Crop-based irrigation | irrigation scheduling | irrigation operation
irrigation canals | water control

Report # R-72

Operations Supports for
Pehur High-Level Canal Project

SCHEDULING MODEL FOR CROP-BASED IRRIGATION OPERATIONS

By

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ABBREVIATIONS

AF	Acre Feet
CBIO	Crop-Based Irrigation Operations
CCA	Culturable Command Area
CRBIP	Chasma Right Bank Irrigation Project
CRBC	Chasma Right Bank Canal
GCA	Gross Command Area
FSL	Full Supply Level
FDD	Full Design Discharge
IRSA	Indus River System Authority
IIMI	International Irrigation Management Institute
MAF	Million Acre Feet
MSBO	Modified Supply-Based Operations
NWFP	North West Frontier Province
PC-1	Planning Commission Document 1
PHLC	Pehur High-Level Canal
SAR	Staff Appraisal Report
SBO	Supply Based Operations
SIC	Simulation of Irrigation Canals
SPMP	Systems Performance Monitoring Project
TAM	Technical Assistance Mission
USC	Upper Swat Canal
WAA	Water Apportionment Accord
WAPDA	Water and Power Development Authority

GLOSSARY OF LOCAL TERMS

Chak	Area irrigated for a single watercourse.
Chakbandi	Process of demarcating the individual chaks.
Kharif	The hot (summer) season.
Mogha	Outlet from minor or distributary into the watercourse.
Nucca	Outlet from watercourse into a farm ditch.
Nullah	Gully (flood or hill torrent channel).
Rabi	The cool (winter) season.
Warabandi	Seven-day water allocation or scheduling pattern where each farmer is allotted a date and time for water diversion to his fields from the nuccas.

FOREWORD

The concepts underlying crop-based irrigation operations (CBIO) were derived during April 1995. Initial discussions were held with Dr. Kobkiat Pongput, Professor of Water Resources Engineering, Kasetsart University, Bangkok in early 1998 to develop a scheduling model for CBIO. During the months of February, March and April of 1998, Dr. Kobkiat developed a draft report of the CBIO Scheduling Model.

Mr. Juan Carlos Aluralde, a citizen of Bolivia pursuing on M.Sc. degree at the Katholic University in Leuven, Belgium, arrived in Lahore during late April to spend six months with IIMI. His assignment was to apply the CBIO Scheduling Model to Chasma Right Bank Canal (CRBC) under a contract, "Computerised Planning for Operating CRBC." This assignment was completed in late October of 1998.

During November and December of 1998, we have refined the CBIO Scheduling Model as contained in this report. Next year, we will apply this model to the Upper Swat Canal (USC) and Pehur High-Level Canal (PHLC). When PHLC is commissioned, we well undertake in co-operation with the Irrigation Department of North West Fronteir Province the collection of field data as specified in Section 5 of this report in order to effectively implement CBIO for the USC-PHLC system.

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SUMMARY

For canals having a high water duty, say exceeding six cusecs per thousand acres of culturable command area (CCA), crop-based irrigation operations (CBIO) becomes an attractive option early and late in the cropping season when the crop water requirements are much less than the peak water demands. In fact, CBIO become increasingly more beneficial as the water duty is increased.

One of the principal benefits resulting from CBIO is reduced groundwater recharge. This is particularly important for irrigated areas that are susceptible to waterlogging and salinity, However, the major benefit is in terms of increased agricultural productivity. Farmers will establish a cropping pattern commensurate with the water duty, employing crops that provide higher farm incomes as much as possible, which are often the crops having higher crop water requirements.

There are two approaches for applying CBIO: (1) provide reduced discharge rates to the secondary canals; or (2) operate the distributaries at full supply discharge, but rotate among these canals so that some are open and some closed. The second approach is best because more cropland can be irrigated and there will be less sediment deposition in the secondary and tertiary canals.

A cycle duration is the sum of the open period plus the closed period, with each period begin measured in terms of the time length of a warabandi, which is commonly one week. To maximise crop production, the closed period during a cycle duration should only be one warabandi.

Generally, the cycle durations to be employed for CBIO will be: one warabandi open and one warabandi closed, which would imply operating the canal or branch canal at 50 percent discharge capacity, although this could be increased by 10-20 percent if desirable; two warabandis open and one warabandi closed, with the canal operating at 67 percent capacity; and three warabandis open and one warabandi closed, which would imply operating the canal or branch canal at 75 percent discharge capacity.

Three methods are presented for arriving at groups at distributaries, with the main objective of having each of the groups with nearly the same total discharge requirement. For example, if the distributaries are formed into twelve groups, then it becomes easy to combine groups into two clusters (one warbandi open and one warabandi closed), three clusters (two warabandis open and one warabandi closed), or four clusters (three warabandis open and one warabandi closed).

The daily discharge schedules for each distributary head regulator, each cross-regulator and the canal headworks can be prepared prior to each season. However, the actual operations require the field calibration of each flow control structure, channel losses are measured for each reach between two cross-regultors, and the lag times have been measured for each canal reach and each distributary channel.

When implementing CBIO, considerable monitoring will be required for about two years in order to refine the daily discharge schedules. This monitoring should include periodic discussions with the farmers during each season to assess the quality of services being provided, as well as making adjustments to improve service in order to enhance agricultural productivity.

SCHEDULING MODEL FOR CROP-BASED IRRIGATION OPERATIONS

1. INTRODUCTION

1.1 BACKGROUND

Water Duty is a term that expresses the allocation of water (expressed as a discharge rate) per unit of cultivated land. In Pakistan, water duty has been calculated as the design discharge at the head of a canal in cusecs divided by the culturable command area (CCA) of the canal command area in thousands of acres. Thus, water duty is presented in terms of cusecs per thousand acres of CCA.

Most of the 43 canal commands in Pakistan were designed with a water duty in the range of 3.5-4.5 cusecs per thousand acres of CCA. During the last decade, or more, irrigation development in North West Frontier Province (NWFP) has focused on achieving higher canal water duties, such as 8-12 cusecs per thousand acres of CCA. For example, Lower Swat Canal has been remodelled to provide a water duty of 14 cusecs per thousand acres of CCA. Pehur High-Level Canal (PHLC) is presently under construction from Tarbela Reservoir on the Indus River to Machai Branch of Upper Swat Canal (USC) that will result in a water duty of 8.6 cusecs per thousand acres of CCA. Stages I and II of the Chasma Right Bank Canal (CRBC) has been completed and the construction of Stage III is underway that will complete this project having a water duty exceeding 8 cusecs per thousand acres of CCA.

High water duties are very beneficial to farmers because they can choose crops that have higher crop water requirements (e.g. rice) and higher farm income (e.g. sugarcane). However, larger discharges will most likely result in greater recharge to the groundwater and a higher likelihood of waterlogging. Also, there is a tendency at times to "drown" the surface drain network.

Crop-based irrigation operations (CBIO) is to be employed at both USC-PHLC and CRBC. This is an improvement on supply-based operations wherein less water is supplied early in the season and late in the season when crop water requirements are lower. CBIO is definitely not a demand method of operations. In fact, the term "crop-based" tends to indicate or imply an operational methodology where the crop water requirements are being satisfied. A more understandable terminology would be "modified supply-based irrigation operations."

1.2 ISSUES

A methodology needs to be developed for applying CBIO to operate canals having a high water duty (say greater than 6 cusecs per thousand acres). The CBIO schedules resulting from applying this methodology will be field tested in a few years at both USC-PHLC and CRBC, which will provide even more sensitivity about implementing CBIO.

The major issue being addressed in this report is developing the methodology for arriving at appropriate CBIO schedules. An important point is that these water delivery schedules can be developed prior to an irrigation season. These schedules include the times for each distributary when open or closed, which can be posted at each distributary head regulator; in addition, the discharge rate schedule for each cross-regulator and the headworks of a canal is provided.

1.3 APPROACH

The International Irrigation Management Institute (IIMI) has a contract with the Irrigation Department of NWFP on "Operations Support for Pehur High-Level Canal Project". Beginning in February 1998, IIMI began developing a CBIO model with the assistance of a consultant, Dr. Kobkiat Pongput, Kasetsart University, Thailand.

IIMI also has a contract with WAPDA on "Computerized Planning for Operating Chasma Right Bank Canal". The CBIO model was applied to CRBC under this contract in another report (Alurralde, Gandarillas and Skogerboe, 1998). This is a very simple model that provides the open/closed schedule during the early and late portions of an irrigation season for clusters of distributaries located along a canal reach between two cross-regulators, or scattered along the full length of the canal.

Applying the CBIO model to CRBC (Alurralde et al, 1998) provided insights regarding the open/closed scheduling of individual distributaries. Two methods have been developed: (1) a rotation schedule for each of the distributaries in a reach when the cross-regulators are far apart, such as in NWFP; and (2) rotation schedule among reaches when there are sufficient cross-regulators such as in Punjab Province of CRBC.

The learning derived from applying the CBIO model to CRBC has been incorporated into this improved CBIO scheduling model. This report describes in detail this model. Then, this model will be applied to the USC-PHLC system under the PHLC contract during 1999.

2. CROP-BASED IRRIGATION OPERATIONS

2.1 CONCEPT

The concept of crop-based irrigation operations (CBIO) is to reduce the amount of groundwater recharge, which will consequently reduce waterlogging, as compared with supply-based operations. CBIO is a modification of supply-based operations that becomes increasingly more beneficial as the water duty allocated to a canal command area increases. For example, many of the canal commands in the Indus Basin Irrigation System have water duties of 3.5-4.5 cusecs per thousand acres wherein implementing CBIO would only provide nominal benefits. In contrast, the Chasma Right Bank Irrigation Project (CRBIP), or the Upper Swat Canal and Pehur High-Level Canal (USC-PHLC) system, each with a water duty of more than 8 cusecs/1,000 acres, are highly suited for CBIO.

A typical curvilinear relationship of crop water requirements during an irrigation season is shown in Figure 1 for a canal or distributary command area. With supply-based operations, the peak water requirement is dictated by the water duty. Farmers decide upon their cropping pattern based on the allocated water duty, as well as their past experiences with the reliability of the canal water deliveries and the degree of equity in water distribution. Thus, CBIO is applied when the crop water requirements are less than the water duty, which occurs at the beginning of the irrigation season and late in the season.

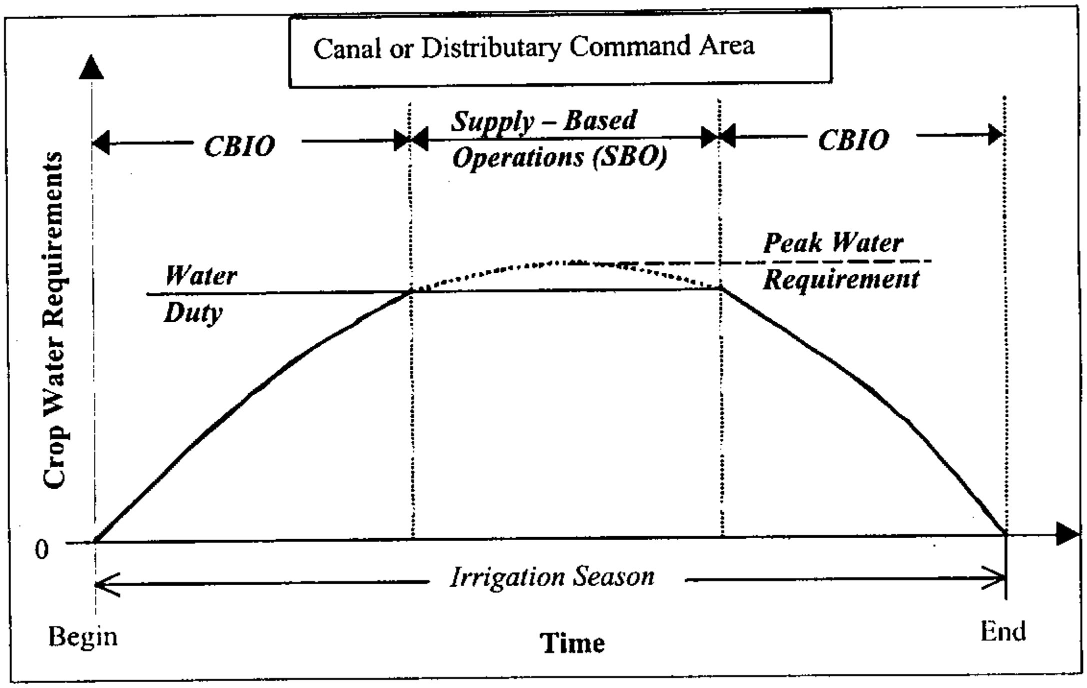


Figure 1. Schematic of crop water requirements during an irrigation season for a irrigation channel command area.

There are two possible approaches for implementing CBIO. During periods of lower crop water requirements, each distributary head regulator can be operated at : (1) a lower discharge rate; or (2) the Full Supply Level (FSL) discharge rate (equal to the water duty in cusecs/1,000 acres multiplied by the culturable command area, CCA, in acres divided by 1,000) can be maintained for some number of days and then closed for a number of days. There are three very important considerations in deciding which approach to implement.

Reducing the discharge rate at the distributary head regulator will definitely alter the distribution of water through the moghas that control the inflow to each tertiary watercourse channel. Since these moghas have fixed openings without gates, the discharge through a mogha is dictated by the water level in the distributary (as well as the downstream water level in the watercourse when submerged flow occurs). Changing the discharge rate entering the distributary will change the water surface gradient along the distributary channel, which in turn, will modify the distribution of water into the watercourses, where more and more of the watercourses in the tail reach receive no water as the discharge continues to be decreased at the distributary head regulator.

Watercourses are operated on a warabandi, which is usually a seven-day schedule of water turns for each landowner, whose turn in minutes each week is allocated on the basis of culturable command area owned. When a farmer receives a fraction of the normal discharge, the amount of land that can be irrigated will be less than this fraction. For example, if a farmer receives only half of the normal watercourse discharge rate, then perhaps only one-third, and in some cases one-fourth, of the bunded fields can be irrigated as compared with normal flow.

Decreasing the discharge rate entering a distributary channel will reduce the sediment transport capacity for the channel that will result in increased sediment deposition in the distributary.

Based on these three considerations, the most favourable approach is to operate the distributaries at their FSL discharge rate on a rotational basis that closely resembles the curve of changing crop water requirements throughout each season.

2.2 METHODOLOGY

The methodology described below is fairly general; however, the situation at CRBC will be used to illustrate some points.

2.2.1 Water Duty

In Pakistan, the water duty, WD or Q_{WD}, is expressed in cusecs per 1,000 acres of culturable command area (CCA).

In general, the water duty is the difference between the canal capacity and the canal conveyance losses divided by the area of the croplands to be irrigated, which can be expressed as :

$$Water\ Duty = \frac{Canal\ Capacity - Canal\ Conveyance\ Losses}{Irrigated\ Area} \tag{1}$$

The canal capacity may be an allocated discharge, design discharge or a measured discharge. Often, the canal conveyance losses are estimated. For designing a canal, this has to be the case. For an operating canal, the canal conveyance losses should be measured.

2.2.2 Hydrograph of Canal Water Deliveries

Of major importance is defining the hydrograph at the canal headworks. During the middle of the irrigation season, supply-based operations (SBO) will be used. Thus, the real difficulty is developing the hydrographs for CBIO early and late in the season as illustrated in Figure 1, which are the result of pre-project planned cropping patterns.

For existing irrigation projects, the cropping patterns are fairly well known. Therefore, the crop water requirements can be calculated for various time intervals during the season, plot the data, and draw a curvilinear relationship similar to Figure 1. Also, historical operating experiences can be drawn upon in defining the shape of this curvilinear relationship.

In developing the canal hydrograph, it is better to error by showing a higher crop water requirement. When implementing CBIO, a monitoring and evaluation program should be used to refine the water delivery schedules. The preference is to move from water deliveries that are too high and lower these supplies based on field experience while implementing CBIO.

Once the canal hydrograph has been developed, then the time periods for CBIO and SBO can be delineated as illustrated in Figure 1. This delineation will be adjusted in accordance with the procedures described in the next section.

2.2.3 Seasonal CBIO Hydrograph Analysis

2.2.3.1 Canal CBIO Duration

A common practice in Pakistan is to rotate water turns in tertiary watercourse irrigation channels, called warabandi, where a farmer has the full watercourse supply for a duration of time in accordance to landholding as culturable command area (CCA). Most frequently, the warabandi has a duration of one week. Thus, the duration of CBIO, either early or late in the season, should in both cases be some multiple of the warabandi duration. For most canal commands, the duration of crop-based irrigation operations should be in multiples of weeks.

2.2.3.2 Canal Cycle Duration Options

Another important consideration for CBIO is the duration of a cycle period, which is the sum of the time that the secondary canals are open plus closed. Most importantly, preference is given to having the duration of the closed period only one tertiary channel rotation (warabandi) period. Since the warabandi for most canals is one week, this would imply that the closed period during each cycle duration should preferably be only one week.

The minimum cycle period for a canal would generally be two weeks, with one week open and one week closed. This would be followed by two weeks open and one week closed,.which is a cycle of three weeks duration. In turn, the secondary canals (distributaries) can be open for three weeks, four weeks and more, with one week closed.

2.2.3.3 Canal Cycle Discharge Rates

For a two-week cycle duration consisting of one week open and one week closed, the discharge rate at the canal headworks should be 50 percent of the design discharge, or full supply discharge (FSD). The simple relationship is :

$$Canal\,Cycle\,Discharge = \frac{Open\,Period}{Cycle\,Duration} \cdot FSD \tag{2}$$

$$= Discharge\ \ Fraction \cdot (FSD) \tag{3}$$

The results are given in Table 1.

Table 1. Discharge fraction for various cycle durations.

Open Period	Closed Period	Cycle Duration	Discharge Fraction
1	1	2	0.50
2	1	3	0.67
3	1	4	0.75
4	1	5	0.80
5	1	6	0.83

As the cycle duration increases, the discharge fraction increases only nominally. This would imply the use of shorter cycle durations of two, three and four, but this is not a rigid guideline, rather it is a practical consideration.

2.2.3.4 Adjusting Canal Cycle Discharge Rates

There is another degree of flexibility in implementing CBIO. The discharge rates can be either increased or decreased a nominal amount. Most secondary canals can be operated at a discharge rate 10 percent greater than FSD.

Generally, it is most desirable to increase the discharge rate for the shortest cycle durations; primarily to reduce the amount of sediment deposition in the canal. Consequently, first preference would be given to increasing the discharge rate for the shortest cycle duration.

At the same time, discharge rates can be reduced. Usually, this is avoided for the reasons given in Section 2.1. However, this may have to occur where there is a water supply constraint. If this is the case, then preference would be given, first of all, to reduce the water duty for supply-based operations (SBO), followed by the longer cycle durations being used during crop-based irrigation operations (CBIO).

2.2.4 Distributary Rotation Schedules

2.2.4.1 Rotation Among Reaches

If there are sufficient cross-regulators along a canal, then it may be feasible to rotate among reaches defined by these cross-regulators. Then, all of the distributaries between two cross-regulators will either be open or closed.

For a cycle duration of two, with one time period open and one time period closed, the rotation would be done among two reaches. Likewise, for a cycle duration of three, with two time periods open and one time period closed, three clusters of reaches would be used for developing the rotation schedule for each reach.

The number of reaches along a canal is not likely to be some multiple of two, three or four. Thus, there may be a need to: (1) group two reaches together, usually selecting the reaches having the lowest discharge requirements for combining with one another or combining with a reach having an intermediate discharge requirement; (2) operate one or two reaches independently without combining with any other reaches; or (3) operate one or two reaches where the distributaries within the reach are rotated as described below.

2.2.4.2 Rotation Among Distributaries

Most commonly, CBIO will be implemented by rotating water deliveries among the distributaries in a reach, or developing clusters of distributaries scattered along the full length of the canal. Either each reach is an independent exercise, or the full length of the canal is used to develop clusters of distributaries. For a cycle duration of two, with one time period open and one time period closed, the distributaries in a reach will have to be clustered into two groups of nearly equal total discharge requirement. Similarly, a cycle duration of three, with one time period closed, requires that the distributaries in a reach be clustered into three groups of fairly equal total discharge requirement. A cycle duration of four, with one time period closed, requires four clusters of distributaries in each reach. The alternative is to define these clusters along the full length of the canal, which has the advantage of minimizing the variation in total discharge for each cluster.

2.2.4.3 Schedule Adjustments for Lag Times

One time period in a cycle duration represents the time required to rotate the water supply in a tertiary irrigation channel to all of the farmers. However, when the gates of a secondary canal are opened, a tertiary channel located nearby will begin to receive water in just a few minutes, while the last tertiary channel at the tail of the secondary canal will not receive any water until hours later. Also, when the secondary canal gates are closed, the discharge rate entering the head tertiary channel will rapidly decline, while the tail tertiary channel will continue to receive water. A perfect solution would be that the lag times to the tail tertiary channel are identical when opening the secondary canal gates and when closing them. Unfortunately, this is usually not the case.

There is a crucial need to adjust the secondary canal (distributary) rotation schedules so that each tertiary channel receives water for a sufficient duration so that every farmer receives water. This can be accomplished by field measurements of lag times, which will be described in Section 5 on "Field Measurements for Refining Schedules".

3. CANAL HYDROGRAPH ANALYSIS

3.1 IRRIGATION CANAL SYSTEM

3.1.1 Canal System

An irrigation canal system is a linkage of different size canals for carrying water to serve the irrigated area (see Figure 2). The main canal system is typically composed of principal and secondary canals. In the principal canals, there are canals and branch canals, which is a branch from the main canal. The secondary canals are distributaries and minors.

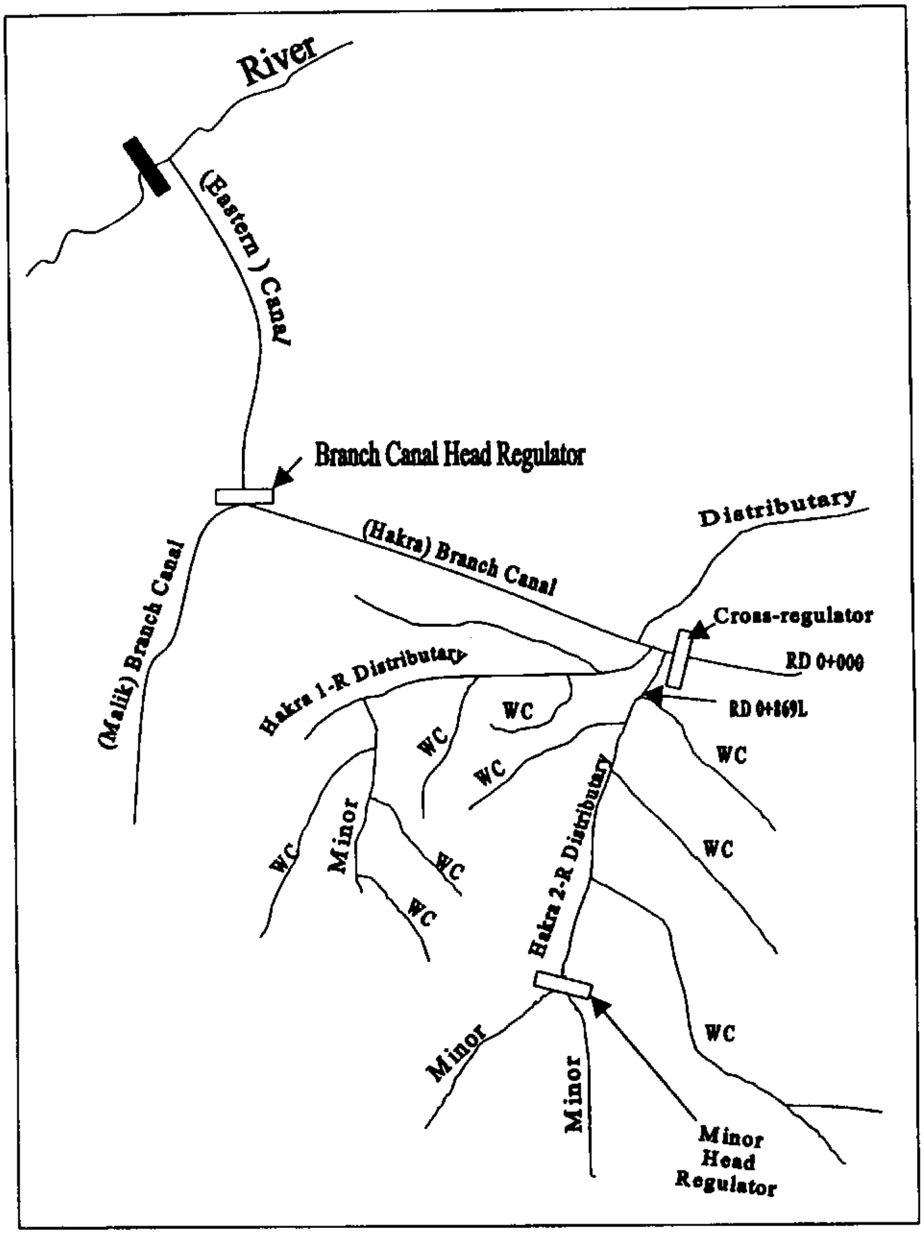


Figure 2. Example of an irrigation canal system.

The lowest levels of the canal system are tertiary and quaternary canals. The tertiary canals are called watercourses. The quaternary canals are the small channels from the watercourse to the farmer's fields.

In any canal, the maximum allowable canal discharge is the designed canal capacity. While the minimum operating canal discharge typically depends on the operation criteria, such as maintaining sufficient velocity to minimize sediment deposition.

3.1.2 Water Control Structures

There are also many control structures in the canal system. The structures can be classified as main structures and ancillary structures such as bridges and canal drains. The main structures along the canal are cross regulators, escape regulators, and distributary head regulators.

The main functions of the cross regulators are:

- Maintaining the upstream water level required for the off-taking distributaries; and
- Regulating the supply of water downstream depending on the demand.

The purposes of the escape regulators are to:

- Operate as a temporary control during the construction of the canal;
- Pass the canal full supply discharge to the natural surface drain channel in the event of sudden closure due to a breach; and
- Remove sediment that accumulates in the canal reach upstream.

The purpose of the distributary head regulators is to control the flow of water into the distributary canals.

3.2 WATER SUPPLY CHARACTERISTICS

Water supply characteristics typically depend on the type of water source for the canal system. There are two main types of water sources; namely, the run-of-the-river source and the reservoir source.

3.2.1 Run-of-the-river Sources

The run-of-the-river source supplies water available in the river directly to the canal system without reservoir storage. A barrage or a weir would be constructed in the river to sufficiently raise the head in the main irrigation canal as shown in Figure 3. Available runoff in the river is dependent on the physical and climatic characteristics of the watershed. Sources of water in the watershed come mainly from either rainfall or snowmelt, or both.

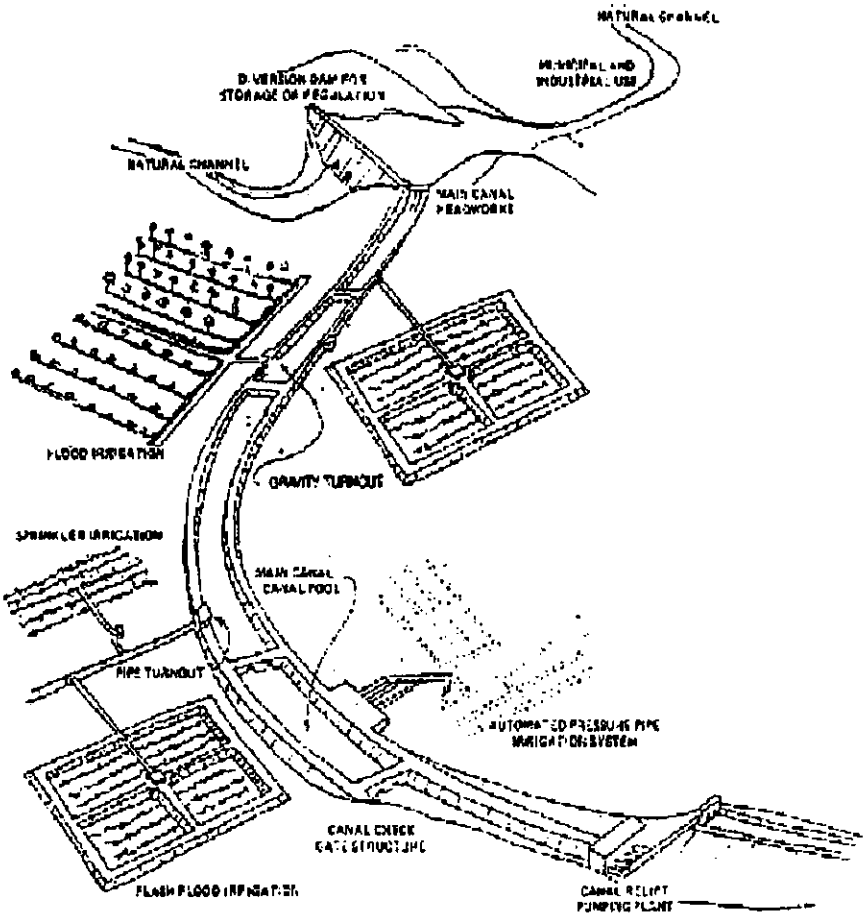


Figure 3. Schematic of run-of-the-river water source and irrigation canal system.

Often, a problem of mismatch between supply and demand occurs because of the uncertainly of the available water in the river sources. If inadequate supplies are available at the time of sowing, the area being cultivated will be restricted. Excess supplies available later in the season will cause the sowing period to be protracted beyond the proper time for sowing of some crops. Low agricultural productivity results as the water supply falls short of the crop water requirements during critical stages of crop growth.

3.2.2 Reservoir Sources

The reservoir source has a volume of reserved water to be supplied to the irrigation canal system. Excess water in the river could be stored in the reservoir for use during low flows in the river. This could minimize the uncertainty of water in the river. If sufficient reserved water is available in the reservoir, the water supply to the cropland will only be restricted by the discharge capacity of the irrigation canals.

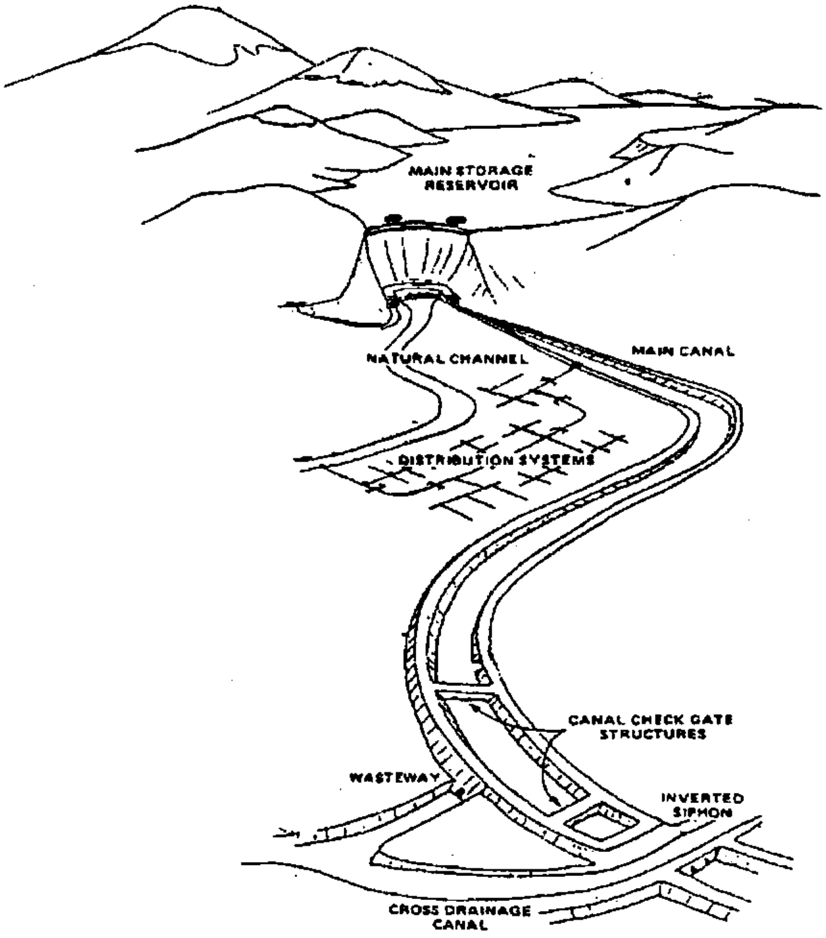


Figure 4. Schematic of reservoir water source and irrigation canal system.

3.3 GENERAL SHAPE OF CROP WATER REQUIREMENTS

Crop water requirements are theoretically calculated as a crop coefficient multiplied by potential evapotranspiration. The general shape of a crop water requirement, which is a relationship of crop water requirement with time, is a combination of crop coefficient, cropping pattern, and potential evapotranspiration.

3.3.1 Crop Coefficients

Crop coefficients vary from crop to crop. For a crop type, the crop coefficient also varies with crop age. Figure 5 shows some crop coefficient relationships as adapted from FAO CROPWAT 7.0.

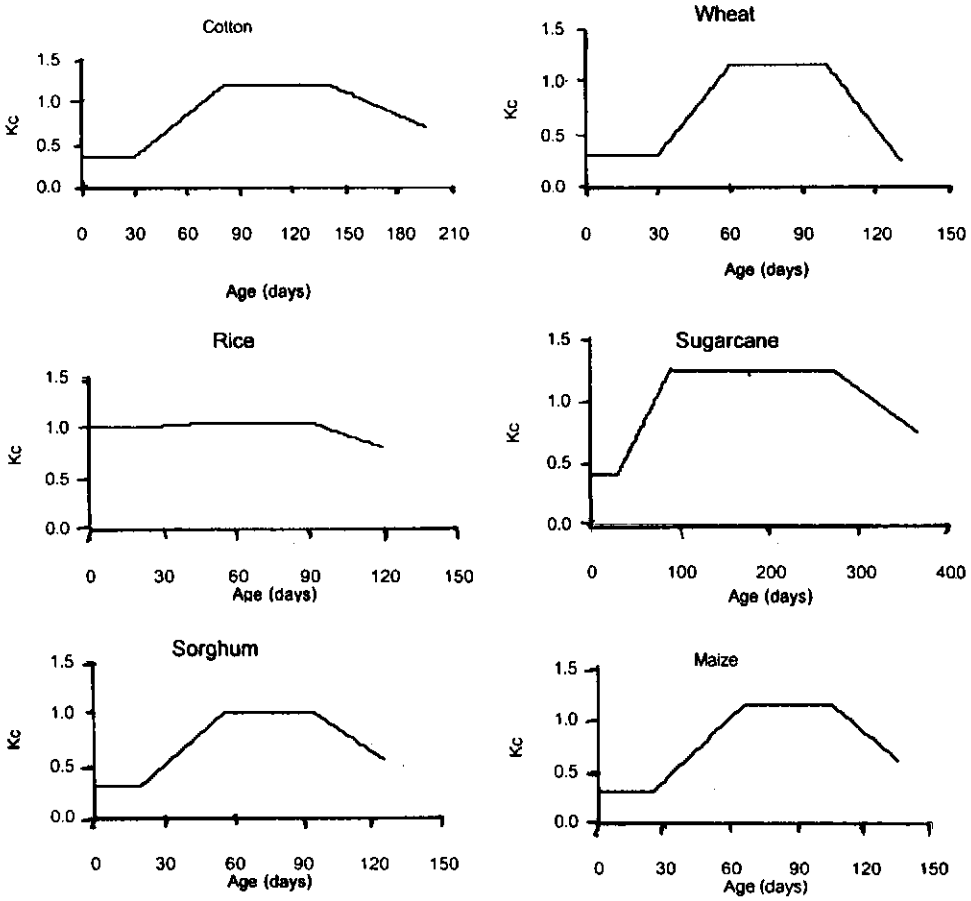


Figure 5. Crop coefficients for selected crops as adapted from FAO CROPWAT 7.0.

3.3.2 Cropping Pattern

Within any one irrigated area, the cropping pattern is a result of numerous individual decisions made by the farmers who are cropping the land. The mix of crop options open to the farmer is normally constrained by physical and financial factors.

In Pakistan, within the major irrigated areas, the choice of suitable crops having major economic importance is comparatively small. In summer, heat-tolerant crops are required, such as paddy, cotton, sugarcane, maize, millet and sorghum, and a few grain legumes. Because of the cooler weather and occasionally frost in the rabi winter season, the choice is largely confined to wheat and barley, brassica oilseeds, various grain legumes and berseem. Sunflower, being quick maturing, is also finding a niche as a late summer, or alternatively, a late spring sown crop.

In practice, farmers are expected to respond to soil conditions by attempting to crop paddy at low intensities wherever the heavier soils occur. The planners felt that it would be desirable that the concentration of paddy culture in any one location should be discouraged. Severe drainage problems can be expected to develop if the intensity of paddy is allowed to increase.

Under these considerations, an example of a design cropping pattern under a cropping intensity of 140% is shown in Figure 6.

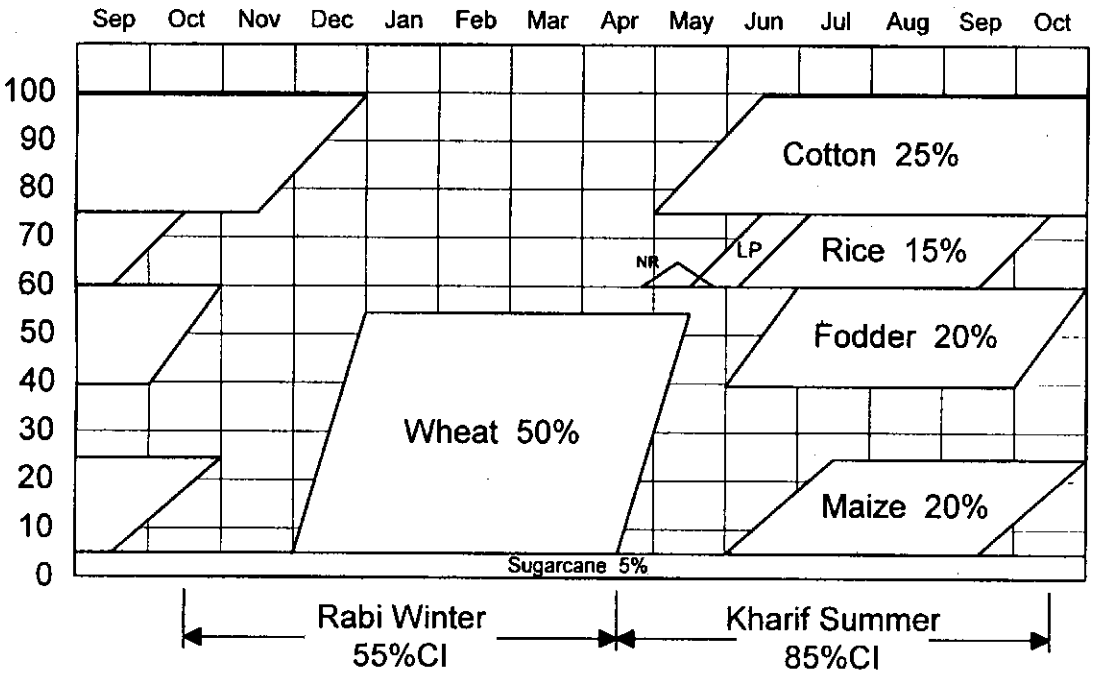


Figure 6. Design cropping pattern for use as an example.

3.3.3 Potential Evapotranspiration

Potential evapotranspiration is a function of climatic data. The calculations are somewhat complicated. Fortunately, FAO CROPWAT 7.0, using data from Peshawar and Chaklala, facilitates these calculations. The average daily potential evapotranspiration for each month is presented in Table 2.

Table 2. Potential evapotranspiration for two selected meteorological stations in North West Frontier Province.

	Peshawar	Chaklala	Average (mm/day)	Average (cusecs/1000 acres)
January	1.70	1.90	1.20	1.98
February	2.30	3.10	1.80	2.98
March	3.20	4.00	2.40	3.97
April	4.50	6.50	3.67	6.06
May	7.30	8.90	5.40	8.93
June	8.40	10.10	6.17	10.20
July	7.40	7.10	4.83	7.99
August	6.30	5.70	4.00	6.61
September	5.00	5.30	3.43	5.68
October	3.90	4.30	2.73	4.52
November	2.60	3.20	1.93	3.20
December	1.80	2.10	1.30	2.15

3.3.4 Crop Water Requirement

Crop water requirements are calculated for a fixed cropping pattern. Figures 7 and 8 show relative crop water requirements. Figure 8 shows crop water requirements for an example CCA of 2.2 million acres. The fixed cropping pattern for the Rabi and Kharif seasons is presented in the previous section.

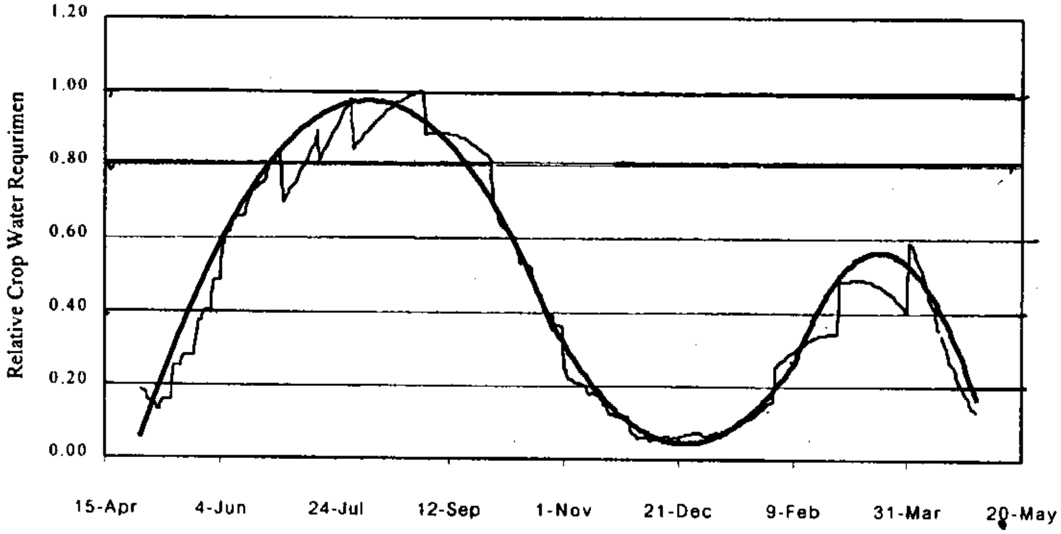


Figure 7. Relative crop water requirement for the example cropping pattern in Figure 6.

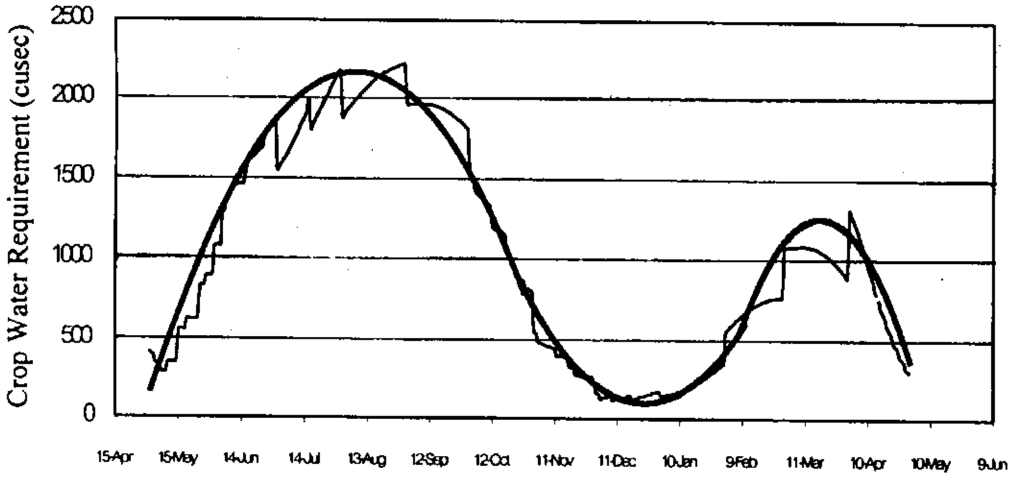


Figure 8. Crop water requirement for an example CCA of 2.2 million acres.

3.4 WATER DUTY

The water duty for a culturable command area is based on available water supplies and canal constraints. For a culturable command area, the water supply can be calculated based on the command area and water duty. The maximum water duty, as illustrated in Figure 3, is limited by the maximum canal discharge and can be calculated using the follow equation:

$$Q_{WD} = \frac{Q_{MX} - Q_{LS}}{CCA_C} \cdot 1{,}000 \tag{4}$$

Where

Q_{wd}	Water duty	[cusecs/1,000 acres]
Q_{MX}	Maximum discharge rate entering the canal head regulator	[cusecs]
Q_{LS}	Seepage from the canal	[cusecs]
CCA_C	Canal culturable command area	[acres]

Water supplies at the beginning (Q_{BoS}) and the end of season (Q_{EoS}) can vary depending upon crop types, characteristics of a canal, or other constraints. Water supplies during a season are divided into three phases. In Phase I, the water supply increases from Q_{BoS} to Q_{WD} and then remains constant at Q_{WD} during Phase II. In Phase III, the water supply decreases from Q_{WD} to Q_{EoS} as shown in Figure 9.

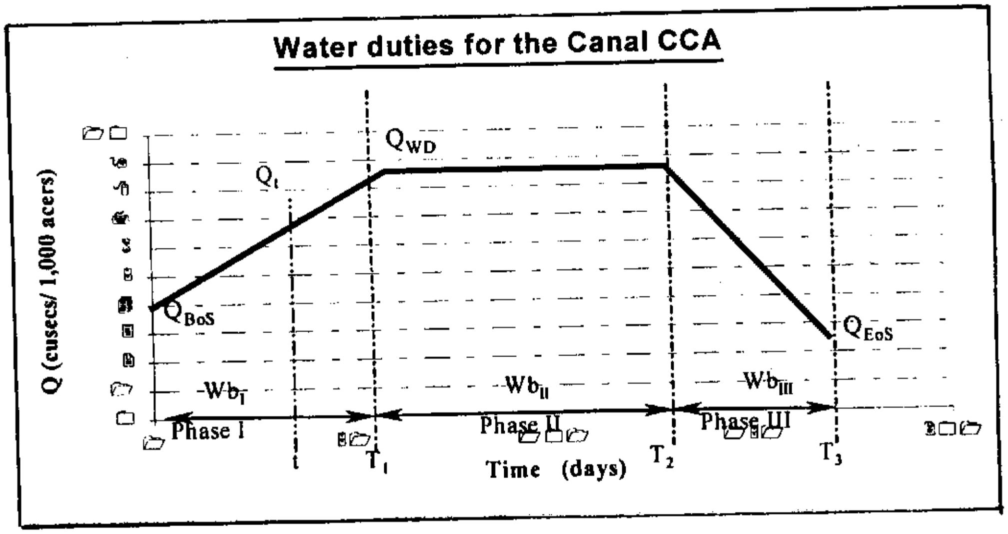


Figure 9. Parameters used in calculating the water supplies.

For a season, water supplies can be divided into three phases. The duration of each phase would probably be certain for any particular crop. However, for a culturable command area, where many crops are planted at different times, the duration of each phase is a combination of different stages of crop growth with many crop types, so that it becomes quite variable (see Table 3).

Table 3. Range of duration of the three phases in the water supply hydrograph.

Phase	Number of days, (weeks)
I	40-60, (6-9)
II	60-80, (9-11)
III	20-40, (3-6)
Total	120-180, (17-27)

The water supply at any day during Phase I could be calculated using the following equation:

$$Q_t = \left(\frac{Q_{WD} - Q_{BoS}}{T_I}\right)\cdot t + Q_{BoS} \tag{5}$$

Where

Q_t	Water supply at the day t	[cusecs/1,000 acres]
t	Time in Phase I from the beginning of the season	[days]
Q_{WD}	Maximum water duty	[cusecs/1,000 acres]
Q_{BoS}	Water supply at the beginning of the season	[cusecs/1,000 acres]
T_I	Time at the end of Phase I	[days]

The water supply at any day during Phase III could be calculated using the following equation:

$$Q_t = \left(\frac{Q_{EoS} - Q_{WD}}{T_{III} - T_{II}} \right) \cdot (t - T_{III}) + Q_{EoS} \tag{6}$$

Where;

Q_t	Water supply at the day t	[cusecs/1,000 acres]
t	Time in Phase III from the beginning of the season	[days]
Q_{WD}	Maximum water duty	[cusecs/1,000 acres]
Q_{EoS}	Water supply at the beginning of the season	[cusecs/1,000 acres]
T_{II}	Time at the end of Phase II	[days]
T_{III}	Time at the end of Phase III (end of the season)	[days]

Table 4. Summary of time, duration, and water supplies for each phase of a season.

Phase	Time	Duration (warabandis)	Water duties (cusecs/1,000 acres)
I	$0 < t \leq T_I$	Wb_I	$Q_{BoS} < Q_t \leq Q_{WD}$
II	$T_I < t \leq T_{II}$	Wb_{II}	$Q_t = Q_{WD}$
III	$T_{II} < t \leq T_{III}$	Wb_{III}	$Q_{WD} > Q_t \geq Q_{EoS}$
Total	$0 \rightarrow T_{III}$	$Wb_I + Wb_{II +} Wb_{III}$	

According to past experiences, the values of Q_{BoS} and Q_{EoS} can be roughly assumed as 50% and 40% of Q_{WD}, respectively (see Table 5).

Table 5. Roughly estimated values of water supplies compared with water duty.

Water Duties	Roughly Estimated Values
Q_{WD}	Calculated by Equation (4)
Q_{BoS}	50-75% of Q_{WD}
Q_{EoS}	40-50% of Q_{WD}

4. DEVELOPMENT OF SCHEDULING MODEL

This chapter explains the development of the scheduling model. Examples used in this chapter are based on the crop water requirement calculation in Chapter 3. The irrigation canal systems in these examples are assumed to be typical systems found around the world, but certainly in the Indian Subcontinent.

4.1 CLOSURE PERIOD AND OPERATIONAL SEASONS

4.1.1 Closure Period

A closure period is needed for annual repairs and maintenance, such as sediment removal. A 30-day closure period would executed every year during December and January. Although the closure period will always have a negative impact on the crops, its timing must be selected in terms of reducing crop water stress. Figure 10 shows an example for the selected closure period.

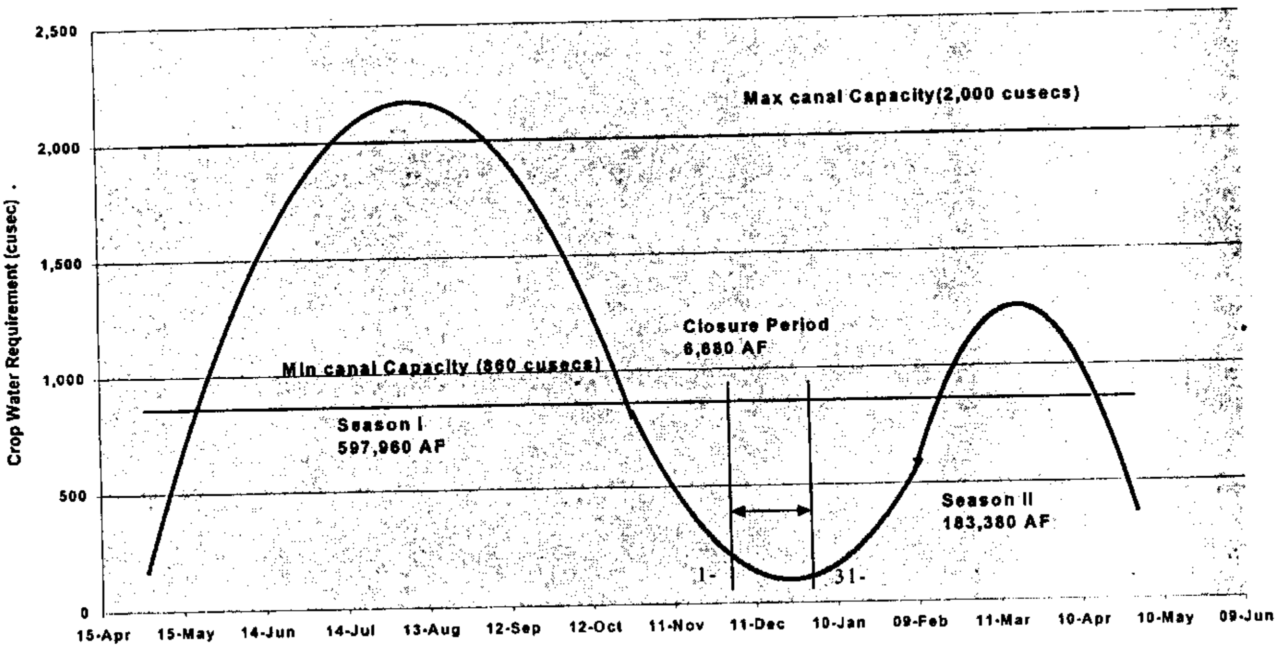


Figure 10. An example for the selected closure period.

4.1.2 Operational Seasons

According to the CBIO concept, it is necessary to select two seasons that closely resembles the curve of changing crop water requirements. For the example illustrated in Figure 11, a first period from the beginning of May to the beginning of December is selected, and a second period from the beginning of January to the end of April.

The CBIO seasons do not have to coincide necessarily with the traditional cropping seasons (rabi and kharif). The CBIO schedules must follow the shape of the crop water requirements. For example, Season 1 in Figure 11 contains the summer kharif season and the beginning of the winter rabi season (late October, November and December).

4.2 CBIO PHASES FOR EACH SEASON

In a CBIO phase, the water supply is a fraction of the maximum water supply requirements. To develop the water duty fraction during a CBIO phase, first of all, inclined lines must be drawn following the shape of the water supply requirements. Start at the lowest point of the seasonal beginning and draw a sloping straight line upwards to the highest level which defines Phase I (CBIO). Then, continue through the maximum water supply requirements to define Phase II (SBO). Finally, decrease to the lowest level at the end of the season, which is Phase III (CBIO). Figure 11 shows the CBIO and SBO phases with four deflection points.

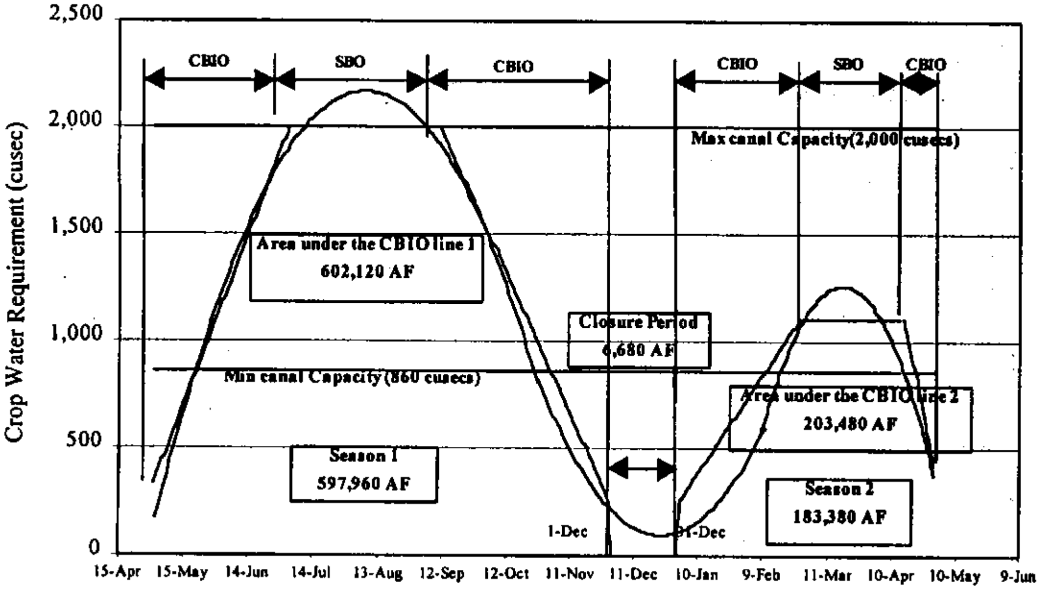


Figure 11. Defining the CBIO periods for each operational season.

The inclined lines connect (Q_{BoS}, 0) and (Q_{WD}, T_I) in Phase I, and (Q_{WD}, T_{II}) and (Q_{EoS}, T_{III}) in Phase III. The area under the inclined and horizontal lines define the volume of water supply during Phases I, II, and III. In addition, the volume of water supply should be close to the volume of crop water requirements during the season.

The volume of water supply, for each Phase, could be calculated using the following equations:

$$Vol_I = \frac{(Q_{BoS} + Q_{WD})}{2} \cdot Wb_I \tag{7}$$

$$Vol_{II} = Q_{WD} \cdot Wb_{II} \tag{8}$$

$$Vol_{III} = \frac{(Q_{WD} + Q_{EoS})}{2} \cdot Wb_{III} \tag{9}$$

Where;

Vol_I	**Volume of water supply during Phase I**	**[AF]**
Vol_{II}	**Volume of water supply during Phase II**	**[AF]**
Vol_{III}	**Volume of water supply during Phase III**	**[AF]**

4.3 OPEN WARABANDIS FOR EACH CBIO PHASE

In order to relate the volume of water required with the number of open weeks, a graphical procedure is established, which is shown in Figure 12. The two horizontal lines in Figure 12 represent the volume of water needed for the Phase I CBIO and Phase III CBIO. The sloping line is called the "volume function line", which represents the accumulated volume of water carried by the canal at full supply discharge.

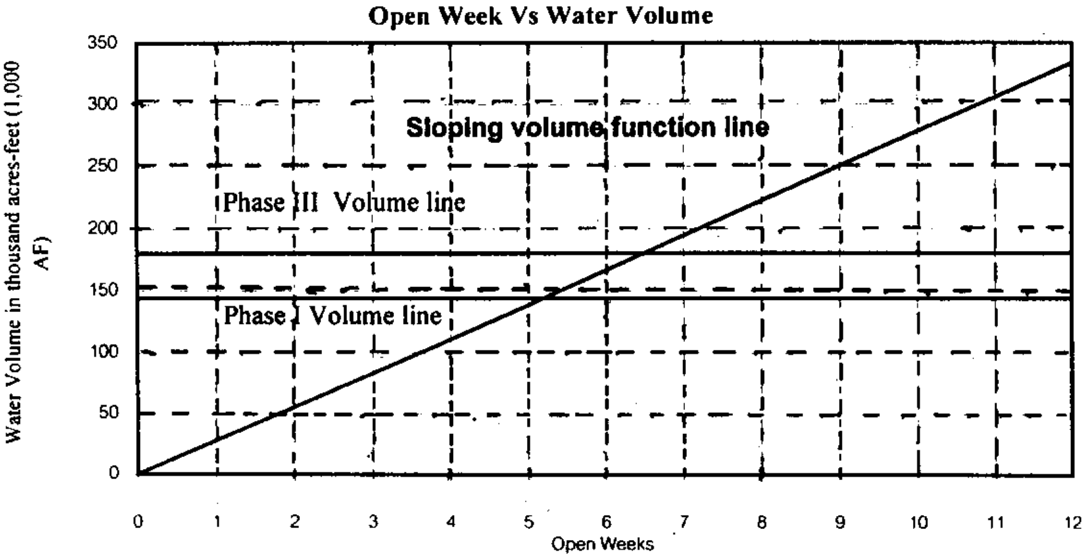


Figure 12. Example of selecting the number of open weeks for each CBIO phase of the first season.

The intersection with the "volume function line" gives the needed number of weeks open for each phase. Although it is not probable to match exactly the number of weeks for the volume required, the closest value in weeks should be selected. In the example, 6 weeks are selected corresponding to Phase I and 7 weeks for Phase III of the Season 1. Figure 12 shows that the selection corresponds to the closest lines for each phase.

The open warabandis for each CBIO phase can also be calculated by the following equations;

For Phase I,

$$Wb_I = \frac{Vol_I}{Q_{FSD}} \cdot \tag{10}$$

For Phase III,

$$Wb_{III} = \frac{Vol_{III}}{Q_{FSD}} \cdot \tag{11}$$

The number of open weeks calculated from the equations must be adjusted by rounding up (or off) to the nearest integer. Consequently, the volume of water, Vol_I and Vol_{III}, must be calculated using the reverse of Equations 10 and 11.

The number of closed weeks in Phases I and III simply are the difference between the total weeks minus the open weeks in each phase.

4.4 ROTATION CYCLE DURATIONS

Once the number of open and closed weeks for each CBIO phase of the season have been defined, there is a need to find the best combination possible in order to fit the CBIO graph with the initial hydrograph as illustrated in Figure 11.

Depending on the number of open and closed weeks selected, there are many combinations possible. For the example, 6 weeks open and 3 closed is selected for the Phase I CBIO. This selection has many possible combinations mathematically, but only a few combinations when the closed time period is only one week in a cycle duration.

Table 6. Cycle combinations in weeks for Phase I CBIO with the example CBIO-SBO-CBIO hydrograph.

Option	Cycle 1		Cycle 2		Cycle 3	
	Closed	Open	Closed	Open	Closed	Open
1	1	2	1	2	1	2
2	1	1	1	2	1	3
3	1	3	1	2	1	1
4	1	1	1	3	1	2
5	1	3	1	1	1	2
6	1	2	1	1	1	3
7	1	2	1	3	1	1

Although any selection will give the same water volume, there is a big difference in terms of temporal distribution. Also there is a significant difference in the discharge fraction. The cycle duration of three weeks may be preferred (two weeks open and one week closed) because the canal would be operated at two-thirds of full design discharge (FDD) rather than half of FSD for the two week cycle duration. However, if the available water supply is only half of FSD in the weeks of Cycle 1, the Options 2 and 4 might be appropriate.

In the Phase III CBIO of Season 1, 7 open weeks and 4 closed are selected. The options are in Table 7. The appropriate option should be the Option 4 because the discharge in the canal will be decreased with time.

Table 7. Cycle combinations in weeks for Phase III CBIO with the example CBIO-SBO-CBIO hydrograph.

Option	Cycle 1		Cycle 2		Cycle 3		Cycle 4	
	Closed	Open	Closed	Open	Closed	Open	Closed	Open
1	1	1	1	2	1	2	1	2
2	1	1	1	1	1	2	1	3
3	1	1	1	2	1	2	1	2
4	1	3	1	2	1	1	1	1

In Phase I of Season 2, 4 weeks open and 4 weeks closed were selected. This selection can be combined reasonably in the ways shown in Table 8. Finally, in Phase III of Season 2, 1-week open and 1 closed is selected.

Table 8. Cycle combinations for Phase I CBIO of Season 2 with the example CBIO-SBO-CBIO hydrograph.

Option	Cycle 1		Cycle 2		Cycle 3		Cycle 4	
	Open	Closed	Open	Closed	Open	Closed	Open	Closed
1	1	1	1	1	1	1	1	1

To establish the best fit in the crop water requirement hydrograph, a graphical procedure is developed which can be used to analyse the different alternatives. For example, analysing the different possibilities, the combinations shown in Figure 13 have been chosen.

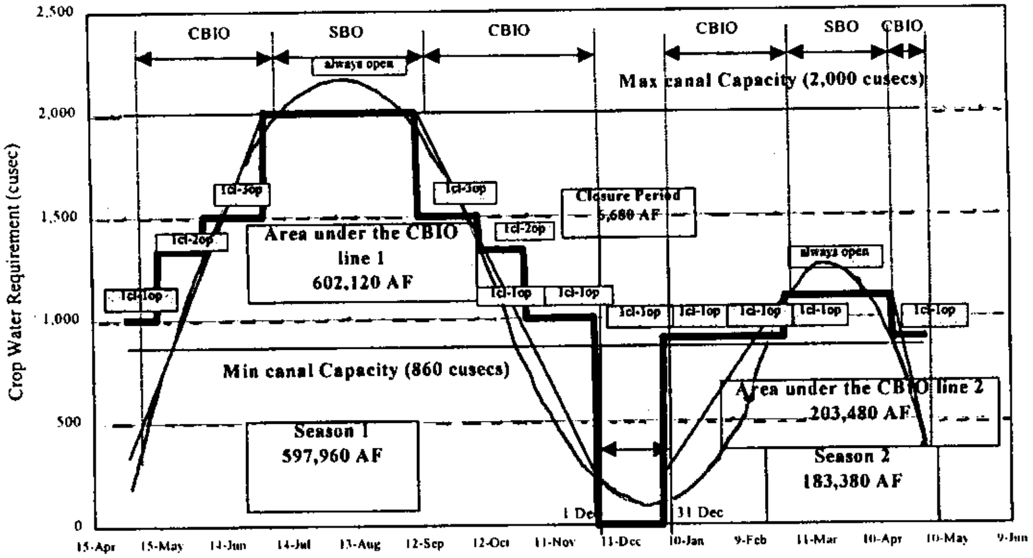


Figure 13. Graphically selected cycle durations for CBIO.

There are no levels under the minimum canal capacity and the surplus in the first ten-daily of December tries to store water in the soil before the closure period.

4.5 DISCHARGE ADJUSTMENTS

A discharge adjustment is a supply discharge for a cycle duration. The equation for the discharge adjustment is:

$$Qadj = \frac{\sum_{g=1}^{ng} Gd_g}{C} \cdot (C-1) + \sum_{g=1}^{ng} l \qquad (12)$$

Where;

Q_a	Adjusted discharge	[cusecs]
G	Demand of the group	[cusecs]
G	Group number (1, 2, 3,..., nc)	
C	Number of clusters in the respective cycle	
l	Losses in the group reach	[cusecs]

4.6 ROTATION OF DISTRIBUTARIES

4.6.1 Determination of Distributary Clusters

Distributary clusters are groups of distributaries. The clusters would be established to simplify organizing distributary groups. There are three methods in setting groups. The first method is to set all distributaries between two cross-regulators to be in the same group; this method has the advantage of facilitating the operation of the rotation schedule. The second method is to set at least one distributary per reach in any groups; in this method, most of the reaches will be operating at the same time. The last method is to not define distributary groups, but each distributary act individually and then design each cluster; the advantage is that the discharge along the canal can be kept nearly equal from cycle to cycle.

For the first method, all of the distributaries in a reach between two cross-regulators constitute a group. Therefore, the number of distributary groups will be equal to the number of reaches.

For the second method, an appropriate number of groups in a canal system should be twelve. For two-cycle operation, two clusters of six groups each will be developed. Similarly, three clusters of four groups will be defined for a cycle duration of three werabandis. The only restriction is that the total discharge for each cluster, must be nearly identical.

The following example demonstrates the establishment of groups using the first method. In Table 9a, Columns 1, 2, and 3 contain the number, structure name, and route (reduced) distance, respectively. Column 4 provides the distributary discharge.

Column 5 contains the seepage loss from a reach. The total distributary discharge and seepage losses in this canal are 1,964.13 and 35.87 cusecs, respectively. Column 6 contains the discharge for each cross-section along the canal. The last column (Column 7) of Table 9a contains the group number for each distributary.

Table 9a. Demonstration of making groups using the first method.

No [1]	Structure Name [2]	RD ft [3]	Distri. Disch. cusecs [4]	Loss in Canal cusecs [5]	Canal Disch. cusecs [6]	Assigned Group No. (for Distri.) [7]
1	Canal Head	527,950			2,000	
2	D-01	529,500	18.89	0.24	2,000	1
3	D-02	532,470	30.19	0.45	1,981	1
4	D-03	537,260	92.91	0.71	1,950	1
5	Esc-1	541,535		0.63	1,857	
6	X-Reg. 1	541,578		0.01	1,856	
7	D-04	549,975	12.86	1.24	1,856	2
8	D-05	558,080	68.58	1.17	1,842	2
9	D-06	573,170	59.78	2.18	1,772	2
10	X-Reg. 2	574,230		0.15	1,710	
11	D-07	582,810	82.15	1.20	1,710	3
12	D-08	597,110	88.96	1.94	1,627	3
13	Esc-2	602,423		0.72	1,536	
14	X-Reg. 3	602,466		0.01	1,535	
15	D-O-1	608,500	6.92	0.82	1,535	4
16	D-09	611,850	17.18	0.45	1,527	4
17	D-O-2	619,000	5.14	0.96	1,510	4
18	D-10	623,820	53.11	0.64	1,504	4
19	D-11	632,000	59.41	1.09	1,450	4
20	X-Reg 4	632,060		0.01	1,389	
21	D-12	643,820	53.29	1.51	1,389	5
22	D-13	652,020	72.93	1.02	1,335	5
23	D-14	664,900	64.56	1.60	1,261	5
24	X-Reg 5	664,960		0.01	1,194	
25	D-15	680,375	113.34	1.78	1,194	6
26	D-16	699,299	55.86	2.19	1,079	6
27	X-Reg 6	699,359		0.01	1,021	
28	D-O-3	705,500	5.19	0.69	1,021	7
29	D-17	712,275	79.25	0.73	1,015	7
30	D-18	721,125	17.18	0.95	935	7
31	D-19	730,530	59.38	0.97	917	7
32	D-20	741,470	21.49	1.13	857	7
33	X-Reg 7	741,530		0.01	834	
34	D-O-4	745,500	5.94	0.40	834	8
35	D-21	760,020	47.46	1.44	828	8
36	D-22	764,100	7.80	0.40	779	8
37	Esc-3	768,900		0.47	771	
38	X-Reg 8	769,000		0.01	770	
39	D-23	777,580	80.65	0.71	770	9
40	D-O-5	779,465	2.53	0.16	689	9
41	D-O-6	784,000	4.93	0.37	686	9
42	D-24	786,965	7.13	0.24	681	9
43	Esc-4	787,980		0.08	674	
44	X-Reg 9	788,430		0.04	674	
45	D-25	791,220	77.65	0.21	673	10
46	D-26	791,340	71.00	0.02	596	10
47	D-27	791,450	56.00	0.02	525	10
48	X-Reg 10	791,530		0.00	469	
49	D-28	803,770	15.06	0.92	469	11
50	D-29	814,295	49.60	0.79	453	11
51	X-Reg 11	814,360		0.00	402	
52	D-30	823,170	60.55	0.57	402	12
53	D-31	829,030	90.28	0.38	341	12
54	X-Reg 12	829,090		0.00	250	
55	D-32	840,520	76.00	0.62	250	13
56	D-33	840,980	63.00	0.04	174	13
57	X-Reg 13	841,371		0.04	111	
58	D-34	850,200	59.00	0.32	111	14
59	D-35	850,309	51.00	0.40	51	14
	Total		1,964.13	35.87		

There are a total of 14 groups in this example. Each group is between two cross-regulators (e.g. the first group is between cross-regulators 1 and 2 located in a reach). Table 9b shows the total discharge for each group and the seepage loss between two cross-regulators.

Table 9b. Total discharge for each group and the seepage loss between two cross-regulators.

Group Or Reach	Water Control Structure	Total Off-takes in the Reach cusecs	Total Losses in the Reach cusecs	Total Demand cusecs
	Canal Head			
1		141.99	2.04	144.03
	X-Reg 1			
2		141.22	4.74	145.96
	X-Reg 2			
3		171.11	3.87	174.98
	X-Reg 3			
4		141.76	3.97	145.73
	X-Reg 4			
5		190.78	4.14	194.92
	X-Reg 5			
6		169.20	3.98	173.18
	X-Reg 6			
7		182.49	4.48	186.97
	X-Reg 7			
8		61.20	2.72	63.92
	X-Reg 8			
9		95.24	1.60	96.84
	X-Reg 9			
10		204.65	0.25	204.90
	X-Reg 10			
11		64.66	1.71	66.37
	X-Reg 11			
12		150.83	0.95	151.78
	X-Reg 12			
13		139.00	0.70	139.70
	X-Reg 13			
14		110.00	0.72	110.72
	D-35			
TOTAL		1964.13	35.87	2000

Now, these groups can be combined into clusters depending on the cycle duration. The clusters for cycle durations of two warabandis, three warabandis and four warabandis are listed in Tables 9c, 9d and 9e, respectively. Note the variation in total cluster discharge for each cycle duration (Tables 9c, 9d and 9e), where an attempt has been made to minimize the variation in total discharge among clusters for each cycle duration.

Next >>

Table 9c. The clusters (groups assigned by the first method) for cycle durations of two warabandis.

No [1]	Structure Name [2]	RD ft [3]	Distri. Disch. cusecs [4]	loss in Canal cusecs [5]	Canal Disch. cusecs [6]	Assigned Group No. (for Distri.) [7]	Assigned Cluster No. [8]	Cluster No. 1 cusecs [10]	Cluster No. 2 cusecs [11]
1	Canal Head	527,950			2,000				
2	D-01	529,500	18.89	0.24	2,000	1	1	18.89	0.00
3	D-02	532,470	30.19	0.45	1,981	1	1	30.19	0.00
4	D-03	537,260	92.91	0.71	1,950	1	1	92.91	0.00
5	Esc-1	541,535		0.63	1,857				
6	X-Reg. 4	541,578		0.01	1,856				
7	D-04	549,975	12.86	1.24	1,856	2	1	12.86	0.00
8	D-05	558,080	68.58	1.17	1,842	2	1	68.58	0.00
9	D-06	573,170	59.78	2.18	1,772	2	1	59.78	0.00
10	X-Reg. 5	574,230		0.15	1,710				
11	D-07	582,810	82.15	1.20	1,710	3	2	0.00	82.15
12	D-08	597,110	88.96	1.94	1,627	3	2	0.00	88.96
13	Esc-2	602,423		0.72	1,536				
14	X-Reg. 6	602,466		0.01	1,535				
15	D-O-1	608,500	6.92	0.82	1,535	4	2	0.00	6.92
16	D-09	611,850	17.18	0.45	1,527	4	2	0.00	17.18
17	D-O-2	619,000	5.14	0.96	1,510	4	2	0.00	5.14
18	D-10	623,820	53.11	0.64	1,504	4	2	0.00	53.11
19	D-11	632,000	59.41	1.09	1,450	4	2	0.00	59.41
20	X-Reg 7	632,060		0.01	1,389				
21	D-12	643,820	53.29	1.51	1,389	5	1	53.29	0.00
22	D-13	652,020	72.93	1.02	1,335	5	1	72.93	0.00
23	D-14	664,900	64.56	1.60	1,261	5	1	64.56	0.00
24	X-Reg 8	664,960		0.01	1,194				
25	D-15	680,375	113.34	1.78	1,194	6	1	113.34	0.00
26	D-16	699,299	55.86	2.19	1,079	6	1	55.86	0.00
27	X-Reg 9	699,359		0.01	1,021				
28	D-O-3	705,500	5.19	0.69	1,021	7	1	5.19	0.00
29	D-17	712,275	79.25	0.73	1,015	7	1	79.25	0.00
30	D-18	721,125	17.18	0.95	935	7	1	17.18	0.00
31	D-19	730,530	59.38	0.97	917	7	1	59.38	0.00
32	D-20	741,470	21.49	1.13	857	7	1	21.49	0.00
33	X-Reg 10	741,530		0.01	834				
34	D-O-4	745,500	5.94	0.40	834	8	1	5.94	0.00
35	D-21	760,020	47.46	1.44	828	8	1	47.46	0.00
36	D-22	764,100	7.80	0.40	779	8	1	7.80	0.00
37	Esc-3	768,900		0.47	771				
38	X-Reg 11	769,000		0.01	770				
39	D-23	777,580	80.65	0.71	770	9	1	80.65	0.00
40	D-O-5	779,465	2.53	0.16	689	9	1	2.53	0.00
41	D-O-6	784,000	4.93	0.37	686	9	1	4.93	0.00
42	D-24	786,965	7.13	0.24	681	9	1	7.13	0.00
43	Esc-4	787,980		0.08	674				
44	X-Reg 12	788,430		0.04	674				
45	D-25	791,220	77.65	0.21	673	10	2	0.00	77.65
46	D-26	791,340	71.00	0.02	596	10	2	0.00	71.00
47	D-27	791,450	56.00	0.02	525	10	2	0.00	56.00
48	X-Reg 13	791,530		0.00	469				
49	D-28	803,770	15.06	0.92	469	11	2	0.00	15.06
50	D-29	814,295	49.60	0.79	453	11	2	0.00	49.60
51	X-Reg 14	814,360		0.00	402				
52	D-30	823,170	60.55	0.57	402	12	2	0.00	60.55
53	D-31	829,030	90.28	0.38	341	12	2	0.00	90.28
54	X-Reg 15	829,090		0.00	250				
55	D-32	840,520	76.00	0.62	250	13	2	0.00	76.00
56	D-33	840,980	63.00	0.04	174	13	2	0.00	63.00
57	X-Reg 16	841,371		0.04	111				
58	D-34	850,200	59.00	0.32	111	14	2	0.00	59.00
59	D-35	850,309	51.00	0.40	51	14	2	0.00	51.00
	Total Cycle duration Discharge		1,964.13	35.87				982.12	982.01

Table 9d. The clusters (groups assigned by the first method) for cycle durations of three warabandis.

No [1]	Structure Name [2]	RD ft [3]	Distri. Disch. cusecs [4]	loss in Canal cusecs [5]	Canal Disch. cusecs [6]	Assigned Group No. (for Distri.) [7]	Assigned Cluster No. [8]	Cluster No. 1 cusecs [10]	Cluster No. 2 cusecs [11]	Cluster No. 3 cusecs [12]
1	Canal Head	527,950			2,000					
2	D-01	529,500	18.89	0.24	2,000	1	1	18.89	0.00	0.00
3	D-02	532,470	30.19	0.45	1,981	1	1	30.19	0.00	0.00
4	D-03	537,260	92.91	0.71	1,950	1	1	92.91	0.00	0.00
5	Esc-1	541,535		0.63	1,857					
6	X-Reg. 4	541,578		0.01	1,856					
7	D-04	549,975	12.86	1.24	1,856	2	3	0.00	0.00	12.86
8	D-05	558,080	68.58	1.17	1,842	2	3	0.00	0.00	68.58
9	D-06	573,170	59.78	2.18	1,772	2	3	0.00	0.00	59.78
10	X-Reg. 5	574,230		0.15	1,710					
11	D-07	582,810	82.15	1.20	1,710	3	3	0.00	0.00	82.15
12	D-08	597,110	88.96	1.94	1,627	3	3	0.00	0.00	88.96
13	Esc-2	602,423		0.72	1,536					
14	X-Reg. 6	602,466		0.01	1,535					
15	D-O-1	608,500	6.92	0.82	1,535	4	2	0.00	6.92	0.00
16	D-09	611,850	17.18	0.45	1,527	4	2	0.00	17.18	0.00
17	D-O-2	619,000	5.14	0.96	1,510	4	2	0.00	5.14	0.00
18	D-10	623,820	53.11	0.64	1,504	4	2	0.00	53.11	0.00
19	D-11	632,000	59.41	1.09	1,450	4	2	0.00	59.41	0.00
20	X-Reg 7	632,060		0.01	1,389					
21	D-12	643,820	53.29	1.51	1,389	5	2	0.00	53.29	0.00
22	D-13	652,020	72.93	1.02	1,335	5	2	0.00	72.93	0.00
23	D-14	664,900	64.56	1.60	1,261	5	2	0.00	64.56	0.00
24	X-Reg 8	664,960		0.01	1,194					
25	D-15	680,375	113.34	1.78	1,194	6	2	0.00	113.34	0.00
26	D-16	699,299	55.86	2.19	1,079	6	2	0.00	55.86	0.00
27	X-Reg 9	699,359		0.01	1,021					
28	D-O-3	705,500	5.19	0.69	1,021	7	3	0.00	0.00	5.19
29	D-17	712,275	79.25	0.73	1,015	7	3	0.00	0.00	79.25
30	D-18	721,125	17.18	0.95	935	7	3	0.00	0.00	17.18
31	D-19	730,530	59.38	0.97	917	7	3	0.00	0.00	59.38
32	D-20	741,470	21.49	1.13	857	7	3	0.00	0.00	21.49
33	X-Reg 10	741,530		0.01	834					
34	D-O-4	745,500	5.94	0.40	834	8	1	5.94	0.00	0.00
35	D-21	760,020	47.46	1.44	828	8	1	47.46	0.00	0.00
36	D-22	764,100	7.80	0.40	779	8	1	7.80	0.00	0.00
37	Esc-3	768,900		0.47	771					
38	X-Reg 11	769,000		0.01	770					
39	D-23	777,580	80.65	0.71	770	9	3	0.00	0.00	80.65
40	D-O-5	779,465	2.53	0.16	689	9	3	0.00	0.00	2.53
41	D-O-6	784,000	4.93	0.37	686	9	3	0.00	0.00	4.93
42	D-24	786,965	7.13	0.24	681	9	3	0.00	0.00	7.13
43	Esc-4	787,980		0.08	674					
44	X-Reg 12	788,430		0.04	674					
45	D-25	791,220	77.65	0.21	673	10	1	77.65	0.00	0.00
46	D-26	791,340	71.00	0.02	596	10	1	71.00	0.00	0.00
47	D-27	791,450	56.00	0.02	525	10	1	56.00	0.00	0.00
48	X-Reg 13	791,530		0.00	469					
49	D-28	803,770	15.06	0.92	469	11	3	0.00	0.00	15.06
50	D-29	814,295	49.60	0.79	453	11	3	0.00	0.00	49.60
51	X-Reg 14	814,360		0.00	402					
52	D-30	823,170	60.55	0.57	402	12	1	60.55	0.00	0.00
53	D-31	829,030	90.28	0.38	341	12	1	90.28	0.00	0.00
54	X-Reg 15	829,090		0.00	250					
55	D-32	840,520	76.00	0.62	250	13	2	0.00	76.00	0.00
56	D-33	840,980	63.00	0.04	174	13	2	0.00	63.00	0.00
57	X-Reg 16	841,371		0.04	111					
58	D-34	850,200	59.00	0.32	111	14	1	59.00	0.00	0.00
59	D-35	850,309	51.00	0.40	51	14	1	51.00	0.00	0.00
	Total Cycle duration Discharge		1,964.13	35.87				668.67	640.74	654.72

Table 9e. The clusters (groups assigned by the first method) for cycle durations of four warabandis.

No [1]	Structure Name [2]	RD ft [3]	Distri. Disch. cusecs [4]	loss in Canal cusecs [5]	Canal Disch. cusecs [6]	Assigned Group No. (for Distri.) [7]	Assigned Cluster No. [8]	Cluster No. 1 cusecs [10]	Cluster No. 2 cusecs [11]
1	Canal Head	527,950			2,000				
2	D-01	529,500	18.89	0.24	2,000	1	2	0.00	18.89
3	D-02	532,470	30.19	0.45	1,981	1	2	0.00	30.19
4	D-03	537,260	92.91	0.71	1,950	1	2	0.00	92.91
5	Esc-1	541,535		0.63	1,857				
6	X-Reg. 4	541,578		0.01	1,856				
7	D-04	549,975	12.86	1.24	1,856	2	1	12.86	0.00
8	D-05	558,080	68.58	1.17	1,842	2	1	68.58	0.00
9	D-06	573,170	59.78	2.18	1,772	2	1	59.78	0.00
10	X-Reg. 5	574,230		0.15	1,710				
11	D-07	582,810	82.15	1.20	1,710	3	4	0.00	0.00
12	D-08	597,110	88.96	1.94	1,627	3	4	0.00	0.00
13	Esc-2	602,423		0.72	1,536				
14	X-Reg. 6	602,466		0.01	1,535				
15	D-O-1	608,500	6.92	0.82	1,535	4	1	6.92	0.00
16	D-09	611,850	17.18	0.45	1,527	4	1	17.18	0.00
17	D-O-2	619,000	5.14	0.96	1,510	4	1	5.14	0.00
18	D-10	623,820	53.11	0.64	1,504	4	1	53.11	0.00
19	D-11	632,000	59.41	1.09	1,450	4	1	59.41	0.00
20	X-Reg 7	632,060		0.01	1,389				
21	D-12	643,820	53.29	1.51	1,389	5	2	0.00	53.29
22	D-13	652,020	72.93	1.02	1,335	5	2	0.00	72.93
23	D-14	664,900	64.56	1.60	1,261	5	2	0.00	64.56
24	X-Reg 8	664,960		0.01	1,194				
25	D-15	680,375	113.34	1.78	1,194	6	4	0.00	0.00
26	D-16	699,299	55.86	2.19	1,079	6	4	0.00	0.00
27	X-Reg 9	699,359		0.01	1,021				
28	D-O-3	705,500	5.19	0.69	1,021	7	3	0.00	0.00
29	D-17	712,275	79.25	0.73	1,015	7	3	0.00	0.00
30	D-18	721,125	17.18	0.95	935	7	3	0.00	0.00
31	D-19	730,530	59.38	0.97	917	7	3	0.00	0.00
32	D-20	741,470	21.49	1.13	857	7	3	0.00	0.00
33	X-Reg 10	741,530		0.01	834				
34	D-O-4	745,500	5.94	0.40	834	8	3	0.00	0.00
35	D-21	760,020	47.46	1.44	828	8	3	0.00	0.00
36	D-22	764,100	7.80	0.40	779	8	3	0.00	0.00
37	Esc-3	768,900		0.47	771				
38	X-Reg 11	769,000		0.01	770				
39	D-23	777,580	80.65	0.71	770	9	4	0.00	0.00
40	D-O-5	779,465	2.53	0.16	689	9	4	0.00	0.00
41	D-O-6	784,000	4.93	0.37	686	9	4	0.00	0.00
42	D-24	786,985	7.13	0.24	681	9	4	0.00	0.00
43	Esc-4	787,980		0.08	674				
44	X-Reg 12	788,430		0.04	674				
45	D-25	791,220	77.65	0.21	673	10	1	77.65	0.00
46	D-26	791,340	71.00	0.02	596	10	1	71.00	0.00
47	D-27	791,450	56.00	0.02	525	10	1	56.00	0.00
48	X-Reg 13	791,530		0.00	469				
49	D-28	803,770	15.06	0.92	469	11	4	0.00	0.00
50	D-29	814,295	49.60	0.79	453	11	4	0.00	0.00
51	X-Reg 14	814,360		0.00	402				
52	D-30	823,170	60.55	0.57	402	12	3	0.00	0.00
53	D-31	829,030	90.28	0.38	341	12	3	0.00	0.00
54	X-Reg 15	829,090		0.00	250				
55	D-32	840,520	76.00	0.62	250	13	2	0.00	76.00
56	D-33	840,980	63.00	0.04	174	13	2	0.00	63.00
57	X-Reg 16	841,371		0.04	111				
58	D-34	850,200	59.00	0.32	111	14	3	0.00	0.00
59	D-35	850,309	51.00	0.40	51	14	3	0.00	0.00
	Total Cycle duration Discharge		1,964.13	35.87				487.63	471.77

Table 10a demonstrates groups developed by the second method. Column 7 shows group numbers one, two, and three in between the first and second cross-regulators. Similarly, group numbers four, five, and six are in between the second and third cross-regulators. There are twelve groups in this example. Table 10b shows the total discharge for each group. The clusters for cycle durations of two, three and four warabandis are listed in Tables 10c, 10d, and 10e.

Table 10.a Demonstration of defining groups using the second method.

No [1]	Structure Name [2]	RD ft [3]	Distri. Disch. cusecs [4]	Loss in Canal cusecs [5]	Canal Disch. cusecs [6]	Assigned Group No. (for Distri.) [7]
1	Canal Head	527,950			2,000	
2	D-01	529,500	18.89	0.24	2,000	1
3	D-02	532,470	30.19	0.45	1,981	2
4	D-03	537,260	92.91	0.71	1,950	3
5	Esc-1	541,535		0.63	1,857	
6	X-Reg. 1	541,578		0.01	1,856	
7	D-04	549,975	12.86	1.24	1,856	4
8	D-05	558,080	68.58	1.17	1,842	5
9	D-06	573,170	59.78	2.18	1,772	6
10	X-Reg. 2	574,230		0.15	1,710	
11	D-07	582,810	82.15	1.20	1,710	7
12	D-08	597,110	88.96	1.94	1,627	8
13	Esc-2	602,423		0.72	1,536	
14	X-Reg. 3	602,466		0.01	1,535	
15	D-O-1	608,500	6.92	0.82	1,535	9
16	D-09	611,850	17.18	0.45	1,527	10
17	D-O-2	619,000	5.14	0.96	1,510	11
18	D-10	623,820	53.11	0.64	1,504	12
19	D-11	632,000	59.41	1.09	1,450	1
20	X-Reg 4	632,060		0.01	1,389	
21	D-12	643,820	53.29	1.51	1,389	2
22	D-13	652,020	72.93	1.02	1,335	3
23	D-14	664,900	64.56	1.60	1,261	4
24	X-Reg 5	664,960		0.01	1,194	
25	D-15	680,375	113.34	1.78	1,194	5
26	D-16	699,299	55.86	2.19	1,079	6
27	X-Reg 6	699,359		0.01	1,021	
28	D-O-3	705,500	5.19	0.69	1,021	7
29	D-17	712,275	79.25	0.73	1,015	8
30	D-18	721,125	17.18	0.95	935	9
31	D-19	730,530	59.38	0.97	917	10
32	D-20	741,470	21.49	1.13	857	11
33	X-Reg 7	741,530		0.01	834	
34	D-O-4	745,500	5.94	0.40	834	12
35	D-21	760,020	47.46	1.44	828	1
36	D-22	764,100	7.80	0.40	779	2
37	Esc-3	768,900		0.47	771	
38	X-Reg 8	769,000		0.01	770	
39	D-23	777,580	80.65	0.71	770	3
40	D-O-5	779,465	2.53	0.16	689	4
41	D-O-6	784,000	4.93	0.37	686	5
42	D-24	786,965	7.13	0.24	681	6
43	Esc-4	787,980		0.08	674	
44	X-Reg 9	788,430		0.04	674	
45	D-25	791,220	77.65	0.21	673	7
46	D-26	791,340	71.00	0.02	596	8
47	D-27	791,450	56.00	0.02	525	9
48	X-Reg 10	791,530		0.00	469	
49	D-28	803,770	15.06	0.92	469	10
50	D-29	814,295	49.60	0.79	453	11
51	X-Reg 11	814,360		0.00	402	
52	D-30	823,170	60.55	0.57	402	12
53	D-31	829,030	90.28	0.38	341	1
54	X-Reg 12	829,090		0.00	250	
55	D-32	840,520	76.00	0.62	250	2
56	D-33	840,980	63.00	0.04	174	3
57	X-Reg 13	841,371		0.04	111	
58	D-34	850,200	59.00	0.32	111	4
59	D-35	850,309	51.00	0.40	51	5
	Total		1,964.13	35.87		

Table 10.b Total discharge for each group developed by the second method.

Group Or Reach	Total Off-takes in the group Cusecs
1	216.04
2	167.28
3	309.49
4	138.95
5	237.85
6	122.77
7	164.99
8	239.21
9	80.10
10	91.62
11	76.23
12	119.60
Total	1,964.13

Table 10.c The clusters (groups assigned by the second method) for cycle durations of two warabandis.

No [1]	Structure Name [2]	RD ft [3]	Distri. Disch. cusecs [4]	loss in Canal cusecs [5]	Canal Disch. cusecs [6]	Assigned Group No. (for Distri.) [7]	Assigned Cluster No. [8]	Cluster No. 1 cusecs [10]	Cluster No. 2 cusecs [11]
1	Canal Head	527,950			2,000				
2	D-01	529,500	18.89	0.24	2,000	1	1	18.89	0.00
3	D-02	532,470	30.19	0.45	1,981	2	1	30.19	0.00
4	D-03	537,260	92.91	0.71	1,950	3	1	92.91	0.00
5	Esc-1	541,535		0.63	1,857				
6	X-Reg. 4	541,578		0.01	1,856				
7	D-04	549,975	12.86	1.24	1,856	4	1	12.86	0.00
8	D-05	558,080	68.58	1.17	1,842	5	2	0.00	68.58
9	D-06	573,170	59.78	2.18	1,772	6	1	59.78	0.00
10	X-Reg. 5	574,230		0.15	1,710				
11	D-07	582,810	82.15	1.20	1,710	7	2	0.00	82.15
12	D-08	597,110	88.96	1.94	1,627	8	2	0.00	88.96
13	Esc-2	602,423		0.72	1,536				
14	X-Reg. 6	602,466		0.01	1,535				
15	D-O-1	608,500	6.92	0.82	1,535	9	2	0.00	6.92
16	D-09	611,850	17.18	0.45	1,527	10	2	0.00	17.18
17	D-O-2	619,000	5.14	0.96	1,510	11	2	0.00	5.14
18	D-10	623,820	53.11	0.64	1,504	12	2	0.00	53.11
19	D-11	632,000	59.41	1.09	1,450	1	1	59.41	0.00
20	X-Reg 7	632,060		0.01	1,389				
21	D-12	643,820	53.29	1.51	1,389	2	1	53.29	0.00
22	D-13	652,020	72.93	1.02	1,335	3	1	72.93	0.00
23	D-14	664,900	64.56	1.60	1,261	4	1	64.56	0.00
24	X-Reg 8	664,960		0.01	1,194				
25	D-15	680,375	113.34	1.78	1,194	5	2	0.00	113.34
26	D-16	699,299	55.86	2.19	1,079	6	1	55.86	0.00
27	X-Reg 9	699,359		0.01	1,021				
28	D-O-3	705,500	5.19	0.69	1,021	7	2	0.00	5.19
29	D-17	712,275	79.25	0.73	1,015	8	2	0.00	79.25
30	D-18	721,125	17.18	0.95	935	9	2	0.00	17.18
31	D-19	730,530	59.38	0.97	917	10	2	0.00	59.38
32	D-20	741,470	21.49	1.13	857	11	2	0.00	21.49
33	X-Reg 10	741,530		0.01	834				
34	D-O-4	745,500	5.94	0.40	834	12	2	0.00	5.94
35	D-21	760,020	47.46	1.44	828	1	1	47.46	0.00
36	D-22	764,100	7.80	0.40	779	2	1	7.80	0.00
37	Esc-3	768,900		0.47	771				
38	X-Reg 11	769,000		0.01	770				
39	D-23	777,580	80.65	0.71	770	3	1	80.65	0.00
40	D-O-5	779,465	2.53	0.16	689	4	1	2.53	0.00
41	D-O-6	784,000	4.93	0.37	686	5	2	0.00	4.93
42	D-24	786,965	7.13	0.24	681	6	1	7.13	0.00
43	Esc-4	787,980		0.08	674				
44	X-Reg 12	788,430		0.04	674				
45	D-25	791,220	77.65	0.21	673	7	2	0.00	77.65
46	D-26	791,340	71.00	0.02	596	8	2	0.00	71.00
47	D-27	791,450	56.00	0.02	525	9	2	0.00	56.00
48	X-Reg 13	791,530		0.00	469				
49	D-28	803,770	15.06	0.92	469	10	2	0.00	15.06
50	D-29	814,295	49.60	0.79	453	11	2	0.00	49.60
51	X-Reg 14	814,360		0.00	402				
52	D-30	823,170	60.55	0.57	402	12	2	0.00	60.55
53	D-31	829,030	90.28	0.38	341	1	1	90.28	0.00
54	X-Reg 15	829,090		0.00	250				
55	D-32	840,520	76.00	0.62	250	2	1	76.00	0.00
56	D-33	840,980	63.00	0.04	174	3	1	63.00	0.00
57	X-Reg 16	841,371		0.04	111				
58	D-34	850,200	59.00	0.32	111	4	1	59.00	0.00
59	D-35	850,309	51.00	0.40	51	5	2	0.00	51.00
	Total		1,964.13	35.87				954.53	1,009.60
	Cycle duration Discharge			1,017.94					

Table 10.d The clusters (groups assigned by the second method) for cycle durations of three warabandis.

No [1]	Structure Name [2]	RD ft [3]	Distri. Disch. cusecs [4]	loss in CRBC cusecs [5]	CRBC Disch. cusecs [6]	Assigned Cluster No. (for Distri.) [7]	Assigned Group No. [8]	Group No. 1 cusecs [10]	Group No. 2 cusecs [11]	Group No. 3 cusecs [12]
1	Canal Head	527,950			2,000					
2	D-01	529,500	18.89	0.24	2,000	1	1	18.89	0.00	0.00
3	D-02	532,470	30.19	0.45	1,981	2	3	0.00	0.00	30.19
4	D-03	537,260	92.91	0.71	1,950	3	3	0.00	0.00	92.91
5	Esc-1	541,535		0.63	1,857					
6	X-Reg. 4	541,578		0.01	1,856					
7	D-04	549,975	12.86	1.24	1,856	4	2	0.00	12.86	0.00
8	D-05	558,080	68.58	1.17	1,842	5	1	68.58	0.00	0.00
9	D-06	573,170	59.78	2.18	1,772	6	3	0.00	0.00	59.78
10	X-Reg. 5	574,230		0.15	1,710					
11	D-07	582,810	82.15	1.20	1,710	7	2	0.00	82.15	0.00
12	D-08	597,110	88.96	1.94	1,627	8	2	0.00	88.96	0.00
13	Esc-2	602,423		0.72	1,536					
14	X-Reg. 6	602,466		0.01	1,535					
15	D-O-1	608,500	6.92	0.82	1,535	9	2	0.00	6.92	0.00
16	D-09	611,850	17.18	0.45	1,527	10	1	17.18	0.00	0.00
17	D-O-2	619,000	5.14	0.96	1,510	11	3	0.00	0.00	5.14
18	D-10	623,820	53.11	0.64	1,504	12	1	53.11	0.00	0.00
19	D-11	632,000	59.41	1.09	1,450	1	1	59.41	0.00	0.00
20	X-Reg 7	632,060		0.01	1,389					
21	D-12	643,820	53.29	1.51	1,389	2	3	0.00	0.00	53.29
22	D-13	652,020	72.93	1.02	1,335	3	3	0.00	0.00	72.93
23	D-14	664,900	64.56	1.60	1,261	4	2	0.00	64.56	0.00
24	X-Reg 8	664,960		0.01	1,194					
25	D-15	680,375	113.34	1.78	1,194	5	1	113.34	0.00	0.00
26	D-16	699,299	55.86	2.19	1,079	6	3	0.00	0.00	55.86
27	X-Reg 9	699,359		0.01	1,021					
28	D-O-3	705,500	5.19	0.69	1,021	7	2	0.00	5.19	0.00
29	D-17	712,275	79.25	0.73	1,015	8	2	0.00	79.25	0.00
30	D-18	721,125	17.18	0.95	935	9	2	0.00	17.18	0.00
31	D-19	730,530	59.38	0.97	917	10	1	59.38	0.00	0.00
32	D-20	741,470	21.49	1.13	857	11	3	0.00	0.00	21.49
33	X-Reg 10	741,530		0.01	834					
34	D-O-4	745,500	5.94	0.40	834	12	1	5.94	0.00	0.00
35	D-21	760,020	47.46	1.44	828	1	1	47.46	0.00	0.00
36	D-22	764,100	7.80	0.40	779	2	3	0.00	0.00	7.80
37	Esc-3	768,900		0.47	771					
38	X-Reg 11	769,000		0.01	770					
39	D-23	777,580	80.65	0.71	770	3	3	0.00	0.00	80.65
40	D-O-5	779,465	2.53	0.16	689	4	2	0.00	2.53	0.00
41	D-O-6	784,000	4.93	0.37	686	5	1	4.93	0.00	0.00
42	D-24	786,965	7.13	0.24	681	6	3	0.00	0.00	7.13
43	Esc-4	787,980		0.08	674					
44	X-Reg 12	788,430		0.04	674					
45	D-25	791,220	77.65	0.21	673	7	2	0.00	77.65	0.00
46	D-26	791,340	71.00	0.02	596	8	2	0.00	71.00	0.00
47	D-27	791,450	56.00	0.02	525	9	2	0.00	56.00	0.00
48	X-Reg 13	791,530		0.00	469					
49	D-28	803,770	15.06	0.92	469	10	1	15.06	0.00	0.00
50	D-29	814,295	49.60	0.79	453	11	3	0.00	0.00	49.60
51	X-Reg 14	814,360		0.00	402					
52	D-30	823,170	60.55	0.57	402	12	1	60.55	0.00	0.00
53	D-31	829,030	90.28	0.38	341	1	1	90.28	0.00	0.00
54	X-Reg 15	829,090		0.00	250					
55	D-32	840,520	76.00	0.62	250	2	3	0.00	0.00	76.00
56	D-33	840,980	63.00	0.04	174	3	3	0.00	0.00	63.00
57	X-Reg 16	841,371		0.04	111					
58	D-34	850,200	59.00	0.32	111	4	2	0.00	59.00	0.00
59	D-35	850,309	51.00	0.40	51	5	1	51.00	0.00	0.00
	Total		1,964.13	35.87				665.11	623.25	675.77
	Cycle duration Discharge			1,017.94						

Table 10.e The clusters (groups assigned by the second method) for cycle durations of four warabandis.

No [1]	Structure Name [2]	RD ft [3]	Distri. Disch. cusecs [4]	loss in Canal cusecs [5]	Canal Disch. cusecs [6]	Assigned Group No. (for Distri.) [7]	Assigned Cluster No. [8]	Cluster No. 1 cusecs [10]	Cluster No. 2 cusecs [11]	Cluster No. 3 cusecs [12]	Cluster No. 4 cusecs [13]
1	Canal Head	527,950			2,000						
2	D-01	529,500	18.89	0.24	2,000	1	1	18.89	0.00	0.00	0.00
3	D-02	532,470	30.19	0.45	1,981	2	1	30.19	0.00	0.00	0.00
4	D-03	537,260	92.91	0.71	1,950	3	4	0.00	0.00	0.00	92.91
5	Esc-1	541,535		0.63	1,857						
6	X-Reg. 4	541,578		0.01	1,856						
7	D-04	549,975	12.86	1.24	1,856	4	3	0.00	0.00	12.86	0.00
8	D-05	558,080	68.58	1.17	1,842	5	2	0.00	68.58	0.00	0.00
9	D-06	573,170	59.78	2.18	1,772	6	4	0.00	0.00	0.00	59.78
10	X-Reg. 5	574,230		0.15	1,710						
11	D-07	582,810	82.15	1.20	1,710	7	2	0.00	82.15	0.00	0.00
12	D-08	597,110	88.96	1.94	1,627	8	3	0.00	0.00	88.96	0.00
13	Esc-2	602,423		0.72	1,536						
14	X-Reg. 6	602,466		0.01	1,535						
15	D-O-1	608,500	6.92	0.82	1,535	9	2	0.00	6.92	0.00	0.00
16	D-09	611,850	17.18	0.45	1,527	10	3	0.00	0.00	17.18	0.00
17	D-O-2	619,000	5.14	0.96	1,510	11	4	0.00	0.00	0.00	5.14
18	D-10	623,820	53.11	0.64	1,504	12	1	53.11	0.00	0.00	0.00
19	D-11	632,000	59.41	1.09	1,450	1	1	59.41	0.00	0.00	0.00
20	X-Reg 7	632,060		0.01	1,389						
21	D-12	643,820	53.29	1.51	1,389	2	1	53.29	0.00	0.00	0.00
22	D-13	652,020	72.93	1.02	1,335	3	4	0.00	0.00	0.00	72.93
23	D-14	664,900	64.56	1.60	1,261	4	3	0.00	0.00	64.56	0.00
24	X-Reg 8	664,960		0.01	1,194						
25	D-15	680,375	113.34	1.78	1,194	5	2	0.00	113.34	0.00	0.00
26	D-16	699,299	55.86	2.19	1,079	6	4	0.00	0.00	0.00	55.86
27	X-Reg 9	699,359		0.01	1,021						
28	D-O-3	705,500	5.19	0.69	1,021	7	2	0.00	5.19	0.00	0.00
29	D-17	712,275	79.25	0.73	1,015	8	3	0.00	0.00	79.25	0.00
30	D-18	721,125	17.18	0.95	935	9	2	0.00	17.18	0.00	0.00
31	D-19	730,530	59.38	0.97	917	10	3	0.00	0.00	59.38	0.00
32	D-20	741,470	21.49	1.13	857	11	4	0.00	0.00	0.00	21.49
33	X-Reg 10	741,530		0.01	834						
34	D-O-4	745,500	5.94	0.40	834	12	1	5.94	0.00	0.00	0.00
35	D-21	760,020	47.46	1.44	828	1	1	47.46	0.00	0.00	0.00
36	D-22	764,100	7.80	0.40	779	2	1	7.80	0.00	0.00	0.00
37	Esc-3	768,900		0.47	771						
38	X-Reg 11	769,000		0.01	770						
39	D-23	777,580	80.65	0.71	770	3	4	0.00	0.00	0.00	80.65
40	D-O-5	779,465	2.53	0.16	689	4	3	0.00	0.00	2.53	0.00
41	D-O-6	784,000	4.93	0.37	686	5	2	0.00	4.93	0.00	0.00
42	D-24	786,965	7.13	0.24	681	6	4	0.00	0.00	0.00	7.13
43	Esc-4	787,980		0.08	674						
44	X-Reg 12	788,430		0.04	674						
45	D-25	791,220	77.65	0.21	673	7	2	0.00	77.65	0.00	0.00
46	D-26	791,340	71.00	0.02	596	8	3	0.00	0.00	71.00	0.00
47	D-27	791,450	56.00	0.02	525	9	2	0.00	56.00	0.00	0.00
48	X-Reg 13	791,530		0.00	469						
49	D-28	803,770	15.06	0.92	469	10	3	0.00	0.00	15.06	0.00
50	D-29	814,295	49.60	0.79	453	11	4	0.00	0.00	0.00	49.60
51	X-Reg 14	814,360		0.00	402						
52	D-30	823,170	60.55	0.57	402	12	1	60.55	0.00	0.00	0.00
53	D-31	829,030	90.28	0.38	341	1	1	90.28	0.00	0.00	0.00
54	X-Reg 15	829,090		0.00	250						
55	D-32	840,520	76.00	0.62	250	2	1	76.00	0.00	0.00	0.00
56	D-33	840,980	63.00	0.04	174	3	4	0.00	0.00	0.00	63.00
57	X-Reg 16	841,371		0.04	111						
58	D-34	850,200	59.00	0.32	111	4	3	0.00	0.00	59.00	0.00
59	D-35	850,309	51.00	0.40	51	5	2	0.00	51.00	0.00	0.00
	Total		1,964.13	35.87				502.92	482.94	469.78	508.49
	Cycle duration Discharge			1,017.94							

Table 11a shows the last method for establishing groups. Actually, there is no groups for this method. The last column of Table 10a shows that the number zero is assigned to all distributaries along the canal. Tables 10b, 10c and 10d illustrate how these distributaries can be combined into clusters for cycle durations of two, three and four warabandis, respectively. The major criteria in formulating these clusters is to minimize the variation in total discharge among the clusters for each cycle duration. This will be further elaborated in the next section.

Table 11.a Demonstration of making groups using the third method.

No [1]	Structure Name [2]	RD ft [3]	Distri. Disch. cusecs [4]	loss in Canal cusecs [5]	Canal Disch. cusecs [6]	Assigned Group No. (for Distri.) [7]
1	Canal Head	527,950			2,000	
2	D-01	529,500	18.89	0.24	2,000	0
3	D-02	532,470	30.19	0.45	1,981	0
4	D-03	537,260	92.91	0.71	1,950	0
5	Esc-1	541,535		0.63	1,857	
6	X-Reg. 1	541,578		0.01	1,856	
7	D-04	549,975	12.86	1.24	1,856	0
8	D-05	558,080	68.58	1.17	1,842	0
9	D-06	573,170	59.78	2.18	1,772	0
10	X-Reg. 2	574,230		0.15	1,710	
11	D-07	582,810	82.15	1.20	1,710	0
12	D-08	597,110	88.96	1.94	1,627	0
13	Esc-2	602,423		0.72	1,536	
14	X-Reg. 3	602,466		0.01	1,535	
15	D-O-1	608,500	6.92	0.82	1,535	0
16	D-09	611,850	17.18	0.45	1,527	0
17	D-O-2	619,000	5.14	0.96	1,510	0
18	D-10	623,820	53.11	0.64	1,504	0
19	D-11	632,000	59.41	1.09	1,450	0
20	X-Reg 4	632,060		0.01	1,389	
21	D-12	643,820	53.29	1.51	1,389	0
22	D-13	652,020	72.93	1.02	1,335	0
23	D-14	664,900	64.56	1.60	1,261	0
24	X-Reg 5	664,960		0.01	1,194	
25	D-15	680,375	113.34	1.78	1,194	0
26	D-16	699,299	55.86	2.19	1,079	0
27	X-Reg 6	699,359		0.01	1,021	
28	D-O-3	705,500	5.19	0.69	1,021	0
29	D-17	712,275	79.25	0.73	1,015	0
30	D-18	721,125	17.18	0.95	935	0
31	D-19	730,530	59.38	0.97	917	0
32	D-20	741,470	21.49	1.13	857	0
33	X-Reg 7	741,530		0.01	834	
34	D-O-4	745,500	5.94	0.40	834	0
35	D-21	760,020	47.46	1.44	828	0
36	D-22	764,100	7.80	0.40	779	0
37	Esc-3	768,900		0.47	771	
38	X-Reg 8	769,000		0.01	770	
39	D-23	777,580	80.65	0.71	770	0
40	D-O-5	779,465	2.53	0.16	689	0
41	D-O-6	784,000	4.93	0.37	686	0
42	D-24	786,965	7.13	0.24	681	0
43	Esc-4	787,980		0.08	674	
44	X-Reg 9	788,430		0.04	674	
45	D-25	791,220	77.65	0.21	673	0
46	D-26	791,340	71.00	0.02	596	0
47	D-27	791,450	56.00	0.02	525	0
48	X-Reg 10	791,530		0.00	469	
49	D-28	803,770	15.06	0.92	469	0
50	D-29	814,295	49.60	0.79	453	0
51	X-Reg 11	814,360		0.00	402	
52	D-30	823,170	60.55	0.57	402	0
53	D-31	829,030	90.28	0.38	341	0
54	X-Reg 12	829,090		0.00	250	
55	D-32	840,520	76.00	0.62	250	0
56	D-33	840,980	63.00	0.04	174	0
57	X-Reg 13	841,371		0.04	111	
58	D-34	850,200	59.00	0.32	111	0
59	D-35	850,309	51.00	0.40	51	0
Total			1,964.13	35.87		

Table 11b. The clusters (groups assigned by the third method) for cycle durations of two warabandis.

No [1]	Structure Name [2]	RD ft [3]	Distri. Disch. cusecs [4]	loss in Canal cusecs [5]	Canal Disch. cusecs [6]	Assigned Group No. (for Distri.) [7]	Assigned Cluster No. [8]	Cluster No. 0 (direct outlet) cusecs [9]	Cluster No. 1 cusecs [10]	Cluster No. 2 cusecs [11]
1	Canal Head	527,950			2,000					
2	D-01	529,500	18.89	0.24	2,000	0	1	0.00	18.89	0.00
3	D-02	532,470	30.19	0.45	1,981	0	2	0.00	0.00	30.19
4	D-03	537,260	92.91	0.71	1,950	0	1	0.00	92.91	0.00
5	Esc-1	541,535		0.63	1,857					
6	X-Reg. 4	541,578		0.01	1,856					
7	D-04	549,975	12.86	1.24	1,856	0	2	0.00	0.00	12.86
8	D-05	558,080	68.58	1.17	1,842	0	2	0.00	0.00	68.58
9	D-06	573,170	59.78	2.18	1,772	0	2	0.00	0.00	59.78
10	X-Reg. 5	574,230		0.15	1,710					
11	D-07	582,810	82.15	1.20	1,710	0	1	0.00	82.15	0.00
12	D-08	597,110	88.96	1.94	1,627	0	2	0.00	0.00	88.96
13	Esc-2	602,423		0.72	1,536					
14	X-Reg. 6	602,466		0.01	1,535					
15	D-O-1	608,500	6.92	0.82	1,535	0	0	6.92	0.00	0.00
16	D-09	611,850	17.18	0.45	1,527	0	1	0.00	17.18	0.00
17	D-O-2	619,000	5.14	0.96	1,510	0	0	5.14	0.00	0.00
18	D-10	623,820	53.11	0.64	1,504	0	1	0.00	53.11	0.00
19	D-11	632,000	59.41	1.09	1,450	0	2	0.00	0.00	59.41
20	X-Reg 7	632,060		0.01	1,389					
21	D-12	643,820	53.29	1.51	1,389	0	1	0.00	53.29	0.00
22	D-13	652,020	72.93	1.02	1,335	0	1	0.00	72.93	0.00
23	D-14	664,900	64.56	1.60	1,261	0	2	0.00	0.00	64.56
24	X-Reg 8	664,960		0.01	1,194					
25	D-15	680,375	113.34	1.78	1,194	0	2	0.00	0.00	113.34
26	D-16	699,299	55.86	2.19	1,079	0	1	0.00	55.86	0.00
27	X-Reg 9	699,359		0.01	1,021					
28	D-O-3	705,500	5.19	0.69	1,021	0	0	5.19	0.00	0.00
29	D-17	712,275	79.25	0.73	1,015	0	1	0.00	79.25	0.00
30	D-18	721,125	17.18	0.95	935	0	2	0.00	0.00	17.18
31	D-19	730,530	59.38	0.97	917	0	2	0.00	0.00	59.38
32	D-20	741,470	21.49	1.13	857	0	1	0.00	21.49	0.00
33	X-Reg 10	741,530		0.01	834					
34	D-O-4	745,500	5.94	0.40	834	0	0	5.94	0.00	0.00
35	D-21	760,020	47.46	1.44	828	0	1	0.00	47.46	0.00
36	D-22	764,100	7.80	0.40	779	0	2	0.00	0.00	7.80
37	Esc-3	768,900		0.47	771					
38	X-Reg 11	769,000		0.01	770					
39	D-23	777,580	80.65	0.71	770	0	2	0.00	0.00	80.65
40	D-O-5	779,465	2.53	0.16	689	0	0	2.53	0.00	0.00
41	D-O-6	784,000	4.93	0.37	686	0	0	4.93	0.00	0.00
42	D-24	786,965	7.13	0.24	681	0	1	0.00	7.13	0.00
43	Esc-4	787,980		0.08	674					
44	X-Reg 12	788,430		0.04	674					
45	D-25	791,220	77.65	0.21	673	0	1	0.00	77.65	0.00
46	D-26	791,340	71.00	0.02	596	0	2	0.00	0.00	71.00
47	D-27	791,450	56.00	0.02	525	0	1	0.00	56.00	0.00
48	X-Reg 13	791,530		0.00	469					
49	D-28	803,770	15.06	0.92	469	0	2	0.00	0.00	15.06
50	D-29	814,295	49.60	0.79	453	0	2	0.00	0.00	49.60
51	X-Reg 14	814,360		0.00	402					
52	D-30	823,170	60.55	0.57	402	0	1	0.00	60.55	0.00
53	D-31	829,030	90.28	0.38	341	0	2	0.00	0.00	90.28
54	X-Reg 15	829,090		0.00	250					
55	D-32	840,520	76.00	0.62	250	0	1	0.00	76.00	0.00
56	D-33	840,980	63.00	0.04	174	0	1	0.00	63.00	0.00
57	X-Reg 16	841,371		0.04	111					
58	D-34	850,200	59.00	0.32	111	0	1	0.00	59.00	0.00
59	D-35	850,309	51.00	0.40	51	0	2	0.00	0.00	51.00
	Total		1,964.13	35.87				30.65	993.85	939.63
	Cycle duration Discharge			1,033.26						

Table 11c. The clusters (groups assigned by the third method) for cycle durations of three warabandis

No [1]	Structure Name [2]	RD ft [3]	Distri. Disch. cusecs [4]	loss in Canal cusecs [5]	Canal Disch. cusecs [6]	Assigned Group No. (for Distri.) [7]	Assigned Cluster No. [8]	Group No. 0 (direct outlet) cusecs [9]	Cluster No. 1 cusecs [10]	Cluster No. 2 cusecs [11]	Cluster No. 3 cusecs [12]
1	Canal Head	527,950			2,000						
2	D-01	529,500	18.89	0.24	2,000	0	1	0.00	18.89	0.00	0.00
3	D-02	532,470	30.19	0.45	1,981	0	2	0.00	0.00	30.19	0.00
4	D-03	537,260	92.91	0.71	1,950	0	3	0.00	0.00	0.00	92.91
5	Esc-1	541,535		0.63	1,857						
6	X-Reg. 4	541,578		0.01	1,856						
7	D-04	549,975	12.86	1.24	1,856	0	2	0.00	0.00	12.86	0.00
8	D-05	558,080	68.58	1.17	1,842	0	3	0.00	0.00	0.00	68.58
9	D-06	573,170	59.78	2.18	1,772	0	2	0.00	0.00	59.78	0.00
10	X-Reg. 5	574,230		0.15	1,710						
11	D-07	582,810	82.15	1.20	1,710	0	1	0.00	82.15	0.00	0.00
12	D-08	597,110	88.96	1.94	1,627	0	2	0.00	0.00	88.96	0.00
13	Esc-2	602,423		0.72	1,536						
14	X-Reg. 6	602,466		0.01	1,535						
15	D-O-1	608,500	6.92	0.82	1,535	0	0	6.92	0.00	0.00	0.00
16	D-09	611,850	17.18	0.45	1,527	0	1	0.00	17.18	0.00	0.00
17	D-O-2	619,000	5.14	0.96	1,510	0	0	5.14	0.00	0.00	0.00
18	D-10	623,820	53.11	0.64	1,504	0	1	0.00	53.11	0.00	0.00
19	D-11	632,000	59.41	1.09	1,450	0	3	0.00	0.00	0.00	59.41
20	X-Reg 7	632,060		0.01	1,389						
21	D-12	643,820	53.29	1.51	1,389	0	1	0.00	53.29	0.00	0.00
22	D-13	652,020	72.93	1.02	1,335	0	2	0.00	0.00	72.93	0.00
23	D-14	664,900	64.56	1.60	1,261	0	3	0.00	0.00	0.00	64.56
24	X-Reg 8	664,960		0.01	1,194						
25	D-15	680,375	113.34	1.78	1,194	0	2	0.00	0.00	113.34	0.00
26	D-16	699,299	55.86	2.19	1,079	0	1	0.00	55.86	0.00	0.00
27	X-Reg 9	699,359		0.01	1,021						
28	D-O-3	705,500	5.19	0.69	1,021	0	0	5.19	0.00	0.00	0.00
29	D-17	712,275	79.25	0.73	1,015	0	1	0.00	79.25	0.00	0.00
30	D-18	721,125	17.18	0.95	935	0	3	0.00	0.00	0.00	17.18
31	D-19	730,530	59.38	0.97	917	0	3	0.00	0.00	0.00	59.38
32	D-20	741,470	21.49	1.13	857	0	1	0.00	21.49	0.00	0.00
33	X-Reg 10	741,530		0.01	834						
34	D-O-4	745,500	5.94	0.40	834	0	0	5.94	0.00	0.00	0.00
35	D-21	760,020	47.46	1.44	828	0	3	0.00	0.00	0.00	47.46
36	D-22	764,100	7.80	0.40	779	0	2	0.00	0.00	7.80	0.00
37	Esc-3	768,900		0.47	771						
38	X-Reg 11	769,000		0.01	770						
39	D-23	777,580	80.65	0.71	770	0	2	0.00	0.00	80.65	0.00
40	D-O-5	779,465	2.53	0.16	689	0	0	2.53	0.00	0.00	0.00
41	D-O-6	784,000	4.93	0.37	686	0	0	4.93	0.00	0.00	0.00
42	D-24	786,965	7.13	0.24	681	0	1	0.00	7.13	0.00	0.00
43	Esc-4	787,980		0.08	674						
44	X-Reg 12	788,430		0.04	674						
45	D-25	791,220	77.65	0.21	673	0	1	0.00	77.65	0.00	0.00
46	D-26	791,340	71.00	0.02	596	0	3	0.00	0.00	0.00	71.00
47	D-27	791,450	56.00	0.02	525	0	1	0.00	56.00	0.00	0.00
48	X-Reg 13	791,530		0.00	469						
49	D-28	803,770	15.06	0.92	469	0	3	0.00	0.00	0.00	15.06
50	D-29	814,295	49.60	0.79	453	0	3	0.00	0.00	0.00	49.60
51	X-Reg 14	814,360		0.00	402						
52	D-30	823,170	60.55	0.57	402	0	2	0.00	0.00	60.55	0.00
53	D-31	829,030	90.28	0.38	341	0	3	0.00	0.00	0.00	90.28
54	X-Reg 15	829,090		0.00	250						
55	D-32	840,520	76.00	0.62	250	0	1	0.00	76.00	0.00	0.00
56	D-33	840,980	63.00	0.04	174	0	2	0.00	0.00	63.00	0.00
57	X-Reg 16	841,371		0.04	111						
58	D-34	850,200	59.00	0.32	111	0	1	0.00	59.00	0.00	0.00
59	D-35	850,309	51.00	0.40	51	0	2	0.00	0.00	51.00	0.00
	Total		1,964.13	35.87				30.65	657.00	641.06	635.42
	Cycle duration Discharge			1,355.51							

Table 11d. The clusters (groups assigned by the third method) for cycle durations of four warabandis

No [1]	Structure Name [2]	RD ft [3]	Distri. Disch. cusecs [4]	loss in Canal cusecs [5]	Canal Disch. cusecs [6]	Assigned Group No. (for Distri.) [7]	Assigned Cluster No. [8]	Cluster No. 0 (direct outlet) cusecs [9]	Cluster No. 1 cusecs [10]	Cluster No. 2 cusecs [11]	Cluster No. 3 cusecs [12]	Cluster No. 4 cusecs [13]
1	Canal Head	527,950			2,000							
2	D-01	529,500	18.89	0.24	2,000	0	1	0.00	18.89	0.00	0.00	0.00
3	D-02	532,470	30.19	0.45	1,981	0	2	0.00	0.00	30.19	0.00	0.00
4	D-03	537,260	92.91	0.71	1,950	0	3	0.00	0.00	0.00	92.91	0.00
5	Esc-1	541,535		0.63	1,857							
6	X-Reg. 4	541,578		0.01	1,856							
7	D-04	549,975	12.86	1.24	1,856	0	4	0.00	0.00	0.00	0.00	12.86
8	D-05	558,080	68.58	1.17	1,842	0	4	0.00	0.00	0.00	0.00	68.58
9	D-06	573,170	59.78	2.18	1,772	0	1	0.00	59.78	0.00	0.00	0.00
10	X-Reg. 5	574,230		0.15	1,710							
11	D-07	582,810	82.15	1.20	1,710	0	2	0.00	0.00	82.15	0.00	0.00
12	D-08	597,110	88.96	1.94	1,627	0	1	0.00	88.96	0.00	0.00	0.00
13	Esc-2	602,423		0.72	1,536							
14	X-Reg. 6	602,486		0.01	1,535							
15	D-O-1	608,500	6.92	0.82	1,535	0	0	6.92	0.00	0.00	0.00	0.00
16	D-09	611,850	17.18	0.45	1,527	0	4	0.00	0.00	0.00	0.00	17.18
17	D-O-2	619,000	5.14	0.96	1,510	0	0	5.14	0.00	0.00	0.00	0.00
18	D-10	623,820	53.11	0.64	1,504	0	3	0.00	0.00	0.00	53.11	0.00
19	D-11	632,000	59.41	1.09	1,450	0	2	0.00	0.00	59.41	0.00	0.00
20	X-Reg 7	632,060		0.01	1,389							
21	D-12	643,820	53.29	1.51	1,389	0	4	0.00	0.00	0.00	0.00	53.29
22	D-13	652,020	72.93	1.02	1,335	0	3	0.00	0.00	0.00	72.93	0.00
23	D-14	664,900	64.56	1.60	1,261	0	4	0.00	0.00	0.00	0.00	64.56
24	X-Reg 8	664,960		0.01	1,194							
25	D-15	680,375	113.34	1.78	1,194	0	1	0.00	113.34	0.00	0.00	0.00
26	D-16	699,299	55.86	2.19	1,079	0	2	0.00	0.00	55.86	0.00	0.00
27	X-Reg 9	699,359		0.01	1,021							
28	D-O-3	705,500	5.19	0.69	4,021	0	0	5.19	0.00	0.00	0.00	0.00
29	D-17	712,275	79.25	0.73	1,015	0	4	0.00	0.00	0.00	0.00	79.25
30	D-18	721,125	17.18	0.95	935	0	3	0.00	0.00	0.00	17.18	0.00
31	D-19	730,530	59.38	0.97	917	0	2	0.00	0.00	59.38	0.00	0.00
32	D-20	741,470	21.49	1.13	857	0	3	0.00	0.00	0.00	21.49	0.00
33	X-Reg 10	741,530		0.01	834							
34	D-O-4	745,500	5.94	0.40	834	0	0	5.94	0.00	0.00	0.00	0.00
35	D-21	760,020	47.46	1.44	828	0	3	0.00	0.00	0.00	47.46	0.00
36	D-22	764,100	7.80	0.40	779	0	1	0.00	7.80	0.00	0.00	0.00
37	Esc-3	768,900		0.47	771							
38	X-Reg 11	769,000		0.01	770							
39	D-23	777,580	80.65	0.71	770	0	2	0.00	0.00	80.65	0.00	0.00
40	D-O-5	779,465	2.53	0.16	689	0	0	2.53	0.00	0.00	0.00	0.00
41	D-O-6	784,000	4.93	0.37	686	0	0	4.93	0.00	0.00	0.00	0.00
42	D-24	786,965	7.13	0.24	681	0	1	0.00	7.13	0.00	0.00	0.00
43	Esc-4	787,980		0.08	674							
44	X-Reg 12	788,430		0.04	674							
45	D-25	791,220	77.65	0.21	673	0	1	0.00	77.65	0.00	0.00	0.00
46	D-26	791,340	71.00	0.02	596	0	4	0.00	0.00	0.00	0.00	71.00
47	D-27	791,450	56.00	0.02	525	0	3	0.00	0.00	0.00	56.00	0.00
48	X-Reg 13	791,530		0.00	469							
49	D-28	803,770	15.06	0.92	469	0	4	0.00	0.00	0.00	0.00	15.06
50	D-29	814,295	49.60	0.79	453	0	3	0.00	0.00	0.00	49.60	0.00
51	X-Reg 14	814,360		0.00	402							
52	D-30	823,170	60.55	0.57	402	0	1	0.00	60.55	0.00	0.00	0.00
53	D-31	829,030	90.28	0.38	341	0	4	0.00	0.00	0.00	0.00	90.28
54	X-Reg 15	829,090		0.00	250							
55	D-32	840,520	76.00	0.62	250	0	3	0.00	0.00	0.00	76.00	0.00
56	D-33	840,980	63.00	0.04	174	0	2	0.00	0.00	63.00	0.00	0.00
57	X-Reg 16	841,371		0.04	111							
58	D-34	850,200	59.00	0.32	111	0	2	0.00	0.00	59.00	0.00	0.00
59	D-35	850,309	51.00	0.40	51	0	1	0.00	51.00	0.00	0.00	0.00
	Total		1,964.13	35.87				30.65	485.10	489.64	486.68	472.06
	Cycle duration Discharge			1,516.63								

4.6.2 Developing Rotation Schedules

Developing rotation schedules is needed to correlate the water supply with the cluster demands. To do that, some groups must be combined in a way that the total demand is nearly the same for each cluster. For example, two clusters need to be developed for a cycle duration of two warabandis, with one closed and the another open, during the first warabandis period, which is just the opposite for the second warabandi period.

For two clusters of groups, the total distributary discharge of 1,964.13 cusecs is divided by two. Therefore, the total distributary discharge for each group should be 982.07 cusecs. Fortunately, three percent (more or less) is allowed in total discharge variation among clusters, which is between 952.61 and 1,011.53 cusecs for this example case.

During the selection of the groups, it has to be taken into account that every section has certain flow limits, such as maximum and minimum discharges. The selection of groups must fulfill these infra-structural operational conditions. For example, in the Punjab system of CRBC, the backwater level has to be such that heading up results in 43% of the head regulator discharge for the farthest upstream distributary in the reach. This criterion is used in this example. Table 14 shows the maximum (Column 6) and minimum (Column 18) discharge of each reach. The minimum discharge is 43% of the maximum discharge.

4.6.2.1 Grouping Into Cluster

Assigning groups to form a cluster could be made with the same criteria, no matter how clusters are made, either with the first or second method. In order to understand the methodology, examples will be used for two clusters with one closed and another open.

In a canal system with 1,964.13 cusecs of total distributary discharge, the two clusters should have nearly 982.07 cusecs for each cluster. There are numerous combinations of clusters. In this example, 10 combinations are selected and presented in Table 12 and 13.

Groups in Table 12 are developed by the first method. There are 10 selected combinations of groups. In the combination 1, Groups 1, 2, 3, 4, 5, and 6 are in Cluster 1 with a total distributary discharge of 956.06 cusecs, and Groups 7, 8, 9, 10, 11, 12, 13, and 14 are in Cluster 2 with 1,008.07 cusecs.

Table 12. Combinations of the 1st method groups for Cluster 1 of 2.

Combination1		Combination2		Combination3		Combination4		Combination5	
Group	Closed	Group	Closed	Group	Closed	Group	Closed	Group	Closed
1	141.99	1	141.99	1	141.99	1	141.99	1	141.99
2	141.22	3	171.11	4	141.76	8	61.20	2	141.22
3	171.11	4	141.76	5	190.78	9	95.24	4	141.76
4	141.76	5	190.78	6	169.20	10	204.65	5	190.78
5	190.78	6	169.20	7	182.49	11	64.66	6	169.20
6	169.20	7	182.49	8	61.20	12	150.83	7	182.49
				9	95.24	13	139.00		
						14	110.00		
Total	956.06	Total	997.33	Total	982.66	Total	967.57	Total	967.44

Combination6		Combination7		Combination8		Combination9		Combination10	
Group	Closed	Group	Closed	Group	Closed	Group	Closed	Group	Closed
1	141.99	1	141.99	1	141.99	1	141.99	1	141.99
2	141.22	2	141.22	2	141.22	2	141.22	3	171.11
5	190.78	6	169.20	8	61.20	9	95.24	10	204.65
6	169.20	7	182.49	9	95.24	10	204.65	11	64.66
7	182.49	8	61.20	10	204.65	11	64.66	12	150.83
8	61.20	9	95.24	11	64.66	12	150.83	13	139.00
9	95.24	10	204.65	12	150.83	13	139.00	14	110.00
				13	139.00				
Total	982.12	Total	995.99	Total	998.79	Total	937.59	Total	982.24

Clusters in Table 13 are developed by the second method. As previously explained, 12 groups are developed. For clusters, there are 10 selected combinations of groups present in Table 13 for example. In the Combination 1, Groups 1, 2, 3, 4, and 6 are in Cluster 1 with 954.57 cusecs, and Groups 5, 7, 8, 9, 10, 11, and 12 are in Cluster 2 with 1,009.6 cusecs of total distributary discharge.

Table 13. Combinations of the 2nd method groups for Cluster 1 of 2.

Combination1		Combination2		Combination3		Combination4		Combination5	
Group	Closed	Group	Closed	Group	Closed	Group	Closed	Group	Closed
1	216.04	1	216.04	1	216.04	1	216.04	1	216.04
2	167.28	2	167.28	2	167.28	2	167.28	3	309.49
3	309.49	3	309.49	3	309.49	5	237.85	4	138.95
4	138.95	4	138.95	6	122.77	7	164.99	5	237.85
6	122.77	7	164.99	7	164.99	9	80.10	9	80.10
						12	119.60		
Total	954.53	Total	996.75	Total	980.57	Total	985.86	Total	982.43

Combination6		Combination7		Combination8		Combination9		Combination10	
Group	Closed	Group	Closed	Group	Closed	Group	Closed	Group	Closed
1	216.04	2	167.28	2	167.28	3	309.49	3	309.49
3	309.49	3	309.49	3	309.49	5	237.85	5	237.85
4	138.95	5	237.85	5	237.85	8	239.21	8	239.21
8	239.21	7	164.99	7	164.99	10	91.62	9	80.10
11	76.23	10	91.62	12	119.60	12	119.60	12	119.60
Total	979.92	Total	971.23	Total	999.21	Total	997.77	Total	986.25

Each combination has to be tested so that the flow conditions of the canal are fulfilled for every reach. For example, the third combination in Table 12 will be tested. Table 14 shows open and closed groups in the first and second cycle duration. Column 14 and 15 show discharges along the canal with closed distributaries in Cluster 1 and 2, respectively.

Column 20 shows a lower allowable discharge at Cross-regulator 9. Therefore, this combination is not acceptable.

Table 14. Flow conditions testing for the Combination 3 in Table 12.

No	Structure Name	RD	Distri. Disch.	loss in Canal	Canal Disch.	Assigned Group No. (for Distri.)	Assigned Cluster No.	Cluster No. 1	Cluster No. 2	Discharge in Canal when				Allowable Min. Canal Disch.	Higher than Allow. Min. Disch.			
										close Cluster No. 1	close Cluster No. 2	close Cluster No. 3	close Cluster No. 4		close Cluster No. 1	close Cluster No. 2	close Cluster No. 3	close Cluster No. 4
		ft	cusecs	cusecs	cusecs			cusecs	cusecs	cusecs	cusecs	cusecs	cusecs	cusecs	cusecs	cusecs	cusecs	cusecs
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[10]	[11]	[14]	[15]	[16]	[17]	[18]	[19]	[20]	[21]	[22]
1	Canal Head	527,950			2,000					1,017.94	1,017.94	0.00	0.00	860.00	157.94	157.94	-860.00	-860.000
2	D-01	529,500	18.89	0.24	2,000	1	1	18.89	0.00	1,017.70	998.81	-19.13	-19.13					
3	D-02	532,470	30.19	0.45	1,981	1	1	30.19	0.00	1,017.25	968.17	-49.77	-49.77					
4	D-03	537,260	92.91	0.71	1,950	1	1	92.91	0.00	1,016.54	874.55	-143.39	-143.39					
5	Esc-1	541,535		0.63	1,857					1,015.91	873.92	-144.02	-144.02					
6	X-Reg. 4	541,578		0.01	1,856					1,015.90	873.91	-144.03	-144.03	798.07	217.82	75.83	-942.10	-942.101
7	D-04	549,975	12.86	1.24	1,856	2	2	0.00	12.86	1,001.80	872.67	-158.13	-158.13					
8	D-05	558,080	68.58	1.17	1,842	2	2	0.00	68.58	932.05	871.50	-227.88	-227.88					
9	D-06	573,170	59.78	2.18	1,772	2	2	0.00	59.78	870.09	869.32	-289.84	-289.84					
10	X-Reg. 5	574,230		0.15	1,710					869.94	869.17	-289.99	-289.99	735.37	134.57	133.80	-1,025.36	-1,025.359
11	D-07	582,810	82.15	1.20	1,710	3	2	0.00	82.15	786.59	867.97	-373.34	-373.34					
12	D-08	597,110	88.96	1.94	1,627	3	2	0.00	88.96	695.69	866.03	-464.24	-464.24					
13	Esc-2	602,423		0.72	1,536					694.97	865.31	-464.96	-464.96					
14	X-Reg. 6	602,466		0.01	1,535					694.96	865.30	-464.97	-464.97	660.07	34.89	205.23	-1,125.04	-1,125.037
15	D-O-1	608,500	6.92	0.82	1,535	4	1	6.92	0.00	694.14	857.56	-472.71	-472.71					
16	D-09	611,850	17.18	0.45	1,527	4	1	17.18	0.00	693.69	839.93	-490.34	-490.34					
17	D-O-2	619,000	5.14	0.96	1,510	4	1	5.14	0.00	692.73	833.83	-496.44	-496.44					
18	D-10	623,820	53.11	0.64	1,504	4	1	53.11	0.00	692.09	780.08	-550.19	-550.19					
19	D-11	632,000	59.41	1.09	1,450	4	1	59.41	0.00	691.00	719.58	-610.69	-610.69					
20	X-Reg 7	632,060		0.01	1,389					690.99	719.57	-610.70	-610.70	597.40	93.58	122.16	-1,208.10	-1,208.103
21	D-12	643,820	53.29	1.51	1,389	5	1	53.29	0.00	689.48	664.77	-665.50	-665.50					
22	D-13	652,020	72.93	1.02	1,335	5	1	72.93	0.00	688.46	590.82	-739.45	-739.45					
23	D-14	664,900	64.56	1.60	1,261	5	1	64.56	0.00	686.86	524.66	-805.61	-805.61					
24	X-Reg 8	664,960		0.01	1,194					686.85	524.65	-805.62	-805.62	513.59	173.26	11.06	-1,319.21	-1,319.208
25	D-15	680,375	113.34	1.78	1,194	6	1	113.34	0.00	685.07	409.53	-920.74	-920.74					
26	D-16	699,299	55.86	2.19	1,079	6	1	55.86	0.00	682.88	351.48	-978.79	-978.79					
27	X-Reg 9	699,359		0.01	1,021					682.87	351.47	-978.80	-978.80	439.12	243.74	-87.66	-1,417.92	-1,417.920

Table 15 demonstrates another flow condition testing. The Combination 1 from Table 13 will be tested. Column 7 of Table 15 shows group numbers as developed using the second method. Column 8 shows the cluster number for Combination 1 in Table 13. Column 10 and 11 show the distributary discharge in Cluster 1 and 2,respectively. Column 14 and 15 shows discharges along the canal with closed distributaries in Cluster 1 and 2, respectively. Column 18 contains allowable minimum discharges in the canal. Column 19 and 20 show that higher than minimum allowable discharges occur through the cross-regulators.

Table 15. Flow condition testing for Combination 1 in Table 13.

No	Structure Name	RD	Distri. Disch.	loss in Canal	Canal Disch	Assigned Group No. (for Distri)	Assigned Cluster No.	Cluster No. 1	Cluster No. 2	Discharge in Canal when				Allowable Min. Canal Disch.	Higher than Allow. Min. Disch.			
		ft	cusecs	cusecs	cusecs			cusecs	cusecs	close Cluster No. 1 cusecs	close Cluster No. 2 cusecs	close Cluster No. 3 cusecs	close Cluster No. 4 cusecs	cusecs	close Cluster No. 1 cusecs	close Cluster No. 2 cusecs	close Cluster No. 3 cusecs	close Cluster No. 4 cusecs
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[10]	[11]	[14]	[15]	[16]	[17]	[18]	[19]	[20]	[21]	[22]
1	Canal Head	527,950			2,000					1,017.94	1,017.94	1,017.94	1,017.94	776.32	241.61	241.61	241.61	241.613
2	D-01	529,500	18.89	0.24	2,000	1	1	18.89	0.00	1,017.70	998.81	998.81	998.81					
3	D-02	532,470	30.19	0.45	1,981	2	1	30.19	0.00	1,017.25	988.17	988 17	988.17					
4	D-03	537,260	92.91	0.71	1,950	3	1	92.91	0.00	1,016 54	874.55	874.55	874.55					
5	Esc-1	541,535		0 63	1,857					1,015.91	873.92	873.92	873.92					
6	X-Reg. 4	541,578		0.01	1,856					1,015.90	873.91	873.91	873.91	715.68	300.22	158.23	158.23	158.226
7	D-04	549,975	12.86	1.24	1,856	4	1	12.86	0.00	1,014.66	859.81	859.81	859.81					
8	D-05	558,080	68.58	1.17	1,842	5	2	0.00	68.58	944.91	858.64	790.06	790.06					
9	D-06	573,170	59.78	2.18	1,772	6	1	59.78	0.00	942.73	796.88	728.10	728.10					
10	X-Reg. 5	574,230		0.15	1,710					942.58	796.53	727.95	727.95	654.21	288.37	142.32	73.74	73.739
11	D-07	582,810	82.15	1.20	1,710	7	2	0.00	82.15	859.23	795.33	644.60	644.60					
12	D-08	597,110	88.96	1.94	1,627	8	2	0.00	88.96	768.33	793.39	553.70	553.70					
13	Esc-2	602,423		0 72	1,536					767.61	792.67	552.98	552.98					
14	X-Reg. 6	602,466		0.01	1,535					767.60	792.66	552.97	552.97	579.82	187.77	212.83	-26.86	-26.860
15	D-O-1	608,500	6.92	0.82	1,535	9	2	0.00	6.92	759.86	791.84	545.23	545.23					
16	D-09	611,850	17.18	0.45	1,527	10	2	0.00	17.18	742.23	791.39	527.60	527.60					
17	D-O-2	619,000	5.14	0.96	1,510	11	2	0.00	5.14	736.13	790.43	521.50	521.50					
18	D-10	623,820	53.11	0.64	1,504	12	2	0.00	53.11	682.38	789.79	467.75	467.75					
19	D-11	632,000	59.41	1.09	1,450	1	1	59.41	0.00	681.29	729.29	407.25	407.25					
20	X-Reg 7	632,060		0.01	1,389					681.28	729.28	407.24	407.24	519.31	161.96	209.96	-112.08	-112.076
21	D-12	643,820	53.29	1.51	1,389	2	1	53.29	0.00	679.77	674.48	352.44	352.44					
22	D-13	652,020	72.93	1.02	1,335	3	1	72.93	0.00	678.75	600.53	278.49	278.49					
23	D-14	664,900	64.56	1.60	1,281	4	1	64.56	0.00	677.15	534.37	212.33	212.33					
24	X-Reg 8	664,960		0 01	1,194					677.14	534.36	212.32	212.32	436.79	240.35	97.57	-224.47	-224.470
25	D-15	680,375	113.34	1.78	1,194	5	2	0.00	113.34	562.02	532.58	97.20	97.20					
26	D-16	699,299	55.86	2.19	1,079	6	1	55.86	0.00	559.83	474.53	39.15	39.15					
27	X-Reg 9	699,359		0.01	1,021					559.82	474.52	39.14	39.14	355.44	204.38	119.06	-316.30	-316.303

4.6.2.2 Individual Distributary Clustering

Individual distributrary clustering means that distributaries will be clustered without making groups. In Table 16, Column 7 show that all distributaries are in group zero. Column 8 is cluster number for individual distributary. All direct outlets (D-O-1 to D-O-6 distributaries) are in Cluster 0 which is always open. Total discharge for the direct outlets is 30.65 cusecs. Total discharge of each rotation group should be (1,964.13-30.65)/2 = 966.74 cusecs. Therefore, the water supply at head regulator is 966.74+35.87 = 1,002.61 cusecs.

Columns 14 and 15 are discharges along the canal when the distributaries in Clusters 1 and 2 are closed. Assigning of a cluster number in Column 8 is in a way so the discharges in Columns 14 and 15 are kept nearly the same for each canal section.

Table 16. Flow condition testing for individual distributary groupings.

No	Structure Name	RD	Distr. Disch.	loss in Canal	Canal Disch.	Assigned Group No. (for Distn.)	Assigned Cluster No.	Cluster No 0 (direct outlet)	Cluster No. 1	Cluster No. 2	Discharge in canal when		Allowable Min. Canal Disch.	Higher than Allow. Min. Disch.	
											close Cluster No. 1	close Cluster No. 2		close Cluster No. 1	close Cluster No. 2
-		ft	cusecs	cusecs	cusecs			cusecs	cusecs	cusecs	cusecs	cusecs	cusecs	cusecs	cusecs
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[14]	[15]	[18]	[19]	[20]
1	Canal Head	527,950			2,000						1,033.26	1,033.26	776.32	256.94	256.94
2	D-01	529,500	18.89	0.24	2,000	0	1	0.00	18.89	0.00	1,033.02	1,014.13			
3	D-02	532,470	30.19	0.45	1,981	0	2	0.00	0.00	30.19	1,002.38	1,013.68			
4	D-03	537,260	92.91	0.71	1,950	0	1	0.00	92.91	0.00	1,001.67	920.06			
5	Esc-1	541,535		0.63	1,857						1,001.04	919.43			
6	X-Reg. 4	541,578		0.01	1,856						1,001.03	919.42	715.68	285.35	203.74
7	D-04	549,975	12.86	1.24	1,856	0	2	0.00	0.00	12.86	986.93	918.18			
8	D-05	558,080	68.58	1.17	1,842	0	2	0.00	0.00	68.58	917.18	917.01			
9	D-06	573,170	59.78	2.18	1,772	0	2	0.00	0.00	59.78	855.22	914.83			
10	X-Reg. 5	574,230		0.15	1,710						855.07	914.68	654.21	200.86	260.47
11	D-07	582,810	82.15	1.20	1,710	0	1	0.00	82.15	0.00	853.87	831.33			
12	D-08	597,110	88.96	1.94	1,627	0	2	0.00	0.00	88.96	762.97	829.39			
13	Esc-2	602,423		0.72	1,536						762.25	828.67			
14	X-Reg. 6	602,466		0.01	1,535						762.24	828.66	579.82	182.42	248.84
15	D-O-1	608,500	6.92	0.82	1,535	0	0	6.92	0.00	0.00	754.50	820.92			
16	D-09	611,850	17.18	0.45	1,527	0	1	0.00	17.18	0.00	754.05	803.29			
17	D-O-2	619,000	5.14	0.96	1,510	0	0	5.14	0.00	0.00	747.95	797.19			
18	D-10	623,820	53.11	0.64	1,504	0	1	0.00	53.11	0.00	747.31	743.44			
19	D-11	632,000	59.41	1.09	1,450	0	2	0.00	0.00	59.41	686.81	742.35			
20	X-Reg 7	632,060		0.01	1,389						686.80	742.34	519.31	167.49	223.03
21	D-12	643,820	53.29	1.51	1,389	0	1	0.00	53.29	0.00	685.29	687.54			
22	D-13	652,020	72.93	1.02	1,335	0	1	0.00	72.93	0.00	684.27	613.59			
23	D-14	664,900	64.56	1.60	1,261	0	2	0.00	0.00	64.56	618.11	611.99			
24	X-Reg 8	664,960		0.01	1,194						618.10	611.98	436.79	181.31	175.19
25	D-15	680,375	113.34	1.78	1,194	0	2	0.00	0.00	113.34	502.98	610.20			
26	D-16	699,299	55.86	2.19	1,079	0	1	0.00	55.86	0.00	500.79	552.15			
27	X-Reg 9	699,359		0.01	1,021						500.78	552.14	355.44	145.34	196.70
28	D-O-3	705,500	5.19	0.69	1,021	0	0	5.19	0.00	0.00	494.90	546.26			
29	D-17	712,275	79.25	0.73	1,015	0	1	0.00	79.25	0.00	494.17	466.28			
30	D-18	721,125	17.18	0.95	935	0	2	0.00	0.00	17.18	476.04	465.33			
31	D-19	730,530	59.38	0.97	917	0	2	0.00	0.00	59.38	415.69	464.36			
32	D-20	741,470	21.49	1.13	857	0	1	0.00	21.49	0.00	414.56	441.74			
33	X-Reg 10	741,530		0.01	834						414.55	441.73	277.19	137.36	164.54
34	D-O-4	745,500	5.94	0.40	834	0	0	5.94	0.00	0.00	408.21	435.39			
35	D-21	760,020	47.46	1.44	828	0	1	0.00	47.46	0.00	406.77	386.49			
36	D-22	764,100	7.80	0.40	779	0	2	0.00	0.00	7.80	398.57	386.09			
37	Esc-3	768,900		0.47	771						398.10	385.62			
38	X-Reg 11	769,000		0.01	770						398.09	385.61	251.00	147.09	134.61
39	D-23	777,580	80.65	0.71	770	0	2	0.00	0.00	80.65	316.73	384.90			
40	D-O-5	779,465	2.53	0.16	689	0	0	2.53	0.00	0.00	314.04	382.21			
41	D-O-6	784,000	4.93	0.37	686	0	0	4.93	0.00	0.00	308.74	376.91			
42	D-24	786,965	7.13	0.24	681	0	1	0.00	7.13	0.00	308.50	369.54			
43	Esc-4	787,980		0.08	674						308.42	369.46			
44	X-Reg 12	788,430		0.04	674						308.38	369.42	211.07	97.31	158.35
45	D-25	791,220	77.65	0.21	673	0	1	0.00	77.65	0.00	308.17	291.56			
46	D-26	791,340	71.00	0.02	596	0	2	0.00	0.00	71.00	237.15	291.54			
47	D-27	791,450	56.00	0.02	525	0	1	0.00	56.00	0.00	237.13	235.52			
48	X-Reg 13	791,530		0.00	469						308.17	291.56	178.01	130.16	113.55
49	D-28	803,770	15.06	0.92	469	0	2	0.00	0.00	15.06	292.19	290.64			
50	D-29	814,295	49.60	0.79	453	0	2	0.00	0.00	49.60	241.80	289.65			
51	X-Reg 14	814,360		0.00	402						241.80	289.85	150.33	91.47	130.52
52	D-30	823,170	60.55	0.57	402	0	1	0.00	60.55	0.00	241.23	228.73			
53	D-31	829,030	90.28	0.38	341	0	2	0.00	0.00	90.28	150.57	228.35			
54	X-Reg 15	829,090		0.00	250						150.57	228.35	85.92	64.65	142.43
55	D-32	840,520	76.00	0.62	250	0	1	0.00	76.00	0.00	149.95	151.73			
56	D-33	840,980	63.00	0.04	174	0	1	0.00	63.00	0.00	149.91	88.69			
57	X-Reg 16	841,371		0.04	111						149.87	88.65	85.92	63.95	2.73
58	D-34	850,200	59.00	0.32	111	0	1	0.00	59.00	0.00	149.55	29.33			
59	D-35	850,309	51.00	0.40	51	0	2	0.00	0.00	51.00	98.15	28.93			
	Total		1,964.13	35.87				30.65	993.85	939.63					
	Cycle duration Discharge			1,033.26											

4.7 DEVELOPING A DAILY DISCHARGE SCHEDULE

Developing a daily discharge schedule is the last step for CBIO of making schedules. This step consists of the final adjustment of discharges for the daily schedule in order to match this with the volume of water required for the crops.

5. FIELD MEASUREMENTS FOR REFINING SCHEDULES

The daily operating schedules should be refined based on field measurements. Much of the necessary fieldwork should be undertaken before implementing CBIO.

5.1 STRUCTURE CALIBRATIONS

All essential flow control structures should be field calibrated to develop discharge ratings. These structures would be the canal headworks, each cross-regulator, and each distributary head regulator, as well as all of the direct outlets.

Discharge measurements using a current meter are preferably done during steady state flow conditions. However, the canals in Pakistan are usually operating under unsteady flow conditions. A technique has been developed (Khan, et al, 1997) for correcting current meter measurements taken during unsteady flow conditions.

The procedures to develop discharge ratings for flow control structures have been reported (Skogerboe and Merkley, 1996). These procedures can be used to systematically develop all of the required discharge ratings for a canal.

5.2 DOWNSTREAM GAUGE RATINGS

A common practice in Pakistan is to install a vertical gauge downstream of a flow control structure. This downstream gauge is sometimes placed in the middle of the canal and other times alongside the canal bank. The downstream gauge rating is actually a discharge calibration of the irrigation channel cross-section. The gate operator is provided a discharge rating table, so when the irrigation manager specifies a particular discharge rate, the gate operator can establish the required water level on the downstream gauge, then maneuver the gate(s) to provide the required water level.

The recommended procedure for developing a downstream gauge rating has been reported by Vehmeyer, et al (1998). An important part of the procedure is to simultaneously field calibrate the flow control structure and downstream gauge. This implies that for each current meter measurement, the water level on the downstream gauge would be recorded, as well as the water levels and gate openings for the flow control structure. Usually, four current meter measurements, or more, would be undertaken, with each one being a different discharge rate.

The downstream gauge rating is quite sensitive to sediment deposition and removal. Thus, there is a need to periodically adjust the rating, sometimes as frequently as every other month. Instead of taking a current meter measurement to adjust the downstream gauge rating, the water levels and gate openings at the nearby flow control structure can be used to provide the discharge rate.

5.3 CANAL CONVEYANCE LOSSES

A good technique is to use the inflow-outflow method under steady state flow conditions. For each reach between two flow control structures (e.g., cross-regulators), the conveyance losses should be measured as the difference in the discharge rates at the upstream and downstream flow control structures. This should be done for at least three different water levels in the reach that essentially covers the range of operating flow conditions. The wetted perimeter for the reach should be measured for each water level. The seepage loss rate, Q_{slr}, can be expressed in cubic meters per day of conveyance loss divided by the square meters of wetter perimeter, which can be reduced to millimetres (mm) per day or feet per day. In the Indian Subcontinent, the seepage loss rate is expressed in cusecs of conveyance loss divided by million square feet (msf) of wetted perimeter, which is calculated from an inflow-outflow test as:

$$Q_{slr}(cusecs/msf) = \frac{Q_u(cusecs) - Q_d(cusecs)}{WP(ft^2)/1{,}000{,}000} \tag{13}$$

Where Q_u is the discharge rate measured at the upstream flow control structure, Q_d is the discharge rate at the downstream flow control structure, and WP is the wetted perimeter for the reach. The seepage loss rate will increase as the water levels increase. An example of a typical seepage loss rate curve is shown in Figure 14. In any reach, there is a water surface gradient, so a water surface elevation has to be selected at any desired location, where often the water surface elevation selected is either : (1) a short distance downstream from the flow control structure at the head of the reach, which is termed a downstream gauge; or (2) immediately upstream from the flow control structure at the tail of the reach.

5.4 EVALUATION OF CANAL LAG TIMES

The designs for both USC-PHLC and CBRC have been placed in the unsteady flow hydrodynamic model, "Simulation of Irrigation Canals (SIC)". This is highly beneficial for checking the design and planning future operations. However, for actual operations, the SIC model needs to be calibrated for actual field conditions.

First of all, the results from the field calibration of the flow control structures (Section 5.1) will be inputted into SIC in order to replace the design discharge equation for each structure. Also, the results from measuring canal conveyance losses (Section 5.3) will be incorporated into SIC to replace the design conveyance losses. At the same time, the water levels recorded while conducting the inflow-outflow tests (Section 5.3) will be used to calibrate the steady state version of SIC.

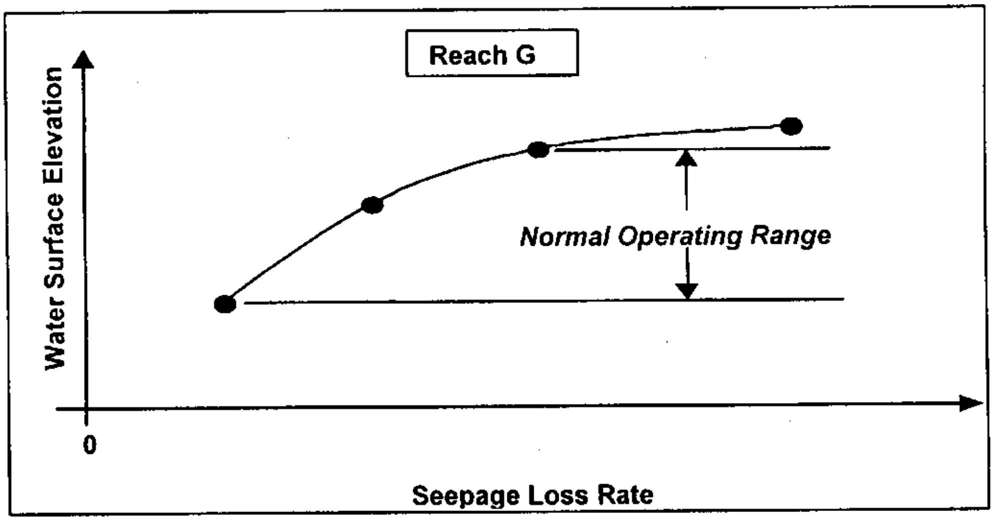


Figure 14. Example of a seepage loss rate curve for a canal reach.

Now, SIC can be used to predict lag times between any two cross-sections along a canal for a wide variety of operating conditions. These lag times can be incorporated into the CBIO-SBO-CBIO schedules. Also, these lag times can be checked during actual operations to determine whether any adjustments are required. Or, if SIC is not used, then such field measurements during actual operations would suffice for adjusting the discharge schedule at each cross-regulator.

5.5 SCHEDULE ADJUSTMENTS FOR DISTRIBUTARY LAG TIMES

Initially, three or four secondary canals should be selected for intensive study. The selection criteria would be a wide range of discharge rates and secondary canal lengths. The longest secondary canal should be included. Then, a tertiary channel is selected near the head, middle and tail of each selected secondary canal. The structure at the head of each tertiary channel is field calibrated for discharge measurement using a small current meter for lined tertiary channels or a flow measuring flume for unlined tertiary channels. Once these discharge ratings have been completed, then the appropriate water levels can be monitored and the corresponding discharge rate calculated. Now, the selected secondary canals should be monitored for at least two cycle durations. When the secondary canal gate(s) are opened, the monitoring should continue until a steady state flow condition has been reached at the head of the tail tertiary channel. When the secondary canal gate(s) are closed, the monitoring should continue until the discharge rate entering the tail tertiary channel is only half, or less, of the steady state discharge rates. During each cycle duration being monitored, the water distribution in each selected tertiary channel should also be monitored to verify whether or not each farmer was able to receive water according to schedule. If not, evaluate what changes are required in the opening and closing of the secondary canal gate(s). Then, using these lag time adjustments, monitor another cycle duration and refine these adjustments. Repeat this procedure until satisfactory results are achieved.

Based on the experiences resulting from the above procedure, the lag times should be assessed for the remaining secondary canals. Again, a tertiary channel should be selected near the head, middle and tail of the secondary canal, but the structure at the head of each tertiary channel does not need to be field calibrated for discharge measurement. Design the monitoring procedure based on the results from the intensive study described above. Monitor one cycle duration and determine the lag time adjustments for opening and closing the secondary canal gate(s). Using these adjustments, monitor another cycle duration and refine the lag time adjustments. This should be sufficient, but if there are some doubts, then this procedure should be repeated.

5.6 POST-SEASON SCHEDULE ADJUSTMENTS

Based on the results of implementing the CBIO-SBO-CBIO schedules for one calendar year, then these schedules should be adjusted. The primary basis for adjustment would be water surpluses or shortages during any period of time. Largely, farmer complaints will occur during periods of water shortage, which should be checked by the field staff at the time of the complaint and a situation letter prepared for later action (or immediate action if a serious situation has occurred). Information about water surpluses can be determined, first of all, by monitoring whether or not any of the moghas are closed by farmers and, secondly, by farmer interviews. Certainly, during the first two years of CBIO-SBO-CBIO, there will be a strong need to monitor the operation schedules so that any necessary adjustments can be made.

5.7 PERIODIC CHECKS AND REFINEMENTS

In order to provide good services, there is a continual need to periodically check the data being used in developing the delivery schedules. For example, a systematic schedule should be established to check the discharge rating for each flow control structure; this could be done over a time period of five years so that one-fifth of the structures are checked each year. Likewise, the canal conveyance losses could be measured once every three years to evaluate whether any significant changes are occurring in any of the reaches, while at the same time rechecking the steady state calibration of SIC. Then, canal lag times can be checked, as well as distributary lag times. Finally, farmers should be interviewed regarding suggestions for improved services; perhaps, six distributary channels, or more, could be selected each season for farmer interviews, which would require a number of years to cover all of the secondary canal command areas.

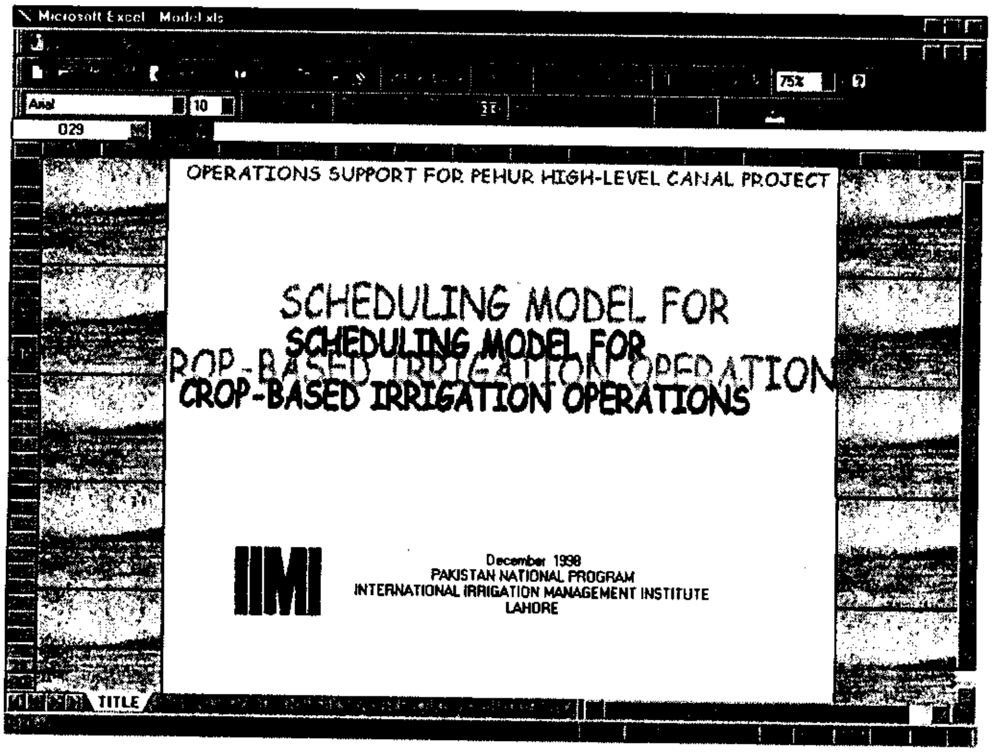
6. CBIO SCHEDULING MODEL

The CBIO scheduling model is a computer program developed in MS Excel on the Windows 95 environment. The model is in an Excel file that is called a workbook, which contains many worksheets. The Excel Workbook of the CBIO Scheduling Model is for a canal system. There are eight worksheets; namely, *TITLE, CWR, CBIO, Open_WEEKS, STEP_CBIO, SCHEDULING, DAILY SCHEDULING,* and *PRINTING* worksheets.

The user has to provide some information to the model by entering date into the green and light green color cells on the worksheets. The user will not be allowed to enter or change any other color of cells.

6.1 TITLE WORKSHEET

The *TITLE* worksheet contains information about the CBIO scheduling model as shown in Figure 15. The user is not allowed to work on this sheet because it is an information worksheet only.



OPERATIONS SUPPORT FOR PEHUR HIGH-LEVEL CANAL PROJECT

SCHEDULING MODEL FOR
CROP-BASED IRRIGATION OPERATIONS

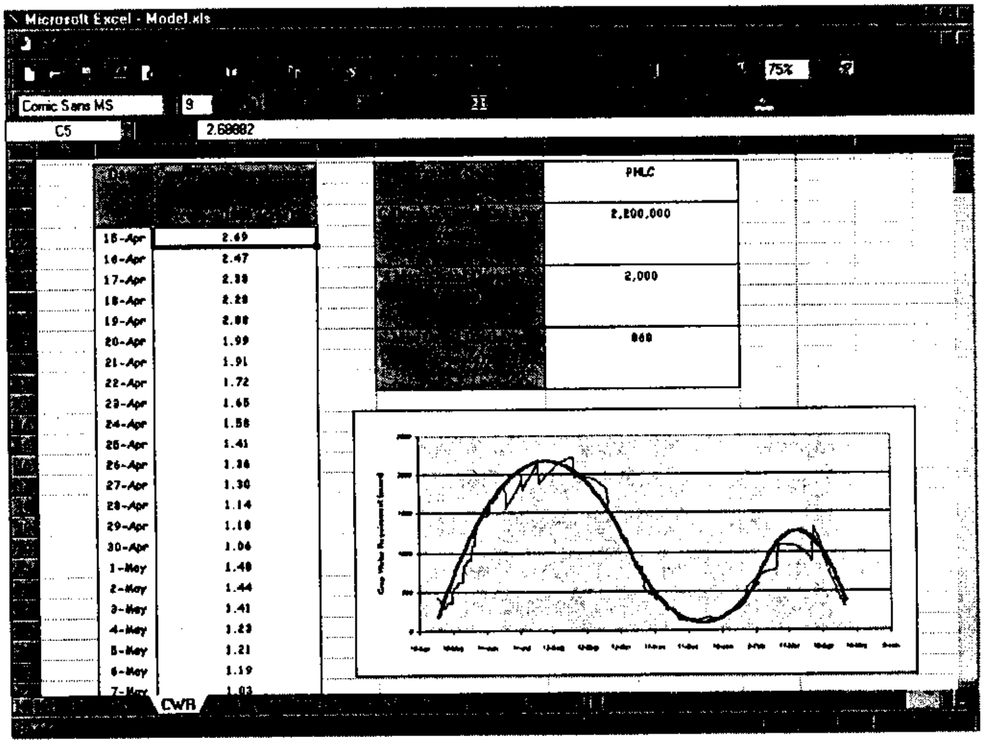
IIMI

December 1998
PAKISTAN NATIONAL PROGRAM
INTERNATIONAL IRRIGATION MANAGEMENT INSTITUTE
LAHORE

Figure 15. Crop-based Irrigation Operation Scheduling Model.

6.2 CWR WORKSHEET

The *CWR* worksheet is for data on crop water requirements. The user needs to enter the crop water requirements to the green color cells as shown in Figure 16. Some more information concerning the irrigation project and canal system is also needed. The version of the model can not calculate the crop water requirements. The graph of crop water requirement is plotted according to values provided by the user.



15-Apr	2.69
16-Apr	2.47
17-Apr	2.38
18-Apr	2.28
19-Apr	2.08
20-Apr	1.99
21-Apr	1.91
22-Apr	1.72
23-Apr	1.65
24-Apr	1.58
25-Apr	1.41
26-Apr	1.36
27-Apr	1.30
28-Apr	1.14
29-Apr	1.10
30-Apr	1.06
1-May	1.49
2-May	1.44
3-May	1.41
4-May	1.23
5-May	1.21
6-May	1.19
7-May	1.03

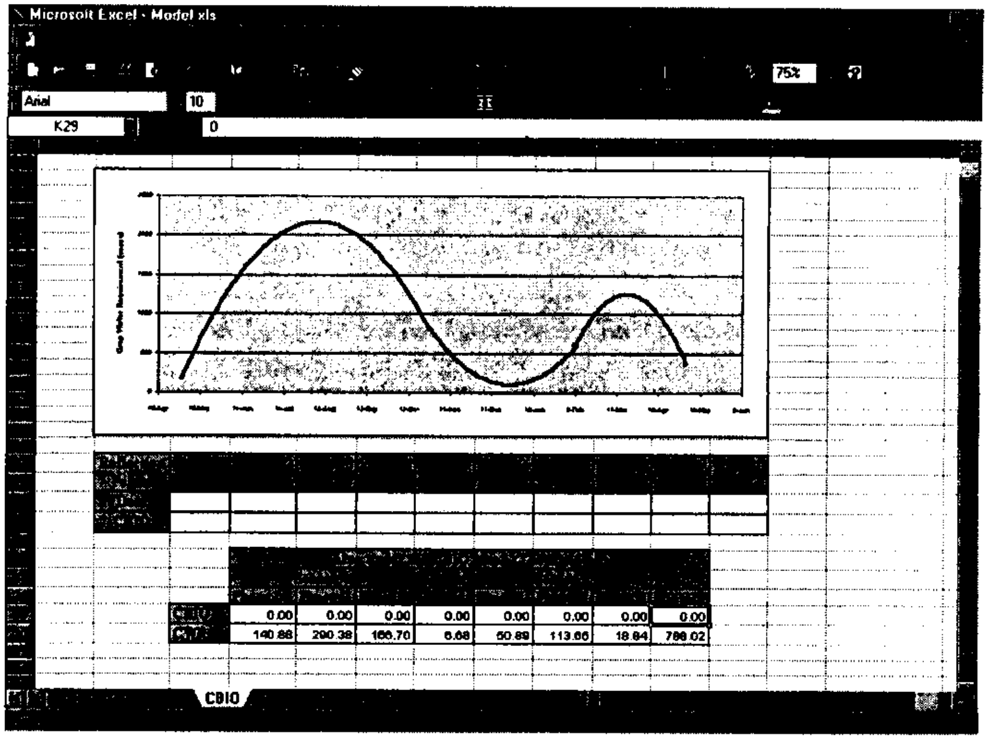
PHLC
2,200,000
2,000
868

Figure 16. CWR Worksheet.

6.3 CBIO WORKSHEET

The *CBIO* Worksheet will assist the user to define the closure and operational periods. The CBIO Worksheet will also help in the defining of CBIO lines. Taking into consideration the crop water requirements from the *CWR* Worksheet, the *CBIO* Worksheet shows the crop water requirement graph for the whole season. Figure 17 shows a blank *CBIO* Worksheet, which is composed of the crop water requirements graph, and two tables below the graph. The upper table needs the user to enter 10 reflection points. Points 1 and 2 connect the inclined line in Phase I of Season 1. Points 2 and 3 connect the horizontal line in Phase II of Season 1, while Points 3 and 4 connect the declining line in Phase III of Season 1.

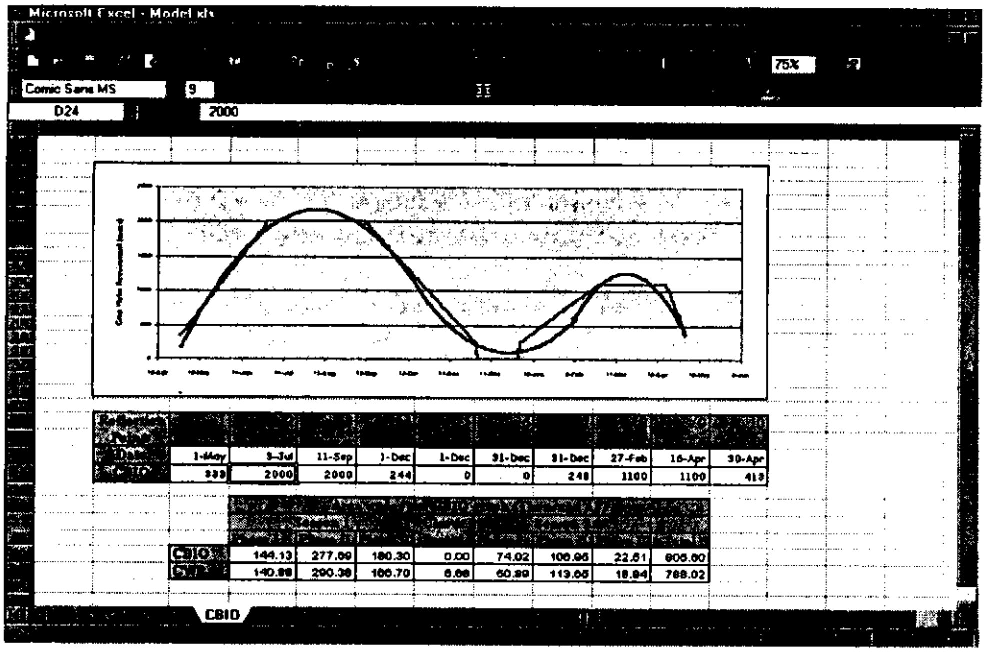
Points 5 and 6 are the beginning and the end of the closure period. For Season 2, Points 7, 8, 9, and 10 connect the inclined and horizontal lines similar to those in Season 1.



CBIO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CWR	140.88	290.38	166.70	6.68	60.89	113.66	18.84	786.02

Figure 17. CBIO Worksheet – blank sheet.

The table on the bottom of Figure 17 contains the area under the CWR and CBIO graphs. These areas are volumes of water. While the user enters the Date and CBIO data for the 10 reflection points, he or she needs to consider the total volume of water under the *CWR* and *CBIO* hydrograph. The total water volume is automatically calculated and the results are listed in the last column of the table, as shown in Figure 18.



Date	1-May	3-Jul	11-Sep	1-Dec	1-Dec	31-Dec	31-Dec	27-Feb	16-Apr	30-Apr
CBIO	333	2000	2000	244	0	0	248	1100	1100	413

CBIO	144.13	277.09	180.30	0.00	74.02	106.96	22.61	805.60
CWR	140.88	290.38	166.70	6.68	60.89	113.66	18.84	786.02

Figure 18 CBIO Worksheet – complete sheet.

6.4 *OPEN_WEEKS* WORKSHEET

The Open Weeks Worksheet assists the user in determining the open weeks during Phases I and III. User could use the graph on the sheet as a guide, then enter the open weeks for Phases I and III of Seasons 1 and 2 as shown in Figure 19.

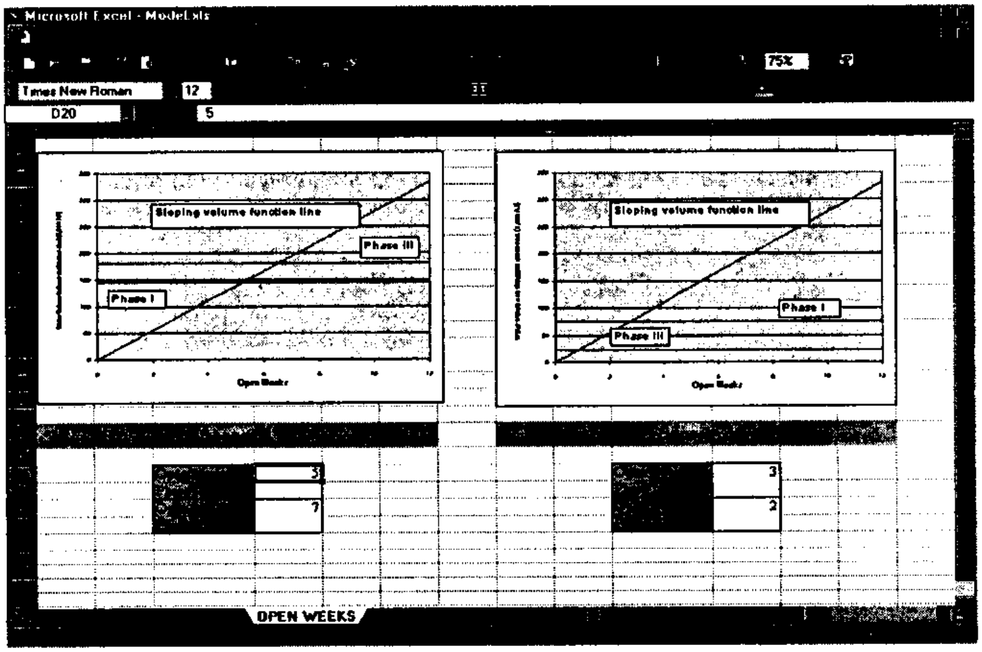
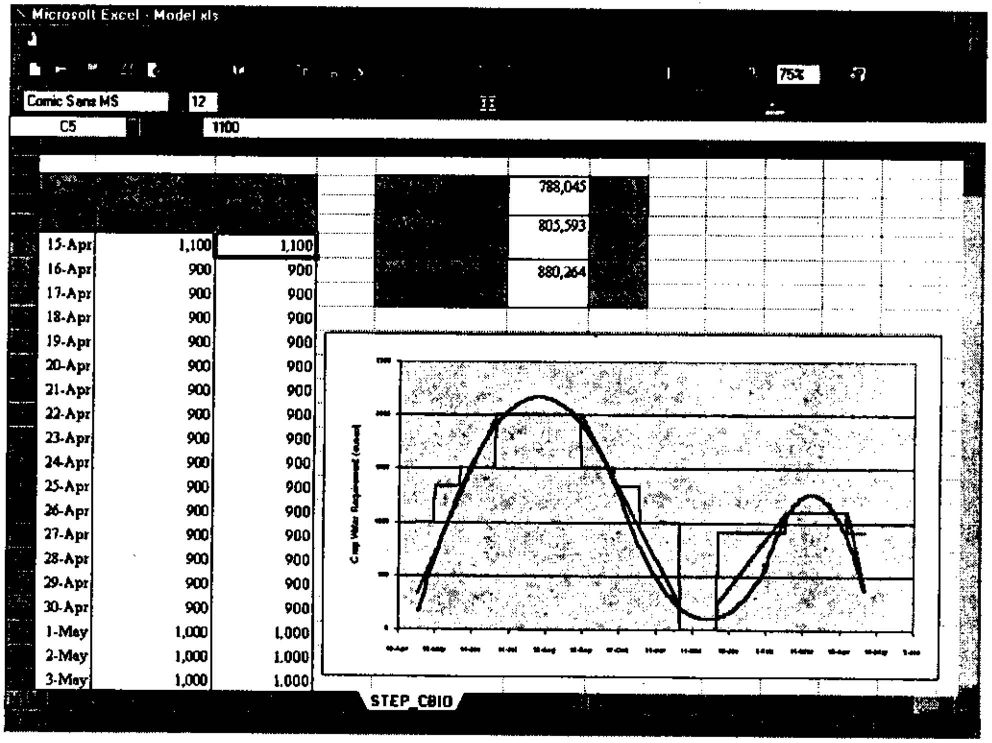


Figure 19. Graphical procedure for determination of the open weeks.

6.5 *STEP CBIO* WORKSHEET

The *STEP_CBIO* Worksheet takes the number of open weeks from the *OPEN_WEEKS* Worksheet and then suggests an appropriate combination of open and closed weeks (see Figure 20). The user still has the opportunity to modify the cycle duration. The green color cells on the right hand side of the table are provided for the user to modify the CBIO step hydrograph. The total volume of water under the CWR, CBIO, and step CBIO hydrograph are provided so that the user can compare and make appropriate adjustments.



C5 1100

15-Apr	1,100	1,100
16-Apr	900	900
17-Apr	900	900
18-Apr	900	900
19-Apr	900	900
20-Apr	900	900
21-Apr	900	900
22-Apr	900	900
23-Apr	900	900
24-Apr	900	900
25-Apr	900	900
26-Apr	900	900
27-Apr	900	900
28-Apr	900	900
29-Apr	900	900
30-Apr	900	900
1-May	1,000	1,000
2-May	1,000	1,000
3-May	1,000	1,000

788,045

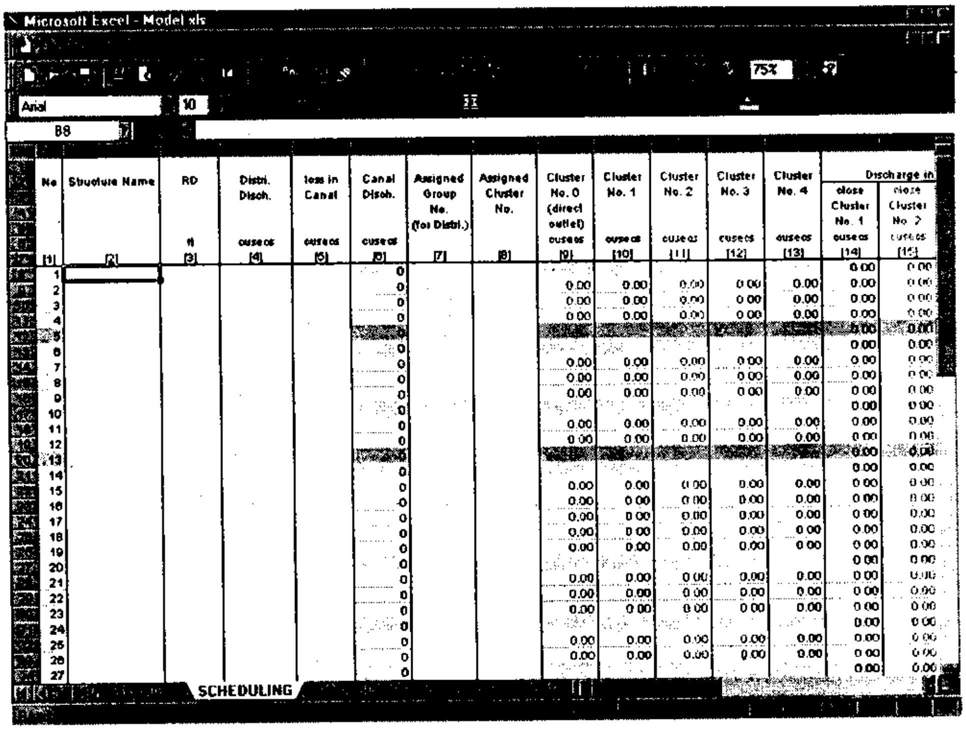
805,593

880,264

Figure 20. Graphically selected cycle durations for CBIO scheduling.

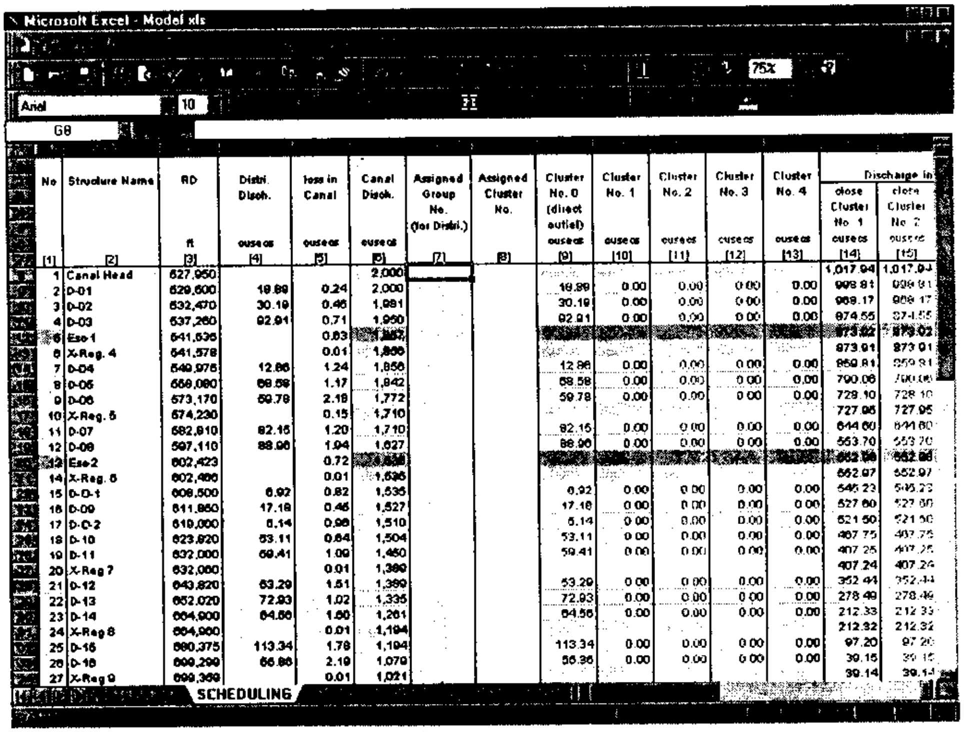
6.6 SCHEDULING WORKSHEET

The *SCHEDULING* Worksheet calculates and presents water schedules for the distributaries in the irrigation canal. Figure 21 shows a blank of the *SCHEDULING* Worksheet. The user has to first enter the configuration of the irrigation canal as demonstrated in Figure 22. The worksheet will provide appropriate colors so that the user can easily identify flow control structures and distributaries along the canal.



No	Structure Name	RD	Distri. Disch.	loss in Canal	Canal Disch.	Assigned Group No. (for Distri.)	Assigned Cluster No.	Cluster No. 0 (direct outlet)	Cluster No. 1	Cluster No. 2	Cluster No. 3	Cluster No. 4	Discharge in	
													close Cluster No. 1	close Cluster No. 2
		ft	cusecs	cusecs	cusecs			cusecs	cusecs	cusecs	cusecs	cusecs	cusecs	cusecs
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]
1					0								0.00	0.00
2					0			0.00	0.00	0.00	0.00	0.00	0.00	0.00
3					0			0.00	0.00	0.00	0.00	0.00	0.00	0.00
4					0			0.00	0.00	0.00	0.00	0.00	0.00	0.00
5													0.00	0.00
6					0								0.00	0.00
7					0			0.00	0.00	0.00	0.00	0.00	0.00	0.00
8					0			0.00	0.00	0.00	0.00	0.00	0.00	0.00
9					0			0.00	0.00	0.00	0.00	0.00	0.00	0.00
10					0								0.00	0.00
11					0			0.00	0.00	0.00	0.00	0.00	0.00	0.00
12					0			0.00	0.00	0.00	0.00	0.00	0.00	0.00
13													0.00	0.00
14					0								0.00	0.00
15					0			0.00	0.00	0.00	0.00	0.00	0.00	0.00
16					0			0.00	0.00	0.00	0.00	0.00	0.00	0.00
17					0			0.00	0.00	0.00	0.00	0.00	0.00	0.00
18					0			0.00	0.00	0.00	0.00	0.00	0.00	0.00
19					0			0.00	0.00	0.00	0.00	0.00	0.00	0.00
20					0								0.00	0.00
21					0			0.00	0.00	0.00	0.00	0.00	0.00	0.00
22					0			0.00	0.00	0.00	0.00	0.00	0.00	0.00
23					0			0.00	0.00	0.00	0.00	0.00	0.00	0.00
24					0								0.00	0.00
25					0			0.00	0.00	0.00	0.00	0.00	0.00	0.00
26					0			0.00	0.00	0.00	0.00	0.00	0.00	0.00
27					0								0.00	0.00

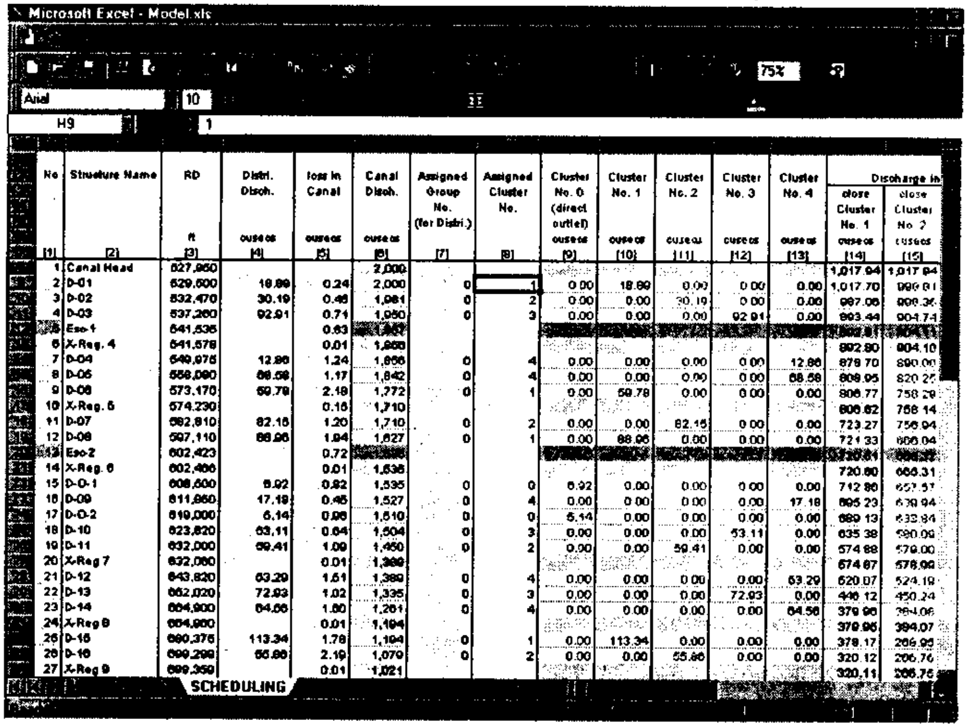
Figure 21. A blank *SCHEDULING* Worksheet.



No	Structure Name	RD	Distri. Disch.	loss in Canal	Canal Disch.	Assigned Group No. (for Distri.)	Assigned Cluster No.	Cluster No. 0 (direct outlet)	Cluster No. 1	Cluster No. 2	Cluster No. 3	Cluster No. 4	Discharge in	
													close Cluster No. 1	close Cluster No. 2
		ft	cusecs	cusecs	cusecs			cusecs	cusecs	cusecs	cusecs	cusecs	cusecs	cusecs
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]
1	Canal Head	627,950			2,000								1,017.94	1,017.94
2	D-01	629,600	18.89	0.24	2,000			18.89	0.00	0.00	0.00	0.00	998.81	998.81
3	D-02	632,470	30.19	0.46	1,981			30.19	0.00	0.00	0.00	0.00	969.17	969.17
4	D-03	637,260	92.91	0.71	1,950			92.91	0.00	0.00	0.00	0.00	874.55	874.55
5	Eso-1	641,536		0.83	[illegible]								873.02	873.02
6	X-Reg. 4	641,578		0.01	1,869								873.91	873.91
7	D-04	649,976	12.86	1.24	1,856			12.86	0.00	0.00	0.00	0.00	859.81	859.81
8	D-05	659,080	68.58	1.17	1,842			68.58	0.00	0.00	0.00	0.00	790.06	790.06
9	D-06	673,170	59.78	2.18	1,772			59.78	0.00	0.00	0.00	0.00	729.10	729.10
10	X-Reg. 5	674,230		0.15	1,710								727.95	727.95
11	D-07	682,810	82.15	1.20	1,710			82.15	0.00	0.00	0.00	0.00	644.60	644.60
12	D-08	597,110	88.96	1.94	1,627			88.96	0.00	0.00	0.00	0.00	553.70	553.70
13	Eso-2	602,423		0.72	[illegible]								552.98	552.98
14	X-Reg. 6	602,466		0.01	1,636								552.97	552.97
15	D-D-1	608,500	6.92	0.82	1,536			6.92	0.00	0.00	0.00	0.00	546.23	546.23
16	D-09	611,860	17.18	0.46	1,527			17.18	0.00	0.00	0.00	0.00	527.60	527.60
17	D-D-2	619,000	6.14	0.98	1,510			6.14	0.00	0.00	0.00	0.00	521.50	521.50
18	D-10	623,920	53.11	0.64	1,504			53.11	0.00	0.00	0.00	0.00	467.75	467.75
19	D-11	632,000	59.41	1.09	1,450			59.41	0.00	0.00	0.00	0.00	407.25	407.25
20	X-Reg 7	632,080		0.01	1,390								407.24	407.24
21	D-12	643,820	53.29	1.51	1,389			53.29	0.00	0.00	0.00	0.00	352.44	352.44
22	D-13	652,020	72.93	1.02	1,335			72.93	0.00	0.00	0.00	0.00	278.49	278.49
23	D-14	664,900	64.56	1.60	1,261			64.56	0.00	0.00	0.00	0.00	212.33	212.33
24	X-Reg 8	664,960		0.01	1,194								212.32	212.32
25	D-15	680,375	113.34	1.78	1,194			113.34	0.00	0.00	0.00	0.00	97.20	97.20
26	D-16	699,290	56.86	2.19	1,079			56.36	0.00	0.00	0.00	0.00	39.15	39.15
27	X-Reg 9	699,369		0.01	1,021								39.14	39.14

Figure 22. *SCHEDULING* Worksheet – configuration of irrigation canal.

The user also has to assign distributaries to appropriate clusters for all distributaries as previously explained in Section 4. In Column 7 of Figure 23, the cluster number is demonstrated as assigned by the user. According to the open and closed weeks calculated by the *STEP`CBIO*, the *SCHEDULING* Worksheet will automatically suggest the grouping of distributaries to form groups and test flow conditions along the canal as presented in Columns 8 to 17. The user still has the opportunity to modify the clusters by using the light blue color in Column 8.

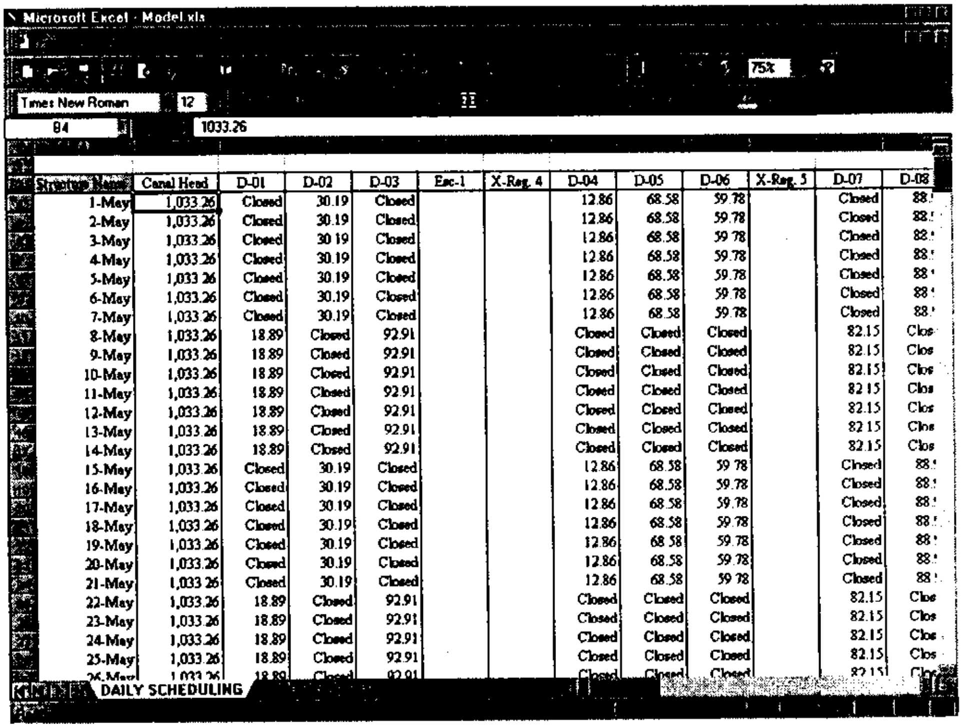


No	Structure Name	RD	Distri. Disch.	loss in Canal	Canal Disch.	Assigned Group No. (for Distri.)	Assigned Cluster No.	Cluster No. 0 (direct outlet)	Cluster No. 1	Cluster No. 2	Cluster No. 3	Cluster No. 4	Discharge in	
													close Cluster No. 1	close Cluster No. 2
		ft	cusecs	cusecs	cusecs			cusecs	cusecs	cusecs	cusecs	cusecs	cusecs	cusecs
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]
1	Canal Head	527,960			2,000								1,017.94	1,017.94
2	D-01	529,600	18.89	0.24	2,000	0	1	0.00	18.89	0.00	0.00	0.00	1,017.70	998.81
3	D-02	532,470	30.19	0.46	1,981	0	2	0.00	0.00	30.19	0.00	0.00	987.06	999.36
4	D-03	537,260	92.91	0.71	1,950	0	3	0.00	0.00	0.00	92.91	0.00	893.44	904.74
5	Esc-1	541,535		0.63	1,857								892.81	904.11
6	X-Reg. 4	541,576		0.01	1,856								892.80	904.10
7	D-04	549,975	12.86	1.24	1,856	0	4	0.00	0.00	0.00	0.00	12.86	878.70	890.00
8	D-05	558,090	68.58	1.17	1,842	0	4	0.00	0.00	0.00	0.00	68.58	808.95	820.25
9	D-06	573,170	59.78	2.18	1,772	0	1	0.00	59.78	0.00	0.00	0.00	806.77	758.29
10	X-Reg. 5	574,230		0.16	1,710								806.62	758.14
11	D-07	582,810	82.15	1.20	1,710	0	2	0.00	0.00	82.15	0.00	0.00	723.27	756.94
12	D-08	597,110	88.96	1.94	1,627	0	1	0.00	88.96	0.00	0.00	0.00	721.33	666.04
13	Esc-2	602,423		0.72	[illegible]								720.81	666.32
14	X-Reg. 6	602,466		0.01	1,536								720.80	666.31
15	D-O-1	608,600	6.92	0.82	1,535	0	0	6.92	0.00	0.00	0.00	0.00	712.80	657.57
16	D-09	611,860	17.18	0.45	1,527	0	4	0.00	0.00	0.00	0.00	17.18	695.23	639.94
17	D-O-2	619,000	6.14	0.96	1,510	0	0	6.14	0.00	0.00	0.00	0.00	689.13	632.84
18	D-10	623,820	53.11	0.64	1,504	0	3	0.00	0.00	0.00	53.11	0.00	635.38	579.09
19	D-11	632,000	59.41	1.09	1,450	0	2	0.00	0.00	59.41	0.00	0.00	574.88	578.00
20	X-Reg 7	632,060		0.01	1,389								574.87	577.99
21	D-12	643,820	53.29	1.51	1,389	0	4	0.00	0.00	0.00	0.00	53.29	520.07	524.19
22	D-13	662,020	72.93	1.02	1,335	0	3	0.00	0.00	0.00	72.93	0.00	446.12	450.24
23	D-14	664,900	64.56	1.80	1,261	0	4	0.00	0.00	0.00	0.00	64.56	379.96	384.08
24	X-Reg 8	664,960		0.01	1,194								379.95	384.07
25	D-15	680,375	113.34	1.78	1,194	0	1	0.00	113.34	0.00	0.00	0.00	378.17	266.95
26	D-16	699,299	55.86	2.19	1,079	0	2	0.00	0.00	55.86	0.00	0.00	320.12	266.76
27	X-Reg 9	699,350		0.01	1,021								320.11	266.75

Figure 23. *SCHEDULING* Worksheet – assigned clusters.

6.7 DAILY SCHEDULING WORKSHEET

The *DAILY SCHEDULING* worksheet presents the results of daily scheduling for the irrigation canal. The user is not allowed to modify these results. Figure 24 shows the *DAILY SCHEDULING* Worksheet. Instead, Figure 23 could be modified.



Structure Name	Canal Head	D-01	D-02	D-03	Esc-1	X-Reg. 4	D-04	D-05	D-06	X-Reg. 5	D-07	D-08
1-May	1,033.26	Closed	30.19	Closed			12.86	68.58	59.78		Closed	88
2-May	1,033.26	Closed	30.19	Closed			12.86	68.58	59.78		Closed	88
3-May	1,033.26	Closed	30.19	Closed			12.86	68.58	59.78		Closed	88
4-May	1,033.26	Closed	30.19	Closed			12.86	68.58	59.78		Closed	88
5-May	1,033.26	Closed	30.19	Closed			12.86	68.58	59.78		Closed	88
6-May	1,033.26	Closed	30.19	Closed			12.86	68.58	59.78		Closed	88
7-May	1,033.26	Closed	30.19	Closed			12.86	68.58	59.78		Closed	88
8-May	1,033.26	18.89	Closed	92.91			Closed	Closed	Closed		82.15	Clos
9-May	1,033.26	18.89	Closed	92.91			Closed	Closed	Closed		82.15	Clos
10-May	1,033.26	18.89	Closed	92.91			Closed	Closed	Closed		82.15	Clos
11-May	1,033.26	18.89	Closed	92.91			Closed	Closed	Closed		82.15	Clos
12-May	1,033.26	18.89	Closed	92.91			Closed	Closed	Closed		82.15	Clos
13-May	1,033.26	18.89	Closed	92.91			Closed	Closed	Closed		82.15	Clos
14-May	1,033.26	18.89	Closed	92.91			Closed	Closed	Closed		82.15	Clos
15-May	1,033.26	Closed	30.19	Closed			12.86	68.58	59.78		Closed	88
16-May	1,033.26	Closed	30.19	Closed			12.86	68.58	59.78		Closed	88
17-May	1,033.26	Closed	30.19	Closed			12.86	68.58	59.78		Closed	88
18-May	1,033.26	Closed	30.19	Closed			12.86	68.58	59.78		Closed	88
19-May	1,033.26	Closed	30.19	Closed			12.86	68.58	59.78		Closed	88
20-May	1,033.26	Closed	30.19	Closed			12.86	68.58	59.78		Closed	88
21-May	1,033.26	Closed	30.19	Closed			12.86	68.58	59.78		Closed	88
22-May	1,033.26	18.89	Closed	92.91			Closed	Closed	Closed		82.15	Clos
23-May	1,033.26	18.89	Closed	92.91			Closed	Closed	Closed		82.15	Clos
24-May	1,033.26	18.89	Closed	92.91			Closed	Closed	Closed		82.15	Clos
25-May	1,033.26	18.89	Closed	92.91			Closed	Closed	Closed		82.15	Clos
26-May	1,033.26	18.89	Closed	92.91			Closed	Closed	Closed		82.15	Clo

Figure 24. *DAILY SCHEDULING* Worksheet.

6.8 *PRINTING* WORKSHEET

The *PRINTING* Worksheet is provided for facilitating the user in printing some important information and the results developed by the model. In addition, the user can also select the print area and the print directly. Figure 25 presents an area of information and results that could be directly printed by simply pressing an appropriate button.

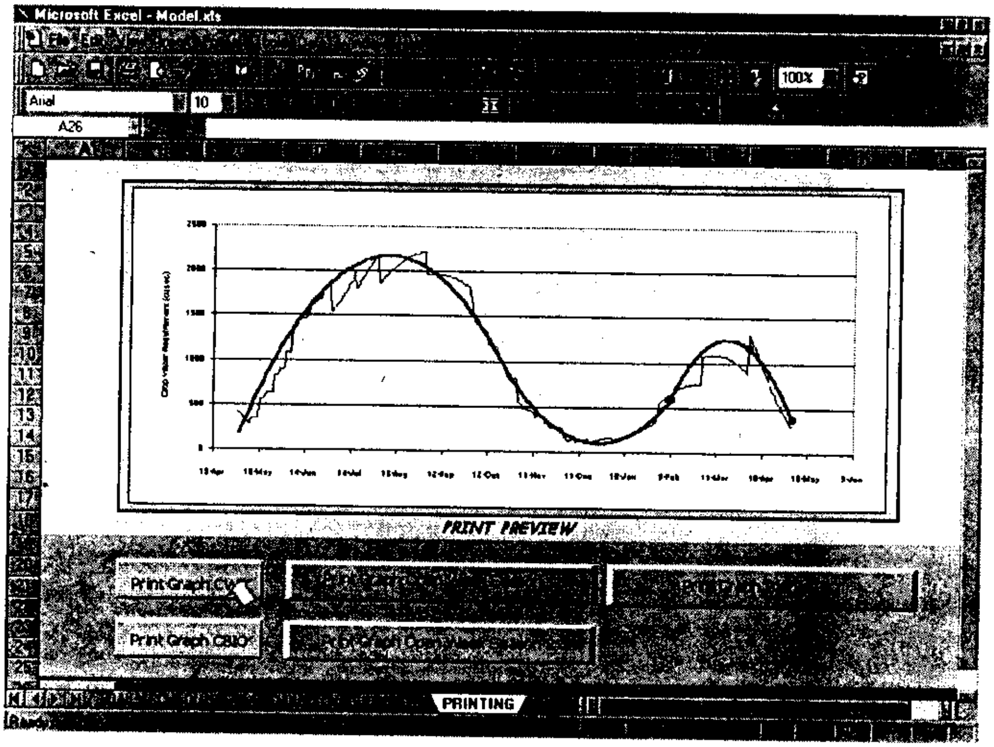


Figure 25. *PRINTING* Worksheet.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

The basic concept to crop-based irrigation operations (CBIO) is not to apply too much water onto the croplands when it is not needed, which would be the case early and late in each growing season (kharif and rabi), particularly for canals having a high water duty.

The Scheduling Model of CBIO has incorporated principles that are used for operating canals in Pakistan. For example, the tertiary watercourse channels are operated in multiples of the warabandi so that every farmer receives water the same number of times. The secondary distributary canals are operated at their full supply discharge, which can be adjusted slightly if desired, but the intent is to minimise sediment deposition and to provide a full water supply to each tertiary outlet.

Since CBIO daily discharge schedules can be planned prior to an irrigation season, this is definitely not a demand method of operation, but rather a "modified supply-based operation."

7.2 RECOMMENDATIONS

Now that a Scheduling Model for CBIO has been developed, the next logical step would be to develop daily discharge schedules for Upper Swat Canal (USC) and Pehur High-Level Cannal (PHLC), Since the USC-PHLC system is already on the unsteady hydrodynamic models (SIC and CANALMAN), they can be used to define the lag times.

Just before PHLC is commissioned, IIMI will establish a field station in the project area. The initial work will be field calibration of essential flow control structures, measuring channel losses, calibrating SIC under actual field operations, and field measurements of lag times as described in Section 5 of this report. This will allow the actual operating conditions to be incorporated into the daily discharge schedules for CBIO. During the first few years of CBIO-SBO-CBIO operations, a monitoring program should be implemented so that the daily discharge schedules can be refined.

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