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Performance Evaluation of Irrigation Water Delivery System of Ganges – Kobadak (G-K) Project

A Thesis

By

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CERTIFICATE OF RESEARCH

This is to certify that the research work described in this thesis, except where specific references to other investigators are made, is the result of the investigation of the candidate. Neither this thesis nor any part thereof has been submitted elsewhere for the award of any degree or diploma.



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ABSTRACT

The study was conducted at Ganges – Kobadak Irrigation Project during the season Kharif-I and Kharif-II, 1999. The main objectives of the study were to critically review the different indicators developed and proposed by different authors for performance evaluation of irrigation project and to assess the performance of the system in terms of adequacy, efficiency, equity and dependability. Performance evaluation was carried out using indicators suggested by Bos et al. (1993). Eight tertiary units of three secondary canals were selected for this purpose. Data were collected through field measurement and from project officials.

A large number of performance indicators for irrigation project performance evaluation are discussed and many of the indicators are not applicable due to nonavailability of data.

Performance standards for the different indicators are required to compare the results and that the performance can be quantified accordingly.

The rotational Relative Water Supply (RWS) to the selected tertiary units varied from 0.29 to 5.26 during Kharif-I season and 0.04 to 8.16 during Kharif-II season. This wide variation of RWS was mainly due to lack of control of flow. The secondary canal near the head of the system always received more water than the tail end canals.

The average seasonal irrigation efficiency of the selected tertiary units varied from 11% to 59% during Kharif-I season and 13% to 77% during Kharif-II season. The low irrigation efficiency was mainly due to misuse of irrigation water and poor water control. Lack of proper maintenance and interference of farmers in water distribution in the upper reaches of the system were also responsible for low irrigation efficiency.

The coefficient of variation of relative water supply to different selected tertiary units varied from 0.01 to 0.68 during Kharif-I and 0.01 to 1.22 during Kharif-II season.

Ratio of actual to planned duration of water supply to the selected tertiary units varied from 0.79 to 1.43 during Kharif-I and 0.45 to 1.61 during Kharif-II. This reflects the fact that actual delivery did not follow the schedule and most of the selected tertiary units received water for greater number of days than programmed.

Overall, the system performed poorly in terms of efficiency and equity but it performed well in terms of adequacy and dependability of supply. Adequacy of the system was 2.31

and 1.7 for Kharif-I and Kharif-II seasons respectively but irrigation efficiency was poor (0.56 and 0.60 for Kharif-I and Kharif-II respectively). Equity in water delivery also found to be poor (0.63 and 0.76 for Kharif-I and Kharif-II respectively). Dependability of supply i.e. the ratio of actual to planned duration of water delivery was 1.20 and 1.06 for Kharif-I and Kharif-II seasons respectably.

Irrigated area performance (1.00) and production performance (0.89) were quite good during the Kharif-II season but these were not satisfactory (0.67 and 0.78) during the Kharif-I season. During the Kharif-I season the water delivery could not be made to a substantial portion of the targeted area due to inadequate head. Yield performance was satisfactory (0.89) during the Kharif-I season but it was not satisfactory (0.72) during Kharif-II. During the Kharif-II season supplementary irrigation could not be provided to the tail end of some secondary canal due to poor condition of canals. Cropping intensity performance was found to be satisfactory (0.995).

Economic performance such as total financial viability (0.55), financial self-sufficiency (0.002) and fee collection performance (0.008) was very poor. To keep the irrigation system functioning O&M allocation must be increased and at the same time emphasis must be given on increasing water tax collection. Without adequate recovery of operation cost, the future of the project will be uncertain.

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LIST OF ABBREVIATIONS

ADB	Asian Development Bank
AMC	Alamdangha Main Canal
BRTC	Bureau of research, Testing and Consultation
BRRI	Bangladesh Rice Research Institute
BWDB	Bangladesh Water Development Board
CAD	Command Area Development
DAE	Department of Agriculture Extension
DPR	Delivery Performance Ratio
DTW	Deep Tubewell
EPC	Engineering and Planning Consultants
EPWAPDA	East Pakistan Water and Power Development Authority
FAO	Food and Agriculture Organization
FAP	Flood Action Plan
FSL	Full Spilly Level
G-K	Ganges-Kobadak
GKIP	Ganges Kobadak Irrigation Project
GMC	Ganges Main Canal
HTW	Hand Tubewell
HYV	High-yielding Variety
ICID	International Commission on Irrigation and Drainage
IIMI	International Irrigation Management Institute
IMP	Irrigation Management Programme
IRR	Internal Rate of Return
IRRI	International Rice Research Institute
KMC	Kushtia Main Canal
KSS	Krishak Samabay Samity
LLP	Low-lift Pump
MIS	Management Information System
MPO	Master Plan Organization
NEDECO	Netherlands Engineering Consultants
NMIDP	National Minor Irrigation Development Programme
NWP	National Water Policy

O&M	Operation and Maintenance
OMC	Outlet Management Committee
PBMU	Project Benefit Monitoring Unit
PCP	Project Concept Paper
PP	Project Proposal
TA	Technical Assistance
T.Aman	Transplanted Aman
T.Aus	Transplanted Aus
TWUA	Tertiary Water Users Association
S & P	Seepage and Percolation
SWMC	Surface Water Modelling Centre
UN	United Nations
UNDP	United National Development Programme
WMU	Water Management Unit
WUA	Water Users Association
WSG	Water Users Group

Chapter I

INTRODUCTION



1.1 Background Information

Irrigation development is accepted and recognized as an important factor for increasing agricultural production and about 53% of the irrigable area in Bangladesh has so far been brought under irrigation and the rest is cultivated under rainfed condition (Bari et al., 1999). Significant attention has been given for increasing food production to feed the increasing vast population through irrigation development investing a large portion of national budget in irrigation development projects. Although it is well recognized that there is a significant increase in food production there exists a great gap between the actual and expectation in relation to the performance level of the irrigation projects. In the face of increasing cost of irrigation and limiting resources, the proper evaluation of performance and identification of constraints is a must in order to take necessary measures to minimize that gap.

In recent years there has been a growing concern that performance in the context of irrigated agriculture is less than what was anticipated. The issue of performance in irrigation is of increasing concern to investors, managers and water users alike. As population increases in a finite land, the need for more effective and efficient use of land and water resources cannot be stressed too strongly. Nevertheless, there is a remarkable lack of good framework within which irrigation managers can assess performance and diagnose ways to lead to better performance in the future (Murray-Rust and Snellen, 1993).

The shortfalls in performance can be cited at almost every level of the irrigation sector. Those concerned with major lending program for irrigation; notably the banks and certain bilateral funding agencies, have begun to feel that the return on investment is not readily justified. Greater emphasis has been placed on other sectors as the expense of new investment in irrigation, or in the rehabilitation or modernization of existing systems. Similarly, at system level there is disappointment in levels of cropping intensity, irrigation intensity and yields from many irrigated areas. The economics of irrigated agriculture are such that many farmers have not been able to achieve a more prosperous and healthy life. At the level of water distribution there are innumerable references to inequity of water

distribution leading to major disparities between head and tail areas, to deficit water supplies and loss of production in some locations, or to excess water delivery and development of water logging and salinity in others. Water supplies at any given location are often poorly matched to crop needs, highly variable in both timing and discharge, and are, sometimes, of increasing poor quality (Murray-Rust and Snellen, 1993).

In its path from source to irrigated fields, water is diverted from its natural course, conveyed, and then distributed through water delivery network to farms within the irrigation system. The water delivery networks are comprised of source, canals (main canal, secondary canal, tertiary canal and field channel), the cross regulators and off takes. The success of an irrigation water delivery system can be measured by how well it meets the objectives of delivering an adequate and dependable supply of water in an equitable and efficient manner to users served by the system. If water does not arrive at field level adequately and timely, crop yields may suffer and farm net return may decrease. Also it is important that each farmer receives a fair, while not excessive, amount of water.

Water delivery systems comprised of hydraulic structures and organizations in charge of managing water as it flows through the system. The structural components of water delivery systems include facilities for conveyance, regulation, and measurement of water. The management component is responsible for operation and maintenance of the hydraulic structures. An important aspect of the management component is the implementation of water delivery schedules that specify timing and amount of delivery as policies of water allocation. A water delivery system is limited in its capacity for water control by its structural and management characteristics. If either or both are deficient, system performance suffers.

The Ganges-Kobadak (G-K) irrigation system is the largest irrigation system in Bangladesh. A brief description of the G-K project has been given in chapter-3. The existing G-K irrigation system was designed to provide supplementary irrigation for traditional rice crops in the monsoon season and to serve a net irrigable area of 116,000 ha. From the beginning, the operation of the G-K irrigation system has never achieved full potential. Reliable irrigation water has hardly reached the tail end of the canal network. The system failed to provide adequate water supply during peak water demands because of problems associated with the pumping facilities, damaged water control structures, and

deteriorating canal system. Lack of proper maintenance and interference of farmers in water distribution in the upper reach of the system were also responsible for poor water distribution and low irrigation efficiencies. In addition, changes in agricultural practices in the 1970s particularly the introduction of high yielding variety (HYV) rice cultivation, entailed a higher demand for water and changes in the cropping calendar. In 1982, the G-K distribution system actually irrigated only 37,100 ha during the premonsoon season (Kharif-I) and 72,000 ha during the monsoon season (Kharif-II). Because of the irrigation system's shortcoming, many tertiary canal reaches toward the tail end of the system have never been used or constructed at all.

At the request of the Government, the Asian Development Bank (ADB) provided technical assistance (TA) in March 1982 for the feasibility study of the Ganges-Kobadak Irrigation Rehabilitation Project (TA No. 1454). A consulting firm Netherlands Engineering Company (NEDECO) submitted the feasibility report in June 1983. The consultants recommended the restoration of the existing irrigation facilities in both Phase I and Phase II to their original design. A more recent project for providing technical assistance to G-K irrigation rehabilitation project phase-II was completed by HR Wallingford in association with Engineering Planning Consultant (EPC) Ltd. in 1994.

The objectives of the project were to increase agricultural productivity, create employment opportunities, and improve living standards. The project directly supported the Government's policy of water resources development by giving high priority to the achievement of food grain self sufficiency through rapid expansion of the irrigated area, improvement of irrigation infrastructure, increase in fertilizer use, and improvement of agriculture extension services.

The project facilities, including the main pumps, main and secondary canals and related water control structures have been rehabilitated. However, rehabilitation of nearly one third of the tertiary canals have not yet been done. Water Management Unit (WMU) has been set up and is well supplied with technical staff and equipment. But the unit cannot operate at the optimum level mainly because of the breakdown of the telecommunication system. Project Benefit Monitoring Unit (PBMU) has not been operating at the desired level either. A number of experiments have been going on in the name of institution building (Chasi Club, Water User Group, Krishak Samabaya Samiti) at the beneficiaries' level and hence, not much tangible benefits have been realized in terms of equitable

distribution of water and cost recovery. Significant supplementary benefits have been generated for the farmers of the project area. But the basic objective of providing reliable irrigation water to the tail end farmers has not been realized.

1.2 Importance of the Study

Due to increasing costs of constructing new irrigation systems, developing countries like Bangladesh should direct her attention to the possibilities of improving the performances of existing irrigation systems through modern technology and management techniques. Before going to improve the performance of an existing system, it is first necessary to know how well or poorly it is performing in its existing state (Seckler, 1988). In the G-K Irrigation Project not much attention has been paid to operation yet. From the beginning, the operation of the G-K irrigation system has never achieved its intended full potential. Reliable irrigation water has hardly reached the tail end of the canal network. The farmers complain about an unreliable delivery and an unequal distribution of the available water. The control on the flow of water delivery is poor in the G-K project. There is a lack of proper maintenance of canals. Irrigation efficiency was also low. As a result, there is a need to evaluate the performance of the project. On the basis of this result, measures can be adopted to control or overcome these problems so that the irrigation project can be operated successfully. It is with this view in mind this study was taken up.

1.3 Objectives

The study will focus on the performance evaluation of irrigation water delivery system of G-K Irrigation Project. The specific objects are:

- ❑ To critically review the different indicators developed and proposed by different authors for performance evaluation of irrigation project
- ❑ To assess the performance of the irrigation water delivery system in terms of adequacy, efficiency, dependability and equity of water delivery.
- ❑ To make a quantitative assessment of overall system performance.

Chapter II

PERFORMANCE MEASURES FOR EVALUATION OF IRRIGATION WATER DELIVERY SYSTEM

2.1 Introduction

The water delivery system is the essential part of an irrigation project and the success of the project depends on the functioning of the water delivery system. The performance evaluation of the water delivery system is based on the following four requirements of the water delivery system.

- The system should be able to convey the water with minimum losses. The structures and the canals should perform as per their designs.
- The water provided should be adequate for the crops grown.
- The timing of the water deliveries should match the crop needs. The water deliveries should also conform to the prior expectation of the farmers and certain element of the reliability and flexibility should exist.
- All the users of the system should have a fair share i.e. there should be an equitable distribution of the water.

In order to evaluate the performance of the system based on the above-mentioned requirements, indicators and procedures are developed. Some of these available indicators for this purpose are outlined in the following paragraphs.

2.2 Hydraulic Indicators

Hydraulic indicators are concerned with the assessment of the water supply function of the conveyance system: they cover the volumetric component that is primarily concerned with matching supplies to crop demand, as well as the rather more subjective concept of reliability that may affect the users' capacity to manage water efficiently, and the socially oriented aspects of equity.

The primary task of organizations managing irrigation systems is to deliver water in accordance with a plan. Indicators in this section are therefore those that guide managers in respect to water delivery performance in terms of adequacy, efficiency, equity and dependability.

2.2.1 Adequacy

A fundamental concern of water-delivery systems is to deliver the amount of water required to adequately irrigate crops. It is the capacity of an irrigation system to meet demands of farmers. The required amount is determined as that needed to achieve a given agricultural policy and is a function of the area irrigated, crop consumptive requirement, application and conveyance losses and cultural practices (such as land preparation). Adequacy of delivery is dependent on water supply, specified delivering schedules, the capacity of hydraulic structures and operation and maintenance of the canals and control structures. It can be managed in two ways: by matching cropping plans and calendars with estimated seasonal water availability before the start of the season, and by adjusting operational targets in response to actual demand during the season.

The measure of adequacy proposed by Molden and Gates (1990) is:

$$P_A = \frac{1}{T} \sum_T \left(\frac{1}{R} \sum_R p_A \right) \text{-----(1)}$$

Where,

P_A = performance measure in terms of adequacy;

$$p_A = \frac{Q_D}{Q_R}, \text{ for } Q_D \leq Q_R \text{ otherwise, } p_A = 1$$

Q_D = amount of water delivered by the system (mm);

Q_R = required amount of water for consumptive use, leaching, land preparation etc.;

R = region or sub-region within water delivery system;

T = time period, one irrigation season;

Equation (1) states that the system performance relative to adequacy P_A is a spatial and temporal average of a bounding function of the ratio of amount delivered to amount required.

They suggested some standard values of performance to compare the results. According to this standard a system is said to be perfectly adequate if the value within the range 0.9 to 1.0 and the system is said to be fair if the range is within 0.8 to 0.9 and poor if it is <0.8 .

Relative Water Supply (RWS)

RWS is used as an indicator of the adequacy of the irrigation water deliveries. This indicator, developed by Levine (1982), compares water availability with actual demand. It is normally expressed as:

$$\text{RWS} = \frac{\text{Irrigation} + \text{Effective rainfall}}{\text{Evapotranspiration} + \text{Seepage \& Percolation}} \text{-----}(2)$$

Adequacy needs to be measured over a time period for it to be effective as an indicator. The standard approach is to assess adequacy over the cycle of water deliveries within an irrigation system. To estimate the water adequacy, weekly or 10-day RWS values are used. But use of long periods is difficult because if substantial rainfall occurs during a short time span, most of it will leave the project area but RWS value will give erroneous impression of high water adequacy for the whole period.

The value of RWS is an indicator of the relative abundance of water with respect to adequacy, although it is sensitive to the scale of the area irrigated because of the influence of conveyance losses. At tertiary level an RWS value greater than 1.5 suggests water is sufficiently abundant that management inputs need not be very intensive, but with values at or close to 1.0 management inputs themselves will not necessarily compensate for the relative scarcity of water.

Again, the rainfall term used in Equation (2) is confusing. In some literatures it can be seen that total rainfall is used, while in others effective rainfall is used. There is a significant difference between these two terms specially when rainfall is high.

There is wide variation of definition of adequacy from one researcher to another. Levine (1982) simply defined it as a ratio of amount delivered to amount required whereas Molden and Gates (1990) defined it as a spatial and temporal average of bounding function of the ratio of amount supplied to amount required.

Water Availability Index (WAI)

The indicator WAI, developed by Wijayaratne (1986) is a simple method of quantifying water adequacy at field level. It is based on a qualitative scale of observations of water conditions in rice field:

- 4.0 Water flowing from paddy to paddy
- 3.0 Standing water in the rice field
- 2.0 Soil is moist, with water in depressions
- 1.0 Soil is dry and surface cracks are appearing

WAI is most effective in describing the water conditions for rice plants during the critical 50-day period that starts 70 days before harvest. This provides a range of values from 200 (continuous water supply throughout the period) down to 50 (no standing water at any time). It is a quantitative scale and provides no information about the depth of water.

Water delivery performance

The simplest, and most short-term, performance indicators are those that compare actual discharge to an intended or targeted discharge at any given location in the system. It is convenient to differentiate between instantaneous measures and those that cumulate performance over a specified period of time.

The simplest and yet probably the most important hydraulic performance indicator is:

$$\text{Delivery Performance Ratio} = \frac{\text{Actual Discharge}}{\text{Target Discharge}} \text{-----}(3)$$

This measure enables to determine the extent to which water is delivered as planned at any moment in time and at any location in the system (IIMI, 1989). The primary utility of Delivery Performance Ratio is that it allows for instantaneous checking of whether discharges at any location in the system are more or less as intended.

Over a longer period of time, however, it may be more useful to modify the ratio by changing discharges into volumes (Clemmens & Bos, 1990; Wolters, 1992). This results in a slightly different indicator:

$$\text{Water Delivery Performance} = \frac{\text{Actual Volume}}{\text{Target Volume}} \text{-----}(4)$$

Over a sufficiently long time frame (e.g., monthly, or over three or four rotational time periods) it can be assumed that if total volume delivered is close to intended, then the management inputs must be effective.

2.2.2 Efficiency

The concept of efficiencies is useful in examining the functioning of a component of the system. For example excessive seepage losses in a canal and consequently low conveyance efficiency will indicate the need for lining. A study of the tertiary unit efficiencies indicates whether it requires attention in terms of water management aspects. Efficiency is computed to determine how well a particular goal is being reached. Since the early thirties, the term irrigation efficiency has been widely used to express or evaluate the performance of a complete irrigation system or component of a system. Generally, to account for losses of water incurred during conveyance, distribution and application to the field, the efficiency factor is considered.

A measure of this objective would be the spatial and temporal average of the ratio of Q_R to Q_D (Molden and Gates, 1990) and expressed as:

$$P_F = \frac{1}{T} \sum_T \left(\frac{1}{R} \sum_R P_F \right)$$

Where, P_F = Performance measure in terms of efficiency.

$$p_F = \frac{Q_R}{Q_D}, \text{ for } Q_R \leq Q_D \text{ otherwise, } p_F = 1$$

As the value of P_F approaches unity, this measure indicates an increasing compatibility with the goal of efficient water delivery for the region. A condition of $P_F = 1$ reveals that system is efficient, but provides no information regarding the extent of underdelivery.

Like adequacy Molden et al. (1990) suggested a set of performance standard to compare the results. According to this standard a system is said to be perfectly efficient if the value is within the range of 0.9 to 1.0 and the system is said to be fair if the range is within 0.8 to 0.9 and poor if it is <0.8 . The measure of efficiency utilized in the indicators incorporate the overall losses below the point of measurement.

Indicators of efficiency have also been discussed in detail by Bos and Nugteren (1990). The most important are:

$$\text{Overall Project Efficiency} = \frac{\text{Crop Irrigation Water Requirement}}{\text{Total Inflow into the Canal}} \text{-----}(5)$$

$$\text{Conveyance Efficiency} = \frac{\text{Total Water Supplied by the Conveyance System}}{\text{Total Inflow into the Delivery System}} \text{-----}(6)$$

$$\text{Distribution Efficiency} = \frac{\text{Total Water Delivered to the Field}}{\text{Total Inflow into the Delivery System}} \text{-----}(7)$$

$$\text{Application Efficiency} = \frac{\text{Crop Irrigation Water Requirement}}{\text{Water Delivery to Field}} \text{-----}(8)$$

The term water use efficiency is widely used in evaluating the performance of water management and thereby the irrigation projects. There are two basic concepts of water use efficiency; one is field water use and the other one is crop water use efficiency (Garces, 1985). For the practical purpose of performance evaluation, the latter one is commonly used.

(a) Crop Water Use Efficiency (kg/ha-cm)

It is the ratio of crop yield (kg) to the amount of water used by crop in the process of evapotranspiration (ha-cm)

(b) Field Water Use Efficiency (kg/ha-cm)

It is the ratio of crop yield (kg) to the total amount of water supplied in the field (ha-cm).

From the engineering point of view, there is another definition of water use efficiency that is the ratio of the amount of water that is beneficially used by the crop in the process of evapotranspiration minus effective rainfall to that of water supplied and is expressed in percentage. For low land rice, seepage and percolation is considered as a more or less inevitable consequence of keeping the soil saturated and it is therefore counted with evapotranspiration. Water use efficiency (WUE) proposed by IRRI (1974) is defined as:

$$\text{WUE (\%)} = \frac{ET + S \& P}{IR + R} \times 100 \text{-----}(9)$$

Where, ET is the evapotranspiration requirement, S & P is the seepage and percolation requirement, IR is the irrigation water supply and R is the rainfall amount.

This indicator does not adequately reflect management action of the system because it cannot separate controlling factors from uncontrollable.

Equation (9) provides a simple way of examining water use related to total water supply from irrigation and rainfall sources. It serves as a useful indicator of the system performance when the rainfall is negligible. A problem arises when there is a substantial

rainfall. Because rainfall is unpredictable and rainwater, beyond a certain amount is not controllable at the field level, the excess rainfall drains from the command area of an irrigation system.

For evaluating system performance in terms of irrigation water delivery in the system, Bhuiyan (1982) defined Irrigation Efficiency (IE) as follows:

$$IE (\%) = \frac{ET + S \& P - Re}{IR} \times 100 \text{ -----(10)}$$

Where, Re is the effective rainfall and the other variables were defined earlier.

The difficulty of measuring effective rainfall in the field is a practical limitation of the use of IE as a performance indicator. Effective rainfall is difficult to measure because it is dependent not only on intensity, duration and distribution of rainfall but also on farmer's field level water management practices.

Through each of the efficiency terms deal with some aspects of irrigation quality, none of them is complete itself. For example, application efficiency, which is defined as a ratio of water stored in the root zone to the amount of water delivered to the field, gives no consideration to the adequacy of application. The application efficiency could be very high and yet the crop may suffer if inadequate quantity water has been applied. Similarly storage efficiency, which is defined as the ratio of water stored in root zone to the quantity of water required to be stored to fulfill the moisture deficit gives no consideration to water losses beyond the root zone. The distribution efficiency, which is defined as the ratio of volume of water furnished to the fields to the volume of water delivered by the system. The distribution efficiency is only concerned with depths of water applied at different points along the field.

2.2.3 Dependability

Dependability is defined as the temporal uniformity of ratio of the water supplied to the required or schedule delivery. A system that performs in a consistent manner may be considered dependable. Dependability of water is important to farmers as it allows for proper planning of agricultural activities. A system that dependently delivers an inadequate amount of water may be more desirable than one that, on average, delivers an adequate but unpredictable supply. Farmers can adapt agricultural activities to a dependable, but inadequate supply of water by planting less water demanding crops,

reducing cropped area or by adjusting other inputs. However farmers cannot plan when water supplies are unpredictable.

An indicator of the degree of dependability of water delivery proposed by Molden and Gates (1990) is the degree of temporal variability in the ratio of amount delivered to amount required that occur over a region. This variability may be measured by:

$$P_D = \frac{1}{R} \sum_R CV_T \left(\frac{Q_D}{Q_R} \right) \text{-----(11)}$$

Where,

P_D = Performance measure in terms of dependability;

$CV_T (Q_D/Q_R)$ = temporal coefficient of variation (ratio of standard deviation to mean) of the ratio Q_D/Q_R over the time period T. As the value of P_D approaches zero, the water delivery is becoming more uniform over time, indicating a more dependable delivery.

The pattern in which water is delivered over time may significantly affect the overall adequacy of water delivered, and hence may have a direct impact on crop production. The rationale for this is that water users may be less efficient in water use if there is an unpredictable variation in volume or timing, and they may not use other inputs such as fertilizer in optimal quantities if they are more concerned with crop survival than crop production.

The primary indicators proposed for use in measuring predictability of water deliveries are concerned with the time of water delivery compared to the plan, and the time between deliveries compared to the plan.

$$\text{Dependability of Supply} = \frac{\text{Actual Duration of Water Delivery}}{\text{Planned Duration of Water Delivery}} \text{-----(12)}$$

$$\text{Regularity of Deliveries} = \frac{\text{Actual Interval between Water Deliveries}}{\text{Planned Interval between Water Deliveries}} \text{-----(13)}$$

In addition to predictability in terms of timing, it is also recommended that the predictability of discharge or water level be included in this part of the assessment (Clemmens and Bos, 1990). The simplest method to assess predictability of discharge is to determine the coefficient of variation.

Reliability is an expression of confidence in the irrigation system to deliver water as promised. In continuous flow systems it refers primarily to the expectation that a particular

water level or discharge will be met or exceeded. Under such conditions, variability is the main concern, although only when water levels drop below a minimum value: if adequacy objectives are met, then variability is of relatively minor concern.

Where flow is intermittent, due to rotational irrigation or other water-sharing arrangements, it also has to describe the predictability of the time when flow will start and stop.

If farmers can be certain when irrigation water is going to arrive, then they can make their own cropping choices to provide the level of adequacy they are willing to accept. Unreliable supplies are likely to prove a major and insurmountable constraint to high agricultural output.

2.2.4 Equity

Equity is an expression of the share for each individual or group that is considered fair by all system members. Equity, related to water-delivery systems, could be defined as a delivery of a fair share of water to users throughout a system. Equity with respect to an irrigation project, we primarily mean the equity in water distribution among the head, middle and tail portion of the irrigation system. Under limiting water supply conditions, specially during the dry season, the tail portion gets less water than the head portion. For successful project performance, this aspects needs to be taken with proper care and maintaining equity in getting water supply at all portions.

If equity is interpreted as spatial uniformity of the relative amount of water delivered, then an appropriate measure of performance in terms of equity would be the average relative spatial variability of the ratio of the amount delivered to the amount required over the time period of interest. This measure proposed by Molden and Gates (1990) is define as

$$P_E = \frac{1}{T} \sum_T CV_R \left(\frac{Q_D}{Q_R} \right) \text{-----(14)}$$

Where, P_E = Performance measure in terms of equity;

$CV_R (Q_D/Q_R)$ = spatial coefficient of variation of the ratio Q_D/Q_R over the region R. This measure describes the degree of variability in terms of water delivery from point to point over the region. The closer the value of the P_E is to zero, the greater the degree of equity (spatial uniformity) in delivery.

To quantify the relative equity between the head and tail of an irrigation system, the parameter is represented as follows:

$$\text{Relative Equity Rate} = \frac{\text{Supply at head}}{\text{Supply at tail}} \text{-----(15)}$$

Considerable attention has been paid to equity of water deliveries in the literature. A potential flaw in many of the proposed indicators is that there is an implicit assumption that equity is the same as equality, and can therefore be easily addressed by statistical measures of deviation from the mean. This assumption is only valid when the specific objective of the irrigation system is equal distribution of water among all users over a single irrigation period.

A simple indicator, based on the Interquartile Ratio of Abernethy (1986), that uses Delivery Performance Ratio (DPR) can be used to give a quick view of over all equity:

$$\text{Modified Interquartile Ratio} = \frac{\text{Average DPR of Best 25\% of the System}}{\text{Average DPR of Worst 25\% of the system}} \text{-----(15)}$$

In some circumstances, particularly when looking at performance of a particular canal, it may be more useful to look at the difference between the head and tail of the canal (Vander Velde, 1991):

$$\text{Head: Tail Equity Ratio} = \frac{\text{Average DPR of Upper 25\% of the System}}{\text{Average DPR of Tail 25\% of the system}} \text{-----(16)}$$

Equity of water delivery is a difficult objective to measure because there are many factors that determine the measuring of 'fair share'. However, it is important to define measures relating to equity so that systems can be designed or rehabilitated to deliver water in an impartial manner to serve by the system. Most standard indicators referring to equity actually measures equality. This is not merely a matter of statistical conveyance, because the concept of equity is different in each community, it requires prior investigation before it can be quantified.

2.3 Maintenance Indicators

The functioning of all the structures in the water delivery system needs periodical evaluation. The structural aspects, which need attention, depend upon the system under consideration. These may include the following:

1. Evaluation of the lining materials of the main, secondary and tertiary canals
2. Siltation and aquatic weeds in the canal system
3. Evaluation of the control structures on the system
4. Evaluation of the outlets
5. Evaluation of the farm irrigation structures

Procedure for the evaluation of the structural components can be locally developed. In contrast to the work done on water delivery performance indicators, remarkably little attention has been paid to assessment of performance in respect of maintenance of irrigation infrastructure. This is despite the fact that physical infrastructure is the most costly item in irrigation development and in the subsequent rehabilitation of older systems.

Maintenance is designed to accomplish three main purposes: keeping canals in sufficiently good condition to minimize losses and sustain designed discharge-head relationships, safety, and keeping water control infrastructure in working conditions. Conveyance efficiencies provide the best way of assessing whether canal maintenance is required. By tracking changes in conveyance efficiencies over time it should be possible to establish criteria that will indicate when canal cleaning or reshaping is necessary. In many systems this is undertaken subjectively on appearance rather than using a more analytical approach.

An alternative measure of maintenance performance suggested by Zhi (1989) is to assess the extent to which control structures can be operated as intended.

$$\text{Effectiveness of Infrastructure} = \frac{\text{Number of Functioning Structures}}{\text{Total Number of Structure}} \text{-----}(17)$$

In general, however, a structure is functioning if it can be operated or utilized to perform its intended function within an accepted level of accuracy.

Another indicator of maintenance is the extent to which equipment provided for use by system managers to maintain and use the infrastructure is in good working condition.

$$\text{Equipment Effectiveness} = \frac{\text{Actually Functioning Equipment}}{\text{Total Equipment Provided}} \text{-----}(18)$$

There is some degree of subjectiveness in this ratio but it certainly gives an indicative measure of the extent to which capital investment for maintenance is being looked after.

Importance should be given on the use of some performance standard to compare the results but no standard values are given for these indicators.

2.4 Agricultural Indicators

Eventhough it is generally understood that irrigation increase crop yields, quantitative assessments of the same are needed. Evaluation of the agricultural aspects should consider the following issues:

1. Overall contribution of irrigation to increased crop production
2. Efficient use of water in relation to cropping pattern
3. Possibilities for crop diversification

Agricultural indicators measure the contribution of the irrigation activity to the economy in relation to consumption of the increasingly scarce resource, water. These indicators provide the basis for comparison of irrigated agriculture performance. The main outputs (measured in terms of such aspects as area actually irrigated and crop production) of the major inputs (water, land and finances) in an irrigated agricultural system are directly reflected by these indicators.

The agricultural indicators used in the performance evaluation are area indicators and production indicators.

2.4.1 Area indicators

Direct indicators for assessing performance in terms of area irrigated include cropped area, cropping intensity, and irrigation intensity. However, to more clearly understand the performance, it is useful to compare these values with an expected target. Without targets, efforts to improve performance will be largely ineffective.

Irrigation Intensity: The general index commonly used in indicating the extent of irrigation is the Irrigation intensity, given by:

$$\text{Irrigation Intensity (CI)} = \frac{\text{Irrigated area}}{\text{Service area}} * 100 \text{ -----(19)}$$

Intensities of more than 100% are reported when more than one season is considered in a year.

Irrigated Area Performance: This is the direct indicator, originally proposed by Zhi (1989), for the assessment of agricultural performance in respect of area irrigated. Where water is a limiting resource towards irrigation development, this indicator may be more important. The indicator is expressed as:

$$\text{Irrigated Area Performance} = \frac{\text{Actual Area}}{\text{Target Area}} \text{-----(20)}$$

Another indicators based on those proposed by Zhi (1989) are suggested for use in assessing agricultural performance in respect to area as:

$$\text{Cropping Intensity Performance} = \frac{\text{Actual Cropping Intensity}}{\text{Target Cropping Intensity}} \text{-----(21)}$$

The targets for both these indicators must be specified very carefully. In some cases it may not include land actually irrigated but outside the command area; in others it may be a seasonally adjusted target. The basis for determining target should be specified clearly such that no confusion arises.

2.4.2 Production indicators

The following are ratio-based indicators of performance applies to measure of production (tons), yield (tons/ha) and productivity of water (kg/cubic meter).

Production Performance: This is the most useful agricultural indicator to evaluate irrigated agricultural systems in such countries like Bangladesh where both water and land are limiting resources towards irrigation development. The indicator is the multiplication of the above two indicators (Irrigated Area Performance and Yield Performance) and expressed as:

$$\text{Production Performance} = \frac{\text{Total Production}}{\text{Target Production}} \text{-----(22)}$$

Yield Performance: This indicator becomes more important where land is a limiting resource to irrigation development. The indicator is expressed as:

$$\text{Yield Performance} = \frac{\text{Actual Yield}}{\text{Target Yield}} \text{-----(23)}$$

Water Productivity Performance: This indicator becomes more important where water is a limiting resource to irrigation development. The indicator is expressed as:

$$\text{Water Productivity Performance} = \frac{\text{Actual Water Productivity}}{\text{Target Water Productivity}} \text{-----}(24)$$

All three of these indicators require the development of targets. The most promising ways to do this include the following: a simple percentage increase over existing levels, a comparison to national targets or norms, or an empirical value which represents the actual performance of the top ten or twenty percent of farmers in the system. The last method of determining targets has the advantage that it is site specific but certainly achievable by a larger number of farmers than is current the case.

In (semi) arid zones, where water is a limiting factor, evapotranspiration and plant growth are related more to water availability than to weather factors. In zones where irrigation is the only way to produce a crop, it is relatively easy to evaluate water use at crop production level. ICID recommends the use of the following terminology (Bos, 1980).

Yield : ET Ratio, given by

$$R_{y\&t} = \frac{Y_i - Y_r}{ET_i - ET_r} \text{-----}(25)$$

Where Y_i = mass of marketable crop produced with irrigation

Y_r = mass of marketable crop (that could be) produced without irrigation

ET_i = mass of water evapotranspired by the irrigated crop

ET_r = mass of water (that could be) evapotranspired by the same crop is not irrigated

Yield : Water Supply Ratio, given by

$$R_{yw} = \frac{Y_i - Y_r}{W_f} \text{-----}(26)$$

Where, W_f = mass of irrigation water furnished to the field

Y_i and Y_r are defined earlier

Yield : Water Cost Ratio, which is the Yield : Water Supply Ratio, rewritten in monetary term as:

$$R_{yw} = \frac{C_i - C_r}{C_f} \text{-----}(27)$$

Where C_i = value of crop produced with irrigation

C_r = value of crop (that could be) produced without irrigation

C_r = cost of applied irrigation water, including amortization, labour and supplementary production costs

Sometimes many of the terms mentioned in different indices are not clearly explained. For yield, to be meaningful indicator for evaluating irrigation performance, information is needed about the factors that are likely to effect the yield. But it is not considered in the definition of crop yield. For crop area no specific definition is given.

2.5 Economic, social and environmental indicators

The socio-economic indicators relate to long-term impacts of pursuing a particular set of operational and agricultural strategies. These indicators have been divided into three primary categories: those relating to economic viability, those relating to social viability and those associated with sustainability of the physical environment for irrigation. Their main utility is to address concerns that may have greater value to policy makers than to irrigate system managers.

2.5.1 Economic indicators

The performance evaluation of irrigation systems on economic principles is complex as the large irrigation systems are in the public sector and no single agency is responsible for their entire operation. In addition, in some of the countries in the region water is delivered free of charge to the farmer. The state supports the entire cost of the management of the system including the management costs. In some systems water charges are collected from the farmers to cover part of the operation and maintenance costs. A comprehensive evaluation of the system based on economic principles, which will bring the benefit-cost ratio is desirable in order to understand and improve the system performance.

The economic indicators used in the performance evaluation are:

Total Financial Viability: This describes the overall financial viability of the irrigation system or irrigation agency. In recent years, there has been increasing concern over the level of recurrent costs required to keep irrigation systems functioning and substantial efforts have been made to raise revenues from water users to bear O&M costs and often some or all of the capital costs of irrigation systems. The indicator proposed by Bos et al. (1993) is defined as:

$$\text{Total Financial Viability} = \frac{\text{Actual O\&M Allocation}}{\text{Total O\&M Requirements}} \text{-----}(28)$$

This indicator says nothing about where the O&M allocation comes from: it may be from government or user fees. A modified indicator as proposed by Bos et al. (1993) was also used that looks at the extent to which a system generates sufficient income to be self-supporting. The indicator is defined as:

$$\text{Financial Self Sufficiency} = \frac{\text{Irrigation Agency Income}}{\text{Total O\&M Requirements}} \text{-----}(29)$$

Both these indicators admittedly subjective because requirements are sometimes difficult to define, but it gives an indication of the extent to which the agency is expected to be self-financing.

Farmers' Profitability: Independently of the economic viability of an irrigation project the farmers are primarily concerned with the profitability of irrigation. The profitability to farmers using irrigation in terms of land can be expressed as:

$$\text{Profitability} = \frac{\text{Benefit of Irrigation per ha}}{\text{Total Irrigation Expenses per ha}} \text{-----}(30)$$

Fee Collection Performance: Svendsen (1992) suggested to use this indicator where the irrigation agency collects money from farmers as irrigation fees. The indicator is expressed as:

$$\text{Fee Collection Performance} = \frac{\text{Irrigation Fees Collected}}{\text{Irrigation Fees Due}} \text{-----}(31)$$

In respect of the economic aspects of the system completed, it is desirable to make the projects self-sufficient in terms of incomes and expenditure. This will however, depend upon the national policy of a particular country.

These indicators are quite simple but in relation to defining the different indices many of the terms mentioned are not clearly explained and no standard values are given to compare the performance.

2.5.2 Social Indicators

The impact of the irrigation system on social aspects could consist of the following issues:

1. Employment generation

- The establishment of an irrigation system will intensify the agricultural operations. Land ownership patterns could be changed as the value of irrigated land is much higher than land under rainfed agriculture. Too much land fragmentation need to be avoided as it may result in uneconomical units. Migrations of people into the irrigated areas or out of the areas need to be studied. Finally the farmers satisfaction which might be reflected through the number of complaints need to be assessed.

In many countries, there are department of agriculture, labor or census, which collect basic agricultural and economic data. These can be used very easily by irrigation managers as sources of information on socio-economic impacts and trends, such as employment, wages and poverty levels. Possible indicators include:

$$\text{Irrigation Wage Generation} = \frac{\text{Annual Average Rural Income}}{\text{Annual National (or Regional) Average Income}} \text{-----}(33)$$

These indicators can also be modified to compare within-scheme levels to adjacent non-irrigated areas, or to other irrigation systems. Similar indicators can be developed for housing quality, nutritional and health status, access to information media (radios, etc.), distribution of access to land and water, and migration patterns.

Social capacity refers to the social (as distinguished from physical, biological, or economical) capacity of people and organizations for managing and sustaining the irrigated agriculture system. Suggested two indicators are:

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$$\text{Users' Stake in Irrigation System} = \frac{\text{Number of Active Users Organizations}}{\text{Total Number of Water Users Organizations}} \text{-----}(36)$$

Actual technical knowledge of staff can be ascertained through simple test while required knowledge is inherent in the job description. Activeness of water users associations can be measured using easily acquired data, such as percent holding regular (or the minimum required) meetings, percent of users participating, or number of organizations fulfilling agreed upon tasks, such as fee collection, maintenance, or rotating water.

All of these indicators are crude, and relatively untested; but they constitute useful and implementable first steps to begin paying greater attention to the social viability of irrigation.

2.5.3 Environmental Indicators

In recent years, there is an increasing demand for paying due attention to the impact of the development programmes or projects on the environment. Because, in the past, in planning, design and implementation of development projects, due attention was given on the possible subsequent impact of the project on the environment. As a result there is an increasing threat of environmental degradations and ecological imbalances (green house effect). Therefore in evaluating the performance of irrigation projects, the environmental parameters are considered as the performance indicators.

Continued irrigation is bringing both favorable and unfavorable changes in the irrigated areas. While the favorable changes consist of increased crop production, better soil moisture conditions conducive toward establishment of vegetation and availability of water for other uses, several environmental hazards in irrigated areas are identified. The major items of concern are as follows:

- i) Soil degradation, salinity and alkalinity
- ii) Deterioration of ground water quality
- iii) Deterioration of surface water quality
- iv) Water logging, formation of stagnant water pools and vector breeding places
- v) Stagnant drainage channels with aquatic weeds
- vi) Changing in cropping patterns resulting in cropping systems injurious to health
- vii) Uptake of undesirable elements by plants causing long term health problems
- viii) Irrigation return flows causing water quality problems for aquatic habitat

ix) Contamination of irrigation water with urban wastes

It is necessary that the performance evaluation should be able to identify these environmental concerns and suggest suitable ways and means to remedy them. In general two issues seem to be important. These are:

- i) Changes occurring in the irrigated area that are detrimental to crop production. These include development of salinity and water logging conditions resulting in possible decrease in crop production in selected areas.
- ii) Changes that detrimental to human health. These could occur all over the irrigated area.

Sustainability of Irrigated Area: This is the basic indicator on which strategic management depends. Looking at the trend of the indicator over a period of time relevant organization/agency/person/country takes necessary interventions and tackle problems (if any). This indicator is expressed as:

$$\text{Sustainability of Irrigated Area} = \frac{\text{Current Irrigable Area}}{\text{Initial Irrigable Area}} \text{-----}(37)$$

Where it is possible, this ratio can be modified to specifically refer to water logged or saline areas as a percentage of the total irrigable area. An individual manager will, of course, need to know what the cause was of losing the land from production.

If drainage is not adequate then there are risks of water tables rising to levels where production is affected and, there may be reduced opportunities for leaching salts from the soil. Indicators that address these concerns include:

Depth to Groundwater: The depth to the groundwater has a threefold effect on the sustainability of irrigated agriculture:

- In (sub-)humid regions a high groundwater table may cause crop yield reductions and limit the number of workable days (e.g., during planting and harvest).
- In (semi-)arid regions a high groundwater table may cause salt accumulation in the root zone of the crop. This in turn will lead to yield reductions or even to the abandoned of agriculture.

- If the irrigation water source is groundwater, mining of this resource causes a gradual lowering of the groundwater table. The related increase in the cost of pumping affects the feasibility of irrigated agriculture.

In all three cases the sustainability of irrigation is determined by the

$$\text{Rate of Change of Depth too Groundwater} = \frac{\text{New Depth} - \text{Old Depth}}{\text{Old Depth}} \text{-----}(38)$$

The time interval between the old and new depth to the ground water depends on the studied trend. One month is suitable to evaluate seasonal trends; one year is suitable for most other purposes (Bos, 1990).

Flooding: In humid zone areas there may be a risk of flooding in the wet season if there is inadequate drainage (or if irrigation deliveries are continued during periods of rainfall).

The degree of severity can be assessed as follows:

$$\text{Impact of Flooding} = \frac{\text{Area Subject to Flooding}}{\text{Total Irrigated Area}} \text{-----}(39)$$

In recent times there is increasing concern with quality of drainage water. Again there may be local standards that can be used in assessing the environmental impact of poor drainage, but to date no widely accepted indicators are available.

More frequently, however, physical sustainability parameters are used in a more strategic sense by looking at the trends of value over a period of time. Most countries threatened by deterioration of the physical environment have standards for such factors as depth to water table, permissible water quality for irrigation, permissible quality of drainage water, soil salinity levels, sodium absorption ratios, and measures of toxins associated with agricultural input use. If there is an effective process of strategic management, the trends in respect of these measures will be the basis for deciding whether to modify operational management practices within the agency, seek regularity action to control input use, make capital investments to reverse the trend, or tackle problems through education.

2.6 Availability of Basic Data

One of the problems of using performance indicators is the unavailability of data required for performance evaluation. A comparative statement of data required for performance evaluation and their availability at the project office of BWDB are given below.

Table 2.2: Comparative statements of data required for different indicators to evaluate the performance and their availability at the project office of BWDB.

Sl. No.	Data Required to Evaluate the Irrigation Project Performance	Availability of Data at the project office of BWDB
1	Cultivable Area (ha)	A
2	Irrigable Area (ha)	A
3	Irrigated Area (ha)	A
4	Total volume of water diverted from the head works for irrigation (m ³)	A
5	Total volume of water diverted to the field by irrigation canal (m ³)	NA
6	Total length of irrigation canal (m) at present	A
7	Total length of drainage canal (m) at present	A
8	Present yields of the major crops per unit area (kg/ha)	A
9	Present cropping pattern (% of area)	A
10	Present Cropping intensity (% of area)	A
11	Seepage & percolation in the field	NA
12	Daily Evaporation and rainfall	A
13	Total number of structures	A
14	Number of functioning structures	A
15	Total number of equipment provided	A
16	Actual number of functioning equipment	NA
17	Project investment cost (Tk.)	A
18	Annual expenditure for operation and maintenance of the project (Tk.)	A
19	Total annual income from water charges and other revenue sources (Tk.)	A
20	Total annual production cost per ha for the different crops of all inputs, irrigation charges and labour cost (Tk.)	A
21	Value of different crops per ha and Annual production cost per ha	A
22	Total number of staff	A
23	Number of water users group formed	A
24	Number of active water users group	A
25	Total number of water users organization	A
26	Present Average land price per hector (Tk.)	A

27	Employment & wages (i) Annual labour use per ha of major crops (Man-days) (ii) Average wages of farm labour (Tk./day)	A
28	Area subject to flooding	A
29	Area under drainage congestion (ha)	A

A = Available

NA = Not available

Chapter III

GANGES-KOBADAK IRRIGATION PROJECT

3.1 Introduction

The Ganges Kobadak Irrigation Project (GKIP) is one of the largest irrigation scheme in Bangladesh which is located in the south-western region of Bangladesh covering part of the districts of Kushtia, Chuadanga, Jhenaidah, Magura, Jessore and Khulna and is situated on the right bank of the Ganges and the Gorai rivers. It covers 13 thanas of the above districts, which are: Kushtia, Bheramara, Mirpur, Daulotpur, Kumarkhali, Khoksha, Chuadanga, Alamdanga, Harinakundu, Jhenidah, Shailkupa, Sreepur, Magura. The present jurisdiction of project is shown in Fig.-3.1. Ganges-Kobadak Project canal system is also shown in Fig.3.2.

3.2 Background

The Ganges-Kobadak irrigation project as conceived in the early fifties was the first major step to provide supplemental irrigation to traditional crops. During the feasibility study and planning stages, it was initially proposed that the project would provide for supplementary irrigation on a net cultivable area of 703,789 ha in Kharif II season in the greater Kushtia, Jessore and Khulna districts. The study suggested the project to be developed in nine phases, which comprises the following:

Phase	Irrigable Area, ha
Kushtia Unit Phase-I & II	141700
Jessore Unit Phase-I	67611
Jessore Unit Phase-II	88000
Jessore Unit Phase-III	90688
Jessore Unit Phase-I V	4858
Jessore Unit Phase-V	153846
Jessore Unit Phase-VI	109312
Khulna Unit	47774
Total	703789

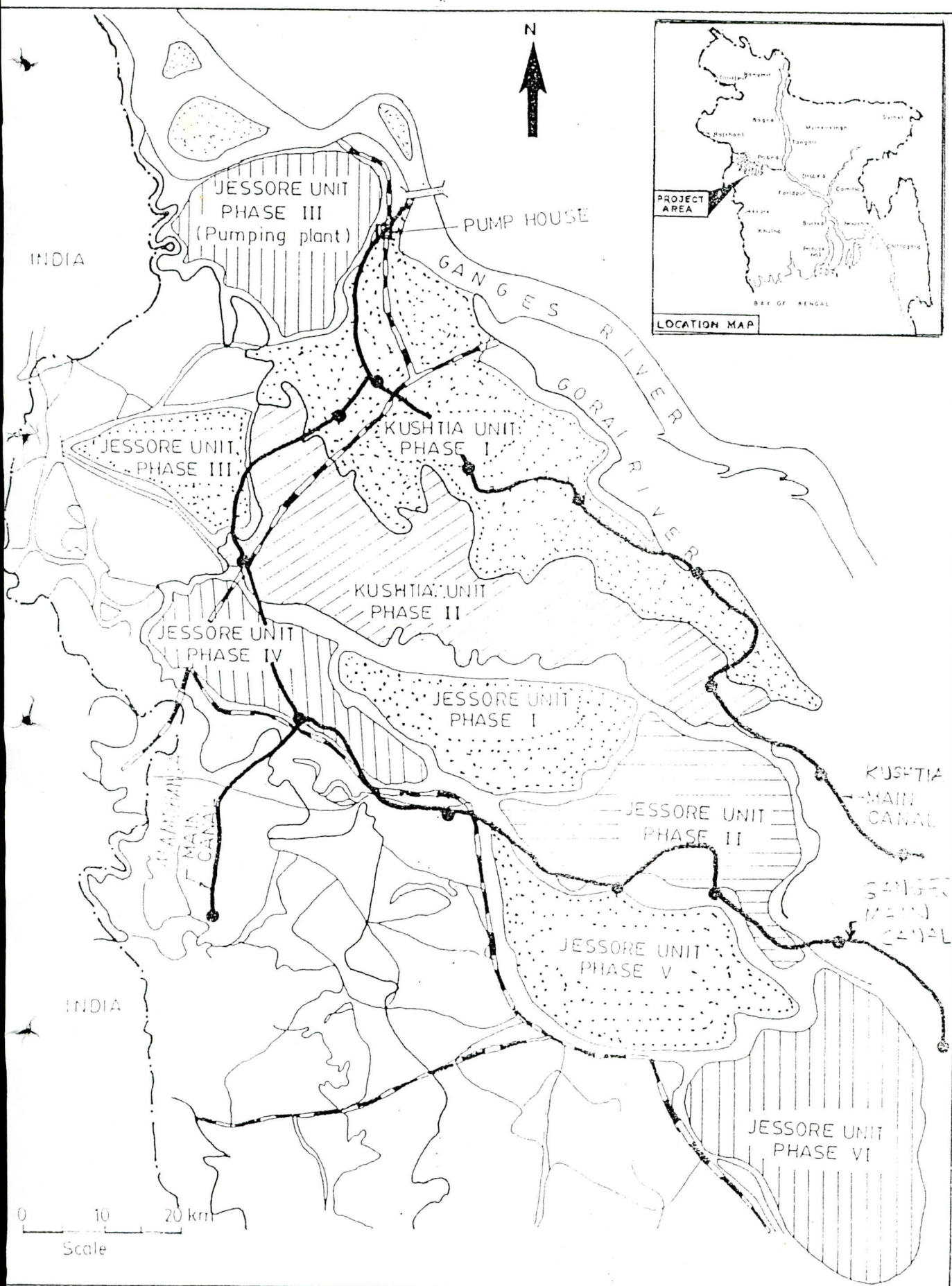
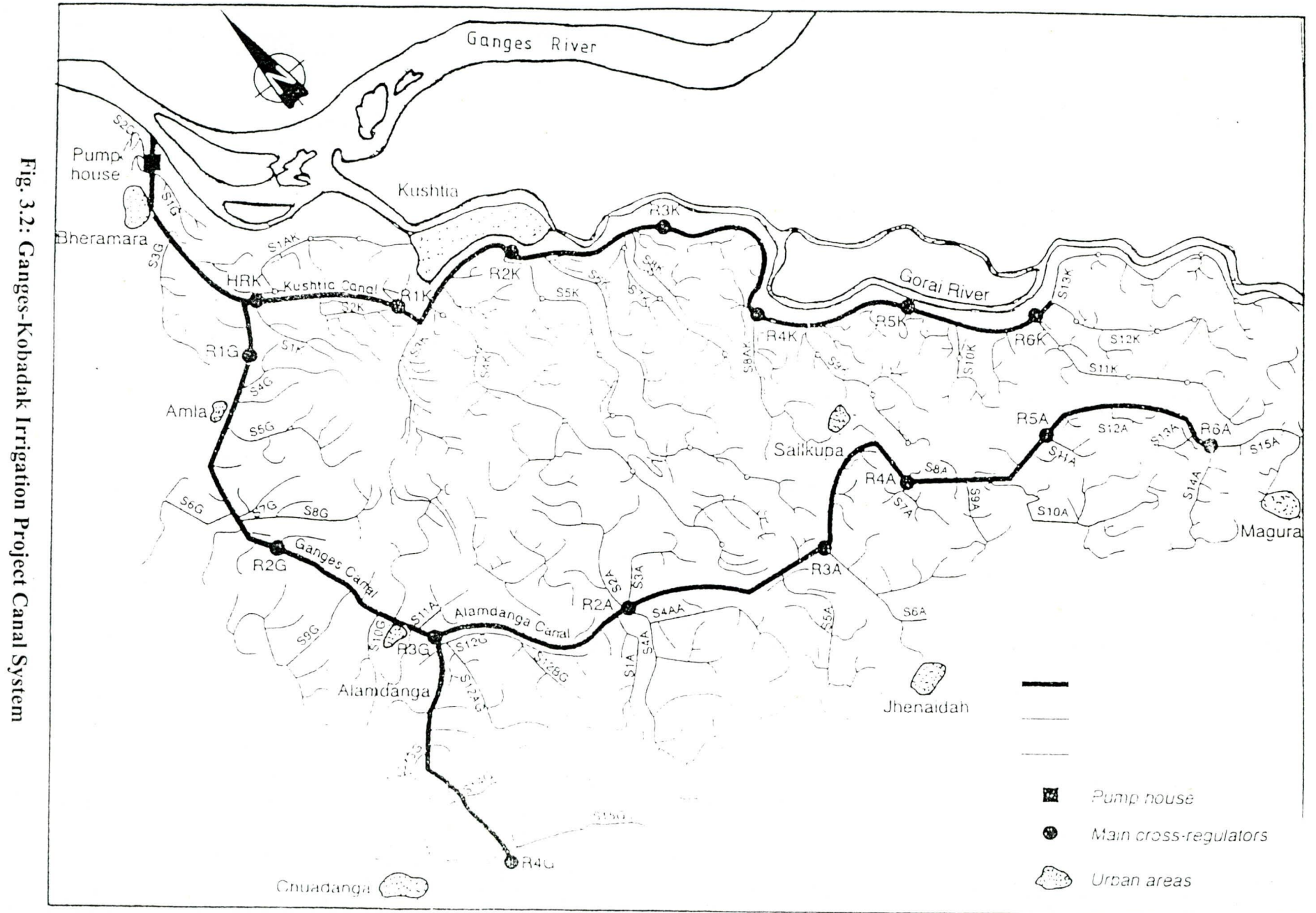


Fig. 3.1: Location Map: Ganges-Kobadak Irrigation Project



The design of the first stage of the greater Ganges-Kobadak Irrigation Project, the Kushtia Unit, Phase I (45000 ha net), was started in 1954 and was assisted by experts of the FAO. In fact many experts were assisting the EPWAPDA, representing all kinds of design and operation philosophies: viz. Dutch Engineers with FAO, French experts of NEYRPIC and GOTHA, Japanese experts from HITACHI, American and Taiwanese experts from IECO, and engineers of EPWAPDA and local consulting firms.

During the feasibility study and planning stages it was proposed that the project would provide for supplementary irrigation on approximately 700,000 ha. of land in Kharif-II season in the Kushtia and Jessore districts. However, only construction of the first two phases out of the nine phases originally envisaged was completed during the early 1980s. The salient features of the project and irrigation achievement at a glance are summarized below:

G-K Irrigation Project Summary Statistics

1. Project Area

Total	: 1,97,500 ha
Cultivable	: 1,42,000 ha
Irrigable	: 1,16,000 ha
2. District : 4Nos.(Kushtia, Chuadanga, Jhenidaha, Magura)
3. Thana (Police Station) : 13 Nos. (Kushtia, Kumarkhali, Khoksha, Mirpur, Bheramara, Chuadanga, Daulatput, Alamdanga, Harinakundu, Jhenidaha, Sailkupa, Magura and Sreepur)
4. Population : 20 lac
5. Owner of land : 1.20 lac
6. Project Implementation Period :

a) Commencement of Project	: 1st Phase : 1955-56
	: 2nd Phase : 1960-61
b) Completion of Project	: 1st Phase : 1969-70
	: 2nd Phase : 1982-83
7. Project implementation Cost.

a) 1st phase	: Tk. 18.50 crore
b) 2nd phase	: Tk. 55.39 crore
8. Project Rehabilitation Cost : Tk. 212.56 crore

9.	Rehabilitation donor agencies	: 1985-1993 ADB Loan Agreement (671-BAN) 1985-1989 UNDP-TA (BGD/83/039) 1st 1990-1993 UNDP-TA (BGD/89/027) 2nd
10.	First Irrigation supply	: 1962
11.	Pump House	: 2 Nos.
12.	Discharge Capacity	
	Total	: 153 cumec
	Main Pumps	: 3 nos. 36.8 cumec each
	Subsidiary Pumps	: 12 nos. 3.5 cumec each
13.	Flood control embankment	: 39 km
14.	Irrigation Cannel	
	a) Main Irrigation Canal	: 193 km (3 Nos)
	b) Secondary Canal	: 467 km (49 Nos)
	c) Tertiary canal	: 995 km (444 Nos)
15.	Drainage Canal	: 971 Km
16.	Hydraulic Structure	: 2184 Nos.
17.	Inspection Road	: 228 km
18.	Project's Electricity requirement	: 14 Mega Watt
19.	Grid Sub- Station	: 1 No.
20.	Highest Irrigation Achievement	: 99,119 ha (Aman) : 42,742 ha (Aus)
21.	Annual Operation Cost	: Tk. 29 crore.
22.	Agricultural Experimental Farm	: 1No.
23.	Irrigation Extension Training Center	: 1 No.
24.	Chashi Club	: 49 Nos.
	Extension Center	: 93 Nos.
25.	Primary co-operative Society	: 749 Nos.
26.	Thana Central Co-operative Association:	7 Nos.
27.	Water Users' Association	: 324 Nos.
28.	Total No. of outlet	: 3500 Nos.

Climatic Information:

Monsoon climate 1,600 mm annual rainfall

Dry season Nov - April : <100 mm/month

Wet season June- Sept	: > 200 mm/month
Pan evaporation min	: 58 mm/month
max	: 189 mm/month
Low flood risk area	: drainage problems in 8,700 ha and solutions identified.

Socio-economic data:

Population in G.K area	Total	: 2,000,000
	Rural	: 1,800,000
Population density		: 1010 per sq. km.
No. of farm holdings		: 120,000
Average size of holding		: 0.1 ha
Average family size		: 6-7
Literacy rate		: approx. 20%
TWUA Created		: 310 (out of 330)

Irrigation achievement at a glance (ha)

Year	Aman	Rabi	Aus	Total
1962- 63	1804	--	5187	6991
1963-64	17707	--	7068	24775
1964-65	20037	--	2585	22622
1965-66	22158	--	2528	24686
1966-67	23229	--	4952	28181
1967-68	25488	--	4222	29710
1968-69	27500	--	5824	33324
1969-70	27040	--	6510	33550
1970-71	27309	--	2636	29945
1971-72	18834	--	2672	21506
1972-73	21002	--	12083	33085
1973-74	21790	--	16022	37812
1974-75	20830	--	16548	37378
1975-76	25248	--	19032	44280
1976-77	28277	--	25999	54276

1977-78	39081	--	28623	67704
1978-79	41976	--	18840	60816
1979-80	54268	--	24394	78662
1980-81	63985	--	33322	97307
1981-82	71694	--	37549	109243
1982-83	78158	--	35609	113767
1983-84	74973	--	34353	109326
1984-85	73652	--	38063	111715
1985-86	84920	--	21784	106704
1986-87	85451	--	30458	115909
1987-88	86008	--	22530	108538
1988-89	76492	--	21323	97815
1989-90	77117	--	30749	107866
1990-91	80817	--	42742	123559
1991-92	88387	--	35637	124024
1992-93	81355	--	--	81355
1993-94	98904	9121 (wheat)	--	108025
1994-95	99080	16075 (wheat)	--	115155
1995-96	99117	10925 (wheat)	--	110042
1996-97	93302		25000	118302
1997-98	72914		25000	97920
1998-99	93500	24877 (Boro)	10654	129131

Source: HR Wallingford and EPC (1995)

The project includes two pump stations at Bheramara to lift water from an intake channel from the Ganges and discharge into the canal system. A network of approximately 1600 km of canals carries water from the pump station through some 2184 hydraulic structures to the field outlets. The canal system consists of three main canals: Ganges canal, Kushtia canal and Alamdanga canal, and more than 40 secondary and 314 tertiary canals.

3.3 Rehabilitation

Soon after completion in 1983, operation of the project was affected by a number of problems. Then an appraisal by NEDECO (1983) identified the primary problems as:

- ◆ sedimentation of intake channel
- ◆ inadequate water supply
- ◆ inadequate and unreliable power supplies
- ◆ inadequate tertiary and field channel development
- ◆ excessive seepage and operational losses in canal system
- ◆ poor system management and O&M procedures
- ◆ inadequate provision of support services to agriculture, particularly extension, credit and inputs
- ◆ poor on-farm water management.

A rehabilitation programme was commissioned in 1985 to address the above problems through:

- improving hydraulic conditions of the intake channel, with revised dredging
- provision of improved power supplies to the pump station through increased transformer capacity and connection to primary national grid;
- rehabilitation of main pump;
- rehabilitation of irrigation distribution system;
- revision of operating procedures and introduction of improved O&M practices;
- formation of water users organizations able to assume responsibility for O&M of tertiary canal systems.

The programme was funded by ADB loan (\$44.37million, loan no. 671-BAN). At the same time it was also funded under UNDP technical assistance BGD/83/039 amounting \$1.74 million, BGD/84/027/A/01/45 and BGD/89/027 and ADB technical assistance (TA no. 1454-BAN). The consulting firms engaged were: DHV Consulting Engineers in association with Associated Consulting Engineers (Bangladesh) Ltd. (1985 to 1990) and HR Wallingford in association with Engineering Planning Consultants (Bangladesh) Ltd. (1989 to 1994).

During the rehabilitation the work components, which were implemented, are:

- **Intake channel modification and dredging:**

Heavy sedimentation, which took place in front of and within the intake channel, used to be a major maintenance problem in the mid-1970s and early 1980s. At present, the deep channel of the Ganges River is near the right bank. There is no sandbar in front of the

intake channel and there is less siltation in this channel because its length has been shortened by about 520 meters because of riverbank erosion. The intake channel is now about 640 m long compared with 1,160 m in 1983. BWDB has recently carried out a river protection program in front of the intake channel. The project provided funds for dredging the intake channel to maintain an optimum design bottom width of 36.5 m and to improve the flow condition. Annual dredging has been improved and carried out in accordance with the recommendations made by the Project consultant.

- **Pumping plant rehabilitation:**

The Project was aimed to bring the main and subsidiary pumping plants to their original design capacity. In the main pumping plant, the Project provided replacement parts, mechanical works and the supervisory services necessary to perform a complete and major overhaul of all three pumps. For the subsidiary pump house the Project replaced trash racks at the twelve entrance bays and upgraded the water cooling system of the twelve pumps.

- **Electric power supply:**

The project provided the materials and civil works necessary to bring the available 132 KV power supply to a proposed sub-station site and made civil works to install a 132/5.5 KV - 20 MVA transformer for an adequate power supply for the two pumping plants.

- **Rehabilitation of main and secondary canals:**

Followings works were conducted for the main and subsidiary canals during the rehabilitation :

- (i) restoration of the main and secondary canals to their original capacities;
- (ii) increased capacity in a number of canal reaches to afford deliveries commensurate with anticipated water requirements;
- (iii) clay lining of highly permeable reaches of the main and secondary canals, totaling about 10 percent of the total length;
- (iv) repair and improvement of various irrigation control structures, including necessary hardware (gates and lifting devices);
- (v) repair and improvement of some 118 km of existing access roads along the main canals.

- **Rehabilitation of tertiary canals and field channels:**

Remodeling and expansion 325 tertiary canals and many field channels, including introduction of necessary water control (turnouts, culverts, etc.) and water measurement structures, were improved. Additional required field channels were installed to enable delivery of water to the entire command area.

- **Improvement of Magura Weir:**

A new regulator (eight vents, each five meters wide) has been constructed at the site of the existing Magura Weir to store water in the main drainage channels (the Nabaganga and Kumar rivers) and reuse it for dry season irrigation by low-lift pumping to serve an additional 3000 ha. An additional Weir was constructed and the by-pass channels were closed with a view to make water available for an additional 3,000 ha of land, which are not irrigated by the G.K system.

- **River training works:**

The Project suggested for river training works at three critical points along the Gorai River where erosion along the right bank threatens the parallel Kushtia Main Canal and Secondary Canal S₁₃K.

- **Telecommunications:**

The project installed 25 Radio sub-stations and a PABX at Kushtia with sufficient extensions for up-to-date communication system throughout the project area to improve communications required for effective operation and management of the irrigation system.

- **Irrigation Management:**

The project provided improved irrigation management at all system levels including the introduction of a 10-day rotational water supply, the installation of adequate water measurements and water control facilities, and institutional development. At the tertiary and field level rotational irrigation and improved on-farm water management was introduced to each Out-let Management Committee (OMC). This was achieved through an intensification of agricultural extension activities, the establishment of farmers' groups and the provision of technical guidance.

- **Formation of Tertiary Water Users Association (TWUA):**

During the rehabilitation a total of 324 Tertiary Water Users Association (TWUA) were formed out of targeted 330 and 1874 Out-let Management Committees (OMC) were formed for proper on-farm management of the irrigation water.

- **Training of BWDB staffs and TWUA members**

During the rehabilitation a number of training programmes were organized through which the following personnel were trained:

Training of Trainer (TOT), BWDB staff:	37
WUA representatives:	465
Monthly field training (WUA representatives)	3434
Extension Over-seers	102

(Tk. in Lac)

3.4 Water Management

The project set up a Water Management Unit (WMU) headed by one Executive Engineer with two Assistant Engineers which is responsible for formulation of water distribution plans, co-ordination of data collected for the field and pump house divisions, production of irrigation schedules and information flows to the Project Director and field divisions. The unit is responsible for determining and comminuting target discharges at the interfaces between the four field divisions and at key locations within the divisions. It advises the field divisions on all aspects of water management including rotation patterns.

3.5 Project Impact Monitoring

A Project Benefit Monitoring and Evaluation (PBME) Unit was established by the Project Authorities in 1985 comprising permanent staff members of the G.K. Project. The PBME unit was established to under take a basic studies. Project monitoring is fundamental to improvements. But it could not function as desired because of lack of appropriate skilled manpower, training of manpower, and required resources.

3.6 Operational Aspects

The Project is being operated by 5 Divisions, 12 Sub-divisions and 36 Sections under a Superintending Engineer along with one Chief Extension Officer, one Deputy-Chief Extension Officer, Water Management Unit, PBME Unit and a Regional Accounting Center (RAC). The field divisions are responsible for the planning and execution of the operation & maintenance of the Project while the Pump Division is responsible for the day-to-day operation and maintenance of the pumps. Division-wise command area is as follows:

Kushtia O&M Division	33705 ha
Chuadanga O&M Division	36777 ha

Jhenidah O&M Division 38238 ha

Maguar O&M Division 12647 ha

3.7 Cost Recovery (Irrigation Taxes)

There is a system of tax collection from the water users. The rate of tax for Kharif-I is Tk. 250.00 per acre and for Kharif-II is Tk. 100.00 per acre. A statement of tax collection is given below:

Yearwise Irrigation Tax Imposed and Collected

(Tk. in Lac)

Financial year	Target Amount	Collection	% of Collection
Upto 1984	142	6.33	4.45%
1985-86	211	12.32	5.84%
1986-87	178	0.38	0.21%
1987-88	120	1.31	1.09%
1988-89	170	6.23	3.66%
1989-90	184	1.47	0.80%
1990-91	150	0.04	0.03%
1991-92	18	0	0
1992-93	49	0	0
1993-94	90	9.34	10.37%
1994-95	99	9.94	10.04%
1995-96	90	13.61	15.12%
1996-97	90	4.14	4.60%
1997-98	65	1.12	1.92%
1998-99	65	0.98	1.51%
1999-2000	58	0.48	0.83%

3.8 Water Distribution System

Pumped irrigation water from Ganges is distributed to the farms by conveying it through a network of gravity canals consisting of the main, secondary, and tertiary canals. The water distribution system was originally designed for distribution of water on a constant downstream water level with automatic downstream control through sophisticated control structures. But this downstream control system did not function well due to low discharge into the system, so that only the tail ends receive water and there was farmers' opportunity of disrupting the whole system by enlarging the off takes at the tail ends (NEDECO, 1983). Thus the system was converted into the upstream control type system with the modification of the structures into the manually operated type and off takes to secondary canals was shifted from downstream to upstream of the regulator where possible.

There are regulators in the main and secondary canals and inlet and check structures in the tertiary canals to control and regulate flow of water.

The automatic downstream control gates installed in Phase-I area were modified to allow manual control in response to unstable water deliveries. Supplies from the pump house were unreliable due to the reliance on power drawn from the local electricity grid that was subject to frequent power cuts and voltage fluctuations that resulted in the pumps 'tripping' out. The problems of unreliable power supplies were compounded as the pumps aged and become more unreliable.

In the absence of sufficient operators (due to change in BWDB policy) and with generally unreliable supplies, water users took unilateral action to obtain supplies. The planned continuous operation of the main canals with rotation at secondary and tertiary canal level broke down. This resulted in supplies becoming increasingly unreliable.

In an attempt to re-establish a level of order in water distribution, the project abandoned continuous operation of the main canal and adopted a nominally two-part rotation by dividing the command area into two. Each part of the rotation was to receive water for five days of every ten-day irrigation period. However, in the absence of quantified estimates of requirements and a lack of detailed operational instructions, secondary and tertiary head regulators were often left fully open and distribution continued to be unreliable and inequitable.

Finally, by the start of the second phase of the Technical Assistant (TA) in 1992, the main canals have been divided into seventeen reaches (fig.3.3). The main canals are controlled to provide full supply level in individual reaches in turn. Each reach of the main canals receives full supply levels for only one to two days out of the ten-day period. A typical irrigation schedule for a 10-day rotational period proposed by the WMU is shown in fig. 3.4. The secondary and corresponding tertiary canals receive water according to the schedule within each reach. The Water Management Unit (WMU) is responsible to coordinate water distribution in the main canal system. The WMU has used the computer based system to provide operational schedules for control of water distribution in the main canal system; issuing direct instructions to operations staff at the Bheramara Pump House; Alamdanga Main Canal (AMC); Kushtia Main canal (KMC); Ganges Main canal (GMC); head & cross regulators of the main canals. Operation of secondary canal regulators and head regulators of tertiary systems remained with individual field divisions. Staff of the

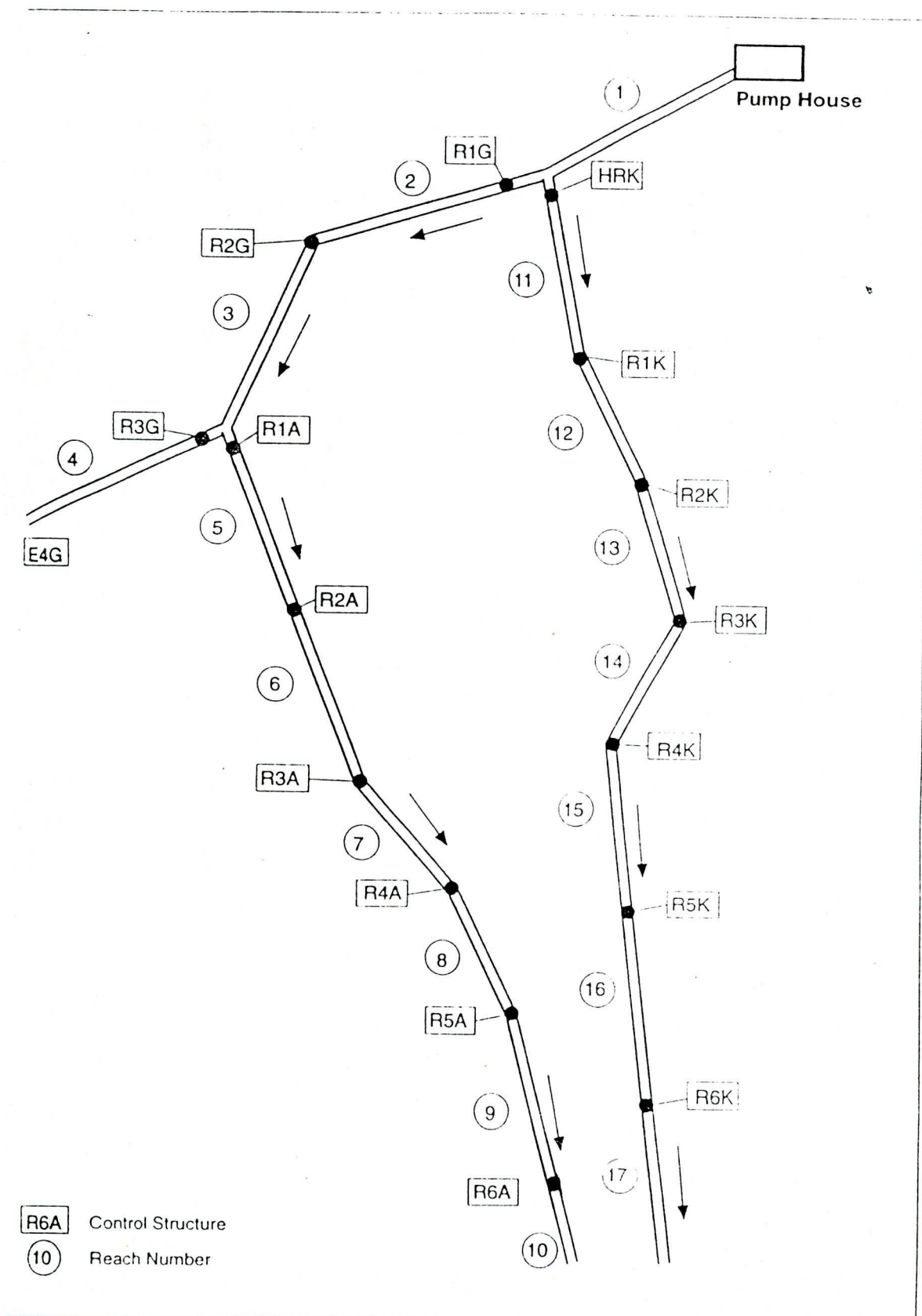


Fig. 3.3: Different reaches of main canal of Ganges-Kobadak Irrigation Project

Reach No.	Location	Days									
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
1	PH-HRK/R1G										
2	R1G-R2G										
3	R2G-R3G										
4	R3G-R4G										
5	R1A-R2A										
6	R2A-R3A										
7	R3A-R4A										
8	R4A-R5A										
9	R5A-R6A										
10											
11	HRK-R1K										
12	R1K-R2K										
13	R2K-R3K										
14	R3K-R4K										
15	R4K-R5K										
16	R5K-R6K										
17	R6K-TAIL										

Fig. 3.4: A typical schedule for a 10-day rotational period

field divisions is instructed to prepare schedules of operation of each structure under the control of the division. The rotation is to be based on the area of each unit in the division to ensure an equitable division of available water.

Gate operators were assigned to control all cross and head regulators. At secondary head regulators and at secondary cross regulators, the operators were expected to live in BWDB accommodation at the duty site or at a nearby BWDB camp to ensure that the gate supervised continuously.

In practice, the main canal cross and head regulators are manned as planned however most secondary and tertiary canal regulators are no longer supervised continuously.

In view of the staffing constraints and a general concern regarding security of staff in field stations during the hours of darkness the approach adopted for improving water management procedures was to identify key structures in the main system which could be staffed and controlled effectively. By controlling these key structures it is assumed that distribution to less well controlled structures will also improve.

Control of the key structures was transferred from the authority of individual field divisions to the Water Management Unit (WMU). By centralizing authority for operation of the main distribution system it was hoped to minimize the impact of local distribution constraints on the overall performance of the main canal network. In practice, field operation staff continued to receive orders through their field division, which undermined the role of centralized authority. On occasions main regulators were adjusted to address localized problems, in contravention of the instructions issued by the WMU, with detrimental effects on downstream operations.

The duration and timing of water supplies to individual systems were thus expected to be fixed by the field divisions. However, despite assistance from the WMU, generally the rotational programme was not implemented and secondary and direct tertiary head regulators were found to remain open throughout the irrigation cycle. This resulted in a continuation of erratic supplies whilst levels and discharges were inadequate for efficient irrigation operations.

3.9 Earlier evaluations of G-K Project

During the last few decades a good number of studies were undertaken for the evaluation and rehabilitation of the Ganges-Kobadak project. Although these studies differed in terms of basic objectives, majority of these dealt with socio-economic aspects with a view to determine

socio-economic impacts of the project, identify socio-economic constraints to further development and evaluate proposed activities and projects in terms of socio-economic criteria. Some of these studies are discussed briefly.

One of the earliest studies on economic evaluation of G-K project was done by International Engineering Company (1967). The purpose of the study was to analyze the economic impacts of the project on farmers living in the area where water was being supplied from the project. Data were collected from 500 randomly selected farmers from different villages. Some of the useful findings of the study were as follows: there was excessive fragmentation of land in the area; the indebtedness of farmers was considerable and over half of the total farmers incurred loans; and over half of the farmers used irrigation water during 1965-66. But traditional cropping pattern did not change much and the modern method of cultivation was not being practiced on a large scale. There was also absence of marketing system for most of the agricultural products. However, the study came to the conclusion that economic condition of many farmers was better than before and in the opinion of half of the farmers the project was useful.

Jalal et al. (1974) evaluated the project performance in order to identify problems and to suggest ways to maximize benefit. Problems identified by them were: poor maintenance of pump house, wastage of water, inadequate power supply, siltation in the intake channel, and lack of interdepartmental and also intradepartmental co-ordination. They recommended maintenance of pump, construction of 'ails' around plots and leveling of land, additional power supply, reexcavation of intake channel, improvement of interdepartmental and intradepartmental co-ordination and implementation of 7-day rotation water distribution at the tertiary outlet level for the improvement of the project performance.

Islam (1978) evaluated the performance of the G-K project in respect of technical, economical and organizational aspects. According to them irregular and inadequate power supply to the pump house, unsatisfactory arrangements for repair and servicing of infrastructure, and insufficient trained staff were the main technical problems. They found that the project had significant positive impact on crop yields but showed no favorable effect on benefit distribution. Among the organizational problems they chalked out that lack of cooperation among organizations, lack of control in water distribution, lack of power in taking independent decision etc. were the main problems.

BWDB (1982) evaluated the project to identify areas requiring special attention to increase the benefit of farmers, including the small farmers. It was mentioned that the project efficiency could considerably be improved provided adequate power supply and regular maintenance of the project were ensured. It was also mentioned that operation and maintenance of the project were neglected. Distribution and use of irrigation water for the full development of the project benefit were interfered by uneven farmlands and high and low pockets.

Ahmed (1984) conducted performance evaluation study in the project area in terms of agricultural production, and physical infrastructure and its performance, economic effects and social and environmental effects. He concluded that unreliable water supply creates problems like water wastage, undesirable cropping patterns, and bitterness between farmers and projects officials. The main reasons for wastage of water were due to absence of rotational systems along with the unreliable water supply and much more water is wasted than used. He recommended the improvement of physical infrastructure, development of additional water resources, improvement of project organization, operation and maintenance.

BRRI and BWDB in collaboration with IRRI started a project in 1981 entitled "Applied Research for Increasing Irrigation Effectiveness and Crop Production" with the overall objectives to develop feasible techniques for efficient and equitable water distribution and promote increased crop production and the general objective to create an awareness and understanding among the personnel and concerned administrators for improving the irrigation system management efficiency (BRRI, 1983). It was found in the study that none of the farmers' co-operatives was functioning well and no irrigation committee was in existence in the study area; the performance of the 'Sectional officers' was unsatisfactory; distribution problems were acute at the tail reaches (BRRI, 1984).

Ghani (1989) carried out a study in the project area to develop a practical methodology for improving the systems performance with improved water management practices. He concluded that (i) the reliability of water supply in the project is low, (ii) the 9-day rotation method is a technically sound and socially desirable method of water allocation and distribution for the project that allows more farmers to be benefited from the limited available irrigation water and (iii) irrigation water deliveries in the Aus season have been uncertain in some tail end irrigation areas. He recommended that areas, which can be served with irrigation

water in Aus season, should be identified and programmed in advance and pump operation should be suspended during the June-July period.

Nath (1989) conducted a study in the project area to identify the technical and institutional constraints in proper implementation of the practiced distribution of G-K project. He concluded that (i) the prepared schedule of the water distribution was not followed strictly in all tertiary areas, (ii) the pump starting date varied from the last week December to first week of March and the farmers do not get information about it, (iii) poor control of water at different levels due to poor condition of the outlet structures and their gates, (iv) lack of communication between the farmers and the authority, the supervisors and the users' groups. (v) average yield of the selected tertiary canals were found to vary from 3.6 t/ha and 5.83 t/ha. (vi) average RWS was 1.12 and (vi) irrigation efficiency was low at the head reach of the canal. He recommended that (i) pump operation should be started within a fixed and short interval of time, (ii) the canal capacity should be increased for the proper implementation of 9-day rotation, (iii) outlet structures should be maintained and repaired properly and (iv) strong and effective water users' group should be developed at each tertiary

Moududi (1991) conducted a study to evaluate the present pump operation schedule followed in the G-K project and to identify the technical and institutional problems. He concluded that most of years, the project water requirement was found to be more than the supply and comparatively higher water requirement was observed during the pre-monsoon (March to May) season. From the comparison, mismatches were observed which implies that the pump operation schedule has not been planned considering the field demand. The reasons for mismatches between the supply and project water requirement are scarcity of water, power failure and repair & maintenance of pumps during operation period.

In recent studies HR Wallingford and EPC (1994) the duty has been calculated as 1.73 l/s ha. The overall water use efficiencies during Kharif-I and Kharif-II of 1992 and Kharif-II of 1993 were 46%, 45% and 45% respectively. Although these levels of efficiencies are not uncommon in surface irrigation systems, they indicate that there is still scope for improvement in management of water distribution. On-farm water distribution by the WUAs remains unsatisfactory in many areas and individual, rather than collective action dominates the control of water allocation.

During the rehabilitation period (May 1991 to June 1994) a study was taken by HR Wallingford and EPC to analysis the performance of irrigation water delivery system of main canals using a set of indicators of performance developed by Molden and Gates (1990). The methodology provides estimates of water distribution adequacy, efficiency, dependability and equity. The overall adequacy and efficiency during Kharif-I and Kharif-II of 1992 and Khaerif-II of 1993 was 0.57, 0.55, 0.61 and 0.94, 0.82, 0.87 respectively. The overall equity and dependability during Kharif-I and Kharif-II of 1992 and Khaerif-II of 1993 was 0.72, 0.81, 0.65 and 0.66, 0.77, 0.63 respectively.

The efficiency term is not project water use efficiency but rather an indicator of how efficiently water was distributed with reference to the delivery schedule. The indicated average efficiencies of 82% to 94% reflect the fact that large areas of the project received inadequate supplies rather than that water use performance was exceptional.

METHODOLOGY

4.1 Introduction

The process of irrigation system performance assessment of evaluation consists of specifically measuring the extent to which goals are being met at the end of a given time, and thus requires that all relevant inputs and outputs are quantified or evaluated. To evaluate and compare the performance of irrigation systems, many researchers have proposed and used different performance indicators. Performance evaluation in this study was carried out using indicators suggested by Bos et al. (1993) which can be broadly classified into three groups: (1) hydraulic, (2) agricultural and (3) socio-economic. Hydraulic indicators deal with the capture, allocation and conveyance of water from the source to the fields. Agricultural indicators address the direct impact of operation inputs (water) on outputs (irrigated area and crop production). Socio-economic indicators deal with the impact of both operational and agricultural inputs on the viability and sustainability of irrigated agriculture.

4.2 Study Site

The field study was conducted in the Ganges –Kobadak Irrigation Project (GKIP), Phase-1 during the Kharif-I and Kharif-II seasons of 1999 to measure the various parameters for evaluation of the performance of irrigation water delivery system. Three secondary canals were randomly selected, two from Kushtia Main Canal (KMC) and another from Ganges Main Canal (GMC). The secondary canals, S₄K and S₅K, represent the middle reach of KMC and the secondary canal S₁G represents head reach of GMC. Two tertiary units of each of the two secondary canals (S₄K & S₅K) were selected such that they represent the head and middle reaches of the secondaries. Similarly two tertiary units were selected from S₁G such that they represent the head and tail reaches of secondary canal. The selected tertiaries are T₃ and T₉ of S₄K, T₂ and T₃ and S₅K and T₁A and T₂ of S₁G which are shown in Fig-4.1. The irrigable area of selected tertiary units are 99.00, 301.00, 100.00, 98.00, 606.00, and 30.00 hectares respectively.

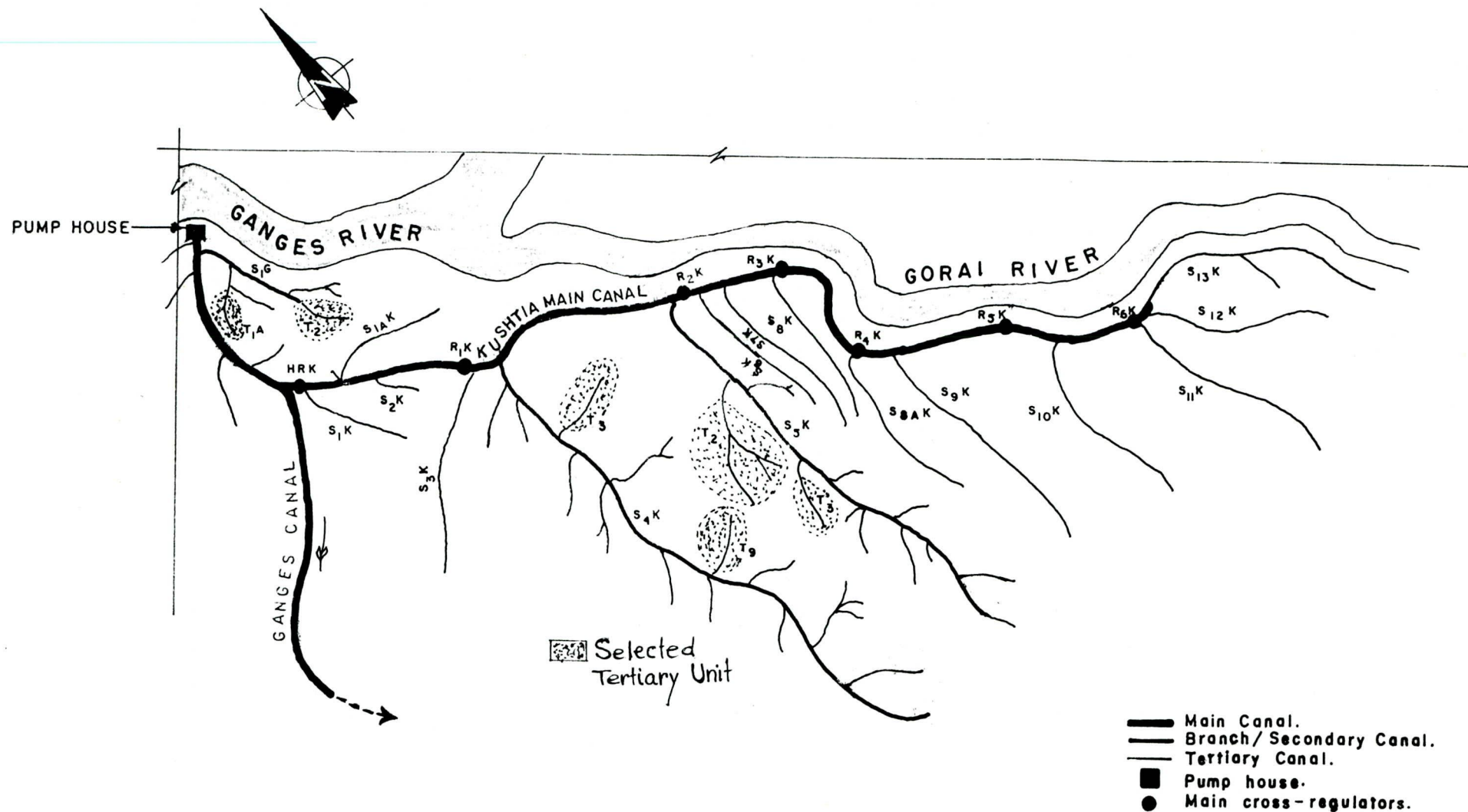


FIG. 4.1 SCHEMATIC DIAGRAM OF THE GANGES KOBADAK PROJECT (PHASE-I)
SHOWING SELECTED MAIN CANALS, SECONDARY CANALS AND TERTIARY UNITS.

4.3 Selected Performance Indicators

The definitions of the three types of indicators –hydraulic, agricultural and socioeconomic used in the performance evaluation of the irrigation water delivery system of G-K project are given below.

4.3.1 Hydraulic indicators

Hydraulic indicators deal with the lifting and conveyance of irrigation water from the source to the farmers' field by management of irrigation facilities. The hydraulic indicators used in the performance evaluation are adequacy, efficiency, predictability and equity.

Adequacy: The most comprehensive measure of adequacy proposed by Levine (1982), is Relative Water Supply (RWS), which is defined as:

$$RWS = \frac{\text{Irrigation} + \text{Effective Rainfall}}{\text{Evapotranspiration} + \text{Seepage \& Percolation}}$$

Adequacy needs to be measured over a time period for it to be effective as an indicator. For this study, a 10-day rotational period was considered as the time period.

Irrigation Efficiency (IE)

For evaluating system performance in terms of irrigation efficiency, the following equation (Bhuiyan, 1982) was used.

$$IE = \frac{ET + S \& P - R_e}{IR} \times 100$$

Where ET is the evapotranspiration requirement, S & P is the seepage and percolation requirement, IR is the irrigation water supply and R_e is the effective rainfall. IE was taken as unity when it exceeded unity.

Predictability:

The primary indicator used in this study for use in measuring predictability of water deliveries are concerned with the time of water delivery compared to the plan. This is express as:

$$\text{Dependability of Supply} = \frac{\text{Actual Duration of Water Delivery}}{\text{Planned Duration of Water Delivery}}$$

Equity:

Equity, related to water-delivery systems, can be defined as a delivery of a fair share of water to users throughout a system. Equity is the average spatial variability of the ratio of the amount delivered to the amount required over the time period of interest. This proposed measure is given as

$$P_E = \frac{1}{T} \sum_T CV_R \left(\frac{Q_D}{Q_R} \right)$$

Where,

P_E = Performance measure in terms of equity;

$CV_R (Q_D/Q_R)$ = spatial coefficient of variation of the ratio Q_D/Q_R over the region R. This measure describes the degree of variability in terms of water delivery from point to point over the region. The closer the value of the P_E is to zero, the greater the degree of equity (spatial uniformity) in delivery.

4.3.2 Agricultural Indicators

Agricultural indicators measure the contribution of the irrigation activity to the economy in relation to consumption of the increasingly scarce resource, water. These indicators provide the basis for comparison of irrigated agriculture performance. The main outputs (measured in terms of such aspects as area actually irrigated and crop production) of the major inputs (water, land and finances) in an irrigated agricultural system are directly reflected by these indicators.

The agricultural indicators used in the performance evaluation are irrigated area performance, cropping intensity performance, yield performance and production performance.

Irrigated Area Performance: This is the direct indicator, originally proposed by Zhi (1989), for the assessment of agricultural performance in respect of area irrigated. Where water is a limiting resource towards irrigation development, this indicator may be more important. The indicator is expressed as:

$$\text{Irrigated Area Performance} = \frac{\text{Actual Area}}{\text{Target Area}}$$

Another indicator as proposed by Zhi (1989) was used in assessing agricultural performance is:

$$\text{Cropping intensity Performance} = \frac{\text{Actual Cropping Intensity}}{\text{Target Cropping Intensity}}$$

Yield Performance: The indicator is expressed as:

$$\text{Yield Performance} = \frac{\text{Actual Yield}}{\text{Target Yield}}$$

In the present study potential yield was taken as target yield to evaluate yield performance.

Production Performance: This is the most useful agricultural indicator to evaluate irrigated agricultural systems in such countries like Bangladesh where both water and land are limiting resources towards irrigation development. The indicator is expressed as:

$$\text{Production Performance} = \frac{\text{Total Production}}{\text{Target Production}}$$

4.3.3 Socio-Economic Indicators

The socio-economic indicators relate to long-term impacts of pursuing a particular set of operational and agricultural strategies. The socio-economic indicators used in the performance evaluation are total financial viability, financial self-sufficiency, fee collection performance and sustainability of irrigated area.

Total Financial Viability: This indicator describes the overall financial viability of the irrigation system or irrigation agency. In recent years, there has been increasing concern over the level of recurrent costs required to keep irrigation systems functioning and substantial efforts have been made to raise revenues from water users to bear O&M costs and often some or all of the capital costs of irrigation systems. The indicator is defined as:

$$\text{Total Financial Viability} = \frac{\text{Actual O \& M Allocation}}{\text{Total O \& M Requirements}}$$

This indicator says nothing about where the O&M allocation comes from: it may be from government or user fees. A modified indicator as proposed by Bos et al. (1993) was also used in this study that looks at the extent to which a system generates sufficient income to be self-supporting. The indicator is defined as:

$$\text{Financial Self Sufficiency} = \frac{\text{Irrigation Agency Income}}{\text{Total O \& M Requirements}}$$

In our country the Government supports the entire cost of the management of the system including the maintenance cost and some charges are collected from the users (farmers) to cover part of the O&M cost but these are very negligible amount.

Fee Collection Performance: An indicator proposed by Svendsen (1992) was used to determine fee collection performance. The indicator is expressed as:

$$\text{Fee Collection Performance} = \frac{\text{Irrigation Fees Collected}}{\text{Irrigation Fees Due}}$$

4.4 Data Collection:

The data were collected from the selected sites through field measurement and observations and also from the organization responsible for water allocation. Frequent field visits, two per month, were made during the irrigation season, 1999 for data collection and monitoring purposes.

Flow Measurement

The flow of water in the selected tertiaries was measured for the period starting from the beginning of May to the middle of November 1999 for the seasons of Kharif-I and Kharif-II. Since off take structures of the selected tertiaries are not provided with measuring device, discharges were determined by taking stage reading and using a stage-discharge relationship. Stage-discharge relationship was developed by measuring the flow rates corresponding to water level from low to high for each canal. The flow rates were measured with the propeller type current meter (BFM001/LCD). Area-velocity method with one point velocity measurement taken at the depth of 0.6 from the water surface in the tertiary canal was applied for computing discharge. Staff gauges were installed at the off takes of the selected canals to record the water level. The water levels were recorded at 6-hour intervals. The stage-discharge relationships for the tertiary offtakes are shown in Appendix-A.

From the stage reading the actual duration of flow for each of the tertiary off takes during the Kharif-I and Kharif-II seasons of 1999 were calculated and presented in Appendix-B. The schedule and actual days of water delivery for each of the tertiary off takes during the two seasons are also presented in Appendix -C.

Pan Evaporation

The daily pan evaporation data as recorded at Amla station were collected from project office.

Seepage and Percolation (S&P) Loss

The average seepage & percolation (S&P) loss for the project was taken as 6 mm/day (BUET and BWDB, 1996).

Rainfall

The Kushtia and Bheramera rainfall stations of BWDB were selected to represent the rainfall in the study area. The location of these stations well represent of the present study area. Daily rainfall data were collected for these stations for the year 1999. The effective rainfall (R_e) was estimated from this rainfall data using water use-rainfall ratio method (Dastane, 1974). For this purpose, rainfall for consecutive 10-days period was accumulated. Evapotranspiration and seepage & percolation for the same 10 days were added together and compared with the 10-day period rainfall to compute effective rainfall as follows:

$$R_e = R, \text{ if } R < (ET + S\&P) \text{ and}$$

$$R_e = (ET + S\&P), \text{ if } R > (ET + S\&P)$$

Where,

R_e = effective rainfall for 10-days period in mm;

R = total amount of rainfall for 10-day period in mm;

ET = reference evapotranspiration for 10-day period in mm; and

$S\&P$ = seepage and percolation for 10-day period in mm.

The calculation of effective rainfall using water use-rainfall ratio method (Dastane, 1974) is very much conservative. Paddy storage is neglected. Rainfall for consecutive 10-days of the Kushtia and Bheramera rainfall stations of BWDB is also shown in Appendix -D.

Agricultural and Socio-economic data

The irrigated area under each selected tertiary unit during the seasons Kharif-I and Kharif-II of 1999 was determined from the records of Zilladers. The Zilladers record the irrigated areas by marking plots in the 'Mouza' map when irrigation water is supplied to these

plots. In recording the irrigated area, a plot was considered irrigated if it received irrigation water once or more during the season. The targeted area was taken from the report of "Crops and Irrigation Programme, 1998-99" of G-K Irrigation Project. Other data such as cropping intensity, actual and target yield, O&M requirement and allocation as well as irrigation fees due and collected were gathered from the project office. The relevant data is shown in Appendix -E

Chapter V

RESULTS AND DISCUSSION

The results and findings from the study during the Kharif-I and Kharif-II seasons, 1999 are presented in this chapter in the form of tables and figures. The hydraulic performance of selected tertiary units are discussed in Section 5.1 whereas agriculture and socio-economic performance of the irrigation system are discussed in Section 5.2.

5.1 Hydraulic Performance of the Selected Tertiary Units

5.1.1 Relative Water Supply (RWS):

Relative Water Supply (RWS) values for each 10-day rotational period were determined for all selected tertiary units during the Kharif-I and Kharif-II seasons of 1999 and are shown in Tables 5.1 and 5.2. The rotational RWS to the selected tertiary units varied from 0.29 to 5.26 with an average of 2.31 during Kharif-I season (Table 5.1). This wide variation in RWS values was mainly due to lack of control of flow. RWS values of the tertiary units of S_1G were found to be much higher than the RWS to other tertiary units. This resulted because the secondary canal S_1G is near the head of the system and had the opportunity of receiving water most of the times. The RWS did not vary significantly among the tertiary units of S_1G and S_4K . The average RWS of S_4K is much smaller than that of the S_5K though they are in the same reach of the main canal (KMC) showing an unequal distribution of water.

It can be seen from Table 5.2 that the average RWS values for most of the 1 tertiary units during Kharif-II season are relatively less (1.94) than that of Kharif-I season (2.31). This is mainly because the irrigated area of these tertiary units during Kharif-I are relatively less but the water supplies to these tertiary offtakes were not proportionately reduced.

Table 5.1: Relative Water Supply (RWS) of selected tertiary units during Kharif-I season of 1999

Rotation	S ₁ G		S ₄ K		S ₅ K	
	T ₁ A	T ₂	T ₃	T ₉	T ₂	T ₃
1	2.91	2.31	0.29	0.42	0.50	2.35
2	3.55	1.84	0.61	0.98	0.69	3.59
3	2.62	3.01	0.76	1.00	1.06	4.69
4	3.74	2.49	0.35	0.51	0.74	2.76
5	2.92	2.71	0.86	0.97	1.31	5.13
6	5.26	5.19	1.01	1.42	1.47	4.50
7	2.42	2.38	1.21	1.27	1.44	5.02
8	4.59	4.27	1.14	1.61	1.53	5.37
9	3.86	4.61	1.08	1.31	1.23	3.77
Average	3.54	3.20	0.81	1.05	1.11	4.13
	3.37		0.93		2.62	
	2.31					

Table 5.2: Relative Water Supply (RWS) of selected tertiary units during Kharif-II season of 1999

Rotation	S ₁ G		S ₄ K		S ₅ K	
	T ₁ A	T ₂	T ₃	T ₉	T ₂	T ₃
1	3.19	3.10	0.76	0.83	1.11	1.75
2	4.39	4.78	1.33	1.68	1.33	2.61
3	4.84	3.51	1.19	1.30	0.86	8.16
4	1.53	0.99	0.67	1.29	0.52	5.13
5	2.49	2.17	0.94	1.41	0.87	2.58
6	1.59	1.48	1.00	1.36	1.07	1.00
7	2.05	1.81	1.65	1.26	0.76	3.72
8	2.53	2.25	1.81	1.56	1.05	3.94
9	1.17	0.92	0.38	0.76	0.42	4.45
10	1.94	1.29	0.04	1.26	0.19	4.12
Average	2.57	2.23	0.98	1.27	0.82	3.75
	2.40		1.13		2.28	
	1.94					

5.1.2 Irrigation Efficiency

Efficiency values of different tertiary units during Kharif-I and Kharif-II season, 1999 are presented in the Tables 5.3 and 5.4 respectively. It can be seen from the Table 5.3 that the average seasonal irrigation efficiency of the selected tertiary units varied from 11% to 59%. The low efficiency of the tertiary units is due to misuse of irrigation water and poor water control. Sometimes it is observed that rainfall was enough to meet the demand of crop water requirement but still pump was not stopped.

From table 5.4 it can be seen that during the Kharif-II season there has been a slight improvement in the performance in terms of efficiency compared the Kharif-I season.

5.1.3 Coefficient of variation of RWS

The coefficient of variation of relative water supply to different selected tertiary units during Kharif-I and Kharif-II seasons are presented in Tables 5.5 and 5.6. It is seen from these tables that the values varied from 0.01 to 0.68 for Kharif-I and 0.01 to 95 for Kharif-II season. It is evident that the equity in water distribution to the selected secondary canals was found to be more or less same during both the seasons. The equity in water distribution among the tertiary units of S₅K was not as good as equity in water distribution of S₁G and S₄K. This was because the delivery was not made proportional to the command area among the tertiary units of S₅K.

Table 5.3: Irrigation Efficiency (%) in the selected tertiary units during Kharif-I season of 1999

Rotation	Name of Tertiary					
	T ₁ A/S ₁ G	T ₂ /S ₁ G	T ₃ /S ₄ K	T ₉ /S ₄ K	T ₂ /S ₅ K	T ₃ /S ₅ K
1	25	32	100	100	100	38
2	10	26	100	100	100	18
3	0	0	100	100	84	8
4	27	40	100	100	100	32
5	34	57	100	100	51	7
6	0	0	0	0	0	0
7	0	0	33	27	19	2
8	0	0	0	0	0	0
9	0	0	0	0	0	0
Average	11	17	59	59	50	12
	14		59		31	
	35					

Table 5.4: Irrigation Efficiency (%) (P_F) in the selected tertiary units during Kharif-II season of 1999

Rotation	Name of Tertiary					
	T ₁ A/S ₁ G	T ₂ /S ₁ G	T ₃ /S ₄ K	T ₉ /S ₄ K	T ₂ /S ₅ K	T ₃ /S ₅ K
1	19	19	100	100	80	37
2	0	0	0	0	0	0
3	5	8	62	50	100	4
4	61	100	100	69	100	13
5	3	4	100	39	100	14
6	0	0	0	0	0	0
7	0	0	31	53	100	1
8	0	0	0	0	0	0
9	85	100	100	100	100	17
10	52	77	100	79	100	24
Average	25	34	66	54	76	13
	30		60		45	
	45					

Table 5.5: Coefficient of variation of RWS in the selected tertiary units during Kharif-I season of 1999

Rotation	Name of canal					
	S ₁ G		S ₄ K		S ₅ K	
	T ₁ A	T ₂	T ₃	T ₉	T ₂	T ₃
1	0.11		0.19		0.65	
2	0.32		0.23		0.68	
3	0.07		0.14		0.63	
4	0.20		0.18		0.58	
5	0.04		0.06		0.59	
6	0.01		0.17		0.51	
7	0.01		0.03		0.55	
8	0.04		0.17		0.56	
9	0.09		0.10		0.51	
Average	0.10		0.14		0.58	
Overall	0.65					

Table 5.6: Coefficient of variation of RWS in the selected tertiary units during Kharif-II season of 1999

Rotation	Name of canal					
	S ₁ G		S ₄ K		S ₅ K	
	T ₁ A	T ₂	T ₃	T ₉	T ₂	T ₃
1	0.01		0.04		0.22	
2	0.04		0.12		0.32	
3	0.16		0.04		0.81	
4	0.21		0.32		0.82	
5	0.07		0.20		0.50	
6	0.04		0.15		0.03	
7	0.06		0.13		0.66	
8	0.06		0.07		0.58	
9	0.12		0.13		0.93	
10	0.20		0.95		0.91	
Average	0.10		0.22		0.58	
Overall	0.63					

5.1.4 Dependability

Dependability of supply to the selected tertiary units are presented in Tables 5.7 and 5.8. It can be seen from these tables that the dependability of supply to different tertiary units varied from 0.79 to 1.43 during Kharif-I season and from 0.45 to 1.61 during Kharif-II season. The average values of dependability for S₁G, S₄K and S₅K are 1.38, 0.88 and 1.34 for Kharif-I and 1.60, 0.65 and 1.34 for Kharif-II seasons respectively. From these tables it is seen that S₁G canal received more water than planned during both the seasons and S₅K canal received more water than planned during Kharif-I. S₄K canal received water for less than the actual schedule during both the seasons. This reflects the facts the actual delivery do not follow the schedule. Delivery schedules are primarily prepared on the basis of previous year's experience and no quantified estimate of water required was made. Due to loose management, the actual sharing of water deviated widely from the official scheduling, as a result of the dominant position of some farmers or uncontrolled extension of irrigated area.

Table 5.7: Ratio of actual to planned duration of water supply in the selected tertiary units during Kharif-I season of 1999

Name of canal					
S ₁ G		S ₄ K		S ₅ K	
T ₁ A	T ₂	T ₃	T ₉	T ₂	T ₃
1.43	1.33	0.79	0.98	1.41	1.26
1.38		0.88		1. 34	
1.20					

Table 5.8: Ratio of actual to planned duration of water supply in the selected tertiary units during Kharif-II season of 1999

Name of canal					
S ₁ G		S ₄ K		S ₅ K	
T ₁ A	T ₂	T ₃	T ₉	T ₂	T ₃
1.61	1.59	0.45	0.85	1.07	0.81
1.60		0.65		0.94	
1.06					

It can be seen from Tables 5.1 to 5.8 that the system performed well in terms of adequacy (2.31 for Kharif-I and 1.94 for Kharif-II) and dependability (1.20 for Kharif-I and 1.06 for Kharif-II) but the performance of the system in terms of efficiency (35% for Kharif-I and 45% for Kharif-II), equity (0.65 for Kharif-I and 0.63 for Kharif-II) was not satisfactory.

The average RWS value during Kharif-II season, 1999 was higher than that of previous studies that conducted by Nath (1989) and HR Wallingford and EPC (1995). Nath (1989) calculated an average RWS value 1.12 during Kharif-II season of 1989 and HR Wallingford and EPC (1995) calculated an overall adequacy value 0.57, 0.55 and 0.61 during Kharif-I and Kharif-II season of 1992 and Kharif-II season of 1993. But efficiency of the system during Kharif-I and Kharif-II season of 1992 and Kharif-II season of 1993 was higher than that of the Kharif-I and Kharif-II season of 1999. These reflect the fact that the quality of water control in the system has been deteriorated in the years.

5.2 Agricultural and Socio-economic Performance

5.2.1 Agricultural Performance

Basic data required for agricultural and socio-economic performance evaluation are shown in Table 5.9. Irrigated Area Performance during the seasons Kharif-I and Kharif-II are presented in Table 5.10. It can be seen from this table that Irrigated Area Performance in Kharif-II season was quite satisfactory (1.00) but in Kharif-I season this was not (0.67). During the Kharif-I season the water delivery could not be made to a substantial portion of the targeted area due to inadequate head. In fact, targeted irrigation coverage is determined each season without due consideration of the available water resources and no estimates of water requirements was made.

From Table 5.10 it is seen that the cropping intensity performance during the year 1998-99 was 0.995, which is satisfactory.

From Table 5.10 it is seen that the production performance was 0.78 and 0.89 for Kharif-I and Kharif-II seasons respectively. The production performance during the season Kharif-I

was not satisfactory because of the fact that some targeted area was not irrigated due to unavailability of irrigation water.

It is also seen from Table 5.9 that yield performance was 0.89 and 0.74 for Kharif-I and Kharif-II seasons. The yield performance during the Kharif-I season was more or less satisfactory but this value for Kharif-II season was not satisfactory. During the Kharif-II season supplementary irrigation could not be provided to the tail end of some secondary canal due to poor condition of canals.

5.2.2 Socio-Economic Performance

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Total O&M requirement for G-K Irrigation Project was Tk.225.00 lac, whereas actual O&M allocation by Government/Board was only Tk.123.75 lac and irrigation agency income i.e. irrigation taxes collected from water users was only Tk.0.48 lac for the financial year 1999-2000. Hence total financial viability and financial self-sufficiency for the project were 0.55 and 0.002 respectively. Financial self-sufficiency was very poor and total financial viability was also not satisfactory. To keep irrigation system functioning O&M allocation must be increased and at the same time emphasis must be given on increasing water tax recovery.

The irrigation fees due (assessed) were determined from multiplication of irrigation water charge per hectare and command area. The assessment of water rate was fixed per acre. For G-K project, the following rates were fixed:

- (i) Tk.100 per acre for the Kharif-II season,
- (ii) Tk.150 per acre for the Rabi season, and
- (iii) Tk.250 per acre for the Kharif-I season.

The irrigation tax collected during the financial year 1999-2000 was only 0.48 lac whereas assessment was 58.00 lac. So, the Fee Collection Performance is only 0.008.

This performance is very poor as the collection rate was very low. Water Users Associations (WUAs) is responsible for collecting this charge. It has been reported that committee members themselves did not pay the charges and hence they did not have moral courage to ask others to pay the tax. Many users continue to regard surface water as a free resource. Sometimes politicians encourage them not to pay irrigation taxes and assure

them to waive the taxes. Collection of water rates is an important factor to improve water use performance. Without adequate recovery of operation cost, the future of the project will be uncertain.

Table 5.10: Agricultural and Socio-economic Performance of G-K project in Kharif-I and Kharif-II seasons of 1999

Performance Indicators		Kharif-I	Kharif-II
Agricultural performance	Irrigated area performance	0.67	1.00
	Cropping intensity performance	0.995	
	Production performance	0.78	0.89
	Yield performance	0.89	0.74
Socio-Economic performance	Total financial viability	0.55	
	Financial self sufficiency	0.002	
	Fee collection performance	0.008	

Chapter VI

CONCLUSIONS & RECOMMENDATIONS

6.1 Conclusions

The following conclusions can be made from the present study.

6.1.1 Performance Measures

The methodologies for the performance evaluation of irrigation water delivery system developed and proposed by different authors have been critically reviewed. There is a wide variation of definitions of some indicators from one author to another. The terminology used in different indicators are not clearly defined, but only conceptualized. It is therefore desirable that the performance evaluation is carried out in a manner that is understandable to others and using accepted terminology and explaining the procedures followed.

Importance should be given on the use of some performance standard to compare the measured performance but no standard values are given for different indicators. Most of the indicators cannot be used for the performance measures due to unavailability of required data.

6.1.2 Hydraulic Performance

There is a wide variation of RWS among the tertiary units (0.29 to 5.26 during Kharif-I and 0.04 to 8.16 during Kharif-II) and also among the secondary canals (0.93 to 3.37 during Kharif-I and 1.13 to 2.4 during Kharif-II).

The coefficient of variation of RWS from head to tail was significant (0.10 to 0.58). The tertiary units near the head of the system always received more water than the tail.

The average seasonal irrigation efficiency also varied from low to high (11% to 66%). Dependability of supply reflects the fact that actual delivery did not follow the schedule and most of the selected tertiary units received water greater number of days than programmed.

Overall, the system performed poor in terms of efficiency and equity but it performed well in terms of adequacy and dependability of supply. However, there has been slight

The control of water at different level was found very poor. Almost every selected canal was found to receive water deliveries for greater number of days than programmed. The daily flow rates in the selected canals were too much fluctuating. The conditions of most outlet structures and their gates were found to be very poor. Some of the off take structures have no gate at all, some have shutters only but no steering wheel to operate them. Moreover, there are no tertiary outlet structures to distribute the water from the tertiary canals to the farm.

6.1.3 Agricultural and Socio-economic Performance

Irrigated area performance and production performance were quite good during the Kharif-II season but these were not satisfactory during the Kharif-I season. Yield performance was satisfactory during the Kharif-I season but it was not satisfactory during Kharif-II. Cropping intensity performance was found satisfactory.

Economic performance such as total financial viability, financial self-sufficiency and fee collection performance was very poor.

6.2 Recommendations for Future Studies

The following recommendation can be made for future studies: -

Performance evaluation has been carried out by taking a sample of only eight tertiary canals of three secondary canals. It is very difficult to draw general conclusions based on the results of only eight tertiary canals. Therefore, performance evaluation should be done taking more representative areas.

Recently a project has undergone a major rehabilitation but no study has been taken to assess the impact of rehabilitation on the project performance. Therefore, a study focusing on the comparison of the pre-rehabilitation situation with post-rehabilitation situation should be conducted.

The present operational schedule is not geared to take full advantage of rainfall during the monsoon. A computer aided water management INCA (Irrigation Network Control and

utilization of rainfall is recommended.

At present the irrigation flow drains to the river causing a considerable loss of pumped water.

Therefore, studies on developing suitable mechanism for reutilization of drainage water or excess rainwater during monsoon is suggested.

A large number of performance indicators have been proposed and many of the indicators are not applicable due to nonavailability of data. Therefore, a study should be taken to establish a minimum set of indicators, which fully describe the performance.

Some performance standards for the different indicators are needed to be established so that the measured performance can be compared with the standard performance and measured performance can be quantified accordingly.

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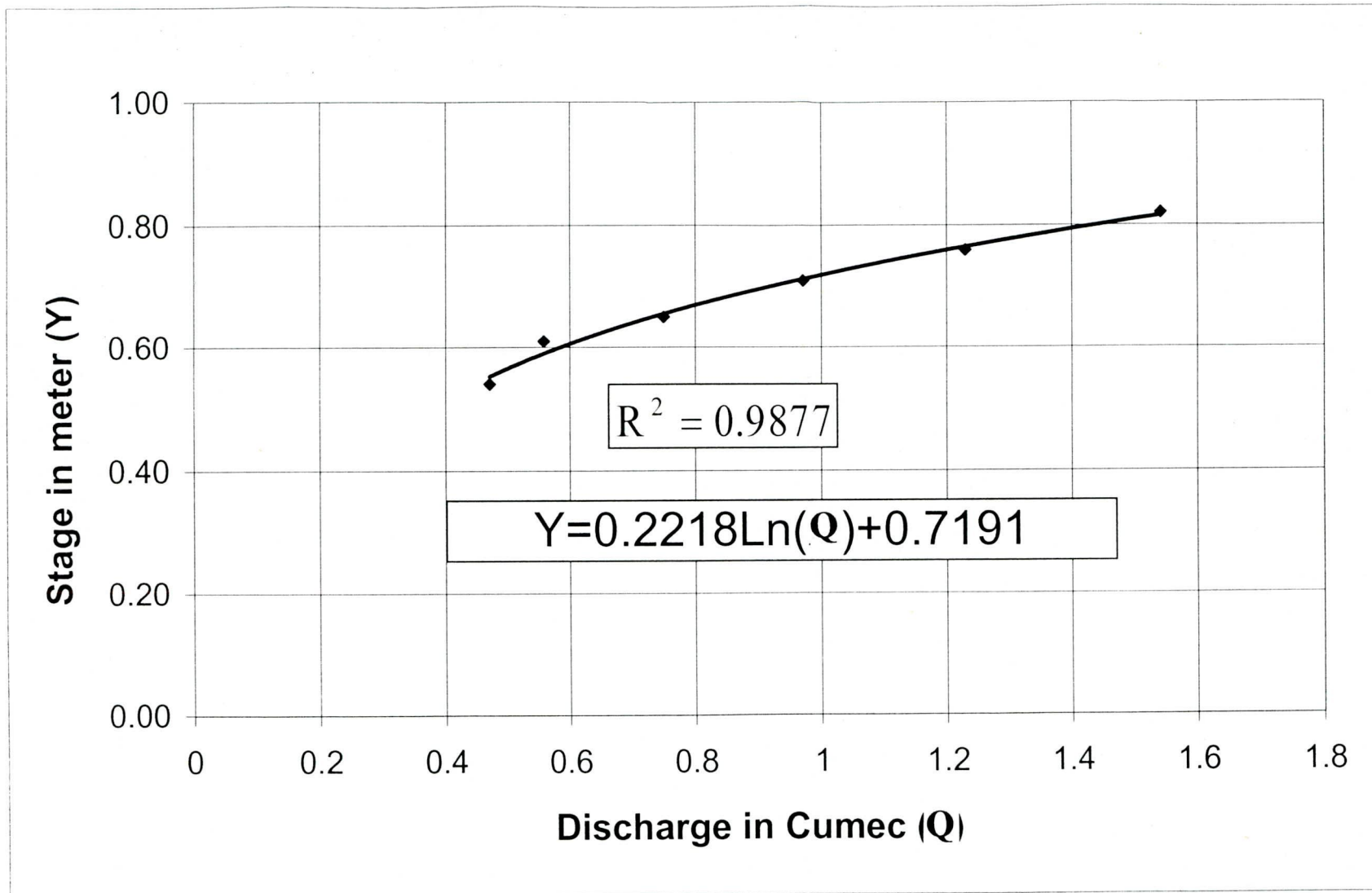
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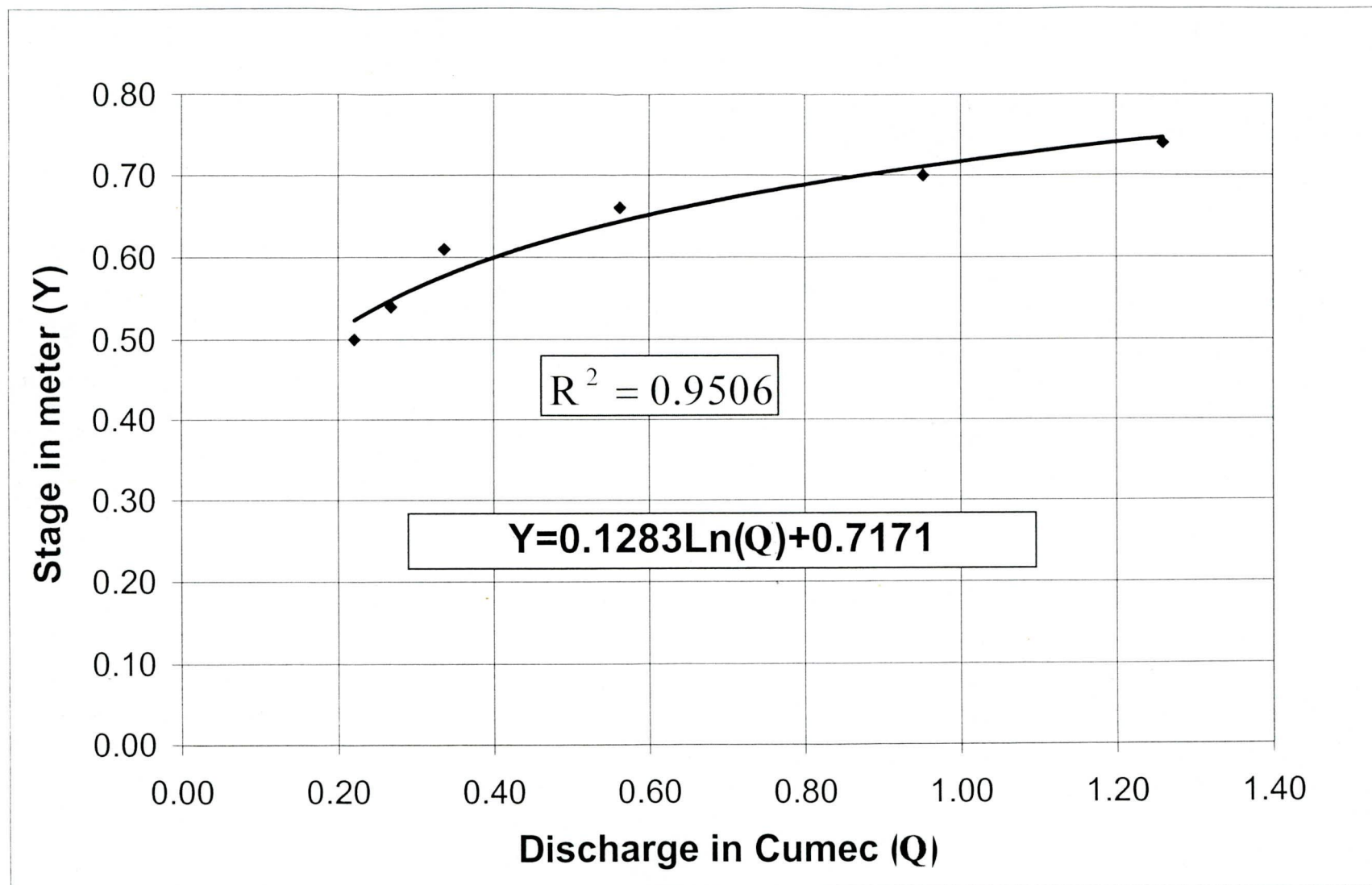
Fig. 3.3: Different reaches of main canal of Ganges-Kobadak Irrigation Project

APPENDIX A

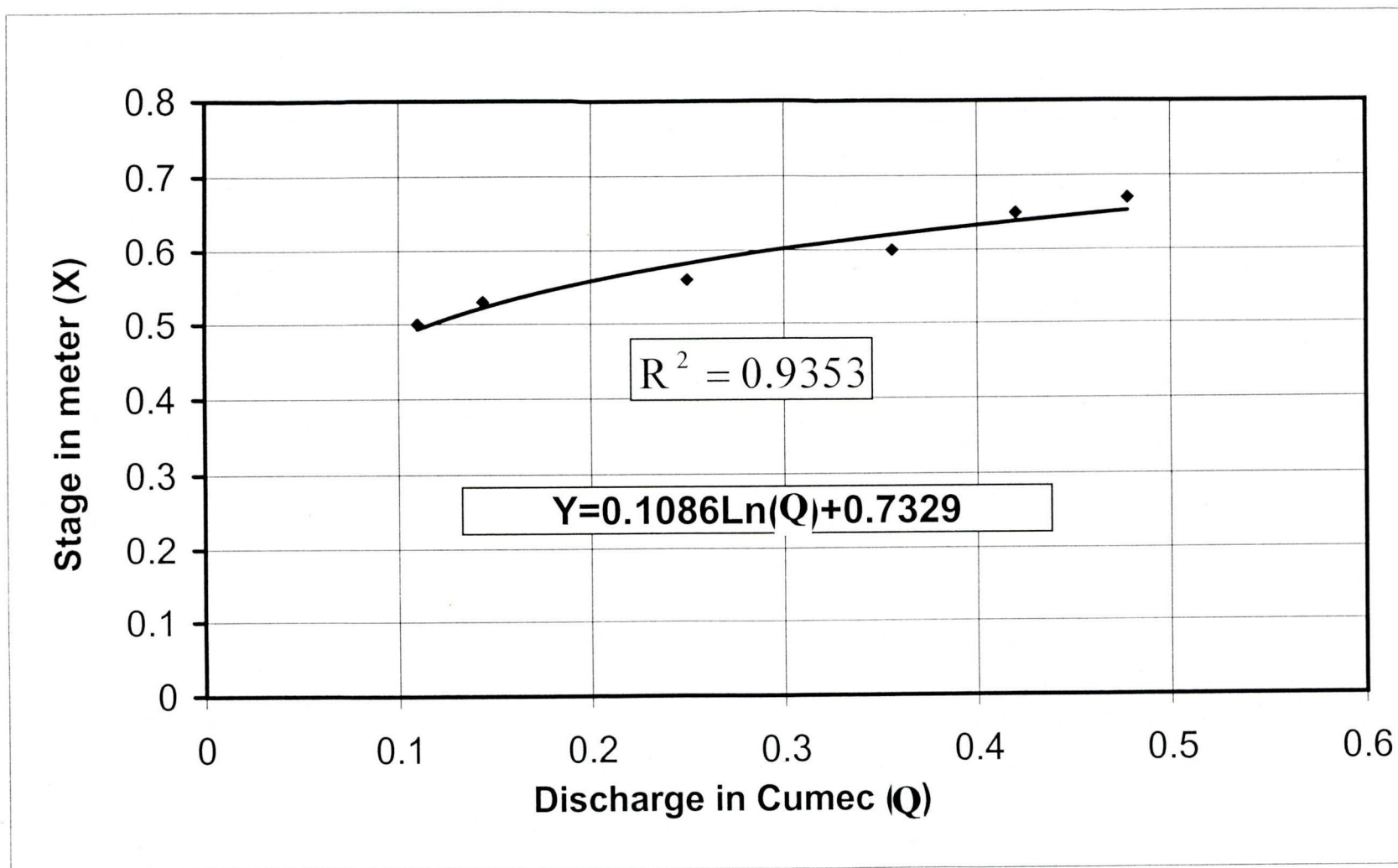
Stage-Discharge relationship developed for the selected tertiary offtake of G-K project.



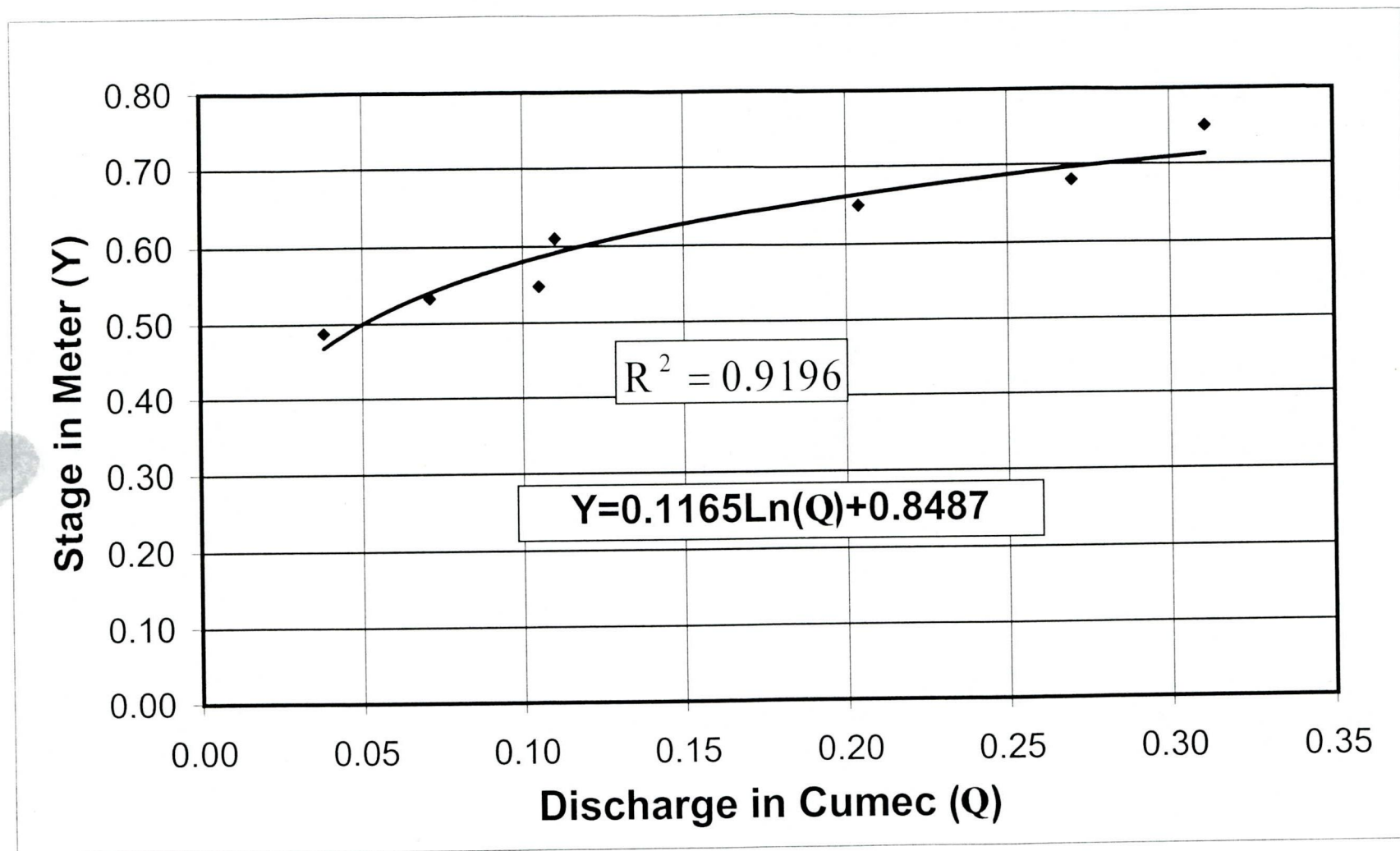
FigA-1 Stage-Discharge Relationship developed for the selected tertiary of T₁A/S₁G



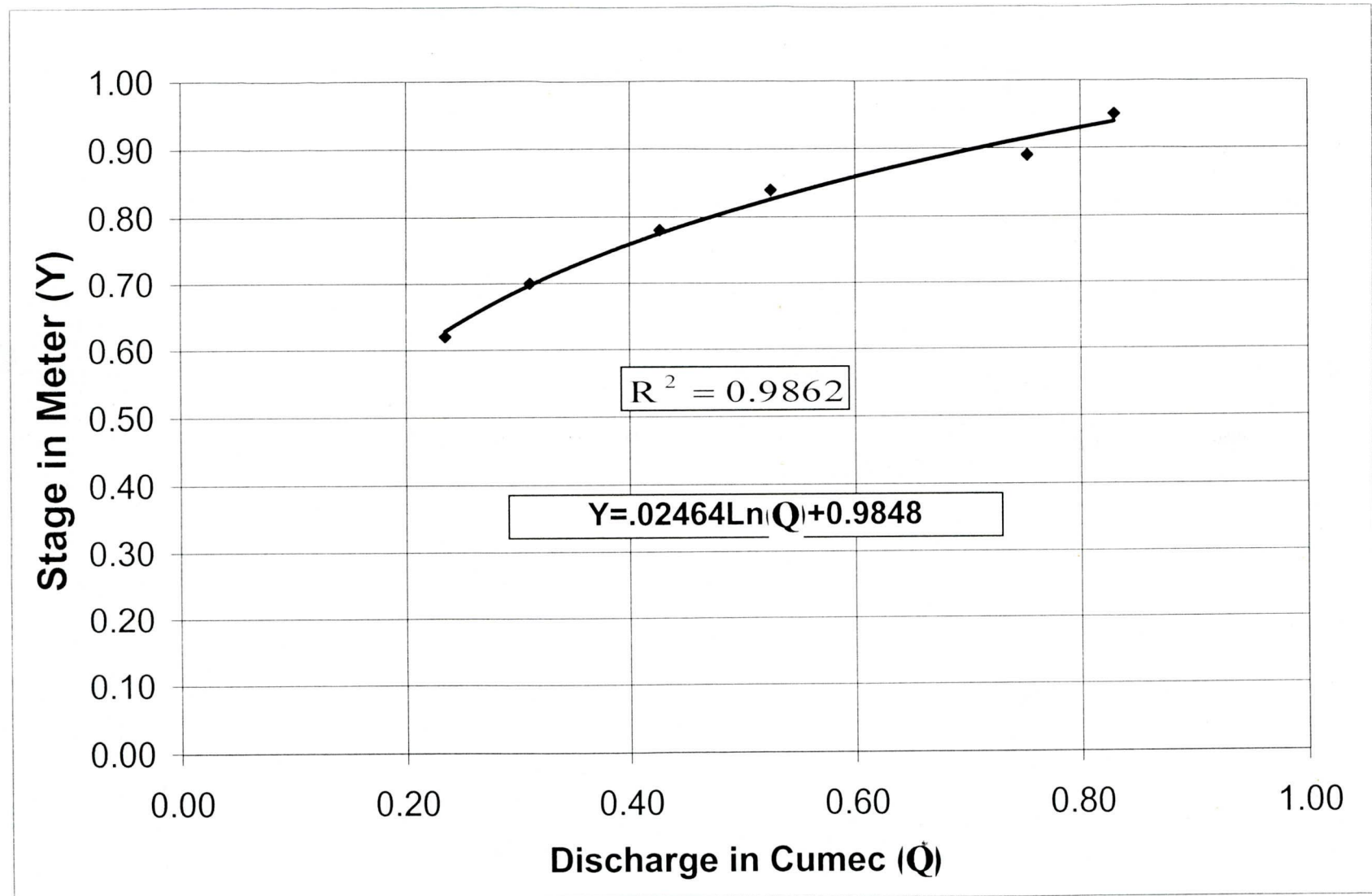
FigA-2 Stage-Discharge Relationship developed for the selected tertiary of T₂/S₁G



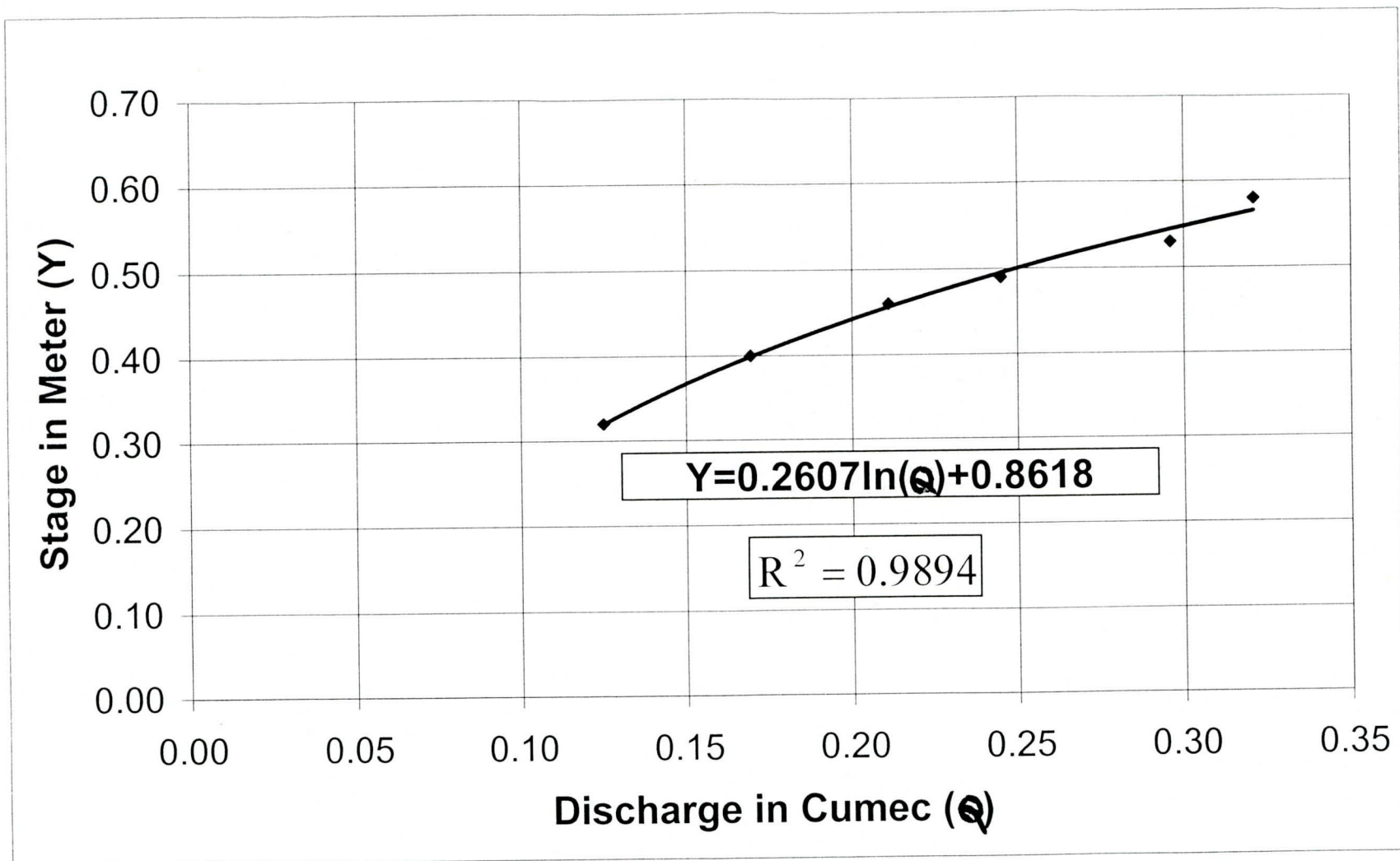
FigA-3 Stage-Discharge Relationship developed for the selected tertiary of T₃/S₄K



FigA-4 Stage-Discharge Relationship developed for the selected tertiary of T₉/S₄K



FigA-5 Stage-Discharge Relationship developed for the selected tertiary of T₂/S₅K



FigA-6 Stage-Discharge Relationship developed for the selected tertiary of T₃/S₅K

APPENDIX B

Flow rate variation in selected tertiary units during Kharif-I and Kharif-II seasons of 1999.

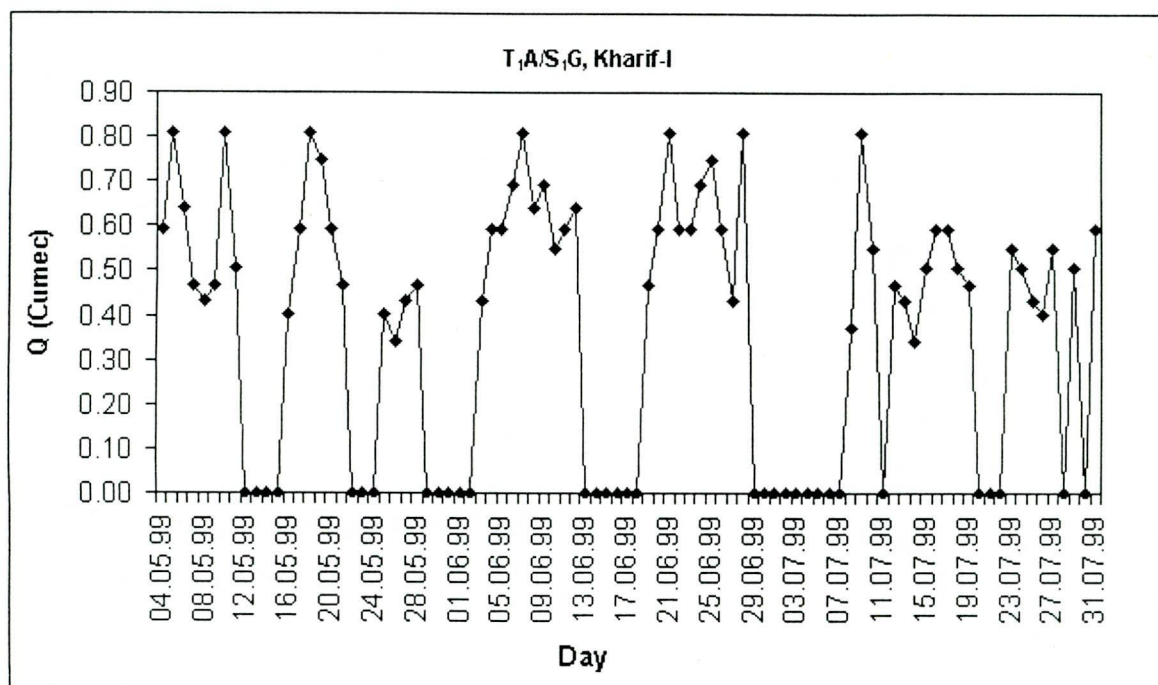


Fig. B-1: Flow rate variation in selected tertiary units of T₁A/S₁G during Kharif-I season of 1999

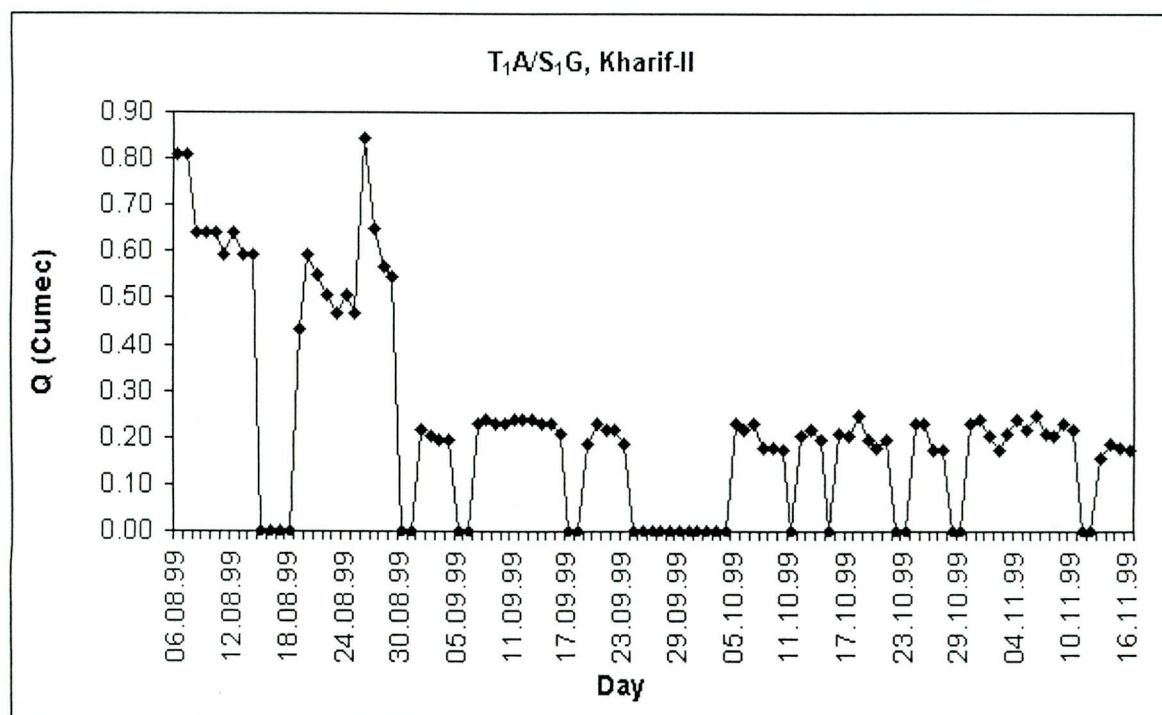


Fig. B-2: Flow rate variation in selected tertiary units of T₁A/S₁G during Kharif-II season of 1999

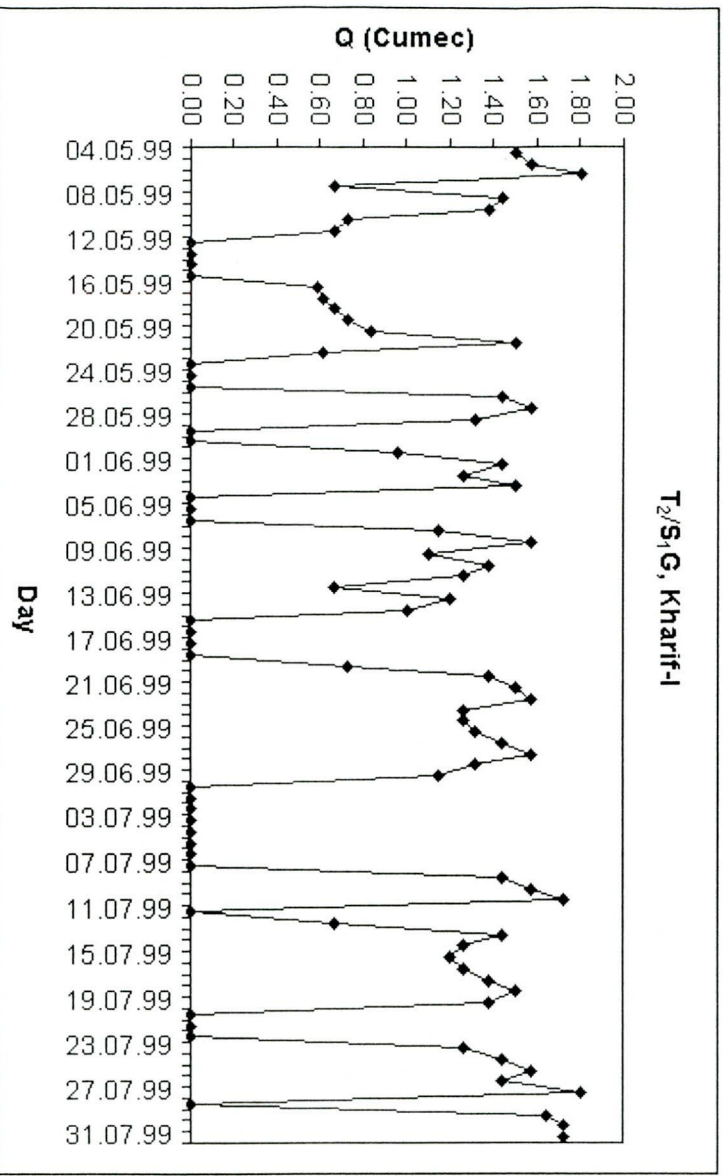


Fig. B-3: Flow rate variation in selected tertiary units of T₂/S₁G during Kharif-I season of 1999

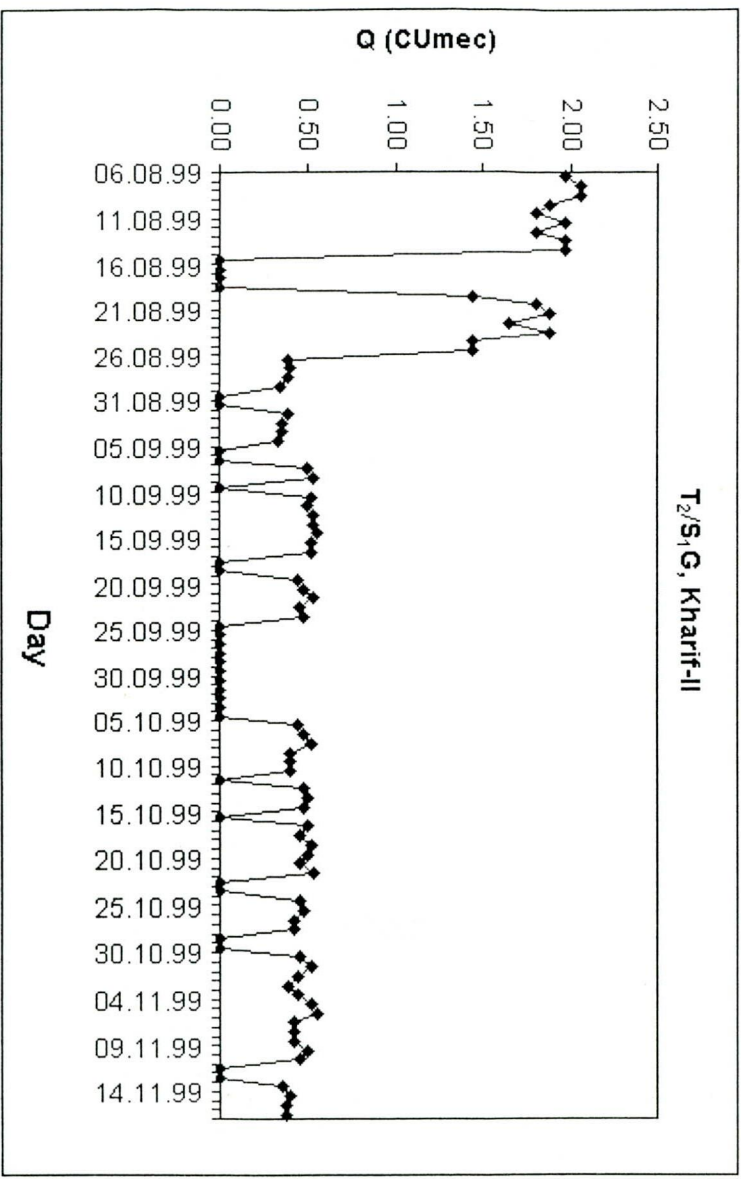


Fig. B-4: Flow rate variation in selected tertiary units of T₂/S₁G during Kharif-II season of 1999

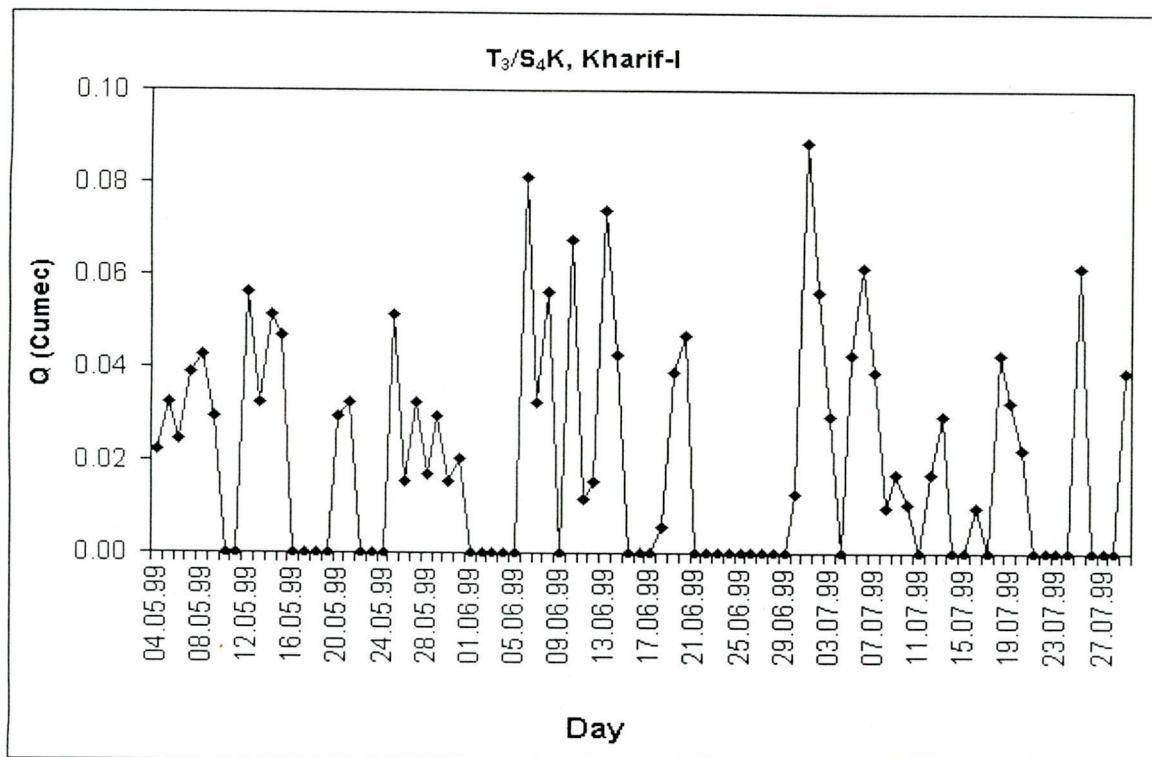


Fig. B-5: Flow rate variation in selected tertiary units of T₃/S₄K during Kharif-I season of 1999

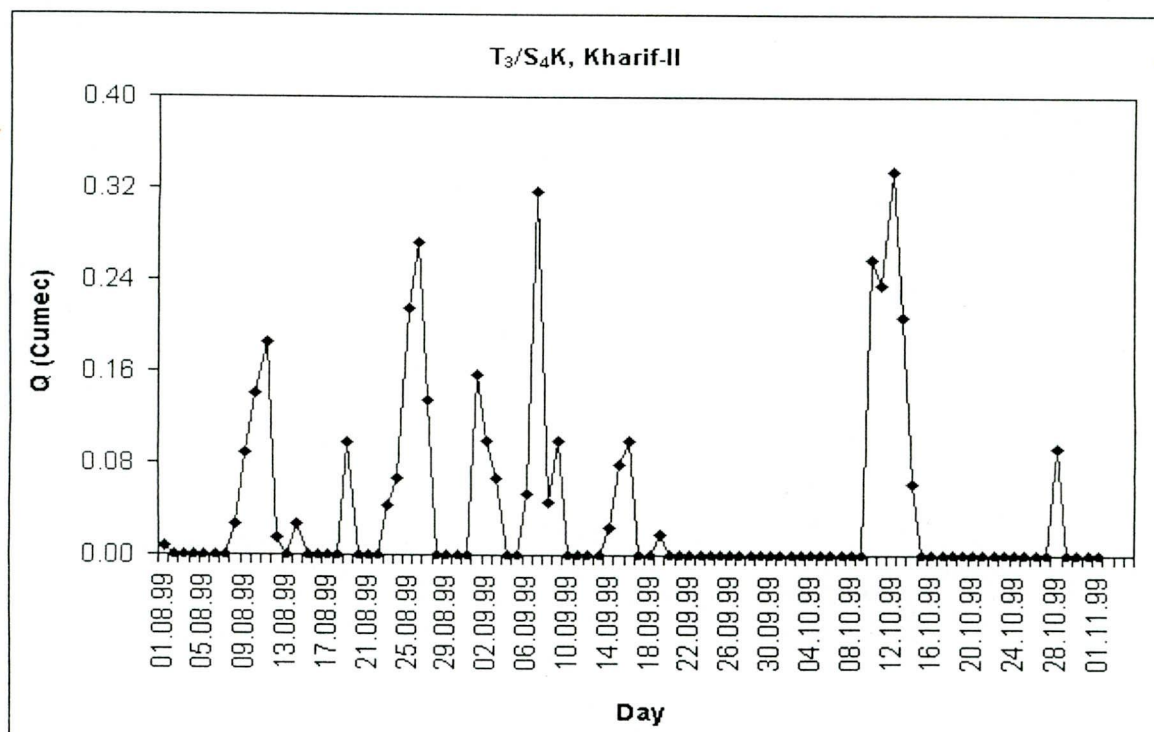


Fig. B-6: Flow rate variation in selected tertiary units of T₃/S₄K during Kharif-II season of 1999

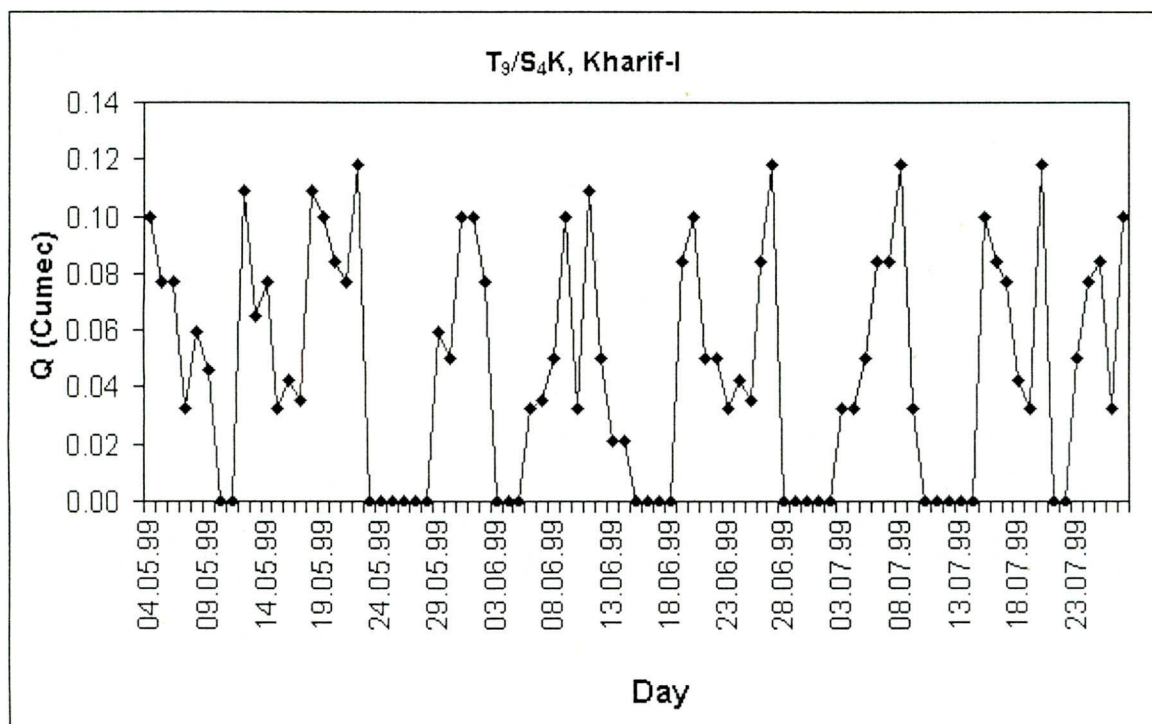


Fig. B-7: Flow rate variation in selected tertiary units of T₉/S₄K during Kharif-I season of 1999

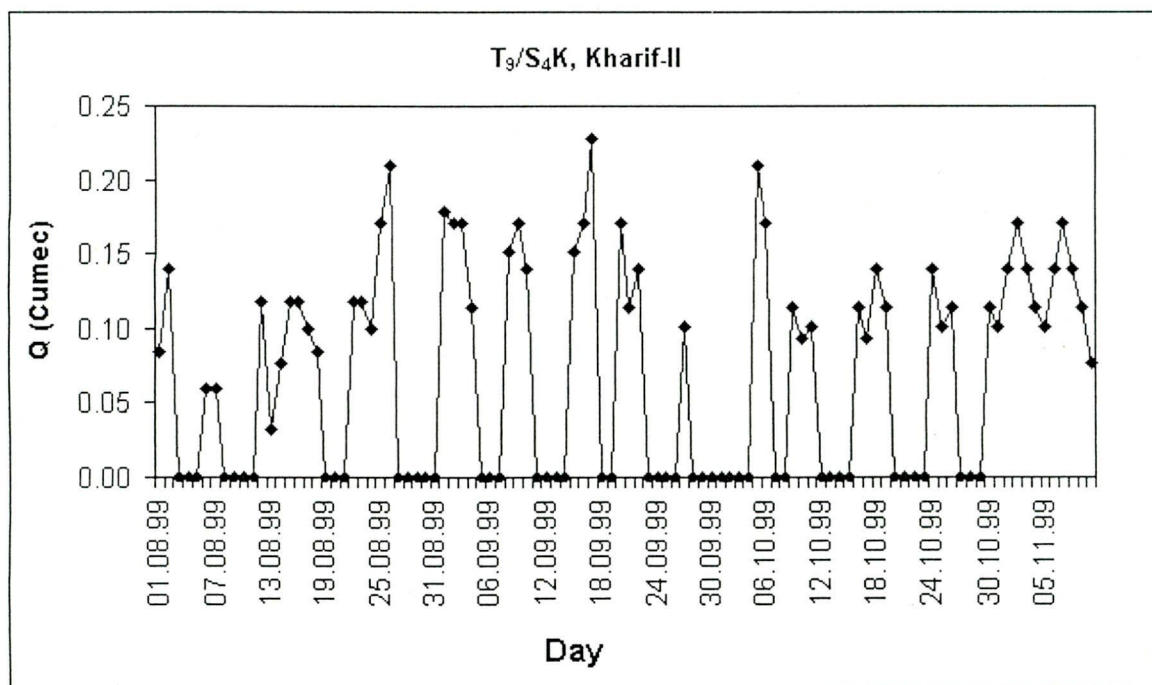


Fig. B-8: Flow rate variation in selected tertiary units of T₉/S₄K during Kharif-II season of 1999

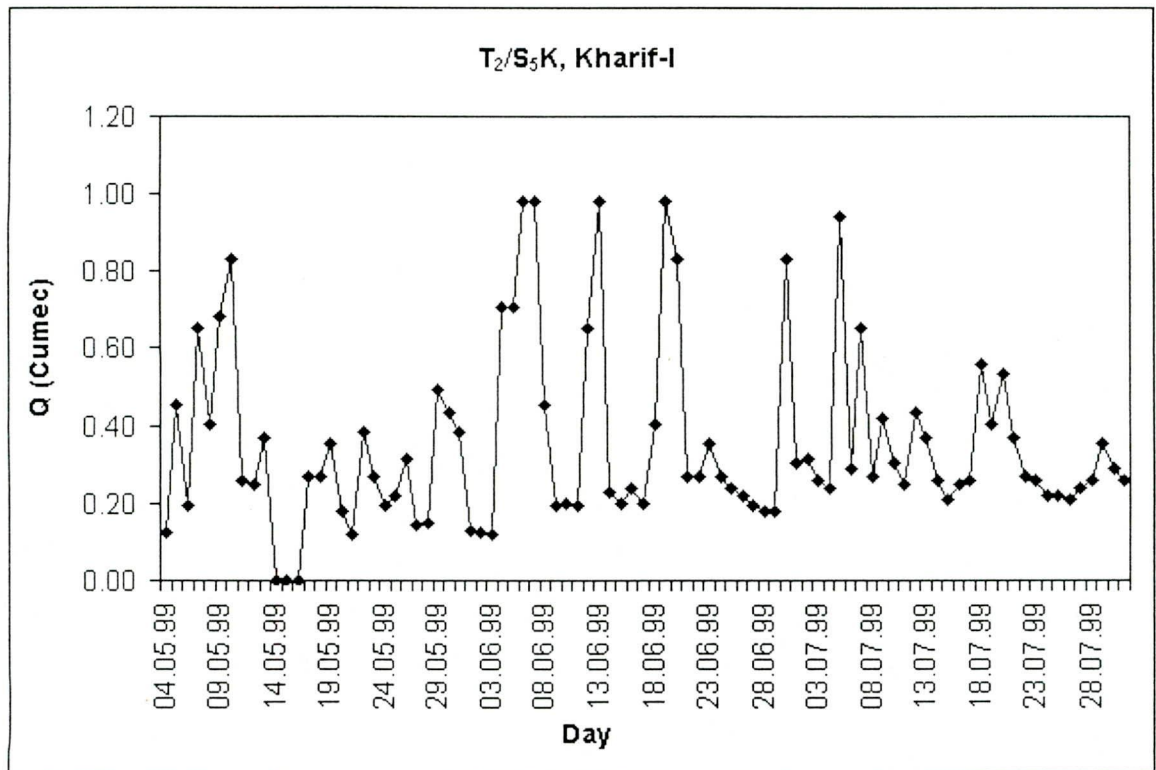


Fig. B-9: Flow rate variation in selected tertiary units of T₂/S₅K during Kharif-I season of 1999

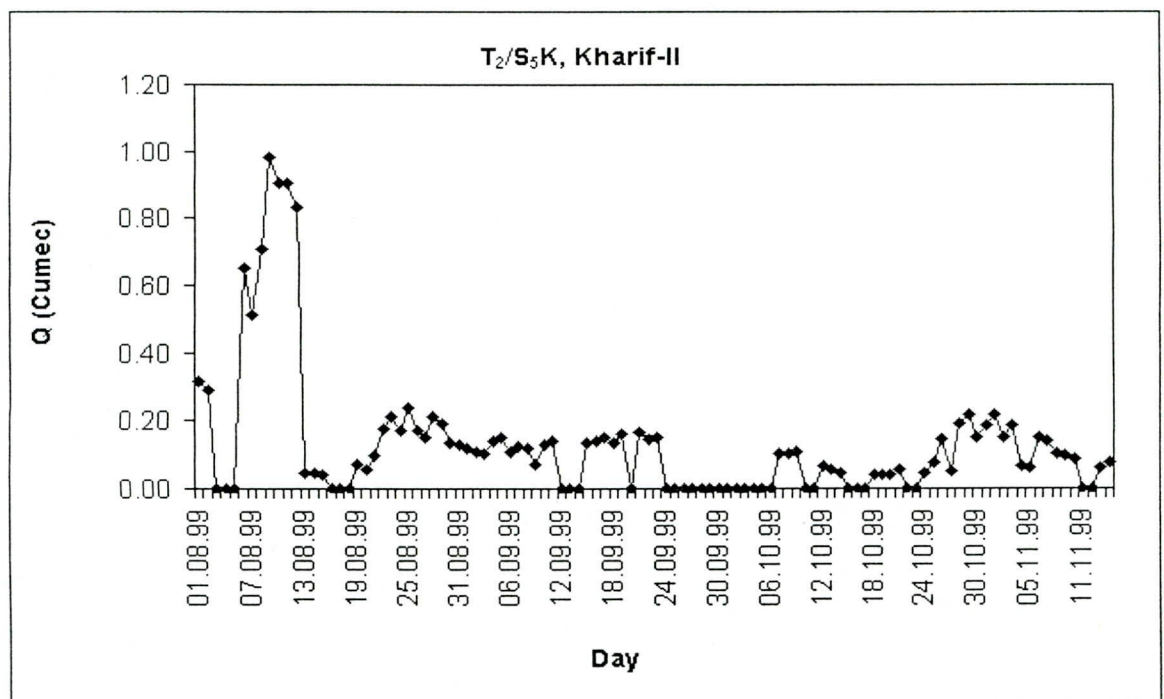


Fig. B-10: Flow rate variation in selected tertiary units of T₂/S₅K during Kharif-II season of 1999

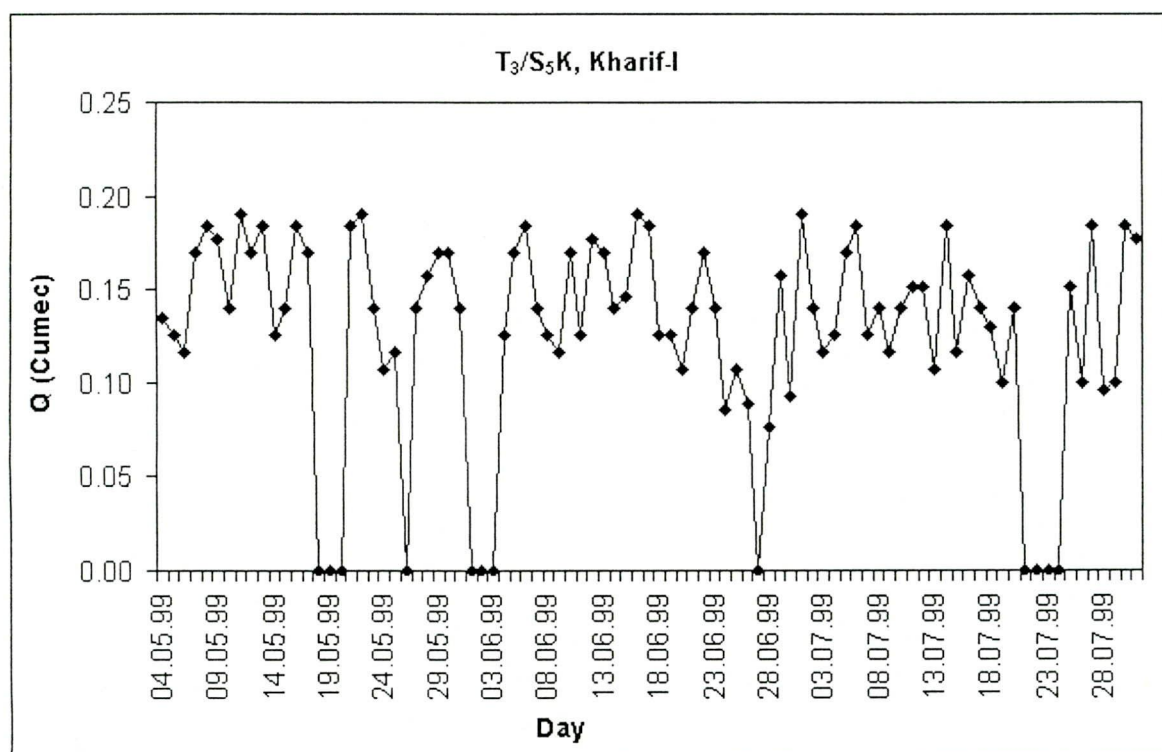


Fig. B-11: Flow rate variation in selected tertiary units of T₃/S₅K during Kharif-I season of 1999

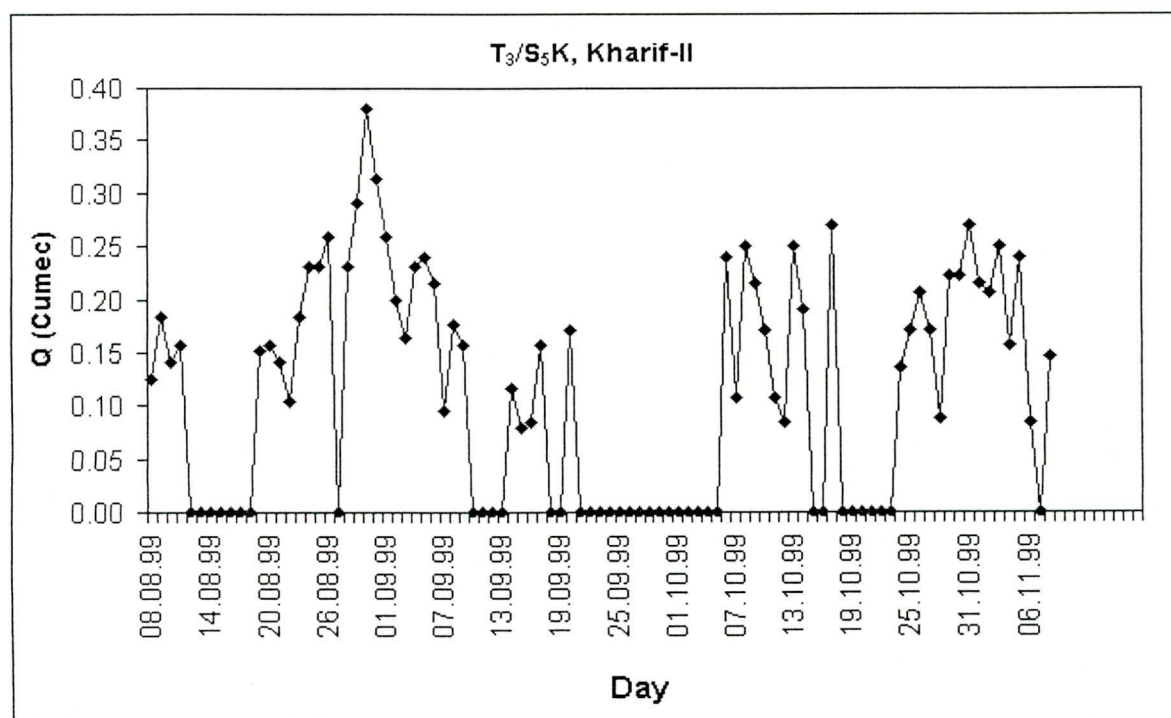


Fig. B-12: Flow rate variation in selected tertiary units of T₃/S₅K during Kharif-II season of 1999

APPENDIX C

Schematic diagram showing schedule and actual water delivery of selected tertiary units during Kharif-I and Kharif-II seasons of 1999.

TIME	PROGRAM	DAYS										
		DAY1	DAY2	DAY3	DAY4	DAY5	DAY6	DAY7	DAY8	DAY9	DAY10	DAY11
1/5/99 to 10/5/99	Schedule Actual											
11/5/99 to 20/5/99	Schedule Actual											
21/5/99 to 31/5/99	Schedule Actual											
1/6/99 to 10/6/99	Schedule Actual											
11/6/99 to 20/6/99	Schedule Actual											
21/6/99 to 30/6/99	Schedule Actual											
1/7/99 to 10/7/99	Schedule Actual											
11/7/99 to 20/7/99	Schedule Actual											
21/7/99 to 31/7/99	Schedule Actual											

Fig. C-1: Schemetic diagram showing scheduled and actual days of water delivery for T₁A/S₁G canal during Kharif-I,1999

TIME	PROGRAM	DAYS										
		DAY1	DAY2	DAY3	DAY4	DAY5	DAY6	DAY7	DAY8	DAY9	DAY10	DAY11
1/8/99 to 10/8/99	Schedule Actual											
11/8/99 to 20/8/99	Schedule Actual											
21/8/99 to 31/8/99	Schedule Actual											
1/9/99 to 10/9/99	Schedule Actual											
11/9/99 to 20/9/99	Schedule Actual											
21/9/99 to 30/9/99	Schedule Actual											
1/10/99 to 10/10/99	Schedule Actual											
11/10/99 to 20/10/99	Schedule Actual											
21/10/99 to 31/10/99	Schedule Actual											
1/11/99 to 10/11/99	Schedule Actual											
11/11/99 to 16/11/99	Schedule Actual											

Fig.C-2: Schemetic diagram showing scheduled and actual days of water delivery for T₁A/S₁G canal at Kharif-II, 1999

TIME	PROGRAM	DAYS										
		DAY1	DAY2	DAY3	DAY4	DAY5	DAY6	DAY7	DAY8	DAY9	DAY10	DAY11
1/5/99 to 10/5/99	Schedule											
	Actual											
11/5/99 to 20/5/99	Schedule											
	Actual											
21/5/99 to 31/5/99	Schedule											
	Actual											
1/6/99 to 10/6/99	Schedule											
	Actual											
11/6/99 to 20/6/99	Schedule											
	Actual											
21/6/99 to 30/6/99	Schedule											
	Actual											
1/7/99 to 10/7/99	Schedule											
	Actual											
11/7/99 to 20/7/99	Schedule											
	Actual											
21/7/99 to 31/7/99	Schedule											
	Actual											

Fig. C-3: Schematic diagram showing scheduled and actual days of water delivery for T₂/S₁G canal during Kharif-I, 1999

TIME	PROGRAM	DAYS										
		DAY1	DAY2	DAY3	DAY4	DAY5	DAY6	DAY7	DAY8	DAY9	DAY10	DAY11
1/8/99 to 10/8/99	Schedule											
	Actual											
11/8/99 to 20/8/99	Schedule											
	Actual											
21/8/99 to 31/8/99	Schedule											
	Actual											
1/9/99 to 10/9/99	Schedule											
	Actual											
11/9/99 to 20/9/99	Schedule											
	Actual											
21/9/99 to 30/9/99	Schedule											
	Actual											
1/10/99 to 10/10/99	Schedule											
	Actual											
11/10/99 to 20/10/99	Schedule											
	Actual											
21/10/99 to 31/10/99	Schedule											
	Actual											
1/11/99 to 10/11/99	Schedule											
	Actual											
11/11/99 to 16/11/99	Schedule											
	Actual											

Fig. C-4: Schematic diagram showing Scheduled and Actual days of water delivery for T₂/S₁G canal at Kharif-II, 1999

TIME	PROGRAM	DAYS										
		DAY1	DAY2	DAY3	DAY4	DAY5	DAY6	DAY7	DAY8	DAY9	DAY10	DAY11
1/5/99 to	Schedule											
10/5/99	Actual											
11/5/99 to	Schedule											
20/5/99	Actual											
21/5/99 to	Schedule											
31/5/99	Actual											
1/6/99 to	Schedule											
10/6/99	Actual											
11/6/99 to	Schedule											
20/6/99	Actual											
21/6/99 to	Schedule											
30/6/99	Actual											
1/7/99 to	Schedule											
10/7/99	Actual											
11/7/99 to	Schedule											
20/7/99	Actual											
21/7/99 to	Schedule											
31/7/99	Actual											

Fig. C-5: Schematic diagram showing scheduled and actual days of water delivery for T₃/S₄K canal during Kharif-I, 1999

TIME	PROGRAM	DAYS										
		DAY1	DAY2	DAY3	DAY4	DAY5	DAY6	DAY7	DAY8	DAY9	DAY10	DAY11
1/8/99 to	Schedule											
10/8/99	Actual											
11/8/99 to	Schedule											
20/8/99	Actual											
21/8/99 to	Schedule											
31/8/99	Actual											
1/9/99 to	Schedule											
10/9/99	Actual											
11/9/99 to	Schedule											
20/9/99	Actual											
21/9/99 to	Schedule											
30/9/99	Actual											
1/10/99 to	Schedule											
10/10/99	Actual											
11/10/99 to	Schedule											
20/10/99	Actual											
21/10/99 to	Schedule											
31/10/99	Actual											
1/11/99 to	Schedule											
10/11/99	Actual											
11/11/99 to	Schedule											
16/11/99	Actual											

Fig. C-6 Schematic diagram showing scheduled and actual days of water delivery for T₃/S₄K canal at Kharif-II, 1999

TIME	PROGRAM	DAYS										
		DAY1	DAY2	DAY3	DAY4	DAY5	DAY6	DAY7	DAY8	DAY9	DAY10	DAY11
1/5/99 to 10/5/99	Schedule											
	Actual											
11/5/99 to 20/5/99	Schedule											
	Actual											
21/5/99 to 31/5/99	Schedule											
	Actual											
1/6/99 to 10/6/99	Schedule											
	Actual											
11/6/99 to 20/6/99	Schedule											
	Actual											
21/6/99 to 30/6/99	Schedule											
	Actual											
1/7/99 to 10/7/99	Schedule											
	Actual											
11/7/99 to 20/7/99	Schedule											
	Actual											
21/7/99 to 31/7/99	Schedule											
	Actual											

Fig. C-7: Schematic diagram showing scheduled and actual days of water delivery for T₉/S₄K canal during Kharif-I, 1999

TIME	PROGRAM	DAYS										
		DAY1	DAY2	DAY3	DAY4	DAY5	DAY6	DAY7	DAY8	DAY9	DAY10	DAY11
1/8/99 to 10/8/99	Schedule											
	Actual											
11/8/99 to 20/8/99	Schedule											
	Actual											
21/8/99 to 31/8/99	Schedule											
	Actual											
1/9/99 to 10/9/99	Schedule											
	Actual											
11/9/99 to 20/9/99	Schedule											
	Actual											
21/9/99 to 30/9/99	Schedule											
	Actual											
1/10/99 to 10/10/99	Schedule											
	Actual											
11/10/99 to 20/10/99	Schedule											
	Actual											
21/10/99 to 31/10/99	Schedule											
	Actual											
1/11/99 to 10/11/99	Schedule											
	Actual											
11/11/99 to 16/11/99	Schedule											
	Actual											

Fig. C-8: Schematic diagram showing scheduled and actual days of water delivery for T₉/S₄K canal at kharif-II, 1999

TIME	PROGRAM	DAYS										
		DAY1	DAY2	DAY3	DAY4	DAY5	DAY6	DAY7	DAY8	DAY9	DAY10	DAY11
1/5/99 to	Schedule											
10/5/99	Actual											
11/5/99 to	Schedule											
20/5/99	Actual											
21/5/99 to	Schedule											
31/5/99	Actual											
1/6/99 to	Schedule											
10/6/99	Actual											
11/6/99 to	Schedule											
20/6/99	Actual											
21/6/99 to	Schedule											
30/6/99	Actual											
1/7/99 to	Schedule											
10/7/99	Actual											
11/7/99 to	Schedule											
20/7/99	Actual											
21/7/99 to	Schedule											
31/7/99	Actual											

Fig. C-9: Schematic diagram showing scheduled and actual days of water delivery for T₂/S₅K canal during Kharif-I,1999

TIME	PROGRAM	DAYS										
		DAY1	DAY2	DAY3	DAY4	DAY5	DAY6	DAY7	DAY8	DAY9	DAY10	DAY11
1/8/99 to	Schedule											
10/8/99	Actual											
11/8/99 to	Schedule											
20/8/99	Actual											
21/8/99 to	Schedule											
31/8/99	Actual											
1/9/99 to	Schedule											
10/9/99	Actual											
11/9/99 to	Schedule											
20/9/99	Actual											
21/9/99 to	Schedule											
30/9/99	Actual											
1/10/99 to	Schedule											
10/10/99	Actual											
11/10/99 to	Schedule											
20/10/99	Actual											
21/10/99 to	Schedule											
31/10/99	Actual											
1/11/99 to	Schedule											
10/11/99	Actual											
11/11/99 to	Schedule											
16/11/99	Actual											

Fig. C-10 Schematic diagram showing scheduled and actual days of water delivery for T₂/S₅K canal at Kharif-II,1999

TIME	PROGRAM	DAYS										
		DAY1	DAY2	DAY3	DAY4	DAY5	DAY6	DAY7	DAY8	DAY9	DAY10	DAY11
1/5/99 to 10/5/99	Schedule											
	Actual											
11/5/99 to 20/5/99	Schedule											
	Actual											
21/5/99 to 31/5/99	Schedule											
	Actual											
1/6/99 to 10/6/99	Schedule											
	Actual											
11/6/99 to 20/6/99	Schedule											
	Actual											
21/6/99 to 30/6/99	Schedule											
	Actual											
1/7/99 to 10/7/99	Schedule											
	Actual											
11/7/99 to 20/7/99	Schedule											
	Actual											
21/7/99 to 31/7/99	Schedule											
	Actual											

Fig.C-11: Schemetic diagram showing scheduled and actual days of water delivery for T₃/S₅K canal during Kharif-I,1999

TIME	PROGRAM	DAYS										
		DAY1	DAY2	DAY3	DAY4	DAY5	DAY6	DAY7	DAY8	DAY9	DAY10	DAY11
1/8/99 to 10/8/99	Schedule											
	Actual											
11/8/99 to 20/8/99	Schedule											
	Actual											
21/8/99 to 31/8/99	Schedule											
	Actual											
1/9/99 to 10/9/99	Schedule											
	Actual											
11/9/99 to 20/9/99	Schedule											
	Actual											
21/9/99 to 30/9/99	Schedule											
	Actual											
1/10/99 to 10/10/99	Schedule											
	Actual											
11/10/99 to 20/10/99	Schedule											
	Actual											
21/10/99 to 31/10/99	Schedule											
	Actual											
1/11/99 to 10/11/99	Schedule											
	Actual											
11/11/99 to 16/11/99	Schedule											
	Actual											

Fig. C-12: Schemetic diagram showing scheduled and actual days of water delivery for T₃/S₅K canal at Kharif-II

APPENDIX D

10-day cumulative rainfall of Kushtia and Beramara rainfall stations during Kharif-I and Kharif-II seasons of 1999.

Table D: 10-day cumulative rainfall (mm) of Kushtia and Beramara rainfall station.

Month	Interval		Rainfall station	
			Kushtia (rainfall in mm)	Beramara (rainfall in mm)
May	1 st	10 day	25.00	60.00
	2 nd	10 day	50.30	80.00
	3 rd	interval	77.70	125.90
June	1 st	10 day	20.20	-
	2 nd	10 day	75.80	109.00
	3 rd	interval	140.50	222.60
July	1 st	10 day	97.40	128.20
	2 nd	10 day	226.30	257.50
	3 rd	interval	145.20	112.20
August	1 st	10 day	60.40	58.20
	2 nd	10 day	217.90	190.10
	3 rd	interval	77.20	86.10
September	1 st	10 day	41.60	20.20
	2 nd	10 day	75.90	96.80
	3 rd	interval	208.10	210.90
October	1 st	10 day	71.38	108.90
	2 nd	10 day	124.20	147.00
	3 rd	interval	29.50	-



APPENDIX E

Agricultural and Socio-economic data