FINAL REPORT

of the

Technical Assistance Study
(TA-1481 PAK)

on

CROP-BASED IRRIGATION OPERATIONS IN THE NORTH WEST FRONTIER PROVINCE OF PAKISTAN

VOLUME II: RESEARCH APPROACH AND INTERPRETATION

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CROP-BASED IRRIGATION OPERATIONS STUDY IN THE NORTH WEST FRONTIER PROVINCE OF PAKISTAN

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Chapter 1

INTRODUCTION

1.1 Context and Scope

This Volume II of the Final Report of the study on "Crop-based Irrigations Operations in the Northwest Frontier Province of Pakistan" is intended to provide the technical and social-economic background to the Recommendations made to the Government of Pakistan (GOP), the Government of NWFP (GONWFP) and the Asian Development Bank (ADB) in Volume I of the Final Report. Those recommendations concern the future direction that applied research efforts addressing the issue of crop-based irrigation, in the context of the country's irrigation sector, should be taking.

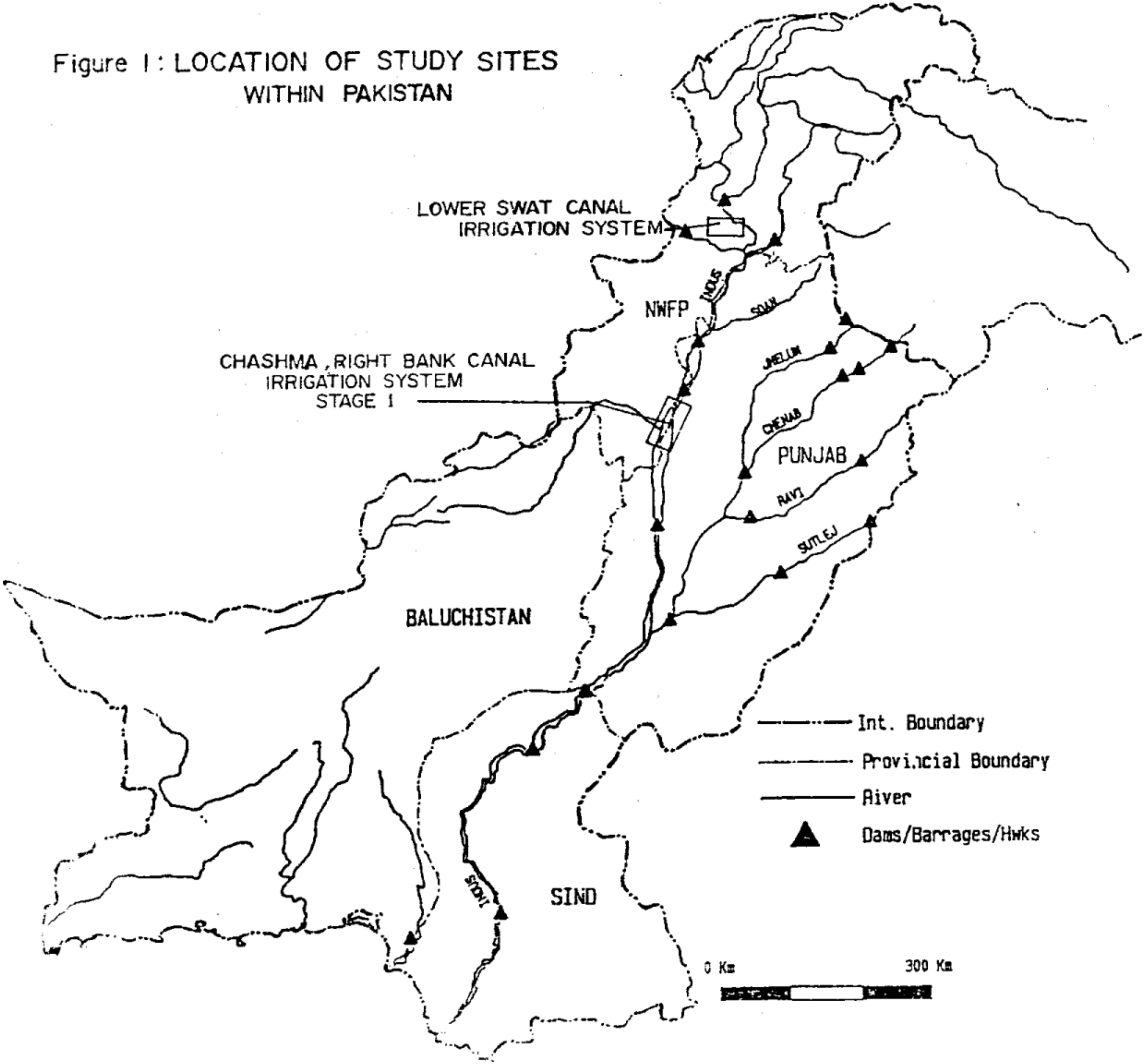
This volume draws upon the results of three years of intensive field and desk-simulation studies conducted at D. I. Khan, NWFP, by IIMI's research team in collaboration with the Water and Power Development Authority (WAPDA), the Provincial Irrigation Department (PID), and in a lesser degree, with the Department of Agriculture (AD).

This report, however, concentrates on the activities undertaken in the Chashma Right Bank Canal Irrigation System (CRBC) where the greatest share of the study's interventions took place. The results and implications of the efforts concerning the Lower Swat Canal Irrigation System (LSC) have been adequately reported in Volume I of the Final Report. This document is intended to be self-contained in the sense that the reader does not have to refer to the other volumes of the Final Report in order to understand the research carried out and the results derived. For an in-depth analysis of the project, all of the final documents (3) should be reviewed. Figure I-1 provides the location of the two irrigation systems, CRBC and LSC, where the study was conducted.

This report has been divided into seven inter-related components. In Chapter **1,** the generalities of the study, an introduction to the concept of "crop-based irrigation, and a brief description of the research layout are provided. Chapter **2** describes the present operation of the system ---from the main canal down to the farm level--- and addresses both physical and human constraints to its operation. Chapter **2** also provides the setting under which the study was designed and implemented.

Chapter 3 deals with the simulation studies undertaken : the justification, the type of **model** applied, the results of the simulation interventions, and the lessons derived. The intervening parameters in the supply and demand of the irrigation water are treated in

Figure 1: LOCATION OF STUDY SITES
WITHIN PAKISTAN



Chapter **4** and subsequently related to the concept of crop-based irrigation. Chapter 5 describes the farmers practices at the watercourse and farm levels, as well as their effect on agricultural production. Chapter 6 closes the irrigation cycle by exploring the performance of the CRBC through both technical and economical considerations.

Finally, in Chapter 7, lessons from the study are derived and the implications of moving towards crop-based irrigation operations are explored.

1.2 Crop-based Irrigation Operations

The method chosen to deliver water to the crops determines the degree *of* complexity under which the system is to be operated. Normally, this decision is taken at the irrigation system's design stage and influences the type, size and quantity of structures and the managerial input level to be required.

Water delivery can be typified in terms of three parameters: frequency, rate and duration. Combination and variations of these factors leads to a wide array of possibilities to fit particular delivery needs dictated by climate, crops, soils, topographical conditions, organizational set-up, etc.

The final mode under which water is eventually delivered to the user constitutes the irrigation delivery schedule. Three main categories are usually defined: **Supply-driven, Arranged** and Demand-driven. In the first one, a good example is the Rotation method, where all three parameters that establish the water delivery approach -- frequency, rate and duration-- are fixed beforehand and, therefore, it is the most restrictive of all irrigation schedules; it does not allow for changes and the user has little, if any, input; he is simply told when, how much and for how long he will have access to water. On the other side of the delivery spectrum, under Demand-driven, no restrictions are imposed on any of the parameters and the user can decide how the water will be received. A classical example of this type of delivery **is** associated with urban water supply, where the user opens a faucet and the water is there for immediate use; this constitutes a "pure-demand" delivery. The Arranged delivery falls somewhat in the middle with certain limitations imposed on one or more of the delivery parameters; crop-based could be viewed here, placed more towards the demand side than the supply side of the alternatives.

What has been described above, indicates that there is a continuum of options on how the irrigation service can be provided. The water detivery mode ranges from one where the user plays an entirely passive role, in which decisions are taken without **his** input (strict Rotatioh), to one where the user has complete control aver the water delivery decision-making process (pure Demand).

The concept of crop-based irrigation operations, while part of the continuum as indicated above, should .not be defined in terms of the frequency, rate and time during which water is delivered to the field. Rather, it should be thought of as being a concept that places itself parallel to the Demand-driven side of the delivery options. The terminology emphasizes the need to seek a better match between the water requirements of the crops and the amount of water available for delivery. It does neither advocate nor encourages the idea that users should be able to satisfy, at all times, their individual needs.

The core of crop-based irrigation operations lies in that the system needs to have a certain degree of design and managerial flexibility, and that users need to play a more active role in determining beforehand what their water needs might be. Because the end-objective *is* to satisfy crop-needs ---as much as possible--- it is a concept that works better under *conditions of* relatively higher water availability than under conditions of extreme water scarcity; it is therefore not conducive to high efficiency of produce per unit of water but rather to high efficiency of produce per' unit area.

The above paragraph would seem to suggest that crop-based irrigation operations is not suitable for the conditions present in Pakistan where water is delivered under a Rotation mode, there is little or no input from **users** in system operation, and water scarcity is a main feature of its irrigation. However, it is the impact that the crop-based concept can have on the water use efficiency that makes it **so** worthwhile to consider its potential in the Pakistani context The country is on the verge of facing food shortages and needs higher yields per unit of area in order to be able to meet the food requirements of **its** population. This is no longer possible under the present irrigation set up. Crop yields are conspicuously low in Pakistan because the emphasis has been more on spreading the limited water resource than in obtaining high production. Since yield increases can come only if more attention is given to the needs of the crops, more attention needs to be given to the primary input ---their water requirements

This dichotomy between "protective" or "productive" irrigation being faced by Pakistan's agricultural sector has led the Government to explore inncvative irrigation approaches. Under certain conditions, crop-based irrigation can be part of a broader strategy to solve the food gap; as such, the efforts pursued under this study are well justified and constitute a legitimate researchable theme The essence of the research has been to explore the merits and demerits that the introduction and application of crop-based irrigation in Pakistan might have. To determine possibilities and constraints, and at the end to guide the GOP in generai. and the GONWFP in particular as to the feasibility and/or viability of this approach in technical. economical and social terms

1.3 Study Layout

A first step in determining the research layout to be implemented was to consider the different area options that existed within the CRBC irrigation system.

The CRBC project, currently under implementation, has been designed in three stages, for construction purposes. Stage I serving 56,680 ha (140,000 acres), a quarter of the total culturable command area (CCA), has been completed. This stage comprises 42,105 ha (104,000 acres) within the old Paharpur Canal System with the remainder constituting the so-called New Area.

Stage II was still under construction at the time of study inception; only three of 13 distributaries had been completed and made operative. The respective command areas, however, were in the initial stages of development. Inspection of those areas led IIMI to conclude that there was little scope for conducting any study-related activities under Stage II at that time. Stage III, on the other hand, is still in the planning phase and not scheduled to be in operation until the late 1990s.

With the above information in mind, it was clear that the alternatives for selecting a study site in the CRBC system lay in Stage I. Three options could be considered: within the new area, within the old Paharpur canal system, or a combination of the above.

Both the new and old **areas** had their advantages and disadvantages with respect to their suitability for conducting research.. For example, the New Area was much more physiographically representative of the areas to be developed in stages II and III. In addition, the soils were generally heavier than those encountered in the Indus alluvial plain. which is also typical of the Old Area.

On the other hand, the Paharpur Canal System, being a relatively old scheme, had farmers who were experienced with irrigation practices. The New Area, on the contrary, was obviously a new settlement where a large percentage of the occupants had little or no previous experience with irrigated agriculture, which would be more relevant to the conditions that would be encountered in the near future by farmers in stages II and III. Therefore, the choice was made to locate the study area in the New Area *of* Stage I. However, as a compromise it was also decided to select a minor canal within the Paharpur Canal System to be included in the field activities.

Within Stage I. four distributaries (numbers 1,2,3,and 4) were considered. However, it became clear that the first two, because of their small command areas, would not be good choices. That left numbers 3 and **4** as potential research sites. The team decided

to start work on Distributary # 3 which presented some practical and technical advantages (related to command area configuration. design discharge and canal hydraulics), and then work on Distributary # 4 as the study made progress. In addition, it was decided to also select the Girsal Minor of the Paharpur System Canal, which receives water *from* the "tail" of Distributary # 3 off-taking at RD 237+320.

The basic characteristics of the three research areas are summarized in Table I-1:

TABLE I-1 CRBC RESEARCH SITES - BASIC INFORMATION

Item (units)	Disty # 3	Disty # 4	Girsal Minor
CCA (ha)	5.363	10.002	1.788
Length (m)	5,058	10,832	9,085
Design Discharge (m^3/s)	3.21	5.81	1.07
Canal bed width (m)	'7.22	9.15	3.43
# of Outlets (pipes) *	20	36	22
# of farmers (approx)	600	1,260	450

The research layout ***per se*** followed a typical irrigation-related configuration, Eight watercourses were selected, along the distributary. for in-depth study that were located two each ---left and right side--- on every canal quartile. A similar treatment was followed for both Distributary # **4** and Girsal Minor, but selecting only four watercourses in the latter, because of logistical constraints. The physical location of Distributary # 3 *is* at the tail-end of the CRBC Stage **I**, an added advantage for the system performance-related studies. The Girsal Minor, in turn, is located at the tail of the distributary. The actual location of the selected areas of study are referenced to their turnout distance from their respective headgate and are given in Table I-2.

TABLE I-2 CRBC RESEARCH SAMPLE OF WATERCOURSE OUTLETS.

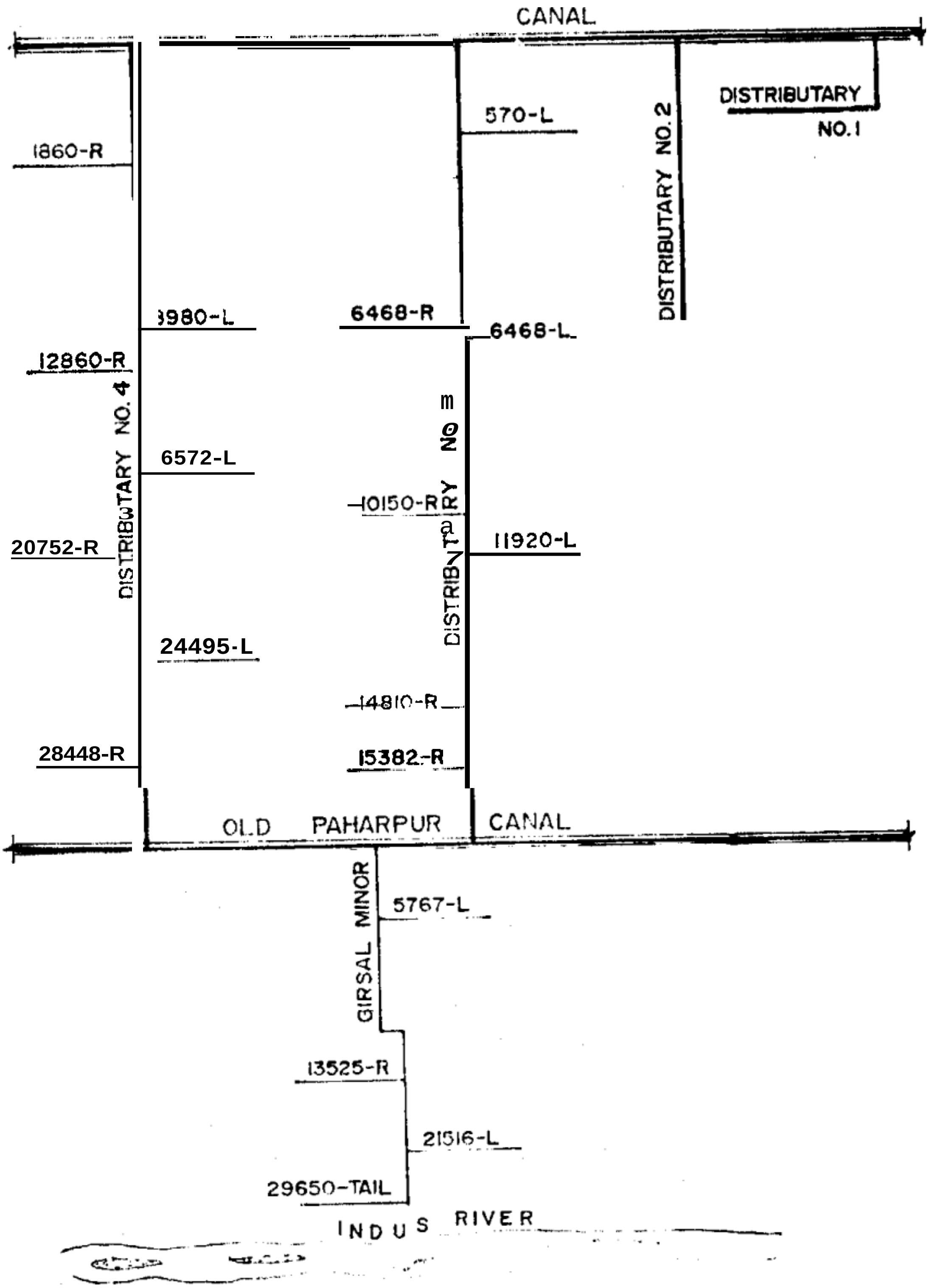
Distributary # 3	Distributary # 4	Girsal Minor
570-L	1860-R	5767-L
690-R	3168-L	13526-R
6468-R	8980-L	21516-L
6468-L	12860-R	29650-TAIL
10150-R	20752-R	
11920-L	21516-L	
14810-R	24495-L	
15382-R	28448-R	

The type and frequency of measurements, and the variables studied will not be addressed here, as the reader will have a chance of becoming familiar with the research process that took place while reading through the report However, a schematic diagram of the research layout is provided in Figure I-2.

A large number of IIMI staff, both national and international were associated with the study, at one time or another, during project implementation. Annex-2 provides the full list of staff by study period.

Figure: 12

SCHEMATIC DIAGRAM OF THE RESEARCH LAYOUT



Chapter 2

CURRENT SYSTEM MANAGEMENT

2.1 Description of CRBC - Stage I

The Chashma Right Bank Canal Project is a major perennial surface irrigation system that, once completed, will cover a gross command area (GCA) of about 280,000 ha (690,000 acres) located along the right bank of the Indus River in central Pakistan, stretching between the Chashma and Taunsa barrages.

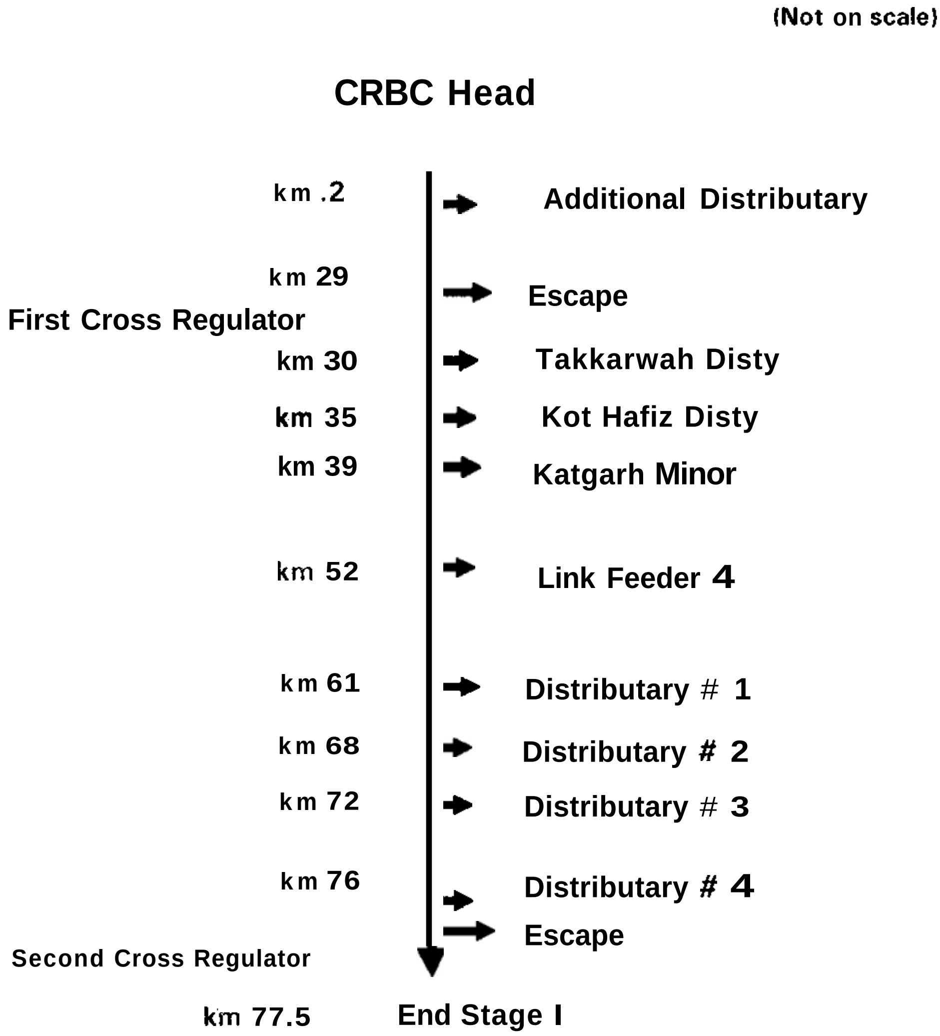
The source of water for the project is the Indus River by means of the Chashma barrage which was commissioned in 1982. The Canal is 258 km (152 miles) long with a culturable command area (CCA) of 230,675 ha (569,767 acres) that spans two provinces, namely, the North West Frontier and the Punjab, in a 60 to 40 percent proportion, respectively.

The Main Canal's full capacity of 138 cumecs (4,800 cfs), to be distributed through 50 distributaries, or so. which will be fully utilized only upon completion of Stage II (presently in an advanced stage of construction) and Stage III (construction scheduled to begin in 1994, while completion is expected in the year 2000, or beyond).

The command area of CRBC presents special topographical features which account for the present design. To cover the maximum command area, the main canal was designed as a contour channel, running on the highest possible contour, with quite flat longitudinal slopes for most of its length and feeding distributary channels on its left side only.

Construction of Stage I has been completed and became operational in early 1987; it includes the old Paharpur Irrigation System, which has been remodelled for increased discharge capacity, and is now being fed by the CRBC through four link channels. In Stage I, the four Paharpur-related link canals are followed by the four distributaries already mentioned. Another canal named "Additional" off-takes before Paharpur, and as its name indicates, was added after the original layout. Two other small canals off-take from the main canal in this stage but, their size and command make them irrelevant within the studies' context. In Figure II-1, a shematic diagram of the CRBC Stage-I Main Canal is provided that indicates the major features of this section of the irrigation system where the study was conducted.

Figure 11-1 SCHEMATIC DIAGRAM OF CRBC STAGE - I



Note:

Takkarwah, Kot Hafiz. Katgarh and Link Feeder # 4 feed the old Paharpur Canal Irrigation System. The first cross regulator its often referred to as the "combined structure" because of its multiple-purpose nature.

2.2 Main Canal Operations

The operation of the CRBC irrigation system is unique within Pakistan because, unlike other systems in the country, it involves two main agencies: (1) the Water and Power Development Authority (WAPDA) responsible for main canal operation; and (2) the Provincial Irrigation Department (PID) responsible for water distribution at the secondary (distributary) level and beyond.

An early step in the study's implementation was to conduct both a field and desk-based assessment of the current operational practices vis-a-vis the main canal. This revealed that while the managing agency was well aware of the concept of crop-based irrigation, and that the CRBC irrigation project had been conceived with the eventual establishment of this innovating practice in mind, no effort had been undertaken to internalize this concept within some institutional framework.

This finding was not at all surprising since it was precisely the lack of a mechanism by which the concept could be introduced'in the country that led to the study in the first place. The exercise, however, was useful because it provided a first glimpse of the constraints that existed regarding the introduction of a relatively revolutionary irrigation concept in the midst of an ingrained irrigation bureaucracy accustomed to supply-based irrigation operations.

The main canal, and by default, the entire .system, was being operated under the traditional supply-driven water Uelivery mode. Inflow into the system was. kept fairly constant at pre-established levels and changed occasionally in response,to rainfall, crop development stage and cropping season ---*Rabi* or *Kharif*--- with the latter drawing relatively higher inflow levels. Actual crop water requirements played only a minor role. There was no indication that derived flows at the Chashma Barrage were following the water delivery pattern advocated in the system design documents.

In essence, water derived into the CRBC system at the Chashma Barrage'had little or no correlation with the area under irrigation, although the PID does provide from time-to-time an irrigation "indent". Other demands playing a more dominant role were:.(1) sediment-load requirements to fill-in the over-designed main canal's unlined section; (2) water elevations required to assure appropriate discharge rates at the off-takes of Stage I tail-end distributaries; (3) construction needs of Stage II; and **(4)** perceived canal losses, sediment load transport needs, etc.

In addition to the rather loose form by which'the agency fixes the irrigation demand, the appraisal study also found that, with the exception of the main cross-regulators, there has been no effort towards calibration of the remaining structures on the main canal. Thus, the agency has very little, if any, control over the amount of water that is actually being diverted into the different off-takes from the main canal. The idea of delivering water under a crop-based approach in a system that totally lacks calibration of its main

structures constitutes a technical impossibility. Great. effort *is* required to overcome particular weakness.

Another problem associated with the current operation of the main canal is the existing day-to-day practice of impounding water at the tail-end of Stage I with the idea of keeping a suitable "head" over the distributaries' off-takes. Such an operational procedure not only defeats the purpose of water savings, through varying flows in the main canal to fit crop water demands, but also affects main canal design velocities and increases the sediment load in that particular reach of the canal. Such an accumulation of sediments. which has a negative impact on the up-keep of the canal, has already been documented as a potential maintenance problem.

2.3 Distributary Level Operations

As expected, and as a consequence of the prevailing operating mode at the main canal level, water delivery into the distributaries followed, likewise, a supply-driven, rather than a demand-driven, water delivery pattern.

The PID, responsible 'for the operation of the system below the main canal, had not readily accepted the principles .required for a crop-based irrigation approach. The idea that the main canal 'could be operated with varying discharges ---in response to crop water demands— and 'therefore, that flows into the distributaries would not be both. 'continuous and constant at full supply level, represented a radical departure *from* the entrenched supply-driven delivery schedule being practiced in the country, with various degress of sucesses and failures; over. the past 100 years or so.

While the study determined'that the PID had placed **staff** gauges at the tail-ends of most distributaries, it also uncovered that the calibration of the gauges had been done only once in the entire period of operation since project inception in 1987. These rating curves, developed at that time, have not been upgraded even when significant changes due to maintenance and remodelling activities have been undertaken in various reaches of'the distributary and minor channels. Thus, as in the case of the main canal, the information on flows distribution at the secondary level is highly unreliable and does not follow the pattern of water demand dictated by the cropping pattern' in the field, as called for in the system's design documents.

A second operational problem at the distributary level deals with the nature of the existing pipe outlets. Construction of these structures was implemented with a view that it was to be a "temporary" arrangement;.the result was a large discrepancy between the design and the actual flow capacity of the outlets. Not only the physical characteristics, but also the location itself of the structures, compounds the inequity and unreliability of the water distribution. The configuration of the canals makes it necessary to rely heavily on the use of harries or stoplogs, in order to maintain adequate hydraulic

head at a large number of the outlet offtakes This poses a burden on an already scarce field staff

The study also disclosed that the PID does develop a water indent. based on crop patterns in the field, that is eventually utilized for purposes of water requirements. But, this is done almost an entire season behind schedule because the primary purpose of the crop survey is more related to water fee collection than to the water requirements *per* se. In fact, this type of survey is done by the revenue section of the agency rather than by its operational arm.

Direct observation of system operations at the secondary level intimated that the PID does respond to farmers behavior; for example, the PID reduces flows in the aflernoans in anticipation of farmers closing outlets for the night. But this response is more related to basic operational principles to protect canal overflows or excessive wastage through canal scapes, rather than as a measure to move towards a demand-.based water delivery pattern.

Finally, through direct field measurements supported by 'close interaction with field personnel, the conclusion was drawn that the lack of control on water distribution was resulting in excessive flows being deliverd throughout CRBC's Stage I. Since the system is under construction, some of the excess may be unavoidable because of operational constraints; but it establishes a precedent of .higher than needed water supplies, which will create an illusion on farmers perception of the systems' capabilities. In the short run, this will have a negative impact on the performance of the system as a whole.

2.4 Watercourse Level Operations

Operation of the watercourses followed the same pattern of water delivery found at the upper levels of the system. Water is being delivered continuously and simultaneously to all watercorses. Once again. it simply reflects that management was unprepared to make changes from the traditional mode of system operation.

However, a unique teature of CRBC was found to be farmers behavior vis-a-vis the operation of the outlets It was mentioned earlier that pipe outlets had been installed along the distributaries. These outlets have no provision for water .control as they are not gated. Nontheless, because of the configuration of the watercourses themselves, with the provision of a simple check structure at its. head (downstream side of the outlets) the farmers are allowed to manipulate at will the amount of water they **do not want to** receive.

The consequence was a *de* facto move towards **a** crop-based irrigation approach in which farmers had the opportunity to exercise some degree of control over the pattern of water delivery. This, in turn, meant that the PID had to be ready to react to farmers behavior at the watercourse level in order to cope with the potential **refusal** water.

Other observations on farmers practices in their watercourses confirmed these perceptions of excess water deliveries. For example, night irrigation was practically non-existant during the Rabi season and observed very ocassionally during the Kharif. In the latter. night irrigation was carried out only in the context of rice; the farmer diverted a small water stream into his plot and went home without providing any further supervision.

Likewise, only in a few watercourses have the farmers made an official request to the PID to set up a *warabandi* scheme. In general, farmers feel that water is abundant and that there is no need to establish a rotation that would have them working night shifts in order to obtain their water. Farmers seem to have been able to establish an unstructured arrangement by which all are able to meet their water demands within a reasonable period of time.

Following the traditional pattern of other areas in the country. an effort had been made to establish Water Users Associations at the watercourse level. These had been organized around the construction and lining of the watercourses. Once this main operation had been accomplished, the WUAs lost their justification and slowly but surely disappeared. Only some remnants of organized behavior are left, which the farmers have used primarily to share water in the watercourses as response to large flow allocations. In addition, they have devised a system by which the responsability for closing or opening the outlets is clearly demarcated.

Maintenance practices were found to be no different than in other systems in the country: farmers make informal arrangements to clean those areas under their respective jurisdictions and get together for larger efforts. In general, the study found the watercourses to be physically in good shape; not a surprising finding since the system is still fairly new. Finally, as expected, farmers have an excellent knowledge on the topographical limitations of both their watercourse and cultivated areas, and they work jointly or individually towards overcoming any difficulties.

2.5 Constraints to Study Implementation

In this section, some of the limitations will be briefly mentioned that were perceived as constraints to project implementation at the time of the study's inception. Because it was obvious that some of the solutions to these constraints fell beyond the reasonable capabilities and responsablities of the implementing agencies involved. they are

presented only to set the context under which the study evolved and not as a criticism of the agencies themselves.

2.5.1 Irrigation Facilities

The foremost constraint in relation to irrigation facilities was the fact that the CRBC irrigation system had been designed having in mind the traditional supply-driven water delivery pattern approach, while its operation was eventually intended to be realized through a relatively innovative ---in the context of Pakistan irrigation--- demand-driven delivery schedule.

This design-operational missmatch becomes obvious by the low numbers of water control structures found in the canal network. By trying to operate the system at full supply level, while at the same time maintaining the flexibility of being able to deliver water to the outlets under a wide range of flows, has resulted in a complex operation at the distributary level that puts undue pressure on both the system's facilities and its human resources.

The operation of the system is further complicated by the dual management arrangement that calls for the close interaction of two agencies with different objectives and perceptions on the type of irrigation service that should be provided. The end-product has been a "no-mans" land in which each agency expects the other to have the responsability for upgrading the irrigation facilities.

The large distances between crucial control points requires that communication facilities be readily available at all times. While both telephone and telegraph are available, they are not entirely reliable, so communications was found to be sluggish. Wireless phones, or walkie-talkies, are another option being used occasionally, Finally, the use of vehicles provides support to expedite operational decisions, but the large area commanded by the system is by itself a constraint because of the relatively high Operation & Maintenance costs for the vehicles.

2.5.2 Human Resources

The main limitation concerning the project's human resource was found to be the actual number of individuals available. Under the guidelines of project implementation, the Government was to establish a System Operations Division under the PID properly staffed with experienced personnel. While the agencies made efforts to comply with this component of project development, standing government labor policies, at the macro-level, prevented its implementation. Less than 25 percent of the intended field personnel had been actually hired; this low percentage remained throughout the study period.

The problem of less than desirable numbers of field personnel was further aggravated by the skill levels of those already in place. For example, distributary gatekeepers were found to be iliterate and therefore incapable of providing adequate support on flow data documentation. Technical staff kept being rotated, both within and outside the project, taking with them the skills acquired in their previous positions. Sometimes, the study also documented people being assigned to jobs either far beyond their capabilities, or even worse, to activities far below their training.

In essence, limitations found in both the irrigation facilities and the availability of human resources to the project were bound to impose delays on the study's implementation. This was evident as the research activities got under way.

In the next chapters, the report builds upon the basic information provided thus far and analyzes the field data collected over the three-year period of the study.. These chapters will provide the justification and technical support for the recommendations made in Volume I of the Final Report.

Chapter 3

SIMULATION OF CHASHMA RIGHT BANK CANAL SYSTEM

3.1 Justification

In the beginning of the study, it was envisaged that the CRBC Irrigation System had peculiar and complex characteristics regarding design, 'hydraulics and operations. The preliminary studies indicated that the physical instability and special operational conditions of the canal, caused by the partial operation of the system and aggravated by the un-optimized functioning of the main and distributary canals, have resulted in increased complexity of the hydraulic phenomena. In addition, a new dimension was added regarding the management of this irrigation system on a crop-based mode, which was a new concept for the managers. The technique of mathematical simulation was applied to capture this multidimensional process and simulate the dynamics of the system. The following paragraphs briefly describe the important features of CRBC Crop-based Irrigation System which have necessitated the introduction of sophisticated techniaues.

Chashma Right Bank canal designed with a flat slope of 1 in 14000 for the 223 km (132 miles) length of lined section and 1 in 8000 for the 35 km (21 miles) length of unlined section. Stage I of the canal runs for 78 km (46 miles) and feeds eight secondary channels. The first reach has been kept unlined due to high water table conditions in the zone. The unlined section is in high "fill", while the lined section is in "cut". The lined section has been designed using Manning's equation with a roughness value of ,016 and a velocity of around 1 m/s (3-4 feet per second). The bed-width to depth ratio is 25:1 for the unlined reach and 2.5:1 for the lined reach. After completing construction, the actual bed of the unlined section was more than 3 m (ten feet) lower than the required (planned) level, which caused a severe seepage problem in the area. Many remedial measures were taken, including special operations of the combined structure at RD 98+000 to trap the sediment in the upstream reaches.

After the trial operation, an important physical modification was the installation of lower offtaking pipes from the main canal to deliver water to Paharpur feeder canals. The remodelling had to be carried out because the original structures were too high to draw water from the main canal.

Water allocation for the CRBC system from Chashma Barrage has been fixed according to the ten-day crop water requirements of the command area for a recommended cropping pattern. However, no means and methods have been suggested to implement the design cropping pattern and allocation schedule. The only facility provided to handle the variable flows in Stage I was the provision of three cross-regulators located along 77 kilometers (46 miles) of main canal. As a consequence, the system was not flexible enough to accommodate' the expected variations.

Contrary *to* the complex situation of the system, a simple operational control has been adopted so far. The operational targets have been defined only for two cross-regulators by fixing their upstream gauges to the maximum. No water distribution plan or operational guidelines have been prepared for the distributary head regulators. Occasionally, operators receive instructions about the downstream gauges which are neither calibrated nor proper flow measuring devices. Virtually, the operators are responsible to satisfy the farmers, or to ensure the security of the canal.

Figures III-1 and III-2 show the physical instability and the operational variability of the system. In the former, the rapid sedimentation that took placed between 1988 and 1990 has slowed down afterwards and design bed-level still remains to be achieved. In the latter, we can see the contrasting structure operation between the head and tail of stage I; during a 200 hour period the head structure was adjusted only once whereas the scape at the tail was done so many (21) times.

The above considerations can be summarized as three major issues that need to be explored:

i) Comprehension of the design limitations of the system with an objective of finding solutions for both permanent and transient problems;

ii) Develop guidelines for the operational practices and procedures at each level (main canal and distributaries) to handle the typical operational problems of the CRBC; and

iii) Evaluate the critical values for some of the hydraulic parameters (like velocity and Froude number) to cope with the variable flows in the main canal.

To address these issues, a hydraulic simulation model was applied, along with other analytical techniques.

3.2 The Model

3.2.1 Selection of the Model

The selection of the model was based on two considerations, its user friendliness and its potential to simulate the variable inflows and the characteristics of alluvial and lined channels. The model selected for this purpose was SIC (Simulation of Irrigation Canals) which had already been field tested in Sri Lanka and Pakistan. The SIC model was developed by CEMAGREF (France) based on three years of experience during a collaborative study with IIMI in Sri Lanka on the Kirindi Oya Right Bank Main Canal

Figure III-1
A Typical Unlined Section of CRBC Stage Sedimentation Pattern (1988-1992)

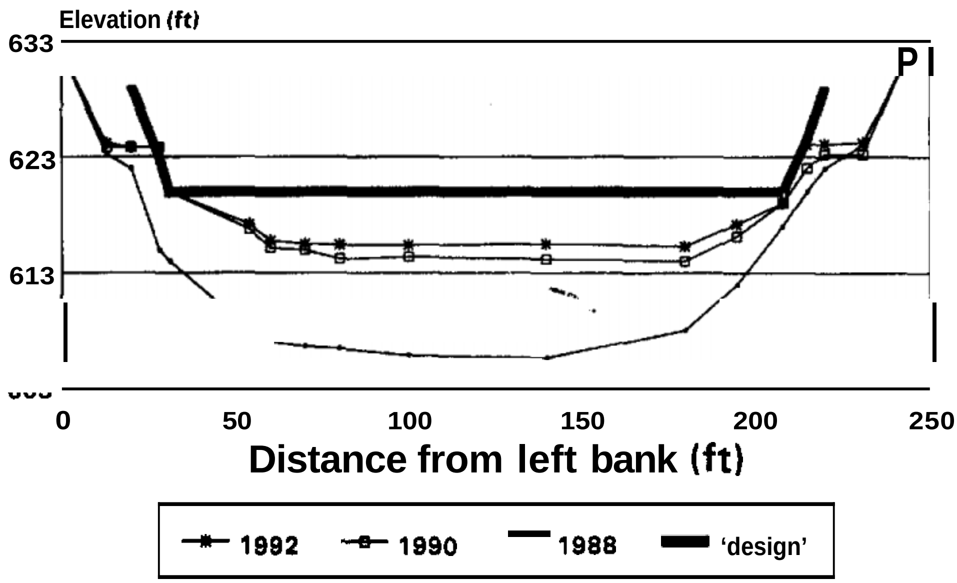
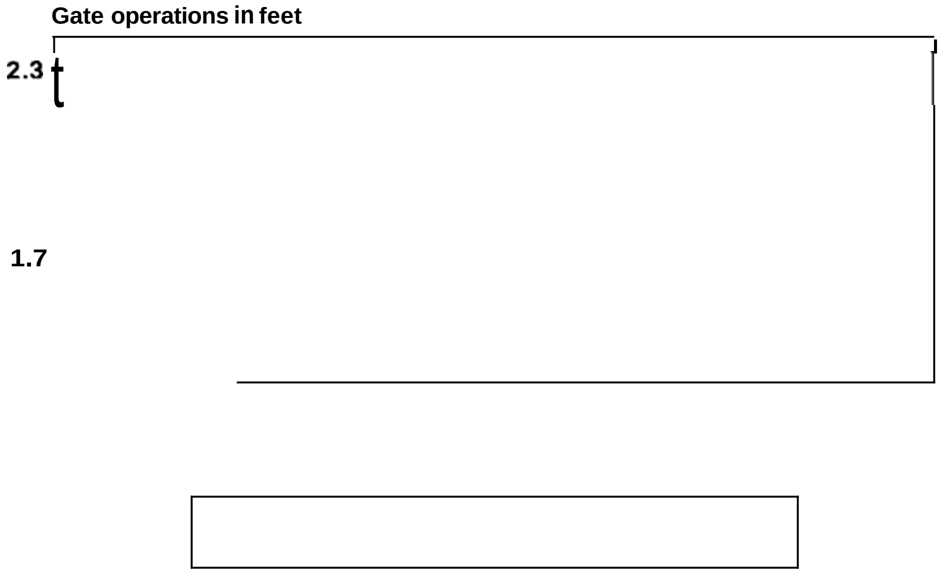


Figure III-2
CRBC-Hourly Operation at Combined Structure and Tail of Stage I



system. IIMI Pakistan adopted the model in 1991 and tested it on a distributary system in the Punjab (Pirmahal Distributary at the tail of Lower Gugera Canal). Application of the model for the main canal and two distributaries of the CRBC has demonstrated its potential to simulate the hydraulics for a wide range of irrigation systems.

The model is built around three main units: (1) topography; (2) steady flow; and (3) unsteady flow. These main units can be run either separately or in sequence. The necessary modifications and additions have been incorporated into the model for addressing canal systems and their offtake structures as encountered in Pakistan.

The simulations in the model are based on one-dimensional hydraulic computations under steady and transient (unsteady) flow regimes. The major limitation of the model is that it cannot simulate a dry-bed condition nor supercritical flows. The main components of the model and its theoretical background is described in the following sections

3.2.2 Components of the Model

Unit **I - Topography Module**

The hydraulic modelling of the open-channel network needs to take into consideration the real canal topography: **(1)** the canal (hydraulic) network topology; and (2) the geometric description of the canal.

Hydraulic Network

Choice of reaches. The hydraulic network is divided into homogeneous reaches in terms of discharge (i.e with no local inflows or ouflows) located between an upstream node and a downstream node. The points of inflow and ouflow (all types of offtakes in the case of the canal network) can occur only at model nodes, so it is a constraint imposed by the model for a reach. The user may, however, divide any part of the canal into several reaches in order to take into account any particularity; for instance, a shift from an unlined to a lined section, or a different administrative zone (for example from one sub-divisional engineer to another).

Choice of branches. A branch is a group of reaches serially linked to one another. A channel can be defined as one branch or can be divided into many branches.

Downstream conditions. The calculation of a water surface profile is initiated at the downstream end of a reach and proceeds upwards. Therefore, a relationship between water surface elevation and discharge is needed as a downstream boundary condition in order to begin the calculations.

Geometric Description of the Canal

The geometry of the reaches is the basic element of all the hydraulic computations. The reach geometry is defined through the cross-section profiles indicating the shape and volume of the canal. The cross sections can be described and entered in three different ways: (1) abscissa-elevation; (2) width-elevation; and (3) parametric form. The type of description may vary from one section to another, within a given reach. Sections of special geometrical shape can be input in parametric form (circle, culvert, power relationship, rectangle, trapezium or triangle).

Singular sections. Cross sections containing structures like regulators and bridges are called singular sections. In these sections, the general hydraulic laws for computing water surface profiles are not applicable. These laws are replaced by the appropriate discharge formula for each structure. This unit does not deal with the geometry of the device itself.

Computational Sections. Data sections may be unequally distributed along the canal, but the user can select sections of any length for the computations. The spacing for these cross-sections depend upon the physical conditions of the canal in each reach.

Unit I generates the topography files for the computational programs of units II and III. It also produces an ASCII file, that shows elevation, width, wetted perimeter and area. In case of problems with topography computations, the ASCII file will indicate the reaches where errors have been found.

Unit II - Steady Flow Module

Unit II computes the water surface profile in a canal under steady flow conditions for any combination of offtake discharges and cross-regulator gate openings. These water surface profiles may be used as initial conditions for the unsteady flow computation in Unit III. A sub-module of the steady flow module computes the offtake gate openings to satisfy given target discharges, while another sub-module computes the cross-regulator gate opening to obtain given targeted water surface elevations upstream of the regulator. These sub-modules, therefore, allow computation of gate settings to satisfy a given demand-supply configuration of water flow. All of the basic hydraulic calculations for canal regime, cross regulator structures and off-take regulators are done in this module.

Equation of Gradually Varied Flow in a Reach

The water surface profile is calculated under subcritical, steady flow conditions in a reach. The classic hypotheses for uni-dimensional hydraulics assumes that:

* The flow direction is sufficiently rectilinear, so that the free surface could be considered to be horizontal in a cross section:

* the transverse velocities are negligible and the pressure distribution is hydrostatic; and

* the friction forces are taken into account through the Manning-Strickler coefficients.

The following well-known differential equation describing the water surface profile is used:

$$dH/dx = -S_f + kqQ/gA^2$$

with:

$$S_f = n^2Q^2/A^2R^{4/3}$$

where:

H = total head;
x = distance in the direction of flow;
Q = volumetric rate of discharge;
A = x-sectional area;
R = hydraulic radius;
q = discharge per unit length; and
S_f = friction slope

To solve this equation, an upstream boundary condition in terms of discharge and a downstream boundary condition in terms of water surface elevation are required. In addition, the lateral inflow and the hydraulic roughness coefficient along the canal should be known. This equation is numerically solved using Newton's Method.

Simulation of Cross Structures and Offtakes:

When a cross structure exists on a canal, the gradually varied flow equation cannot be used locally to calculate the water surface elevation upstream of the structure. The hydraulic law governing the flow through the irrigation structure present in that specific reach of the canal should be applied. In SIC, all structures are modelled either as weir/orifice type of devices (high sill elevation) or weir/undershot gates (low sill elevations).

Unit III - Unsteady Flow Module

Unit III computes the water surface profile in the canal under unsteady flow conditions. The initial water surface profile is provided by Unit II. It allows the user to test various scenarios of water demand schedule and operation at the head works and control

structures. Starting from an initial steady flow regime, it helps the user to identify the best way to attain a new water distribution plan, or to study the transition from one rotational plan to another.

Saint-Venant Equations

To compute the unsteady flow water surface profile in a single reach, the same hypothesis as for Unit II are applicable. Furthermore, only smooth transient phenomena are considered, whereas the propagation of a rapid wave or surge cannot be simulated.

Two equations are needed to describe unsteady flow in open channels: (1) the continuity equation; and (2) the momentum equation. These equations are expressed as:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q$$

$$\frac{\partial Q}{\partial t} \quad \frac{\partial Q^2/A}{\partial x} + gA\frac{\partial z}{\partial x} = -gAS_f + kqV$$

These partial differential equations must include the initial and boundary conditions in order to be solved. These boundary conditions are the hydrographs (water volumes) at the upstream nodes and a rating curve at the downstream node of the model. The initial condition is the water surface profile resulting from the steady flow computation.

The Saint Venant equations have no known analytical solution. They are solved numerically by discretizing the equation; the partial derivatives are replaced' by finite differences. A four point implicit scheme, known as Preissmann's, is used to solve these equations.

3.2.3 A Model of the Main Canal (CRBC Stage I)

Application of the model requires site-specific field data collection to define and calibrate the model. Study-oriented data need to be collected to interpret and evaluate particular scenarios. A brief description of the Model *Input* Data used for the CRBC is given below.

Model Input Data:

These data can be further divided into two categories: (1) topographical & geometrical data; and (2) hydraulic data. The input data requirement for the steady and the unsteady states are the same.

________________________________. A hydraulic survey is recommended for collecting these data because the water volumes in a reach, and flows diverted to the offtakes, are simulated through these information. For the CRBC main canal, yearly monitoring data collected by the Alluvial Channel Observation Project (ACOP), surveys by IIMI's field team, and the data collected by the WAPDA D.I.Khan unit were used. These data include:

- longitudinal profile of the main canal bed from 1987 to 1992;
- cross sections of the canal at appropriate intervals (sections at 1000 foot intervals plus sections representing the design or existing changes in canal geometry);
- exact location of all cross regulators, offtakes and other singularities (structures) and
- dimensions of all regulating and delivery devices (design and survey data).

<u>Hvdraulic data</u>. These data include the following measured and computed hydraulic parameters:

- roughness coefficients for the different reaches of the canal;
- seepage losses along the canal; and
- headdischarge relationship and discharge coefficients for the offtakes and regulators.

Calibration of the Model:

The purpose of calibrating a mathematical model is to make sure that the user's defined geometrical and hydraulic variables or parameters are reliable and appropriate enough to accurately reflect the actually observed field situation in the canal. The calibration of hydraulic models is an essential step of model application; the accuracy requirements of this step are dependent on the objectives of the user's need. For model calibration is necessary to accurately establish the values of roughness coefficient, canal losses and discharge coefficients. A second step is to collect a few

Distance along the canal (in 1000 feet)	Loss Rate at Q < 85 cumecs mm/km of length	Loss Rate at Q > 85 cumecs mm/km of length	Estimated roughness coefficient "n"
unlined			
0 - 51	40	70	.018
51 - 98	40	70	.022
98 - 120	40	70	.022
lined			
120 - 130	32	32	.019
130 - 170	32	32	.019
170 - 210	32	32	.019
210 - 237	32	32	.022
237 - 257	32	32	.022

Roughness Coefficient:

The roughness coefficient is used in the computation of the friction gradient, which accounts for the resistance offered by the canal to the flow of water under steady state conditions. The exact computation of roughness (based on field data) is difficult because the standard equation used for this purpose is valid only for uniform flows, a condition seldom found in the field.

The standard Manning-Strickler equation is represented as:

$$Q = 1/n . A . R^{2/3} . S_0^{1/2}$$

where:

S_0 = bed slope
A = Area of a section
R = Hydraulic radius
n = Manning roughness coefficient

The backwater effects caused by regulators and other structures (like bridges) make it almost impossible to measure the water surface slope of "real" uniform flow. There are also temporal and spatial variations, since the canal conditions vary with time and location.

In the case of CRBC Stage I, the canal has unlined, brick-lined and concrete-lined sections with different side and bed slopes. The regulators at RD 98+000 and RD 257+000 are being used for water ponding in the upstream reaches. Hence, the initial values of the coefficient were calculated for selected reaches where the backwater effects were minimal. The final values of the roughness are adjusted through a trial-and-error method in order to achieve a reasonable agreement between computed and observed water surface levels. These values are shown in Table III-1 above, along with seepage losses.

The final values gbtained (n=.022) for some of the reaches of the lined section are higher than the design values (n=.016). This difference can be explained by the existing physical conditions of the brick/concrete lining and the heavy sedimentation in the canal.

Calibration of the Structures:

Many sets of discharge measurements, water levels and gate openings are required to compute the discharge coefficient for each device (gate, weir, pipe, orifice, culvert etc.). These coefficients are then used by the model to calculate the discharges through the devices when the gate openings and the water levels are known.

The cross regulator at **RD** 98+000 was calibrated using a standard free flow orifice equation (Eq 1) and an experimentally derived equation for slow sill elevation structures (Eq **2).** Both of these are available in the model who by itself selected the latter, because it fitted better the actual structure.

The discharge equation for a free flow cross regulator is:

$$Q = C_d n L (2g)^{.5} (h_1^{3/2} - (h_1 - W_1)^{3/2}) \qquad (Eq\ 1)$$

The equation in the model for a free flow cross regulator with low sill elevation (undershot) gates is:

$$Q = nL(2g)^{.5} (\mu h1^{3/2} - \mu_1 (h1 - W)^{3/2}) \qquad (Eq\ 2)$$

where:

n	= number of gates
L	= width of one gate
W	= gate opening
C_d	= discharge coefficient of equation # 1
$C_{d'}$	= discharge coefficient of equation # **2**
u	= $C_{d'}$ - (.08/(H1/W))
u l	= $C_{d'}$ - (.08/(H1/W-1))

Both equations were calibrated to obtain the appropriate values of C_d & C_d' (hence u & ul). The computed values of C_d vary in a narrow range of 0.38 to 0.40, while u & u1 vary from 0.29 to 0.39.

The evolution of the coefficients using (Eq 2) indicates that the discharge contraction factor varies as a function of the ratio of gate opening and upstream working head. Figure III-3 shows measured discharge as a function of h1/W, while Figure III-4 shows u & u l as a function of H1/W. It is obvious that the second equation (Eq 2) gives better results for the free flow structure because u and u l takes into account the variation of Q with respect to H1/W.

The head regulators for distributaries # 1 to # **4** were calibrated using discharge data collected by the IIMI field team. For other structures, ACOP's measurements were used to calculate the discharge coefficient. A value of C_d equal to 0.4 was found satisfactory for all offtake head gates under free flow conditions.

Figure III-3
Measured Discharge as a Function of Head/Gate Opening at RD 98-CRBC

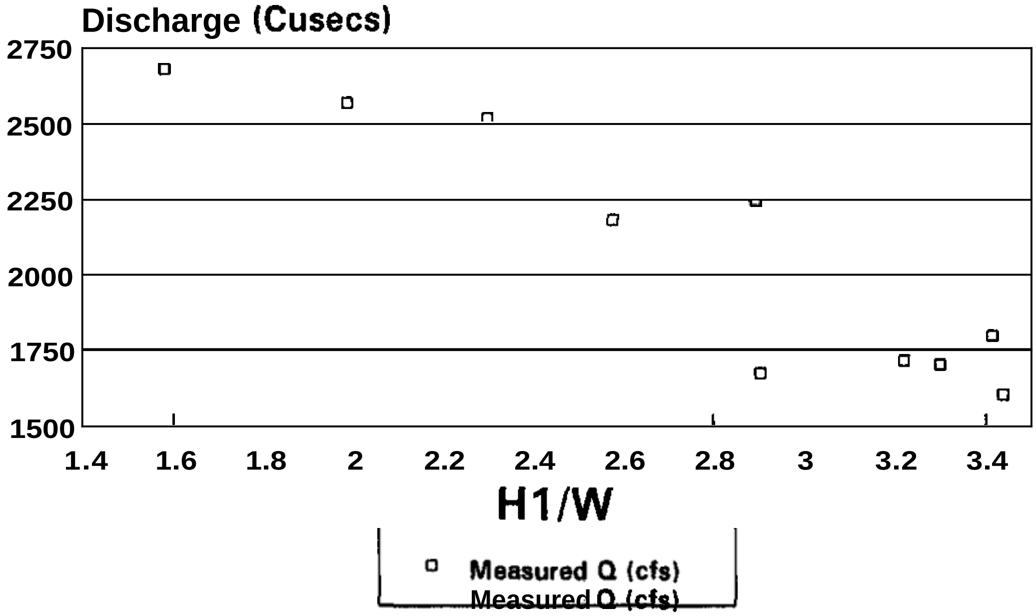
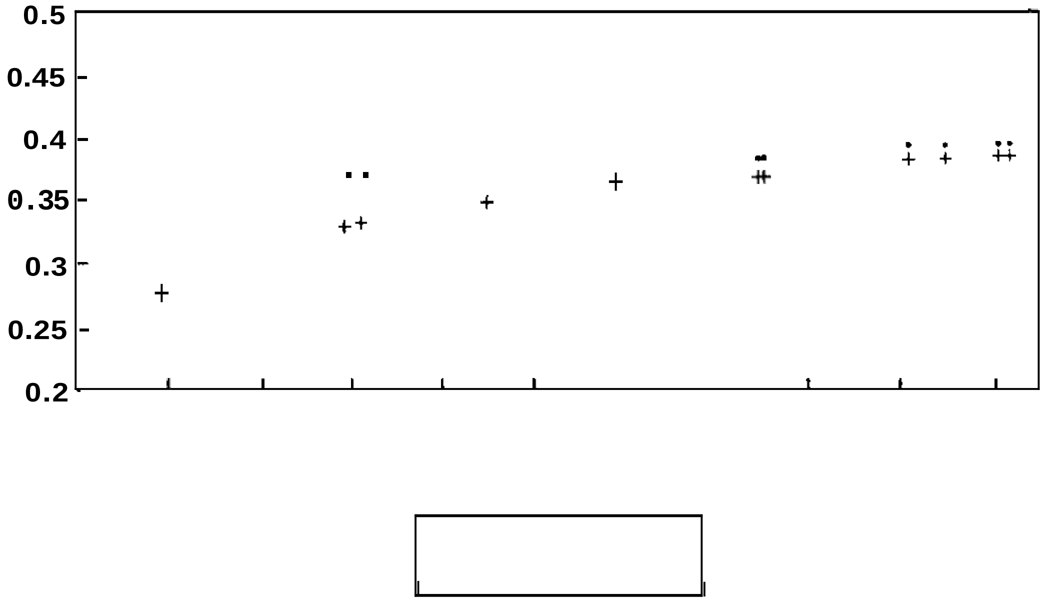


Figure III-4
Discharge Coefficients (u1 & u2) as a Function of Head/Gate Opening at RD 98



Final Verification of the Model for the Main Canal

As a final verification procedure, steady state flow conditions were simulated so that observed water levels in representative reaches of the canal could be used to adjust the roughness coefficient ("n" value). The main canal model was calibrated and verified for inflows of 65 and 105 cumecs (2300 & 3700 cusecs). As the complete field data were available in both cases, measured canal losses and boundary conditions were used for the model validation.. The computed and measured water surface levels show a good fit in both cases as shown in Figure 111-5.

3.2.4 A Model of the Secondary Canal (Distributary # 4)

As discussed above, preliminary studies provided an indication of the appropriateness of using simulation techniques in addressing design and operational.-related problems. After simulating the main canal, it was clear that in order to obtain a better picture of the system performance, the study should be extended beyond the main canal. Thus, it was decided to extend the simulation work, utilizing the same model, down to the distributary level.

Consistent with previous efforts, Distributaries # 3 and # 4 were obvious choices for this work. A detailed topographic survey had been conducted in the former canal, at the beginning of project activities, in anticipation of this very possibility. A partial survey had been done in the latter canal; this survey was upgraded in January 93 for this same purpose.

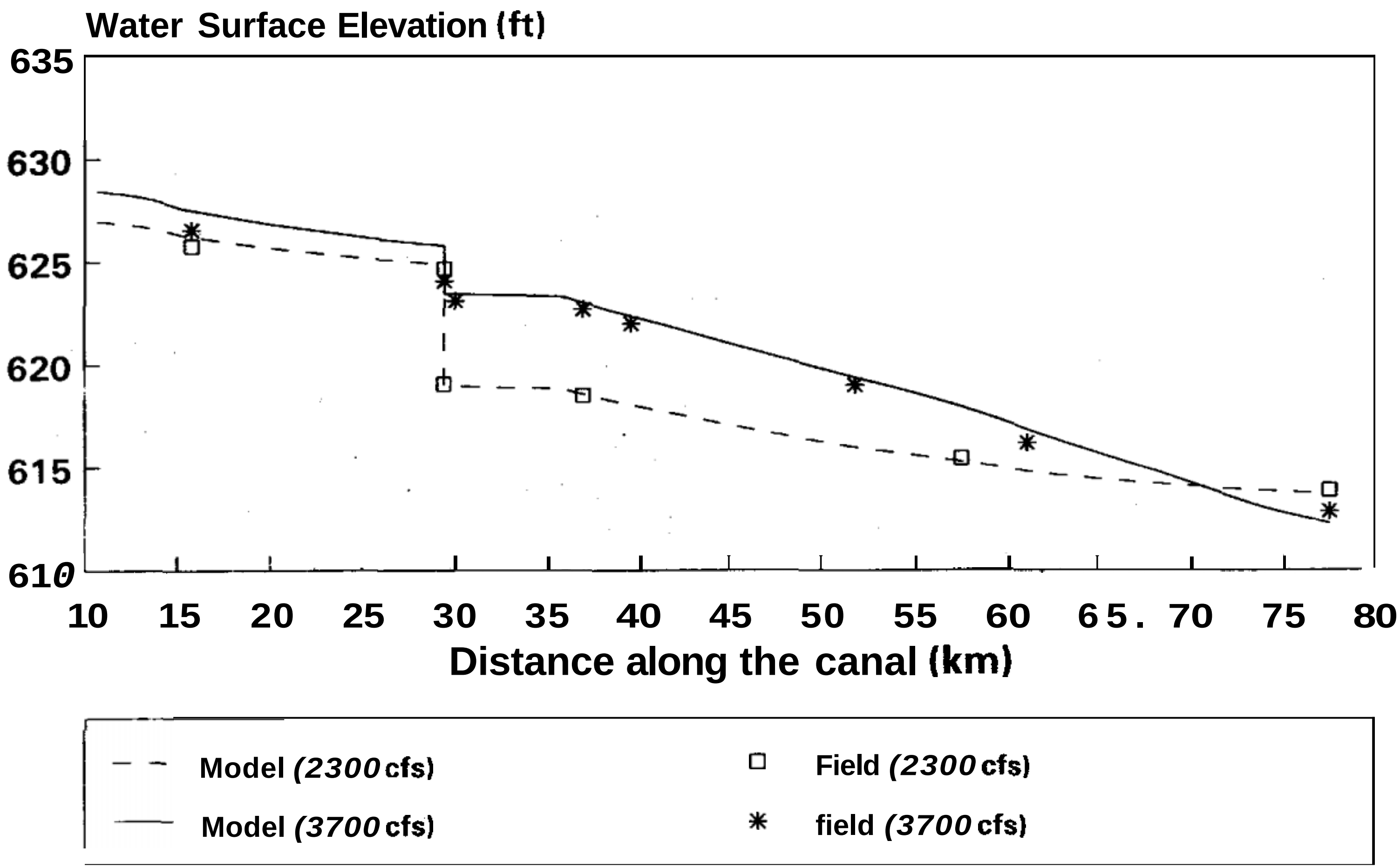
For both distributaries, the model was calibrated for observed field conditions during peak demand at the end of June 92 when all outlets remained open. For Distributary # 3, the discharge was 126 % of the design discharge, while it was 100 % for Distributary # 4. Also, the use of stop-logs in each distributary were closely documented. The observed field values matched the simulated values --in terms of water levels and outlet discharges-- so well that no further effort was considered necessary for the verification.

3.3. Applications of the Model

3.3.1 Main Canal

Afler calibration, the SIC model was used to predict the water surface levels and compute the hydraulic parameters like velocity, Froude number and roughness at different flow rates for both steady and unsteady flow conditions. The scenarios presented in the following sections address the three aspects of main canal functioning:

Figure 111-5
Measured and Predicted Water levels for Different Flow Rates - CRBC



hydraulic behavior of the canal;

* design and physical limitations; and

* significance of the operational interventions.

3.3.1.1 Canal Capacity and Freeboard

A knowledge of the maximum carrying capacity of a canal has always been a practical concern for the canal manager. A feasible and safe discharge for range canal conveyance needs to be known in order to operate the lined canals with appropriate freeboard, and to manage the unlined canals without overtopping or erosion of the embankments. Furthermore. in the case of crop-based irrigation operations, most of the time systems are to be operated at lower than the peak water demand;, hence, field information remains insufficient to confirm the maximum conveyance capacity of such a system.

In the case of the CRBC Stage I, field data indicated the physical and hydraulic constraints on the maximum conveyance capacity of the canal. These findings have been substantiated by recent operations associated with the partial functioning of the main canal. The system has never been operated at the maximum design discharge of 138 cumecs (4800 cusecs), but one complete set of hydraulic data available at 107 cumecs (3800 cusecs) indicates that there are freeboard limitations at two locations;. namely, the lined-unlined transition (RD 120+000) and the tail reach of Stage I (RD 237+000 to RD 253+000).

Many possible scenarios were simulated to desagregate the effects of unusual operations under the prevailing circumstances from the expected canal functioning under normal conditions when the entire project is completed. Results indicate that the main canal possesses physical constraints at the lower, as well as at the upper, limit of the authorized supply (40 to 138 cumecs (1400 to 4800 cfs}) for the CRBC main canal. All of the offtakes could hardly get .their share of water at 47 cumecs (1450 cfs) inflow (29% of the maximum) while at 105 cumecs (3700 cfs; 85% of the maximum) some of the reaches could not maintain the recommended freeboard (Figure III-6).

To evaluate the causes of unexpectedly higher water levels in the main canal, the model was run with the design and actual values of roughness coefficient for the maximum authorized flow of 138 cumecs (4800 cusecs). Figure III-7 shows the predicted water levels for both cases, plus the original design water level for 138 cumecs (4800 cfs) along the left dowel of the canal. It is obvious from the figure that the major reason for freeboard reduction is the increase in the roughness coefficient. The transition structure is locally causing the problem, while at the tail of Stage I heavy

Figure 111-6
CRBC Limitations at existing Maximum and Minimum Flow Rates

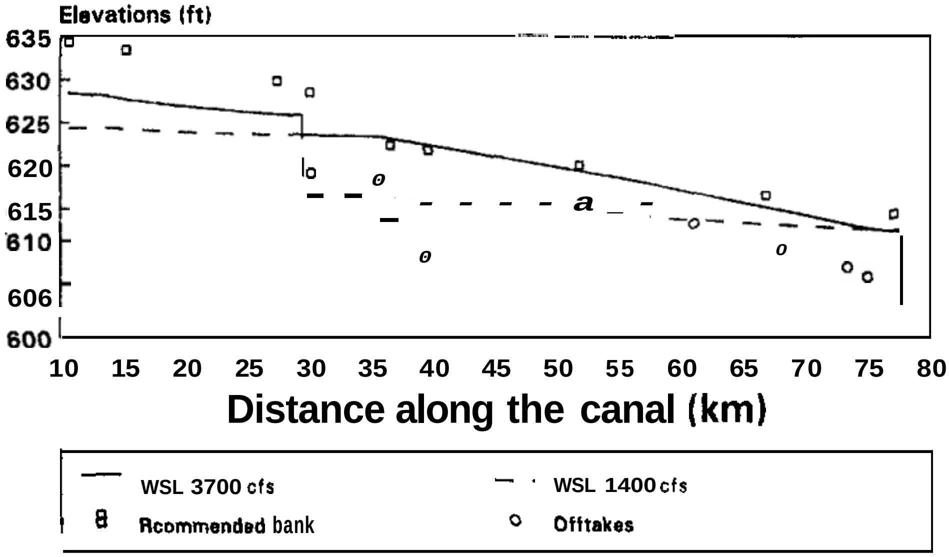
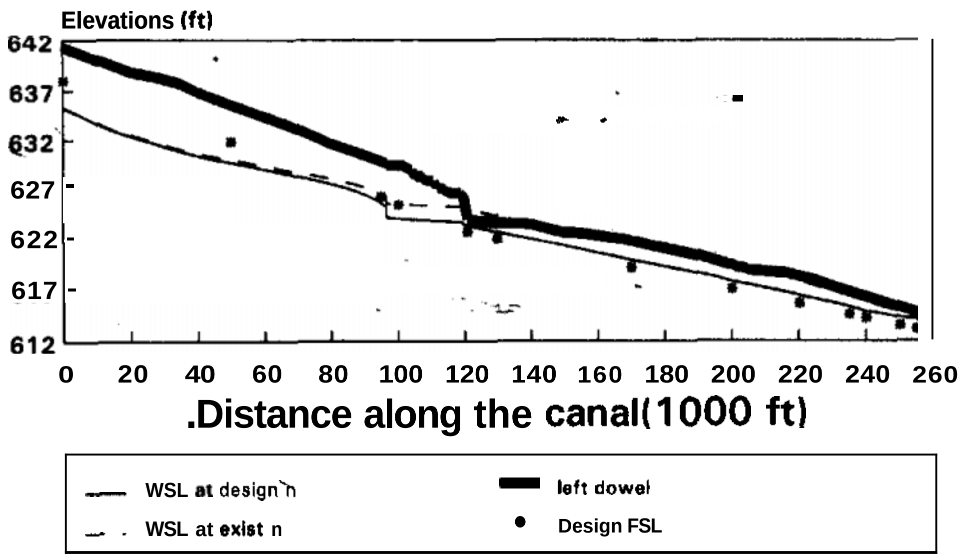


Figure 111-7
Design and Predicted Water Levels CRBC Stage I at FSL (4800 cfs)



sedimentation on the bed and banks has reduced the area of the cross section. Hence, the higher water levels in the main canal can be attributed Io the current operations, higher than design roughness, and local effects.

3.3.1.2 Existing Velocity Profile for Stage I

There is difficulty in maintaining the maximum design velocity when a canal is operated for ,crop-based deliveries (variable flows). The situation may become critical for the management when the need for sediment transportation could not be sacrificed. Alluvial channels of the lndus Basin are expected to run at higher than 70% of the design discharge to avoid siltation. It has also been recommended for these channels that the spatial variation in velocity should not be much different from the discharge variations along the canal to avoid the siltation and scouring caused by the imbalance of stresses aiong the canal prism.

The temporal and spatial variation of velocity in Stage I has been quite pronounced in the last five years. Figure III-8a shows the measured velocities at minimum and maximum flow, while Figure III-8b shows the velocity profile computed by the model along the canal at 85 cumecs (3000 cfs). It could be inferred from the trend shown in these figures that:

i) The maximum design velocity of 1.22 m/s **(4** ft/sec) would be difficult to achieve in the lined section of Stage I;

ii) The velocity profile discloses those reaches which have more likelihood of sedimentation: and

iii) There is a need to estimate and maintain an appropriate operational velocity, which might be different from the design velocity, but must be adequate to carry the sediment load through the main canal.

3.3.1.3 Operational Behavior of the Canal

A number of operational scenarios were simulated to investigate the CRBC main canal behavior under existing operations in order to evaluate and suggest improvements in current operations and management (see CBIO progress reports **#s 1,** 2 & 3). Two scenarios are briefly presented here to address: (1) the question of the function of the cross regulator at RD 257+000; and **(2)** the existing water surface slopes at different flows.

Figure III-8a
Measured Velocities along CRBC for max (3700 cfs) and min (1400 cfs) inflow

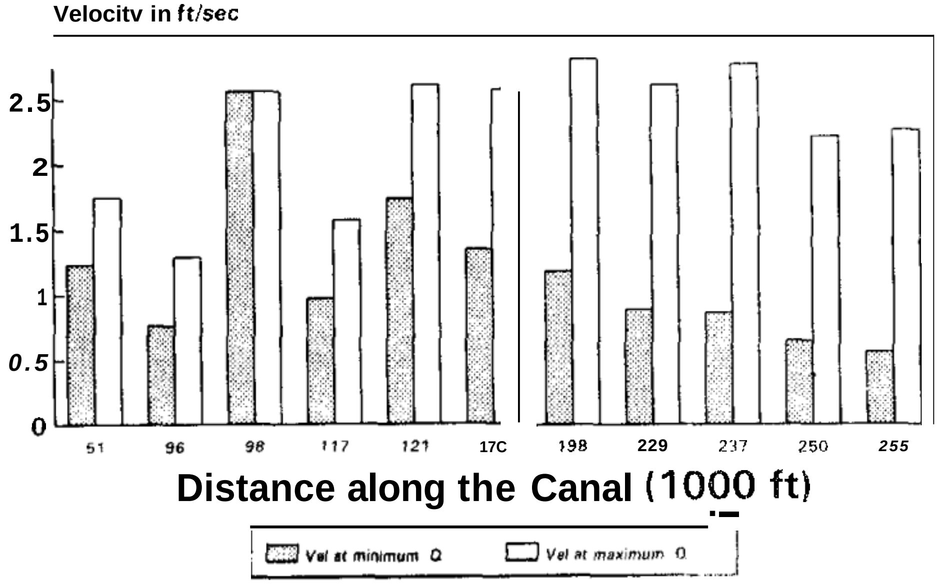
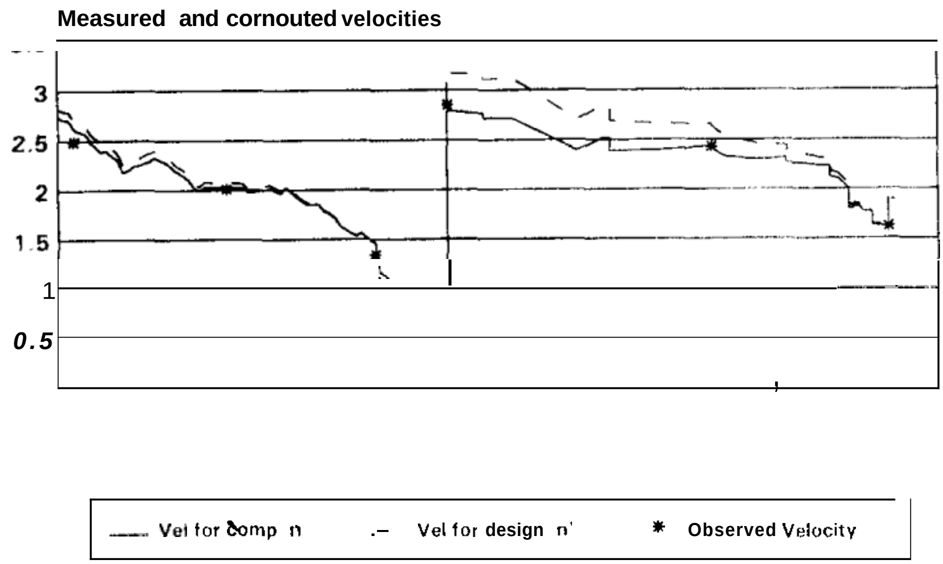


Figure III-8b
Velocity Comparison (at 3000 cfs): Design and Computed 'n' values



Present Functioning of Cross Regulator at RD 257+000

The cross regulator and escape at the tail of Stage I are being used as the major control structures for Stage I The reduced discharge operations of CRBC has been possible only with these control structures To head-up the water and feed the upstream offtakes is the most commonly used function of cross regulators In the case of CRBC, more than three feet of ponding (backwater) is a permanent feature at this location. This has been required to feed a secondary canal eighteen kilometers (11 miles) upstream. Figure III-9 shows the situation with and without cross regulator operations at 47 cumecs (1400 cfs). The water level needs to be raised by about 1.52 m (five feet) at the tail gauge to feed all of the upstream channels according to their crop-based share. Obviously, this much ponding will inevitably cause a drastic, reduction in the flow velocity and consequently increase sediment deposition.

Water Surface Levels at Different Flows:

Normally, backwater effects by on-line structures are considered small and negligible interventions The immense water ponding described in the previous section has an accumulated effect on water surface slopes in the lined section of Stage I.

Figure III-10 shows water surface levels and corresponding hydraulic slopes from the combined structure (RD 98+000) to the tail of Stage I for various inflows As it was mentioned earlier, the design bed slope *is* already quite flat and has been given as the major reason for the canal lining. During the last three years, the canal has been mostly operated between 51 to 85 cumecs (1800 to 3000 cfs) resulting in a hydraulic slope between **42** to 79 percent of the designed slope. The present study indicates that the canal could face problems operating at the above flow range due to the elevation of the offtaking structures and command area Furthermore the slope conditions will result in increased sedimentation throughout Stage I. This already has been observed in the field.

3.3.1.4 Impact of Improved Operations

This section demonstrates that even under the worst of conditions improvements are possible by optimizing the operations of the escape and offtake regulators, and by taking appropriate managerial decisions at the system level. ***No*** changes ***of*** inflow conditions was considered, only the operations have been optimized utilizing the available facilities. Figure III-11 indicates a considerable betterment of the hydraulic conditions in the tail reach under the following conditions

i) The inflow in the canal was 50 cumecs (1750 cfs);

Figure III-9
Cross-Regulator Operations at Tail of STAGE I (CRBC)

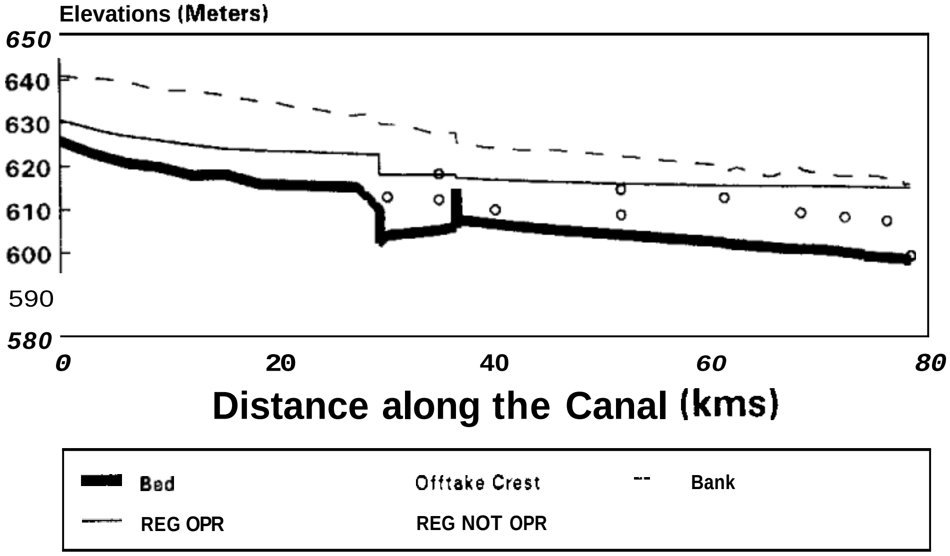


Figure III-10
Water Surface Profiles of CRBC
Design Q is delivered to each Offtake

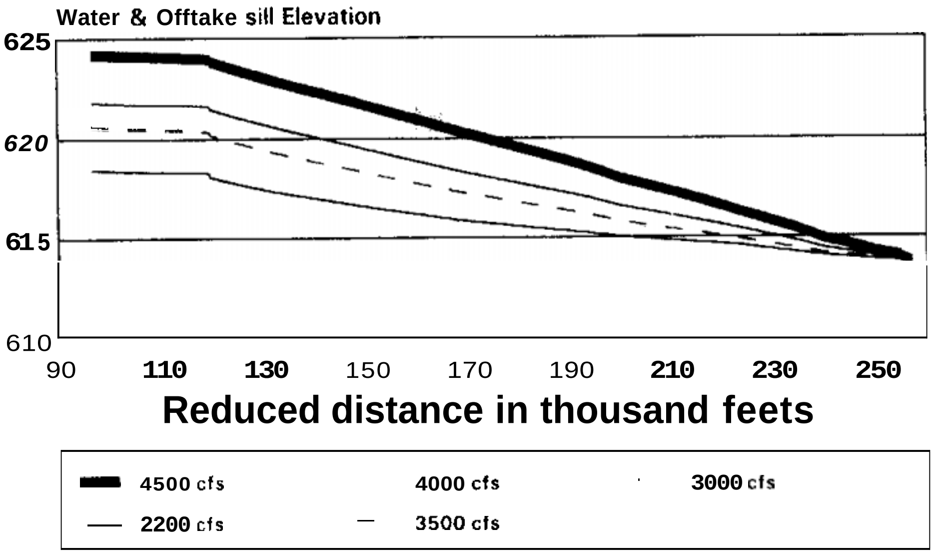
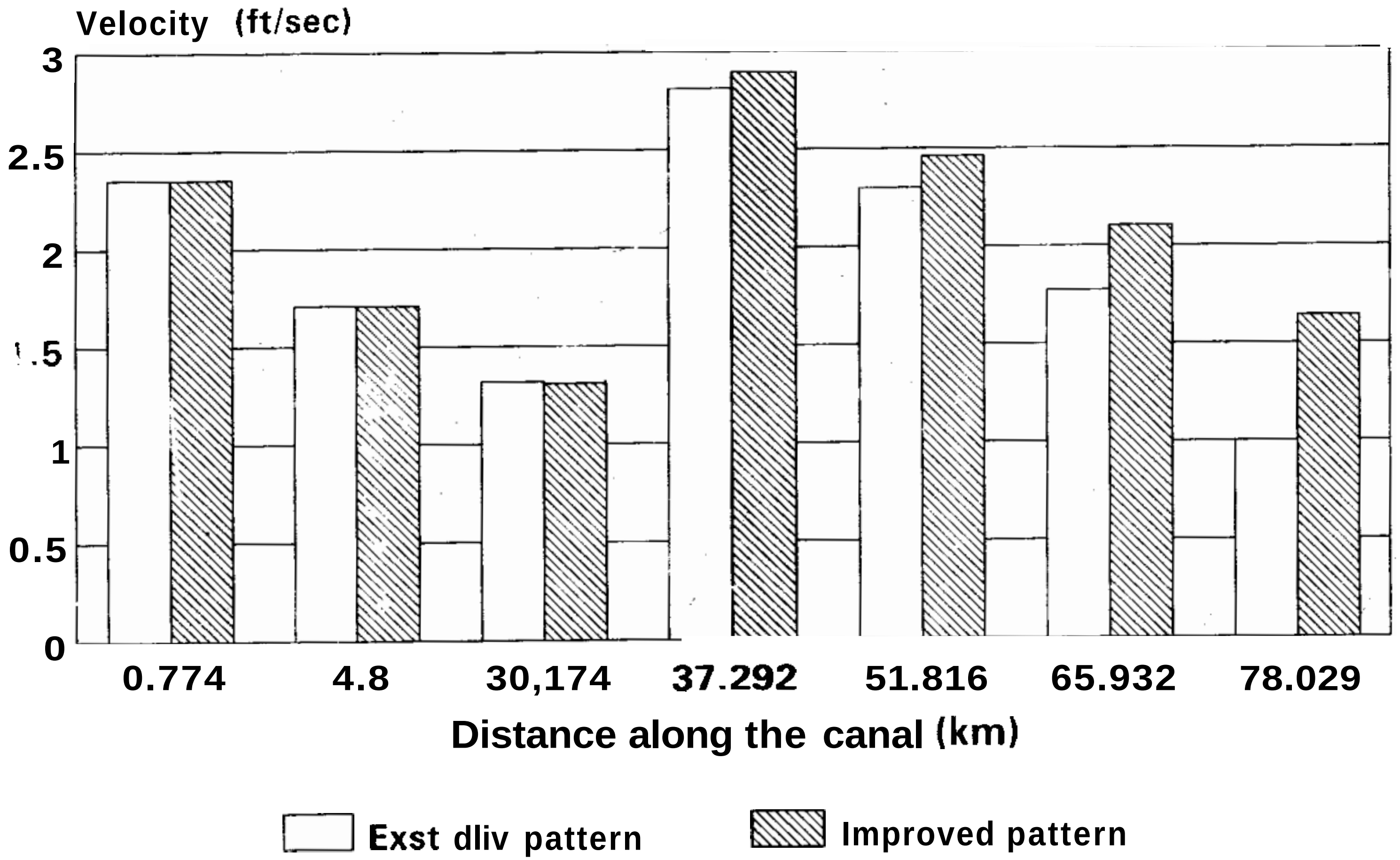


Figure III-11
Improvement at the tail of Stage I
through better operational control



ii) The gates at the head regulators for all distributaries were adjusted to deliver only the appropriate share of water to each channel. The crop water requirements were computed using the *Khasra* records for the cultivated command area of year 1992; and

iii) The operations of the tail regulator and escape structures were optimized to avoid any unnecessary water ponding

During the pre-improvement operations, the gates at the first four distributaries were kept completely open. which caused them to draw much more water than their authorized discharge. During the improved operation, by fixing the share for each distributary, more water was available at the tail. In addition, the water level at the tail was lowered about 0.30 m (1 foot) but still providing a depth of 4.30 m (14 feet) at that point Hence, by restoring the equity among distributaries, and by an active control of the daily operations, considerable improvement is possible.

3.31.5 Alternatives to Solve Water Delivery Problems at the Tail of Stage-I

In the light of the analysis presented in the previous sections, a manager at the tail of Stage I has the dual targets of providing appropriate working heads to all upstream secondary canals and to avoid sedimentation in the upstream reaches of the main canal, while at the same time keeping the extra water supplies to a minimum. To reach a feasible solution, all possible options were hydraulically evaluated (two of them were presented in CBIO Progress Report # 2) The final results are summarized below.

The CRBC main canal is not utilizing its maximum authorized discharge at the present time. The calculations show that until Stage III is completed, the minimum limit could be raised to 67 cumecs (2200 cfs) without exceeding the total authorized volumes. This increase of the minimum limit doubles the velocity at the tail of **CRBC,** although it is still less than 70 % of design, however, during the high demand period, substantial water ponding would still be required

Another possibility for improvement was to consider installing a regulator about eight kilometers upstream of the Stage I tail regulator (see CBIO Progress Report # 1). This additional regulator would improve the situation. in the downstream reach but the velocity problem upstream would be augmented. So this modification was not found very appropriate.

The remodelling *of* the head regulators for distributaries # 1 and # *2* to increase the flow area of the offtake structures is an option which could substantially decrease the required water head and thereby reduce the need for water ponding This type of

treatment has already been successfully applied to the Link Feeder # **4** where an additional regulator barrel of 1 91 x 1.22 meter (6 **25** x **4** feet) has been added.

For this scenario, a .69 m (2.15 ft) diameter offtake pipe *of* distributary # 1 was replaced by a .91 x .91 m (3 x 3 ft) barrel, and a .91 x .91 m barrel of distributary ***# 2*** was replaced by a .91 x **1.22** m (3 x **4** ft) barrel. Figure 111-12 shows the improvement that occur in the velocity profile when the above mentioned modifications were applied. Based on the positive outcome obtained from this part of the study, this option should be considered seriously.

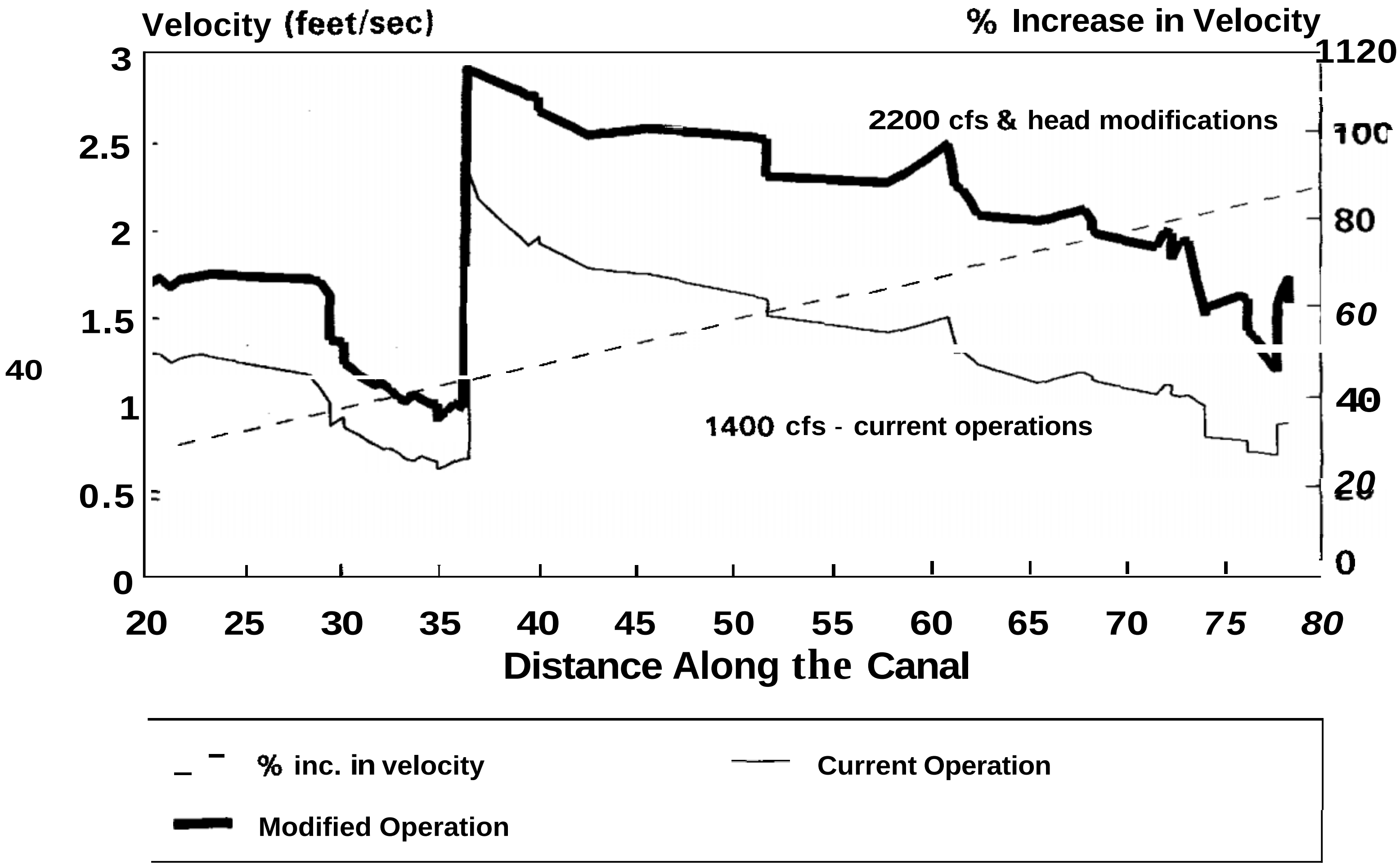
3.3.1.6 Procedure for Developing an Operational Plan

The physical and operational refinements discussed in the previous section suggested the need for well planned, properly scheduled and controlled operations of the CRBC system. Such a plan requires a knowledge of the water demand at each offtake, but no such flow targets exist for CRBC. The monitoring of daily gauges was started during IIMI's work, but still no clear guidelines have been developed by the managers for the operators; hence, each operation **is** practically a localized phenomenon. The targets for the operators at the cross regulators are rigidly defined, but the causes and the effects of these operations have never been studied and established. The CRBC is a relatively complex irrigation system and the proper information about permanent and day-to-day aspects of the system must be available with the manager in order to operate the system efficiently.

A three step procedure for developing an operational plan for the main canal is given below as a guideline. This procedure has been used to develop a set of ten-day operations for **CRBC,** which was presented to the local authorities as an intervention, but unfortunately, was not field tested because of managements reluctance in introducing an "unproven element" in the system's operation. The proposed operational procedure is described below.

Target setting. There are different ways to establish the targets for water distribution. It can be through a crop water requirements approach, through an observation approach by means of an "indent sheet" prepared by the irrigation department, or by requesting from farmers their needs, etc. The crop-based approach was used to calculate the water requirements for *Kharif* 92. The cultivated command area shown in the Khasra data of 1991 was adjusted by 20 % to accommodate the new developed areas. After incorporating farm and canal losses, a 'ten-day table' of water requirements for each distributary was prepared.

Figure 111-12
Velocity Improvement with Modified Structures and Increased Inflow



Simulation **of existing** system **conditions.** This means gathering reliable information about the hydraulic parameters, water distribution and operations of the system at the time of the intervention. These pieces of information are simulated using the steady state option of the model. The boundary condition defined in the model must be verified by comparing the computed and observed water levels Information about the dimensions and the rating tables of the canal structures must be updated before the final computations are made. Time lags at all important node points should also be known, which can be predicted using the model by generating an impulsive wave at the head and following its propagation through the main canal, or using a spread sheet for the calculations, if the velocities are known. Figure III-13 shows the computed time-lags along the CRBC main canal at different flow rates

The Final Operational **Plan.** At this stage, the manager has his water distribution targets and updated information about the system operation. He has already simulated and verified the existing state *of* the system. For his final scheduling, a quantitative estimation of the expected operations and their timings are then required. Utilizing the already verified steady state model, target discharges, and the time lag information, gate operations and their timings were computed. The unsteady state model was used here with small time steps to observe the flows. Timings for the operations were adjusted in a way to assure the minimum fluctuations in the secondary canals. Figure III-14 shows the adequacy of the computed water delivery against the targeted.

3 3.2 Application at the Distributary Level

The objectives of the inodel application at the distributary level were:

i) Test whether the distributary could be run at a range of discharges as required under crop-based operations, and to identify which operational manipulations would be needed to achieve this; and

ii) Simulate a unique practice of farmers, the opening and closure of outlets, and to relate it with the daily flow fluctuations at the distributary head.

3 3 2 1 Implications of Reduced Supply on Water Distribution to the Tertiary Canals

The simulation was undertaken by reducing in steps the discharge at the head of the distributary without changing the respective status of the outlets and drop structures The result was basically the same in both cases

Figure III - 13

Time Lags between Head Regulators for different **Flow** Rates

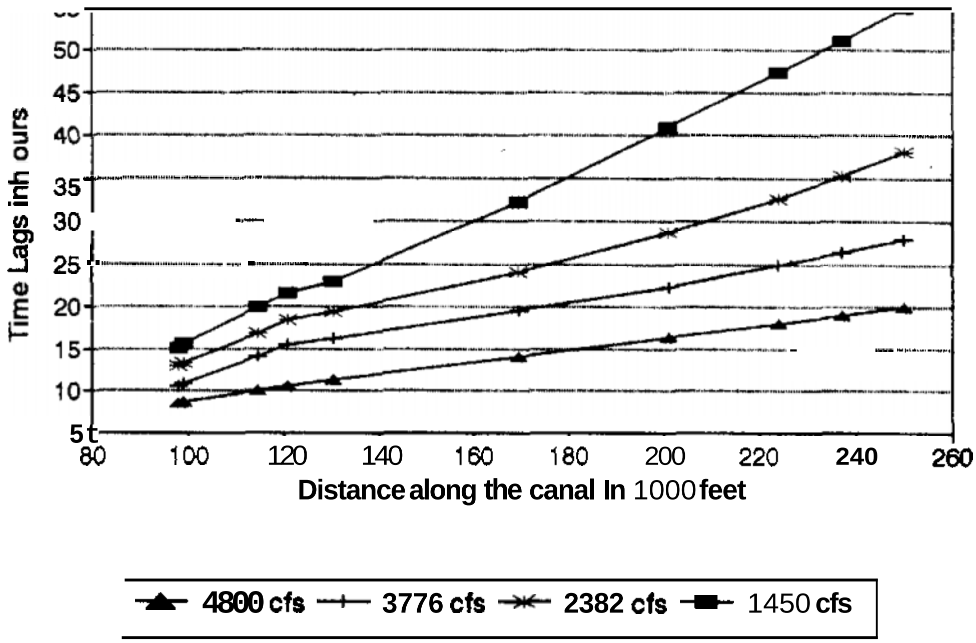


Figure III - 14

Achieved/Targeted Discharge Ratio Computed Adequacy of Water Deliveries

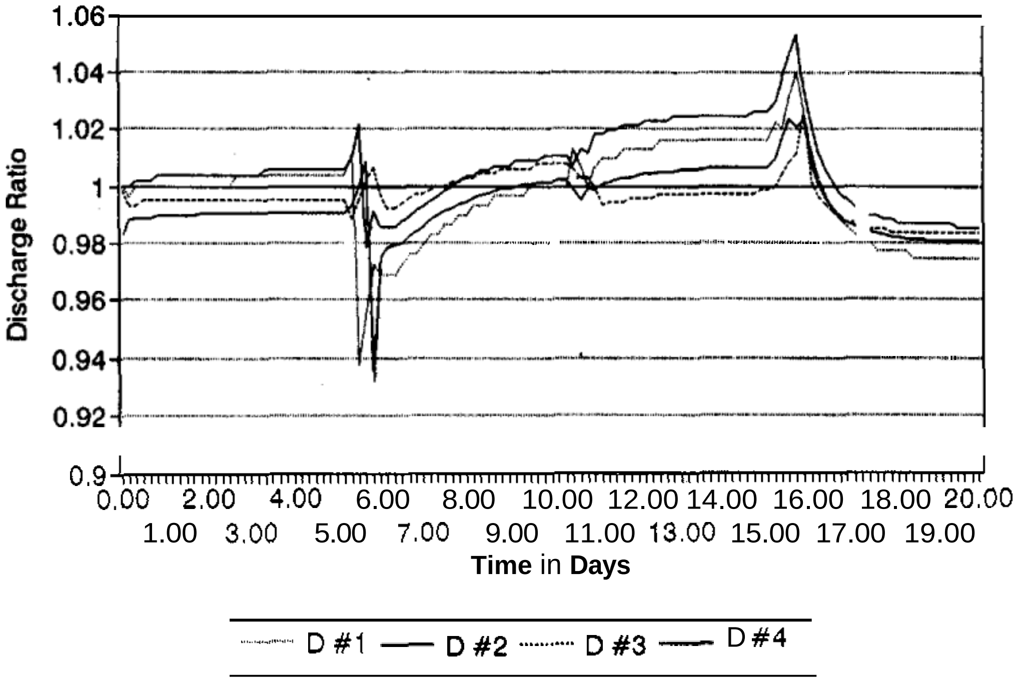


Figure 111-15 summarizes three head-discharge runs and their impact on outlet discharges as a percentage of design discharge. It will be noted, for example, that for 100 % head discharge, the outlet's variations range from 80 to 300 % of the design. Given that almost all outlet sizes are the same throughout the distributary, these variations can only be attributed to the large numbers of outlets in the distributary that function under submerged downstream conditions to various degrees.

The graph shows that it is possible to secure about 40 % discharge (the estimated lowest crop water requirement) in all outlets if those that are currently withdrawing much more than their fair share are kept under control (imposed discharge at 36 % of design) and stop-logs are used to raise head elevations at critical points. It also shows that when the discharge at the heads of distributaries drops to 50 % of design, some outlets fall dry completely due to the lower water levels in the distributary.

In general, the results of the simulation exercise correspond quite well with the observations in the field. Predictions of the model as to the particular heights of stop-logs under several scenarios have already been confirmed in the field in cases where farmers have taken it upon themselves to raise the crest levels of existing structures with brick masonry. As may be expected these profile walls were not able to withstand the increased water pressure and collapsed soon after. The exercise also points towards the need to address the issue of the need for more permanent outlet structures in the system.

3.3.2.2 Open and Closure of Outlets

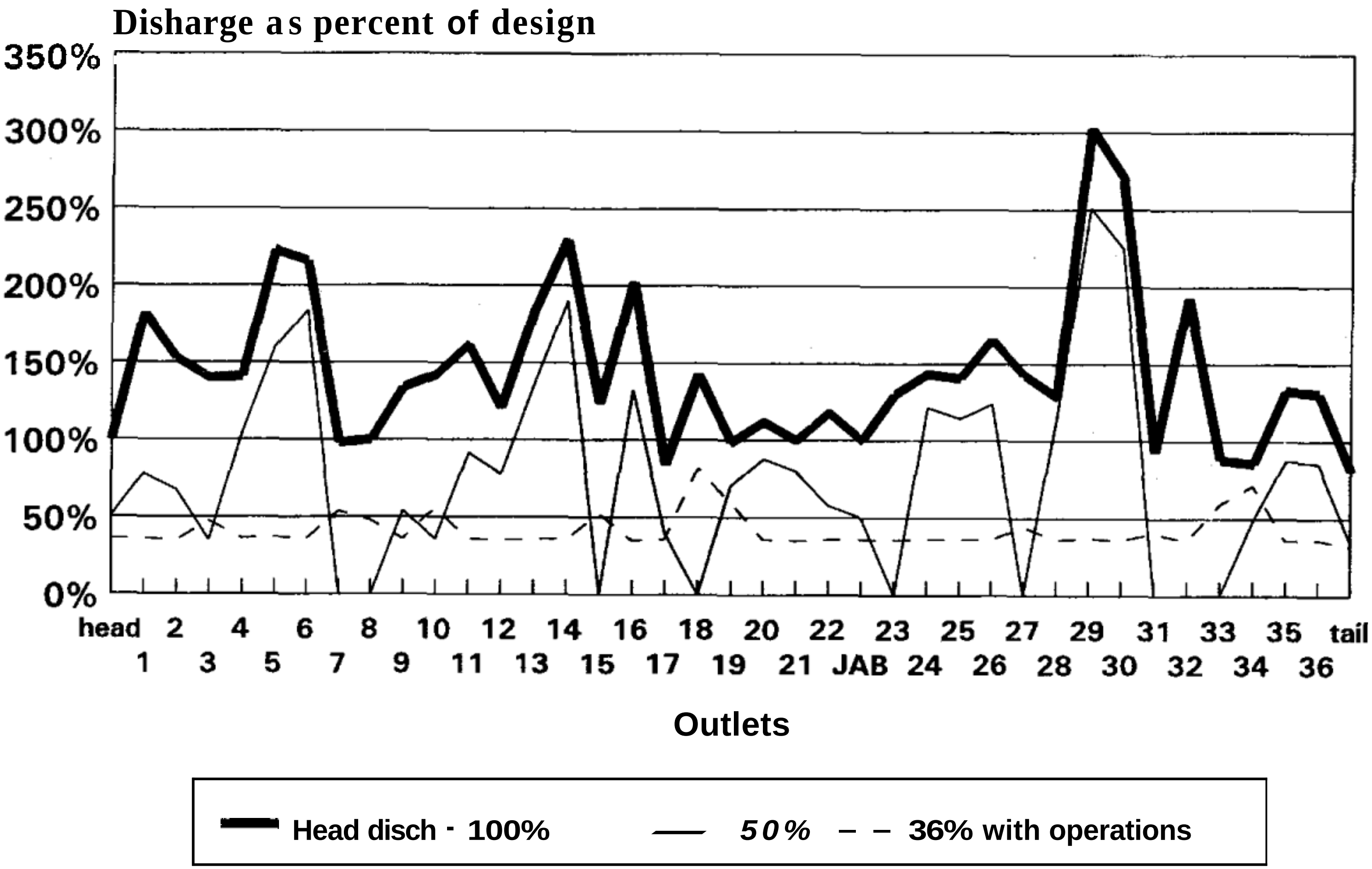
As has been already mentioned elsewhere, the opening and closure of outlets in the distributaries is a unique feature of the CRBC system. It allows the farmers to have a certain degree of control over the amount of water received. Herein lies the importance and the potential of this intervention -- being able to move towards a more flexible approach in system operation.

From interviews conducted with WAPDA's distributaries head-gate operators, it is clear that they are aware of this intervention and that sometimes they react by opening the head gates somewhat more in the morning and reduce the gate opening again a number of turns in the afternoon coinciding with the farmers open/close outlet behavior.

When the farmer faces an excess amount of water, he responds with any (or combinations thereof) of the following decisions:

i) Stop night irrigation (short-term response);

Figure 111-15
SIMULATION OF OUTLET DISCHARGES UNDER DIFFERENT OPERATIONS: DISTY # 4-CRBC



ii) Close the outlet when he thinks that water is no longer required by the crop (short-term response); and

iii) Change the cropping pattern and cropping intensities to match the available supplies (long-term response).

With the model, the same pattern of opening and closure of outlets was simulated. Two scenarios were considered for distributary # 3: a) keeping the head discharge constant for **24** hours, and b) the head discharge was lowered at night and increased during the day. Half of the outlets were kept open constantly, the other half were opened one-by-one between 5:30 and **9:00**hr, and closed again between noon and 19:00 hr.

The result of the two scenarios are shown in Figure 111-16:

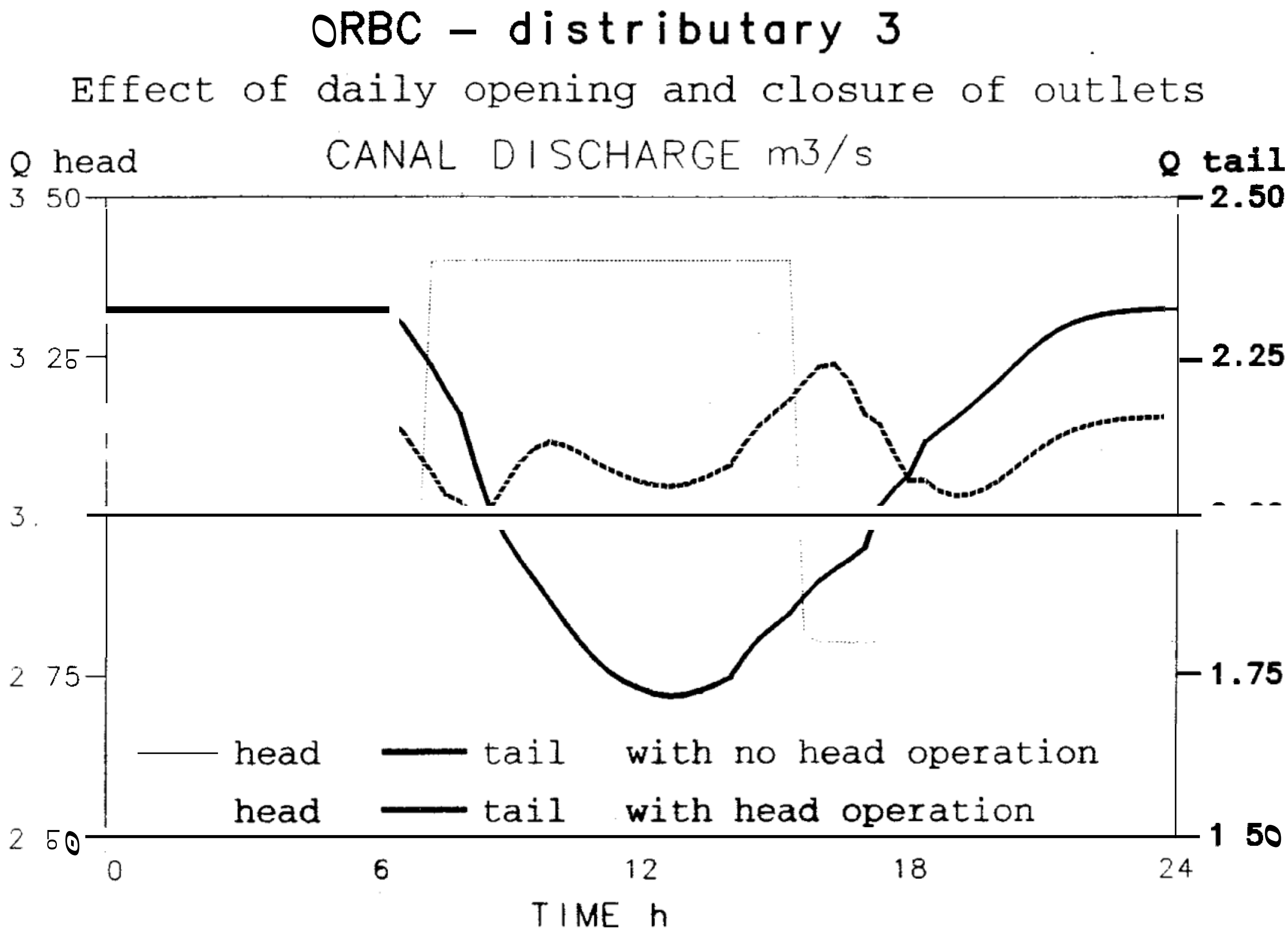
a) A constant head discharge of 3.0 m^3/s produces a large daily fluctuation at the tail (a similar result was observed at the tail of distributary # **4,** though larger in amplitude, under a simulation conducted for that particular canal); and

b) The fluctuation at the tail is reduced when the head discharge is lowered at night to 2.8 m^3/s and increased again during the day from 7.00 to 15:30 hr to **3.4** m^3/s.

Field observations showed that on average about one-quarter of the outlets are closed at night and opened again during the daytime. To stabilize conditions at the tail, the head discharge should be increased by about 15 % during the morning; the rest of the day and at night the discharge can be less than the continuous requirement. The effect of this kind of distributary head operations on the main canal, once it is fully developed, would need to be carefully checked. Presently, there is no problem because the cross regulator and the escape at the end of Stage 1 provide sufficient operational flexibility.

The simulation studies conducted at the distributary level can be considered as very preliminary because this effort came towards the end of the study and was relatively modest. Any further work along these lines should really consider the various impacts that the operation of the stop-logs and drop structures can have on the supply availability at individual watercourses heads. In addition, some simulation should be done to explore the potential of different type of outlet structures to be finally install in the CRBC system.

Figure III-6


ORBC – distributary 3
Effect of daily opening and closure of outlets
CANAL DISCHARGE m3/s
Q head
Q tail
3 50
3 25
3.
2 75
2 50
2.50
2.25
1.75
1 50
head
tail
with no head operation
head
tail
with head operation
0
6
12
18
24
TIME h

3.4 Lessons Learned from CRBC Simulation Study

This section summarizes the results from the simulation model studies and the lessons learned from this experience.

* The comprehensive study of the main canal has demonstrated that a proper understanding of the hydraulic parameters (i.e. velocity, roughness coefficient, and Froude number) of an irrigation canal provides a very useful insight to canal managers on the physical and managerial problems of the system. This type of approach is particularly required for a new system where the physical and managerial modifications usually take place during the first few years of operations. Simulation of canal conditions and its behavior can provide valuable guidelines during this process.

* Existing uncertainties at both the conceptual and implementation levels regarding the operational mode of the CRBC system (crop based variable supplies vs supply driven continuous flows) indicate that the implications of the proposed operational procedures and the physical flexibility of the system should be considered more thoroughly at the planning and design stage. For the supply driven systems, the criteria have been established long ago (by Lacey and others) to maintain relatively stable velocities and water depths; while the critical values (or ranges) of these parameters for the systems designed for variable flows still need to be established. The flow range of 50 to 138 cumecs (1400-4800 cfs) planned for CRBC has not been hydraulically justified and constitute the most disputed issue regarding the operation of the system.

* The study showed the need to seriously consider the sediment, as well as the water, transport capacity of a canal. Especially for lined canals, only a few expensive solutions are available afterwards if the former issue is disregarded.

* The design of CRBC's (Stage-I) main canal and distributary channels is not appropriate, nor sufficiently flexible, to satisfactorily operate the canal at the minimum and maximum discharge limits required. At low flows, a substantial amount of water ponding upstream of cross-regulators is being required to feed the offlaking distributaries; this operation reduces the velocity to one-third of the design velocity, which results in heavy sedimentation upstream of the regulators. At high flows, although currently the discharge is not more than 70 % of the maximum design discharge, the main canal is already facing freeboard problems, which indicates that the actual capacity of the main canal is less than the design capacity.

* The simulation and analysis of the canal capacity, velocity, and optimization of the operations indicate that the factors responsible for the current deterioration should be checked and controlled to save the system from further decline. The major reasons for canal capacity related problems are:

  i) The existing rugosity of the lined section of the canal is considerably higher than the values used for the design -- average values obtained for the Manning's roughness coefficient are .018-.020 as compared to the design value of .016 that results in a 12-25 percent reduction in discharge capacity at full supply level, which is partially compensated by infringing on the freeboard;

  ii) Heavy sedimentation in the lined section has already decreased the cross-sectional area of the canal in several reaches, thereby further reducing the discharge capacity; and

  iii) Present canal operations are not optimized to yield the best velocities for enhancing sediment transport capacity -- although these operations are termed as "transitional", the situation has been worsening during the last seven years.

* During the major part of the year, all secondary channels in Stage-I are drawing more than the required water supply. But, during the low supply period, "equity" problems start arising, with some distributaries more affected than others by the low supplies, depending upon their structures and their position along the canal. The target of "equitable" supplies will become a much more serious challenge for the canal manager once all three stages are fully operating; (hence, no more extra water will be available for Stage-I except by reducing the discharge reaching Stage II and Stage III.

* There is a need to better control the water delivered to the secondary channels. For a system designed based on crop water requirements, the extra water is not only a wastage, but also harmful to the crops and can have a negative environmental impact on the area. Managers must have some better knowledge of the crop water requirements at different times of the year, so that the practice of preparing "Indents" (weekly water targets) can be more effectively pursued.

* An important and positive indication derived from the study is the potential for improvements through better managerial and operational control. Simulation of different scenarios has demonstrated concrete possibilities for improved system control and enhanced management.

* Daily monitoring and recording of water deliveries in the main canal and distributaries is an essential water management activity which cannot be avoided if sufficient water supplies are to be delivered throughout all of the three stages of the CRBC. Gated structures, designed to deliver a wide range of flows, require frequent operational input and quick response to special conditions like, rain, or less demand for water utilization downstream. Hence, a clear set of guidelines, including rating tables and specific instructions for each structure, should be prepared for the field operators.

* To appropriately manage a system like CRBC, a comprehensive operational plan needs to be prepared., even if based on approximate estimates for different values. Such a plan needs to clearly identify the process which should take place at different levels of management in order to simplify operational procedures, as well as provide guidelines for unusual operating events.

* At the distributary level, no gated control structures have been provided; however, distributaries # 3 and # 4 have good natural slopes and drop structures. The present practice of stop-logs is not an authorized procedure, To standardize the operational practices at the secondary canal level, there is a need to provide the proper control structures.

* The active manipulation of the outlet *moghas* by farmers is a unique feature of the system because most of the present "temporary" outlets have larger discharge capacities than required. Without the manipulation of both stop-logs and outlets, actual outlet discharges have little correlation with the design (maximum authorized) discharges. At full supply, there is considerable difference in the discharge drawing capacity of the outlets of the same size due to submerged downstream conditions. At low supply, some outlets go dry, while some can still draw much more than the design discharge. This points to the need for replacement of temporary pipe outlets by more permanent outlet strucutres.

* In conclusion, the abovementioned research results and their field verification indicate that the hydraulic model used during this study has the capacity to simulate and address the technical issues, as well as the operational practices, at each level of the system. Likewise, simulation of farmers practices indicated the potential of the model to handle operations at the tertiary level, which is also useful to canal managers.

Chapter 4

SUPPLY AND DEMAND OF IRRIGATION WATER

4.1 Supply

4.1.1 Source

The water source for the CRBC irrigation system is the mighty Indus, one of the major rivers in the world. The Indus Basin, the mainstay of irrigated agriculture in Pakistan, comprises the river Indus itself, the eastern tributaries of Jhelum, Chenab, Ravi and Sutlej, as 'well as the northern and western tributaries of Kabul, Swat, Haro and Soan. With an average yearly inflow of **75.3** billion cubic meters, the river's basin commands roughly 11.3. million (M) hectares of the 16.8 M under irrigation in the country. The Indus Basin Project, a system of major works comprising the Mangla and Tarbela dams, link canals, barrages (like Chashma) and drainage works, constitutes, in fact, the largest contiguous irrigation systems in the world.

The monthly flows of the Indus River at the Chashma Barrage (offtake point), when compared with the flows required by CRBC, indicate a water supply several magnitudes greater than required for **CRBC.** Thus, the water resource is not a limiting factor at all. The fact that the Chashma barrage has a storage capacity of **0.87** billion cubic meters, already far in excess of project requirements, coupled with an Indus River 80 percent probability inflow of 63 **4** billion cubic meters, seems to assure that the water source will not be a constraining factor in the operation of the system

4 1.2 Flows

The core of the supply-side of the irrigation equation is, of course, the actual flows or water provided by the irrigation system. This is particularly true under the climatic conditions of the study area. **As** it will be shown later, rainfall contributes only marginally for satisfying crop water requirements.

In order to obtain a sense of actual water distribution within Stage I of CRBC, this study monitored daily discharges in several distributaries in this canal reach. While the emphasis was placed primarily on Distributaries # 3 and # **4,** daily flows were also collected for distributaries **# 1** and **#** 2. In addition, for Distributaries **#** 3 and # **4,** flows were also monitored in selected outlets. The general physical characteristics and flow pattern during the study period is presented below, succinctly, for each of the canals monitored.

Distributarv # 1. This distributary serves new agricultural land commanding an area of about 1,180 ha (2,915 ac), which is mostly under-developed, particularly at the canal's head reach where sandy soils at relatively high elevations create water delivery problems A combination of the canal's poor command and the difficulties of developing the area accounts for the low area under rice cultivation in this zone, as compared to other areas in Stage I of CRBC

The head off-take with its relatively high sill elevation presents problems for main canal discharge deliveries, especially during low flow requirements (as discussed in Chapter 3 above) The distributary is brick-lined from'head to tail and runs parallel with the main caiial Its full supply discharge is 0.566 cumecs (19 69 cfs) drawn by 14 outlets, all of them on the left side.

Daily flows were monitored from December 91 to October 93, Figure IV-1 registers the flows as against target discharges as per the design cropping pattern. During the *Khanf* 92 season, flow deliveries were relatively low, especially in the beginning and end of the season due to higher than average rains during April and September.

In the *Rabr* 92/93 season, flows varied between 60 to 80 percent of the full supply discharge for much of the season. The distributary remained closed for a week in December 92 due to the construction of an escape at the tail to allow surplus water to be easily discharged into a surface drain. The distributary again stopped flowing for seven days in March 93 when the main canal was closed to facilitate removal of some scaffolding from a bridge constructed during annual closure.

Finally, during the *Kharif* 93 season flow variability was quite high as compared to those in *Kharif* 92 In the beginning of the season (April, May) flows varied from 30 to 90 percent of the full supply, while from June to September, the variation ranged from 80 to 90 percent for most of the period The distributary's daily supplies rarely reached the design discharges. The reasons for this can be attributed to both the lower area under command and less rice cultivation resulting in lower water requirements and hence demand

Distributarv # 2. This distributary serves both new and old areas The full discharge capacify is 1416 cumecs (49 25 cfs) for a command area of 2,016 ha (4,979 ac) served by 12 outlets in the new area and 2 minors at the tail providing water to the old Paharpur Canal area Most of the new area is under cultivation and has been well developed.

Flows were monitored for the same December 91 to October 93 period. Figure IV-2 presents the flows at the head gate of the distributary showing that flow variability is quite high in both the *Kharif* and *Rabi* seasons During *Kharif* 92, flows gradually increased from 25 percent of full supply in April to 120 percent in June-July and then decreased to about 40 percent towards the end of the season. The *Kharrf* 93 season,

Figure IV-1

Comparison of Daily-Q at Disty #1 Head
(91-92 vs 92-93)

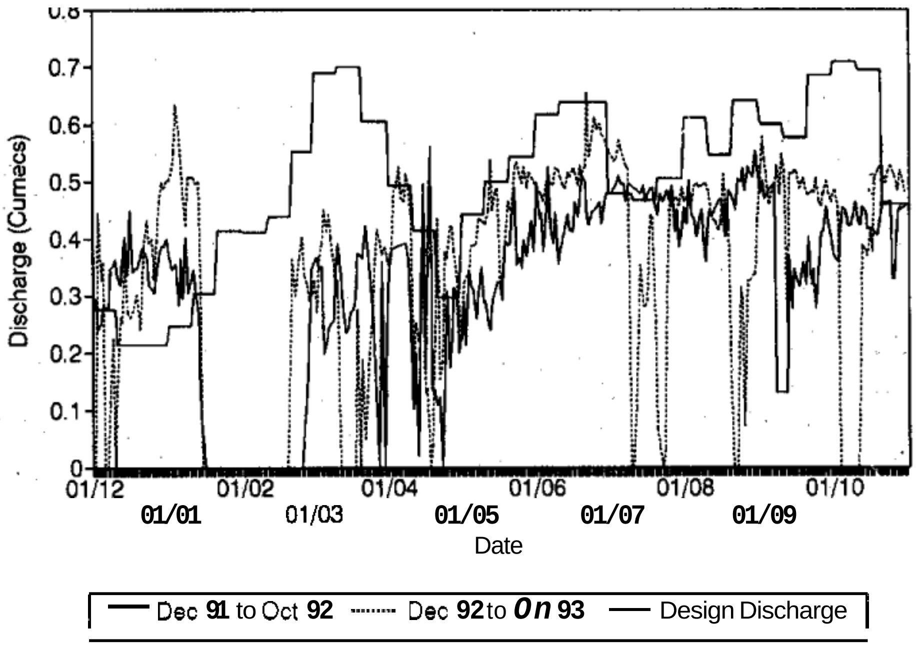
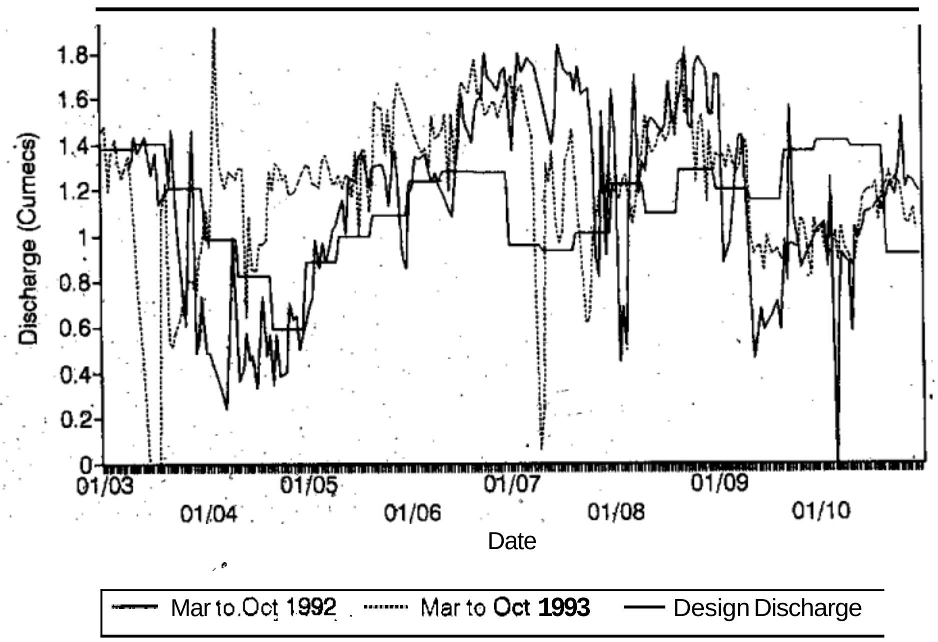


Figure IV-2

Comparison of Daily-Q at Disty #2 Head
(1992 Vs 1993)



on the other hand, shows comparatively less fluctuation but higher average flows; they ranged from 80 to 120 percent of full supply discharge The comparison of the two Khanf seasons data show that the supplies during 1993 were higher than in 1992, on the average a 5 to 10 % increase in daity flows has been noted

The performance of the distributary during the Kharif periods, as given above, suggest that daily supplies at the head were exceeding its upper limit most of the time. Under crop-based irrigation operations, the design upper limit will be required only during a 10 to 20 days peak crop water demand period; otherwise, supplies should remain below the design peak demand. Such high flows during the Kharif seasons are alarming as they can have a negative impact on future water availability in the lower stages, especially Stage III, of the CRBC irrigation system

In the case of the Rabr seasons, not enough information was gathered for the 91/92 period as field staff were only finally in place and operational towards the end of that particular period. However, data collected for the following similar period shows that the earlier half of the Rabr 92/93 season consumed less water than the second half with quite a significant difference For example, the distributary was operated at 20 to 60 percent of its full capacity during October and November, but at 60 to 90 percent in December when farmers normally over-irrigate to "fill-up" before the annual closure. The channel remained in high flow during March-April with the exception of a four day closure of the main canal for repairs.

Distributary # 3. This distributary commands a total area of 5,363 ha (13,247 ac), which includes 1,783 ha (4,404 ac) of new area served by twenty outlets while the remaining 3,580 ha (8,842 ac) are served by two older minors (Kech & Girsal) off-taking from the tail of Distributary # 3. The full supply design discharge is 3.20 cumecs (111.3 cfs) which is supposed to be evenly distributed among the two minors and the distributary channel proper, with each channel receiving one-third of the water supply. Thus, each channel is to receive 1.06 cumecs at full supply (36.9 cfs).

Flow variability was quite high in this distributary, especially in the Kharif seasons. One major reason for this variability is the larger than design capacity of the channel, which coupled with the availability of an escape at the tail-end, allows management to use the canal as a buffer. During the Kharif 92 season, flows fluctuated between 50 and 160 percent of the full supply design discharge. Flows between mid-June and. mid-September were quite high ranging from 100 to 160 percent of the design discharge. Because all of the new area is now well developed and the canal capacity is not a problem, farmers have been increasingly shifting to rice in both the new and 'old 'areas, confident that they can obtain the required crop water.

Likewise, during the Kharif 93 season, June and July received high flows of up to **140** percent of the full supply discharge, while August and the first-half of November drew

100 percent. In contrast, May and October received flows in the range of **40** to 60 percent of the design capacity (full supply discharge).

'As in Distributary # 2, the daiiy supplies at the head of Distributary # 3 exceeded the upper limits of design discharge during the *Kharif* seasons. However, a comparison of flows for 1992 and 1993 (and contrary to the situation found in Distributary # 2) showed a reduction of 5 to 10 % in the supplies at the head during 1993. While there is no solid evidence that this reduction in the discharge could be attributed to the presence of IIMI in the area, the fact is that the proposed flow reduction was part of the study's management innovation, which did take place in this distributary. Thus, it is worth considering that there was indeed some impact since other distributaries showed an increase rather than a decrease in flows during the same period.

The Rabi 92/93 season does not show any significant variation in flows except for November '92 and January **93** when it reached almost 100 percent of the full supply discharge. The higher values can be explained for November when the wheat crop requires its first irrigation after sowing; in January, when 90 percent of the command area is cultivated, every farmer wants to irrigate before the annual closure of the system, as explained earlier.

Figure IV-3 shows the flows during the period December 91 to October 93 when field data collection came to a close. The flows are compared against the crop water demand for the design cropping pattern.

<u>Distributary # 4.</u> This is the second largest distributary of CRBC and located at the tail of Stage **I**, serving an area of 9,683 ha (23,917 ac) corresponding both to new and old areas. There are 36 outlets and a minor to cover the new area and provides service to the older cultivated area by delivering water at its tail into the old Paharpur Canal now known as Dera Distributary. Distributary # 4 also has an escape by means of the Dera Distributary and, therefore, excess supplies do not represent a problem. Distributary # **4** has a design discharge of 5.94 cumecs (206.59 cfs).

Because the head off-take is so close to the end of Stage I, it is affected by the particular operation of the cross-regulator and escape structure located at the end of Stage **I**. The actual practice of ponding water at the tail reach of the main canal (for Stage **I**) results in small inflow fluctuations into the distributary, during specific periods of each cropping season, which are related to main canal operation.

For example, in the beginning of the *Kharif* 92 season, flows ranged from 50 to 60 percent, went up to 100 to 105 percent from mid-June to early August, and again remained fairly constant from mid-August to October when they went down to around **60** percent of the full supply.

Figure IV-3

Comparison of Daily-Q at Disty #3 Head
(91-92 Vs 92-93)

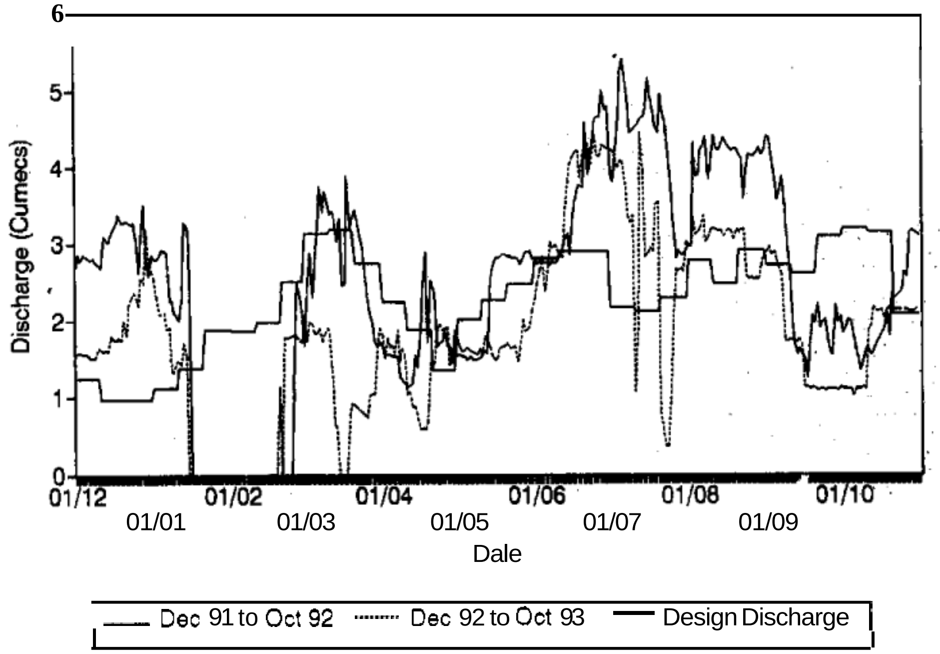
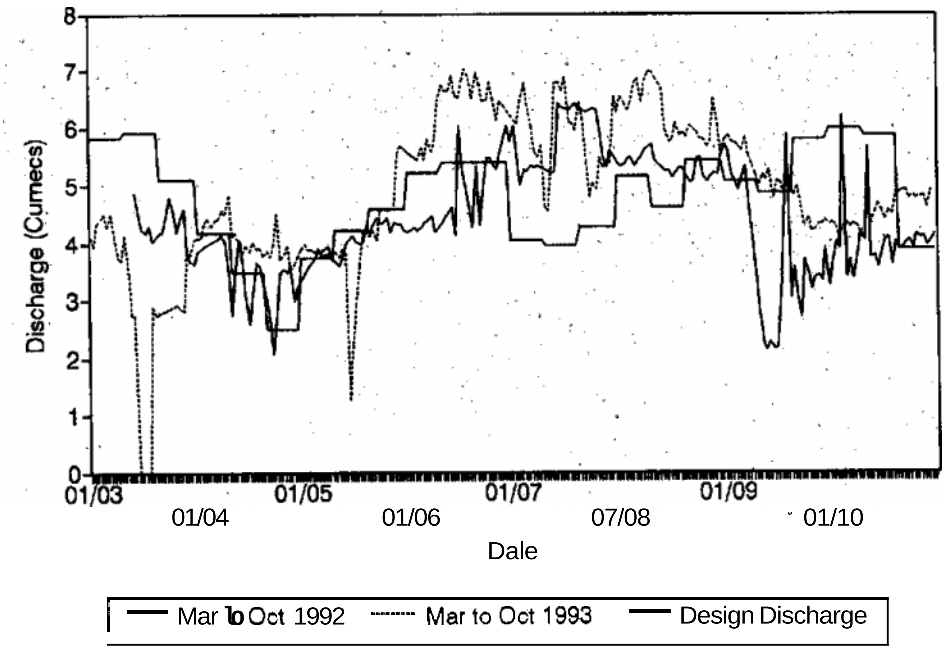


Figure IV-4

Comparison of Daily-Q at Disty #4 Head
(1**992 Vs** 1**993)**



Likewise, for most of the *Kharif* **93** season, the flows remained fairly constant around **11**5 percent of the full supply level. As in previous distributaries (with the exception of # **1)** flows exceeded the upper limits of peak water demands. Again, this draws attention **to** the potential water scarcity problem in the future. Also, a comparison of the two years of data shows a **16 %** average daily flow increase in the supplies during the **1993** season compared with the previous season, thereby reinforcing the likelihood of excessive water withdrawals during future years in the command area of Distributaries # **3** and # **4.**

Data collection for Distributary **# 4** did not get underway until March **92;** therefore, no monitoring was done for the ***Rabi*** **91/92** season. Related to the *Rabi* **92/93** cropping season, the canal was flowing in the range of 50 to **70** percent of the full supply. In general, water deliveries during ***Rabi*** were below deliveries during the *Kharif* seasons. Figure **IV-4** (see previous page) shows the flows situation for Distributary # **4** during the study period.

4 1.3 Rainfall

The climate of the area can be described as arid and hot. Therefore, agriculture is highly dependent on irrigation water. Accordingly, rainfall plays a relatively minor role as a factor in the supply side of the irrigation equation.

Precipitation is fairly uniform geographically, but with wide variations from season to season. The average rainfall for the **1961** to **1992** period, **as** recorded by the nearby D.I.Khan Meteorological Station, is only **250.44** mm **(9.86** in). The maximum rainfall periods, resulting from the summer monsoon, occur during the months of July, with an average for the same time period **1961-92** of **71** mm **(2.79** in), and in August with **67** mm **(2.40** in). On the average, rainfall has been less than **10** mm **(0.4** in) in the months of October, November, December and January.' Detailed rainfall data is provided in Volume III of this Final Report.

However, from an irrigation system's operational standpoint, this amount, particularly depending on its intensity, needs to be considered in relation to the safety of the canal network since it could become a factor in canal overtopping.

Considering rainfall as a component of the irrigation supply, a value ***of*** Effective Rainfall (ER) was utilized by taking **80** percent of the total precipitation. This is perceived as an appropriate value, commonly found in the literature for areas having a similar rainfall pattern. Furthermore, given the relatively low rainfall in the area, and considering other climatic factors like humidity and wind speed, would tend to make this chosen value an appropriate safety margin in the calculations.

4.2 Demand

4.2.1 Water Losses

An important and unavoidable component of the demand side for irrigation water is constituted by the water losses; these are normally divided into conveyance losses accrued at different levels of the system (like main canal, distributaries, and watercourses), plus the seepage and percolation losses on-field. This study excluded the measurements at the main canal level because there was already in place a monitoring program for that purpose being conducted conjunctively by WAPDA and ACOP, in addition, this particular type of loss had received sufficient attention during the design and construction phases of the canal. Thus, for this study, the overall value of 10 percent losses as utilized for the design of the main canal was used.

In any case, the treatment of water losses during thts study was considered of a preliminary nature. A limited number of measurements were made in order to establish orders of magnitude as guideline within the broader context of crop-based irrigation. Only if this concept is finally institutionalized by the GOP, would detailed water losses merit an in-depth analysis in order to fine-tune the demand for irrigation water

Water loss measurements in the watercourses were conducted during *the Rabi* 1991192 season For losses in the distributaries, measurements were made during the *Khanf* 1992 season The inflow-outflow method was used to calculate these losses in three watercourses of Distributary # 3 and two watercourses of Distributary # **4.**

Flow measurements in lined reaches were made using current meters at the begtnning and end of the lined section RBC flumes were used for unlined reaches by taking measurements at the head, middle and tail of the sampled sections. In most eases, seepage losses from the bed and sides of the channel, as well as overtopping, leakages and small flows through open field outlets, were taken into consideration.

The results showed that seepage losses from the lined reaches were in the range of 0 l/s per 1000 m^2 (0 mm/day) in well maintained watercourses to very high values of 8 l/s per 1000 m^2 (691 mm/day) in poorly maintained watercourses. In unlined reaches, the range of losses was from 5 to 10 l/s per 1000 m^2 (432 to 864 mm/day).

Given the small number of measurements eventually made, it was not possible to calculate seepage losses for individual watercourses However, by making certain assumptions based on the limited direct field measurements, and the values obtained from the literature, it is possible to derive a fairly reliable average value for **losses** in a typical watercourse of the sample area Using the following field data, this value will be derived as shown in the box below

CCA	110 ha
Design discharge	60 l/s
Actual discharge	75 l/s
Average watercourse length	2,000 meters
Average lining	500 meters
Length where most of seepage occurs	1,500 meters
Typical wetted perimeter	1.7 meters
Wetted area	2,550 m^2
Average seepage **loss** rate	*7.5* l/s per 1000 m^2
Total seepage loss	19 l/s

The 19 l/s value is equivalent to a seepage **loss** of 1.5 mm/day, if water is running day and night in the watercourse under'the conditions specified in the data presented above.

For the two distributaries, which are unlined, measurements were taken at the head and at the tail. For Distributary **#** 3, the discharge at the head was 1,870 l/s and the tail reading was 1740 l/s or 130 l/s less than the head discharge. There were 14 outlets between the two measuring points; out of these, 8 were fully closed, 2 were drawing **48** l/s and ***2*** were partially closed drawing 28 l/s. **A** flow of 30 l/s was also being pumped from a flooded field into the distributary during the time of measurements. Therefore, the total conveyance **loss** is determined as 70 l/s, or approximately 4 % of the incoming flow into the distributary.

In Distributary **# 4,** the discharges were 3,710 l/s at the head and 3,390 l/s at its tail, or a total difference of 320 l/s. Out of the 19 outlets located between the measuring points, 10 were completely closed and 9 were partially closed. The total measured discharge drawn by these outlets was 227 l/s. Hence, the conveyance **loss** was 93 l/s, or approximately 2.5 % of the incoming flow. The measurements are summarized in the table below.

TABLE IV-I WATER LOSSES AT WATERCOURSE LEVEL

Distributary Number	Head Discharge (l/s)	Tail discharge (l/s)	Distance between two points (m)	Depth (m)	Width (m)	Seepage losses in l/s per 1000 m^2
3	1,870	1,740	**4,570**	1	7	1.7
4	3,710	3,390	6,120	1	10	1.3

4.2.2 Crop Water Requirements

The crop water requirements per se represent the greatest share of the demand side of the irrigation equation. The water requirement of a crop is a function of the climatological conditions of the area in which'the crop is being grown, particularly as it refers both to the amount of water transpired by the plants, and the evaporation taking place in the surrounding soil. These two factors combined constitute the Crop Water Requirement (ETc) parameter required to asses irrigation needs of any crop during any time period. To determine the water requirement of each crop, the following basic universal equation is used:

$$ETc = Kc \cdot ETo$$

Where:

ETc = crop water requirement, (mm/period)
Kc = crop coefficient, (dimensionless)
ETo = reference evapotranspiration, (mm/period)

The reference evapotranspiration, or ETo, represents the potential evaporation of a well watered grass crop and its surroundings (i.e., a crop growing without any water-related constraints). The water needs of other crops are directly linked to this climatic parameter by means of the crop coefficient which is specific to each crop, but also varies with the physiological growth stages of each crop. Thus, for each crop, the crop coefficient varies with time according to the various growth stages. In line with the above, other information normally required pertains to the cropping pattern, crop calendar, length of growth stages (normally described as Initial, Development, Middle and Maturing, for the purpose of establishing ETc values).

Because the relationship described in the equation above is one of the most researched themes in the field of irrigation engineering, the study team decided to rely on the abundant information already available on the subject. This is particularly true in the case of the values needed on crop coefficients. While it would have been ideal to be able to determine the crop coefficient for each particular crop under the D.I.Khan climatic conditions, there has been a considerable amount of research done on this subject worldwide that has allowed the preparation of tables that can be used with a good degree of confidence in the absence of site-specific information.

In order to facilitate the calculations, the CBIO project has used the computer program CROPWAT, a software developed by the FAO to determine both crop water and irrigation requirements based on climatic and crop data[1]. Thus, the project used the appropriate Kc values taken both from the CROPWAT software program and CRBC project-related reports.

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[1] Food and Agricultural Organization. 1989. Guidelines tor Using **CROPWAT** in Planning Design and Management **of** Irrigation Projects. Land and Water Development Division. Rome.

For the determination of ETo, the CROPWAT program uses the Modified Penman Method (also known as the Penman-Monteith equation) which requires information on the following climatic data: average daily temperature, relative humidity, sunshine hours during the day, wind speed, latitude and altitude. This method has proven useful because, normally, these type of data are readily available from basic meteorological stations throughout the world. This proved true in the case of the D. I. Khan area. The monthly ETc values, based on actual cropping pattern, can be seen for distributaries # 3 and # 4 in Figure IV-5a and 5b, respectively. Notice that while the ETc trend is similar, as would be expected, for both areas there are some differences in the total values for particular periods accrued from the differences in the cropping pattern.

The climatological data for the D.I.Khan station was collected from the Regional Meteorological Center based at Lahore, which is responsible for data processing and analysis for that area of the country. The data used for the calculation of water requirements was based on different time series for different parameters available within a span of thirty-one years (1961 to 1992). In the particular case of the rainfall, an average fos 30 years was utilized assuming 80 % as the effective rainfall. This is a reasonable assumption for rainfall below 100 mm/month, which is the normal pattern in the area of study. [For further discussion on climatic data: the reader is referred to Volume. III of this Final Report.]

For information on the cropping pattern, actual crop surveys were undertaken in the sample watercourse already indicated earlier in the report. In Figure **IV-6** one of these *chakbandi* maps is shown for Watercourse 6468-L of Distributary # 3; in this particular case, the cropping pattern pertains to the *Rabi **92*** season.

While the precision of the information obtained under the crop surveys is beyond any doubt, it should be understood that this type of work can only be accomplished in a research setting; IIMI has no expectation that such a detailed ---although unsophisticated--- work could be the norm for an irrigation agency. Therefore, the *Khasra* data[2] was collected from the ID and used in the estimation of crop water requirements for comparison with sampled areas and in other distributaries outside those areas studied. Not unexpectedly, considerable discrepancies were found between the PID and the detailed survey information which was the source of friendly disagreement between different actors involved in the study.

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[2] This is the Provincial irrigation Department's official cropping pattern information for a particular area within an irrigation system; and utilized solely for revenue purposes. Unfortunately, this information only becomes available after the cropping season has ended and therefore its use in the context of crop-based irrigation is rather limited.

Figure IV-5a
Monthly Crop Evapotranspiration (ETc)
Actual Cropping Pattern in Distry # 3

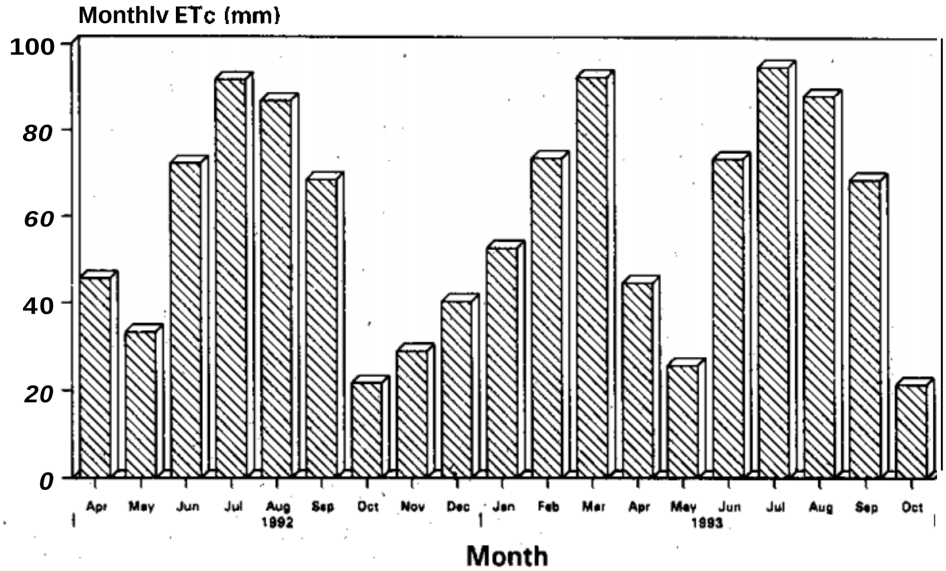


Figure IV-5b
Monthly Crop Evapotranspiration (ETc)
Actual Cropping Pattern of Disty # 4

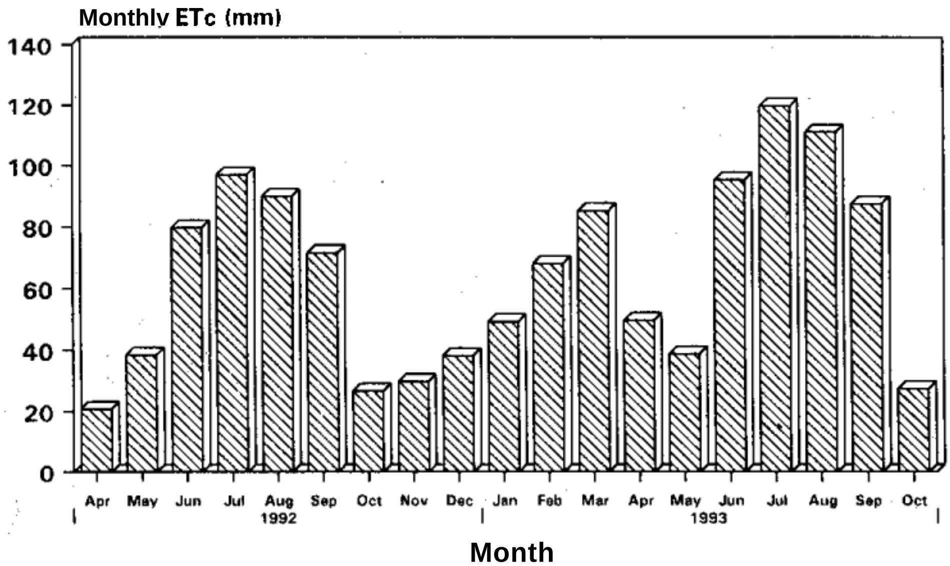
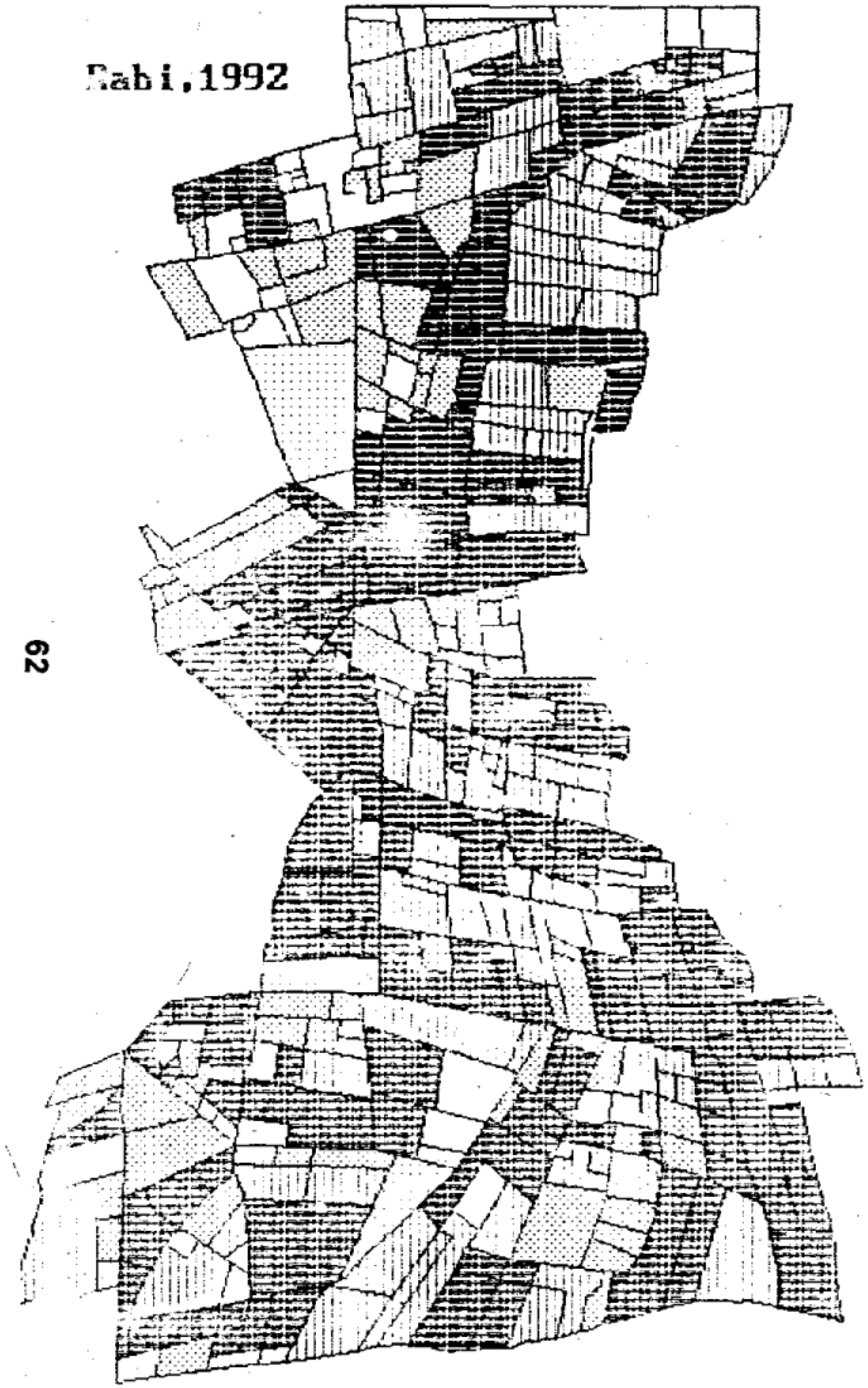


Figure IV-6

Chaphma Right Bank Canal
Distributary No. 3

Predominant Crop Census for Watercourse No. 64681



- Barren
- Grams
- Fodder
- Sugarcane
- Vegetables/Oilseeds/Others
- Wheat
- Fallow

With both cropping intensities and cropping patterns shifting from the originally designed vatues, as has been amply documented and observed during the study period, the crop water requirements for particular areas will likewise experience modifications, thereby having a significant impact on system operation. These changes and their impacts are analyzed more in-depth in the subsequent chapters under the sections dealing with: (1) agricultural production; and **(2)** the performance of the irrigation system.

4.3 Supply-Demand Relationship

The previous two sections provided the details of the two sides of the irrigation equation: the supply to be delivered and the demand to be fulfilled. In this section, the intent is to bring these two parameters together and relate them to the principles of crop-based irrigation operations. Furthermore, implications will be drawn for the future sustainability of the CRBC Irrigation System in view of the present relationship of the two variables.

On the supply side, the data shows that water is being delivered with little consideration to the needs of the crop. Other factors related to the hydraulics and safety of the irrigation netwark have by far taken preference. While the importance of the latter is not in dispute, it should not be the sole consideration as it does have implications towards obtaining the ultimate goal of the project, which is the establishment of a crop-based irrigation operations in the CRBC. In general, more water than needed is being delivered throughout the network. The main reason for the over-deliveries is related to the lack of water control at strategic points since no calibration of structures is in-place. Therefore, water cannot be measured or monitored with any degree of precision.

The lack of water control notwithstanding, there is evidence that project managers do make an effort to adjust to the general farmers' cropping practices in the field. This is observed by the relatively higher water deliveries during the ***Kharif*** season compared with the *Rabi.* Another indication is the response to rainfall, when flows in the network are reduced, or the fact that flows are diminished during the late afternoon accounting for the lack of night irrigation. But these responses are done outside the context of crop-based irrigation.

Analysis of the demand-side data shows that there has been a significant departure from the designed crop water requirements. The shifts in cropping patterns and intensities are addressed further below; however, from the water perspective, the changes have repercussion on the operation of the system. The peak water requirements have "moved" and set the stage for potential water shortages in the near future. Also, there are serious implications for the on-going design of CRBC Stage III. Not only can the design ***per se*** of the canals be affected, but the water allocation among the two provinces would need to be reviewed with all the political consequences this might entail.

In Figure IV-7, a comparison of design and actual crop water requirements is provided for the head of Distributary **# 4.** The peak water requirement can be observed shifted from October, under the design projections, to July under actual existing conditions in the area. The difference is related, of course, to the larger areas under both rice and sugarcane. However, it should be noted that the total crop water requirement has not changed significantly between the two cropping patterns. This is to be expected as the potential evapotranspiration in the area would remain fairly constant.

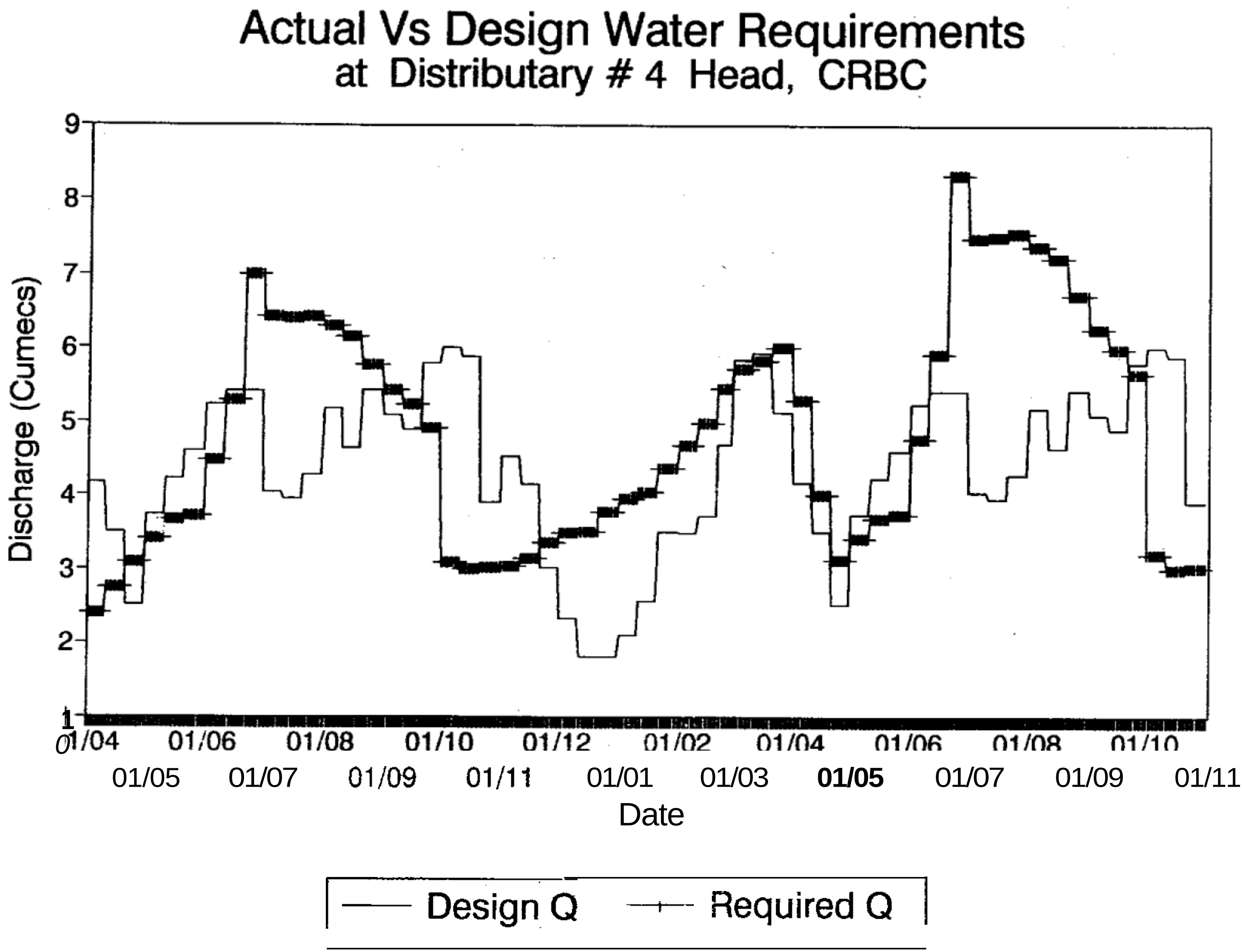
By taking the analysis one step further, it was possible to determine the impact that the present supply over-deliveries, coupled with the relatively significant shift in the cropping pattern (and hence in the demand), would have 'on the systems' short-term sustainability.

A series of scenarios were developed where the management (in terms of the response to water allocations), the operation of the system (in terms of water deliveries), the demand for water (in terms of different crop combinations), the "leaks" in the system (in terms of water losses in the system), and farmers response (in terms of opening and closure of outlets) were assigned different degrees of importance. The end-product was to determine the impact on the potential water availability for each stage of the CRBC under each set of conditions.

While it could be argued that this type of exercise involves a good deal of subjectivity and therefore weakens its use in reaching decisions, the two years of field work provided enough information and insight into the actual behavior of the system in a way that predictions can be made with a fair degree of accuracy regarding the consequences for the various scenarios.

In Figures IV-8a and IV-8b, one such scenario is .depicted related to the present command area of Distributary # 4. Assuming that management will continue the current pattern of water allocation decision-making, and therefore that supply deliveries will remain at the present higher levels, and using the information on water losses, cropping pattern trends and farmers response observed during the last two years, the daily volume of water required per unit area was calculated. This Q vs **A** relationship is shown in Figure IV-8a. If the entire CRBC system were to be operated under the present conditions being observed in the Distributary # **4** command area, not enough water would be available in the system to irrigate the entire area to be commanded by Stage III. The figure shows that the entire areas under Stage I and II would be serviced. However, no less than 50,000 hectares (133,500 ac) in Stage III would be deprived of the irrigation service. The economic and financial implications of this scenario are staggering. Furthermore, the fact that this entire "dry" area is located in the Punjab Province raises some serious' political concerns.

Figure IV-7



Actual Vs Design Water Requirements
at Distributary # 4 Head, CRBC
Discharge (Cumecs)
9
8
7
6
5
4
3
2
1
0
01/04
01/06
01/08
01/10
01/12
01/02
01/04
01/06
01/08
01/10
01/05
01/07
01/09
01/11
01/01
01/03
01/05
01/07
01/09
01/11
Date
Design Q
Required Q

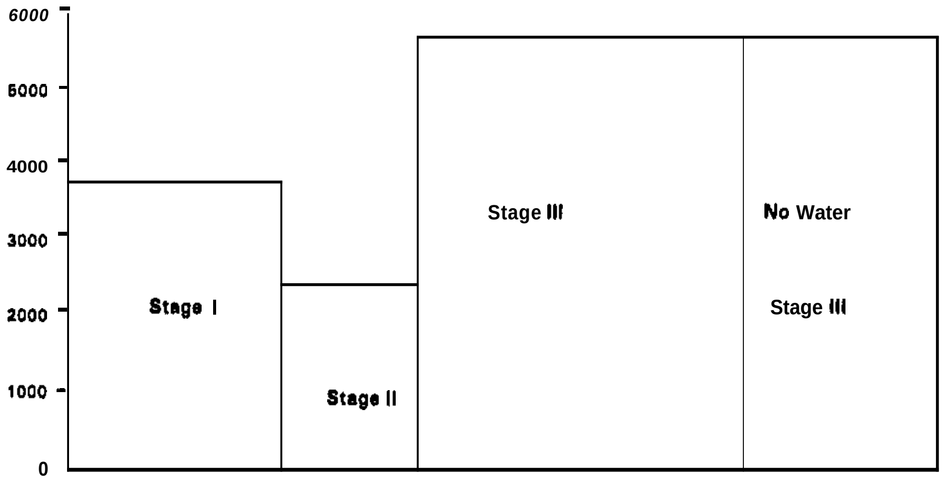
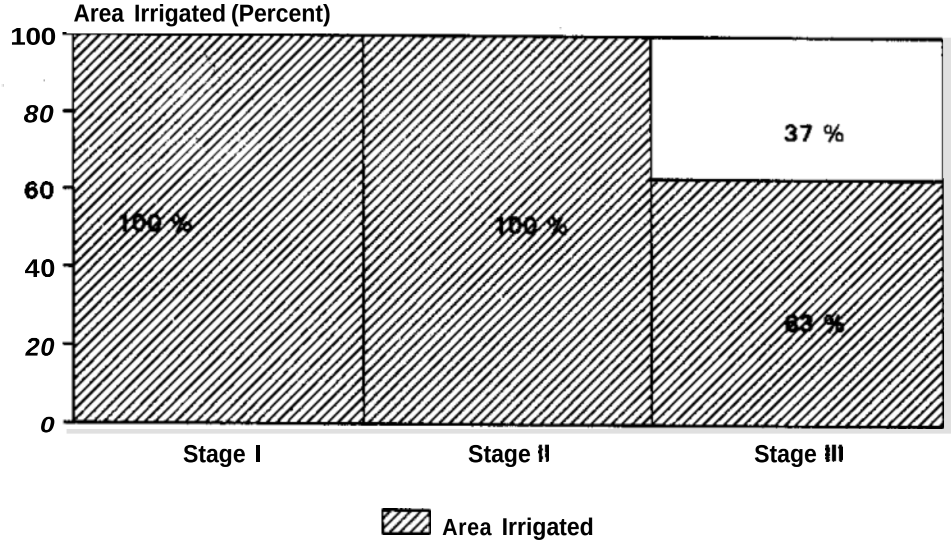


Figure IV-8b

Potential Water Shortage in Stage III
Percentage Area Irrigated by Stage
Actual Cropping Pattern of Disty # 4



In Figure IV-8b, the same information above is given in terms of percentages. While 100 % of Stages I and II can be serviced, 37` % of the area under the forthcoming Stage III would have no water at all. It should be noticed here that because of the relative sizes of the various Stages of CRBC, the area under potential water shortage in Stage III is almost equivalent to the combined area of Stages I and II.

Using combinations of the various parameters, water shortages in Stage III, in terms of percentage, range from 5 to 37 %; the latter situation corresponding to the example just given above. A different scenario that was conceived using improved operating and management conditions and following the cropping pattern of Distributary # 3 resulted in a 10 % shortage of water for Stage III. While this is a much better perspective for the future, it nevertheless entails considerable accountability in water distribution, a condition not yet available in the system. System management should be aiming towards this short-term goal.

However, regardless of the actual percentage of the area that would be affected, the lesson derived from the simulation exercise is one that points to the need for improving the present overall performance of the system. This is **a** challenge that needs to be resolved before further serious consideration can be given to the idea of moving towards a crop-based irrigation operation approach in the CRBC irrigation system,.

Chapter 5

FARMERS PRACTICES AND AGRICULTURAL PRODUCTION

5.1 Watercourse Management

5.1.1 Flexibility

As stated earlier, the higher water allowances given to the two systems (0.60 l/s/ha for CRBC and 0.77 l/s/ha for LSC, as opposed to the traditional 0.21 to 0.28 l/s/ha), provides greater flexibility in overall system operations. However, the effective use of this flexibility would largely depend on how the increased supplies are managed at the tertiary level of the system. In this regard, the way farmers share their water supplies and how they use this water to irrigate their fields become two critically important issues. A study activity was carried out in selected sample watercourses in the CRBC and the LSC irrigation systems to understand the tertiary-level water distribution and management practices prevailing in the two systems. Particular attention was paid to how the farmer's irrigation practices relate to, and are constrained or facilitated by, the existing water rights and water distribution methods. In the following paragraphs, only the results of study activities in the CRBC are reported, since LSC work was already fully reported in Progress Reports # 2 and # 3.

With one watercourse selected from each quartile of the distributary or minor, the study sample included 12 watercourses from Distributaries # 3 and **# 4** of the new CRBC Stage-I area, and Girsal Minor of the old Paharpur canal system. In each selected watercourse, a sample of *6* farmer respondents representing head, middle and tail portions of the watercourse were interviewed and their irrigation practices were observed. The total sample size thus obtained was 72 farmers well distributed throughout the study area. Field observations and interviews with farmers and agency staff were supplemented by a literature review to understand the irrigation traditions prevailing in the study areas.

The analysis of field data collected during this study shows that the increased water supplies so far made available to the project areas have brought about a fair degree of flexibility in water distribution at the watercourse level. This flexibility can be seen in three principal farmer practices observed in the study area:

(1) Farmers in the study areas under the CRBC system do not follow any official *warabandi* schedule:

(2) They close and open distributary outlets at their own discretion, depending on their water needs; and

(3) They exchange, lend, borrow and trade their water turns

These aspects of flexible behavior are deviations from "normal", or officially recognized, water distribution practices in Pakistan, which points toward the fact that farmers are already engaged in some de facto crop-based irrigation management at the watercourse level.

5.1.2 Deviations from Warabandi

Theoretically, an overall shortage of the water supply forms the basis for the official warabandi water distribution method, and the primary objective of the warabandi system is to distribute this restricted supply in an equitable manner. For warabandi to be practiced according to this main objective, certain conditions have to be satisfied. These conditions include, among others: (1) that the main and distributary canals should operate, at least, at 70 % *of* the full supply level; *(2)* only "authorized" outlets draw their allotted share of water from the distributary at the same time; (3) the outlets be un-gated and kept open all of the time in order to deliver a flow rate proportional to the area commanded; and **(4)** each farmer receives the total allocated flow of the watercourse for a duration proportional to his own area. With increased water supplies in the two systems, there seems to be no felt need of ensuring that these conditions are met for sharing water supplies equitably using strict warabandi schedules.

Field investigations during the 1991/92 Rabi season found only one official Pucca Warabandi drawn up by the Irrigation Department, which was for Outlet No. 19248-L served by Distributary **# 4.** For other outlets, farmers had called upon the local *Patwaris* to assist in the drawing up of their unofficial *warabandis*, and this process continued. Of the 8 sample watercourses in Distributaries # 3 and # **4,** warabandi of some sort had been drawn up only in 5 watercourses, whereas in the remaining 3 watercourses, ad-hoc arrangements had been agreed upon by the farmers for sharing the irrigation supplies. The decisions for these ad-hoc arrangements seemed to have been taken by the influential farmers within the watercourse command area. In the old Girsal Minor, all **4** sample watercourses had an official warabandi. Details are shown *in* Table V-1.

TABLE V-1 TYPE OF *WARABANDI* AND WATER ALLOCATION FOR 12 SAMPLE WATERCOURSES IN THE CRBC SYSTEM.

Distributary Or Minor	Watercourse	Weekly Average Water Turn Allocation (hrs/ha)	*Warabandi* type
# 3	570-L	2 12	Unofficial
# 3	6468-L	1 34	Unofficial
# 3	10250-R	2 32	Unofficial
# 3	14810-R	1.90	Unofficial
# 4	1860-R	No *Warabandi*	
# 4	8980-L	No *Warabandt*	
# 4	16512-L	No *Warabandi*	
# 4	28448-R	1.35	Unofficial
Girsal	5767-L	3.15	Official
Girsal	21516-L	3 67	Official
Girsal	24046-L	5.44	Official

A rapid appraisal during 1992 *Kharif* season, following up on the *Rabi* season's observations, found that, by then, the farmers had called upon the local *patwaris* to assist in the drawing up of their unofficial *warabandi* for most of the watercourses; in a few cases, the official *warabandi* schedules had been issued. However, in most areas, the process was still underway. In both sample Distributaries (#s 3 & 4), there were only 2 outlets, numbers 19248-L and 7670-L both under Distributary # 4, for which official *Pucca warabandi* had been drawn up by the Irrigation Department. However, due to excess water supply, these *warabandi* schedules were redundant, and

the farmers returned to the practice of the unofficial warabandi which was drawn up with mutual cooperation among the farmers. Under Outlet No. 1860-R, an official warabandi was in the process of being drawn up because there was a dispute among the farmers regarding water distribution. All the paper work had been completed and only the approval of the Executive Engineer was required. However, this process was abandoned when the dispute was resolved; all the farmers agreed to follow the unofficial warabandi already being practiced.

In many watercourses of CRBC Stage I, no official or informal warabandi has yet been fully established. Water distribution methods are still evolving. In the present context of abundant water supplies during most of the cropping season, farmers make no formal request for an official warabandi. For the same reason, even in the few watercourses where an official warabandi had been developed as a result of rare water disputes that had emerged and then formally presented to the authorities, the need to follow the drawn-up distribution schedules had not been felt by the farmers.

Thus, according to the observations during the study period, water distribution in the two sample distributary commands can be described as being in a state of flux. This can be attributed to several factors. Changes were still being effected in the physical infrastructure, and the farmers lacked experience as water users. Keeping in line with the normal practice, initially only the pipe outlets had been provided in this newly developed area, so that they could later be converted to properly built (*Pucca)* outlets after the farm layout (*Chakbandi*) was fairly stabilized. Some of these outlets were being relocated at the request of the farmers, to better command the area. A new minor, Jabbar Wala, on Distributary # 4, was under construction to better serve the area, which included, among other things, transferring the irrigation of some areas from Distributary # 3 to Distributary # 4.

The evolutionary process for establishing water distribution schedules in the CRBC Stage-I area is illustrated by the pattern observed in Watercourse No.14810-R of Distributary # 3, which is shown in Table V-2.

TABLE V-2 BROTHERHOOD *WARABANDI* FOR OUTLET NO. 14810-R OF DISTRIBUTARY # 3.

FARMER GROUP	NO. OF FARMERS	AREA IN KANALS	AREA IN HECTARES	WATER TURN (HOURS)	AVAILABILITY OF WATER PER HECTARE (HOURS)
1	3	350	17.71	31	1.75
2	8	480	24.28	45	1.85
3	9	921	46.59	92	1.97
OVERALL	20	1751	88.58	168	1.90

Brotherhood *Warabandi* for Outlet No. 14810-R - Group 1

FARMER SUB-GROUP	NO OF FARMERS	AREA IN KANALS	AREA IN HECTARES	WATER TURN (HOURS)	AVAILABILITY OF WATER PER HECTARE (HOURS)
1	1	150	7.59	21	2.77
2	2	200	10.12	10	0.99
OVERALL	3	350	17.71	31	1.75

Brotherhood *Warabandi* for Outlet No. 14810-R - Group 2

FARMER SUB-GROUP	NO. OF FARMERS	AREA IN KANALS	AREA IN HECTARES	WATER TURN (HOURS)	AVAILABILITY OF WATER PER HECTARE (HOURS)
3	3	108	5.46	10	1.83
4	3	72	3.64	9	2.47
5	1	150	7.59	14	1.85
6	1	150	7.59	12	1.85
OVERALL	8	480	24.28	45	1.85

Brotherhood *Warabandi* for Outlet No. 14810-R - Group 3

FARMER SUB-GROUP	NO. OF FARMERS	AREA IN KANALS	AREA IN HECTARES	WATER TURN (HOURS)	AVAILABILITY OF WATER PER HECTARE (HOURS)
7	4	625	31.62	92	2.91
8	1	100	5.06	0	0.00
9	1	24	1.21	0	0.00
10	1	100	5.06	0	0.00
11	1	36	1.82	0	0.00
12	1	36	1.82	0	0.00
OVERALL	9	921	46.59	92	1.97

Initially, the time for each turn was fixed on the basis of three groups within the total of 20 farmers in the watercourse, probably as decided by some influential farmers. Subsequently, each group further distributed the time available to them among its members by their mutual consent. The average time turn for a farmer of this watercourse should be **1.90** hours per hectare on the average, but eventually, in the process of sharing the turns by each of the three groups, substantial inequity evolved. The farmers who were not receiving any water in the third group were later accommodated in the adjoining watercourse. Unless a dispute arises, and a specific request is made to the Irrigation Department authorities, this ad-hoc schedule of turns is likely to persist. Otherwise, after several seasons of this practice, further refinement might be made to this schedule by mutual agreement, and the turns could be fixed on an individual farmer basis.

Field data indicated some differences between the two sample distributaries in this evolutionary process of establishing water distribution practices. Of the 20 watercourses along Distributary # 3, only 3 did not have some form of warabandi. The 17 with warabandi had all unofficial arrangements. In Distributary # 4, the picture was slightly different: out of 36 watercourses, only 14 had warabandi, 2 of which (7670-L and 19248-L) had official warabandi even if it was not strictly followed by the irrigators mainly due to an excessive water supply. One possible explanation for the difference in irrigation practices between the two distributaries is the relatively greater abundance of water in the watercourse commands of Distributary # 4 when compared with Distributary # 3, as reported by farmers[3]. Another explanation relates to the social characteristics; the population in Distributary # 4 being more diversified and with a higher proportion of recent settlers, have not yet been able to agree on a distribution schedule.

In Girsal Minor, official warabandi schedules determined by the Irrigation Department provide the basis for water distribution. At the tail watercourses, although the official warabandis have been drawn up after the remodelling, differences already appear between the design-stage and the current practices. For the last 5 tail watercourses, differences are observed due to soil erosion by the Indus River, which has resulted in a decrease in the culturable command area of these watercourses.

Most of the farmers have reported that water is in excess of their requirements during the Rabi season and that they are not keen about adhering to the warabandi. Thus, changes from whatever warabandi schedules they have commonly accepted frequently

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[3] Farmers perception of somewhat higher water allocations in Distributary # 4 as opposed to # 3 have been confirmed by IIMI's regulator flow monitoring data as discussed in Chapter 4 above. Of particular interest is the impact of water shortages on Stage III when projecting present management effects (see section 4.3).

take place d'uring the Rabi season. During the Kharif season, farmers cultivate a lower percentage of their land; again, they are not particular about following any strict warabandi. In all cases, the duration of the warabandi rotation, which is generally followed as a practice, was found to be 7 days. As no conveyance allowances are provided in the water turns, tail-end farmers reported receiving less water as compared to the farmers near the head of the watercourse. No farmer reported any dispute in the operation of. the present system. Apparently, the Chairmen of the Water Users Associations (which were formed during the watercourse lining program), who were usually the big landowners, or any other big landowner, intervened in the event of a dispute. Interviews with officials of the Irrigation Department confirmed this situation; they stated that there was no *pucca* warabandi for these new watercourses as there had been no formal request by any affected farmer, or farmer group, for the Irrigation Department to step in and lay down the official warabandi.

5.1.3 Closing and Opening of Outlets

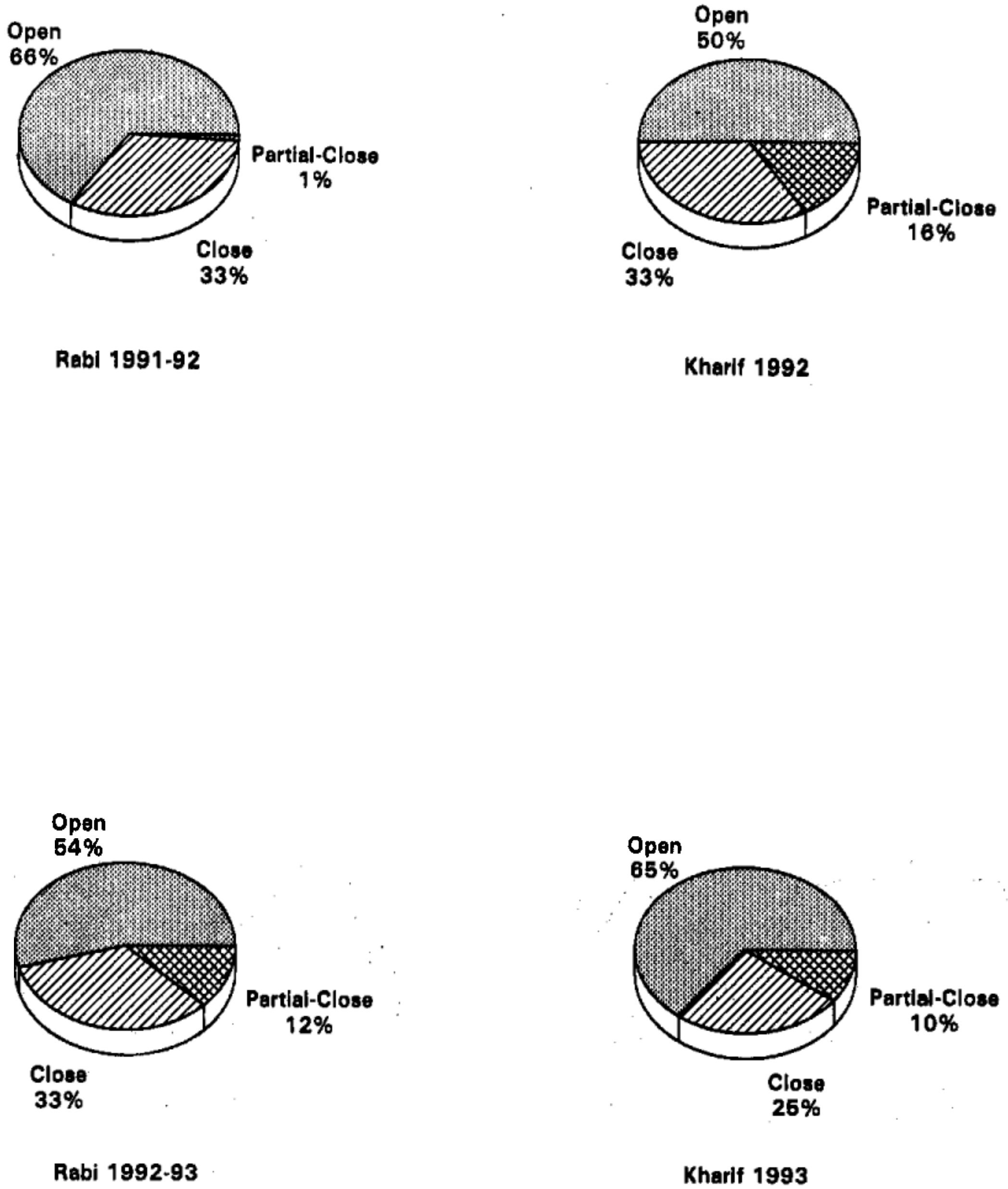
In the newly established CRBC Stage-I irrigation system, the absence of a *warabandi* practice is vividly demonstrated by the unusual farmer-behavior of closing and opening the outlets at the farmers' own discretion. This behavior appears to be wide-spread; 92% of the farmers interviewed in Distributary # 3, and 96 % in Distributary # **4,** have reported participating in closing their outlets, whereas, in the Girsal Minor of the older Paharpur area, the incidence was less, but still at 88 % of the farmers interviewed. Basically, the need to close the outlets is explained by the water supplies being much greater than the crop water requirements as assessed by the farmers. The incidence of outlet closure in the Girsal minor was substantially less, and could be explained by the presence of several escapes in the canal, which tended to reduce its flow level during times of excess water supply.

The number of instances during which the outlets were observed to be kept open, closed, or partially closed, was recorded for four crop seasons. Then results are shown in pie-chart form in Figure V-1

During the first period of observations, which was the 1991/92 Rabi season, the farmers appeared to be hesitant in closing their outlets as the practice was understood to be against Irrigation Department rules, but in the absence of any official reaction, they proceeded to stabilize a **"refusal system"'** in which the farmers closed the outlets whenever water was not needed. 'This development can be seen in the changes of this behavior between the 1991192 Rabi and 1992 Kharif seasons. The percentage of time the outlets were observed to be kept open decreased from 66 % in 1991192 *Rabi* to 50 % in 1992 Kharif, while during the latter period, farmers also resorted to closing the outlets partially 16% of the time during observations. However, the 1993 Kharif, which was conspicuously a water-short season, saw the farmers keeping the outlets open for

Figure V-1

OUTLETS OF DISTRIBUTARY # 3, CRBC
% OF TIME OPEN/CLOSE/PARTIAL-CLOSE



65 % of the time as against the 54 % during the preceding 1992/93 Rabi season, and the 50 % recorded in the 1992 *Kharif* season. Information given in Figure V-2, for the period January 1992 to June 1993, shows the pattern of the open and closure of outlets on a monthly basis.

Interestingly, the pattern of keeping the outlets open is seen to be very closely matching the crop water requirement for the particular cropping pattern (see Figure V-3). This suggests that, even in the absence of any formal arrangement for crop-based irrigation operations, the farmers on their own are managing the supply-oriented delivery system in a manner that water use seems to take into consideration the crop water requirements.

5.1.4 Variability

The allocation of water per watercourse, and per farmer, is an important factor that influences the effectiveness of water management below the outlet. The water allocation in the warabandi system, in which the frequency of the rotational delivery is kept constant (usually once in **7** full days, or 168 hours/CCA), is measured in hours per hectare. This value varies from one watercourse to the other, depending on the command area to be irrigated in each watercourse. The command area determines the size of the outlet through which a constant discharge of water is supplied to the watercourse.

If the warabandi is strictly adhered to, each farmer receives the full supply of the watercourse during his turn, the duration of which is proportional to the size of his farm. Considering that the frequency and the rate of delivery are both kept constant, the allocation of water in terms of hours per hectare for each farmer in a given watercourse should be the same, provided that the CCA of the watercourse does not change once the outlet discharge is fixed. However, considerable variability was found in the study areas, both in terms of actual flow received at different outlets, as well **as** the water turn durations and supplies received, or used, by the different farmers within each observed watercourse.

5.1.4.1 Variability among Outlets

Variability can occur due to the design parameters themselves. This was tested using the Irrigation Departments data; the water allowance (defined for the purpose of this presentation as design discharge per unit of CCA) was calculated for each watercourse along Distributaries # 3 and # **4,** and Girsal Minor. Table V-3 gives the averages and the coefficients of variation of the water allowances given to outlets in the three

Figure V - 2
WATERCOURSES CLOSURE RECORDS: DISTY # 3
DISTY AVERAGE (1192 TO 6/93)

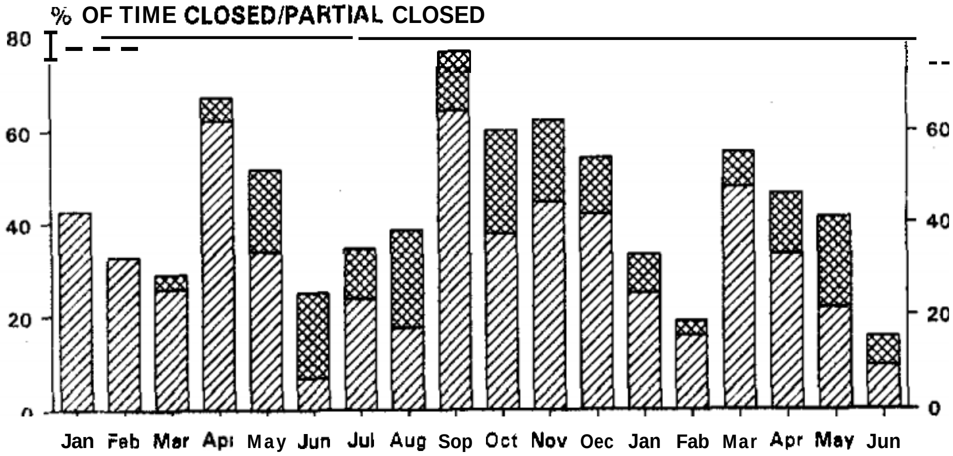
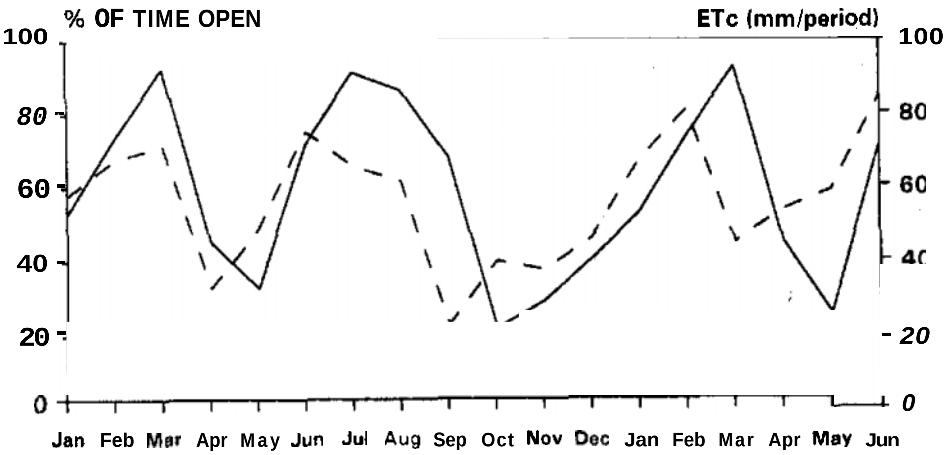


Figure V - 3
WATERCOURSES OPEN RECORDS : DISTY # 3
COMPARISON OF ETc WITH FARMERS BEHAVIOR



Jan 1991 - Jun 1993

channels. Figure V-4 provides a graphical representation of the pattern of distribution of water allowances among the watercourses in the Girsal Minor.

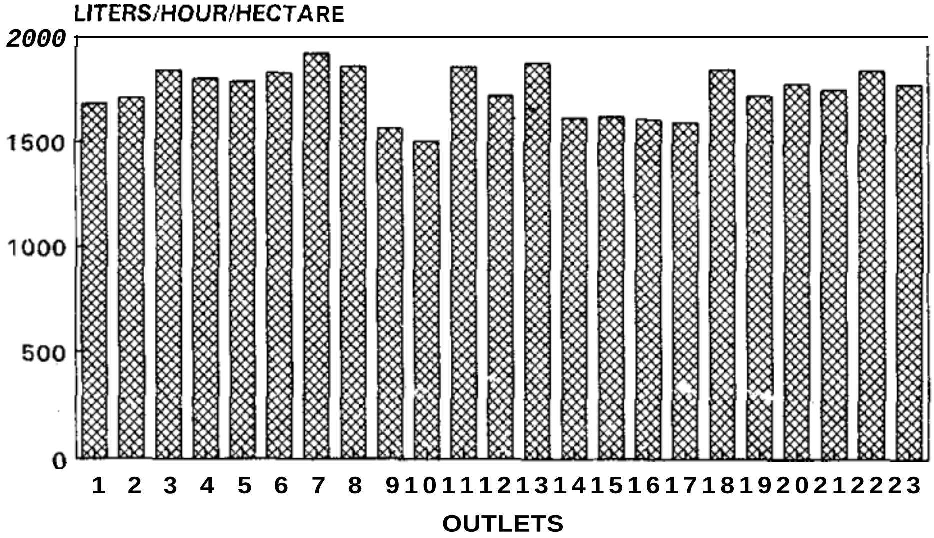
Disty/Minor	Avg Lit/hr/ha (l/s/ha)	Coeff of Variation (%)
Disty # 3 (n=20)	1940 (0.54)	0.20
Disty # 4 (n=35)	1938 (0.54)	0.22
Girsal Minor (n=23)	1742 (0 48)	6 26

The water allowances were found to be almost the same for different outlets along the two new Distributaries # 3 and # 4, as should be the case if the design criteria was applied uniformly. However, as seen in the graph, there is considerable variability in the allowances for outlets along the Girsal Minor. This high variability can be attributed to the post-design changes that may have been occured over a period of time in the old Girsal Minor, which have since been officially recognized.

Table V-1 in Section 5.1.2 above, which gives the type of *warabandi* for the 12 observed sample watercourses in CRBC, also provides their water allocations (hours/hectare) calculated on the basis of their present command areas. If the command areas were not substantially adjusted after the outlets were fixed according to a uniform discharge rate per unit of land, these allocations should represent an equitable distribution of water. This was tested for four sample watercourses along Distributary # 3. Figure V-5, which shows a comparison between the design allocations and the present actual allocations for these four watercourses, indicates that there have been some minor adjustments in the command areas in all four watercourses, the largest change being Watercourse No. 10150-R in which the command area has been reduced.

Another important observation was that, generally, most outlets in all three sample channels were drawing more than the design discharge during this period, the major exceptions being the tail watercourse and the 1993 *Kharif* season water withdrawals in the Girsal Minor. In the case of Distributary # 3, as seen in Table V-4, head and middle outlets are drawing more water as compared to tail outlets, even more than the design allocation, which must be based on the peak crop water requirements. The actual average daily withdrawals rise in the *Kharif* seasons because the area under rice (24 %, for 1992 & 26 %, for 1993) is more than the design (2 %) value.

Figure V-4 DESIGN DISCHARGE PER UNIT AREA FOR OUTLETS ACCORDING TO THE IRRIGATION DEPARTMENTS DATA



GIRSAL MINOR

Figure V-5 DESIGN vs ACTUAL WATER ALLOCATION FOR 4 SAMPLE W/Cs DURATION OF WATER AVAILABILITY

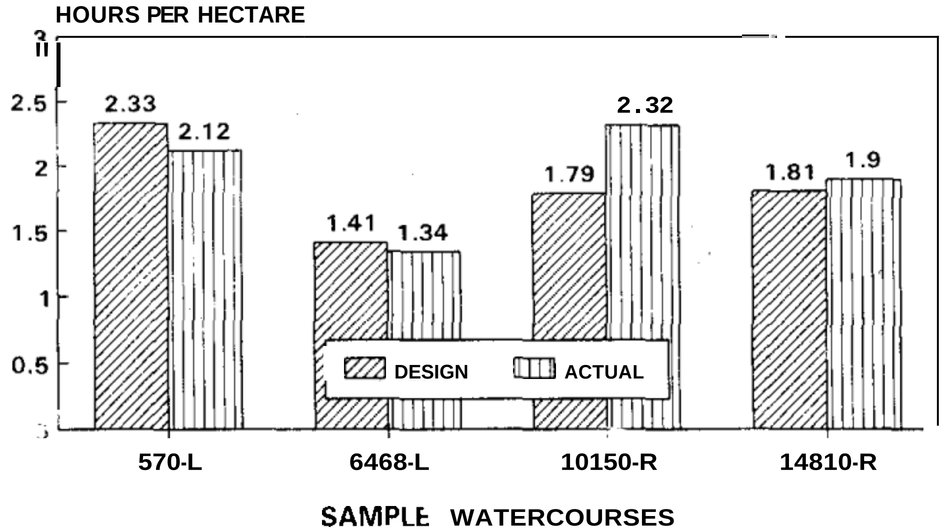


TABLE V-4 ACTUAL DISCHARGES IN SAMPLE WATERCOURSES OF DISTRIBUTARY # 3 FOR FOUR CROP SEASONS.

Outlet No.	Design Q in cusecs	Average of Daily Discharges (Cusecs)			
		Rabi 1991-92	Kharif 1992	Rabi 1992-93	Kharif 1993
570-L	1.29	1.58	1.59	1.54	1.49
690-R	2.44	3.25	3.75	3.13	2.96
6468-L	2.61	3.19	3.69	3.41	3.46
6468-R	1.87	2.18	2.30	1.90	2.47
10150-R	1.56	1.31	2.07	1.22	1.68
11920-L	1.17	2.15	2.60	2.42	2.24
14810-R	1.80	1.77	2.13	1.56	2.49
15382-R	2.83	2.25	2.65	2.31	2.94

5.1.4.2 Variability among Individual Water Turns

An important finding was that, in actual practice, there is considerable variability in the use of water turns by the farmers. In the observed watercourses, farmers irrigated their land taking more or less than their share due to them according to the uniform water allocation for the watercourse. The actual time durations of their irrigation turns were observed for the 9 watercourses supposed to be having some form of *warabandi*, and the data so collected were analyzed. The results are given in Table V-5 below.

TABLE V-5 VARIABILITY OF WATER DISTRIBUTION WITHIN WATERCOURSES

Distributary # 3		Distributary # 4		Girsal minor	
outlet	coef. var	outlet	coef. var.	outlet	coef. var.
570-L	0.37	28448-R	0.10	5767-L	0.05
6468-L	0.17	-	-	13526-R	0.10
14810-R	0.94	-	-	24046-L	0.04

5.1.5 Water Sharing

Even when any form of *warabandi* exists, farmers have *a* tendency to try and increase the flexibility of their water supply by exchanging canal turns, or by purchasing full or partial turns of farmers having an excess of irrigation water. Generally, farmers tend to exchange canal water in partial turns. These partial turns are used to complement the irrigation of some fields when the allocated time is too short for fulfilling the field water requirements. This type of exchange is seen to be a very common occurrence in the area. Table V-6 gives the results of farmer responses on this issue.

Sector	Exchange of Water Turns			
	YES		NO	
	Frequency	Percentage	Frequency	Percentage
Distributary # 3	23	96	1	4
Distributary # 4 *	6	100	-	
Girsai Minor	24	100	-	-
Overall	53	98	[illegible]	[illegible]

* (Farmers without *warabandi* on Distributary # 4 are excluded)

This table shows that almost all farmers in the watercourses having a warabandi are exchanging water turns. In fact, the warabandi turns have little practical meaning for the timing of the irrigation. Their real meaning lies in the fact that they fix the right to irrigation water for the participating farmers, something that they can use for appeal when their access to water is jeopardized in any way. They refer to this function of the warabandi as *"haqooq"*.

When farmers cannot meet their water requirements for one reason or other, they start buying canal or tubewell water. Oflen, sellers are tail-end farmers who cannot fully benefit from their water turn; thus, they sell it to head farmers on a seasonal basis In order to have an irrigation water supply to irrigate their crops, they make a contract with neighboring tubewell owners which usually take 1/3 of the harvest. Purchase and sale of canal water usually takes place during the Kharif season. Another category of water sellers are farmers who do not grow rice during *Kharif*.

Water sellers and buyers have only been found among sample farmers from the Girsal Minor command area. The percentage of farmers in a watercourse involved in water selling activities seems to increase from the head to the tail of the Girsal Minor command area. The last watercourse, however, does not have a single farmer selling or buying water, since ther is an excess of water because of the loss of agricultural land on the Indus River side. The comparison of the level of the water selling activity along the watercourse shows a slightly larger percentage of farmers participating in the sale of water at the head and middle (13% each) reaches of the watercourse than at the tail (8%) of the watercourse; with an average for the minor of 11% Only the number of sellers has been counted, including buyers would give somewhat higher percentages.

In conclusion, there is a substantial degree of flexibility in managing water at the watercourse level. At the same time, a fair degree of variability exists in the use of water turns, and in a context of water abundance, this cannot be seen as a factor that is likely to perpetuate inequity in water distribution. However, the role of big or influential landowners is observed to be significant in contributing to the variability in water use along the watercourse. Since land is still being brought under development in the CRBC area, it is too early to say whether this flexible water management by the farmers has some similarity with crop-based irrigation.

5.2. Agricultural Production and Farming System Analysis

To complement the technical and institutional facets of the Crop-Based Irrigation Operations in the NWFP research study, an economic component was also included Specific activities focused on irrigated agriculture and its relationship with irrigation water supplies were undertaken during the two years of field work. The first activity. a base-line socio-economic survey, has been described in Progress Report # 1 along with

the main results and conclusions. Thus, the results of this activity have not been included in the present report.

The specific objectives of the analysis of irrigated agriculture in the CRBC area were:

i) to assess the current level of agricultural production (i.e. analysis of cropping patterns in selected watercourse command areas, as well as the analysis of yields for major crops among sample farmers);

ii) to estimate the performance of irrigated agriculture in the CRBC command area by comparing design an current levels of production;

iii) to understand the impact of changes in irrigation water supplies on agricultural production. To address this issue, two methods were chosen: (a) analysis and economic modelling of farming systems in the CRBC area; and (b) the analysis of agricultural production in the Old Paharpur command area as a result of the recent changes in water duties; and

iv) to analyze the impact of the current system of water charges on agricultural production within the context of crop-based irrigation operations.

The results from the analysis of irrigated agriculture in the CRBC area were to be used to ***evaluate the benefits of crop-based irrigation operations and identify costs and opportunities for implementation on a wider scale.*** However, it was understood that the economic evaluation would be based on the monitoring of the impact of management changes on agricultural production. As it was not possible to field-test proposed management changes, therefore, it was not possible to assess the impact of these changes on irrigated agriculture in the CRBC area.

5.2.1 Agricultural Production in the CRBC Command Area

Cropping patterns

The main aspect to be stressed in this section is the significant difference between the design and actual cropping patterns. This difference is partially explained by the higher than designed water supplies to the Stage I command area, as highlighted previously in this report. However, as stressed by the analysis of the farming systems as presented below, a significant portion of the difference is related to the use of faulty assumptions at the design stage of the CRBC project regarding the relation between irrigation water supply and the farmers' decision-making process.

Cropping patterns were determined through intensive crop surveys for 12 sample watercourses along Distributary # 3 (8 watercourses) and Distributary # 4 (4

watercourses). The first objective of the crop surveys was to analyze the impact of irrigation water supplies on farmers' cropping decisions; the second, and most important, objective was to calculate the crop water requirements and compare them with the irrigation water supplies (using the Relative Water Supply parameter) as presented in Chapter **4.**

Table V-7 presents the ***Rabi*** 1992/93 and *Kharif* 1993 cropping patterns for Distributaries # 3 and **# 4** and compares them: i) with the original CRBC design cropping pattern; and ii) with the cropping pattern expected after 5 years of operation that was used for the project's economic analysis (see PC-I 1991 (revised)).

TABLE V-7 *RABI* 1992/93 AND *KHARIF* 1993 CROPPING PATTERNS VERSUS DESIGN CROPPING PATTERNS.

Crop	Disty # 3	Disty # 4	Original Design	After 5 years (PC-I 1991)
Wheat	61.0%	56.0%	45.0%	40.0%
Gram/Pulses	16.5%	12.5%	5.0%	**4.0%**
Sugarcane	7.5%	12.5%	15.0%	5.0%
Fodder Rabi	7.5%	5.5%	10.0%	6.0%
Oilseeds	-	-	5.0%	8.0%
Gardens	-	1.0%	5.0%	1.5%
Misc. (veget.)	0.5%	0.5%	5.0%	3.0%
Rabi Crop.Intensity	93.0%	88.0%	90.0%	67.5%
Rice	26.0%	31.5%	2.0%	10.0%
Sugarcane	9.0%	13.5%	15.0%	5.0%
Fodder *Kharif*	4.5%	5.5%	10.0%	7.0%
Maize	-	-	10.0%	12.0%
Millet	-	-	3.0%	1.0%
Cotton	-	0.5%	10.0%	5.0%
Garden	0.5%	1%	5.0%	1.5%
Misc. (veget.)	0.5%	0.5%	5.0%	3.0%
Kharif Crop.Intensity	40.5%	52.0%	60.0%	44.5%

The table suggests that farmers have responded rationally to the high water supplies by cultivating as much as possible of the command area, as confirmed by the high cropping intensities for the *Rabi* season. The table also highlights, however, the high discrepancy between the actual and design cropping patterns. Particularly, the area under rice has been significantly underestimated. The problem of coming to grips with the cropping pattern has long ago been recognized, as stressed by successive consultants involved in the evaluation of Stage I and the design of Stages II and III of CRBC.

The initial cropping pattern used for the design of the CRBC irrigation system estimated that only 2 percent of the area would be under rice; this value was subseqtiently increased to 10 percent for the economic evaluation of the project after **5** years of operation (as shown in the last column of Table V-7). However, this value is still far off from the 25 to 30 percent of the area under rice reported under sample watercourses served by Distributaries # 3 and # 4.

The analysis of the cropping pattern at the watercourse level shows that there is a high variability in the area under rice and sugarcane, which are crops with high water requirements. Figure V-6 compares the ratios between the design and actual percentage of the CCA under rice and sugarcane for the selected sample watercourses.

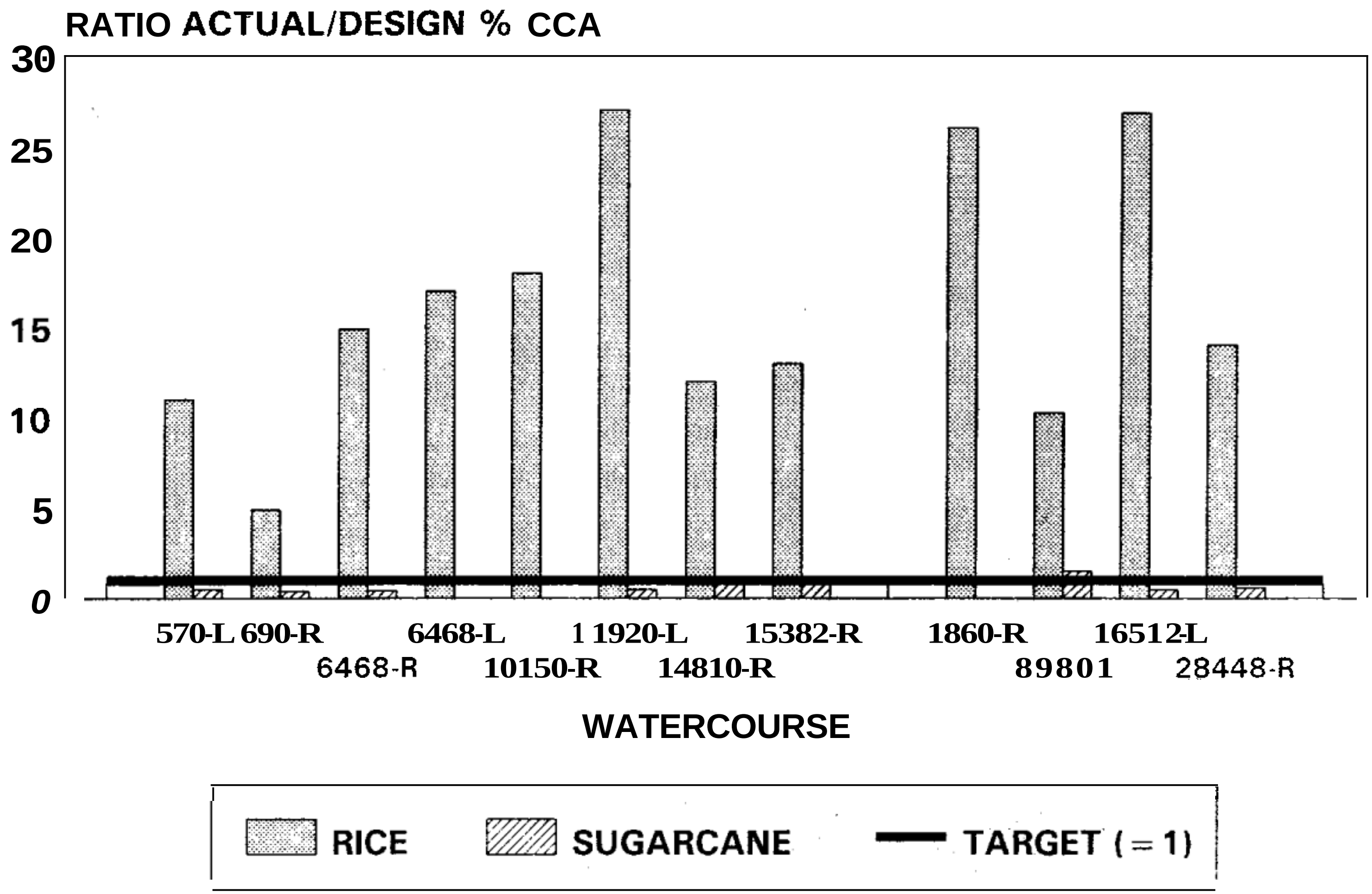
The differences in the area under rice and sugarcane between the different outlets, however, could not be explained **by** the water supply available relative to the crop demand. Regression analysis with the Relative Water Supply as the dependant variable, and the percentage of the area under crops with high water requirements as independent variables, failed to show any significant relationship between the mentioned variables.

Constraints other than water (labour, access to credit, availability of fertilizers, etc) are predominant in influencing farmer's cropping decisions, as there is sufficient water in the distributary as highlighted by the frequent closure of outlets. However, the analysis undertaken, of both the farming systems and the economic modelling of farms, clearly indicated that water can be a constraint for some farms during the rice transplanting period at the beginning of the *Kharif* season.

Rice and wheat yields

The crop-cut method was used for the collection of rice and wheat yields for **4** seasons, i.e. *Rabi* 1991/92, *Kbarif* 1992, *Rabi* 1992/93 and *Kharif* 1993. The comparison between crop-cuts and interview-based yields for the *Rabi* 1991/92 and the *Kharif* 1993 seasons shows that, on average, crop-cut yields are consistently 20 percent higher than

Figure V-6
IMPORTANCE OF RICE IN CRBC AREA
ACTUAL VERSUS DESIGN (KHARIF 1993)



the interview-based yields. Thus, crop-cut yields need to be adjusted by minus 20 percent for the comparison with target yields cited in the CRBC project documents, or other CRBC-related literature.

Figure V-7 shows the average yield per watercourse for wheat *(Rabi 1992/93)* and rice (*Kharif* 1993). The main conclusion drawn from these data are:

i) after taking into account the differences between crop-cuts and interview-based yields, average yields collected in the sample watercourses are rather comparable to the design data in the case of rice, but significantly lower in the case of wheat yield; and

ii) the three different areas (i.e. Distributaries # 3 and # 4 and Girsal Minor) record similar average wheat yields. However, rice yields are significantly higher for the Girsal Minor area as compared with the commands areas of the two other distributaries. Farmers in the Girsal Minor have a long tradition in irrigated agriculture that is still lacking among some of the new settlers-cultivators in the newly developed command areas under Distributaries # 3 and # 4.

To reduce the yield gap between newly developed and Old Paharpur command areas, the extension services of the Provincial Agricultural Department should make a significant effort in supplying irrigation related messages to the former (and less productive) areas, as these areas present a good potential for further yield increases.

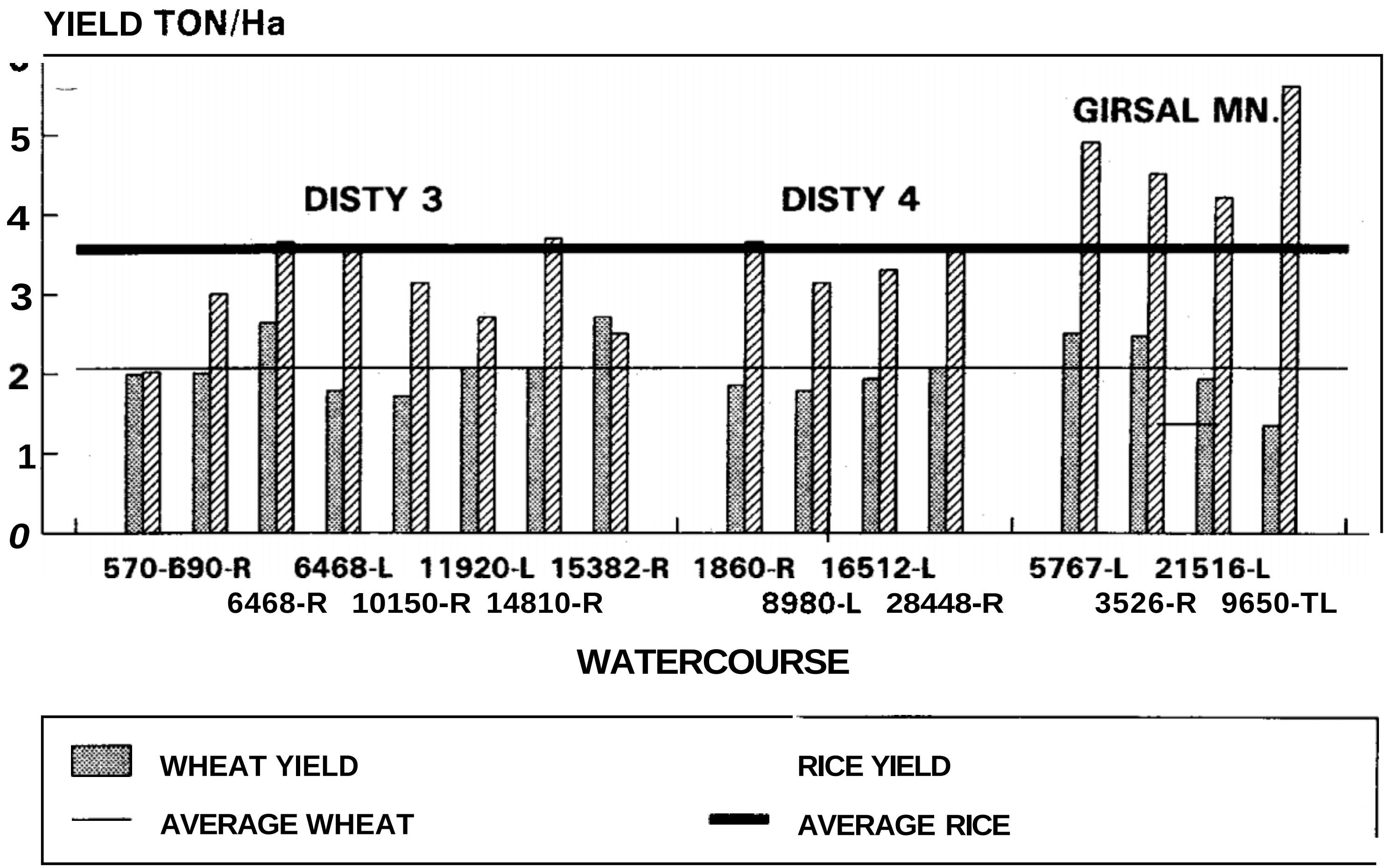
5.2.2. Irrigation Water Supply and Agricultural Production

Farming system analysis

In order to better understand the relationship between irrigation water supplies and agricultural production, an in-depth analysis of farming systems for the Distributary # 3 command area was undertaken, based on data collected during the base-line socio-economic survey (EDC, 1991, see Annex-I) and complemented by information regularly gathered by IIMI field staff during the first two seasons of field activities.

The main issue to be addressed under the analysis was the difference between design and actual cropping patterns. Why do farmers have a cropping pattern different from the design cropping pattern? Are high water supplies the main cause explaining this discrepancy? Or, has the design cropping pattern been based on unsound assumptions regarding the relationship between irrigation water supplies and agricultural production?

Figure V-7
AVERAGE WHEAT AND RICE YIELDS
RABI 1992-93 & KHARIF 1993



For the analysis of farming systems, an approach developed by the Centre National du Machinisme Agricole, des Eaux et des Forêts (CEMAGREF) for assessing the impact of investments in the irrigation sector on agricultural production and farming systems has been applied.

The main steps of the approach are an analysis of farming practices, a classification of farming systems, and an economic modelling (linear programming) of representative farms. The approach itself is detailed in a report by A. Chohin titled *Analysis of farming systems within the context of the Crop-Based Irrigation Operation in the NWFP Project* (see Annex-I).

The economic modelling highlights that by supplying the maximum (design) discharge to representative farms the year round, farmers would grow from 12 to **25** percent of their area under rice, taking into account other farm constraints such as availability of labour and credit, specific farming practices, and crop rotations, etc. The study also revealed that the supply is a constraint to the farmers' decision making process during the month of June only. For the *Rabi* season, the crop water requirements predicted by the economic model are much lower than the maximum design value and in accordance with the closure of outlets observed in the field.

The modelling of farming systems indicated that the design values of the area under rice had little, if any, resemblance with the expected value predicted by the model. This tends to reinforce the idea that some of the current cropping pattern problems (like the impact on the available supply for the other stages of the CRBC) are due mostly to design miscalculations and to the lack of an in-depth analysis of the relationship between irrigation water supply and agricultural production as opposed to supply over-deliveries *per se.*

Impact of changes in water duties on agricultural production

The Old Paharpur irrigation system presents a unique opportunity for assessing the impact of irrigation water supplies on the agricultural production. With the commissioning of CRBC Stage I, the water duties of the Old Paharpur irrigation system have been increased and a significant impact on the agricultural production of the area was expected.

The Girsal Minor, in the Old Paharpur irrigation system, was thus selected for the analysis. Regular data collected by the PID have been analysed and complemented by IIMI primary field data and observations. The full results of the analysis, summarized below, have been presented in IIMI's Working Paper No. 26 by P. Strosser, R.M. Afaq and C. Garces (see Annex-1):

* The average discharge at the head of the minor has been increased by 54 and 31 percent for the *Kharif* season and the *Rabi* season, respectively The analysis of data shows that farmers have used several ways to adapt themselves to the changes in their irrigation water environment

* The changes in water duties did not have any impact on the cropping intensity recorded for the area. However, farmers have reacted very positively to the changes in canal water supplies by modifying their cropping pattern, with a major shift towards more *Kharif* crops.

* Farmers now plant larger areas under rice and sugarcane, and less wheat and gram. However. only the changes in the area under rice are significantly related to changes in water duties as shown by regression analysis. On the other hand, for the area under sugarcane, the installation of a sugarcane mill in the vicinity, and its related incentives for increasing production, is probably the main reason explaining the recent development in area under sugarcane.

* Calculation of the Relative Water Supply (RWS) parameter indicates that farmers now apply more water per unit area than before the remodelling of the Girsal Minor took place. Although the quantity of canal water used has significantly increased between the *Before* and *After* remodelling stages, the increase in the RWS has been minimal, due to increases in the area under rice and sugarcane accompanied by a significant reduction in private tubewell operation and groundwater use. The number of private tubewells, also, has been drastically reduced afler the remodelling and the commissioning of the CRBC.

  The improvement in the quality of irrigation water supplies has favoured farmers' investment in other inputs as well. After the remodelling, farmers apply significantly larger quantities of fertilizers (Urea. DAP) on their rice and wheat crops, compared with the *Before* remodelling situation. The increase in water duties, however, did not modify the effectiveness of fertilizer use.

  Finally, the cumulative effect of the increase in water duties and in fertilizer use has led to a significant increase in yields of the major crops Regression analysis shows that 65 percent of the total increase in rice yield can be attributed directly to the changes in water duties, while the remaining 35 percent is caused by increases in the quantity of urea applied *io* the rice crop Similar values are also found for the wheat crop

Summary

The two previous sections show that the current cropping pattern and trend in agricultural production could have been predicted at the design stage of the CRBC irrigation project. Farmers have reacted in a rather rational way to the large increase in canal water supply.

However, the resulting dilemma should be tackled seriously by the operating agencies and policy makers. Farmers under Stage I are currently receiving quantities of canal water larger than those designed for peak water requirement periods. The water used is still increasing, as shown by the comparison between the percentage of the CCA under rice for two consecutive *Kharif* (1992 and 1993) seasons. the area under rice has increased by **38** percent in the Distributary # **4** command area, and by 10 percent in the Distributary # 3 area Figure V-8 shows the difference between the area under rice for the two seasons considered.

With the current role of rice within the cropping pattern of the Stage I command area, farmers are becoming accustomed to water deliveries higher than what they should receive as per design. In the long term, this situation will have a negative effect on the canal water supply available for Stage III, which is currently under design, as discussed in Chapter 4.

To avoid these already foreseen (and non-acceptable) problems, several solutions could be explored. One solution (often cited by staff from the operating agencies) would be to force farmers to stay within the design cropping pattern. However, experienced gain from other countries shows that it is impossible for an operating agency (and, in fact, for a government) to implement and enforce such a policy

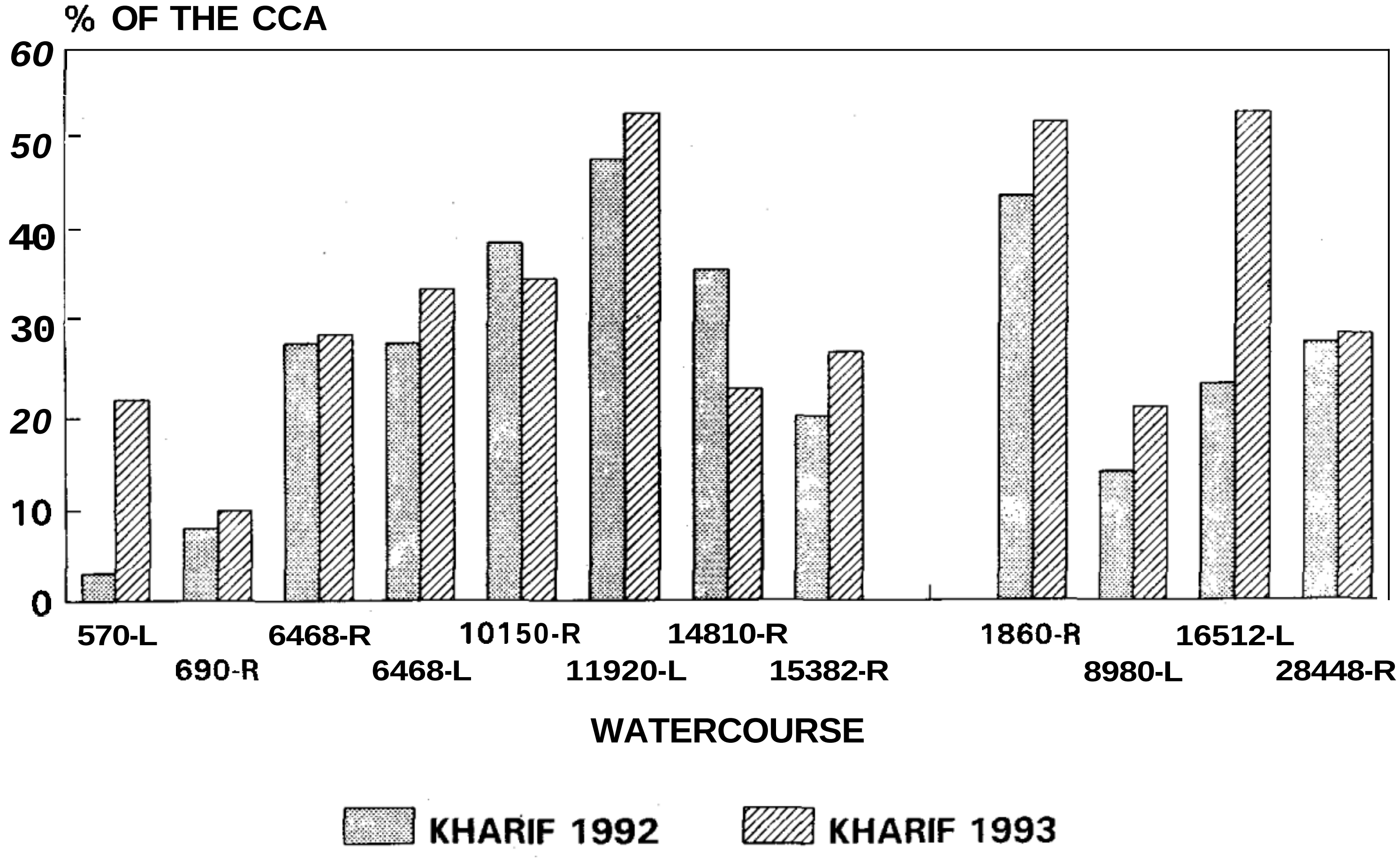
Another solution could be to reduce progressively the water supplied to Stage I farmers This would require a good transfer of information between farmers and the operating agencies, and is seen (at least in the short term) as the only option with a reasonable chance for success. Such a solution was indeed proposed to the operating agencies as part of the CBIO study with little or no interest shown by them.

A last alternative could be to modify the system of water charges, to indirectly influence farmers cropping choices (and ultimately their demand for water). Some aspects related to the impact of this last option are further analysed in the following section.

Figure **V-8**

AREA UNDER RICE CROP

KHARIF 1992 VERSUS KHARIF 1993



5 2 3 Changes in Water Charges and Impact on Agricultural Production

The deficiencies of the current system of water charges has been highlighted by several researchers and planners in Pakistan. Problems often cited are the absence of a relationship between water charges and the quality of irrigation services, the lack of transparency in the allocation of water charges to the Operation and Maintenance of the irrigation systems, the lack of incentive for farmers to use irrigation water efficiently, etc. These problems are not analyzed here, although these need to be addressed effectively by policy makers and operating agencies alike.

During the March 1993 Workshop on Crop-Based Irrigation Operations held in D.I. Khan ***as*** part of the study, the PID highlighted the discrepancy between O&M costs, and water charges assessed and collected. As specified in the the CRBC irrigation project documents, an increase in the level of water charges was planned to reduce this discrepancy, with a related (expected) improvement of water use efficiency.

In this regard, the first important aspect found in the study was that farmers do not know the exact level of water charges for each crop. It came as a surprise to discover that the majority of 100 farmers interviewed during the *Rabi* 1992/93 were not aware of any differences among crops in the level of water charges. Thus, even if water charges are increased, but still remain unknown to farmers, to expect changes in water use efficiency as a result is rather doubtful. A serious effort should be made to **get** farmers to incorporate water charges in their decision making as another important economic variable in their agricultural production process.

A second aspect is that an increase by 30 % on the level of water charges would not have any significant impact on agricultural production and cropping patterns. The economic models, developed under the farming system analysis, for several representative farms of the Distributary # 3 command area show that a change in the current structure of water charges, rather than a uniform increase for each crop, would have more impact on farm's performance indicators and cropping patterns.

The lessons learned from the modelling exercise is that it **is** probably not possible to influence farmers cropping decisions by only increasing the level of water charges under the current system. A major change will be required, one that can offer a better link between the price paid by farmers for their water and the quality of the irrigation service they receive. Moreover, farmers would start to use their water more efficiently only if the adjustments he makes on the water supplied to his fields have a direct impact on the water charges to be paid at the end of the season.

Chapter 6

SYSTEM PERFORMANCE

6.1 Background

The assessment of the performance of any irrigation scheme is undoubtely an important and indispensable component towards the improvement of the effectiveness and efficiency of irrigation systems. Initial research work done by IIMI on this subject matter has focused on the identification of an appropriate framework for performance assessment.

An important aspect stressed by the researchers, however, is that performance assessment needs to remain linked with the objectives of a given irrigation scheme. Thus. a variety of performance indicators can be used to evaluate different systems, although the performance assessment framework itself is expected to be the same regardless of the irrigation system.

In the context of the Crop-Based Irrigation Operations in the NWFP study, performance assessment was an integral part of the research activities, which focused on the analysis of the system's operation. How performance assessment could be institutionalized into the current management was seen to be as important as the evaluation of the CRBC's performance itself.

An initial analysis of the performance of the CRBC irrigation system was undertaken at the end of the *Kharif* 1992 season. The main results of that work, based on primary data collected by IIMI field staff during the first year of the study, and secondary data provided by WAPDA, have already been documented in the paper titled Performance *of* CRBC: Technical and Economic *Indicators* in the Context *of* Crop-Based Irrigation Operations by P. Strosser and C. Garces prepared for the December 1992 IIMI Internal Programme Review, and in a shorter version of the paper (titled Performance *of* the CRBC in the context of Crop-Based Irrigabon Operations by C. Garces and P. Strosser) that was discussed during the Crop-based Irrigation Operations Workshop organized in D.I.Khan in March 1993. (see Annex-I).

Those particular documents concluded that the performance of the CRBC irrigation system ---from a crop-based irrigation operations perspective— was rather low. Although farmers were trying to manage their irrigation water in a crop-based mode, the performance of the system worsened as operations moved (or took place) at higher levels i.e. the distributaries and main canal, in that order. Physical, operational and managerial constraints, already discussed in previous chapters, led the operating

,agencies to impose a supply-based approach rather than one considering crop requirements.

The limitations of the analysis, however, were fully recognized by IIMI as the research results were based. only, on water flow data collected during less than two cropping seasons and for a limited number of locations Furthermore the systems performance analysis --in terms of its agricultural production-- had also some limitations due to the unavailability of appropriate data.

The remainder of this chapter presents the results of the direct follow-up to the initial research work done on the evaluation of the performance of the CRBC Stage I irrigation system. The main objective of this chapter is to assess the current Performance of the CRBC again, within a crop-based irrigation operations context, utilizing a little over two years of primary data (from September 1991 to October 1993) which was collected by IIMI field staff as a part of the regular activities of the study

By providing a comprehensive picture of the CBRC (Stage I) irrigation system performance, this chapter also tries to summarize some of the information presented in previous sections of this report pertaining to. (1) the supply of irrigation water at different levels of the system. **(2)** the demand for irrigation water, and (3) the resulting agricultural production

The analysis of performance presented below focuses on the secondary and tertiary canals only, since Chapter **4** above has already addressed the main canal issues in-depth. Special importance is given to the problem of over-supply deliveries (comparatively with the design expectations) at the distributary and watercourse levels, as this is perceived as a major problem impacting negatively on the environment (salinity and waterlogging) and on the future distribution of water among the three stages of CRBC.

The concluding section of the chapter stresses the need to institutionalize the assessment of system performance on the part of the operating'agencies; this needs. to be carried out within the context of an appropriate and efficient Management Information System (MIS), a component of a decision support system for management of irrigation schemes.

6.2 Performance Assessment and Performance Indicators

6.2.1 Objectives of Crop-based Irrigation Operation

The nature of the indicators used for assessing the performance must be dependant on the objectives of the system. In the study's context, the main objective is to match

as closely as possible the supply of irrigation water with the crop-water requirements However, it should be recognized that crop-based irrigation operation's objectives can be different from the current objectives of the two agencies operating the system -- the PID and WAPDA

Although the definition of the main objective is rather straight forward the analysis of the performance of an irrigation system is generally more complex. as secondary objectives and potential limitations of the system need to be considered In the CBIO study case. it might be prudent to address issues like the water available at the source (barrage, Indus river): that the water allocated to the CRBC irrigation system entails a political decision (within and among two provinces as the CRBC will supply irrigation water to both the NWFP and the Punjab); take into account other potential water uses within and outside the agricultural sector; the characteristics of the canal itself that could constraint the system operations; etc.

However, these aspects will not be further discussed as they have already been analysed in the documents mentioned above. or they are presented in Chapter **4** of the present report under issues related to main canal operation

6.2.2 Selection of Performance Indicators

A literature review would yield that a large number of indicators have been used by different authors for the assessment of irrigation system performance. Thus, in order to carry out the performance study, there was a need to select a limited number of indicators well adapted to crop-based irrigation operation concepts and to the CRBC situation in particular.

Different criteria have been used in the selection of indicators: i) their appropriateness to assess the match between the supply and the demand of irrigation water; ii) the type of data and the effort involved in calculating the indicators (including that readily available at the system level); and iii) the perception of their utility and acceptance by the line agencies involved in system operation.

The indicators selected are presented below, classified into two sub-groups, i.e. Operational Performance indicators related to irrigation water supply *per* **se,** and Output Performance indicators related to agricultural production. The first group of indicators is of direct relevance to the activities of staff from the operating agencies, but also to farmers. The second group of indicators are more relevant to the concerns of policy makers, funding agency staff, and farmers.

Operational performance

As referred to above, the main focus of performance evaluation under this set of indicators is at the watercourse and distributary level. At the former level. the indicators selected are analogous to the ones defined by Strosser and Garces (1992). They are also similar to indicators developed by Molden and Gates (1990), but based on the Relative Water Supply parameter (see Chapter 5) rather than on discharges at specific points in the system.

Four operational indicators have been selected, which are presented in the foilowing paragraphs.

1. **Adequacy,** this indicator averages the relative difference of the actual Relative Water Supply (RWS) to the target RWS over a given period of time and for different locations. The total quantity of water supplied to the crops is compared with the total quantity of water required by the crops over a season. The mathematical expression of the indicator is given below as:

$$\textbf{Adequacy} = \frac{{}_{n}\Sigma\ (\ {}_{t}\Sigma\ (\text{RWS} - \text{Target})/\text{Target}\ )}{\text{N x T}}$$

with	RWS	10-day Relative Water Supply of watercourse "n" during period "t"
	N	total number of locations (watercourses)
	T	total number of time periods (18 in one season)

2. **Dependability,** analyses the variation of the RWS over time A high dependability, represented by a low coefficient value, suggests that farmers much prefer not to have peaks (low or high) in their RWS and will try to strictly adjust the supply to the crop water requirements. The indicator looks at the quality of the operation, and is used in the same way as the Supply Mismatch indicator defined by Strosser and Garces (1992).

$$\textbf{Dependability} = \frac{{}_{n}\Sigma\ (\ {}_{t}\text{C.V.}((\text{RWS} - \text{Target})/\text{Target})\ )}{\text{N}}$$

with	${}_{t}$C V .	temporal Coefficient of Variation for watercourse "n"

(other notations as defined above)

3. Equity, this indicator addresses spatial variations, which has been added because the two previous indicators focus mostly on the adequacy of water supplies. The equity indicator is the average of the spatial coefficient of variation of the ratio between the actual and the target discharges, with the mathematical expression being given below as:

$$\textbf{Equity} = \frac{{}_t\Sigma\ (\ {}_nC.V.((RWS\ -\ Target)/Target))\ )}{T}$$

with ${}_nC.V.$: spatial Coefficient of Variation for time period **"t"**

(other notations as defined above)

The equity indicator is also a distributary-based indicator as it describes how water is allocated among watercourses of a given distributary, or of several distributaries.

The 10-day Relative Water Supply is the basic parameter used in the calculation of the watercourse-based indicators. The target discharge at a specific point of the irrigation system used in the different indicators is equal to a value of 1. Thus the ratio **(RWS - Target)/** Target is simplified into the expression **(RWS - 1)**. The indicators were calculated for different groups of watercourses (Distributary # 3, Distributary # **4,** all sample watercourses) and for each specific season.

The indicators assume that every. watercourse in the system would have the same importance for the operating agencies. However, it is recognized that this is not the case as problems in the operation of larger watercourses, for example, would be seen as relatively more important than similar problems in the water supply of smaller watercourses. To tackle this issue, specific weights could be given to each sub-unit of the system according to its respective command area, maximum design discharge, or current irrigation water demand. However, this would further complicate the indicators. Moreover, calculations completed for some Indicators have shown that very little difference results from the introduction of specific weights.

4. In the case of the distributaries, the main focus has been on the difference between the volume of water currently supplied to the distributaries and the volume of water that should be supplied if the design assumptions were valid. **A** simple indicator is used, the **Volume Ratio,** which is based on the relative difference of the actual volume supplied with the design volume. Here, as there is a large variability in the size of the distributaries, the volume supplied to each distributary is weighted by its respective area served. The mathematical expression is given below as:

$$\text{Volume Ratio} = \frac{{}_n\Sigma\, a_n\, {}_t\Sigma\, ((VOL_a - Vol_d)/Vol_d)}{T}$$

with VOL_a actual volume supplied to distributary "n" during time period "t"

Vol_d design volume to be supplied to distributary "n" during time period "t"

a_n weight for distributary "n" (proportional to the command area)

(other notations as defined above)

Output performance

Three indicators were selected to assess the Output performance of the CRBC Stage I irrigation system.

1. The first indicator is the ratio of the relative difference of the actual cropping intensity *to* the design cropping intensity. This indicator, the **Cropping Intensity Variance,** can **be** calculated **for** a season or a year using the mathematical expression given below:

$$\text{Cropping Intensity Variance} = \frac{{}_n\Sigma\, (CI_a - CI_d)/CI_d}{N}$$

with CI_a cropping intensity for watercourse "n" (yearly or seasonal)

CI_d design cropping intensity (yearly or seasonal)

(other notations as defined above)

2. The objective of the second indicator, **Rice Area Variance,** would be to compare the actual cropping pattern with the design cropping pattern. The formula for such an indicator would become rather complex if the percentage of each crop in the pattern is taken into account. Given that only crops with high water requirements significantly modify the irrigation water demand for a given area under cuitivation, the indicator is deliberately refrained to the average ratio of the actual to the design percentage of the CCA under rice. The mathematical formulation is given below as:

$$\text{Rice Area Variance} = \frac{\sum_{n} (RC_a - RC_d)/RC_d}{N}$$

with RC_a percentage of the CCA under rice for watercourse "n"
RC_d design percentage of the CCA under rice

(other notations as defined above)

In fact, this indicator is strongly correlated with the Volume Ratio and the Volume Inadequacy indicators that aggregate the actual and design crop water requirements, where both indicators are significantly correlated with the percentage of the CCA under rice.

3. The last output performance indicator, **Yield Variance,** compares the actual to the target yield and is defined as the average of the relative difference of the actual yield with the design yield. As only rice and wheat yields have been collected by crop-cuts for the four seasons monitored, the indicator has been calculated for these two crops only. It is obtained through the simple formula presented below:

$$\text{Yield Variance} = \frac{\sum_{n} (Yld_a - Yld_d)/Yld_d}{N}$$

with Yld_a actual average yield for watercourse "n"
Yl_d design yield (value as used for economic calculations in the 1991 (revised) PC-1 document)

As specified previously elsewhere, the values utilized for actual yields were crop-cut yields adjusted by a percentage to take into account the differences between crop-cut and interview-based yield values, in order to make the comparison compatible.

Yield per unit of water, as well as gross margin per unit of land and per unit of water, are also seen as important productivity related variables that should be included in a comprehensive assessment of system performance. These particular indicators, however, have not been presented since no target values were readily available for calculating these productivity parameters. Thus, the performance assessment of the CRBC Stage I system, in terms of agricultural productivity (of land and water), necessarily remains rather subjective. Moreover, the data required to calculate these

indicators (especially the gross margins per unit of water) are numerous, and are not available to any of the different line agencies involved in the system,

6.3 Performance Evaluation

6.3.1 Irrigation System Operations

Watercourse-based indicators

Sea-son	Adequacy			Dependability			Equity			Obj-ective
Unit	Dy 3	Dy 4	All	Dy 3	Dy 4	All	Dy 3	Dy 4	All	
Rabi 91/92	0.14			0.39	-		0.21			0
Kh 92	0.37	0.65	0.46	0.25	0.29	0.26	0.24	0.29	0.30	0
Rabi 92/93	-0.05	-0.01	-0.03	0.48	0.57	0.51	0.18	0.32	0.25	0
Kh 93	0.31	0.29	0.30	0.27	0.32	0.28	0.22	0.36	0.29	0

The Adequacy indicator shows that the seasonal irrigation water supply at the head of the watercourse is in excess during the *Kharif* season as compared with the total demand for irrigation water. This finding does not reinforce the results of the first data

analysis presented by Strosser and Garces (1992), which showed that the supply and the demand of irrigation water were nearly matched at the watercourse level. The reason explaining the difference can be that only **4** watercourses of Distributary # 3 were used in that initial analysis. Furthermore, the focus was only on the Rabi season, which had a much better performance for the Adequacy indicator as compared with the Kbarif seasons.

The Dependability indicator suggests a poor performance for the two distributaries, especially during the Rabi season whcih was negatively influenced by the canal closure period. The differences between the demand for, and the supply of, irrigation water are rather erratic, with a large variability over time.

Figure VI-1 presents the variability of the RWS for two seasons, Kbarif 1992 and 1993, and for the 12 sample watercourses. For all the watercourses but three (570-L and 690-R served by Distributary # 3 and 16512-L under Distributary # **4),** the coefficient of variation has increased between the 1992 and 1993 Kbarif seasons. This points to a deterioration in the performance regarding the water supply variability compared with the target water supply.

The Equity indicator shows that the supply of water is more equitable among the Distributary # 3 watercourses than among those served by Distributary # **4.** The difference between the two distributaries is particularly significant for the *Rabi* season. This is also highlighted by Figure VI-2 where the seasonal RWS for each watercourse is compared with the target value of 1.

Equity has improved in the Distributary # 3 command area, but has decline in Distributary # **4** from Kbarif 1992 to 1993. Important considerations are : (1) farmers can open and close outlets; and (2) there are over-deliveries to the distributaries. Thus, equity depends more on farmers interventions at the head of their respective watercourses, as well as the potential water losses and difficulties in managing water within each watercourse, than on the water distribution at the system level per se.

Actual versus design quantities supplied at *the* distributary level

As stated above, the main emphasis of the analysis has been on the over-supply to the different distributaries of CRBC-Stage I. Table VI-2 presents the Volume Ratio indicator for the four distributaries and their weighted average values.

In this table, similarly to table VI-1, a good performance is given by values of the Volume Ratio Indicator close to 0 (column "Objective"). The volume ratio represents the relative difference between the volume delivered to a given distributary and the maximum volume as per design. A positive value indicates an over-supply as compared to the maximum design supply, and a negative value represents a supply lower than the maximum design supply.

Figure VI-1
SEASONAL VARIABILITY AT WATERCOURSE HEAD
SEASONAL COEFFICIENT OF VARIATION OF RWS

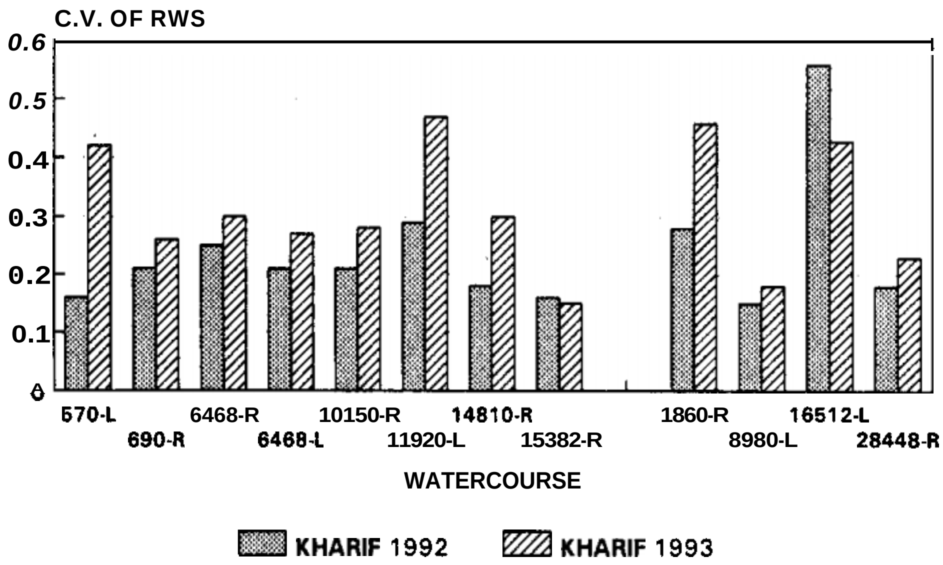
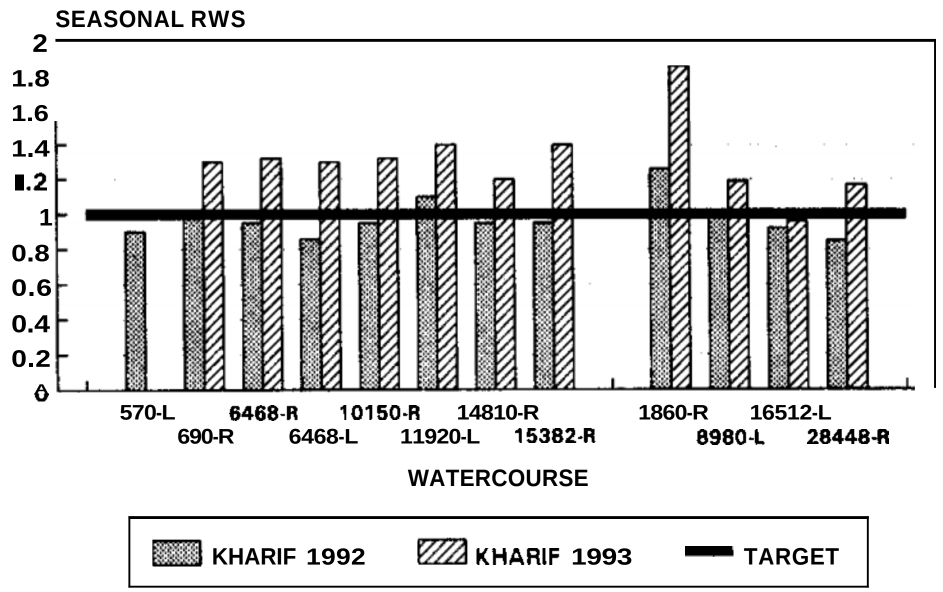


Figure VI-2
SEASONAL RELATIVE WATER SUPPLY
(AVERAGE PER WATERCOURSE)



Season	Disty 1	Disty 2	Disty 3	Disty 4	Aggregated	Objective
Kharif 1992	-0.06	0.14	0.28	0.01	0.11	0
Rabi 92/93	-0.22	-0.22	-0.31	-0.27	-0.27	0
Kharif 1993	-0.05	0.16	-0.02	0.18	0.10	0

Season	Disty 1	Disty 2	Disty 3	Disty 4
Kharif 1992	0	43%	43%	14%
Rabi 92/93	1%	7%	4%	0
Kharif 1993	6%	40%	29%	39%

6.3.2 Agro-economic Indicators

Table VI-4 summarizes the Output performance of Distributaries # 3 and **# 4,** the Girsal Minor (only yield variances) and the whole sample area monitored by IIMI. The Output performance was further evaluated against the design values utilized by the economic evaluation of the 1991 (revised) PC-I under the "after 5 years of operation scenario" (where the design values for the area under rice are supposed to equal only 10 percent of the CCA).

For each output performance indicator, a value of 0 (column "Objective") is desired, showing a good match between expected levels of agricultural output (in term of cropping intensity, area under rice, yields, etc.) and current levels of agricultural output. Values represent the difference from design values in terms of percentage. For example, the value of 0.35 for the *Rabi* Cropping Intensity Variance for the "total sample area" means that the current cropping intensity for the Rabi Season is 35 percent higher than the cropping intensity predicted at the design stage for the "after 5 years of operation" situation of the CRBC Stage **I.** A wheat yield variance of (minus) **-0.44** for the "total sample area" shows that current yields are **44%** lower than expected after **5** years of operation.

TABLE VI-4 OUTPUT PERFORMANCE OF THE CRBC STAGE I IRRIGATION SYSTEM

Indicator	Disty 3	Disty 4	Girsal Minor	Total sample area	Objective
Yearly Cropping Intensity Variance	0.18	0.24	-	0.21	0
Rabi Cropping Intensity Variance	0.37	0.30	-	0.35	0
Kharif Cropping Intensity Variance	-0.09	0.16	-	0	0
Rice Area Variance	2.73	3.15	-	2.87	0
Wheat yield variance	-0.42	-0.49	-0.43	-0.44	0
Rice yield variance	-0.18	-0.08	0.28	-0.04	0

The Cropping Intensity Variances indicate that farmers have cultivated large areas of land (on average **21** percent more than the "after 5 year" scenario, see last column of Table **V-7),** with the major difference due to the area being cultivated during the *Rabi* season. The difference between the distributaries is particularly marked during the *Kharif* season, with Distributary # 3 falling short by **9** percent of the expected (targeted) cropping intensity, while the Distributary # **4** command area records a current cropping intensity higher by **16** percent than the expected value.

The cropping pattern, however, is entirely dominated by the rice crop during the *Kharif* season, as represented by a Rice Area Variance ranging from 2.73 to 3.15. However,

although the RWS values are rather close to but higher than 1, the performance in terms of yields is rather disappointing, especially for the wheat crop. Under the same 5-year scenario, actual wheat yields fall 44 percent short of the expected yield. Fortunately, for the rice crop, the relative difference between actual and expected yields is only (minus) -4 percent, thanks to the Girsal Minor area farmers that record yields 28 percent higher than expected.

Finally, in the case of wheat production, the higher than expected area cultivated is negatively compensated by the poor level of yields, leading to a total production for the area equal to only 75 percent of the expected production.

6.4 Summary of Performance Assessment

The calculations presented above stresses that farmers are using more water to irrigate their crops than required, especially during the *Kharif* season as highlighted by the values of the corresponding adequacy indicators. Specific water related messages should be developed and delivered by the extension services in order to reduce farmers' perceptions about the quantity of irrigation water required for managing their crops. However, the main problem highlighted by the analysis of the operational performance remains at the head of the distributaries through their over-deliveries. The expected negative impact on the water supply downstream of the CRBC Stage I would justify some rapid actions by the operating agencies to reduce flows.

The output performance analysis also indicates that the area now being irrigated is ahead of targets, but is probably not sufficient to compensate for the relatively low yields (especially for the wheat crop) recorded in the newly irrigated areas. Regression analysis was performed to identify the irrigation related factors influencing the average watercourse yields of rice. The best linear equation found is given below:

$$\text{Rice Yield} = 3357 - 678 \times \text{Year} + 43.7 \times \text{Rice \%} - 3130 \times \text{C.V. RWS}$$

with

Rice Yld		average rice yield for a given watercourse
Year		dummy variable, = 0 for year 1992 and = 1 for year 2993
Rice %		percentage of the CCA under rice for a given watercourse
C.V. RWS	:	dependability indicator for a given watercourse (temporal coefficient of variation for a given watercourse and a given *Kharif* season)

(all coefficients significant at 5 percent level; R^2 = 0.45; Number of Observations = 24; Degrees of Freedom = 20)

The regression analysis indicated that the seasonal RWS does not have any impact on the level of yield. However, the coefficient of variation of the RWS shows a significant and negative impact on the average yield under a watercourse: farmers who do not match their crop water requirements and irrigation water supply closely enough during the season (i.e. a high Coefficient of Variation) have lower yields. This is specially true when RWS values are less than 1

The analysis highlights also that yields were significantly higher for the 1992 season (as stressed by the negative coefficient before the dummy variable "Year"), and that yields are higher for those watercourses having a high percentage of the CCA under rice.

The impact of the results of Output performance, presented in Table VI-4, on the economic viability of the CRBC project should be assessed further. At present, Stage I of CRBC is using more water than designed, especially during the peak water requirement period. The expected negative impact on the future water supply downstream, and ultimately on the agricultural production of those areas, can not be overemphasized. At the same time, yields in Stage I areas are still lower than the targeted values, but should not be used as a justification for the high quantities of water currently being supplied.

Although at the design stage, crop-based irrigation operations were partially taken into account, mostly as it relates to canal capacities, current objectives of the operating agencies (which concentrate on main canal safety, sedimentation-related needs, and avoiding disputes) are not conducive to crop-based irrigation operations (this is especially true at the main canal level). The difference between the current objectives and the ones drawn from a crop-based irrigation operation can go a long way towards explaining the poor performance of the CRBC, as discussed here . There is an urgent need to address issues related to the primary objectives of the system at the main canal (WAPDA), and at the distributary and minpr level (PID), in delivering crop-based water requirements.

Once the major objectives are redefined and ready to be mef, the assessment of performance should be included in the day-to-day activities of the operating agencies (i.e., institutionalized). This means that targets need to be well defined, performance indicators need to be identified, set up feedback mechanisms established between different actors in the system and, finally, performance assessment needs to be compared with operational plans. To accomplish this, an appropriate and efficient Management Information System (MIS) should be put in place. Improved system performance should follow! This will be the challenge for current and future managers of the Chashma Right Bank Canal Irrigation System.

Chapter 7

MOVING TOWARDS CROP-BASED IRRIGATION OPERATIONS

7.1 Salient Features of the Study

The broad objective underlying the study on Crop-Based Irrigation Operations in the NWFP, as given in the study proposal, was "to improve the overall productivity of water resources in the two irrigation systems, CRBC and LSC, through improved irrigation operations in accordance with crop water requirements within the authorized water allocations and subject to available water supplies". With this purpose in view, several study activities were initiated in both of the systems, but due to delays in infrastructure development in the LSC, the emphasis of the study efforts shifted to CRBC. The study aimed to identify the main facets of a water delivery system that would correspond with crop water requirements, based on a viable cropping pattern, predictions of rainfall, estimates of evapotranspiration and seepage rates, and observations of existing farming practices and cropping calendars.

The study initially brought out three major concerns arising from the nature of operations observed in the CRBC:

* The rather generous water deliveries to the distributaries encourage the farmers to adopt a more rice intensive cropping pattern than anticipated at the earlier design stage. Seeing more water than currently required, farmers are likely to further increase the area under rice, and probably sugarca'ne as well, depending on the market incentives.

* Persistent delivery of excess water into the canal system is likely to exacerbate drainage problems. Even if escapes are used along distributaries, the effect of frequent escapes may lead to a build-up of watertables in the tail portions of Stage I and Stage II command areas.

* The generous use of water currently in Stage I of CRBC, which possibly could continue in Stage II, is likely to reduce the area that can be irrigated in Stage III. This will affect the profitability of the project as a whole, and also the equity between various stages of the system.

The study results described in the foregoing chapters confirm these initial concerns. Although each of the three concerns taken in isolation does not appear to be so alarming, combined, they can represent a serious water management problem in the CRBC system, which also is described in some detail in Chapter 4 of this Volume II of the Final Report. Although cropping intensities in the areas so far developed in CRBC

correspond to overall project design intentions, 90% in Rabi and 60% in Kharif, the actual cropping pattern has deviated from the design. Rice now accounts for about 25% of the area, as against 2% planned in the original project documents, and **14%** assumed in the later consultancy reports. Even with increased rice cultivation, farmers appear to operate within a favorable Relative Water Supply range of 1.0 to 1.5, while engaging in some unusual farmer behavior of voluntarily closing their outlets when water is not needed. These observations lead to the conclusion that water delivery is substantially more than crop water requirements, which is further evidenced by the absence of *warabandi* practices.

The present situation of water over-deliveries in CRBC Stage I relates to a tendency that can be expected in any newly developing irrigation system; that is, to give rather more water than required to the first areas developed for irrigation. The time has come, therefore, for fine-tuning the operations, before the over-supply of water in Stage I gives rise to stabilized farmer demand for more water than can be actually delivered when all of the three stages are fully developed. Thus, the immediate need underlying the concern regarding crop-based irrigation, as anticipated in the broad study purpose mentioned above, should be to assess appropriately the existing cropping pattern for Stages I and II, and monitor the supply conditions that would meet the crop water requirements for that cropping pattern.

This effort involves the need to fine-tune main system management by WAPDA, distributary system management by the Irrigation Department, and farm and watercourse management by farmers with the necessary technical assistance from the Agriculture Department. Since *de-facto* flexible water management has already been initiated by the farmers through their demonstrated willingness and ability to monitor the flows through the outlets, their efforts will be greatly assisted with some support to establish well-organized water users associations. Based on these conclusions, a set of recommendations have been formulated, which are given in Volume I of the Final Report.

The study also concludes that it is possible to shift away from the traditional supply-oriented irrigation operations to a more flexible management system in which the operations are modified to be more responsive to crop water requirements, particularly in situations where increased water allocations are possible. The rationale lies strongly in an understanding of the limitations with the traditional system operations, which inhibits improvements in agricultural productivity.

7.2 Implementation **of** Crop-based Irrigation Operatians

This section attempts to provide, in brief form, some guidelines for the line agencies -- WAPDA, PID and PAD-. regarding the implementation of Crop-based. Irrigation, Operations ,in a selected area of CRBC. While guidelines that follow pertain, .for

purposes of clarity and simplicity, to Stage I only, it should be understood that both the concept and the resources suggested should be extended, keeping in view the areas involved, to Stage II and eventually to Stage III of the irrigation system.

While recognizing that there will be a good deal of overlapping, the proposed set of activities that follow are presented, again, for convenience reasons, for each agency involved. This, however, should not imply that the activities are either sequential or independent of one another. On the contrary, only a tight coordination and collaboration among agencies involved can lead to the successful field implementation of the crop-based irrigation operations approach. Furthermore, the reader should be able to perceive that although an activity may be listed under a specific agency (the one perhaps that would lead in that particular effort) it still might represent an activity that needs inter-agency input.

Water and Power Development Authority

* Establish a coordination team, the CRBC WATER MANAGEMENT UNIT, composed of representatives from each agency to be involved, that among other things, would oversee the implementation of crop-based irrigation operations in CRBC Stage I.

* On a priority basis, set up a program that will lead, in the shortest time frame possible, to the calibration of all hydraulic structures in the area under consideration. A 3-person team should conduct frequent water measurements in order to increase accountability and accuracy, and to provide feedback information for verification and evaluation of system performance.

* For each of the off-taking channels in Stage I, establish upper flow limits based on peak water requirements under the actual cropping pattern. An all out effort should be made to keep water, deliveries below those imposed limits.

* Introduce the concept of decision support systems into the day-to-day management of the system by establishing a computer center and adopting a mathematical simulation model, as the one utilized during the crop-based study. Appropriate training will be needed and at least one person, from each agency, should be assigned full time to become conversant with this equipment and techniques.

  The model should be used to develop a management schedule for main canal operation which will provide gate settings for cross-regulators, escapes and off-take structures, as well as water supply levels at selected

points in order *to* make water deliveries in accordance with crop requirements. The computer model will also be used *to* simulate different management and operational scenarios that will lead *to* enhanced system performance, like minimum flow working levels, water releases from the barrage, etc. The effective use of this model also requires a good communications between the operations center and all field staff.

* Select and or hire new gatekeeping personnel capable of reading and recording gate settings as well as handling wireless telephone equipment *to* transmit data readily and accurately *to* the Unit center. One gatekeeper per off-take plus one or two .stand-by replacements will be needed.

Provincial irrigation Department

- Formulate and develop a simple method to calculate on a regular basis the seasonal, crop water demands that can provide feedback into operational plans. Start this application in one distributary and extend subsequently to the entire target area.

* Make a serious effort to upgrade daily project monitoring activities, including --but not limited to-- monitoring of target discharges; more frequent calibration of staff gauges, outlets and other strucutures at the distributary level; faster turnaround time in securing cropped area and intensities information; and farmers response *to* excess water (i.e. open and closure of outlet heads).

* Utilize simulation techniques to assess distributary level operations under different management scenarios and tie this information to "live" field observations. This work should include outlet response to different flows, use of drop structures for enhanced delivery, etc.

* Undertake a parallel program to assess and upgrade outlet conditions with the end-objective of replacing those that are clearly undermining the equity of water distribution. Likewise, this effort should lead to the design of better and permanent outlet structures.

* Enhance current human resources of the system by both hiring new personnel, in accordance with original staff project requirements, and by increasing present skills levels through training. At least one sub-divisional engineer per distributary canal should be the norm rather than the exception.

Provincial Agriculture Department

* Identify one or two watercourses where farmers might be willing to cooperate with the agencies in the introduction of crop-based irrigation operations into their areas.

* Develop water management-oriented messages geared towards the crop-based approach and introduce gradually with participating watercourses and, eventually, to all target areas.

* Pursue the formation of "organized behavior" groups with the end-objective of upgrading these groups to full Water Users Associations. In this connection, work on the development of a WUA manual indicating the activities to be undertaken and the benefits derived from farmers belonging to this type of organizatioh.

* Establish a link between the PID and farmers groups by promoting frequent meetings, field and demonstration days, and the potential benefits of crop-based irrigation.

* Enhance the presence of AD personnel in the CRBC Stage I area, no less than one agricultural officer per watercourse to be monitored should be specifically assigned for this purpose. These personnel should work closely with the equivalent PID counterparts in order to keep the crop-based implementation process moving.

* Continue this process until all of the watercourses served by each distributary have incorporated crop-based irrigation operations into their daily water management practices.

If the line agencies can make a coordinated effort in pursuing the activities described above, they could undoubtely be in a position to make an important contributions towards the confirmation of the underlying question that led to this study: Is Crop-based Irrigation Operations a feasible approach in the context of Pakistan's current irrigated agriculture ? The results and discussions brought forward in the three volumes of this study's Final Report offers high hopes for the concept.

ANNEX-I

LIST OF DOCUMENTS PRODUCED BY, AND RELATED TO, THE CROP-BASED IRRIGATION OPERATIONS STUDY

1. Bandaragoda, T. 1990. Selected Bibliography on Irrigation Management in Pakistan. International Irrigation Management Institute. Lahore, Pakistan.

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4. Garces, C. and T. Bandaragoda. 1991b. Crop-based Irrigation Operations in Pakistan: 'Prospects and Constraints. Paper presented in Internal Program Review. International Irrigation Management Institute. Colombo. Sri Lanka.

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14. Bandaragoda, D.J. and M. Badruddin. 1992. Moving Towards Demand-based Operations in Modernized Irrigation Systems in Pakistan. Cdlombo. Sri Lanka. International Irrigation Management Institute. xiv + 42 p. (IIMI Country Paper -Pakistan - No.5)

15. Chohin, A. 1993, Modelling of Farms with Linear Programming-" Main Findings and Results. International Irrigation Management Institute, internal Report. Lahore. Pakistan.

16. Garces, C. and P. Strosser. 1993 Performance of the CRBC in the context of Crop-Based Irrigation Operations. Paper for discussion in the Crop-based Irrigation Operations Workshop. D.I.Khan. Pakistan. March 14-15.

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24. Afaq, R.M., P. Strosser, A.H. Hakim S U. Rahman. and C. Garces. 1994. Final. Report on Crop-based Irrigation Operations in the North West Frontier Province of Pakistan. Volume III: Data Collection Procedures and Data Sets. International Irrigation Management Institute. Lahore. Pakistan

ANNEX-2

LIST OF PARTICIPATING IIMI STAFF IN CBIO'S STUDY ACTIVITIES

IIMI TEAM (JULY TO DECEMBER 1991)

A. International Staff

1. Carlos Garces, Irrigation Engineer and Project Team Leader
2. Tissa Bandaragoda, Senior Management Specialist
3. Pierre Strosser, Agricultural Economist

B. National staff

(fielded at D.I. Khan)

4. Abdul Hakeem Khan, Field Research Professional
5. M. Rafiq Khan, Senior Field Assistant
6. Mahmood Ahmad, Field Assistant
7. Talha Awan, Field Assistant
8. Arshad Nadim, Field Assistant
9. Habibullah Baloch, Field Assistant
10. Mohammad Iqbal, Driver

IIMI TEAM (JANUARY TO JUNE 1992)

A. International Staff

1. Carlos Garces, Irrigation Engineer and Project Team Leader
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4. Marcel Kupper, Agricultural Engineer
5. Erik Vån Waijjen, Agricultural Engineer
6. Jacques Rey. Modelling Specialist (IIMI-HQ)
7. Hamrnond Murray-Rust, Senior Irrigation Specialist (IIMI-HQ)

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9. Irfan H. Siddiqui, Field Research Professional
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11. Mahmood Ahmad, Field Assistant
12. Talha Awan, Field Assistant
13. Habibullah Baloch, Field Assistant
14. Abdul Maroof, Field Assistant
15. Sharif Ahmad, Field Assistant
16. Mohammad Iqbal, Driver

(based in Lahore)

17. Rana **M.** Afaq, Irrigation Engineer
18 Ms. Zhaigham Habib, Systems Analyst
19. Saeed Ur Rahman, Agricultural Economist
20. Muhammad Akram Khan, Secretary/data Entry

IIMI TEAM (JULY TO DECEMBER 1992)

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1 Carlos Garces, Irrigation Engineer and Project Team Leader
2 1issa Bandaragoda, Senior Management Specialist
3 Pierre Strosser, Agricultural Economist
4 Erik Van Waijjen, Agricultural Engineer

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6. M. Rafiq Khan, Senior Field Assistant
7. Talha Awan, Field Assistant
8. Abdul Maroof Field Assistant
9. Sharif Ahmad, Field Assistant
10. Nadir Khan. Field Assistant
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12. Mohammad' Iqbal, Driver

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13. Rana M. Afaq, Irrigation Engineer
'14. Ms. Zhaigham Habib, Systems Analyst
15. Saeed Ur Rahman, Agricultural Economist
16. Muhammad Akram Khan, Secretary/Data Entry

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17. M. Badruddin, IIMI-Pak Associate

IIMI TEAM (JANUARY TO AUGUST 1993)

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8. Abdul Maroof, Field Assistant
9. Sharif Ahmad, Field Assistant
10. Muhammad Ishaque, Field Assistant
11. Muhammad Asif Javed, Field Assistant
12. Mohammad Iqbal, Driver

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13. Rana M. Afaq, Irrigation Engineer
14. Ms. Zhaigham Habib, Systems Analyst
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17. M. Badruddin, IIMI-Pak Associate

IIMI TEAM (AUGUST 1993 TO JUNE 1994)

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1. Carlos Garces, Irrigation Engineer and Project Team Leader
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5. Abdul Hakeem Khan, Field Research Professional
6. M. Rafiq Khan, Senior Field Assistant**
7. Talha Awam. Field Assistant**
8. Abdul Maroof, Field Assistant**
9. Sharif Ahmad, Field Assistant**
10. Muhammad Ishaque, Field Assistant'"
11. Muhammad Asif Javed, Field Assistant**
12. Mohammad Iqbal, Driver**

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13. Rana M. Afaq. Irrigation Engineer
14. Ms. Zhaigham Habib, Systems Analyst
15. Saeed Ur Rehman, Agricultural Economist
16. Muhammad Akrarn Khan, Secretary/Data Entry

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* until end of August 93 only
** until end of October 93 only