CHAPTER 10

Performance of Chashma Right Bank Canal: Technical and Economic Indicators in the Context of Crop-Based Irrigation Operations

Pierre Strosser and Carlos Garces

INTRODUCTION

POPULATION PRESSURE COUPLED with watershed deforestation, secondary salinization, waterlogging and crop yield stagnation are some of the serious issues being faced by the irrigated agriculture sector in Pakistan. This state of affairs has led the Government of Pakistan to search for fresh and innovative ideas on how to improve the performance of irrigation systems and on how to assure their sustainability.

The introduction of crop-based irrigation operations into traditional supply-side irrigation schemes is one of the mechanisms through which the government would like to see a radical departure from longstanding practices.

The construction of a new irrigation system, the Chashma Right Bank Canal (CRBC) and the remodeling of an existing one, the Lower Swat Canal, both in the North-West Frontier Province, provided an excellent opportunity for the provincial government to try out the concept of seeking a better match between the supply and demand of scarce water resources. This approach, referred to as crop-based irrigation operations, was a part of the project plans, but difficulties were encountered in its implementation. Since July 1991, the International Irrigation Management Institute (IIMI) is implementing, in collaboration with concerned local agencies and through funding from the Asian Development Bank, a three-year project to attempt to understand and identify ways of overcoming these problems.

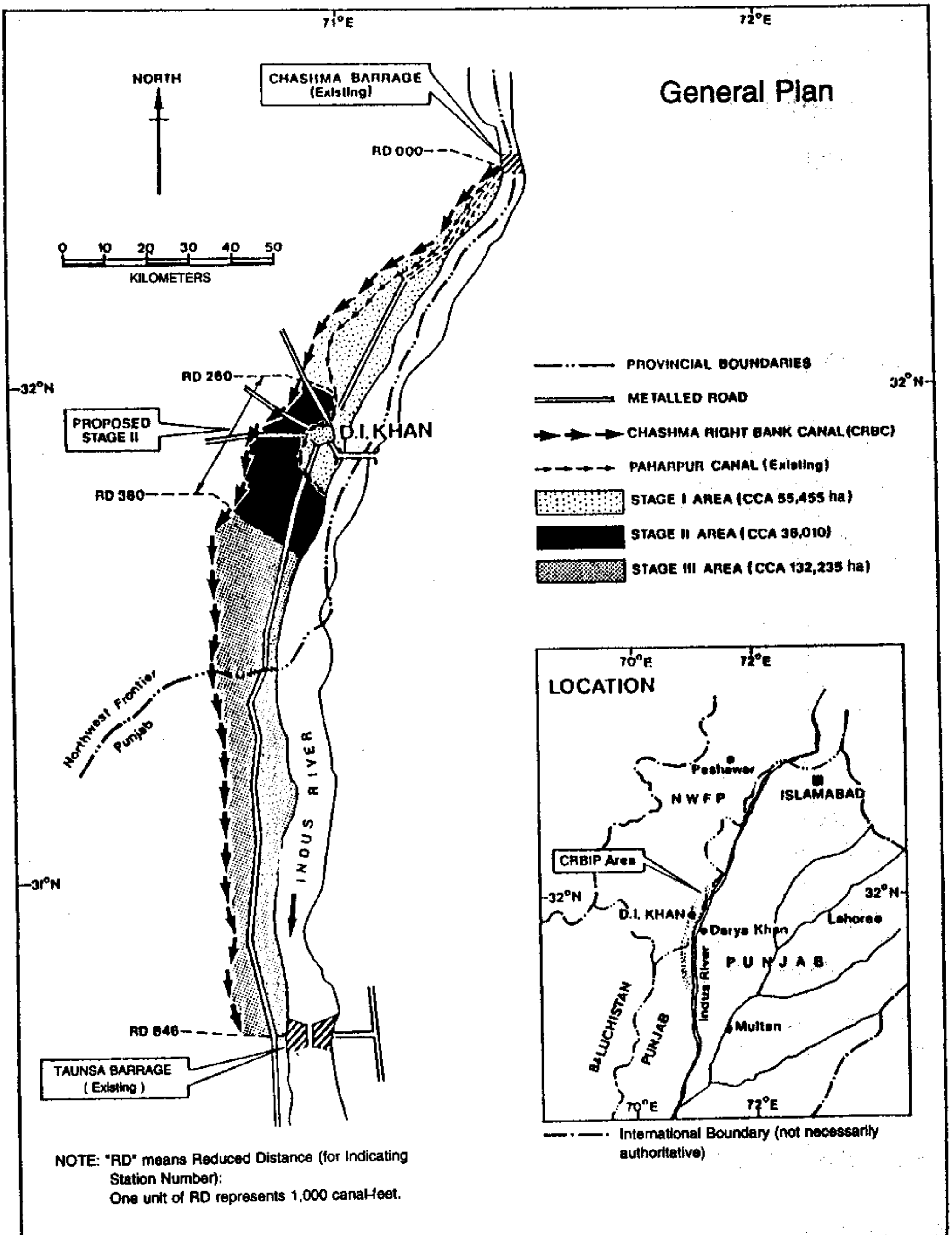
This paper relates some of the constraints encountered during the first year of activities and sets forward a series of performance indicators being utilized in the context of crop-based irrigations but with the caveat that the system continues to operate in the traditional supply-based approach. Wherever possible, performance guidelines proposed by members of IIMI's Performance Task Force (see Murray-Rust 1992) have been followed in order to pursue standardization of concepts throughout the Institute.

THE CRBC IRRIGATION SYSTEM

The Project

The Chashma Right Bank Irrigation Project (CRBIP) will create a major perennial surface irrigation system that, once completed, will cover a gross command area of about 280,000 ha of

Figure 10.1. General plan and location of Chashma Right Bank Irrigation Project (CRBIP).



land on the right bank of the Indus River in Central Pakistan, stretching between Chashma and Taunsa barrages (see Figure 10.1).

The main source of water for the system is the Indus River by means of the Chashma Barrage which was commissioned in 1982. The main canal is 285 km long with a culturable command area (CCA) of 230,675 ha that spans two provinces, the North-West Frontier and Punjab, in a 60 to 40 percent proportion, respectively.

Because of the magnitude of the project, construction of the main canal and the distributaries has been subdivided into three stages. Stage I runs for 79 km (RD 000 to RD 260) and covers a CCA of 56,600 ha, Stage II runs for 37 km (RD 260 to RD 380) with a CCA of 36,240 ha and Stage III runs for 142 km (RD 380 to RD 846) with a CCA of 137,835 ha (one unit of RD represents 1,000 canal-feet).

Construction of Stage I has been completed and the system became operational in early 1987; it includes the old Paharpur Irrigation System which has been remodeled for increased capacity and is now being fed by the CRBC through 4 link channels. The full capacity of 138 cumecs of the main canal, to be distributed through 49 distributaries and 4 link canals, is not likely to be utilized for the remainder of the century upon completion of Stages II (which is in an advance stage of construction, with completion scheduled for mid-1993) and III (construction scheduled to begin in 1993).

The total cost of the project has been pegged at Rs 10,213 million (WAPDA 1991). The project represents the newest system in the country and the largest undertaken to date in the North-West Frontier Province. It is looked upon as a model for future irrigation-expansion-related activities. The main features of the CRBC Irrigation System are summarized in Table 10.1.

Water Distribution at Main-Canal and Secondary-System Levels

The system faces the dichotomy of having been designed in a **supply-based** delivery approach, which is long rooted in the country's irrigation community, while the desire is to operate it in a **crop-based** approach. While the former is being exercised through an administrative system, the latter requires that the process of water distribution be managed. The degree of success expected in operating the system will depend on the extent to which these two different approaches can be reconciled.

For example, designed water deliveries at the main-canal level were calculated on the basis of a 10-day total crop water requirement (losses included) and they vary from a minimum of 40 cumecs to a maximum of 137 cumecs. The distributaries, on the other hand, following traditional supply-based irrigation as advocated by the agency, should run no lower than at 70 percent of their full supply level (FSL). In the main canal, it is possible to achieve the required water elevations by means of existing cross-regulators, escapes and gated offtakes;[51] but, comparable operational flexibility is not found at the distributary level.

The above issue is further clouded when no decision at the highest provincial and/or federal level exists on how flows are to be diverted into the CRBC through continuous peak-requirement flows, with the excess flows returned to the river by means of existing escapes or by varying discharges according to total crop water requirements. The final decision will certainly have an impact on how the system is to be operated.

51 This particular issue of whether the existing main canal infrastructure is sufficient to cope with varying flows is also being studied by IIMI under the Decision Support System sub-component of the Cooperative Agreement Project. See, for example Habib, Z. et al. (1992).

Table 10.1. Main Features of the CRBC Irrigation System.

Construction begun in	:	1986
Supply sources	:	Indus and Kabul rivers
Source regulation	:	Chashma Barrage
Type of system	:	Gravity flow
Average water allowance	:	0.60 lps/ha
Type of main canal	:	RD* 000 to RD 097 unlined; RD 097 to end lined.
Length of canal network	:	603.37 km
Type of outlets	:	Pipe
Drainage system	:	Tile drains in selected areas of Stage 1

	Stage I	Stage II	Stage III	Total
Design discharge (cumecs)	34.73	22.63	80.72	138.07
Length of main canal (km)	87.88	40.56	157.17	285.6
No. of distributaries	5 + (4 links)	8	36	53
CCA (ha)	57,605	35,547	135,523	230,675

	Kharif	Rabi	Total
Designed cropping intensity (%)	60	90	150

* One unit of RD ("Reduced Distance") represents 1,000 canal-feet.

At present, however, project monitoring activities clearly indicate that the water supply being provided to Stage I of the CRBIP exceeds crop water requirements; but, there is considerable inequity in the distribution of water, despite the excess, with those areas at the tails of the command receiving less. The excess water supply, notwithstanding the conditions at some tail reaches of watercourses, has created a sense of abundance of the resource among water users. Clearly, as more and more land is brought under irrigation, the system will necessarily have to reduce water supplies in Stage I creating conflict with the users already accustomed to overdeliveries.

A final comment that can be made in this section relates to the state of flux that still prevails in the development of the system as a whole. While the area under irrigation in Stage I has been, for the most part, consolidated, Stage II is continuously bringing new land into irrigated conditions as construction advances. That changing situation has deterred the operating agencies (Water and Power Development Authority [WAPDA] at main-canal level and the provincial Irrigation Department [ID] at distributary level) from taking firm operational decisions because these may no longer be relevant in a short time. Thus, the government institutions are reluctant to try any bold initiatives at this point in time.

Water Management below the Outlet

Influential farmers appear to be the main individuals who decide on the distribution of water at the watercourse level. Very few formal requests for an official allocation of water among irrigators have been made to the Irrigation Department. In most of the watercourses, water is allocated through an unofficial *warabandi* (fixation [*bandi*] of turns [*wara*]) with a 7-day rotation.

The warabandi system, however, is not always followed by farmers. First, exchange of turns seems to be a rather common practice to increase the flexibility of the warabandi (unofficial or official). This is the case especially for the head-end farmers of the watercourses. Second, differences in water distribution exist between seasons. Farmers are much less concerned by their water turns during the rabi season, with the water supply exceeding the demand by a vast amount. They share their irrigation water turns (for example, up to 6 farmers from the same watercourse have been reported to irrigate at the same time during the last rabi season of 1991/92) or they close their outlets when water is not needed. During the kharif season, they tend to follow their warabandi more closely.

Even if water is in excess at system level, differences are found when comparing watercourses and farmers. Water availability and the management of water, for example, are major concerns of farmers located in the tail reaches where water is scarce. Some of these farmers even purchase water from other farmers in order to have a sufficient irrigation water supply.

Most of the Water Users' Associations organized by the On-Farm Water Management Department at the time of the lining of the watercourses have ceased to exist or do not function anymore. Farmers cooperate to maintain their watercourses, but this cooperation remains limited. They rarely intervene jointly in the management of water above the outlet, except in extreme cases like the tail-end farmers from watercourses of Distributaries 3 and 4, who have been able to organize themselves to influence the operating agencies to build a specific minor (Jabbar Wala Minor) to irrigate their lands.

Farming Systems and Agricultural Production

Nearly all the farmers of the command area of Stage I had experienced irrigated agriculture before the commissioning of the CRBC. However, these experiences were gained mainly in tubewell (public or private) irrigation or canal irrigation with much smaller water flows than the ones delivered by the CRBC. Farmers and their farming systems are still in a transition phase, the farmers trying to incorporate the high water duties specific to this new irrigation environment.

The importance of rice (around 20% of the CCA) and the emergence of sugarcane (although still occupying a relatively small percentage of the CCA) are indicators of the impact of the new water supplies on the cropping patterns and the farming systems. However, farmers remain highly rabi-oriented, the percentage of fallow land being much higher during the kharif season (40% of the CCA) than during the rabi season (10% of the CCA). The migration of a part of the population to the hilly areas at the beginning of the hot season, leaving some land fallow during the kharif season, is one factor that explains this rabi orientation. Another one could be the current irrigation water supply which seems to be relatively more scarce during the kharif season.

Forty to fifty percent of the CCA is cultivated to wheat and around 20 percent of the CCA is under gram (a type of pulse). The importance of gram, rarely irrigated, is explained by the position of this crop in the wheat-rice-gram-rice rotation and by the fact that farmers are not yet fully adapted to the higher irrigation water duties of the CRBC system. The other crops grown are fodder (rabi and kharif seasons), maize and some vegetables and oilseeds.

The average farm size is 12.5 ha (average of data from 318 farms of distributaries 3 and 4), 90 percent being irrigated land. However, more than 50 percent of the farmers cultivate less than 5 ha of land each. Differences in the farming systems exist within the command area of Stage I. The areas supplied by Distributary 1 are not yet fully developed with a substantial percentage of fallow land; in distributary 3, the cropping pattern is more diversified than in the rest of the system; farmers from Distributary 4 are more oriented to raising livestock (mainly goats and sheep), certainly due to the fact that many of the farmers from this distributary are recent settlers including migrant tribes from Afghanistan.

The main constraints on agricultural production reported by farmers are related to land development (fields too high or not leveled), irrigation water supply (as reported in the previous section) and lack of credit to buy the necessary inputs (seeds, fertilizers), machines (tractors) or to develop their land. The last aspect, credit, is seen as especially important for some farmers having invested large amounts of money in the purchase of expensive newly irrigated land. They find themselves without enough money to develop this land or to buy inputs for a cropping season.

PERFORMANCE INDICATORS FOR CROP-BASED IRRIGATION

The main objectives of this part is to define and discuss a set of performance indicators to be used in a crop-based irrigation context. The different aspects taken into account in the selection of appropriate indicators for the performance assessment of the system are primarily the objectives of crop-based irrigation themselves and also some characteristics of the studied irrigation system, Chashma Right Bank Canal.

Objectives of Crop-Based Irrigation

The primary objective of Crop-Based Irrigation is :

> *to increase the utility of land by supplying water to a specified system according to crop water requirements.*

Adequacy and timeliness are two important components of such a supply leading to the necessity to have a flexible supply system, flexible not only over time (to respond to changes in the irrigation water requirements due to changes in crop needs or rainfall) but also over space (to distribute different quantities of water to different parts of the system according to specific needs).

What is meant by "system" here is the irrigated agriculture of a delimited area, in this case the command area of the CRBC. It includes not only the water distribution system per se but also the farming system with its different characteristics in terms of inputs used, transformations undertaken and outputs produced (in the following sections, for example, the output of the system will be related to agricultural production).

The definition of the type of performance to be considered is the first step of the analysis of the performance of an irrigation system. Three different views of performance (Murray-Rust 1992) are chosen to frame the discussion:

1. **Objective-setting performance:** to evaluate the relevance and feasibility of objective(s) selected for the operation of an irrigation system.

2. **Operational performance:** to compare the actual operation of the system with a defined set of targets.

3. **Output performance:** to evaluate the impact of the operation and management of an irrigation system on agricultural production.

It has to be emphasized that these three views are complementary and interrelated. The choice of feasible targets for the operation of the system, for example, will be evaluated in the objective-setting performance analysis.

In a second step, the level of focus has to be clearly defined. Although general objectives are set for an irrigation system, it is useful to understand what is meant in terms of objectives at different levels of the irrigation system (main canal, distributary, watercourse, farm, field). Following the same line, targets for operational performance are expected to vary from one level of the irrigation system to the other. Different individuals or groups are involved in the operation and the control of the water flows at each level and they are responsible for its performance. Finally, the output will be evaluated and more or less aggregated according to specific needs (study of yields at farm level or analysis of the capacity of agricultural production of the system, etc).

Suggested Performance Indicators

Objective setting performance. Three aspects have been identified as having greater importance within a crop-based irrigation environment.

The first one is related to water resources and the **availability of water for irrigation**. The question whether there is enough irrigation water to match water requirements of the crops of the area has to be answered clearly. This issue will be addressed by the calculation of the Allocation Adequacy Indicator, defined as the arithmetic mean of the relative differences between the water allocated and the water required (in absolute values) measured daily for 10 days.

The comparison between the flows in the Indus River at Chashma Barrage ajd the flows required for the CRBC shows that the quantity of water available in the Indus River is not a limiting factor at all. More important than the flows passing through Chashma Barrage, however, is the amount that has been (or will be) allocated to the CRBC Irrigation System.

Although it is stated in the Loan Agreement between the Asian Development Bank and the Government of Pakistan[52] that

> *...CRBIP will have a maximum withdrawal rate of 5,000 cfs from the Chashma Barrage at the Indus River ... available at any time of the year...*

it is difficult to estimate, at present, the amount of water that will be allocated in the future within the context of the recent Water Treaty and negotiations between the 4 Provinces of Pakistan for the allocation of the water resources of the country.[53]

The second question to be addressed is **whether the CRBC Irrigation System can be operated as a crop-based irrigation system**. Has the system been designed in such a way that water can be distributed according to the crop water requirements ? This approach is more technical

52 Para 4, Schedule 6, Loan Agreement No. 330, Chashma Right Bank Irrigation, approved 15 December 1977.

53 This problem of allocation is already playing a role in the delays occurring in the design and construction of Stage III of the CRBC (approximately 80% of which is located in the Punjab Province while Stage I and Stage II are located entirely within the North-West Frontier Province).

and has to consider not only the installed infrastructures and the possibilities of water control at different points of the main and secondary canals but also some hydraulic parameters as velocity or sedimentation rate, important in a proper longer-term evaluation of the constraints and limitations of the physical system.

The Physical System Adequacy is the indicator used to evaluate the adequacy of the physical system, calculated as the percentage of time the objectives of crop-based irrigation could be met. It will be calculated as the ratio of the number of 10-day periods of a year the objectives could be met divided by the total number of 10-day periods in a year.

The third (last) aspect has to do with the operation of the system itself : **are the operators able to operate the system in a crop-based irrigation mode** ? The financial resources of the operating groups (farmers included), the personnel needed to operate the system in a proper manner, or the information system needed for a proper flow of information between agencies and farmers are important components to be considered within this last aspect.

This issue has not been addressed in this paper. However, the comparison between what is needed for the operation under crop-based considerations and what is available is a simple way, in principle, to estimate this third aspect, expressed as a percentage ("funds available/costs of the operation of the system" or "personnel available/personnel needed for crop-based irrigation operation").

Operational performance. The adequacy of water supplied in relation to the water requirements of an irrigation scheme is the main objective of crop-based irrigation. The Relative Water Supply (RWS), the ratio of the supply to the demand (Levine 1982), appears to be an appropriate indicator to assess this adequacy. However, although this indicator appears to be relatively simple, a set of questions related to the definition of supply and demand, levels at which RWS has to be calculated, targets for RWS, etc,. has to be addressed carefully.

Using field water requirements as demand and setting realistic targets for the various levels of the system is the approach recommended by Bird et al. (1992) and it has been used in this paper. The 10-day RWS is the basic indicator calculated at main-canal, distributary and watercourse levels. For each 10-day period, the RWS is calculated as presented below:

$$\text{RWS} = \frac{\text{Irrigation + Effective Rainfall}}{\text{Crop Water Requirements + Seepage and Percolation}}$$

Due to the impossibility of collecting irrigation application data for sample farms in the CRBC area, it is not possible to calculate the RWS at farm level, which is necessary for the analysis of the variability of this indicator in the farm population.

Four different indicators (based on 10-day RWS and the amount by which it differs from the target supply over time) have been chosen for the evaluation of the operational performance at different levels of the CRBC Irrigation System. The first two indicators are related to the adequacy of the supply and are:

- *The Seasonal Adequacy Indicator.* This indicator is an estimate of the relative difference of the RWS to the target[54] for each location and period of time and its arithmetic mean is used to calculate the value of the indicator for a given period of time (in this case, a

54 Target values to be used at different levels of the system are respectively 1.38, 1.45 and 1.55 for watercourse, distributary and main-canal levels, based on estimates of conveyance losses at watercourse, distributary and main-canal levels.

season). It is an estimate of the adequacy of the total supply of irrigation water for a season, assuming that an oversupply during a period of time can be used during the next under-supplied period.

- *The Supply Inadequacy Indicator* is the same relative difference as above but when the target supply is greater than the RWS (negative values of this difference). As the basic Molden and Gates Adequacy Indicator (Molden and Gates 1990), it indicates undersupply which could lead to crop stress and yield reduction.

The other two indicators selected, which are more oriented towards the operator itself, are:

- *The Supply Mismatch Indicator*, an evaluation of the performance of the operators themselves, is the average over the season of the difference between the actual operation and specific targets (varying over time) in absolute values.

- *The Equity Indicator* is the average of the spatial coefficients of variation of the RWS, which is an evaluation of the discrepancies among locations of the CRBC Irrigation System.

The four indicators are compared to zero, which represents the ideal crop-based irrigation operations. The indicators calculated in current conditions represent the deviation in terms of percentage from the target value, an estimation of the discrepancy between crop-based irrigation operations and current operations of the system.

Output performance. Different aspects of the farming system have to be considered in the analysis of the impact of the irrigation water supply on the agricultural production: cropped area, cropping pattern, yields or inputs used, etc. In order to aggregate the different aspects of the farming system, the weighted gross margin per unit of land is used as an economic indicator.

This average gross margin is ultimately calculated for different watercourses and distributaries.[55] Its spatial coefficient of variation is also calculated to estimate an economic equity among different locations of the present irrigation system.

The analysis of the different components of this indicator, however, is still needed in order to understand the decision-making process of the farmers. Cropping intensity, cropping pattern, yields and gross margins for specific crops are analyzed and compared to design values (for cropping intensity and cropping pattern) or values available from other sources.

In this paper, cropping intensity and cropping pattern at a watercourse level are evaluated against design values. Yields per unit of land (kilogram per hectare) and gross margin per unit of land (rupees per hectare) for the wheat crop only are computed and compared to available secondary data.[56] Moreover these will serve as benchmark values for IIMI's work in the area.

55 Similar indicators could be calculated using the energy content of a kilogram of each crop product or using wheat equivalent values as described by Carruthers et al. (1983).

56 For the next seasons, data will be collected for other main crops and the weighted gross margin per ha computed.

IIMI's Crop-Based Irrigation Operation (CBIO) Project: Some Comments

The previous discussion has been based on crop-based irrigation considerations only, without including other objectives or constraints of the CRBC Irrigation System. Although IIMI's Crop-Based Irrigation Operation Project in the North-West Frontier Province (NWFP) is mainly oriented towards crop-based irrigation, one of its many objectives is:

> *to improve the overall productivity of water resources within the authorized water allocations and subject to the available supplies.*

This is not an explicit objective for the operation of the CRBC Irrigation System. But given the scarcity of the water resources in the country, it is an implicit one. The weighted gross margin per unit of water will be the other output performance indicator to be compared with available secondary data and to assess changes in productivity. The monitoring of the productivity of water, however, has a real meaning only if water saved within the CRBC is used somewhere else downstream along the Indus River.

The problem of water allocation is raised here, leaving open the possibility of crop-based irrigation operations within a water-scarce environment (by water-scarce it is meant that enough water is not available for the crops planted by the farmers of the area). Although water is in excess in the current situation, new land developments, changes in cropping intensities and cropping patterns are expected. Moreover, Stage II and Stage III of the CRBC will become functional and draw a part of the available water supply. If water is scarce, the primary operational objective becomes equity and the minimization of the spatial coefficient of variation of the RWS.

Some of the constraints of the CRBC Irrigation System operation have to be taken into account when defining the targets for the operation of the system. The need to close the canal for maintenance during a certain period of the year is one of these constraints. The target for the operating agencies during this period is not to match the irrigation water supply to the crop irrigation requirements anymore but to deliver no water. Out of all the indicators described and selected, only the Supply Mismatch Indicator has to be modified accordingly.

Table 10.2. Performance indicators for the CRBC Crop-Based Irrigation Operation Project.

Performance	Indicator	Target
Objective setting	* Allocation Adequacy * Physical System Adequacy * Personnel (or Financial) Availability Ratio (in %)	0 100% 100%
Operation	* Seasonal Adequacy * Supply Inadequacy * Supply Mismatch * Equity	0 0 0 0
Output	* Weighted gross margin (per unit of land and per unit of water) * Cropping intensity * Cropping pattern * Crop yield and gross margin per unit of land * Crop yield and gross margin per unit of water	Compared to secondary data Design Design Compared to secondary data Compared to secondary data

Summary of Performance Indicators

To address issues related to objective-setting performance, operational performance and output performance, a set of indicators has been selected. These indicators are presented in Table 10.2, along with their target values. Their mathematical formulae are described in the Appendix.

APPLICATION OF INDICATORS TO THE CRBC, RABI 1991/92 SEASON

Methodology and Data Collection

The first objective of IIMI's project in the CRBC area has been to analyze the current operation of the irrigation system and to assess its level of performance (operational performance and output performance). To calculate the different indicators proposed in the previous section of this paper, a large set of data (primary and secondary) has to be collected. At the main-canal level, the core of data which has been used is secondary data (collected by WAPDA). Primary data collected by IIMI field team are increasingly important while addressing issues at smaller irrigation units (distributary, watercourse, farm and field levels). Table 10.3 summarizes the main components of the primary data set collected during the first rabi season.

Table 10.3. IIMI Data Collection Program, the CRBC, rabi, 1991/92.

Study	Component	Field activity	Main canal	Distributary	Watercourse/ Farm
Irrigation system operation	Simulation Water management	Canal monitoring Interviews, Warabandi	XXX —	XXX XXX	— XXX
Supply and demand of irrigation water	Water supply Water losses Crop requirements	 Flow measurements Maps, crop survey	— — —	XXX XXX —	XXX XXX XXX
Irrigation institutions	Role of agencies Role of farmers	Officials' interviews Farmers' interviews	XXX —	XXX XXX	XXX XXX
Economics of the CBIO	Farming practices Agricultural input/output	Survey (contractor) and regular monitoring	— —	— —	XXX XXX
Others	Social environment Meteorology	Survey (contractor) Rainfall, Evaporation	— XXX	— —	XXX —

Note: XXX denotes that the data in a row were collected at the level in the corresponding column.

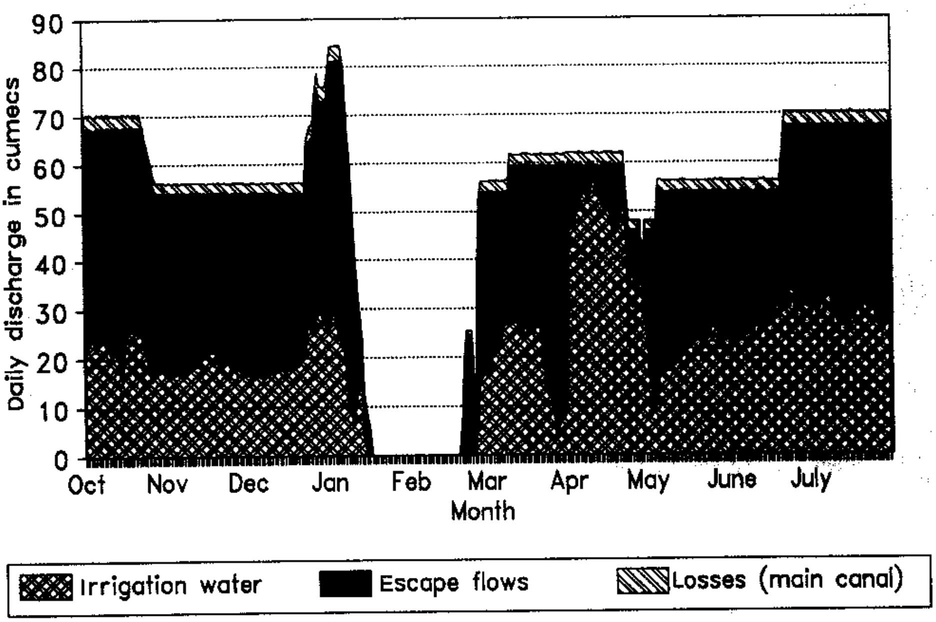
Two distributaries (Distributary 3 and Distributary 4) have been monitored since November 1991. In each distributary, 8 watercourses have been selected, 2 in each quartile of the distributary command area. Because of the integration of the Paharpur Canal Irrigation System into the CRBC Irrigation System, Girsal Minor, continuation of Distributary 3 in Paharpur command area, has been included in the regular monitoring as well. In four watercourses from Distributary 3, six sample farmers have been monitored regularly to gain a better understanding of their farming practices and water management at farm level.

The present study focuses on the operation of the main canal and one distributary, Distributary 3, and its watercourses. For this distributary, management changes at a secondary and tertiary level were tested ultimately. Distributary 4 was used as a control and its performances was compared to the performance of Distributary 3 with improved irrigation operations. Most of the data cover the 1991/92 rabi season period. To understand the operation of the system, however, data on the water supply up to June–July, 1992 were also used.

Current System Operation and Operational Performance

The discharge of the water released from the Chashma Barrage at the head of the CRBC is fairly constant for a season. WAPDA data reveal that the discharge for rabi 1991/92 (between November 1991 and April 1992) has, most of the time, been equal to 55 cumecs, varying from 48 cumecs to 60 cumecs. For the kharif season (end of kharif 1991 and beginning of kharif 1992), the discharge is equally constant and close to 70 cumecs (see Figure 10.2).

Figure 10.2. Discharge of water from the CRBC: Irrigation, escape flows and losses.

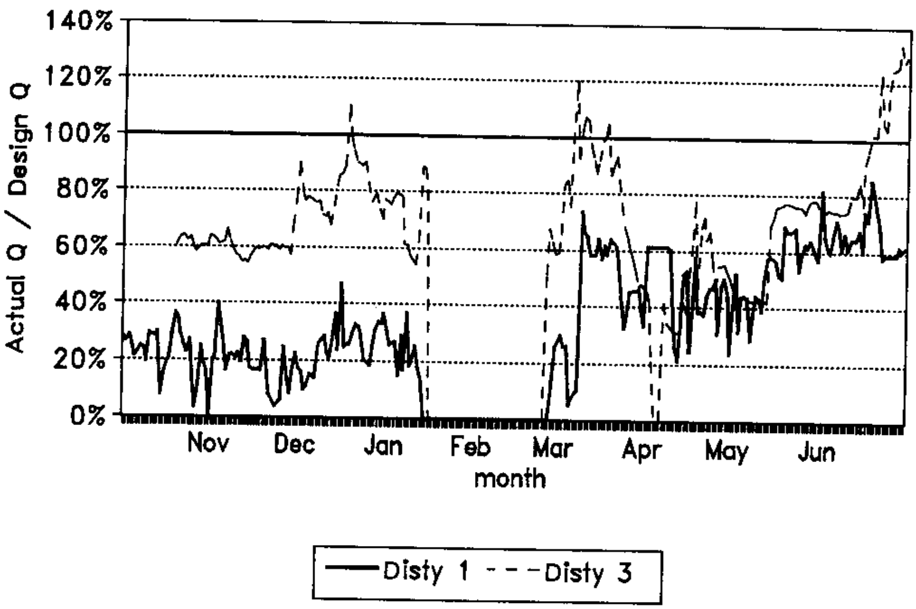


For two periods, however, the discharge of the head of the CRBC has been different. No water has been released into the canal from January 15 to February 25, 1992, for the maintenance of the irrigation water supply network. This canal-closure period was first supposed to take place from the 1st of January to the 31st of January. However, it started only on January 15 for technical reasons related to the Chashma Barrage operation and lasted 10 days more than planned because some structures had to be repaired at distributary level. The discharge of the two weeks before the canal closure, on the contrary, is rather high. The peak is related to repairs and/or maintenance work at the barrage; the CRBC canal was used as an escape to facilitate the work.

Figure 10.2 also highlights the discrepancy between the amount of water released at the head of the CRBC and the amount used for irrigation. It shows that the supply at the head does not follow recorded changes in irrigation water. Both are quite similar for one period only (April 1992). This, however, is mainly due to the way WAPDA records the amount of water for irrigation,[57] which does not represent what is effectively used for irrigation by farmers. For most of the time, the discrepancy between the volume of water released at the head and the volume of water used for irrigation is due to the widespread use of the escapes (in fact, mainly, the escape at the end of Stage I) at main-canal level.

The four distributaries monitored by IIMI during the same period do not follow the same trend as the main canal as could be suspected by looking at the changes in the volume of irrigation water reported by WAPDA. The discharges recorded by WAPDA are much more variable as shown in Figure 10.3, which presents the ratio of the actual discharge to the design discharge,[58] recorded daily from October 1991 to June 1992 for Distributary 1 and Distributary 3.

Figure 10.3. Ratio of actual discharge to design discharge: Distributaries 1 and 3 of the CRBC, October 1991 to June 1992.



57 During April 1992, repairs were made at the escape structure at the end of Stage I. A part of the extra water flowing in the canal has escaped into Stage II. This water, although not used for irrigation, is recorded as irrigation water following WAPDA data collection formats.

58 What is defined here as the design discharge is the value used to calculate the required capacity of the different distributaries to carry the maximum discharge during the peak crop water requirement period. It is not an operational target discharge.

For the period March to June, the four distributaries follow a similar trend, with, first, a decrease in the daily water supplied to the distributaries (at the wheat harvesting time) followed by a marked increase starting in May, the beginning of the kharif season with higher irrigation water needs. It is interesting to note that the discharge at the head of the CRBC has also increased at the beginning of the kharif season but only one month later than the increase recorded at distributary level.

The comparison of the ratio of the daily discharge over design discharge with two threshold values, 100 percent of the design discharge and 70 percent of the design discharge (indicated by the Irrigation Department as the lower limit at which they could run the distributaries) leads to the following conclusions:

- The discharge of Distributary 1 is well below the 70 percent the threshold most of the time, due to the low level of development of the agricultural land in its command area.

- The discharge at Distributary 3 head varies from 50 percent to 100 percent of the design discharge during the rabi season. The trend for the beginning of the kharif season shows that much higher values will be attained.

- The discharge at the head of Distributary 4 is fairly constant and close to 70 percent of the design during the rabi season. The first values for the kharif season seem to predict a constant discharge for kharif but at a higher level, close to 100 percent of the design discharge.

- Distributary 2 discharge covers the largest range of discharges, from 20 percent to 120 percent during the rabi season and more than 150 percent at the beginning of the kharif season.

Moreover, the analysis of the monthly coefficient of variation of the discharge shows that the largest distributary and the one closest to the cross regulator at the end of Stage I, Distributary 4, has the lowest monthly coefficient of variation for every month. Most of the time, Distributary 3 has the highest coefficient of variation of the four distributaries of the group, except for March 1992 when Distributary 1 has the highest coefficient..

To understand the behavior and the operation of the distributaries, data collected in Distributary 3 has been used. The water supplied to Distributary 3 served three different areas: the area of Distributary 3 itself, the area commanded by Kech Minor taking off at the tail of Distributary 3, and the command area of Girsal Minor which is the continuation of Distributary 3 in the Paharpur Canal Irrigation system. From January to June 1992, water delivered at the head of the distributary has been much higher than the requirements of the distributary itself and Kech and Girsal Minors. The oversupply released to the downstream part of Paharpur Canal is represented in Figure 10.4 in comparison with the three other components of the Distributary 3 water supply.

The 8 sample watercourses monitored in Distributary 3 since October 1991 react differently to changes in the discharge at the head of the distributary. The average discharge into the watercourses varies from one watercourse to the other. Watercourse 6468-L, for example, has an Average Q/Design Q ratio of 1.2 against a value of only 0.65 for the last watercourse of the distributary, 15382-R. However, the analysis of the average discharge at a watercourse head is not sufficient to estimate the quantity of water used by irrigators. They can control the discharge by closing and opening their *moghas* at the distributary side or at the watercourse side. Data collected by IIMI from November 1991 to August 1992 highlight the extent of this practice, from one month

Figure 10.4. Water distribution below Distributary 3 head: Daily discharges in cumecs.

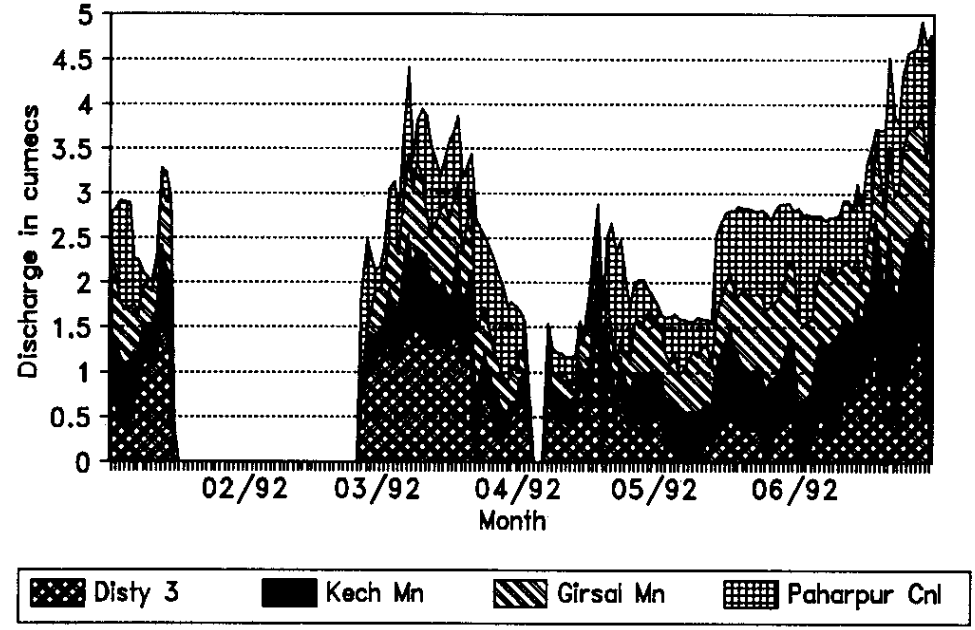
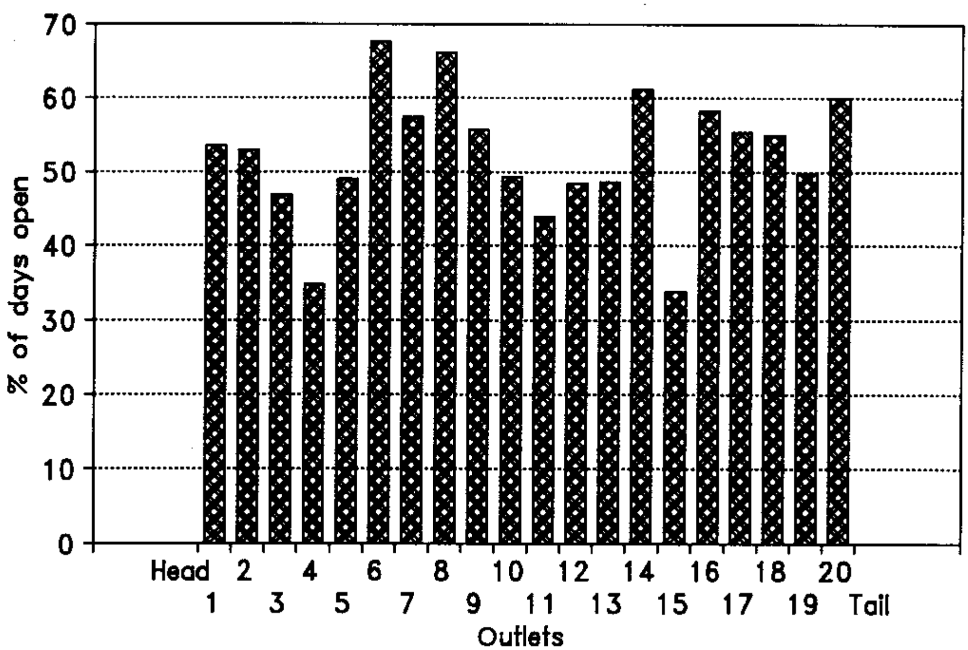


Figure 10.5. Duration (% of days) for which outlets are open: Distributary 3, CRBC (11/91 to 08/92).



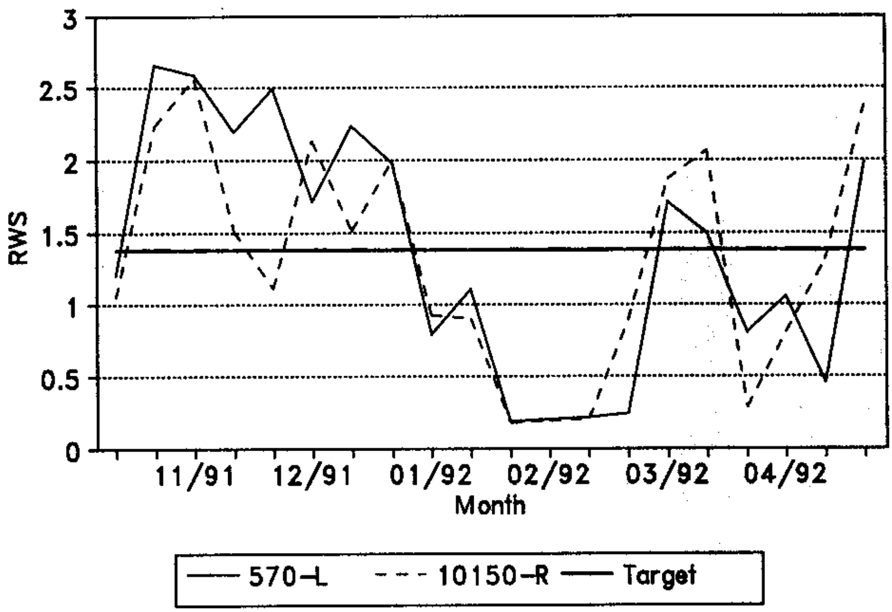
to the other, where outlets are closed by farmers from 30 percent (June 1992, at the time of rice transplanting) to 70 percent (April 1992, at the time of wheat harvesting) of the time.[59]

The duration (% of days) for which outlets were open is shown in Figure 10.5. There is no relationship between the percentage of days the outlet is closed and the position of the outlet along the distributary, from the head to the tail. Moreover, the proximity of a drop structure, which may allow control of the water surface level in the distributary, does not have any impact on the percentage of days watercourses are open.

Using flow data presented above and the cropping pattern for 8 watercourses in Distributary 3 (see Impact on Agricultural Production on p. 263), the Relative Water Supply has been computed for each 10-day period of rabi 1991/92 at different levels of the irrigation system as discussed earlier under Performance Indicators for Crop-Based Irrigation (p. 252). At every level (the CRBC head, Distributary 3 head and heads of sample watercourses), the variation in the RWS has been quite significant over time.

Figure 10.6 highlights this temporal variation of the RWS for 2 sample watercourses monitored by IIMI. The cut in the irrigation water supply during the canal closure of January-February 1992 period is naturally expressed by a very low RWS for three periods of 10 days. For the whole season, three localized peaks are observed, corresponding mainly to the periods of pre-irrigation (end of October), first irrigation (December) and second irrigation (March) of the wheat crop, which is predominant in the current cropping pattern of the sample watercourses. Two of these three peaks surround the canal-closure period and thus partly compensate for the shortage of water during this 40-day-long period.

Figure 10.6. Variation of RWS of two sample watercourses, 570-L and 1015-R of Distributary 3, CRBC.



59 Percentage of the time outlets are closed calculated as percentage of the days water was available in the distributary; thus it does not include the canal-closure period.

Based on the 10-day RWS, the main operational indicators described earlier have been calculated at different levels (watercourses of Distributary 3, Distributary 3 head and the CRBC main-canal head) and are presented in Table 10.4. For each of the indicators, the target is zero and calculated values represent the relative deviation from the target.

Figures calculated for Seasonal Adequacy and Supply Mismatch show that the performance of the operation decreases from the watercourse to the main-canal level. At a watercourse level, farmers compensate their deficits (-28% for Supply Inadequacy) by applying more water during the rest of the season leading to a value of zero for Seasonal Adequacy. Differences between watercourses, however, are relatively high as shown by the value 0.27 of the Equity Indicator (0.25 is considered the limit between fair and poor performances [Molden and Gates, 1990]). At higher levels, Supply Inadequacy is lower due to an excess of water supplied to the system, expressed by high values of Seasonal Adequacy and Supply Mismatch. These last figures indicate a relatively poor performance at main-canal level.

Table 10.4. Performance indicators at three levels of the CRBC Irrigation System, rabi 1991/92.

Level	Seasonal Adequacy	Supply Inadequacy	Supply Mismatch	Equity
CRBC[60] head	70%	-11%	73%	—
Distributary 3 head	12%	-21%	37%	—
Distributary 3 watercourse	0%	-28%	40%	0.27

Impact on Agricultural Production (Output Performance)

Although farmers are said to be still adjusting to changes in irrigation water supply, the cropping intensity for different watercourses monitored in Distributary 3 is surprisingly close to the design value of 90 percent, with a low spatial variability over the watercourses (the coefficient of variation for the cropping intensity is equal to 0.02). However, large differences in terms of cropping pattern are reported from one watercourse to the other. The actual area under wheat is higher than the design value (55% versus 45% in the cropping pattern used for the design for the irrigation system; see WAPDA 1991, page 45), but the main differences lie in the areas under gram (a crop requiring very low irrigation) and sugarcane (with high irrigation-water requirements): for all the sample watercourses (see Figure 10.7), the percentage of the CCA under gram is higher and the percentage of the CCA under sugarcane is lower than the design values.

The differences in the area cropped for these two particular crops highlight the current transitory state with farmers still taking decisions as if the water duties would be lower than the present ones, and closing their outlets to prevent the water supply exceeding their requirements. The specific position of gram within a wheat-rice-gram-fallow cropping pattern and the competition in terms of irrigation water between sugarcane and rice during certain periods of the kharif season could be due to other factors to be taken into consideration in explaining differences between the design cropping pattern and the actual one.

60 At the head of the CRBC canal, the 10-day RWS have been approximated to the ratio of water released at the head to volume of irrigation water recorded as such by WAPDA. Thus values given in the Table are underestimates of the real values for the different indicators.

Figure 10.7. Ratio of actual area under crop to design area, for 8 watercourses of Distributary 3 of the CRBC during rabi 1991/92.

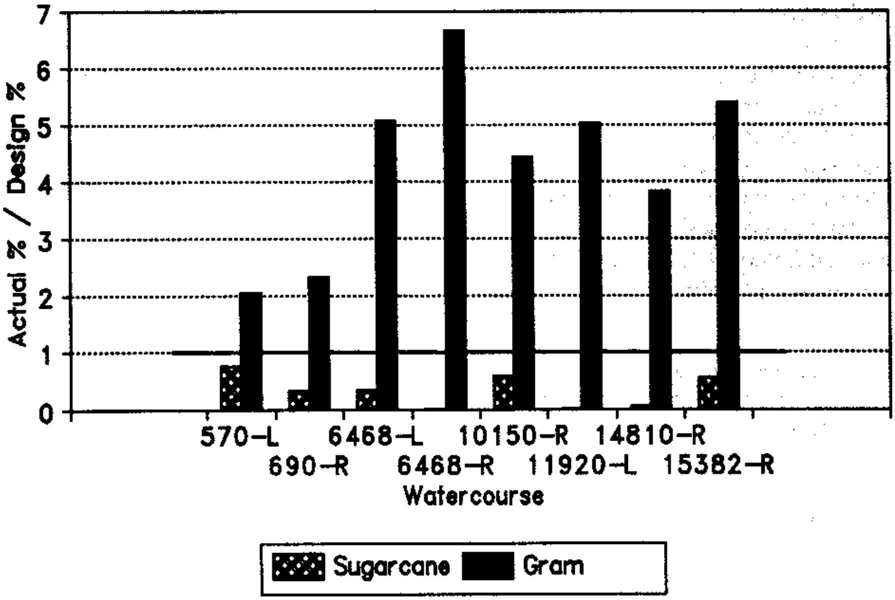
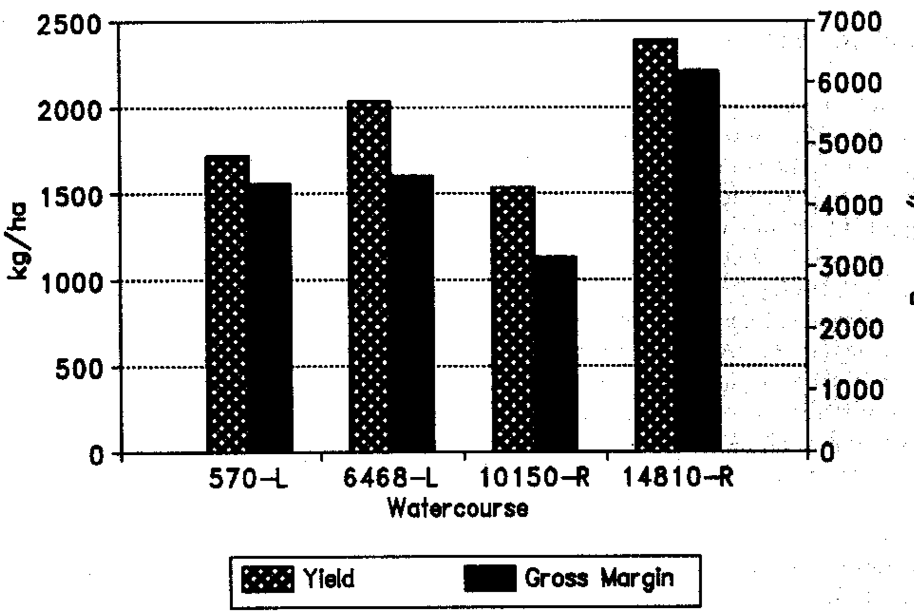


Figure 10.8. Yield (kg/ha) and gross margin (rupees/ha) of wheat crop for 4 sample watercourses.



The comparison between Seasonal Adequacy and cropping intensity shows a significant relationship between these two factors: the higher the cropping intensity, the lower the average RWS of the watercourse. To explain this relationship, however, is difficult and would certainly require a more in-depth analysis of the factors influencing the RWS at watercourse level.

Analysis of average wheat yields and gross income from wheat per watercourse shows that high yields and gross income per hectare of land are found when the average RWS is high. Figure 10.8 highlights the differences in both indicators from one watercourse to the other. It is interesting to note that the relative differences between watercourses is higher for gross margin than for yield, due to differences in costs of production. Wheat yields in the area are 20 percent higher than average values for the North-West Frontier Province.

The average productivity of water for wheat has been estimated for 4 sample watercourses. Table 10.5 shows its variability among these watercourses and gives the weighted average for them as well. Watercourse 14810-R has the highest productivity of water in terms of yield (kg) or gross income (rupees) per unit of water (m^3). The fact that some tubewells are still operated by tail-end farmers of this watercourse and that tubewell water has not been included in the "total quantity of water supplied" used to calculate the productivity of water could be an explanation of its much higher productivity. The differences between the other three watercourses are marginal. The comparison between these values and the average RWS for the four watercourses does not lead to any clear relationship between the factors involved, due mainly to the too low number of watercourses monitored.

Table 10.5. Average productivity of irrigation water for 4 sample watercourses: Wheat yield and gross margin per unit of water.

Watercourse	570-L	6468-L	10150-R	14810-R	Average
Yield per unit of water (kg/m^3)	0.25	0.26	0.25	0.42	0.30
Gross margin per unit of water ($rupees/m^3$)	0.63	0.57	0.52	1.10	0.72

When converted into kg/mm, values of productivity computed for the four watercourses are really low (between 2.5 and 3.1 kg/mm) compared to values given by Bhatti et al. (1991) for Pakistan. The main reason for these differences, however, is that these authors use irrigation application data to estimate the productivity of irrigation water. In this case, because of the nonavailability of irrigation application data, values have been computed at watercourse level thus including conveyance and other losses (Garces et al. 1992) in the irrigation water supply. In fact, a large part of the water is lost before reaching the fields and thus could lead to serious problems of waterlogging, already existing in areas close to the head of the CRBC. But the gap between Bhatti et al. (1991) values and those presented in Table 10.5 still remains important even when subtracting conveyance losses from the supply at the head of a watercourse. A possible explanation of this difference could be the relative inexperience of farmers in the CRBC area and their inability to properly manage an adequate water supply at watercourse and field levels, compared to farmers in Punjab.

Limitations of the Indicators and the Data Collected

- WAPDA gatekeepers at the head of the distributaries report that often they partially close the gates during the night because few farmers irrigate and most of the outlets remain closed. This nightly decrease of the water supply has not yet been taken into account in estimating the water supply to distributaries or watercourses. The analysis of the data collected through automatic stage recorders installed at the head and tail of Distributary 3 would allow the modification of the supply factor of the RWS accordingly.

- The water requirements of the gram crop have been included in the calculation of the demand of water during rabi. However, gram is very rarely irrigated, being usually sown after rice to use the moisture remaining in the soil. Thus the requirements of this crop should be removed from the rabi season and included at the end of kharif season irrigation water demand.

- The same conveyance losses have been used to estimate the targets for the RWS. However, some field measurements have shown that losses could be different from one watercourse to the other, meaning that targets would be different as well. Thus the use of the Equity Indicator will have to be made cautiously.

- Although wheat is the most important crop during the rabi season, the economic indicators (weighted gross margin per unit of land and per unit of water) will have to be calculated by taking into account other crops grown by farmers of the Distributary 3 command area.

- It was not possible to collect data of irrigation applications at field level or farm level, due to the way farmers manage water below the outlet and the current status of organization of the irrigators. It is not possible to estimate the variability of the water supply, the RWS and the productivity of water within watercourses although the first year of data collection and field work have shown that this variability could be quite substantial.

- The canal-closure period has introduced a bias in two indicators, Seasonal Adequacy and Supply Inadequacy. These indicators will be more appropriate for the kharif season when the target used in the calculation of these two indicators and the target for the operators used in the calculation of Supply Mismatch are the same over time.

- The targets used for the calculation of the Supply Mismatch indicator would have to be modified in order to include the canal-closure period. A higher target for the periods preceding and following the canal closure will have to be calculated and fixed as targets for the operation of the main canal and the distributaries by WAPDA and the Irrigation Department.

DISCUSSION

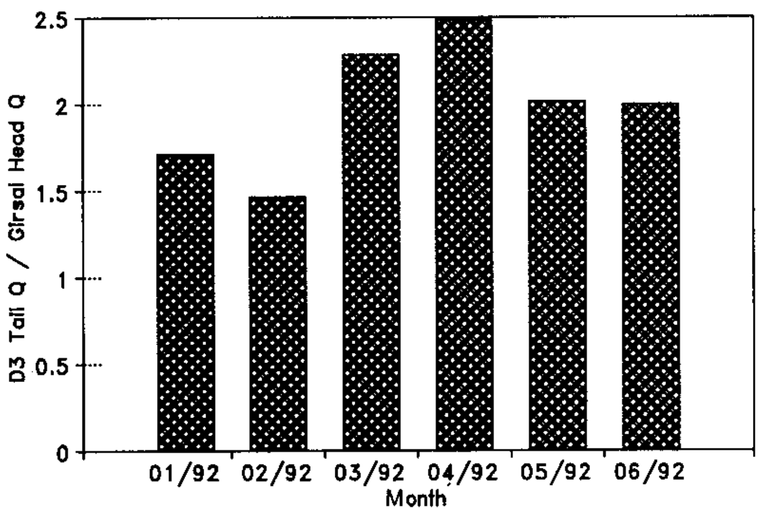
Crop-Based versus Supply-Based Considerations

Although some periods of the season are characterized by an undersupply (equivalent to 28% of the appropriate supply), the quantity of water applied for the season equals the needs at watercourse level. Farmers are managing their water below the outlet in a crop-based mode via a refusal system made possible by an excess of water at a distributary level and the capability to partially control the water going into the watercourse by closing or opening their outlets. Differences, however, exist among watercourses as shown by an equity indicator equal to 0.27. The differences within watercourses appear to be quite substantial as well and relate to nondevelopment of certain areas of the watercourse CCA: some farmers have an excess of water while others suffer a water shortage. Even if the RWS at watercourse level is close to the target, numerous losses within the watercourse lead eventually to relatively low yields, compared to the water available, and enforce the risk of waterlogging.

The distribution of water at distributary level is variable over time and seems to follow a pattern more or less related to crop water needs. However, two important aspects have to be considered: water is always supplied in excess at the head of Distributary 3 and changes in the supply appear to react to changes at lower level rather than follow a specific operation plan based on crop water requirements. Even the 40 days of canal closure do not compensate for the excess of water during the rest of the time (the RWS is on average 12% higher than the target at distributary level).

The larger-than-design cross section of Distributary 3 is the main reason for the operation of Distributary 3 at higher discharges than required. At the construction stage, Distributary 3 was provided with larger cross sections with the expectation that deposition of silt will take place and the cross sections will get reduced to the design sizes. After five years of operation, however, silt deposits have not developed .[61] This problem has a direct impact not only on the RWS calculated at distributary level but also on the water released at the tail of Distributary 3. By design, the discharge of the water released at the tail should be equal po the discharge (supply) to the head of Girsal Minor. The monthly average ratio of these two discharges presented in Figure 10.9 shows

Figure 10.9. Ratio of discharge at tail of Distributary 3 to discharge (supply) at head of Girsal Minor, monthly averages.



61 The higher-than-design discharge could explain the absence of silt deposits at the level of the distributaries.

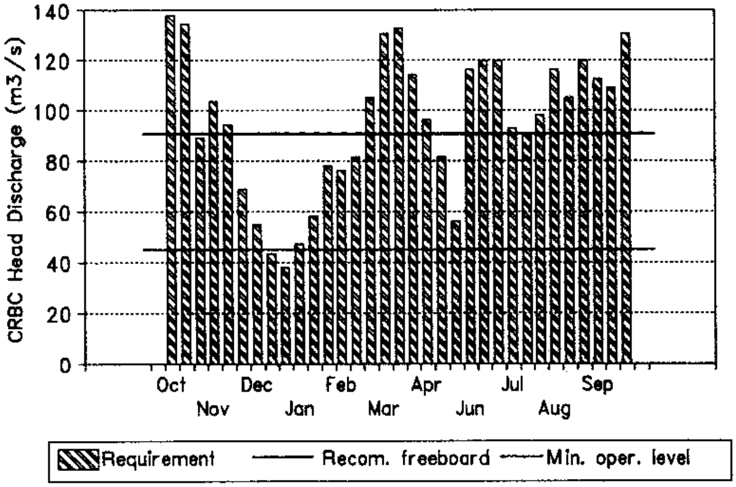
that the current situation is far from that designed (as stated in the section on Current System Operation and Operational Performance; page 258).

Whether the excess water is used downstream in the Paharpur Irrigation System should be ascertained and this would have an impact on the calculation of the productivity of water at the distributary level. If the water is used downstream, a better management of the water would improve the productivity of water for Distributary 3 but would not change the productivity of the total quantity of water available. It is interesting to note that the Supply Mismatch is better at distributary level than at watercourse level. Deviations from the targets for the different watercourses compensate for each other.

At main-canal level, when undersupply occurs, the deviation is only -11 percent from the target, due to the canal closure period; it is not due to an efficient (crop-based) operation of the irrigation water but to a general oversupply. On average, 70 percent more water than that required to irrigate crops has been released at the head of the CRBC and has escaped back into the Indus River ! The main reason for this, advocated by WAPDA, is that it is not possible to operate the CRBC at the very low discharges required for Stage I of the CRBC only; control structures are not adequate and the operation is constrained by the limitations of the canal system itself. To supply water adequately to all the distributaries of Stage I, WAPDA uses the Full Supply Level at the end of Stage I as the target for the operation of the main canal.

Investigations of the behavior of the CRBC using the simulation model SIC has supported the WAPDA position and shown that limitations will exist even when the three stages are operational. Problems of supplying the appropriate discharge to some offtakes exist at low discharge (less than 45 cumecs), while problems of inadequate freeboard appear for high discharges (more than 85 cumecs). The comparison between the irrigation water requirements (based on the design cropping pattern) and these two limits (see Figure 10.10) shows that for most of the year, required discharges are outside the range of 45–85 cumecs and thus cannot be accommodated by the CRBC under crop-based irrigation operations.

Figure 10.10. Physical system adequacy: Limitations at mail canal under crop-based irrigation operation (CBIO).



In fact, the objectives of crop-based irrigation operation (based on the design crop water requirements) could only be met 30 percent of the time with the current characteristics of the main canal. WAPDA, already aware of some of the problems, started to raise the banks at certain locations along the CRBC to increase the freeboard and maintain it below the accepted limit of 3 feet at high discharges.

Another aspect considered by WAPDA when operating the main canal is the problem of velocity and silt deposits. Although there is not enough silt in the unlined part of the canal, too much silt has been deposited in some places of the lined part close to the cross regulators. In some periods of the year, in order to wash the silt deposits, an excess of water is released at the head of the CRBC and it escapes at the level of the first cross-regulator. WAPDA tries to maintain a minimum discharge in the main canal to have a minimum velocity and avoid silt deposits in the lined section. This management of the system by WAPDA has a negative impact on the indicators based on the RWS.

Constraints on the operation, however, are not only related to the physical aspects of the system. WAPDA and the Irrigation Department (ID) do not have adequate staff to operate the system in a crop-based irrigation mode. The Irrigation Department, especially, finds itself in a very difficult position; while it had asked for a staff of 60 to operate Stage I of the new system, only 15 staff members (or 25% of its demand) have been allocated to the CRBC. Moreover, the communication systems of the Irrigation Department and WAPDA are inadequate; only a few regulating structures have being provided with telephone connections and there is no proper flow of information between sensible points being planned by the agencies (Garces et al. 1991).

Up to now, WAPDA and the ID have been quite static in defining new operation procedures for the CRBC Irrigation System. They do not have any operation plans for crop-based irrigation, although they react to changes in the water demand in the system over time. The conservatism of the two agencies is due to many reasons. An important one is that the Irrigation Department is an operating agency with a very low level of control over the system. All the control structures at main-canal level and at distributary-head level are within the hands of WAPDA. The Irrigation Department, for the first time, finds itself in the role of a subagency of WAPDA dealing only with the maintenance of the secondary canal system. This loss of power of control on the water flows combined with the control farmers have gained through the *pakka* structure at the head of the outlets weakens its position vis-a-vis the farmers as well.

Technical and Economic Considerations

Several indicators were defined and their calculations explained in the earlier sections of this paper. An important question to be addressed at this stage is how to establish a hierarchy of these indicators, technical or economic, according to importance or priority. For the different actors of the irrigated agriculture system, objectives are in fact different and the main indicators to be used will be different as well.

For farmers, economic indicators would be the first to be considered once they are sure of receiving a minimum irrigation water supply. It is assumed that farmers react as economic agents of the system and thus tend to optimize an objective function taking into account not only the maximization of their revenue, but also the minimization of the risk involved in their decisions or the maximization of a specific utility function.

For the operating agencies, these economic indicators are only secondary indicators. Technical indicators related to the operation of the system have much more importance as they are directly related to their daily work, tasks and responsibilities.

For policymakers, economic indicators are important as well, not only the returns per unit of land or the returns per farm but also the returns per unit of water. What is important here is related to investments in the use of a specific resource, water.

Finally, for IIMI researchers, it is slightly more difficult to make a choice. Economic indicators, on the one hand, are important to assess the impact of any change in the operation of the system to find out, whether it is beneficial or not, and as matters for discussion with policymakers and funding agencies. On the other hand, however, the operating agencies are the first clients of IIMI for the implementation of changes and thus have first to be convinced of the benefits (from their point of view as operating agencies) of management innovations. One could always expect that an improvement in the operation of the system (in terms of matching more closely irrigation water supply to crop water requirements) would lead to an improvement in terms of yields and agricultural production. This, however, has to be checked.

Implication of Results on Performance Assessment

The analysis of the performance of the CRBC Irrigation System under the current situation has shown that the performance of the system is low, mainly because the constraints in the system have led the different agencies to select a mode of operation based on aspects of supply rather than on crop water requirements.

The constraints imposed by the physical system have to be taken into consideration when evaluating the performance of the actual system and the changes in this performance due to innovations implemented jointly by WAPDA, the Irrigation Department and IIMI. Plausible targets for the operation will have to be selected and included in the calculation of the selected performance indicators in order to isolate the deviation in performance related to a poor management of the available water from the deviation related to constraints of the physical system.

The current objectives of the different operators involved in the CRBC Irrigation System (i.e., WAPDA [Barrage], WAPDA [CRBC], ID and farmers) have to be considered and analyzed. The formal and informal relationships between these groups and the way the information travels from one to the other will be of particular interest.

For the evaluation of the economic performance of the system, data will have to be collected to compute the selected indicators (GM_{ha} and GM_{m^3}) and these discussed with the agencies operating the system, with farmers and with the Department of Agriculture (AD).

CONCLUSIONS

The analysis of the present situation has shown that farmers are managing their water in a crop-based mode. There is no direct relation, however, between the operation at watercourse level and at higher levels of the system. At distributary and main-canal level, the main objective of the two agencies (WAPDA and Irrigation Department) is to operate the system in a certain range of discharges to cope with issues related to the operation of the canal itself rather than the demand for irrigation water. This disruption of the objectives is clearly seen in the values of the performance indicators chosen to characterize a crop-based system: the higher the level, the worse the indicators are (except for Supply Inadequacy), leading to a poor performance of the CRBC Irrigation System as a whole.

The selected performance indicators have to be tested and their behavior evaluated (robustness, sensitivity to extreme values, etc.). The analysis of the kharif 1992 data will be the first step of the evaluation to identify advantages and disadvantages of the indicators. An important aspect to be considered will be their effectiveness as communication tools with the operating agencies. For this specific purpose, RWS, for example, will have to be translated into discharges or efficiencies and intermediate indicators calculated and discussed with the operating agencies.

The different groups (WAPDA [Barrage], WAPDA [CRBC], Irrigation Department and farmers) have different objectives and do not have a proper system to communicate with each other. The Irrigation Department especially finds itself in a strange position between WAPDA and the farmers without controlling the flows of water into the distributaries or into the watercourses. The analysis of the objectives of the operating agencies and comparison with CBIO objectives will be a key component of IIMI's future research work in the CRBC area. The constraints in terms of resources available (funds and staff), differences between current objectives and CBIO objectives (see the third aspect of the Objective Setting Performance) will be evaluated and solutions to overcome them proposed. Results will have an impact on the performance indicators as well; better estimates of (attainable) operational targets at different levels of the irrigation system will be proposed and included in the calculation of the selected indicators.

Even if quite static, WAPDA and the Irrigation Department have started to address some of the issues related to crop-based irrigation operation (for example, WAPDA plans to increase the bank level at locations where there would be a freeboard problem for the highest discharges). Moreover, they have accepted the idea of collaboration with IIMI. In view of the project findings and their implications, three management "innovations" have been proposed by IIMI for implementation during the next rabi season and they have been accepted by high officials of WAPDA, ID and AD. The first "innovation" will address issues of the operation of the main canal and involve WAPDA; the second one will focus on the water supplied to distributaries and will involve the Irrigation Department and WAPDA indirectly; the third one is related to the lack of communication between the different groups involved in the operation of the system, especially between the end-users, the farmers, and the operating agencies. With the help of the Directorate of Agricultural Research and Extension of the AD, organized-behavior groups of farmers will be formed and will be involved in the operation of the irrigation system, a prerequisite for a successful crop-based irrigation operation, especially if water becomes scarce. For these management interventions, monitoring jointly by WAPDA, ID and IIMI will take place, leading to the analysis of the performance of the system with the proposed operations.

It seems important at this stage of the project to start discussion of the expected water scarcity with farmers and staff of the operating agencies. This situation is to be expected when Stage II and Stage III of the CRBC become operational with the command area of Stage I fully developed.[62] This aspect will have to be taken into account when the modeling of canals is being done and when preparing operational plans with the agencies. For the operation of the water below the outlet, the actual flexibility seems to be sufficient and produces a good performance at this level. The situation with water scarcity, however, will be of prime importance at this level because important changes could be expected.

Further efforts have to be made to understand the irrigation system. The next steps in IIMI's research, with primary data to be collected by the IIMI field team, will have two important components. The first one will be the hydraulic modeling of the behavior of the distributaries (focus on Distributary 3) to identify problems of the operation at this level and to propose scenarios taking

62 It has been roughly estimated (based on PID *kharsra* data) that 25 to 30 percent of the total command area of the CRBC would not receive adequate water supplies if the current trends of water supply, cropping pattern and land development continue. This calculation, however, needs to be checked beyond the "back-of-the-envelope" approach.

into account constraints of the distributaries. The second one will be the economic modeling of farms to predict impact of changes in the irrigation water supply and irrigation system operation on the agricultural production.

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Appendix

MATHEMATICAL DEFINITION OF PERFORMANCE INDICATORS

Objective-Setting Performance

Allocation Adequacy

$$= \sum_i^n \left(\frac{| VOL_i - T |}{T} \right) / N$$

Physical System Adequacy

$$= \sum_i^n \frac{O_i}{N}$$

Operational Performance

Seasonal Adequacy

$$= \sum_i^m \left(\sum_i^n \left[\frac{RWS_{i,j} - T}{T} \right] / N \right) M$$

Supply Inadequacy

$$= \sum_j^m \left(\sum_i^n \left[\frac{Pa_{i,j} - T}{T} \right] / N \right) / M$$

Supply Mismatch

$$= {}_{j}\sum^{m} \left({}_{i}\sum^{n} \left[\frac{|RWS_{i,j} - T|}{T} \right] / N \right) / M$$

Equity

$$= {}_{i}\sum^{n} \left(\frac{\sqrt{[({}_{j}\sum^{m} (RWS_{i,j.} - ({}_{j}\sum^{m} RWS_{i,j}) / M)^{2}) / M]}}{({}_{j}\sum^{m} RWS_{i,j}) / M} \right) / N$$

Output Performance

Weighted gross margin per ha

$$GM_{ha} = \frac{\sum^{l} (a_k * GM_k)}{\sum^{l} a^k}$$

Weighted gross margin per unit of water

$$GM_{m3} = \frac{\sum^{l} (a_k * GM_k)}{W_{m3}}$$

whereT = Target (variable).
Vol_i = Volume allocated at the head of the CRBC for the period i.
Oi= 1, if the objectives of CBIO can be met during the period i;
otherwise $O_i = 0$.
$RWS_{i,j}$ = actual RWS calculated for the period i at the location j.
$Pa_{i,j}$ = $RWS_{i,j}$ for $RWS_{i,j} \leq T$, equal to T otherwise.
a_k = area in ha under crop k.
GM_k = gross margin per ha for crop k.
W_{m3} = Total quantity of water (in m^3) supplied during the season to the area ${}_k\Sigma^l a_k$.
N = number of 10-day periods.
M = number of locations considered.
L = number of crops cultivated in the area.