for several years would be needed to assess, with confidence, the changes in cropping intensities after 1989.

Possible factors explaining the trend from 1970 to 1983 are the development of groundwater use in the area: private tubewells were installed by farmers in the 1960s and the 1970s, new varieties and new crops were introduced in the cropping pattern, and agriculture was developed during the 1970s, characterized by an increase in agricultural inputs subsidies (Mallick 1992).

The remodeling of the system during the period 1983 - 1985, however, affected the favorable increase in cropping intensity. The negative impact of the remodeling on the canal water supply (highly variable and unpredictable during the transition period) was translated directly into a decrease in the area planted by farmers. A more dramatic decrease in the cropping intensity would certainly have taken place without the private tubewells that were already installed in the area, These tubewells partly compensated for the changes in the canal water supply.

After 1985, farmers reached the same level of cropping intensity as in 1983. It is interesting to see that the increase in cropping intensity (+15%) is rather small compared to the large increase in canal water supplies discussed in the previous section. Several aspects have to be considered at this point. After 1985, farmers had abandoned their tubewells to rely mainly on the new canal water supply. Thus, the impact of the higher canal water duties was partially offset by a decrease in tubewell operation and groundwater use.[12] The time needed by farmers to adapt themselves to the new conditions and constraints faced by their farming system could be another factor explaining the relatively small increase in cropping intensity. Risk-averse behavior could be yet another explanation to be considered. Data for the next two to three years will be useful in checking the future evolution of cropping intensity of the whole minor.

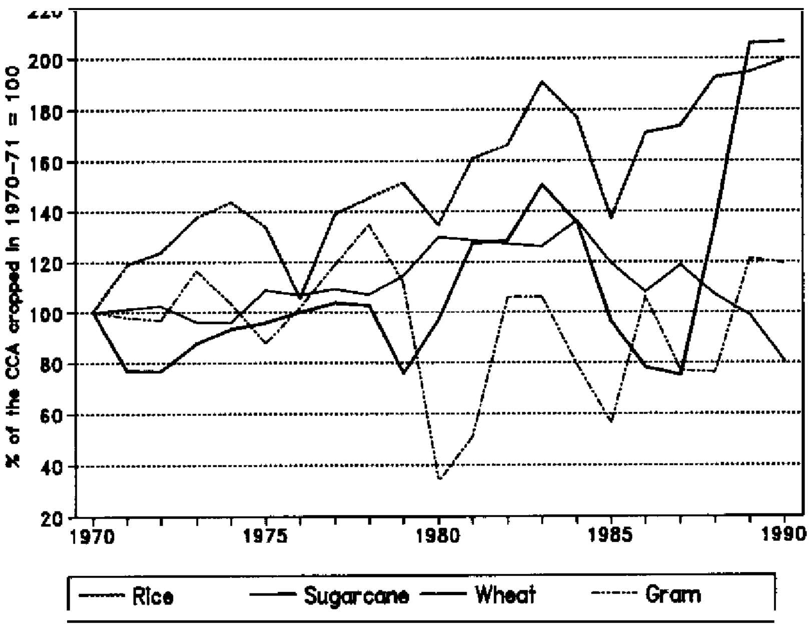
A look at the seasonal cropping intensities for the Kharif and the Rabi seasons shows that Kharif crops have gained some importance in the farming system. Before the remodeling and the increased water duties, the ratio of area cultivated during the Kharif season to that in the Rabi eason was close to 0.5. The ratio has increased to a value of 0.8 in 1990. This change in the ratio is mainly due to a change in the area under Kharif crops and a stagnation of the cropped area during the Rabi season. Regression analysis has shown that there is a positive and significant relationship between the Kharif cropping intensity and the quantity of water supplied to the Girsal Minor during that season. There was, however, no such significant relationship during the Rabi season between the cropping intensity and the canal water supply. Although the changes in water duties have not led to a major change in the yearly cropping intensity, some modifications within the cropping pattern have taken place and are discussed below.

CHANGES IN CROPPING PATTERN

When the cropping pattern of 1970 is compared with that in 1991 the main differences that emerge are more rice and sugarcane, (the same level of gram), and less wheat. Figure 7 presents the relative changes in the area under the four main crops from 1970 to 1991, where the percentage of the area under a specific crop in 1970 = 100.

[12] The shift from tubewell water to canal water use. from a costly source of irrigation water to a less costly one, has led to a decrease in the average costs of agricultural production.

Figure 7. Relative changes in area for the main crops in the Girsal Minor Command Area (1970-71 = 100).



This figure shows that during the transition years of the remodeling there has been a decrease in the percentage of the CCA cultivated. Rice and sugarcane have recorded important increases after the remodeling, while the changes in the water duties seem to have a negative impact on the area sown in wheat. Trends in the cultivated area for the various crops from 1970 to 1991 are detailed below.

The increase in the area growing rice has been rather regular from 1970 to 1983. Rice represented 13 percent of the area in 1970 and 24 percent of the CCA in 1983 (equivalent to an increase of more than 80%). The remodeling had a negative impact and produced an opposite trend for two years. After 1985, however, the recorded yearly increase in the area under rice was higher than before the remodeling.

The CCA under sugarcane has increased slowly from 1970 to 1983, reaching a value of 5 percent of the CCA. As with other crops, the remodeling has had a negative impact on the area under sugarcane for 3 years. Once farmers adapted to their new environment, sugarcane has been increasingly important in the area. For 1990 - 1991, around 7 percent of the CCA has been planted to sugarcane.

The wheat crop has had a much different behavior than the two previous Kharif crops. From 30 percent of the CCA in 1970, it reached more than 40 percent in 1984 and thereafter began to decline. The decrease in the area under wheat continued after 1985 to reach a low level of only 24 percent of the CCA in 1990.

Explanations for this decrease are certainly numerous and complex. The increase of the area under sugarcane has certainly a major role in this evolution; sugarcane competes (from the points of view of labor and land) with the preparation of the land and the sowing of wheat. The competition with gram (see below) is another factor to be taken into account.

It is difficult to detect any trend in the evolution of the area under grain over the whole period 1970 - 1991. A main feature of the evolution of the percentage of the CCA under gram is its high variability. Factors others than irrigation supply (the level of rainfall for a given Rabi season, for example) have a much higher influence on the decision of farmers whether to grow or not to grow this crop.

For the period 1985-1991, however, the area under gram has significantly increased. Farmers report that the areas under rice and gram are closely related. Gram usually follows rice in the crop sequence (because gram efficiently uses the moisture still in the soil after the rice harvesting); therefore, the increase in the rice area has a positive impact on the area under grain, which in turn has a negative impact on the area under wheat. However, no significant positive correlation was found between the area under gram and rice.

The trend in the area under fodder in the Kharif season seems to follow the common Kharif crop rule, highlighted for rice and sugarcane: after an increase in the 1970s, the percentage of the area under fodder dropped sharply in the 1980s and increased again from 1985 to 1991. The remodeling activities and their consequences on the water supply have certainly influenced this crop as well. The trend in the area under fodder during the Rabi seasons is hardly explicable with the changes in the canal water supply, with an important depression from 1979 to 1983. After the remodeling, however, the area planted to fodder during the Rabi season has a low variability and has stabilized around 12 percent of the CCA.

No real trends have been observed for the other crops in the cropping pattern: Maize is occupying a similar 2 percent of the CCA over time; and the areas under cotton and barley are too variable to allow any conclusions to be drawn regarding their relation with the canal water supply. Orchards and vegetables, however, have increased their share in the CCA as well, but still remain negligible (at least from the point of view of area) with less than I percent of the CCA each.

To check whether the remodeling has accelerated or decelerated the changes (or has not had any impact at all) in this general process, a more in-depth analysis of the cropping pattern is needed. To determine the possible impact of the remodeling and the higher water duties on the cropping pattern, only the main crops (i.e., rice, sugarcane, wheat and gram) will be considered in the present analysis. The Relative Crop Profitability (RCP), along with the level of the canal water supply, is expected to have an impact on the percentage of the CCA under a given crop. Thus, regression analysis has been performed for the four crops using the following model (Equation 1):

$$P_i = a_i + b_i*RCP_i + c_i*D + d_i*D*RCP_i \qquad (1)$$

where

- P_i — Percentage of the CCA under crop i,
- RCP_i — Relative Crop Profitability for crop i[13],
- D — Dummy Variable, equal to 1 with high water duties (*After*) and equal to 0 with low water duties (*Before*), and
- a_i, b_i, c_i, d_i — Constants to be estimated for crop i.

The percentages of the area under the four main crops were not found to be significantly related to the RCP variable and the interaction term between the dummy variable D and RCP. The use of output prices as a proxy for the Relative Crop Profitability is certainly the main factor explaining the absence of this (expected) correlation. Thus, simplified equations were tested for the analysis, including only the dummy variable D as an independent variable, as presented below (Equation 2).

$$P_i = a_i + b_i*D \qquad (2)$$

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[13] Constant output prices (Government of Pakistan, *Economic Survey 1987-88* and *Economic Survey 1990-91*) have been used as proxy for the Relative Crop Profitability variable. Output prices do not include prices of other crops, input use and input prices, etc., and do not constitute a very good proxy for Relative Crop Profitability. However, they were the only data available for the period considered.

Notations used are the same as for Equation 1. The **estimated** parameters for the four crops are **summarized** in the following Table, along with the calculated R^2 (correlation coefficient) for each equation.

vheat, gram)

Crop	a_i	b_i	R^2
Rice	18.4 (3.2)	4.7 (1.5)	0.33
Sugarcane	3.4 (1.2)	1.0 (0.6)	0.13
Wheat	33.6 (4.1)	-2.2 (2.0)	0.06
Gram	10.0 (2.7)	-0.4 (1.3)	0.004

(Standard errors of the estimated coefficients are given in brackets1

The sign of the coefficient **before** the dummy variable D, b_i, is as one would have expected for the four crops: the increase in water duties had **a** positive impact on the area under rice and sugarcane -- crops with high water requirements that are more sensitive to changes in the irrigation water supply -- and a negative impact on **the** area under wheat **and** gram. However, the coefficient ***for*** rice is only significant at a ***5*** percent level.

The lower significance of **the** coefficient b_i for the sugarcane crop **would** mean that factors other **than** the change in the water duties have influenced farmers in their decision whether or not to plant sugarcane. **The** installation of a sugarcane mill in the **area** and **the** associated incentives provided to farmers for growing **sugarcane** are important factors, more recent than the increase in water duties, that would explain the increase in the **area** under sugarcane compared to changes in the **quantity** of water supplied to farmers.

AGRICULTURAL OUTPUTS AND INPUTS

Data provided by the Provincial Agriculture Department (PAD) for the D.I.Khan District show that yields for rice, wheat and sugarcane have increased in the area by 18 percent, ***25*** percent **and 45** percent, respectively, for the last four years. **The** main problem **with** these dab **is** that they constitute a **summary** of data **from the** Paharpur Canal and the surrounding **area.** The low increase recorded for the wheat crop, for example, could be related to the fact that **the** district level data are **a** mixture of irrigated and rain-fed production and productivity. Yield **data** collected **through** fanners' interviews **are** more site-specific **and can be** related to the use of inputs (mainly fertilizers) **as** well. **They** will be **used** in the following paragraphs of this section, keeping in mind that the accuracy of the answers given by farmers is questionable, especially when the information pertains to the before *remodeling* situation.

From a value of 2,900 kg per ha at the time of the remodeling, rice yields have reached the value of 5,000 kg per ha on average for the interviewed farmers, an increase **of** nearly 70 percent for the period, or about **10** percent per year. The increase is relatively high, but rice yields remain **on** the same order of magnitude **as** those given **by** the **PAD.** Changes in wheat yields **are** slightly less impressive: **the** reported increase is **equal** to "only" ***50*** percent, on average, from **1,540** kg per ha to **2,340** kg per ha.

A similar change for the two crops has been a decrease in the coefficient of variation of **the** yields, **from 0.53** to **0.31 and** from 0.52 to 0.41, respectively, for rice and wheat. Farmers' responses have shown that the irrigation water supply is now more uniformly distributed **among** watercourses and within watercourses, which **has** now been translated into a higher homogeneity in rice and wheat yields.

The average yields for rice and wheat have been calculated for the four sample watercourses. Table 5 highlights the differences observed in rice and wheat yields among watercourses. These are consistent with the changes in the water supply reported by farmers and the differences in the cropping pattern among watercourses.

Table 5. Average changes in rice and wheat yields per sample watercourse based on farmers' interviews.

WC number	Rice yields			wheat yields		
	Before (ton/ha)	After (ton/ha)	Difference. in %	Before (ton/ha)	After (ton/ha)	Difference in %
5767-L	2.4	3.7	+55	1.1	1.9	+70
13526-R	4.2	5.9	+40	2.5	3.1	+25
21516-L	2.2	4.4	+100	1.1	2.1	+90
29650TL	3.1	6.0	+95	1.4	2.3	+65

The comparison of the data on yields with those on the changes in the water supply reported by farmers show that there is a strong correlation between the two. Tail watercourses (especially, 21516-L), which have benefited the most from the remodeling and the increase in the water duties have higher increases in yields; head watercourses, with some farmers recognizing the benefits of the remodeling and others claiming that they now have less irrigation canal water available record the lower increases in yields. This is particularly the case for rice, which is more sensitive to changes in the water environment, given its higher water requirements.

Farmers report also an important increase (two to three times) in their sugarcane yields in all watercourses except for 5767-L (due to a decrease in the availability of canal water during the Kharif season as indicated by some farmers of this watercourse). No real trend was found in gram yields, an expected result in view of the low irrigation water requirements of this crop. The few farmers who reported some changes in gram yields were relating it to erratic climatic conditions of specific years.

Only a share of the increase in yields, however, can be directly attributed to the increase in the canal water supply. Changes in the water supply and the increase in yields have been accompanied by changes in the use of the main input (other than water), i.e., fertilizers (Di-Amino-Phosphate [DAP] and Urea), as reported by farmers.

The use of fertilizers has changed dramatically during recent years. For both crops, rice and wheat, the highest increase in the use of fertilizers has been reported for farmers located in the command area of Watercourse 21516-L where the higher yield increases as well as the best improvement in canal water supply have occurred. With an improved canal water supply (not only in terms of quantity but also in terms of reliability), farmers would now face a less-risky environment and invest more in fertilizers and other inputs. Water and fertilizers, jointly, have had a positive and cumulative impact on the crop yields.

In order to evaluate the marginal impact of the change in water duties on yields, a regression analysis has been performed for rice and wheat, using yield and input data (quantity of DAP and urea applied per hectare) of the *Before* and *After* situations. A dummy variable has been used to estimate yield changes attributed to the increase in water duties. The best equations obtained for the two crops relate yields to the quantity of urea applied and the dummy variable -- used to compare the situation with low water duties to that with high water duties. Other variables included in the model (U^2, DAP and DAP^2) were not significantly correlated to rice and wheat yields. They have been dropped out of the model after the first runs of the regression analysis.

An interaction term between the dummy variable and the quantity of urea applied was also included in the equation, to take into account the possibility that changes in water duties could have changed the effectiveness of the fertilizers. However, rice and wheat yields were not significantly related to the interaction term, which was consequently dropped from the equations as well.

The equations for rice and wheat are presented below.[14]

$$Y_{rice} = \underset{(1.5)}{2060} + \underset{(3.4)_a}{8.8*U} + \underset{(3.2)_a}{1410*D} \qquad (3)$$

$$Y_{wheat} = \underset{(1.3)}{950} + \underset{(4.7)_a}{7.0*U} + \underset{(2.0)_b}{450*D} \qquad (4)$$

where, Y_{rice} : Rice yield in kg/ha,
Y_{wheat} : Wheat yield in kg/ha,
U : Quantity of urea applied (in kg/ha), and
D Dummy variable, equal to 1 for high water duties (*After*), equal to 0 for low water duties (Before).

The significance of the dummy variable in the two equations is to explain that the increase in the water duties has had a direct and positive impact on rice and wheat yields, equivalent to an increase of 1,410 kg/ha and 450 kg/ha for rice and wheat, respectively. The high response of the rice crop compared to the wheat crop was expected. With its high water requirements, rice is more sensitive than wheat to changes in the irrigation water supply.

Thus, 65 percent of the total increase in rice yield (+ 2,100 kg/ha on average) can be attributed directly to a larger quantity of water supplied to the crops, while the remaining part (+35%) is related to the increased use of other inputs. Values for wheat are rather similar with a bit less than 60 percent of the total yield increase (+ 800 kg/ha on average) attributed directly to the increase in irrigation water available for the crop.

With these important changes in the constraints faced by farmers, and their impact on farming practices and use of inputs, the average productivity of the system has changed, not only the productivity with respect to land as presented above, but also the productivity with respect to water. The returns to irrigation water for rice and wheat crops have been estimated using farm level information and water supply data collected by the PID. Yields per unit of water for the two crops are presented in Table 6.

[14] Equation 3 : Number of observations = 48; Degrees of freedom = 45; R^2 = 0.46
Equation 4 : Number of observations = 46; Degrees of freedom = 43; R^2 = 0.45
t-test given into brackets with

a : significant at a 5 percent probability level.
b : significant at a 10 percent probability level.

Table 6.

Crop	Before (low water duties)	After (high water duties)
Rice	0.7 kg/m^3	0.65 kg/m^3
wheal	1.15 kg/m^3	0.95 kg/m^3

While *the* canal water supply has been increased by 54 and 31 percent for the Kharif season and the Rabi season, respectively, the productivity of irrigation water has been reduced by 7 percent in the case of rice, and 17 percent in the case of wheat, The productivity of water, however, did not decrease as much as feared. There has been a positive and significant response by farmers in the Girsal Minor Command Area *to* the increased canal water supplies.

Conclusions

1. The integration of the old Paharpur Irrigation System into the new Chashma Right Bank Canal Irrigation System resulted in a definite increase in its water duties. The average discharge at the head of the Girsal Minor has been increased by 54 and 31 percent for the Kharif season and Rabi season, respectively. But, the increase in the water supply has not necessarily brought about an improvement in the operation of the system.

2. Our findings show that farmers have reacted to the changes in canal water supplies by several ways: Modifying their cropping pattern, applying larger quantities of canal water per unit area, shifting their irrigation supply away from the use of more expensive tubewell water, etc. The number of private tubewells has been reduced by 80 percent in the command area of the Girsal Minor and the remaining private tubewells have decreased their operations significantly.

3. Farmers have responded to the new water allocations by shifting their cropping pattern towards more Kharif crops. However, the yearly cropping intensity has remained fairly the same. The percentage of the CCA under rice and sugarcane has increased. The change over time in the area under rice is significantly related to the changes in water duties. For sugarcane, other factors -- as the economic incentives provided by a new sugar mill installed in the area -- are mainly responsible for changes in the area under this crop.

4. Along with the change in cropping pattern, large increases in yields are reported by farmers. Analysis of rice and wheat yields show that part of the increase is related to the new water duties, with the changes in the use of fertilizers also responsible for the great differences between the *Before* and *After* remodeling situations. The analysis also confirms that there has been no impact of the increased water supply on the efficiency of fertilizer use.

5. The productivity of irrigation water, in kg of produce per cubic meter of water utilized, has been reduced by 7 percent for rice and 17 percent for wheat after the remodeling. Given the percent increases in canal water supplies, the productivity reduction is relatively small; it also indicates that farmers have responded effectively to the new water conditions.

6. The relatively small increases in the RWS values (+12% and +10% for the Kharif season and the Rabi season, respectively) can also be tied to the above. Instead of farmers expanding or intensifying the area under cultivation, they are supplying more water per unit area planted with higher water demanding crops, thus maintaining the RWS fairly constant. Given the economic returns of both rice and sugarcane this again indicates rational allocation of the water resource by farmers.

7. The comparison of the design cropping pattern for the CRBC Irrigation System (WAPDA 1991) with the current cropping pattern in the Girsal Minor shows that there is no similarity between the two, It was estimated, for example, that 2 percent of the area would be planted under rice while fanners in the Girsal Minor grow nearly 25 percent of the command area under this crop. And current cropping

intensities are still far below the intended 150 percent. If the area under rice and sugarcane remains at its current level or even continues to increase, it is doubtful that the cropping intensity will rise beyond the current 100 percent value.

8. While it is agreed that the changes observed in the area under rice and sugarcane are the result of fanners' rational behavior in their allocation of the enhanced water resource, a more serious and direct implication (at least for the farmers of the project area) of the difference between the current cropping pattern and the design one is that the current water requirements of farmers of the Girsal Minor are much higher than designed, especially during the Kharif season with its higher percentage of the area under rice crop. Similar differences exist for the whole Paharpur Command Area and the newly expanded area of CRBC (Strosser 1993). The maximum irrigation water available for the whole system being specified and equal to 5,000 cfs (ADB 1977), it is expected that the higher water requirements of farmers of the Old Paharpur Canal Command Area and CRBC Stage-I would have a negative impact on the (future) supply of water for farmers located downstream in Stages II and III of the irrigation system.

9. The significant increase in crop yields and the low decrease in the productivity of water show that the policy of the NWFP Government, to increase agricultural production by increasing the canal water duties, has been successful in the case of the Girsal Minor and the old Paharpur Irrigation System. However, due to cropping intensities lower than designed and the expected negative impact on the supply of water for downstream farmers, it is not sure that the aggregated increase in agricultural production for the whole CRBC Irrigation System would be at expected levels.

10. Finally, it can be concluded that the use of the analysis of the farming systems at the appraisal stage of irrigation projects would be beneficial and should be generalized, in order to gain further understanding of the relationship between increased water duties and their impact on the agricultural production of an area. Different ways could be used to assess the potential impact of new irrigation supplies (or modifications in existing supplies) on farming systems and agricultural production: (i) to analyze existing systems where changes in water supplies have occurred and where monitoring of water supply and agricultural production has taken place (an analysis similar to the one presented in this paper); and (ii) to analyze farming systems in a given location, to classify farms according to their water constraints, to model representative farms (using linear programming techniques, for example) and to predict how fanners would react to specific changes in their irrigation water supply.

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