APPLICATION OF A LINEAR MATHEMATICAL MODEL TO MAXIMIZE THE TOTAL COMMAND AREA AND THE YIELD OF TEESTA BARRAGE PROJECT

by

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In partial fulfillment of the requirements for the Degree of Master of Science in Engineering (Water Resources)

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CERTIFICATE

This is to certify that this thesis work has been done by me and neither this thesis nor any part thereof has been submitted elsewhere for the award of any degree or diploma.

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ABSTRACT

A mathematical model has been developed using linear programming optimization technique which can be used to optimize the total command area and the total yield of any irrigation project. The developed model was applied to Teesta Barrage Project to determine the optimal acreages, optimal yields and the best transplanting date of HYV T. Aman grown under supplemental irrigation condition. The model also predicts the critical periods of the availability of water from Teesta river.

In model development, the field application efficiency and the overall irrigation efficiency have been calculated for seepage and percolation rates: 3 and 5 mm/day for Barind Tracts and 6 and 10 mm/day for Floodplain areas, for average reference crop evapotranspiration rate: 4.64 mm/day for Barind Tracts and 4.56 mm/day for Floodplain areas of the project area and for the canal systems and the field canal efficiency values of 85 percent each. The diversion requirements at the head regulator have been calculated using simple dynamic water balance equation for irrigated rice. Other necessary input data have either been obtained from literature or collected from project site and field level experimental farms.

The results of the model application reveal that for optimal

acreages, optimal yields and the best irrigation plan of Teesta Barrage Project, crop staggering approach should be adopted as land management practice. The optimal acreages and optimal yields were found to be dependent on seepage and percolation rate, transplanting date, land management practice and the availability of Teesta flow. The optimal yields were also dependent on the yield data of the variety of rice used. The optimized command area through crop staggering approach is 744,227 acres which is 64.5 percent of total area available for Aman cultivation. The optimal yield is 1,101,159 tons which corresponds to the BR-3 variety of Amla Farm, Kushtia. The optimal transplanting dates are 21-30 June for total fallow Barind Tracts in zone-II and zone-III, 11-20 July for 19,018 acres of Floodplain land in zone-I, 21-31 July for 35,148 acres of Barind Tracts in zone-III and 1-10 August for the remaining irrigable acreages.

The findings of the model provide a reasonable irrigation plan alongwith optimal acreages and optimal yields of Teesta Barrage Project and can be used for planning future irrigation development.

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LIST OF ABBREVIATIONS

ASAE	:	American Society for Agricultural Engineers.
ASCE	:	American Society for Civil Engineers.
BBS	:	Bangladesh Bureau of Statistics.
BP	:	Binnie and Partners Ltd.
BR-1	:	This is a Boro and Aus variety (HYV) recommended by BRRI. This is also suitable as a late T. Aman variety.
BR-3	:	This is a HYV Aman variety recommended by BRRI.
BRRI	:	Bangladesh Rice Research Institute.
BRTC	:	Bureau of Research, Testing and Consultation.
BUET	:	Bangladesh University of Engineering and Technology.
BWDB	:	Bangladesh Water Development Board.
DND	:	Dhaka - Narayanganj -Demra.
DP	:	Dynamic Programming.
EPWAPDA	:	East Pakistan Water and Power Development Authority.
FAO	:	Food and Agriculture Organization.
G.K.	:	Ganges Kobadak.
HYV	:	High Yielding Variety.
HZ	:	Haigh, Zinn and Associates.
ICID	:	International Commission on Irrigation and Drainage.
ILRI	:	International Institute for Land Reclamation and Improvement.
IRRI	:	International Rice Research Institute.
LIV	:	Local Improved Variety.
LP	:	Linear Programming.
MPO	:	Master Plan Organization.

SRDI : Soil Resources Development Institute.

TFYP : Third Five Year Plan.

UPRIIS : Upper Pampanga River Intagrated Irrigation System.

CHAPTER 1

INTRODUCTION

1.1 Background Information

Use of surface water for irrigation is an age-old art as civilization. The pressure for survival and the need for additional food supply are causing the rapid expansion of irrigation throughout the whole world. This is particularly true for a developing country like Bangladesh which is passing through acute shortage of food for her teeming millions. Bangladesh, stretching over 35.31 million acres and lying in the confluence of the three great rivers of the world - the Ganges, the Brahmaputra and the Meghna, has a population of about 105 million people (BBS, 1986). Out of the total land, the cultivable land is only 23.21 million acres. In recent years, the population growth rate has been higher than that of food production. So, the deficit of food grains would be fulfilled by importing food grain in every year. It is estimated that by the year 2000 Bangladesh will have a population of about 140 million with a corresponding food grain requirement of 27 million tons (MPO, 1984 & Planning Commission, 1985). Thus cereal production should be increased to feed the rapidly growing population. Moreover, the economy of Bangladesh is highly dependent on agriculture. Land use pattern of Bangladesh over last few years indicates a decreasing trend in the availability of cultivable land due to the expansion of habitat and the increased development activities in the rural areas. Hence, the main thrust of agricultural expansion can come only from increased productivity through the application of modern agricultural practices - the use of irrigation water to crops, new and better seeds, better and fuller use of fertilizers and pesticides, drainage and flood protection. In agricultural development, efficient use of water plays a vital role.

The Third Five Year Plan (TFYP) of Bangladesh (1985-90) aims at achieving a food grain production of 20.7 million tons in the terminal year 1989/90 against a bench mark level of 16.1 million tons in the year 1984/85 (Planning Commission, 1985). It has also been estimated that the total food grain produced will be enough to feed the projected population by the end of 1990 and make the country self-sufficient in food. The development of Bangladesh agriculture is fundamentaly tied to rice, to its production and its price. To make the country self-suffcient in food, the use of irrigation water in rice fields with expanded cultivation of high yielding varieties (HYV) of rice supported by intensive managemant will act as one of the quickest and surest means of increased production. But about 20 percent of the total cultivable area is now under irrigation and the rest is cultivated under rainfed condition (BBS, 1986). The rainfed cultivation is highly dependent on the mercy of nature.

In total, Bangladesh has abundant water resources. The sources of these water resources are the river inflow from India and rainfall within the country. Most of the inflow occurs in the monsoon months and can not be stored for dry months because suitable reservoir facilities are not available. Mean annual rainfall in the country varies from 1400 mm in the northwest to over 5000 mm in the northeast (MPO, 1985). However, ninty percent of this rainfall occurs during four monsoon months from June to September. Rainfall is scarce and highly unpredictable during the months of October to May. Therefore, drought of varying intensities occurs almost in all parts of Bangladesh during October to May period and hence irrigation is a pre-requisite to extend the crop growing season over the entire year. Moreover, uneven periodical distribution of water stresses the importance of allocation of water seperately for each period. Insufficient allocation of irrigation water not only causes the monetary losses but retards agricultural growth to a great extent. Efficient allocation of scarce water resources in irrigation projects would ensure the best possible gain from the available resources.

Efficient allocation of available resources of any system can be well done by using optimization techniques. There are a great number of optimization programming models. But the most commonly used models are the Linear Programming (LP) and Dynamic Programming (DP) models.. For better utilization of the available resources of the irrigation project, linear programming model is widely used throughout the world due to its linear characteristics, the capability of handling very large system efficiently and the availability of LP algorithm as a pre-programmed or canned package at most computer installations.

In Bangladesh, there are a large number of irrigation projects which are either on-going or now under construction. The on-going projects include Ganges-Kobadak Project, Monu River Project, Chandpur Irrigation Project, Muhuri Irrigation Project, Karnaphuli Irrigation Project, North-Bangladesh Tubewell Project, Barisal Irrigation Project, etc. Teesta Barrage Project and Pabna Integrated Rural Development Project are two of the largest irrigation projects undertaken by BWDB and are currently under implementation. But optimization approach was not applied in any of these projects. In the present study, a linear mathematical model has been developed for an irrigation system for maximum utilization of the available resources.

The idea of utilizing water of Teesta River for irrigation of the north-western districts of Bangladesh dates back to British period. Systematic investigations started from that time. An initial plan for irrigating 1.12 million acres of project area was formulated in 1955 by diverting the Teesta flow. Subsequently, the plan was revised to increase the project area on the basis of the recommendations of the feasibility reports of the consultants. Two separate feasibility studies for the Teesta Barrage Project were conducted in sixties - the first one was prepared in 1960 by M/S. Haigh, Zinn and Associates in collaboration with the Associated Consulting Engineers Ltd. and the second one was prepared by M/S. Binnie and Partners in 1969. Finally, the project was undertaken by BWDB in 1980 for implementation as per decision of the then Government on the basis of the recommendations of the feasibility study conducted by M/S. Binnie and Partners in 1969. The purpose of the project is to provide supplemental irrigation to high yielding varieties (HYV) and local improved varieties (LIV) of rice during Kharif-II season (from July to November). Irrigation to the Rabi (Boro) and Kharif-I (Aus) crops to a limited area might be provided depending on the availability of water. The project is proposed to cover a gross area of 1.85 million acres and a net area of 1.335 million acres. The salient features of the project include construction of a barrage across the Teesta River at Doani, along with canal headworks to divert water under gravity to the canal distribution system and development of a network of irrigation and drainage systems over the entire project area to deliver irrigation water to the farms and to drain out the excess water.

1.2 Scope of Study

The purpose of this study is to develop a mathematical model to maximize the total command area and the yield of an irrigation project which can be used as an effective tool for the planning of irrigation systems. The developed model will be applied to Teesta Barrage Project where the development of irrigation facilities is still at planning stage.

The specific objectives of the study are :

1. To develop a linear mathematical model for Teesta Barrage Project in order to maximize the total command area and the yield.
2. To apply the model for the determination of an optimal transplanting date for a rice grown in Kharif-II season with irrigation.
3. To apply the model predicted results for determining the suitable irrigation plan for Teesta Barrage Project.
4. To predict the effect of seepage and percolation rates, cropping practices and the probability levels of Teesta flow on optimal acreages, optimal yields and the irrigation planning of the project.

If the model developed is found to be suitable and valid for Teesta Barrage Project, then it could be used in future planning of similar water resources projects for effective utilization of the resources through irrigation.

CHAPTER 2

REVIEW OF LITERATURE

In modern agriculture, water plays an important and vital role. It is, therefore, essential to have the optimum use of land and water resources. In many countries, with the need to feed a rapidly growing population, both land and water for irrigation are becoming scarce resources. Thus, the problem of choosing the optimal acreages for crops to be grown in view of limited resources is becoming increasingly important. For optimal planning, design, construction and operation of schemes, it is necessary to apply the systems approach or analysis, which is now a common practice in many parts of the world. The technique has also been applied to select a mix of crops and to develop an irrigation plan. However, such systems approaches are seldom done in many developing countries like Bangladesh, where cropping pattern is chosen arbitrarily based on the experience of past, and intuition of future price and demand of crops. Moreover, irrigation planning is also designed traditionaly.

The purpose of this chapter is to review the basic principle of systems approach, the solution procedures of systems analysis and the application of systems approach for irrigation project planning in different parts of the world. The mathematical modeling techniques in irrigation planning have also been reviewed for the selection of a suitable technique to be used in present study.

2.1 Systems Approach

2.1.1 Definition:

The definition of systems approach was given by different authors in different ways. But the abstract of each definition is more or less the same. Some of these definitions are presented below.

According to Hall and Dracup (1975), systems analysis may be defined as the art and science of selecting from a large number of feasible alternatives, involving substantial engineering content, that particular set of actions which will best accomplish the overall objectives of the decision makers, within the constraints of law, morality, economics, resources, political, life and other natural sciences. By this definition, systems approach is concerned with only one phase of the total task of the water resources engineer - that of decision making in relation to planning, design, construction and operations.

According to Biswas (1976), systems approach may be defined as an analytical study that helps a decision maker to identify and select a preferred course of action among several feasible alternatives. It is a logical and systematic approach wherein assumptions, objectives and criteria are clearly defined and specified. He also mentioned that systems analysis had added a totally new dimension to the science of policy-planning and decision-making.

Haith (1982) defined systems approach as the study of collection of things that function together.

Actualy, systems analysis is a problem-solving technique wherein attempts are made to build a replica of a real world system or situation, with the objective of experimenting with the replica to gain some insight into the real world problem. The system is reprsented by a series of mathematical expressions in such a manner that the resulting relationships describe the real situation. The parameters that affect the system are included, as well as the factors that infleunce the parameters. The system may already be in existence or may still be an idea awaiting for execution. In the first case, the model's objective is to analyze the behavior of the system in order to improve its performance. In the second, the objective is to identify the best structure of the future system. Therefore, in a real sense, it is implied that a good mathematical model of a system needs a thorough knowledge and understanding of that system.

2.1.2 Stages of Systems Approach:

The stages (Haith, 1982) of the systems approach may be expressed as:

A. Definition of system and objectives
   1. Identification of decision maker(s)
   2. Definition of system boundaries and components
   3. Quantification of objectives

B. Generation and evaluation of alternatives
   1. Construction of an optimization model
      a. Definition of decision variables
      b. Relationships between variables
   2. Solution of the optimization model

C. Selection of an alternative

2.1.3 Types of Systems Analysis Model:

The most important type of systems approach model is the symbolic or mathematical model. In formulating this type of model, one assumes that all relevant variables are quantifiable. Thus, mathematical symbols are used to represent variables, which are then related by the appropriate mathematical functions to describe the behavior of the system.

Sometimes the mathematical formulation of a system may be too complex and its corresponding solution procedure may be tedious and time consuming. In this case, simulation and heuristic models are used. Simulation models imitate the behavior of the system over a period of time. These type of models do not need explicit mathematical functions to relate variables. The main drawback of simulation model is that the analysis is equivalent to conducting experiments and is thus subject to experimental error.

2.1.4 Elements of Mathematical Model:

Unlike simulation or heuristic models for which no fixed structure can be suggested, a mathematical model includes three basic sets of elements:

1. Decision variables and parameters - The decision variables are the unknown to be determined from the solution of the model. The parameters represent the controlled variables of the system. In general, the parameters of the model may be deterministic or probabilistic.
2. Objective function - This defines the measure of effectiveness of the system as a mathematical function of its decision variables. Generally, the objective function acts as an indicator for the achievement of the optimum solution.

3. Constraints or restrictions - To account for the physical, technological and financial limitations of the system, the model must include constraints which limit the decision variables to their feasible values.

Generally, mathematical model may be expressed as:

Optimize

$$Z = f(X_j) \qquad [2.1]$$

Subject to

$$g_i(X_j) \leq b_i \qquad [2.2]$$

$$X_j \geq 0 \qquad [2.3]$$

in which $f(X_j)$ = the objective function; X_j = the decision variables; j = the number of decision variables; $g_i(X_j) \leq b_i$ represents the ith constraint; i = the number of constraints. The constraints $X_j \geq 0$ are known as the non-negativity constraints, which restrict the variables to zero or positive values only.

2.2 Solution Procedures for a Systems Approach

There are two basic approaches for solving systems planning models - Simulation approach and Optimization approach. Simulation approach is a search procedure that relies on trial-and-error to identify near-optimal solutions. Search method intelligently moves from one solution point to another with the objective of improving the value of the model criterion. When no further improvements can be achieved, the best attained solution is the approximate solution to the model. The difficulty with the simulation approach is that there is often a frustratingly large number of feasible solutions or plans. The advantage of this approach is that this approach is able to solve water resources systems planning models with highly non-linear relationships both for objective function and/or constraints. Constrained optimization procedures are seldom able to solve or deal with all the complexities and non-linearities which are easily incorporated in a simulation technique.

Constrained optimization approach is more systematic and advanced technique. Optimization algorithms include a diverse set of techniques that uses matrix algebra and advanced calculus. Optimization techniques include Lagrange multipliers, Linear programming, Dynamic programming, Quadratic programming, Geometric programming, etc. Each of these and other constrained optimizatiion solution procedures are highly dependent on the mathematical structures of the water management models. The most commonly used optimization techniques in water resources systems planning are Dynamic programming and Linear programming.

2.2.1 Dynamic programming:

Dynamic programming, which is denoted as DP is a mathematical programming technique that can sometimes be used to solve optimization models. It is a straightforward method designed primarily to improve the computational efficiency of certain optimization problems. The procedure consists of breaking down a problem into a series of smaller problems that are solved in a sequential and cumulative fashion. DP is adaptable to both linear and non-linear models. In addition, discontinuous variables and functions cause no particular difficulties with DP.

The common characteristics of optimization models that can be solved by DP are:

1. It must be possible to visualize the model as a series of sequential decisions.
2. The return from any stage must be a function only of the decisions made at that stage and the state of the system at that stage.
3. There must be a presence of one or more resources that are to be allocated. Moreover, the number of resources to be allocated must be small.

The main disadvantage of DP is the "Problem of Dimensionality" or the "Curse of Dimensionality" (Bellman, 1957). There is no standard algorithm or canned computer program for solving DP problems. A new algorithm or computer program is usually developed for each DP model.

2.2.2 Linear programming:

Linear programming, which is denoted by LP is a class of mathematical models concerned with the efficient allocation of limited resources to known activities with the objective of meeting a desired goal. It is simple but very efficient method of mathematical programming. The distinct characteristic of LP models is that the functions representing the objective and the constraints are linear and all variables associated with the models are non-negative. The diverse application of LP are in the following areas:

a. Production planning
b. Inventory
c. Water quality management
d. Project planning
e. Transportation problems
f. Assembly balancing

A general linear programming model in a more compact form is usually defined as:

Optimize

$$Z = \sum_{j=1}^{N} C_j * X_j \qquad [2.4]$$

Subject to

$$\sum_{j=1}^{N} a_{ij} * X_j \ (\leq, =, \text{or} \geq) \ b_i ; \quad i=1,2,3, \ . \ . \ M \qquad [2.5]$$

$$X_j \geq 0 ; \quad j=1,2,3, \ . \ . \ N \qquad [2.6]$$

where, Z is the objective function value; C_j, a_{ij} and b_i are constants determined from the technology of the problem; X_j are the decision variables; N is the number of decision variables and M is the number of constraints.

By using matrix notation, the general LP model may be expressed as:

Optimize

$$Z = [C][X] \qquad [2.7]$$

Subject to

$$[A].[X] \ (\leq , = , \text{or} \geq) \ [b] \qquad [2.8]$$

$$[X] \geq 0 \qquad [2.9]$$

where, [C] is a 1*N row vector of worth,

$$[C] = [c_1 \ c_2 \ c_3 \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ c_N]; \qquad [2.10]$$

[X] is an N*1 column vector of decision variables,

$$[X] = [X_1 \ X_2 \ X_3 \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ X_N]'; \qquad [2.11]$$

[A] is an M*N technology coefficient matrix,

$$[A] = \begin{bmatrix} a_{11} & a_{12} & a_{13} & . & . & . & a_{1N} \\ a_{21} & a_{22} & a_{23} & . & . & . & a_{2N} \\ a_{31} & a_{32} & a_{33} & . & . & . & a_{3N} \\ : & : & : & : & : & : & : \\ : & : & : & : & : & : & : \\ a_{M1} & a_{M2} & a_{M3} & . & . & . & a_{MN} \end{bmatrix} \qquad [2.12]$$

and [b] is an M*1 resource contants column vector,

$$[b] = [b_1 \ b_2 \ b_3 \ . \ . \ . \ . \ . \ . \ . \ . \ . \ b_M]'. \qquad [2.13]$$

Because LP models are presented in a variety of forms i.e., maximization or minimization for the objective function and ($\leq$, $=$, or $\geq$) for the constraints, it is necessary to modify the above mentioned forms to fit the solution procedure. For this purpose, the commonly used forms are the standard form and the canonical form. The standard form is used directly for solving the model, while the canonical form is particularly useful in presenting duality theory.

The characteristics of the standard form are:

1. The objective function is of the maximization or minimization type.
2. All constraints are equations except for the non-negativity constraints which remain inequalities

i.e., ≥ 0.

3. All decision variables are non-negative.
4. The right hand side element of each constraint equation is non-negative.

Inequality constraints can be changed to equations by augmenting i.e., adding the left hand side of each such constraints by a non-negative variable known as slack or surplus variable. Slack variable is associsted with $\leq$ constraint, while surplus variable with $\geq$ constraint.

The characteristics of the canonical form of LP are:

1. The objective function is of the maximization or minimization type.
2. All constraints are of the $\leq$ type for the maximizing objective function and of the $\geq$ type for the minimizing objective function.
3. All decision variables are non-negative.

LP models can be solved graphically and by using LP algorithms. The graphical approach is a more straightforward way of obtaining optimal solutions but it is limited to LP models with two variables only. The most commonly used algorithm is the simplex method. The simplex method is an algebraic procedure used to examine extreme points efficiently. This method is based on the theory of simultaneous linear equations and is available as a pre-programmed or canned package at most computer installations. Therefore, once an LP model is formulated, it can be rapidly and easily solved by computer. An important feature of a linear programming is that it can be used to solve very large models, even thousands of variables and constraints. No other mathematical programming method has a simillar capability. Another most important characteristic of LP models that is very useful in post-optimality or sensitivity analysis is the existence of dual LP models. Every LP model has a parallel or dual model that can be used to generate additional information about the problem being studied. The objective of duality or the analysis of the dual LP models is to quantify the marginal values associated with constraints of primal LP models.

One of the significant disadvantage of LP is implied by its name. That is , it can only be used for optimization models with the linear objective function as well as the linear constraints.

2.3 Systems Approach for Irrigation Project Planning

The systems approach or analysis for an irrigation project envisages development of variuos alternatives, their evaluation and comparison. The alternatives have to be studied over a wide range of performances. This could be expedited by using mathematical programming.

Many researchers have applied mathematical programming techniques such as linear and dynamic programming to irrigation planning and other farm management problems. In reviewing the role of operation research techniques in farm management, Hutton (1965) discussed the application of these programming techniques in choosing the cropping pattern. A number of papers have been published in different journals (Cummings et al., 1970 and Rogers et al., 1970, after Bari, 1985; Chaudhury et al., 1974; and Lakshminarayana et al., 1977) where linear and dynamic programming were used to determine the optimal cropping pattern and the schedule of releases from surface water and that of pumpage from ground water. Other researchers (Hall et al., 1965, after Bari, 1985; Dudley et al., 1971 and 1972) presented dynamic programming models to determine the optimal allocation of water to crops assuming the production function (yield versus water applied) to be known.

Soltani-Mohammadi (1972) conducted a study of the problem of choosing irrigation techniques i.e., conventional modern surface irrigation (labor intensive) and portable or semi-portable sprinkler irrigation (capital intensive) in a newly developing agricultural region of Iran. An LP model was developed to select an adequate system of irrigation in two irrigation projects in Iran. The analysis of the model indicated that under the specified conditions and assumptions a portable or semi-portable sprinkler system would prove to be economically superior to modern surface irrigation for the development of new lands. However, in lands where a modern surface irrigation system has already been installed it is not feasible to transform to sprinkler system. This model was also tested for "Dez Irrigation Project" in Khuzestan region of Iran.

Sarkar and Maji (1976) attempted a study to develop an optimal drainage programme and a cropping pattern consistent with the most efficient use of available resources through the application of linear programming for an existing canal irrigation system in India. The objective of the model developed by them was to maximize the net economic return subject to the area, canal capacity, reservoir capacity and resources availability constraints.

Singh and Sirohi (1976) developed an LP model for optimal allocation of canal and tubewell water among crop areas. The developed model has been applied for the command area of "Upper Ganga Canal". The objective function of the model was to maximize the net economic return subject to the canal and tubewell water supply constraints, water budget constraints, canal capacity constraints, land, fertilizer and cropped area contraints. The result of the model indicated that the total cropped area increased considerably and the total returns in the optimal plan increased by 24 percent over the existing plan in the canal command area.

Singh et al.(1976) developed an LP model, which has been used as an analytical tool to determine optimum area under different rabi season crops at Haryana Agricultural University Farm, India to maximize the net profit on a command area of 70 ha for a canal outlet having discharge of 1.19 cusecs. This model is very relevant to the present study. The mathematical statement of this model can be written as:

$$\text{Max. } Z = \sum_{j=1}^{K} C_j * X_j \qquad [2.14]$$

subject to

$$\sum_{j=1}^{K} a_{ij} * X_j \leq b_i \; ; \quad i = 1,2,3, \ldots \ldots \qquad [2.15]$$

$$X_j \geq 0 \; ; \qquad j = 1,2,3, \ldots \ldots K \qquad [2.16]$$

in which Z = the total net profit, C_j = net profit from an unit of jth activity, X_j = the level of jth activity, a_{ij} = amount of ith input required per unit of jth activity, and b_i = the quantity of ith available resources. The analysis of the result indicated that the optimum area of 30.3 ha, 21.3 ha and 16.7 ha under wheat, gram and lentil respectively gave a maximum profit of Rs. 114053.60.

Saksena and Chandra (1978) conducted a study for a development of optimal cropping pattern in the command area of "Upper Ganga Canal" alongwith planned conjunctive use of surface and ground water. They formulated an LP model as Smith (1970, after Saksena et al., 1978) to maximize the annual aggregate benefits subject to the cropped area constraints, reservoir and tubewell capacity constraints and resources availability constraints. The model was solved by IBM 360 computer for ten crops and four decision variables. The results of the study indicated that to increase the irrigation intensity to its ultimate value (200 percent) more surface water should be needed in the command area. The study also demonstrated that to increase the agricultural production and to avoid waterlogging and salinity problems conjunctive planning of surface and ground water should be done.

Kumar and Khepar (1980) conducted a study to demonstrate the usefulness of alternative levels of water use over the fixed yield approach when there is a constraint on water. The water production functions used in this study were square root and quadratic type. The fixed yields model developed by them is an LP model. The model with alternative levels of water use is linear except the objective function which is seperable into a sum of convex functions of individual variables. The objective function of the model was to maximize the annual net returns subject to constraints on the availability of water and other inputs. The models considering fixed yields and alternative levels of water use were applied on a selected canal command area (Kotkapura distributory, Ferozpur district, Punjab) having a discharge of 45 l/sec to determine the optimal cropping patterns. The conclusion of the study was that alternative levels of water use was superior to fixed yields for optimal utilization of land and water resources.

Vedula (1981) carried out an intensive study for the optimal irrigation planning of the Cauvery River basin in peninsular India which was extensively developed in the downstream reaches and had a high potential for development in the upper reaches. A twelve season (monthly) LP model was formulated to find optimum cropping pattern for the reservoir system in the upper basin. Two models were formulated, one for the four reservoir system and another for the three reservoir system. For both the models, three objectives viz., maximizing (1) the net benefit from agriculture, (2) the total irrigated cropped area and (3) the total reservoir diversions were studied. The trade-off relationships between the first two objectives were also discussed. The decision variables considered by him were the cropped area (irrigated and nonirrigated) and the constraints were storage capacity, storage continuity equations, land availability and downstream release constraints.

Kumar et al. (1982) analysed the problems associated with Gandak Command Area. They developed an LP model to maximize the benefits of the farmers with the consideration of the constraints due to the demand of existing sugar industries in the study area, availability of water and the needs of the people.

A regional optimization model of municipal wastewater treatment and reuse in irrigation was presented by Dinar and Yaron (1986). They developed the model to maximize the region's income subject to the constraints - the available production factors, a given technologies of agricultural production, wastewater treatment technologies, prices and environmental regulations. The model was applied for a small Ramla region on the coastal plain of Israel and solved for both non-cooperative and cooperative conditions. The optimal solution enabled to reallocate the fresh water quota among the different land sections, to cultivate new land areas, and to expand the irrigated crops by using effluent.

A study was conducted by Faux et al. (1986) to demonstrate the versatility and usefulness of the interactive river basin network flow computer model called MODSIM2 for improving the performance of existing complex irrigation/hydropower projects. MODSIM2 model was applied to the Upper Pampanga River Integrated Irrigation System (UPRIIS) of the Philippines. The problems studied by them are examples of planning future capacity expansion, maximizing firm energy in a system primarily oriented to irrigation supply, and developing operating rules to guide real-time management under multiple objectives.

An LP model was developed by Glen (1986) for an integrated crop and intensive beef production enterprise. The overall approach of this study consisted of three optimization models in series, namely a ration formulaton LP model, a DP model for costs and quantities computation and finally an LP model. The total model was run on an IBM 3081 computer and the cattle feeding policy and the crop production policy were developed. The size of the model was such that it was not suitable for use by individual farmers, although it could be used in research and extension services.

In Bangladesh, the optimization technique has not been widely used in irrigation planning in order to maximize use of available resources. A few number of research papers have been published for the situation of Bangladesh. Some of those are presented below.

Smith (1973) performed a system analysis in a situation where there was conflict between the agregrate consumption and the food grain self-sufficiency objectives. He developed a linear programming model, consisting of the water balance of generalized irrigation system, to maximize the present value of additional agregrate consumption benefits of the project. The model was applied for an irrigation project in Bangladesh, where an aquifer of high potential underlies the project area and ground water exploitation to supplement the surface water is possible, to determine the project configuration that maximizes net benefits.

Elias (1977) presented a paper in which he developed a multiperiod LP model specially for a project where the facility of irrigation in dry season and drainage and flood control in wet season is available. This model can be used to select a cropping pattern for a command area. The objective of the model was the maximization of the net return from the command area due to the constraints of limited availability of resources. The model was emperically tested on the Dhaka-Narayanganj-Demra (DND) irrigation project in Bangladesh. The model decided the optimal cropping pattern which would give maximum return under limited land, water, labor and nitrogen availability and also decided the optimal number of pumps required to drain out excess rain water during wet season.

Bari (1985) developed a mathematical modeling approach (LP) of determining optimal cropping pattern suitable for the situation where both land and irrigation water are scarce resources. The objective function of the formulated model was to maximize the net economic return from cropping activity. The model was solved using available data for Bangladesh. The output of the model solution included cropping patern, allocation of irrigation water by month and by crops, yield of crops, etc. The sensitivity analysis of the model was done by parametric linear programming.

In terms of current interest in the agricultural sector of Bangladesh, a great deal of attention is being focussed to increase agricultural production and to attain self-sufficiency in food grains. So, there is a great need of optimization analyses and that of mathematical models for optimal allocaton of agricultural land and irrigation water. It is with this view in mind that this study has been taken up.

CHAPTER 3

BASIC CONSIDERATIONS OF MODEL DEVELOPMENT

The performance of any irrigation system is optimized when the suitable moisture level in the root zone soil is maintained, and the evaporation, surface run-off, and seepage and percolation losses are minimized. For optimum utilization of the available resources of such system, a mathematical modeling approach should be applied to predict the system performance in terms of command area and crop yield from a given set of known physical and operational parameters.

In this chapter, the hydro-meteorological and soil characteristics of the area to which the developed model is applicable are evaluated first to quantify the available resources of the area and to predict the dependable rainfall. The crop irrigation water requirements, overall irrigation efficiencies and diversion requirements at head regulator are calculated and presented here.

3.1 The Study Area

3.1.1 Location and Topography:

Teesta Barrage Project is located in the north-western region of Bangladesh. The project area extends from latitude 24^{o}-48' to 26^{o}-05' north and longitude 88^{o}-47' to 89^{o}-32' east and covers partly the area of Nilphamari, Rangpur, Gaibandha, Dinajpur, Joypurhat and Bogra districts. The project is proposed to cover a gross area of 1.85 million acres (BWDB, 1985). The project area can be divided into two parts each having characteristic topographical features differing from the other. The slightly higher area on the western part of the project is called Barind Tract which has steeper land slope of about 2.5 ft/mile, while the Floodplain area to the east has a more mild land slope of about 0.5 ft/mile.

3.1.2 Climate:

The climate of the project area is characterized by two distinct seasons - the wet season from June to September and the dry season during the rest of the year. The project area is climatologically represented by the average of the three principal meteorological recording stations namely Bogra, Rangpur and Dinajpur. Annual mean rainfall of the project area is about 1900 mm. Almost 80 percent of the rainfall occurs in the months of June, July, August and September. During the months from November to April evapotranspiration greatly exceeds the rainfall. The distribution of mean monthly rainfall and average reference crop evapotranspiration of the project is shown in Fig. 3.1. The average maximum monthly temperature ranges from

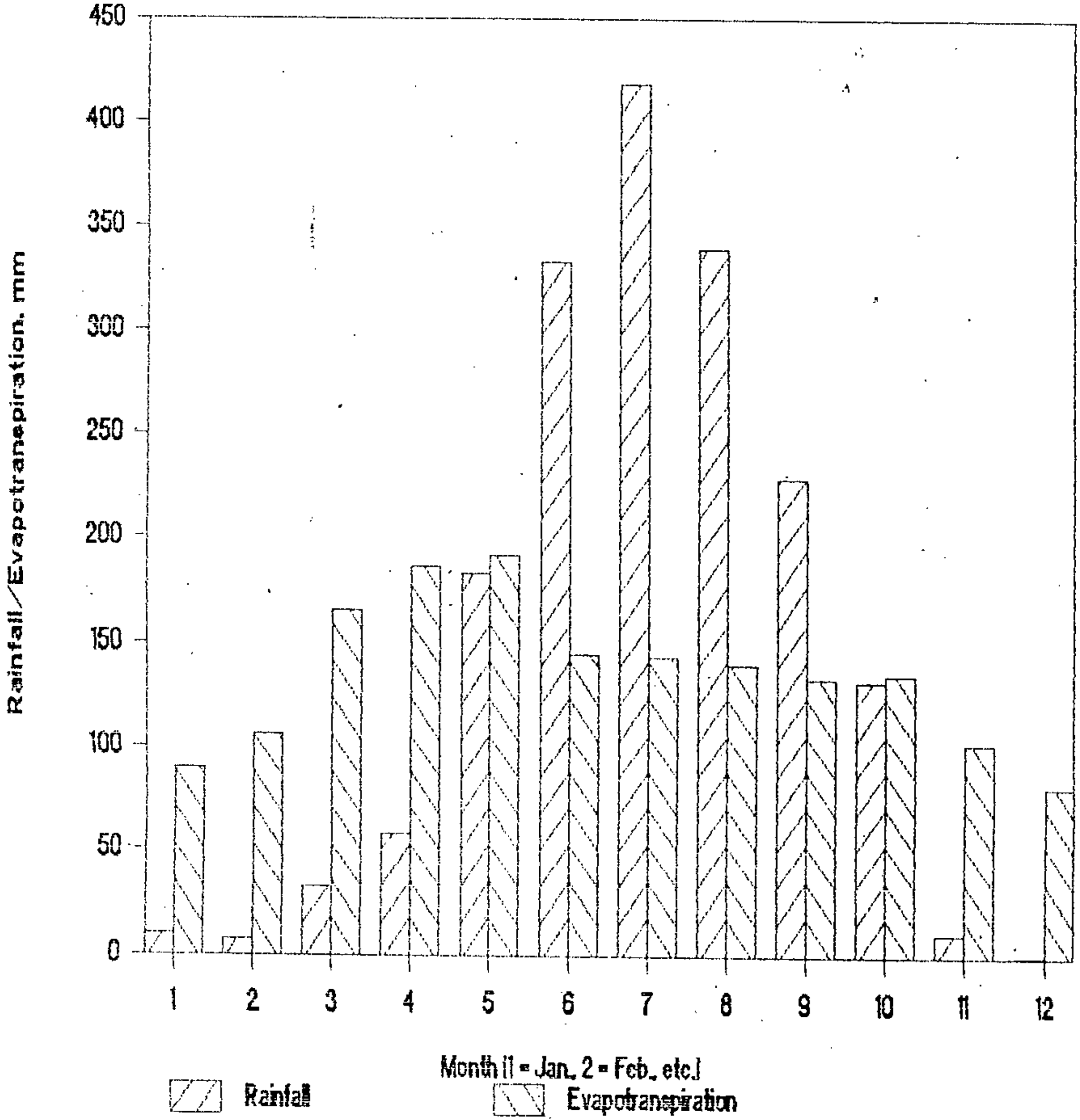

Fig. 3.1 Bar Diagram Showing the Distribution of Mean Monthly Rainfall and Reference Crop Evapotranspiration of Study Area.

$25^{o}c$ in dry season to $34^{o}c$ in wet season while the average minimum temperature varies from $10^{o}c$ in dry season to $25.5^{o}c$ in wet season. The average relative humidity varies from 95 percent to 78 percent in wet season and from 93 percent to 44 percent in dry season. The average wind speed of the project area ranges from 35 km/day to 105 km/day. The solar radiation of the project area is favourable for the intensive cultivation of HYV crops throughout the whole year.

3.2 Resources Quantification

3.2.1 Water Resources:

The irrigation development is mainly affected by two climatic factors - rainfall and evaporation. The main source of water supply for meeting the water requirement of the crops in the project area is rainfall. The mean annual precipitation of the project area varies from 1500 mm to 2400 mm. The distribution of mean annual precipitation of the project area is shown in Fig. 3.2. On the basis of mean annual precipitation, the total project area can be divided into three distinct hydrologic zones (BRTC, 1986). These are shown in Fig.3.2 and given below.

1. Zone-I is the northern zone where the mean annual precipitation varies from 2100 mm to 2400 mm.
2. Zone-II is the central zone where the mean annual

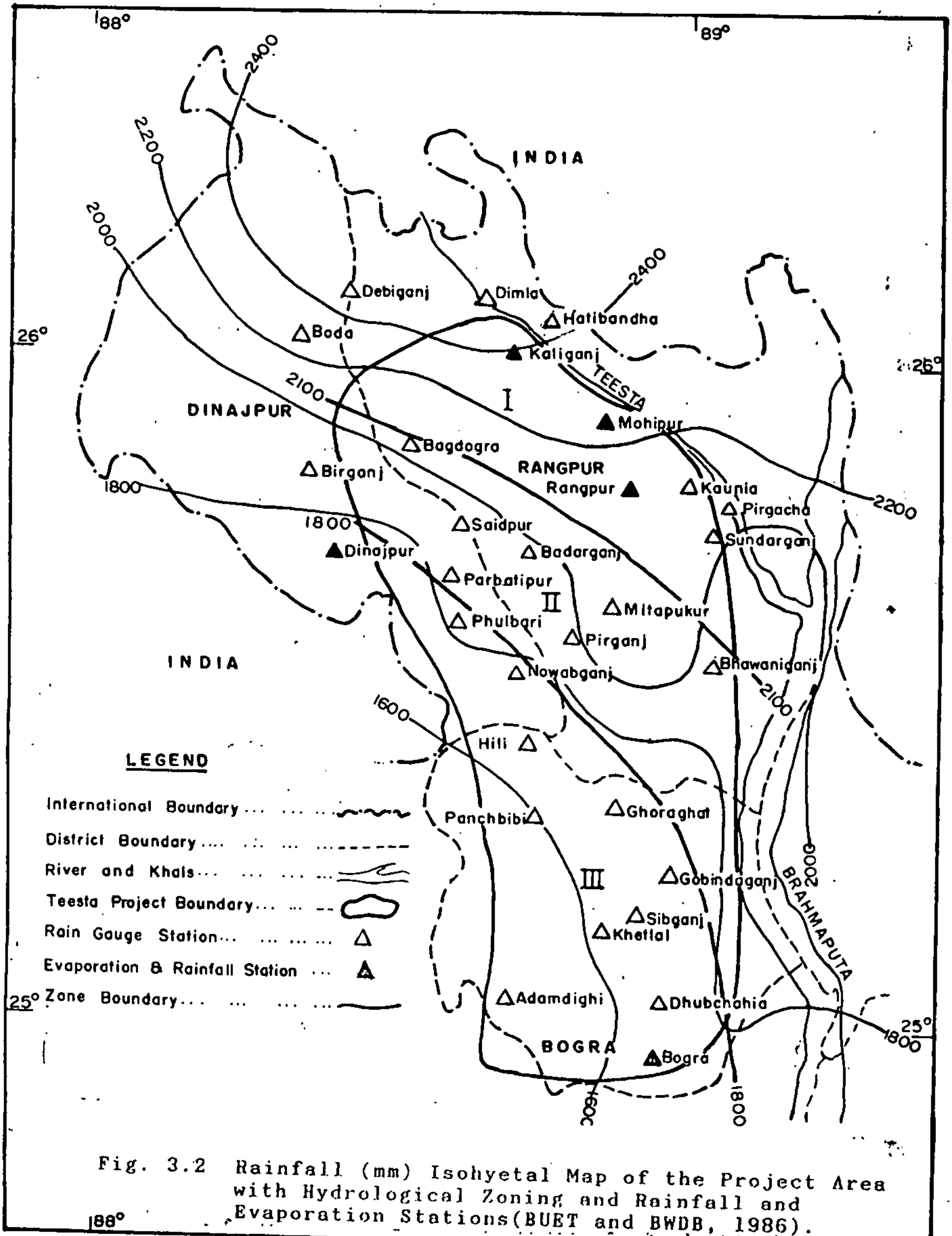

Fig. 3.2 Rainfall (mm) Isohyetal Map of the Project Area with Hydrological Zoning and Rainfall and Evaporation Stations (BUET and BWDB, 1986).

precipitation varies from 1800 mm to 2100 mm.

3. Zone-III is the southern zone where the mean annual precipitation varies from 1500 mm to 1800 mm.

In addition to rainfall, other sources of water supply for fulfiling the water requirement of the agricultural crops in the project area are surface water and ground water. There are numerous rivers, streams and flood-channels in the project area (Fig. 3.3). The majority of them carry little or no water in the dry season. The Teesta is the only river available to the project which has a considerable flow throughout the year.

Uptil now a large number of studies have been carried out by different consultants and authorities (M/S. Haigh, Zinn and Associates, 1960; M/S. Binnie and Partners, 1969; BWDB, 1984 and BUET and BWDB, 1987) to quantify the water availability to the project.

M/S. Haigh, Zinn and Associates (1960) mainly concentrated their study on water availability considering the maximum discharges of Teesta River in order to decide upon the design criteria of Barrage. They analyzed the data of the discharges of Teesta River for the years 1946 to 1958 and computed average discharges on ten day basis. The results are presented in Fig. 3.4.

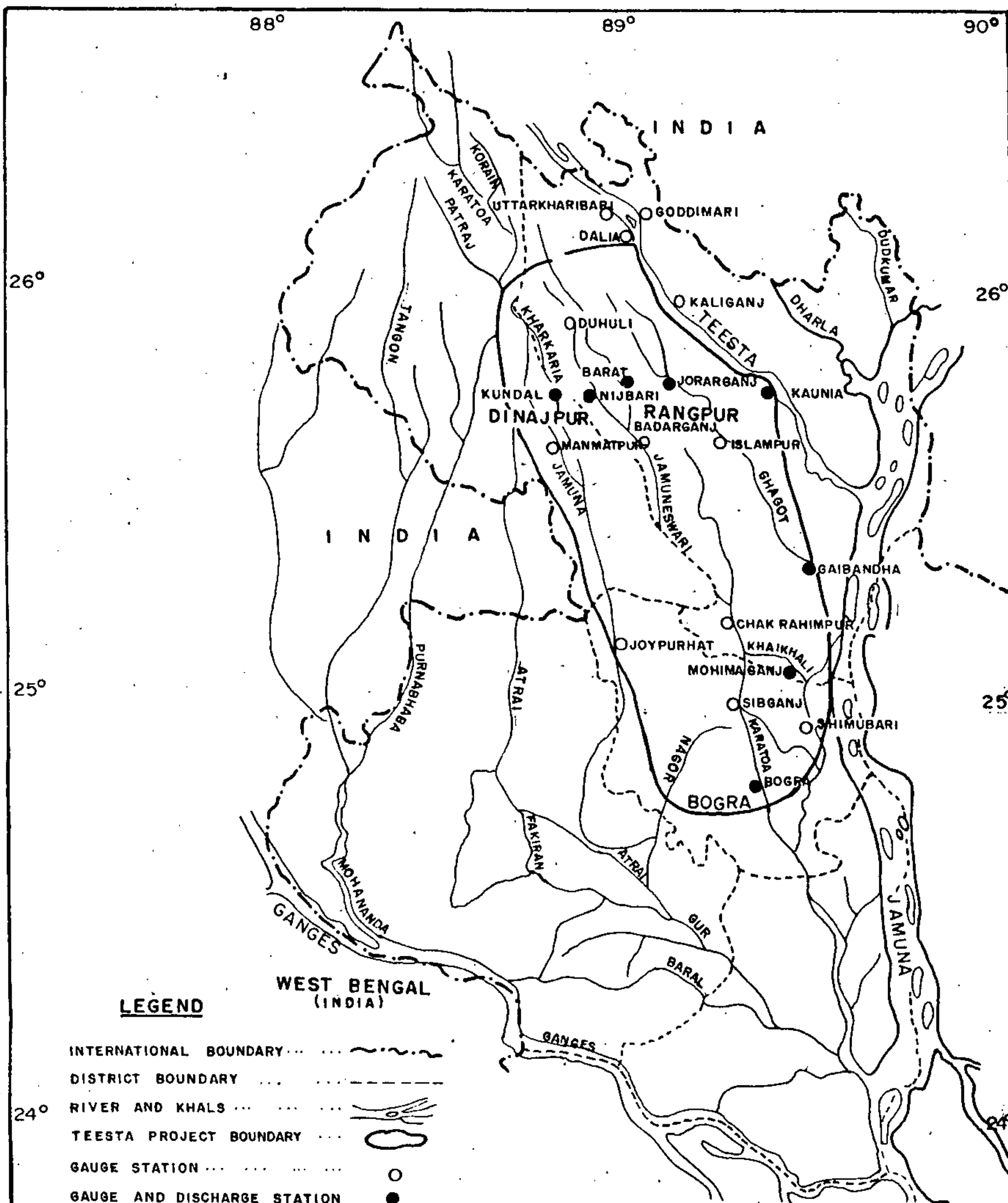

Fig. 3.3 Map Showing the Project Area with its Internal River Systems and the Location of Gauging Stations (BUET and BWDB, 1986).

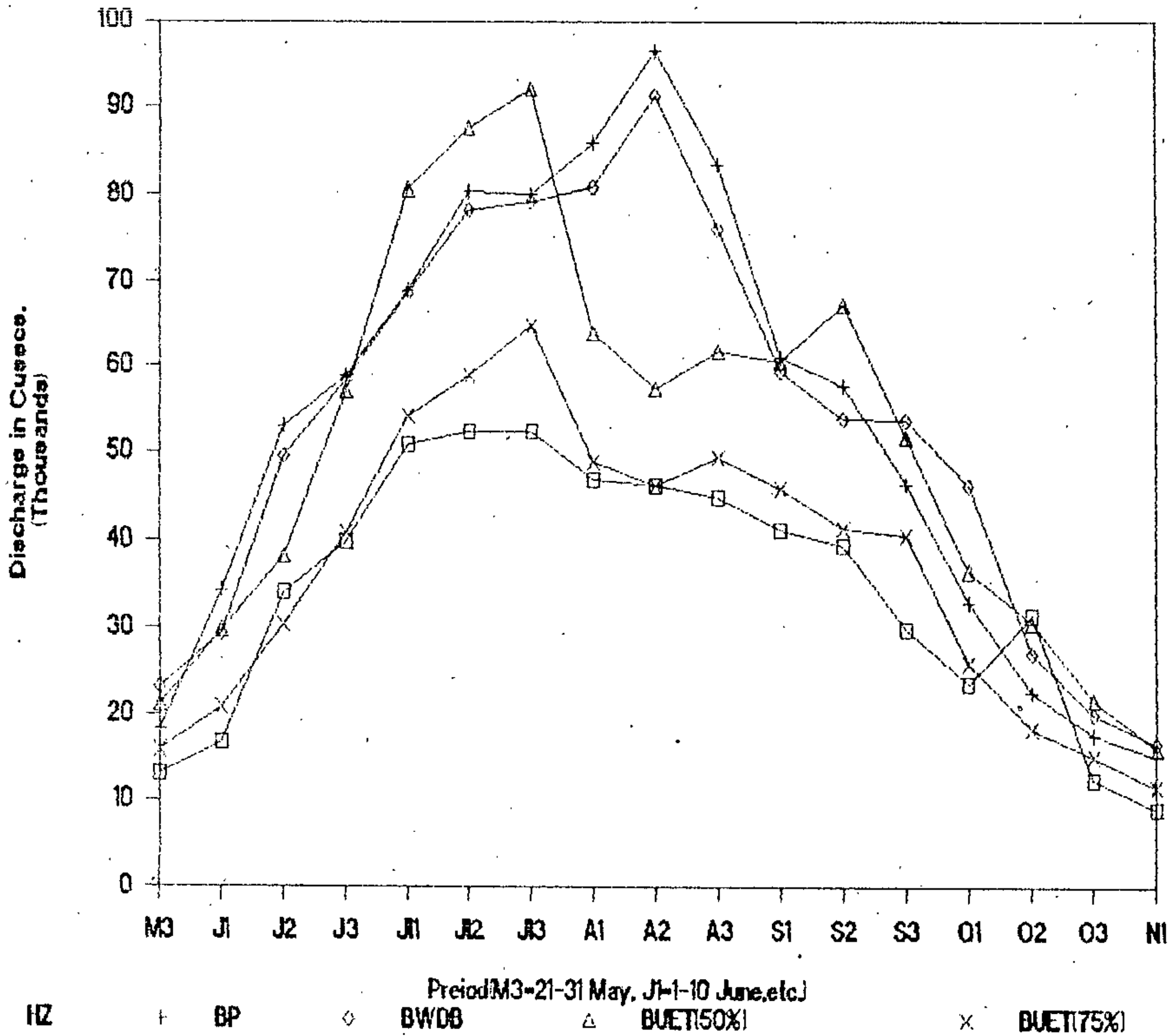

Fig. 3.4 Diagram Showing Discharges, Computed/Measured by Different Authorities, of Teesta River of Study Area on Ten Day Basis (May to November).

M/S. Binnie and Partners made a study of the availability of flow of Teesta River by analysing the data for the years 1961 to 1967. They estimated average discharges of Teesta River on ten day basis. The result is summarized in Fig. 3.4. They also considered small rivers and drainage channels within the project area and mentioned that Deonai-Charalkata and Jamuneswari-Karatoya river systems could act as auxiliary sources of surface water for irrigation. They gathered information about ground water resources of the project area mainly from the reports of Lackner (1965) and Russo (1966) and it was observed by them that one of the major source of irrigation in the Floodplain of the project area is ground water. They formulated the irrigation planning considering that irrigation requirements in the Floodplain will be met from ground water and in the Barind Tracts from the flow of Teesta river.

BWDB (1984) made a detailed study on the availability of irrigation water from the flow of Teesta river and analysed the discharge of Teesta river at Dalia for the years 1961 to 1980 on a ten day basis. The discharges at 50 percent probability level are summarized in Fig. 3.4. They did not undertake any study on the availability of irrrigation water either from other rivers or ground water sources.

BUET and BWDB (1987) conducted jointly an elaborate study on the availability of irrigation water from the flow of Teesta and other internal river systems as well as from the ground water resource of the project area. They analyzed the discharge data of Teesta river at Dalia for the years 1961 to 1984 on the basis of ten day period. They estimated the ten day flow of Teesta river at 50 percent and 75 percent probability level. These are presented in Fig. 3.4.

For the present study, the ten day discharges of Teesta river estimated jointly by BUET and BWDB (1987) have been taken as the available flow of Teesta River. It is understood from the sharing agreement on Teesta flow with India that Bangladesh will get 36 percent of the total lean period flow for irrigation at Dalia. Considering this fact, the available 50 percent and 75 percent dependable Teesta flow for irrigation have been computed. The results are presented in Table 3.1.

3.2.2 Soil Pattern and Land Use:

The project area is formed by the deposition of three different parent materials, namely piedmont alluvium, Teesta alluvium and Barind tracts. Piedmont alluvium are developed by unconsolidated subrecent sediments laid down by the rivers draining the foot hills of the Himalayas. Teesta alluvium is underlain by recent, subrecent and older flood plain sediment of Teesta river and its tributaries. Barind tracts present older, somewhat compact alluvium termed Madhupur clay. According to the

Table 3.1 Available Flow of Teesta River for Irrigation (May to November).

Month	Period	Available Teesta Flow (cusecs) at	
		50% Probability	75% Probability
May	21-31	7,980	5,700
June	1-10	10,700	7,460
	11-20	13,730	10,900
	21-30	20,530	14,700
July	1-10	29,000	19,500
	11-20	31,500	21,200
	21-31	33,100	23,300
August	1-10	23,000	17,600
	11-20	20,690	16,600
	21-31	22,200	17,800
September	1-10	21,800	16,500
	11-20	24,200	14,900
	21-30	18,600	14,600
October	1-10	13,100	9,300
	11-20	11,000	6,600
	21-31	7,800	5,450
November	1-10	5,800	4,150

Source : BRTC, BUET and BWDB, 1987

reconnaissance soil survey conducted by erstwhile Soil Survey Directorate, presently the Soil Resource Development Institute, in the late sixties, the project area consists of 75 soil associations as shown in the soil association map (Fig. 3.5). The soils of the project area are deep and the texture ranges from sand to clay. Most of the soils are suitable for irrigation. The relief of the project area is variable but well within the limit of irigation management.

According to the above mentioned soil survey report, the land of Teesta Project area may be broadly classified into two catagories viz., (a) Floodplain and (b) Barind Tracts. The catagories of land classification are shown below.

	Gross Area (Acres)	Percentage
a) Teesta Alluvium Floodplain	1,100,000	60%
b) Barind Tracts	750,000	40%
Total:	1,850,000	100%

According to the hydrologic zones mentioned earlier, the type of area under each hydrologic zone has been estimated as:

Fig. 3.5 Soil Associations Map (Teesta Barrage Project).

Hydrologic Zone	Gross Area (Acres) in	
	Floodplain	Barind Tracts
Zone-I	421,250	0
Zone-II	516,065	212,575
Zone-III	162,685	537,425
Total:	1,100,000	750,000

Grand total = 1,850,000 Acres

Land use pattern in the project area over last few years indicates a decreasing trend in the availability of the cultivable land. This might be due to the expansion of habitat and the increased developmental activities in the rural areas. It is observed from the recent figures of the Bangladesh Bureau of Statistcs (BBS, 1986) that about 80 percent land in the Barind Tracts is cultivable whereas this figure for Floodplain areas is about 72 percent. In view of this trend, the availability of land for cultivation in future will not increase rather decrease. In post project condition it is reasonable to consider that about 70 percent of Floodplain lands and 76 percent of the Barind Tracts may be available for cultivation (BUET and BWDB, 1987). According to this fact, the total cultivable area in each hydrologic zone comes out to be:

Hydrologic Zone	Cultivable Area (Acres) in	
	Floodplain	Barind Tracts
Zone-I	292,960	0
Zone-II	358,900	161,557
Zone-III	113,140	408,443
Total:	765,000	570,000
Grand total = 1,335,000 Acres		

According to the recommendation made by BUET and BWDB (1987), it is observed that out of total cultivable area, about 97.5 percent area of Floodplain and about 94 percent area of Barind Tracts might be brought under irrigation. The remaining area can not be brought under irrigation because the contours of these area are very high. Since Teesta Barrage Project is a gravity irrigation project it is not feasible to irrigate these elevated areas. Therefore, the cultivable area for irrigation becomes:

Hydrologic Zone	Irrigable Area (Acres) in	
	Floodplain	Barind Tracts
Zone-I	285,939	0
Zone-II	350,299	151,794
Zone-III	110,429	383,761
Total:	746,667	535,555
Grand total = 1,282,222 Acres		

Present cropping practices and cropping pattern in the project area mainly depend on the vagaries of nature. From the available data on crop statistics for the years 1974-75 to 1981-82, BWDB (1985) mentioned that the cropping intensity was increased from 162 percent in the year 1974-75 to 178 percent in the year 1981-82. They proposed the cropping intensity as 198 percent during post project condition. The project area is predominantly a rice growing area. Other important crops in the project area are jute, wheat, tobacco, sugercane, potato, oilseeds, spices etc. Rice will be the main crop grown in the project area. Out of the three varieties of rice (Aus, Aman and Boro) the predominant variety in the project area is Aman, which occupies about 85 percent of the cultivable lands in the Barind Tracts and about 80 percent in the Floodplain areas (BUET and BWDB, 1987). For the present study, HYV Transplanted Aman (T. Aman) has been selected as the crop to be grown during the post project condition when supplemental irrigation will be provided. According to the recommendation made jointly by BUET and BWDB (1987), it can be confortably presumed that 90 percent of the cultivable land under irrigation command may be brought under HYV T. Aman cultivation. Considering this fact the total T. Aman area becomes:

Hydrologic Zone	T. Aman Area (Acres) in	
	Floodplain	Barind Tracts
Zone-I	257,345	0
Zone-II	315,269	136,615
Zone-III	99,386	345,385
Total:	672,000	482,000
Grand Total = 1,154,000 Acres.		

For better utilization of the available water resource and optimization of the command area, crop staggering approach with early transplantation should be adopted as cropping practice. This crop staggering is possible only in those areas where HYV T. Aman can be transplanted earlier. It is observed from agricultural statistics of last few years that about 35 percent of Barind land under Rangpur canal and about 70 percent of Barind land under Bogra canal remains fallow during Kharif-I season (BWDB and BUET, 1987). In this fallow Barind land HYV T. Aman can be transplanted earlier than normal transplanting. This is possible in case of HYV T. Aman which is not photo-sensitive like the traditional varieties. Considering the above mentioned fact, the Barind Tracts can be grouped as:

Hydrologic Zone	Fallow Barind Land During Kharif-I Season (Acres)	Barind Land with Kharif-I Crops (Acres)
Zone-I	0	0
Zone-II	72,679	63,936
Zone-III	241,770	103,615
Total:	314,449	167,615

Grand Total = 482,000 Acres

3.2.3 Other Resource Inputs:

In order to develop an optimal irrigation plan of any irrigation project, the irrigation management practice to be applied depends not only upon the availability of water for irrigation and agricultural land but also upon the irrigation infra-structure, the availability of labor, equipment and capital, the expertise of the irrigators, quality seeds and fertilizers used, and insect, disease and weed control measures. For simplicity, all these inputs other than agricultural land and irrigation water are assumed to be available in adequate quantities when required.

3.3 Irrigation Water Requirements for HYV Rice

The requirement of water for a rice crop varies with seasons, time of sowing/planting, texture and structure of the soil, fertility level of the land and the cultivars grown. The components of water requirement for rice are evapotraspiration, seepage and percolation and surface drainage. The actual water requirement of a rice crop during its normal growth period is primarily for evapotraspiration, but in applying water in the field, some seepage, percolation and surface drainage is inevitable (Fig. 3.6). In addition, water is also required for land preparation before the seedlings can be transplanted.

3.3.1 Land Preparation Requirements:

Land preparation for rice cultivation involves soaking the root zone soil to saturation and then plowing and harrowing to a puddled condition. It is necessary to - provide a soil surface suitable for transplantation; mix organic matter like rice straw, stubbles and weeds with the soil to encourage decomposition; level the field for uniform distribution of agricultural inputs (irrigation water, fertilizers, pesticides etc.) and minimize the water losses by the formation of a puddled layer. Land preparation requires a substantial part of the total water supplied in growing rice. The land preparation requirement depends upon the type of soil and the pre-tillage water content

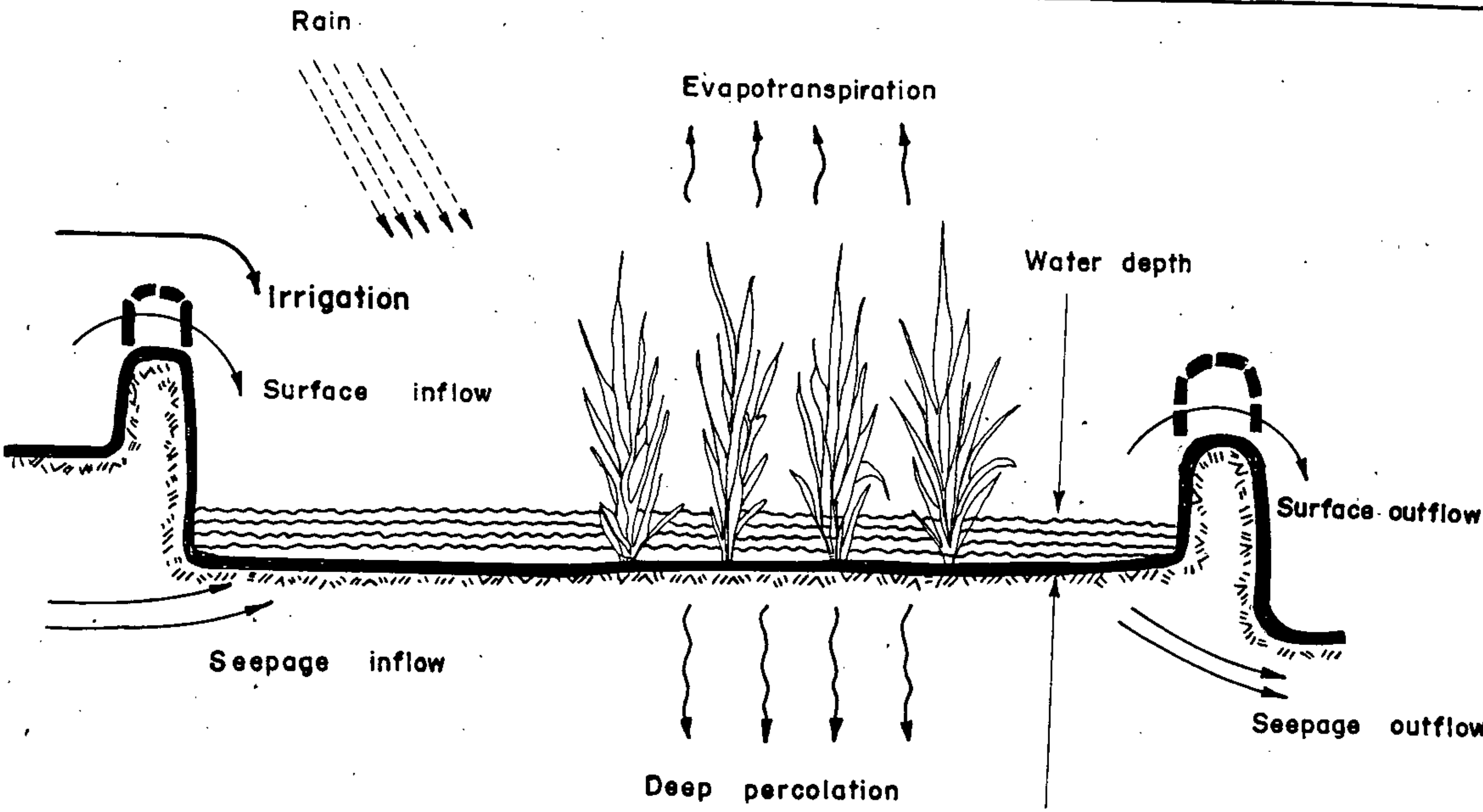

Fig. 3.6 Water Balance in Irrigated Rice(Saleh, 1981).

of soil. Rice fields require about 100-150 mm of water for land preparation and puddling operations (Datta et al., 1975; Khan,1979).

BRTC, BUET (1987) suggested to apply 200 mm of water for land preparation of both Floodplain and Barind Tracts of Teesta Barrage Project, of which 150 mm is to be applied ten days before transplantation for plowing, land soaking and puddling and the additional 50 mm in the next ten days in order to keep some standing water in the field during transplantation. This suggestion was based on the study done by Saleh (1981) at BRRI farm at Joydebpur during the Kharif season. In the present study, the aforementioned recommendations (BUET,1987) for land preparation have been taken.

3.3.2 Evapotranspiration:

Evapotranspiration is the combined effect of evaporation and transpiration. Evaporation of water takes place from either the wet soil, water surface or plant leaves. While transpiration is the water entering plant roots that is used to build plant tissue or that is passed through plant leaves into the atmosphere. The rate of evapotranspiration depends mainly upon the soil moisture status and the weather data i.e., temperature, humidity, wind speed, solar radiation. But evapotranspiration is essentially independent of the stages of crop plant growth.

There are a great number of methods available to determine or estimate the potential evapotranspiration of a reference crop. These methods are either direct or indirect. Detailed. measurements of evapotranspiration are very time consuming and expensive. But evapotranspiration data plays a vital role in managing water resources and acts as the foundation for the planning and design of most irrigation schemes.

The detailed calculation of evapotranspiration is beyond the scope of the present research. For the present study, the mean monthly evapotranspiration rate as estimated by BWDB (1985) for Teesta Barrage Project area has been taken. These are presented in Table 3.2.

As the major portion of the Floodplain area of the Teesta Barrage Project is within the greater Rangpur district and that of the Barind Tracts is within the greater Bogra district, the evapotranspirations of Rangpur and Bogra stations have been considered as the representative values for Floodplain and Barind Tracts respectively. The values presented in Table 3.2 are potential evapotranspiration of a reference crop. The potential evapotranspiration of a specific crop can be obtained by relating the crop characteristics to the potential evapotranspiration of the reference crop. This can be expressed as:

Table 3.2 Mean Monthly Potential Evapotranspiration Rate (May to November).

Month	Evapotranspiration Rate, mm/day			
	Dinajpur	Rangpur*	Rangpur	Bogra
May	6.5	5.9	5.9	6.1
June	4.8	4.4	5.0	4.7
July	4.6	4.6	4.7	4.6
August	4.4	4.4	4.6	4.5
September	4.5	4.5	4.5	4.3
October	4.4	4.3	4.2	4.5
November	3.4	3.1	3.0	3.8

* Values Calculated By BRTC, BUET Using Modified Penman Method

Sources: BWDB, 1985

BRTC, BUET, 1987

$$ET_{crop} = K_C * ET_R \qquad [3.1]$$

where, ET_{crop} = Evapotranspiration of a specific crop grown in large fields under optimal soil, water and land fertility conditions

K_C = Crop coefficient

and ET_R = Reference crop potential evapotranspiration.

Crop coefficient, K_C in a specified climatic condition varies with the development stages of the crop. For rice K_C values can be obtained from FAO Irrigation and Drainage Paper-24 (Doorenbos and Pruitt, 1984). For the present study, the K_C values presented in Table 3.3 have been used.

Table 3.3 Crop Coefficient (K_C) Values for Rice.

Season	Planting	Harvest	First and Second Month	Mid-Season	Last 4 weeks
Wet season	June-July	November-December	1.10	1.05	0.95

Source: FAO Irrigation and Drainage Paper - 24, 1984.

3.3.3 Seepage and Percolation:

Theoritically, seepage is the lateral movement of sub-surface water, while percolation is the downward movement of sub-surface water beyond the root zone to the water table. However, these two terms may be considered together as a collective term, seepage and percolation, because it is very difficult to artificially seperate them in the field and because they occur simultaneously. The rate of seepage and percolation is highly variables and is influenced by the texture and structure of the soil, depth of the water table, topography of land and density of drainage network. Seepage and percolation rate is also affected by management factors e.g. puddling of the soil, soil compaction and depth of standing water. Puddling of the soil reduces the rate of seepage and percolation effectively.

For rice, the cultural practice is to maintain standing water in the field or atleast saturated soil conditions and hence seepage and percolastion loss is unavoidable and may be a major component of total water requirements. However, it can be minimized through extensive puddling of the soil during the land preparation period and avoiding drying and cracking of the soil. For irrigation planning and design purposes, seepage and percolation rate is assumed to be constant during the normal growth stages.

A great deal of research works was conducted to predict seepage and percolation losses under different field conditions. From the results of field studies conducted by Kampen, 1970;

Ghani, 1978 and Karim et al., 1983 (after Mirjahan, 1984) it is found that there is a wide variation of seepage and percolation rates.

Ghani (1978) conducted field studies to measure seepage and percolation loss in Joydebpur, Bangladesh. He used water subsidence technique and found that the weighted average seepage and percolation rate for clay loam was 1.6 mm/day. Saleh (1981) determined the seepage and percolation loss for the soil of BRRI farm at Joydebpur during the Kharif season by applying water balance approach and found that seepage and percolation losses varied from 2.32 mm to 3.68 mm per day for the Kharif-I (Aus) season and from 4.68 mm to 5.23 mm per day for Kharif-II (Aman) season.

The texture and structure of Floodplain soil of Teesta Barrage Project is more favourable for seepage and percolation losses than that of Barind Tracts soil. So, it is reasonable to consider higher values of seepage and percolation rate for Floodplain soil than Barind Tracts soil. For the present study, seepage and percolation rate has been taken as 3 mm/day and 6 mm/day for Barind Tracts and Floodplain respectively. The basis is the field study conducted by Saleh (1981) and values of seepage and percolation rate considered for different projects of BWDB.

For sensitivity analysis, another set of seepage and percolation rate i.e., 5 mm/day for Barind Tracts and 10 mm/day for Floodplain has been considered.

3.4 Dependable Rainfall

Effective rainfall refers the useful or utilizable rainfall at the time, rate or amount in which it is received. It should be interpreted as that portion of total annual or seasonal rainfall which is useful directly and/or indirectly for crop production at the site where it falls. It,therefore, includes water intercepted by living or dry vegetation, that lost by evaporation from the soil surface, the precipitation lost by evapotranspiration during growth, that fraction which contributes to leaching, percolation or facilitates other cultural operation either before or after sowing without any harm to yield and quality of the principal crops. The proportion of effective rainfall to the total rainfall received depends upon meteorological parameters, land and soil characteristics, water management practice, crop characteristics, soil water characteristics, etc.

There are several methods or formulae of assesing effective rainfall. Each method or formula has certain merits and limitations.

BRTC, BUET (1987) calculated the effective rainfall values by using the Rainfall-Potential Evapotranspiration Ratio method suggested by Dastane (1974) in FAO paper no-25. For irrigation planning, they used the rainfall at 75% probability level as dependable rainfall. The values of the dependable rainfall for each hydrologic zone are given in Table 3.4. In the present research work, the effective rainfall values suggested by BRTC team have been taken.

3.5 Water Balance for Irrigation Water Requirement

The simplest form of dynamic water balance equation for a flooded rice field is:

During the land preparation period,

$$WD_i = WD_{i-1} + IR_i + RN_i - EW_i - (S\&P)_i - SD_i \qquad [3.2]$$

During the normal growth period,

$$WD_i = WD_{i-1} + IR_i + RN_i - ET_i - (S\&P)_i - SD_i \qquad [3.3]$$

where, WD_i, WD_{i-1} = total depth of water in the field on ith and (i-1)th day respectively

IR_i = Irrigation water on ith day

RN_i = Rainfall on ith day

EW_i = Evaporation from wet surface on ith day

$(S\&P)_i$ = Seepage and percolation loss on ith day

SD_i = Surface drainage due to excessive rainfall or irrigation on ith day

Table 3.4 Dependable Rainfall of the Study Area at 75 percent Probability Level, mm (May to November).

Month	Period	Hydrologic Zones		
		zone-I	zone-II	zone-III
May	21-31	36	28	24
June	1-10	44	33	24
	11-20	70	57	44
	21-30	43	32	26
July	1-10	78	55	45
	11-20	87	57	54
	21-31	64	65	44
August	1-10	24	23	27
	11-20	33	30	29
	21-31	53	42	42
September	1-10	23	22	22
	11-20	42	37	32
	21-30	34	23	23
October	1-10	9	12	12
	11-20	2	0	0
	21-31	0	0	2
November	1-10	0	0	0

Source : BRTC, BUET, 1987

ET_i = Evapotranspiration from crop field on ith day

The different components of the water balance for irrigated rice has been shown in Fig. 3.6.

If it is assumed that water storage (WD_i ~ WD_{i-1}) does not change significantly over a period considered, and surface run-off in and out of an individual paddy field are equal, the above dynamic water balance equation to determine irrigation requirements for rice reduces to:

During the land preparation period,

$$IR_i = (EW_i + (S\&P)_i) - RN_i \tag{3.4}$$

During the normal growth period,

$$IR_i = (ET_i + (S\&P)_i) - RN_i \tag{3.5}$$

3.6 Irrigation Efficiency

Water losses occur throughout the whole irrigation system and it is convenient to group them into three catagories:

a. Water losses on the field

b. Water losses in the field canal

and c. Water losses in the main delivery system.

To describe the performance of irrigation system, the project efficiency, E_p, which is also known as overall irrigation efficiency or total efficiency of a project, should be used. The overall irrigation efficiency usually means the ratio between water made directly available to the crop and total water diverted at headworks. Project efficiency is normally subdivided into three components according to water losses. These are:

i) Conveyance efficiency, E_c: A measure of the water delivery network is its conveyance efficiency which is defined as the ratio between the volume or depth of water delivered to the field and the volume or depth of water diverted from the source.

ii) Field canal efficiency, E_b: It can be defined as the ratio between the volume or depth of water received at field inlet and the volume or depth of water diverted from the outlet main of the conveyance system.

iii) Field application efficiency, E_a: It can be defined as the ratio between the volume or depth of water directly available to the crop and the volume or depth of water delivered from the field canal outlet.

The aforementioned four efficiency values can be related by the following expression:

$$E_p = E_c * E_b * E_a \qquad [3.6]$$

For the planning of irrigation project, efficiency values are estimated on the basis of the past experience. On the basis of recommendations of ICID/ILRI, the values of conveyance, field canal and field application efficiencies are 80 percent, 80 percent and 32 percent respectively (FAO Irrigation and Drainage Paper-24). A recent study on the field water management in Ganges-Kobadak and Thakurgaon Tubewell Irrigation Projects was jointly conducted by IRRI, BRRI and BWDB and it is observed from that study that the value of field application efficiency corresponds to the value recommended by FAO.

BRTC, BUET (1987) suggested higher efficiency values for Teesta project area. According to their recommendations, each of the conveyance and field canal efficiency values is 85 percent and the field application efficiency values are 42 percent for Floodplain and 60 percent for Barind Tracts. The basis of two seperate field application efficiency values is the different seepage and percolation rates for Barind Tracts and Floodplain area. The higher efficiency values can be achieved by the proper water management in the project.

For the present study, the field application efficiency and the overall irrigation efficiency for different conditions have been calculated and presented in Table 3.5. The calculation is based on the following assumptions:

a. The average evapotranspiration rates of Rangpur and Bogra stations during May to November period have been taken as the representative values for Floodplain and Barind Tracts respectively. These are:
For Floodplain, average evapotranspiration rate = 4.56 mm/day and for Barind Tracts, the value = 4.64 mm/day.

b. The canal systems and field canal efficiencies have each been taken as 85 percent.

Table 3.5 Field Application Efficiency, E_a and Overall Irrigation Efficiency, E_p.

Land Type	Average Evapotranspiration Rate, (mm/day)	Seepage and Percolation Rate, (mm/day)	Field Application Efficiency, $E_a = ET/(ET+S\&P)*100$ (Percent)	Overall Irrigation Efficiency, $E_p = E_c * E_b * E_a$ (Percent)
Floodplain	4.56	6	43	31
		10	31	22
Barind Tracts	4.64	3	61	44
		5	48	35

3.7 Diversion Requirements:

The calculation of net irrigation requirements during land preparation and normal growth period of the crop is based upon the respective dynamic water balance equations mentioned earlier. The net irrigation requirements for Floodplain and Barind areas for each of the hydrologic zones and for each ten day period were calculated by subtracting the ten day effective rainfall from the ten day land preparation or crop water requirements. The irrigation diversion requirements at head regulator are then calculated by dividing the net irrigation requiermments by the values of irrigation efficiency.

A sample calculation of diversion requirements for Floodplain and Barind areas during the first ten day period of July for land preparation and first ten day period of October for normal growth stage for hydrologic zone-I is given in Appendix-A. The diversion requirements for different zones with different seepage and percolation rates are presented in Table 3.6 through Table 3.11.

3.8 Crop Yield

Crop yield is a function of various inputs including water, which is critically important. Inputs can be grouped as two distinct catagories viz., (a) Natural inputs and (b) Managed

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Table 3.6 Diversion Requirement for Zone-I (cusecs/100 acres).

(Seepage and Percolation Rates: 3 mm/day for Barind Tracts and 6 mm/day for Floodplain areas).

Land	May	June			July			August			September			October			November
Type	21-31	1-10	11-20	21-30	1-10	11-20	21-31	1-10	11-20	21-31	1-10	11-20	21-30	1-10	11-20	21-31	1-10
Flood-					LP*	T**											
Plain					1.648	0	0	1.419	0.939	0.129	1.414	0.280	0.467	1.649	2.022		
						LP	T										
						1.442	0	1.419	0.939	0.129	1.414	0.400	0.707	1.649	2.022	2.129	
							LP	T									
							1.790	0.595	0.939	0.129	1.414	0.400	0.827	1.873	2.022	2.129	1.521
Barind	LP	T															
Tracrs	2.373	0.137	0	0.327	0	0	0	0.874	0.367	0	0.671						
		LP	T														
		2.427	0	0.327	0	0	0	0.959	0.536	0	0.671	0					
			LP	T													
			1.832	0.160	0	0	0	0.959	0.620	0	0.671	0	0.258				
					LP	T											
					1.648	0	0	0.959	0.620	0.050	0.914	0.118	0.258	1.269	1.532		
						LP	T										
						1.442	0	0.959	0.620	0.050	0.914	0.199	0.419	1.269	1.532	1.607	
							LP	T									
							1.790	0.595	0.620	0.050	0.914	0.199	0.500	1.438	1.532	1.607	1.357

* LP = Land Preparation

** T = Transplantation

Table 3.7 Diversion Requirement for Zone-II (cusecs/100 acres).

(Seepage and Percolation Rates: 3 mm/day for Barind Tracts and 6 mm/day for Floodplain areas).

Land	May	June			July			August			September			October			November
Type	21-31	1-10	11-20	21-30	1-10	11-20	21-31	1-10	11-20	21-31	1-10	11-20	21-30	1-10	11-20	21-31	1-10
Flood-					LP*	T**											
Plain					2.175	0	0	1.473	1.099	0.663	1.467	0.547	0.244	1.489	2.129		
						LP	T										
						2.129	0	1.473	1.099	0.663	1.467	0.667	1.294	1.489	2.129	2.129	
							LP	T									
							1.769	0.618	1.099	0.663	1.467	0.667	1.414	1.713	2.129	2.129	1.521
Barind	LP	T															
Tracrs	2.539	0.389	0	0.741	0	0	0	0.912	0.479	0.172	0.709						
		LP	T														
		2.679	0	0.741	0	0	0	0.996	0.668	0.172	0.709	0.145					
			LP	T													
			2.129	0.412	0	0	0	0.996	0.733	0.341	0.709	0.145	0.671				
					LP	T											
					2.175	0	0	0.996	0.733	0.425	0.951	0.306	0.671	1.156	1.607		
						LP	T										
						2.129	0	0.996	0.733	0.425	0.951	0.387	0.833	1.156	1.607	1.607	
							LP	T									
							1.769	0.618	0.733	0.425	0.951	0.387	0.914	1.325	1.607	1.607	1.357

* LP = Land Preparation

** T = Transplantation

Table 3.8 Diversion Requirement for Zone-III (cusecs/100 acres).

(Seepage and Percolation Rates: 3 mm/day for Barind Tracts and 6 mm/day for Floodplain areas).

Land	May	June			July			August			September			October			November
Type	21-31	1-10	11-20	21-30	1-10	11-20	21-31	1-10	11-20	21-31	1-10	11-20	21-30	1-10	11-20	21-31	1-10
Flood-					LP*	T**											
Plain					2.404	0	0.624	1.259	1.153	0.663	1.467	0.814	1.054	1.489	2.129		
						LP	T										
						2.198	0.125	1.259	1.153	0.663	1.467	0.934	1.294	1.489	2.129	2.032	
							LP	T									
							2.206	0.527	1.153	0.663	1.467	0.934	1.414	1.713	2.129	2.032	1.521
Barind	LP	T															
Tracrs	2.623	0.595	0.289	0.966	0.211	0	0.398	0.761	0.517	0.172	0.709						
		LP	T														
		2.885	0.137	0.966	0.211	0	0.398	0.846	0.686	0.172	0.709	0.333					
			LP	T													
			2.427	0.549	0.211	0	0.398	0.846	0.771	0.341	0.709	0.333	0.671				
					LP	T											
					2.404	0	0.398	0.846	0.771	0.425	0.951	0.494	0.671	1.156	1.607		
						LP	T										
						2.198	0.125	0.846	0.771	0.425	0.951	0.575	0.833	1.156	1.607	1.539	
							LP	T									
							2.206	0.527	0.771	0.425	0.951	0.575	0.914	1.325	1.607	1.539	1.357

* LP = Land Preparation

** T = Transplantation

Table 3.9 Diversion Requirement for Zone-I (cusecs/100 acres).

(Seepage and Percolation Rates: 5 mm/day for Barind Tracts and 10 mm/day for Floodplain areas).

Land	May	June			July			August			September			October			November
Type	21-31	1-10	11-20	21-30	1-10	11-20	21-31	1-10	11-20	21-31	1-10	11-20	21-30	1-10	11-20	21-31	1-10
Flood-					LP*	T**											
Plain					1.648	0	0	2.000	1.323	0.182	1.992	0.395	0.658	2.323	2.850		
						LP	T										
						1.442	0	2.000	1.323	0.182	1.992	0.564	0.996	2.323	2.850	3.000	
							LP	T									
							1.790	0.595	1.323	0.182	1.992	0.564	1.165	2.639	2.850	3.000	2.143
Barind	LP	T															
Tracrs	2.373	0.137	0	0.411	0	0	0	1.099	0.461	0	0.844						
		LP	T														
		2.427	0	0.411	0	0	0	1.205	0.673	0	0.844	0					
			LP	T													
			1.832	0.160	0	0	0	1.205	0.780	0	0.844	0	0.324				
					LP	T											
					1.648	0	0	1.205	0.780	0.062	1.148	0.149	0.324	1.595	1.926		
						LP	T										
						1.442	0	1.205	0.780	0.062	1.148	0.250	0.527	1.595	1.926	2.020	
							LP	T									
							1.790	0.595	0.780	0.062	1.148	0.250	0.629	1.808	1.926	2.020	1.706

* LP = Land Preparation

** T = Transplantation

Table 3.10 Diversion Requirement for Zone-II (cusecs/100 acres).

(Seepage and Percolation Rates: 5 mm/day for Barind Tracts and 10 mm/day for Floodplain areas).

Land	May	June			July			August			September			October			November
Type	21-31	1-10	11-20	21-30	1-10	11-20	21-31	1-10	11-20	21-31	1-10	11-20	21-30	1-10	11-20	21-31	1-10
Flood-					LP*	T**											
Plain					2.175	0	0	2.075	1.549	0.934	2.068	0.771	1.485	2.098	3.000		
						LP	T										
						2.129	0	2.075	1.549	0.934	2.068	0.940	1.823	2.098	3.000	3.000	
							LP	T									
							1.769	0.618	1.549	0.934	2.068	0.940	1.992	2.413	3.000	3.000	2.143
Barind	LP	T															
Tracrs	2.539	0.389	0	0.931	0	0	0	1.146	0.603	0.216	0.891						
		LP	T														
		2.679	0	0.931	0	0	0	1.252	0.815	0.216	0.891	0.182					
			LP	T													
			2.129	0.412	0	0-	0	1.252	0.922	0.429	0.891	0.182	0.844				
					LP	T											
					2.175	0	0	1.252	0.922	0.535	1.196	0.385	0.844	1.453	2.020		
						LP	T										
						2.129	0	1.252	0.922	0.535	1.196	0.487	1.047	1.453	2.020	2.020	
							LP	T									
							1.769	0.618	0.922	0.535	1.196	0.487	1.148	1.666	2.020	2.020	1.706

* LP = Land Preparation

** T = Transplantation

Table 3.11 Diversion Requirement for Zone-III (cusecs/100 acres).

(Seepage and Percolation Rates: 5 mm/day for Barind Tracts and 10 mm/day for Floodplain areas).

Land	May	June			July			August			September			October			November
Type	21-31	1-10	11-20	21-30	1-10	11-20	21-31	1-10	11-20	21-31	1-10	11-20	21-30	1-10	11-20	21-31	1-10
Flood-					LP*	T**											
Plain					2.404	0	0.880	1.774	1.624	0.934	2.068	1.147	1.485	2.098	3.000		
						LP	T										
						2.198	0.125	1.774	1.624	0.934	2.068	1.316	1.823	2.098	3.000	2.863	
							LP	T									
							2.206	0.527	1.624	0.934	2.068	1.316	1.992	2.413	3.000	2.863	2.143
Barind	LP	T															
Tracrs	2.623	0.595	0.364	1.215	0.265	0	0.501	0.957	0.650	0.216	0.891						
		LP	T														
		2.885	0.137	1.215	0.265	0	0.501	1.063	0.862	0.216	0.891	0.418					
			LP	T													
			2.427	0.549	0.265	0	0.501	1.063	0.969	0.429	0.891	0.418	0.844				
					LP	T											
					2.404	0	0.501	1.063	0.969	0.535	1.196	0.621	0.844	1.453	2.020		
						LP	T										
						2.198	0.125	1.063	0.969	0.535	1.196	0.723	1.047	1.453	2.020	1.934	
							LP	T									
							2.206	0.527	0.969	0.535	1.196	0.723	1.148	1.666	2.020	1.934	1.706

* LP = Land Preparation

** T = Transplantation

inputs. Natural inputs include environmental variables such as solar radiation, rainfall, temperature, humidity, and insect and disease incidence while managed inputs include irrigation water, variety of crop grown, fertilizers used, and insect, disease and weed control measures.

The yield of HYV rice depends upon the soil, season, inputs application, and method of cultivation. Under optimum condition the yield potentials of HYV paddy may significantly vary with the time of transplantation.

BWDB (1987) conducted a field experiment at Amla Farm of Kushtia, Mohipur Farm of Rangpur and Thakurgoan Farm to evaluate the growth and yield performance of HYV rice under different early transplantation dates in Kharif-II season. The main purpose of this study is to propose the future cropping pattern for Teesta Project area during post project condition. They performed the experiment for HYV varieties BR-1 and BR-3, both of which are photo-insensitive. During this research work the agronomical and the yield data of this study have been collected from the Land and Water Use Directorate, BWDB, Dhaka and also from each of the farms. The collected yield data are presented in Table 3.12.

It is evident from Table 3.12 that the yield performance of BR-1 and BR-3 varieties grown in Mohipur Farm, Rangpur and Thakurgaon Farm are very poor compared to that of Amla Farm,

Table 3.12 Yield Data of BR-1 and BR-3 Under Different Transplanting Dates.

Transplanting Date	Yield Per Acre in Tons					
	Amla Farm		Mohipur Farm		Thakurgaon Farm	
	BR-1	BR-3	BR-1	BR-3	BR-1	BR-3
30-5-87	1.307	1.492	0.661	0.944	0.393	0.449
13-6-87	1.203	1.306	0.508	1.134	0.477	0.449
27-6-87	0.911	0.834	0.480	1.039	0.618	0.618

For Normal Transplantation (Transplanting Date: 11-20 July to 1-10 August), Yield = 1.5 Tons/Acre.

Source: BWDB, 1985 and 1987.

Kushtia. Personal contacts with Mr. M. U. Howlader, Chief Agronomist, Land and Water Use Directorate, BWDB, Dhaka and Mr. Tafazzol Hossain, Deputy Chief Agronomist, BWDB, Rangpur reveal that the reasons for the yield reduction at Thakurgaon Farm are early flooding and severe attack of various insects while the reasons for reduced yield at Mohipur Farm are - reduction of the fertility of farm soil due to leaching of water, excessive rainfall, flooding, heavy wind blows and attack of insects and diseases (blast and loose smut).

For the present study, the yield data for early transplanted HYV rice of Amla Farm have been used. For normal transplantation (Transplanting Date: 11-20 July to 1-10 August), the yield data of HYV T. Aman proposed by BWDB (1985) for Teesta Project area have been used.

CHAPTER 4

MODEL DEVELOPMENT AND APPLICATION

The planning of any irrigation project can be well demonstrated by the mathematical modelling approach by taking into account the scarce and limited resources. In this chapter, a linear mathematical model to maximize the total command area and the yield, and to determine optimal transplanting date for a crop grown under irrigation is formulated and the developed model is applied in Teesta Barrage Project which is situated in the north-western part of Bangladesh. The aim of Teesta project is to provide supplemental irrigation for Kharif-II crops in the project area during the pre and post monsoon drought period and to ensure higher yield of the Kharif-II crops through the cultivation of HYV rice under irrigation. The project features include construction of a barrage across the Teesta River at Doani, along with canal system and development of a network of irrigation and drainage systems over the entire project area to deliver irrigation water to the farms and to drain out the excess water from the farms.

Teesta Barrage Project has been selected for the application of optimization model developed in this study due to the following reasons:

1. It is still under execution stage,

2. It lies in the north-western drought prone region of Bangladesh,

and 3. Availability of data required for model application.

The LP model, explained here, is developed for predominantly rice growing areas with a monsoon climate. The model can also be applied to irrigated rice areas in other climates.

4.1 Formulation of LP Model

The formulation of the model is based upon the following assumptions:

a. All resource inputs other than agricultural land and irrigation water viz., quality seeds, fertilizers, weedicides and presticides, labour and equipment, capital or credit etc. are available in adequaate quantities.

b. Factors other than water availability in the soil do not have any effect on crop yield.

and c. For the yield maximization model, the yield of Amla Farm, Kushtia has been taken as the representative yield for the Teesta Project.

4.1.1 Decision Variables:

The decision variables used in the model are the irrigable cropped area which is denoted as X_{ijc}, where i refers to the hydrologic zone which exhibits similar hydrological characteristics; j refers to the land type which exhibits similar physical characteristics; and c refers to a particular crop to be planted.

4.1.2 Objective Functions:

The objectives of the model are to maximize the total command area and the yield of the project area. Mathematically, it can be written as:

For maximization of command area,

$$\text{Max. } Z_1 = \sum_{i=1}^{N} \sum_{j=1}^{M} \sum_{c=1}^{K} X_{ijc} \qquad [4.1]$$

For maximization of yield,

$$\text{Max. } Z_2 = \sum_{i=1}^{N} \sum_{j=1}^{M} \sum_{c=1}^{K} Y_{ijc} * X_{ijc} \qquad [4.2]$$

in which Z_1 is the total command of the study area; Z_2 is the total yield of agricultural products in the study area; N is the number of hydrologic zones in study area; M is the number of land types in the study area; K is the number of crops to be planted;

and Y_{ijc} is the yield of crop per acre of cropped area, X_{ijc}.

4.1.3 Constraints:

The constraints considered for the development of the model are as follows:

1. The total cropped area in any particular period should not exceed the area available for agriculture. Mathematically, it can be stated as:

$$\sum_{i=1}^{N} \sum_{j=1}^{M} \sum_{c=1}^{K} X_{ijc} \leq A \qquad [4.3]$$

where, A is the total area available for cultivation.

2. The total area planted with any crop, c in any particular land type, j can not exceed the area available in land type, j in each zone, i. The symbolic representation of this constrtaint is:

$$\sum_{c=1}^{K} X_{ijc} \leq A_{ij}, \; i = 1, 2, . . N \;\&\; j = 1, 2, . . M \qquad [4.4]$$

where, A_{ij} is the area available in land type, j and in hydrological zone, i.

3. The total amount of irrigation water required during a particular period of growing season should not exceed the total available water for irrigation purposes.

$$\sum_{i=1}^{N} \sum_{j=1}^{M} \sum_{c=1}^{K} W_{ijct} * X_{ijc} \leq Q_t, \text{ for all values of t.} \qquad [4.5]$$

and $Q_t \leq$ Design capacity of canal system.

where, W_{ijct} is the total amount of water required per unit cropped area in each hydrologic zone, i and in each land type, j with crop, c in each period, t of a particular growing season; and Q_t is the available irrigation water in period, t.

4. Each decision variables should have a zero or non-negative values.

   i.e., $X_{ijc} \geq 0$, for all values of i, j, c. [4.6]

4.2 Application

The model developed in the previous article of this chapter has been applied for Teesta Barrage Project under two seperate cropping practices: (1) the normal transplantation condition where HYV T. Aman can be transplanted in normal transplantation period (Second and Third ten days of July and First ten day of August) and (2) the early transplantation condition where crop staggering approach with early transplantation dates can be adopted. This crop staggering is possible only in those area where HYV T. Aman can be transplanted earlier than normal season. For early transplantation, certain percentage of Barind Tracts as stated in the previous chapter have been selected. The model is developed for two seperate objective functions viz., maximizing (1) the total acreages and (2) the total crop yield of the project area. The decision variables of the model are the irrigable cropped areas in each hydrologic zone and in each land type with a particular crop to be planted.

For the present study, only HYV T. Aman has been selected for irrigation. Hence the decision variables can be defined as X_{ij}, where i refers to the hydrologic zones (I to III) and j refers to the land types (Floodplain and Barind Tracts). These variables can be stated as:

X_{11} = Acreages in zone-I and in Floodplain.

X_{12} = Acreages in zone-I and in Barind Tracts.

= 0; since there is no Barind Tracts area in zone-I.

X_{21} = Acreages in zone-II and in Floodplain.

X_{22} = Acreages in zone-II and in Barind Tracts.

X_{31} = Acreages in zone-III and in Floodplain.

X_{32} = Acreages in zone-III and in Barind Tracts.

4.2.1 Description of LP model:

The development of LP model for Teesta Barrage Project is based upon the considerations stated in the previous chapter. The mathematical statement of the model under different conditions can be written as:

4.2.1.1 Under Normal Transplantation Condition:

The decision variables of the model are defined as:

X_{11}^{1} = Irrigable area of Floodplain in zone-I with a transplantation date, 11-20 July.

X_{11}^{2} = Irrigable area of Floodplain in zone-I with a transplantation date, 21-31 July.

X_{11}^{3} = Irrigable area of Floodplain in zone-I with a transplantation date, 1-10 August.

X_{21}^{1} = Irrigable area of Floodplain in zone-II with a transplantation date, 11-20 July.

X_{21}^{2} = Irrigable area of Floodplain in zone-II with a transplantation date, 21-31 July.

X_{21}^{3} = Irrigable area of Floodplain in zone-II with a transplantation date, 1-10 August.

X_{22}^{1} = Irrigable area of Barind Tracts in zone-II with a transplantation date, 11-20 July.

X_{22}^{2} = Irrigable area of Barind Tracts in zone-II with a transplantation date, 21-31 July.

X_{22}^{3} = Irrigable area of Barind Tracts in zone-II with a transplantation date, 1-10 August.

X_{31}^{1} = Irrigable area of Floodplain in zone-III with a transplantation date, 11-20 July.

X_{31}^{2} = Irrigable area of Floodplain in zone-III with a transplantation date, 21-31 July.

X_{31}^{3} = Irrigable area of Floodplain in zone-III with a transplantation date, 1-10 August.

X_{32}^{1} = Irrigable area of Barind Tracts in zone-III with a transplantation date, 11-20 July.

X_{32}^{2} = Irrigable area of Barind Tracts in zone-III with a transplantation date, 21-31 July.

X_{32}^{3} = Irrigable area of Barind Tracts in zone-III with a transplantation date, 1-10 August.

The objective functions are:

$$\text{Max. } Z_1 = X_{11}^{1} + X_{11}^{2} + X_{11}^{3} + X_{21}^{1} + X_{21}^{2} + X_{21}^{3} + X_{22}^{1} + X_{22}^{2} + X_{22}^{3} + X_{31}^{1} + X_{31}^{2} + X_{31}^{3} + X_{32}^{1} + X_{32}^{2} + X_{32}^{3}. \quad [4.7]$$

$$\text{Max. } Z_2 = 0.911*X_{11}^{1} + 1.5*(X_{11}^{2} + X_{11}^{3}) + 0.911*X_{21}^{1} + 1.5*(X_{21}^{2} + X_{21}^{3}) + 0.911*X_{22}^{1} + 1.5*(X_{22}^{2} + X_{22}^{3}) + 0.911*X_{31}^{1} + 1.5*(X_{31}^{2} + X_{31}^{3}) + 0.911*X_{32}^{1} + 1.5*(X_{32}^{2} + X_{32}^{3}). \quad [4.8]$$

$$\text{Max. } Z_3 = 0.834*X_{11}^{1} + 1.5*(X_{11}^{2} + X_{11}^{3}) + 0.834*X_{21}^{1} + 1.5*(X_{21}^{2} + X_{21}^{3}) + 0.834*X_{22}^{1} + 1.5*(X_{22}^{2} + X_{22}^{3}) + 0.834*X_{31}^{1} + 1.5*(X_{31}^{2} + X_{31}^{3}) + 0.834*X_{32}^{1} + 1.5*(X_{32}^{2} + X_{32}^{3}). \quad [4.9]$$

in which Z_1 = Total irrigable cropped area.

Z_2 = Total crop yield for crop yield data of Amla farm (BR-1).

Z_3 = Total crop yield for crop yield data of Amla farm (BR-3).

The constraints are:

Land Availability Constraints:-

$$X_{11}^1 + X_{11}^2 + X_{11}^3 + X_{21}^1 + X_{21}^2 + X_{21}^3 + X_{22}^1 + X_{22}^2 + X_{22}^3 + X_{31}^1 + X_{31}^2 + X_{31}^3 + X_{32}^1 + X_{32}^2 + X_{32}^3 \leq 1,154,000. \quad [4.10]$$

$$X_{11}^1 + X_{11}^2 + X_{11}^3 \leq 257,345. \quad [4.11]$$

$$X_{21}^1 + X_{21}^2 + X_{21}^3 \leq 315,269. \quad [4.12]$$

$$X_{22}^1 + X_{22}^2 + X_{22}^3 \leq 136,615. \quad [4.13]$$

$$X_{31}^1 + X_{31}^2 + X_{31}^3 \leq 99,386. \quad [4.14]$$

$$X_{32}^1 + X_{32}^2 + X_{32}^3 \leq 345,385. \quad [4.15]$$

The value on the left hand side of Eqn. [4.10] is the total irrigable area and those of Eqns. [4.11] to [4.15] are the areas of each land type in each hydrologic zone and have been obtained from Art. 3.2.2 of Chapter 3.

Irrigation Water Availability Constraints:-

The irrigation water availability constraints for different ten day periods (First ten day of July to first ten day of

November) and for different seepage and percolation rates are presented in Table 4.1 and Table 4.2. The coefficient matrices of these tables are developed from Table 3.6 to Table 3.11.

Non-negativity Constraints:-

All the decision variables mentioned above should have zero or positive values.

i.e., $[X] \geq 0.$ [4.16]

where, $[X]$ is a column matrix which is defined as -

$$[X] = [X_{11}^{1} \quad X_{11}^{2} \quad X_{11}^{3} \quad X_{21}^{1} \quad X_{21}^{2} \quad X_{21}^{3} \quad X_{22}^{1} \quad X_{22}^{2} \quad X_{22}^{3} \quad X_{31}^{1} \quad X_{31}^{2} \quad X_{31}^{3} \quad X_{32}^{1} \quad X_{32}^{2} \quad X_{32}^{3}]'.$$

4.2.1.2 Under Early Transplantation Condition:

The decision variables of the model are defined as:

X_{11}^{1} = Irrigable area of Floodplain in zone-I with a transplantation date, 11-20 July.

X_{11}^{2} = Irrigable area of Floodplain in zone-I with a transplantation date, 21-31 July.

X_{11}^{3} = Irrigable area of Floodplain in zone-I with a transplantation date, 1-10 August.

X_{21}^{1} = Irrigable area of Floodplain in zone-II with a transplantation date, 11-20 July.

Table 4.1 Irrigation Water Availability Constraints Under Normal Transplantation Condition.

(Seepage and Percolation Rates: 3 mm/day for Barind Tracts and 6 mm/day for Floodplain).

Probability Level of Teesta Flow: 50% (first right-hand column), 75% (second right-hand column)

$$\begin{bmatrix} 1.648 & & & 2.175 & & & 2.175 & & & 2.404 & & & 2.404 & & \\ 0 & 1.442 & & 0 & 2.129 & & 0 & 2.129 & & 0 & 2.198 & & 0 & 2.198 & \\ 0 & 0 & 1.790 & 0 & 0 & 1.769 & 0 & 0 & 1.769 & .624 & .125 & 2.206 & .398 & .125 & 2.206 \\ 1.419 & 1.419 & .595 & 1.473 & 1.473 & .618 & .996 & .996 & .618 & 1.259 & 1.259 & .527 & .846 & .846 & .527 \\ .939 & .939 & .939 & 1.099 & 1.099 & 1.099 & .733 & .733 & .733 & 1.153 & 1.153 & 1.153 & .771 & .771 & .771 \\ .129 & .129 & .129 & .663 & .663 & .663 & .425 & .425 & .425 & .663 & .663 & .663 & .425 & .425 & .425 \\ 1.414 & 1.414 & 1.414 & 1.467 & 1.467 & 1.467 & .951 & .951 & .951 & 1.467 & 1.467 & 1.467 & .951 & .951 & .951 \\ .280 & .400 & .400 & .547 & .667 & .667 & .306 & .387 & .387 & .814 & .934 & .934 & .494 & .575 & .575 \\ .467 & .707 & .827 & .244 & 1.294 & 1.414 & .671 & .833 & .914 & 1.054 & 1.294 & 1.414 & .671 & .833 & .914 \\ 1.649 & 1.649 & 1.873 & 1.489 & 1.489 & 1.713 & 1.156 & 1.156 & 1.325 & 1.489 & 1.489 & 1.713 & 1.156 & 1.156 & 1.325 \\ 2.022 & 2.022 & 2.022 & 2.129 & 2.129 & 2.129 & 1.607 & 1.607 & 1.607 & 2.129 & 2.129 & 2.129 & 1.607 & 1.607 & 1.607 \\ & 2.129 & 2.129 & & 2.129 & 2.129 & & 1.607 & 1.607 & & 2.032 & 2.032 & & 1.539 & 1.539 \\ & & 1.521 & & & 1.521 & & & 1.357 & & & 1.521 & & & 1.357 \end{bmatrix} * 1/100^{*} \begin{bmatrix} X_{11}^{1} \\ X_{11}^{2} \\ X_{11}^{3} \\ X_{21}^{1} \\ X_{21}^{2} \\ X_{21}^{3} \\ X_{22}^{1} \\ X_{22}^{2} \\ X_{22}^{3} \\ X_{31}^{1} \\ X_{31}^{2} \\ X_{31}^{3} \\ X_{32}^{1} \\ X_{32}^{2} \\ X_{32}^{3} \end{bmatrix} \leq \begin{bmatrix} 8,000^{*} \\ 8,000 \\ 8,000 \\ 8,000 \\ 8,000 \\ 8,000 \\ 8,000 \\ 8,000 \\ 8,000 \\ 8,000 \\ 8,000 \\ 7,800 \\ 5,800 \end{bmatrix} \quad \begin{bmatrix} 8,000 \\ 8,000 \\ 8,000 \\ 8,000 \\ 8,000 \\ 8,000 \\ 8,000 \\ 8,000 \\ 8,000 \\ 8,000 \\ 6,600 \\ 5,450 \\ 4,150 \end{bmatrix}$$

* Design Capacity of the Canal

Table 4.2 Irrigation Water Availability Constraints Under Normal Transplantation Condition.

(Seepage and Percolation Rates: 5 mm/day for Barind Tracts and 10 mm/day for Floodplain).

Probability Level of Teesta Flow

																		50%	75%
1.648			2.175			2.175			2.404			2.404			*1/100*	X_{11}^{1}	≤	8,000*	8,000
0	1.442		0	2.129		0	2.129		0	2.198		0	2.198			X_{11}^{2}		8,000	8,008
0	0	1.79	0	0	1.769	0	0	1.769	.880	.125	2.206	.501	.125	2.206		X_{11}^{3}		8,000	8,000
2.000	2.000	.595	2.075	2.075	.618	1.252	1.252	.618	1.774	1.774	.527	1.063	1.063	.527		X_{21}^{1}		8,000	8,000
1.323	1.323	1.323	1.549	1.549	1.549	.922	.922	.922	1.642	1.642	1.642	.969	.969	.969		X_{21}^{2}		8,000	8,000
.182	.182	.182	.934	.934	.934	.535	.535	.535	.934	.934	.934	.535	.535	.535		X_{21}^{3}		8,000	8,000
1.992	1.992	1.992	2.068	2.068	2.068	1.196	1.196	1.196	2.068	2.068	2.068	1.196	1.196	1.196		X_{22}^{1}		8,000	8,000
.395	.564	.564	.771	.940	.940	.385	.487	.487	1.147	1.316	1.316	.621	.723	.723		X_{22}^{2}		8,000	8,000
.658	.996	1.165	1.485	1.823	1.992	.844	1.047	1.148	1.485	1.823	1.992	.844	1.047	1.148		X_{22}^{3}		8,000	8,000
2.323	2.323	2.639	2.098	2.098	2.413	1.453	1.453	1.666	2.098	2.089	2.413	1.453	1.453	1.666		X_{31}^{1}		8,000	8,000
2.850	2.850	2.850	3.000	3.000	3.000	2.020	2.020	2.020	3.000	3.000	3.000	2.020	2.020	2.020		X_{31}^{2}		8,000	6,600
	3.000	3.000		3.000	3.000		2.020	2.020		2.863	2.863		1.934	1.934		X_{31}^{3}		7,800	5,450
		2.143			2.143			1.706			2.143			1.706		X_{32}^{1}		5,800	4,150
																X_{32}^{2}			
																X_{32}^{3}			

* Design Capacity of the Canal

X_{21}^{2} = Irrigable area of Floodplain in zone-II with a transplantation date, 21-31 July.

X_{21}^{3} = Irrigable area of Floodplain in zone-II with a transplantation date, 1-10 August.

X_{22}^{I} = Irrigable area of Barind Tracts in zone-II with a transplantation date, 1-10 June.

X_{22}^{II} = Irrigable area of Barind Tracts in zone-II with a transplantation date, 11-20 June.

X_{22}^{III} = Irrigable area of Barind Tracts in zone-II with a transplantation date, 21-30 June.

X_{22}^{1} = Irrigable area of Barind Tracts in zone-II with a transplantation date, 11-20 July.

X_{22}^{2} = Irrigable area of Barind Tracts in zone-II with a transplantation date, 21-31 July.

X_{22}^{3} = Irrigable area of Barind Tracts in zone-II with a transplantation date, 1-10 August.

X_{31}^{1} = Irrigable area of Floodplain in zone-III with a transplantation date, 11-20 July.

X_{31}^{2} = Irrigable area of Floodplain in zone-III with a transplantation date, 21-31 July.

X_{31}^{3} = Irrigable area of Floodplain in zone-III with a transplantation date, 1-10 August.

X_{32}^{I} = Irrigable area of Barind Tracts in zone-III with a transplantation date, 1-10 June.

X_{32}^{II} = Irrigable area of Barind Tracts in zone-III with a transplantation date, 11-20 June.

X_{32}^{III} = Irrigable area of Barind Tracts in zone-III with a transplantation date, 21-30 June.

X_{32}^{1} = Irrigable area of Barind Tracts in zone-III with a transplantation date, 11-20 July.

X_{32}^{2} = Irrigable area of Barind Tracts in zone-III with a transplantation date, 21-31 July.

X_{32}^{3} = Irrigable area of Barind Tracts in zone-III with a transplantation date, 1-10 August.

The objective functions are:

$$\text{Max. } Z_a = X_{11}^{1} + X_{11}^{2} + X_{11}^{3} + X_{21}^{1} + X_{21}^{2} + X_{21}^{3} + X_{22}^{I} + X_{22}^{II} + X_{22}^{III} + X_{22}^{1} + X_{22}^{2} + X_{22}^{3} + X_{31}^{1} + X_{31}^{2} + X_{31}^{3} + X_{32}^{I} + X_{32}^{II} + X_{32}^{III} + X_{32}^{1} + X_{32}^{2} + X_{32}^{3}. \qquad [4.17]$$

$$\text{Max. } Z_b = 0.911*X_{11}^{1} + 1.5*(X_{11}^{2} + X_{11}^{3}) + 0.911*X_{21}^{1} + 1.5*(X_{21}^{2} + X_{21}^{3}) + 1.307*(X_{22}^{I} + X_{22}^{II}) + 1.203*X_{22}^{III} + 0.911*X_{22}^{1} + 1.5*(X_{22}^{2} + X_{22}^{3}) + 0.911*X_{31}^{1} + 1.5*(X_{31}^{2} + X_{31}^{3}) + 1.307*(X_{32}^{I} + X_{32}^{II}) + 1.203*X_{32}^{III} + 0.911*X_{32}^{1} + 1.5*(X_{32}^{2} + X_{32}^{3}). \qquad [4.18]$$

$$\text{Max. } Z_c = 0.834*X_{11}^{1} + 1.5*(X_{11}^{2} + X_{11}^{3}) + 0.834*X_{21}^{1} + 1.5*(X_{21}^{2} + X_{21}^{3}) + 1.492*(X_{22}^{I} + X_{22}^{II}) + 1.306*X_{22}^{III} + 0.834*X_{22}^{1} + 1.5*(X_{22}^{2} + X_{22}^{3}) + 0.834*X_{31}^{1} + 1.5*(X_{31}^{2} + X_{31}^{3}) + 1.492*(X_{32}^{I} + X_{32}^{II}) + 1.306*X_{32}^{III} + 0.834*X_{32}^{1} + 1.5*(X_{32}^{2} + X_{32}^{3}). \qquad [4.19]$$

in which Z_a = Total irrigable cropped area.

Z_b = Total crop yield for crop yield data of Amla farm (BR-1).

Z_c = Total crop yield for crop yield data of Amla farm (BR-3).

The constraints are:

Land Availability Constraints:-

$$X_{11}^{1} + X_{11}^{2} + X_{11}^{3} + X_{21}^{1} + X_{21}^{2} + X_{21}^{3} + X_{22}^{I} + X_{22}^{II} + X_{22}^{III} + X_{22}^{1} + X_{22}^{2} + X_{22}^{3} + X_{31}^{1} + X_{31}^{2} + X_{31}^{3} + X_{32}^{I} + X_{32}^{II} + X_{32}^{III} + X_{32}^{1} + X_{32}^{2} + X_{32}^{3} \leq 1{,}154{,}000 \quad [4.20]$$

$$X_{11}^{1} + X_{11}^{2} + X_{11}^{3} \leq 257{,}345 \quad [4.21]$$

$$X_{21}^{1} + X_{21}^{2} + X_{21}^{3} \leq 315{,}269 \quad [4.22]$$

$$X_{22}^{I} + X_{22}^{II} + X_{22}^{III} \leq 72{,}679 \quad [4.23]$$

$$X_{22}^{1} + X_{22}^{2} + X_{22}^{3} \leq 63{,}936 \quad [4.24]$$

$$X_{31}^{1} + X_{31}^{2} + X_{31}^{3} \leq 99{,}386 \quad [4.25]$$

$$X_{32}^{I} + X_{32}^{II} + X_{32}^{III} \leq 241{,}770 \quad [4.26]$$

$$X_{32}^{1} + X_{32}^{2} + X_{32}^{3} \leq 106{,}615 \quad [4.27]$$

The value on the left hand side of Eqn. [4.20] is the total irrigable area and those of Eqns. [4.21] to [4.27] are the areas of each land type in each hydrologic zone and have been taken from the Art.3.2.2 of Chapter 3.

Irrigation Water Availability Constraints:-

The irrigation water availability constraints for different ten day period(Third ten day of May to First ten day of November) and for different seepage and percolation rates are presented in Table 4.3 and Table 4.4. The elements of the coefficient matrices of these tables have been taken from Table 3.6 to Table 3.11.

Non-negativity Constraints:-

All the decision variables mentioned above should have zero or positive values.

i.e., $[X] \geq 0$. [4.28]

where, [X] is a column matrix which is defined as -

$$[X] = [X_{11}^{1} \quad X_{11}^{2} \quad X_{11}^{3} \quad X_{21}^{1} \quad X_{21}^{2} \quad X_{21}^{3} \quad X_{22}^{I} \quad X_{22}^{II}$$
$$X_{22}^{III} \quad X_{22}^{1} \quad X_{22}^{2} \quad X_{22}^{3} \quad X_{31}^{1} \quad X_{31}^{2} \quad X_{31}^{3} \quad X_{32}^{I}$$
$$X_{32}^{II} \quad X_{32}^{III} \quad X_{32}^{1} \quad X_{32}^{2} \quad X_{32}^{3}]'.$$

The model described above have been run in IBM PC with the help of LP software, NICELP2.BAS for the determination of optimal acreages and optimal yields of Teesta Barrage Project.

Table 4.3 Irrigation Water Availability Constraints Under Early Transplantation Condition.

(Seepage and Percolation Rates: 3 mm/day for Barind Tracts and 6 mm/day for Floodplain).

						2.539									2.623					
						.389	2.679								.595	2.885				
						0	0	2.129							.289	.137	2.427			
						.741	.741	.412							.966	.966	.549			
1.648			2.175			0	0	0	2.175			2.404			.211	.211	.211	2.404		
0	1.442		0	2.129		0	0	0	0	2.129		0	2.198		0	0	0	0	2.198	
0	0	1.790	0	0	1.769	0	0	0	0	0	1.769	.624	.125	2.206	.398	.398	.398	.398	.125	2.206
1.419	1.419	.595	1.473	1.473	.618	.912	.996	.996	.996	.996	.618	1.259	1.259	.527	.761	.846	.846	.846	.846	.527
.939	.939	.939	1.099	1.099	1.099	.479	.668	.733	.733	.733	.733	1.153	1.153	1.153	.517	.686	.771	.771	.771	.771
.129	.129	.129	.663	.663	.663	.172	.172	.341	.425	.425	.425	.663	.663	.663	.172	.172	.341	.425	.425	.425
1.414	1.414	1.414	1.467	1.467	1.467	.709	.709	.709	.951	.951	.951	1.467	1.467	1.467	.709	.709	.709	.951	.951	.951
.280	.400	.400	.547	.667	.667		.145	.145	.306	.387	.387	.814	.934	.934		.333	.333	.494	.575	.575
.467	.707	.827	.244	1.294	1.414			.671	.671	.833	.914	1.054	1.294	1.414			.671	.671	.833	.914
1.649	1.649	1.873	1.489	1.489	1.713				1.156	1.156	1.325	1.489	1.489	1.713				1.156	1.156	1.325
2.022	2.022	2.022	2.129	2.129	2.129				1.607	1.607	1.607	2.129	2.129	2.129				1.607	1.607	1.607
	2.129	2.129		2.129	2.129					1.607	1.607		2.032	2.032					1.539	1.539
		1.521			1.521						1.357			1.521						1.357

1/100

X_{11}^{1}
X_{11}^{2}
X_{11}^{3}
X_{21}^{1}
X_{21}^{2}
X_{21}^{3}
X_{22}^{I}
X_{22}^{II}
X_{22}^{III}
X_{22}^{1}
X_{22}^{2}
X_{22}^{3}
X_{31}^{1}
X_{31}^{2}
X_{31}^{3}
X_{32}^{I}
X_{32}^{II}
X_{32}^{III}
X_{32}^{1}
X_{32}^{2}
X_{32}^{3}

≤

Probability level of Teesta Flow

50%	75%
7,980	5,700
8,000*	7,460
8,000	8,000
8,000	8,000
8,000	8,000
8,000	8,000
8,000	8,000
8,000	8,000
8,000	8,000
8,000	8,000
8,000	8,000
8,000	8,000
8,000	8,000
8,000	8,000
8,000	6,600
7,800	5,450
5,800	4,150

* Design Capacity of the Canal

Table 4.4 Irrigation Water Availability Constraints Under Early Transplantation Condition.

(Seepage and Percolation Rates: 5 mm/day for Barind Tracts and 10 mm/day for Floodplain).

						2.539									2.623					
						.389	2.679								.595	2.885				
						0	0	2.129							.364	.137	2.427			
						.931	.931	.412							1.215	1.215	.549			
1.648			2.175			0	0	0	2.175			2.404			.265	.265	.265	2.404		
0	1.442		0	2.129		0	0	0	0	2.129		0	2.198		0	0	0	0	2.198	
0	0	1.790	0	0	1.769	0	0	0	0	0	1.769	.880	.125	2.206	.501	.501	.501	.501	.125	2.206
2.000	2.000	.595	2.075	2.075	.618	1.146	1.252	1.252	1.252	1.252	.618	1.774	1.774	.527	.957	1.063	1.063	1.063	1.063	.527
1.323	1.323	1.323	1.549	1.549	1.549	.603	.815	.922	.922	.922	.922	1.642	1.642	1.642	.650	.862	.969	.969	.969	.969
.182	.182	.182	.934	.934	.934	.216	.216	.429	.535	.535	.535	.934	.934	.934	.216	.216	.429	.535	.535	.535
1.992	1.992	1.992	2.068	2.068	2.068	.891	.891	.891	1.196	1.196	1.196	2.068	2.068	2.068	.891	.891	.891	1.196	1.196	1.196
.395	.564	.564	.771	.940	.940		.182	.182	.385	.487	.487	1.147	1.316	1.316		.418	.418	.621	.723	.723
.658	.996	1.165	1.485	1.823	1.992			.844	.844	1.047	1.148	1.485	1.823	1.992			.844	.844	1.047	1.148
2.323	2.323	2.639	2.098	2.098	2.413				1.453	1.453	1.666	2.098	2.089	2.413				1.453	1.453	1.666
2.850	2.850	2.850	3.000	3.000	3.000				2.020	2.020	2.020	3.000	3.000	3.000				2.020	2.020	2.020
	3.000	3.000		3.000	3.000					2.020	2.020		2.863	2.863					1.934	1.934
		2.143			2.143						1.706			2.143						1.706

1/100

X_{11}^{1}
X_{11}^{2}
X_{11}^{3}
X_{21}^{1}
X_{21}^{2}
X_{21}^{3}
X_{22}^{I}
X_{22}^{II}
X_{22}^{III}
X_{22}^{1}
X_{22}^{2}
X_{22}^{3}
X_{31}^{1}
X_{31}^{2}
X_{31}^{3}
X_{32}^{I}
X_{32}^{II}
X_{32}^{III}
X_{32}^{1}
X_{32}^{2}
X_{32}^{3}

$\leq$

Probability Level of Teesta Flow 50%	75%
7,980	5,700
8,000*	7,460
8,000	8,000
8,000	8,000
8,000	8,000
8,000	8,000
8,000	8,000
8,000	8,000
8,000	8,000
8,000	8,000
8,000	8,000
8,000	8,000
8,000	8,000
8,000	8,000
8,000	6,600
7,800	5,450
5,800	4,150

* Design Capacity of the Canal

CHAPTER 5

RESULTS AND DISCUSSION

In this chapter, the usefulness of the model developed in Chapter 4 has been demonstrated through its application in the irrigation planning of Teesta Barrage Project in order to determine the optimum transplanting dates, optimal acreages and optimal yields of HYV T. Aman. The optimal acreages and optimal yields for different cropping practices, different seepage and percolation rates, different probability levels of Teesta flow and different yield data have been obtained from a large number of computer runs in IBM PC. The results with discussion are presented in the following sections.

5.1 Determination of Optimal Acreages:

The model predicted optimal acreages of Teesta Barrage Project during Aman season under normal and early transplantation conditions for different seepage and percolation rates (3 and 5 mm/day for Barind Tracts and 6 and 10 mm/day for Floodplain areas) and different probability levels of available Teesta flow (50 percent and 75 percent) are shown in Tables 5.1 to 5.8. It is evident from these tables that under both normal and early transplantation conditions, optimal acreages of Teesta Barrage Project during Aman season vary with the seepage and

Table 5.1 Optimal Acreages of Teesta Barrage Project during Aman Season Under Normal Transplantation Condition (Seepage and Percolation Rate: 3 mm/day for Barind Tracts and 6 mm/day for Floodplain areas & Teesta Flow: At 50% Probability Level).

Hydrologic Zone	Land Type	Net Area Available for Aman Cultivation (Acres)	Irrigable HYV T. Aman Area (Acres)	Transplanting Date	Critical Period
Zone-I	Floodplain	257,345	12,575	1-10 August	21-31 July &
	Barind Tracts	0	0		11-20 October
Zone-II	Floodplain	315,269	0		
	Barind Tracts	136,615	127,812 8,803	21-31 July 1-10 August	
Zone-III	Floodplain	99,386	0		
	Barind Tracts	345,385	345,385	1-10 August	
	Total:	1,154,000	494,575		

<u>Table 5.2</u> Optimal Acreages of Teesta Barrage Project during Aman Season Under Normal Transplantation Condition (Seepage and Percolation Rate: 3 mm/day for Barind Tracts and 6 mm/day for Floodplain areas & Teesta Flow: At 75% Probability Level).

Hydrologic Zone	Land Type	Net Area Available for Aman Cultivation (Acres)	Irrigable HYV T. Aman Area (Acres)	Transplanting Date	Critical Period
Zone-I	Floodplain	257,345	0		11-20 October, 21-31 October & 1-10 November
	Barind Tracts	0	0		
Zone-II	Floodplain	315,269	0		
	Barind Tracts	136,615	45,418 19,900	21-31 July 1-10 August	
Zone-III	Floodplain	99,386	0		
	Barind Tracts	345,385	59,463 285,922	11-20 July 1-10 August	
	Total:	1,154,000	410,703		

Table 5.3 Optimal Acreages of Teesta Barrage Project during Aman Season Under Normal Transplantation Condition (Seepage and Percolation Rate: 5 mm/day for Barind Tracts and 10 mm/day for Floodplain areas & Teesta Flow: At 50% Probability Level).

Hydrologic Zone	Land Type	Net Area Available for Aman Cultivation (Acres)	Irrigable HYV T. Aman Area (Acres)	Transplanting Date	Critical Period
Zone-I	Floodplain	257,345	0		11-20 October & 1-10 November
	Barind Tracts	0	0		
Zone-II	Floodplain	315,269	0		
	Barind Tracts	136,615	50,655	1-10 August	
Zone-III	Floodplain	99,386	0		
	Barind Tracts	345,385	56,063 289,322	21-31 July 1-10 August	
	Total:	1,154,000	396,040		

Table 5.4 Optimal Acreages of Teesta Barrage Project during Aman Season Under Normal Transplantation Condition (Seepage and Percolation Rate: 5 mm/day for Barind Tracts and 10 mm/day for Floodplain areas & Teesta Flow: At 75% Probability Level).

Hydrologic Zone	Land Type	Net Area Available for Aman Cultivation (Acres)	Irrigable HYV T. Aman Area (Acres)	Transplanting Date	Critical Period
Zone-I	Floodplain	257,345	0		11-20 October, 21-31 October & 1-10 November
	Barind Tracts	0	0		
Zone-II	Floodplain	315,269	0		
	Barind Tracts	136,615	0		
Zone-III	Floodplain	99,386	0		
	Barind Tracts	345,385	44,934 38,540 243,259	11-20 July 21-31 July 1-10 August	
	Total:	1,154,000	326,733		

Table 5.5 Optimal Acreages of Teesta Barrage Project during Aman Season Under Early Transplantation Condition (Seepage and Percolation Rate: 3 mm/day for Barind Tracts and 6 mm/day for Floodplain areas & Teesta Flow: At 50% Probability Level).

Hydro-logic Zone	Land Type	Net Area Available for Aman Cultivation (Acres)	Irrigable HYV T. Aman Area (Acres)	Transplanting Date	Critical Period
Zone-I	Floodplain	257,345	19,018 238,327	11-20 July 1-10 August	21-31 July, 11-20 October &
	Barind Tracts	0	0		21-31 October
Zone-II	Floodplain	315,269	4,882	1-10 August	
	Barind Tracts(ET)	72,679	72,679	21-30 June	
	Barind Tracts(NT)	63,936	63,936	1-10 August	
Zone-III	Floodplain	99,386	0		
	Barind Tracts(ET)	241,770	241,770	21-30 June	
	Barind Tracts(NT)	103,615	35,148 68,467	21-31 July 1-10 August	
	Total:	1,154,000	744,227		

* ET - Early Transplantation
  NT - Normal Transplantation

Table 5.6 Optimal Acreages of Teesta Barrage Project during Aman Season Under Early Transplantation Condition (Seepage and Percolation Rate: 3 mm/day for Barind Tracts and 6 mm/day for Floodplain areas & Teesta Flow: At 75% Probability Level).

Hydro-logic Zone	Land Type	Net Area Available for Aman Cultivation (Acres)	Irrigable HYV T. Aman Area (Acres)	Transplanting Date	Critical Period
Zone-I	Floodplain	257,345	60,419 9,466 123,362	11-20 July 21-31 July 1-10 August	11-20 October, 21-31 October & 1-10 November
	Barind Tracts	0	0		
Zone-II	Floodplain	315,269	0		
	Barind Tracts(ET)	72,679	72,679	21-30 June	
	Barind Tracts(NT)	63,936	63,936	1-10 August	
Zone-III	Floodplain	99,386	0		
	Barind Tracts(ET)	241,770	241,770	21-30 June	
	Barind Tracts(NT)	103,615	103,615	1-10 August	
	Total:	1,154,000	675,247		

* ET - Early Transplantation
NT - Normal Transplantation

Table 5.7 Optimal Acreages of Teesta Barrage Project during Aman Season Under Early Transplantation Condition (Seepage and Percolation Rate: 5 mm/day for Barind Tracts and 10 mm/day for Floodplain areas & Teesta Flow: At 50% Probability Level).

Hydrologic Zone	Land Type	Net Area Available for Aman Cultivation (Acres)	Irrigable HYV T. Aman Area (Acres)	Transplanting Date	Critical Period
Zone-I	Floodplain	257,345	118,434 41,925	21-31 July 1-10 August	1-10 August & 1-10 September
	Barind Tracts	0	0		
Zone-II	Floodplain	315,269	0		
	Barind Tracts(ET)	72,679	72,679	21-30 June	
	Barind Tracts(NT)	63,936	63,936	11-20 July	
Zone-III	Floodplain	99,386	0		
	Barind Tracts(ET)	241,770	241,770	21-30 June	
	Barind Tracts(NT)	103,615	103,615	11-20 July	
	Total:	1,154,000	642,359		

* ET - Early Transplantation
NT - Normal Transplantation

Table 5.8 Optimal Acreages of Teesta Barrage Project during Aman Season Under Early Transplantation Condition (Seepage and Percolation Rate: 5 mm/day for Barind Tracts and 10 mm/day for Floodplain areas & Teesta Flow: At 75% Probability Level).

Hydrologic Zone	Land Type	Net Area Available for Aman Cultivation (Acres)	Irrigable HYV T. Aman Area (Acres)	Transplanting Date	Critical Period
Zone-I	Floodplain	257,345	112,824	11-20 July	11-20 October
	Barind Tracts	0	0		
Zone-II	Floodplain	315,269	0		
	Barind Tracts(ET)	72,679	72,679	21-30 June	
	Barind Tracts(NT)	63,936	63,936	1-10 August	
Zone-III	Floodplain	99,386	0		
	Barind Tracts(ET)	241,770	241,770	21-30 June	
	Barind Tracts(NT)	103,615	103,615	1-10 August	
	Total:	1,154,000	594,824		

* ET - Early Transplantation
NT - Normal Transplantation

percolation rates of the soil of the project area and the probability levels of available Teesta flow.

Under normal transplantation condition (Table 5.1 to Table 5.4), optimal acreages vary from 494,575 acres (Gross area = 770,130 acres) for seepage and percolation rate: 3 mm/day for Barind Tracts and 6 mm/day for Flooodplain areas and at 50 percent probability level of Teesta flow to 326,733 acres (Gross area = 508,170 acres) for seepage and percolation rate: 5 mm/day for Barind Tracts and 10 mm/day for Floodplain areas and at 75 percent probability level of Teesta flow. As a percentage of the total irrigable area available for Aman cultivation the values become 43 percent and 28 percent. These values are very low. But the acreages computed by BRTC, BUET(1987) by applying traditional methods of computing command area is 400,000 acres (Gross area = 617,000 acres) which is 35 percent of total irrigable area available for Aman cultivation. They considered seepage and percolation rates of 3 mm/day for Barind Tracts and 6 mm/day for Floodplain areas and 75 percent dependable flow in their analysis. Under BRTC condition the model predicted acreages is 410,703 acres (Table 5.2).

Under early transplantation condition (Table 5.5 to Table 5.8), optimal acreages vary from 744,227 acres (Gross area = 1,176,564 acres) for seepage and percolation rate: 3 mm/day for Barind Tracts and 6 mm/day for Flooodplain areas and at 50 percent probability level of Teesta flow to 594,824 acres (Gross area = 933,335 acres) for seepage and percolation rate: 5 mm/day for Barind Tracts and 10 mm/day for Floodplain areas and at 75 percent probability level of Teesta flow. As a percentage of the total irrigable area available for Aman cultivation the values are 64.5 percent and 51.5 percent. These values are also low but much higher than those under normal transplantation condition. But, as computed by BRTC, BUET (1987), optimal acreages with crop staggering approach with early transplantation dates is 515,000 acres (Gross area = 795,000 acres) which is 45 percent of total irrigable area available for Aman cultivation. For this case they also considered seepage and percolation rates of 3 mm/day and 6 mm/day for Barind Tracts and Floodplain areas respectively and 75 percent depedable flow of Teesta River. Under BRTC condition, the model predicted optimal acreages is 675,247 acres (Table 5.6) which is 58.5 percent of total irrigable area available for Aman cultivation. This value is 13.5 percent higher than the value estimated by BRTC, BUET.

Hence, crop staggering approach with early transplantation dates should be adopted for Barind Tracts to increase the optimal acreage for HYV T. Aman in Teesta Project. The transplanting date of early transplanted crop can be advanced upto the second ten day period of June (Table 5.5). Further advancement of the transplanting date in Barind Tracts does not increase the acreages of the project area.

Considering crop staggering approach with early transplantation dates as a cropping practice, the best irrigation plan for optimal acreages of Teesta Barrage Project is as presented in Table 5.5. The transplanting dates (21-30 June, 11-20 July, 21-31 July and 1-10 August) mentioned in this table for different land types in different hydrologic zones are optimal transplanting dates because these give optimal acreages of Teesta Barrage Project. The above mentioned transplanting dates should be strictly followed during post project condition to give irrigation facilities to maximum areas. It is evident from this best irigation plan that the total irrigable Floodplain area is 262,227 acres which is 39 percent of total available Floodplain area for Aman cultivation whereas the total irrigable Barind Tracts area is 482,000 acres which is 100 percent of its available value. This happens because of lower value of seepage and percolation rate and resulting higher duty of water for Barind Tracts than that for Floodplain area.

The lower value of irrigable Floodplain area may not be feasible because of social and political reasons since the farmers of these areas will not get any irrigation facility although, the irrigation canal may run through their land. M/S. Binnie and Partners (1969) raised this issue in their feasibility report and suggested that, in general, Floodplain being better aquifer be provided with grounwater irrigation in order to optimize the command area of Teesta Project. Grounwater being scarce in the Barind Tracts, the suggested irrigation plan of this study will optimize the total command area of Teesta Project.

The above mentioned tables also reveal that critical periods for almost all irrigation plan are third ten day period of July, second and third ten day periods of October and first ten day period of November. Critical period is defined as that period when the available supply of Teesta River, which is less than or equal to the design capacity of Teesta main canal, just meets the demand of the optimized command area. The supply of Teesta River exceeds the demand in all other periods. During third ten day period of July the available Teesta flow exceeds the design capacity of the main canal but the design capacity is fully utilized by the optimized command area whereas during the remaining critical periods the available flows of Teesta falls short of the design capacity. So, the command area of the project during Kharif-II season can be increased by supplying more irrigation water at these critical periods. This can be made possible by using the water from the minor rivers, if available, of the project area and by adopting the conjunctive use of ground water with surface water.

5.2 Determination of Optimal Yields:

The model predicted optimal yields of HYV T. Aman and the corresponding acreages of Teesta Barrage Project under normal and early transplantation conditions for different seepage and percolation rates (3 and 5 mm/day for Barind Tracts and 6 and 10 mm/day for Floodplain areas), different probability levels of available Teesta flow (50 percent and 75 percent) and different yield data (BR-1 and BR-3 of Amla Farm, Kushtia) are shown in Table 5.9 to Table 5.17.

Tables 5.9 to 5.12 reveal that under normal transplantation condition; optimal acreages alongwith critical periods for yield optimization objective function are same as respective acreages for land optimization objective function (Tables 5.1 to 5.4). The maximum yield can be attained from the irrigation plan presented in Table 5.9. The total yield for this irrigation plan is 741,862 tons. This value corresponds to yield data of both BR-1 and BR-3 varieties with seepage and percolation rate : 3 mm/day and 6 mm/day for Barind Tracts and Floodplain areas respectively and at 50 percent probability level of Teesta flow. Under BRTC condition the model predicted optimal yield is 582,518 tons (Table 5.10). This value corresponds to the yield data of BR-1 variety.

Under early transplantation condition (Table 5.13 to Table 5.17), the total yield varies from 1,101,159 tons (Table 5.14) to 807,395 tons (Table 5.17). The maximum yield corresponds to the yield data of BR-3 variety at 50 percent probability level of Teesta flow with seepage and percolation rate : 3 mm/day and 6

Table 5.9 Optimal Yield of HYV T. Aman and the corresponding Acreages of Teesta Barrage Project Under Normal Transplantation Condition (Seepage and Percolation Rate: 3 mm/day for Barind Tracts and 6 mm/day for Floodplain areas ; Teesta Flow: At 50% Probability Level & Yield Data: BR-1, Amla Farm).

Hydrologic Zone	Land Type	Net Area Available for Aman Cultivation (Acres)	Irrigable HYV T. Aman Area (Acres)	Transplanting Date	Critical Period
Zone-I	Floodplain	257,345	12,575	1-10 August	21-31 July &
	Barind Tracts	0	0		11-20 October
Zone-II	Floodplain	315,269	0		
	Barind Tracts	136,615	127,812 8,803	21-31 July 1-10 August	
Zone-III	Floodplain	99,386	0		
	Barind Tracts	345,385	345,385	1-10 August	
	Total:	1,154,000	494,575		

Total Yield = 741,862 Tons.

Note: Irrigation planning alongwith total yield is same as above for yield data of Amla Farm (BR-3).

Table 5.10 Optimal Yield of HYV T. Aman and the corresponding Acreages of Teesta Barrage Project Under Normal Transplantation Condition (Seepage and Percolation Rate: 3 mm/day for Barind Tracts and 6 mm/day for Floodplain areas; Teesta Flow: At 75% Probability Level and Yield Data: BR-1, Amla Farm).

Hydrologic Zone	Land Type	Net Area Available for Aman Cultivation (Acres)	Irrigable HYV T. Aman Area (Acres)	Transplanting Date	Critical Period
Zone-I	Floodplain	257,345	0		11-20 October, 21-31 October & 1-10 November
	Barind Tracts	0	0		
Zone-II	Floodplain	315,269	0		
	Barind Tracts	136,615	56,947 8,371	11-20 July 1-10 August	
Zone-III	Floodplain	99,386	0		
	Barind Tracts	345,385	47,935 297,450	21-31 July 1-10 August	
	Total:	1,154,000	410,703		
	Total Yield = 582,513 Tons.				

Note: Irrigation planning is same as above for yield data of Amla Farm (BR-3) except total yield (=578,128 tons).

Table 5.11 Optimal Yield of HYV T. Aman and the corresponding Acreages of Teesta Barrage Project Under Normal Transplantation Condition (Seepage and Percolation Rate: 5 mm/day for Barind Tracts and 10 mm/day for Floodplain areas; Teesta Flow: At 50% Probability Level and Yield Data: BR-1, Amla Farm).

Hydrologic Zone	Land Type	Net Area Available for Aman Cultivation (Acres)	Irrigable HYV T. Aman Area (Acres)	Transplanting Date	Critical Period
Zone-I	Floodplain	257,345	0		11-20 October & 1-10 November
	Barind Tracts	0	0		
Zone-II	Floodplain	315,269	0		
	Barind Tracts	136,615	50,655	21-31 July	
Zone-III	Floodplain	99,386	0		
	Barind Tracts	345,385	5,408 339,977	21-31 July 1-10 August	
	Total:	1,154,000	396,040		

Total Yield = 594,060 Tons.

Note: Irrigation planning alongwith total yield is same as above for the yield data of Amla Farm (BR-3).

Table 5.12 Optimal Yield of HYV T. Aman and the corresponding Acreages of Teesta Barrage Project Under Normal Transplantation Condition (Seepage and Percolation Rate: 5 mm/day for Barind Tracts and 10 mm/day for Floodplain areas ; Teesta Flow: At 75% Probability Level and Yield Data: BR-1, Amla Farm).

Hydrologic Zone	Land Type	Net Area Available for Aman Cultivation (Acres)	Irrigable HYV T. Aman Area (Acres)	Transplanting Date	Critical Period
Zone-I	Floodplain	257,345	0		11-20 October, 21-31 October & 1-10 November
	Barind Tracts	0	0		
Zone-II	Floodplain	315,269	0		
	Barind Tracts	136,615	0		
Zone-III	Floodplain	99,386	0		
	Barind Tracts	345,385	44,933 38,540 243,259	11-20 July 21-31 July 1-10 August	
	Total:	1,154,000	326,732		
	Total Yield = 463,633 Tons.				

Note: Irrigation planning is same as above for the yield data of Amla Farm (BR-3) except total yield (=460,173 tons).

Table 5.13 Optimal Yields of HYV T. Aman and the corresponding Acreages of Teesta Barrage Project Under Early Transplantation Condition (Seepage and Percolation Rate: 3 mm/day for Barind Tracts and 6 mm/day for Floodplain areas ; Teesta Flow: At 50% Probability Level & Yield data: BR-1, Amla Farm).

Hydro-logic Zone	Land Type	Net Area Available for Aman Cultivation (Acres)	Irrigable HYV T. Aman Area (Acres)	Transplanting Date	Critical Period
Zone-I	Floodplain	257,345	18,796 238,549	11-20 July 21-31 July	1-10 June, 11-20 October & 21-31 October
	Barind Tracts	0	0		
Zone-II	Floodplain	315,269	0		
	Barind Tracts(ET)	72,679	72,679	11-20 June	
	Barind Tracts(NT)	63,936	63,936	1-10 August	
Zone-III	Floodplain	99,386	4,882	1-10 August	
	Barind Tracts(ET)	241,770	40,268 201,502	1-10 June 11-20 June	
	Barind Tracts(NT)	103,615	103,615	1-10 August	
	Total:	1,154,000	744,227		

Total Yield = 1,044,581 Tons.

* ET - Early Transplantation
NT - Normal Transplantation

Table 5.14 Optimal Yields of HYV T. Aman and the corresponding Acreages of Teesta Barrage Project Under Early Transplantation Condition (Seepage and Percolation Rate: 3 mm/day for Barind Tracts and 6 mm/day for Floodplain areas ; Teesta Flow: At 50% Probability Level & Yield data: BR-3, Amla Farm).

Hydrologic Zone	Land Type	Net Area Available for Aman Cultivation (Acres)	Irrigable HYV T. Aman Area (Acres)	Transplanting Date	Critical Period
Zone-I	Floodplain	257,345	19,018 238,327	11-20 July 1-10 August	21-31 July, 11-20 October & 21-31 October
	Barind Tracts	0	0		
Zone-II	Floodplain	315,269	4,882	1-10 August	
	Barind Tracts(ET)	72,679	72,679	21-30 June	
	Barind Tracts(NT)	63,936	63,936	1-10 August	
Zone-III	Floodplain	99,386	0		
	Barind Tracts(ET)	241,770	241,770	21-30 June	
	Barind Tracts(NT)	103,615	35,148 68,467	21-31 July 1-10 August	
	Total:	1,154,000	744,227		

Total Yield = 1,101,159 Tons.

* ET - Early Transplantation
NT - Normal Transplantation

Table 5.15 Optimal Yields of HYV T. Aman and the corresponding Acreages of Teesta Barrage Project Under Early Transplantation Condition (Seepage and Percolation Rate: 3 mm/day for Barind Tracts and 6 mm/day for Floodplain areas ; Teesta Flow: At 75% Probability Level & Yield data: BR-1, Amla Farm).

Hydrologic Zone	Land Type	Net Area Available for Aman Cultivation (Acres)	Irrigable HYV T. Aman Area (Acres)	Transplanting Date	Critical Period
Zone-I	Floodplain	257,345	60,419 132,828	11-20 July 1-10 August	1-10 June, 11-20 October, 21-31 October & 1-10 November
	Barind Tracts	0	0		
Zone-II	Floodplain	315,269	0		
	Barind Tracts(ET)	72,679	72,679	11-20 June	
	Barind Tracts(NT)	63,936	63,936	1-10 August	
Zone-III	Floodplain	99,386	0		
	Barind Tracts(ET)	241,770	63,849 177,921	1-10 June 11-20 June	
	Barind Tracts(NT)	103,615	10,611 99,004	21-31 July 1-10 August	
	Total:	1,154,000	675,247		

Total Yield = 916,595 Tons

* ET - Early Transplantation
NT - Normal Transplantation

Note: Irrigation planning is same as above for yield data of Amla Farm (BR-3) except total yield (= 970,116 Tons.

Table 5.16 Optimal Yields of HYV T. Aman and the corresponding Acreages of Teesta Barrage Project Under Early Transplantation Condition (Seepage and Percolation Rate:5 mm/day for Barind Tracts and 10 mm/day for Floodplain areas ; Teesta Flow: At 50% Probability Level & Yield data: BR-1, Amla Farm).

Hydrologic Zone	Land Type	Net Area Available for Aman Cultivation (Acres)	Irrigable HYV T. Aman Area (Acres)	Transplanting Date	Critical Period
Zone-I	Floodplain	257,345	10,206 12,888 137,265	11-20 July 21-31 July 1-10 August	1-10 June, 1-10 Sept., 21-31 October & 1-10 November
	Barind Tracts	0	0		
Zone-II	Floodplain	315,269	0		
	Barind Tracts(ET)	72,679	72,679	11-20 June	
	Barind Tracts(NT)	63,936	63,936	1-10 August	
Zone-III	Floodplain	99,386	0		
	Barind Tracts(ET)	241,770	40,268 201,502	1-10 June 11-20 June	
	Barind Tracts(NT)	103,615	103,615	1-10 August	
	Total:	1,154,000	642,359		

Total Yield = 896,838 Tons

* ET - Early Transplantation
. NT - Normal Transplantation

Note: Irrigation planning is same as above for the yield data of Amla Farm (BR-3) except total yield (=954,225 tons).

Table 5.17 Optimal Yields of HYV T. Aman and the corresponding Acreages of Teesta Barrage Project Under Early Transplantation Condition (Seepage and Percolation Rate: 5 mm/day for Barind Tracts and 10 mm/day for Floodplain areas ; Teesta Flow: At 75% Probability Level & Yield data: BR-1, Amla Farm).

Hydro-logic Zone	Land Type	Net Area Available for Aman Cultivation (Acres)	Irrigable HYV T. Aman Area (Acres)	Transplanting Date	Critical Period
Zone-I	Floodplain	257,345	41,004 71,819	11-20 July 21-31 July	1-10 June, 11-20 October & 21-31 October
	Barind Tracts	0	0		
Zone-II	Floodplain	315,269	0		
	Barind Tracts(ET)	72,679	72,679	11-20 June	
	Barind Tracts(NT)	63,936	63,936	1-10 August	
Zone-III	Floodplain	99,386	0		
	Barind Tracts(ET)	241,770	63,849 177,921	1-10 June 11-20 June	
	Barind Tracts(NT)	103,615	103,615	1-10 August	
	Total:	1,154,000	594,823		

Total Yield = 807,395 Tons

* ET - Early Transplantation
. NT - Normal Transplantation

Note: Irrigation planning is same as above for the yield data of Amla Farm (BR-3) except total yield (=862,410 tons).

mm/day for Barind Tracts and Floodplain areas respectively. The irrigation plan presented in Table 5.14 is the best of all other alternative plans because this plan gives maximum yield as well as maximum cropped area. This plan is identical with the best irigation plan for land optimization objective function. Under BRTC condition, the model predicted optimal yield is 970,116 tons (Table 5.15) which corresponds to the yield data of BR-3 variety. It should be noted here that for the yield data of early transplanted HYV T. Aman, only one year experimental data of Amla farm have been used due to lack of more yield data. So, field experiments conducted by BWDB at different farms need to be repeated with care.

From Tables 5.1 to 5.17, it is clear that under both normal and early transplantation conditions, lower values of seepage and percolation rate and lower probability level of Teesta flow results in higher values of optimal acreages and optimal yields. Moreover, crop staggering approach with early transplantation as cropping practice plays a vital role in increasing the acreages and yields of Teesta Barrage Project.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

6.1 Conclusions

On the basis of results of model application the following conclusions can be made:

1. Under normal cropping practice, 494,575 acres of HYV T. Aman area can be brought under supplemental irrigation with the proper management of available Teesta flow for both land and yield optimization objectives. This corresponds to 770,130 acres of gross area. Total yield attained from this optimal plan is 741,862 tons. This yield value corresponds to yield data of both BR-1 and BR-3 varieties of Amla Farm, Kushtia. The optimal transplanting dates of HYV T. Aman for this plan are 21-31 July for 127,812 acres of Barind land in zone-II and 1-10 August for the remaining irrigable acreages and the critical periods are 21-31 July and 11-20 October.

2. Through crop staggering with early transplantation of HYV T. Aman in the fallow Barind Tracts, 744,227 acres of HYV T. Aman area can be brought under supplemental irrigation with available Teesta flow for both land and yield optimization objectives. This value gives a gross area of 1,176,564 acres. The

maximum yield can be attained from this plan for yield data of BR-3 variety of Amla Farm, Kushtia. The total yield is 1,101,159 tons. The critical periods for this plan are 21-31 July, 11-20 October and 21-31 October and the optimal transplanting dates are 21-30 June for total fallow Barind land in zone-II and zone-III, 11-20 July for 19,018 acres of Floodplain land in zone-I, 21-31 July for 35,148 acres of Barind land in zone-III and 1-10 August for the remaining irrigable acreages.

3. For optimal acreages, optimal yields and the best irrigation plan (Table 5.14) of Teesta Barrage Project, crop staggering approach with early transplantation dates should be adopted as cropping practice.

4. For the above mentioned conclusions, the design discharge of the main canal of Teesta Barrage Project should be 8,000 cusecs.

5. The increased rate of seepage and percolation increases the irrigation water requirement of the crop and thus decreases acreages and yields of Teesta Barrage Project since the availability of Teesta flow for irrigation is constant. Hence, seepage and percolation rate should be minimized through extensive puddling of crop field during land preparation period and by lining the entire conveyance system of the project.

In model application, most of the data have either been obtained from literature or collected from field level experimental farms. In case when no information were available, judicious assumptions were made. Hence verification of data and updating of the conclusions may be necessary. Nevertheless the developed model provides a useful tool to the decision makers of the project authority dealing with irrigation planning.

6.2 Recommendations for Further Study

The following recommendations are made for further refinement of the present research work:

a. Systematic collection of recent weather data to determine actual evapotranspiration rate of the project area and discharge data of Teesta River are necessary to update the model predicted results.

b. Field experiments to determine the actual seepage and percolation losses from the rice field under irrigation are necessary. The model has shown that the optimized command area is very sensitive to this parameters. Field experiments are also necessary to determine the water requirement of the crop during land preparation.

c. Detail studies on (i) internal sources of surface water other than Teesta River within the project area; (ii) conjunctive use of surface water and ground water resources within the project and (iii) inter-basin water transfer from the major sources of surface water outside but adjacent to the project area to increase the availability of irrigation water during the critical periods are necessary. Increased available flow during the critical periods will increase the optimum command area.

d. Field experiments should be continued to varify the yield data used in this study. The experiments should also be conducted within the project area and in farmers' fields to asses the impact of early transplantation on the yield performance of HYV rice.

e. An economic analysis on the production cost of HYV T. Aman including irrigation and the corresponding return from yield need to be carried out.

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Appendix - A

Sample Calculation of Diversion Requirements.

During Land Preparation Period

For both Floodplain and Barind Tracts areas:

Zone-I, Period : 11-20 July

Land Preparation Requirement = 150 mm

Rainfall at 75% Probability Level = 87 mm (From Table 3.4)

Field canal Efficiency = 85%

Conveyance or Canal System Efficiency = 85%

Diversion Requirement = (150 - 87)/.85/.85 = 87.20 mm/10 days

= 87.20*43560*100/304.8/10/24/60/60 cusecs/100 acres

= 1.442 cusecs/100 acres

During Normal Growth Period

Zone-I, Period :11-20 October.

For Floodplain Area:

Seepage and Percolation Rate = 6 mm/day

Reference Crop Evapotranspiration = 4.2 mm/day (From Table 3.2)

Crop Coefficient for Rice = 0.95 (From Table 3.3)

Rainfall at 75% Probability Level = 2 mm/day (From Table 3.4)

Overall Irrigation Efficiency, E_P = 31% (From Table 3.5)

Diversion Requirement =(4.2*0.95*10 - 2)/0.31 = 122.26 mm/10 days

= 122.26*43560*100/304.8/10/24/60/60 cusecs/100 acres

= 2.022 cusecs/100 acres

For Barind Tracts :

Seepage and Percolation Rate = 3 mm/day

Reference Crop Evapotranspiration = 4.5 mm/day (From Table 3.2)

Crop Coefficient for Rice = 0.95 (From Table 3.3)

Rainfall at 75% Probability Level = 2 mm (From Table 3.4)

Overall Irrigation Efficiency, E_P = 44% (From Table 3.5)

Diversion Requirement = (4.5*0.95*10 - 2)/0.44 =92.61 mm/10 days

= 92.61*43560*100/304.8/10/24/60/60 cusecs/100 acres

= 1.532 cusecs/100 acres