A COMPARATIVE STUDY OF DRAINAGE COEFFICIENT

OF

TEESTA BARRAGE PROJECT

SUBASH CHANDRA ROY

DEPARTMENT OF WATER RESOURCES ENGINEERING

BUET, DHAKA

NOVEMBER, 1993

A COMPARATIVE STUDY OF DRAINAGE COEFFICIENT

OF

TEESTA BARRAGE PROJECT

SUBASH CHANDRA ROY

In the partial fulfilment of the requirements

for

Degree of Master of Engineering (Water Resources)

Department of Water Resources Engineering

Bangladesh University of Engineering and Technology, Dhaka

November, 1993

CERTIFICATE

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

M. Mirjahan

(Dr. M. Mirjahan Miah)

Countersigned by Supervisor

Subash Ch. Roy.

(Subash Chandra Roy)

Signature of Candidate

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF WATER RESOURCES ENGINEERING

November 27, 1993

We hereby recommend that the report presented by Mr. Subash Chandra Roy entitled " A COMPARATIVE STUDY OF DRAINAGE COEFFICIENT OF TEESTA BARRAGE PROJECT" be accepted as fulfilling this part of the requirements for the degree of Master of Engineering (Water Resources).

Chairman of the Committee

(Supervisor)

M. Mirjahan

Dr. M. Mirjahan Miah

Member

(Head of the Department)

M. Fazlul Bari

Prof. Dr. M. Fazlul Bari

Member

S Begum

Dr. Selina Begum

ABSTRACT

Many large and small scale Flood Control and Drainage Projects have been implemented in Bangladesh. It is reported that due to drainage congestion very few projects are functioning properly. The present study was taken up to critically review the procedures for determination of drainage coefficient used by consultants and agencies. The methods developed by MPO, BWDB/UNDP and BRTC/BUET for determination of drainage coefficient have been reviewed during the present study.

Teesta Barrage Project, the largest irrigation and drainage project in Bangladesh, is now under implementation. BWDB (1985) planned and designed the drainage system of the project which have been reviewed by the Bureau of Research Testing and Consultation (BRTC, 1989) of BUET. The drainage coefficient value was re-assessed for the design of drainage channels without considering the crop specific drainage requirement. The present study was also taken up to determine the drainage coefficient by two recent methods, graphical and analytical, using 25-years recent rainfall data in the project area and compare the results.

From the present analysis, it is observed that the drainage coefficient by graphical method is lower in premonsoon season but higher in monsoon season. The results of the drainage coefficient obtained by BRTC are 15% lower in central and southern zones and 12% higher in northern zone in the project area compared to the present study results. This is due to the provision of 3-day 5-year cumulative rainfall in contrast to 10-day 10-year in present study.

ACKNOWLEDGMENT

The author gratefully acknowledges his deepest gratitude and indebtedness to his supervisor Dr. M. Mirjahan Miah, Associate Professor, Department of Water Resources Engineering for his continuous encouragement, affectionate guidance and inspiration to carry out the courses at various stages during the preparation of the study.

Special thanks are extended to Dr. M. Fazlul Bari, Professor and Head of the Department of Water Resource Engineering, BUET for best cooperation. The author also wishes to express his gratitude to Dr. Selina Begum, Assistant Professor of the same department for her valuable comments, cooperation and helpful suggestions as a member of the board of examiners.

The author is also grateful to Mr. Shyamal Bikash Chowdhury, Planning Coordinator, Northwest Hydraulic Consultants Ltd. for his valuable suggestion and technical advise for the analysis of the study.

Finally, the author wishes to thank Mr. Bahauddin Bhuiyan, Library Assistant, BUET, for help in collecting of the relevant reports and Mr. A.K.M. Monir Hossain, Technical Assistant, Northwest Hydraulic Consultants Ltd. for graphics used in this study.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

BWDB	-	Bangladesh Water Development Board
BARC	-	Bangladesh Agricultural Research Council
BRTC	-	Bureau of Research Testing and Consultation
BUET	-	Bangladesh University of Engineering and Technology
B	-	Broadcast
CIDA	-	Canadian International Development Agency
DDP	-	Delta Development Project
EPC	-	Engineering, Planning and Consultants
FPCO	-	Flood Plan Coordination Organization
FCD	-	Flood Control and Drainage
FAP	-	Flood Action Plan
HYV	-	High Yield Variety
IECO	-	International Engineering Co. Inc.
ILRI	-	International Institute For Land Reclamation and Improvement
LDL	-	Leedshill - De Leuw Engineering
MPO	-	Master Plan Organization
NHCL	-	Northwest Hydraulic Consultants Ltd.
NWR	-	North West Region
PIRDP	-	Pabna Irrigation and Rural Development Project

SSFCDI	-	Small Scale Flood Control Drainage and Irrigation
SCS	-	Soil Conservation Services
T	-	Transplant
UNDP	-	United Nations Development Programme
UK	-	United Kingdom

CHAPTER - 1

INTRODUCTION

1.1 Background and Statement of the Problem

Most of the flood control and drainage projects in Bangladesh are of polder type in which river flooding is prevented by peripheral embankments. The internal rainfall runoff generated during premonsoon and monsoon seasons are usually drained out through the drainage canals when the outside river stages permit gravity drainage. The runoff from the drainage compartment is conveyed by the tertiary, secondary and main drainage canals to the outfall river via the drainage regulators. The drainage system should have adequate conveyance capacity to provide effective drainage, lack of which restricts crop cultivation due to drainage congestion.

Drainage canal systems are generally designed on the basis of drainage coefficient. The amount of excess water to be removed from the watershed per day to provide a certain degree of crop protection is important for designing of a drainage system. The rate at which the excess water must be removed is termed as "drainage coefficient" and is expressed in mm per day. Some empirical criteria are often used for the computation of drainage coefficient as well as design of drainage canals in Bangladesh (LDL, 1968; IECO, 1980 and

SCS, 1973). All these methods have limitations and the selection of a particular method depends upon the individual drainage basin characteristics.

An improvement in current drainage canal design and their standardization are of prime importance. As a step in this direction, the present study attempts to critically review the drainage design methods followed in Bangladesh.

BWDB planned and designed a drainage system for the Teesta Barrage Project which has been reviewed by the Bureau of Research Testing and Consultation of BUET (BWDB, 1985; BRTC, 1989). In calculating the drainage coefficient, BWDB used 5-day 5-year accumulated rainfall. The analysis was done using 14 years of rainfall records. During the analysis, BWDB did not take into consideration the tolerance of crop submergence. BRTC has reviewed the works done by BWDB and re-assessed drainage coefficients for the Teesta Barrage Project. BRTC used 3-day 5-year accumulated rainfall. The analysis for drainage coefficient was done considering the susceptibility of rice crop to submergence beyond 3 days. In designing drainage coefficient, both BWDB and BRTC did not take into consideration the drainage period. Moreover, 14 years of rainfall data were used for frequency analysis which is not enough for the determination of drainage coefficient.

The present study attempts to apply two methods, graphical and water balance equation, for the estimation of drainage coefficient of the project taking into consideration the drainage period for specific crop and using 25 years recent rainfall data.

1.2 Objectives

The objectives of this study are the following :

1) to review the techniques and methodologies followed for estimating drainage coefficient in Bangladesh.

2) to compute the drainage coefficient of Teesta Barrage Project using two methods and compare the results.

CHAPTER - 2

LITERATURE REVIEW

2.1 Drainage Design Practices in Bangladesh

Two types of drainage projects normally exist in Bangladesh: large scale and small scale. About three hundred and five flood control and drainage projects have so far been implemented in Bangladesh. Out of which 191 projects have been implemented by BWDB till June'87 providing drainage facilities to about 277 million hectares of land (Shajahan and Hossain, 1990). A number of approaches have been applied to derive the drainage coefficient for different drainage projects. The procedures used by Northwest Hydraulic Consultants Ltd, Leedshill De Leuw Engineering and United Nations Development Programme are classified as graphical approach and those followed by Master Plan Organization, Engineering and Planning Consultants Ltd known as analytical approach. These are briefly presented below:

2.1.1 Procedure Followed by Northwest Hydraulic Consultants Ltd.

The Northwest Hydraulic Consultants Ltd (NHCL) has developed the criteria for derivation of drainage coefficient for small scale drainage projects in Bangladesh based on the drainage design principles recommended by ILRI (1979). The design criteria are:

i) Return Period : 1 in 10 Year.

ii) Duration of Rainfall : 10 days

iii) Period of Analysis : Entire rainy seasons (April - October)

iv) Drainage Period

April and early May	:	Boro Crop; flooding upto 300 mm.
April, May and June	:	Aus Crop; flooding upto 300 mm for a period upto 3 days with turbid water.
July and August	:	Aman Crop; flooding upto 250 mm for a period upto 3 days with turbid water.

For the purpose of estimating drainage coefficient, it is assumed that the pre-storage water depth on the paddy field during premonsoon and monsoon seasons will be 50 and 100 mm respectively. With this, the additional water depth that can be stored from the storm under consideration in the field without harming the plants is 250 mm for premonsoon and 150 mm for monsoon seasons.

The procedure to determine the drainage coefficient includes an analysis of the daily rainfall data for the selected stations in the project area. From these daily rainfall data, 1-day, 2-day, 3-day, ...,10-day maximum successive rainfalls are extracted for each year for the month of April to October. Then, a frequency analysis is performed to find out the design 10-year rainfall for 1-day, 2-day, 3-day, ..., and 10-day duration using Extreme Value Type 1 distribution. The cumulative rainfall depths are then plotted against 10-day duration (Figure - 2.1.1). To find the required design drainage coefficient, the following plotting procedures

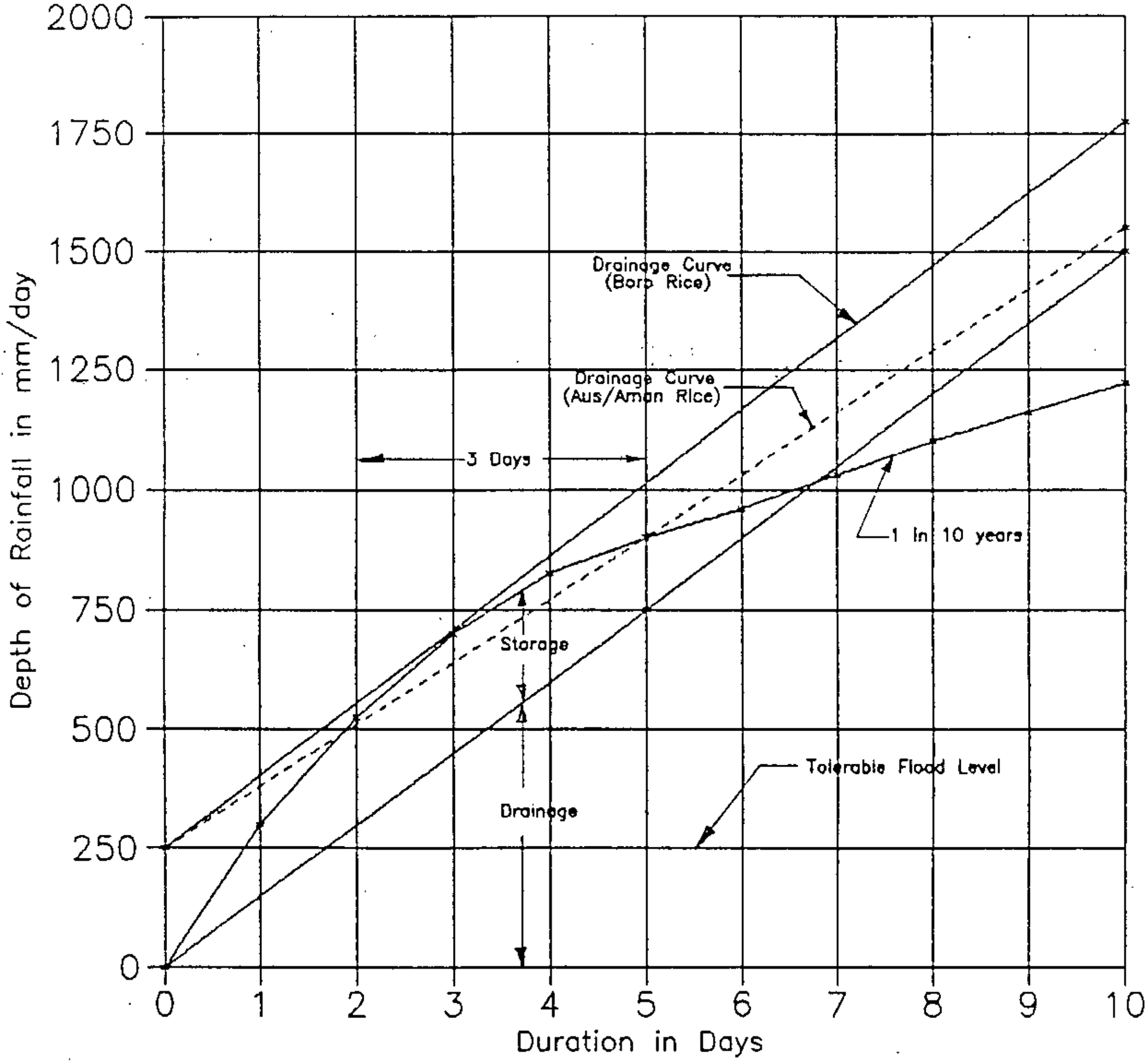


Figure - 2.1.1: Depth-Duration-Frequency Relations to Determine Drainage Coefficient of a Typical Polder

are followed:

i) for Boro crop, a tangent line is drawn from 250 mm point on the rainfall axis to the cumulative rainfall curve.

ii) for T. Aus crop, a straight line is drawn from 250 mm point of the rainfall axis making a 3-days interceptor on the cumulative rainfall curve.

iii) for T. Aman crop, a straight line is drawn from 150 mm point on the rainfall axis making a 3-days interceptor on the cumulative rainfall curve.

The slope of the straight or tangent line indicates the design drainage coefficient for the respective crop. If the straight or tangent line is shifted parallel to pass through the origin of the coordinate axes, it would indicate the drainage curve for the crop. Thus, the distance between the drainage curve and the horizontal axis represents the amount of water drained and the distance between drainage curve and the depth duration curve represents the amount of water stored in the field.

This method assumes that the evapotranspiration and percolation losses are compensated for any runoff from adjacent area or any irrigation water entering the drainage system.

To date NHCL has implemented fifty Flood Control and Drainage Projects under Second Small Scale Flood Control Drainage and Irrigation Projects in Bangladesh. Design of drainage canal was carried out following the above approach in all projects. It is reported that the projects are functioning well without any drainage problems.

2.1.2 Leedshill De Leuw (LDL) Method

LDL (1968) developed a isohyetal map (Figure - 2.1.2) for estimating design runoff rate of drainage system in Bangladesh based on rainfall intensity, duration and frequency data. The drainage coefficient can be readily obtained from the map for any location in the country. This method was generally used for very small drainage basin, less than 25 acres and also in absence of detail rainfall records.

2.1.3 United Nations Development Programme (UNDP) Approach

A study was made to determine the drainage requirement for rice crops due to on-site rainfall. (BWDB & UNDP; 1983). The design was based on 1 in 5 years maximum 2 - 6 days precipitation. The following assumptions were made to calculate the drainage coefficient:

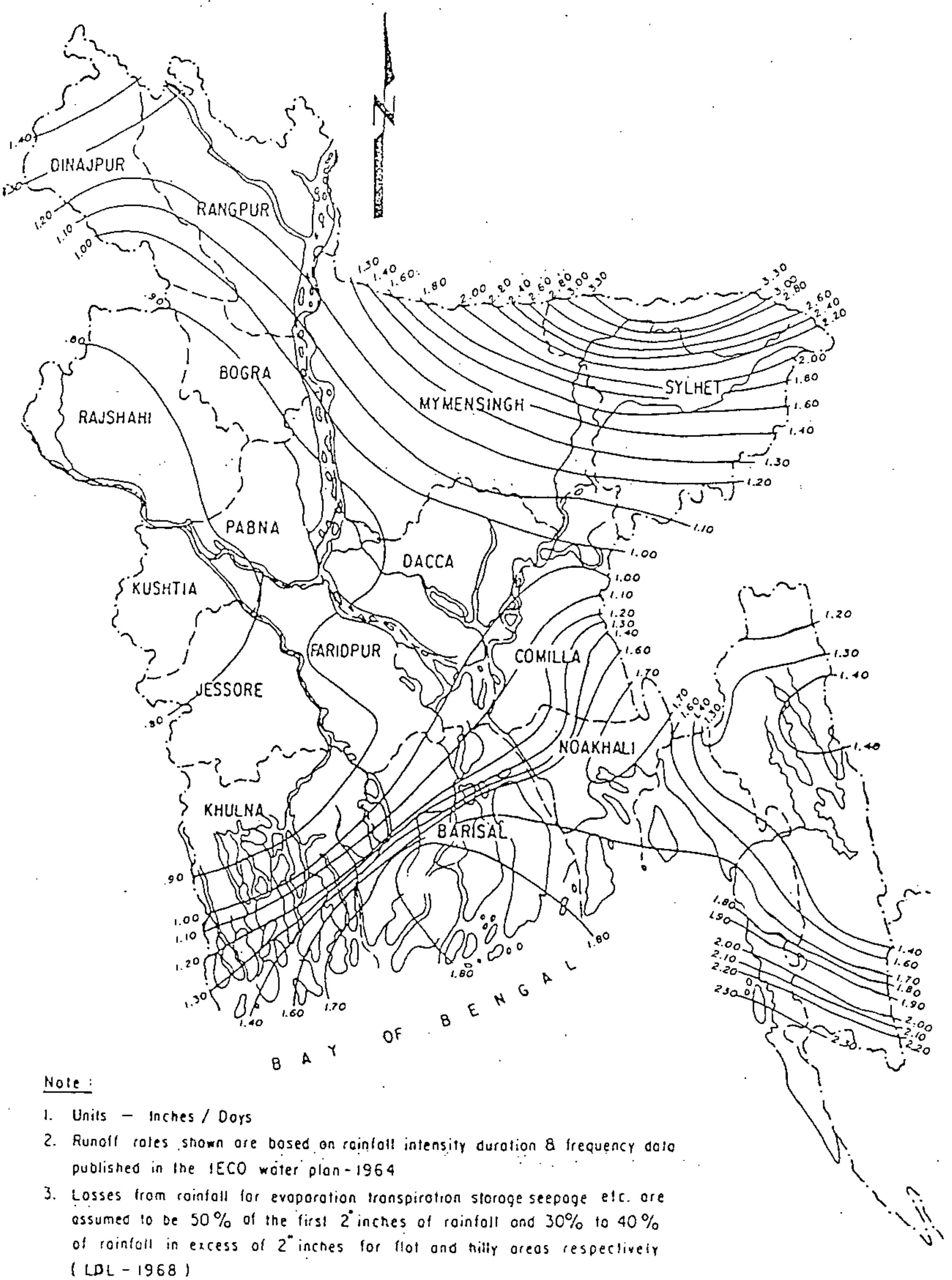
a) The initial depth of water in the field from previous rain = 100 mm.

b) Tolerable flood depth of water before drainage is required = 200 mm

c) Allowable submergence when the depth of water exceeds 300 mm for duration = 6 days

d) Evapotranspiration and percolation losses were considered to be small and ignored.

These assumptions mean that drainage will commence when the depth of water exceeds 200 mm and will be required to remove excess water so that the water level is not greater than 300 mm for more than 6 days.



Note :

1. Units — Inches / Days
2. Runoff rates shown are based on rainfall intensity duration & frequency data published in the IECO water plan - 1964
3. Losses from rainfall for evaporation transpiration storage seepage etc. are assumed to be 50 % of the first 2" inches of rainfall and 30% to 40 % of rainfall in excess of 2" inches for flat and hilly areas respectively (LDL - 1968)

Figure - 2.1.2 : Design Runoff for Drainage System in Bangladesh

The drainage coefficient (Q) in mm/day was calculated using the following equation:

$$Q\,(t_2 - t_1 + 6) + 100 = (10)^{\{b \log (t_2 + 6) + a\}} - 100$$

$$Q = [(10)^{\{b \log (t_2 + 6) + a\}} - 200] \,/\, (t_2 - t_1 + 6)$$

where

t_1 = time (day) from commencement of rainfall until water depth is 200 mm

t_2 = time (day) from commencement of rainfall until water depth is 300 mm

The values of t_1, t_2, Q, and the maximum water depth for 3 selected stations are given in Table -2.1.

Table - 2.1 : Computation of Drainage Coefficient (Q)

Stations	t_1 in day	t_2 in day	Q in mm/day	Maximum water depth (mm)
Bogra	0.14	1.11	24.3	312
Dinajpur	0.32	1.81	21.3	303
Rangpur	0.18	0.98	36.5	317

Using the results of the analysis a map was produced showing the isolines for different drainage coefficient (Figure - 2.1.3). The approximate value of drainage coefficient can be obtained for any particular area in the districts of Rangpur, Bogra and Dinajpur.

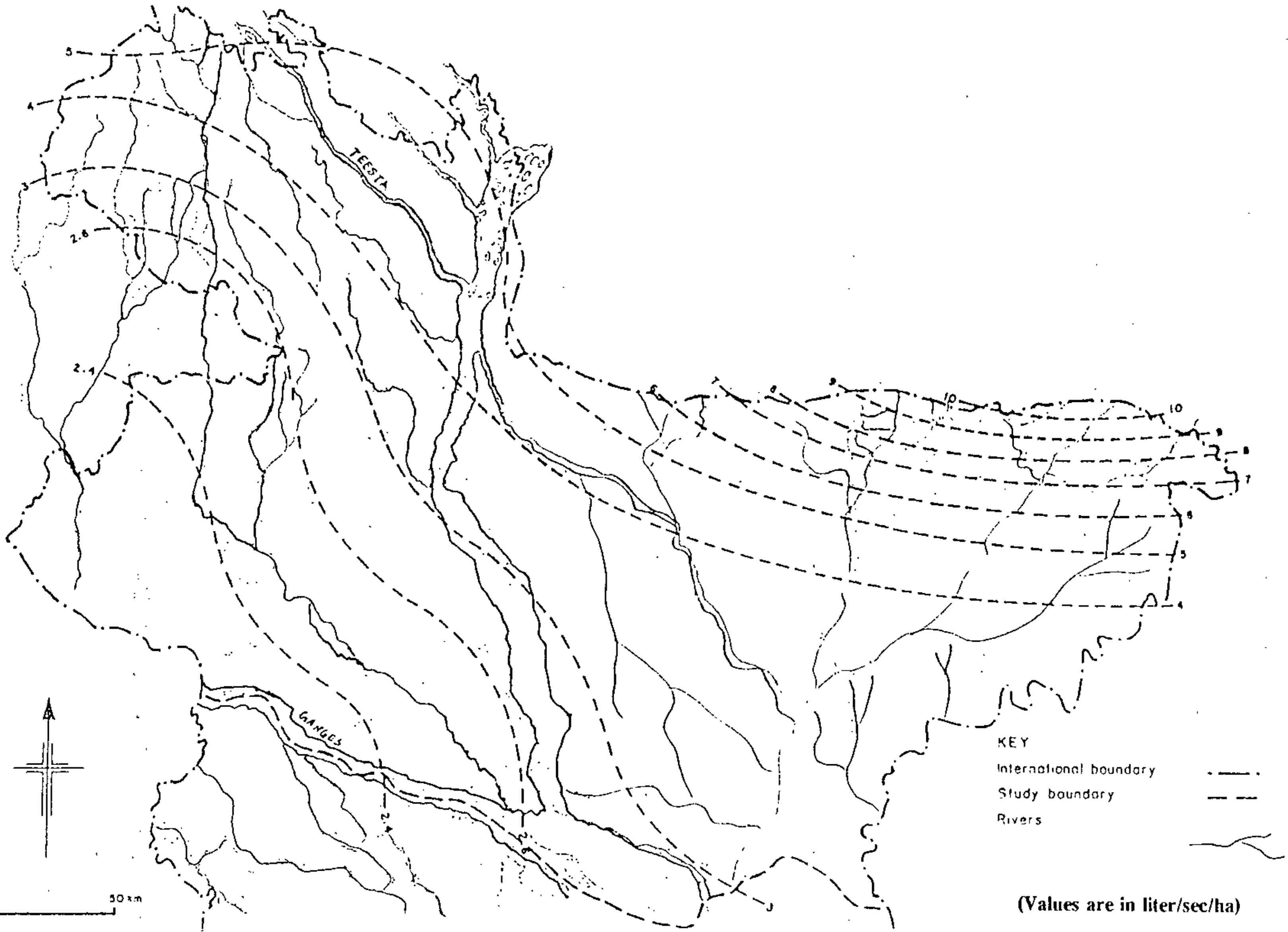


Figure - 2.1.3 : 6-Days Average Drainage Coefficient

Source : UNDP

In the analysis, crop evapotranspiration and percolation losses were ignored which may cause overdesign of drainage coefficient. Also the actual seasons for which this analysis was conducted was not mentioned. The basis for the selection of constants a and b used in the equation were not mentioned.

2.1.4 Procedure Followed by Engineering, Planning and Consultants Ltd (EPC)

The Third Flood Control and Drainage Project involves flood control and drainage improvements to three sub-projects namely Gumti Phase - I, Naogaon Polder - I and Madhumati - Nabaganga (BWDB and EPC, 1985). The drainage coefficient for the design of drainage channel has been estimated in all subprojects by using a computer programme based on the following design criteria.

i) Return Period : 1 in 10 year

ii) Duration : 10 days

iii) Period of Drainage : Premonsoon (May and June)

iv) Initial pre-storage water depth : 50 mm

v) Deep percolation loss : 2 mm per day

vi) An evapotranspiration loss of half the average potential rate for May and June was taken. This is based on the fact that evapotranspiration will be significantly less than the potential rate during prolonged rainfall periods.

vii) B. Aman, T. Aman and B. aus can survive submergence upto 150 mm to 200 mm for a period of 2 days in muddy water or a period of 4 days in clear water.

The drainage coefficient has been computed using the following water balance equation on the basis of the above criteria:

$$Ip + R_{Ti} - Ti\ (E_t + S + D_c) \geq F_{lt}$$

where D_c = drainage coefficient in mm per day

Ip = pre-storage depth from previous rain, 50 mm

R_{Ti} = cumulative rainfall for Ti days (where i = 1, 2, 3, ..., 10)

Ti = Time in days for i = 1, 2, 3, ..., 10

E_t = evapotranspiration in mm/day

S = deep percolation loss in mm/day

F_{lt} = long term flood depth in mm

The permissible limit of long term flood depth for Aus/Aman rice is three consecutive days where as submergence even for a single day has not been allowed for Boro rice.

The construction of the three aforesaid sub-projects was completed in 1991. It is reported that flood control and drainage has fully been achieved and performing effectively without any drainage problems except the silting of drainage canals.

2.1.5 Master Plan Organization (MPO) Method

MPO (1984) published a report regarding crop drainage requirement due to on-site rainfall in Bangladesh. In this study, five drainage classes have been defined for the computation of drainage coefficient; Class 1 for B. Aman, Class 2 for T. Aman and Aus, Class 3 for HYV rice. The Classes 4 and 5 were defined for upland crops (Begum, 1985). The crop tolerance limit to submergence at different growth stages were also mentioned.

Drainage coefficient for classes 2 and 3 was calculated using the following formula:

$$P_t + 50 - t(Q + ETc + S) \leq 200 \text{ mm}$$

where Q = drainage coefficient, mm/day

P_t = 10-day rainfall with 10-year frequency, mm

ETc = evapotranspiration, mm/day

S = deep percolation, mm/day

t = number of days

The pre-storage depth and tolerable flooding depth were taken as 50 and 200 mm respectively.

The following equation was used to obtain a first estimate of Q.

$$Q = \{P_t - 10\ (ETc + S) - 8\}\ /\ 8$$

If this inequality is not met for more than three consecutive days for all values of 10 days, then Q should be increased until it satisfies the condition. The results of the study for the selected stations of Rangpur, Bogra and Rajshahi are presented in Figure - 2.1.5.

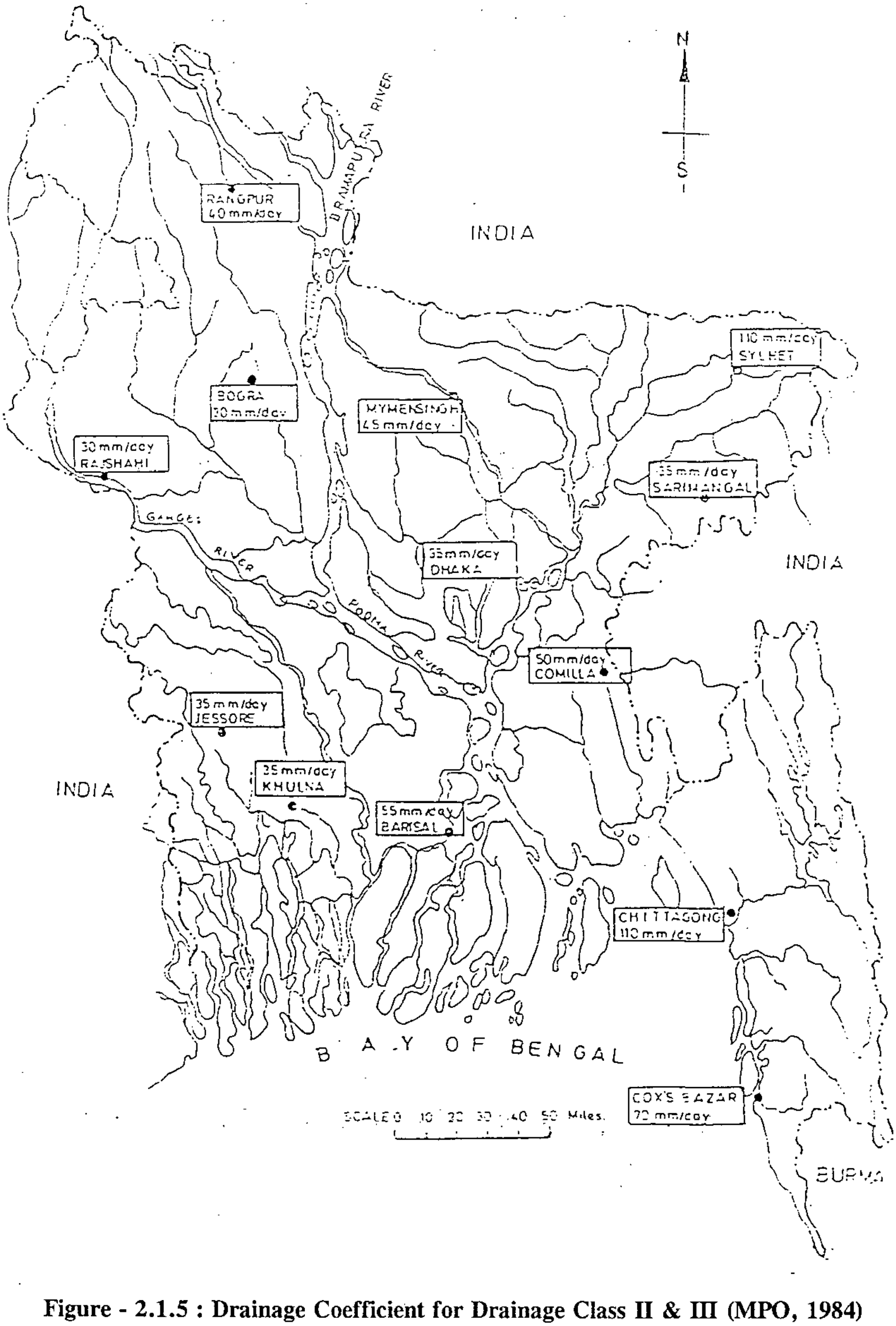


Figure - 2.1.5 : Drainage Coefficient for Drainage Class II & III (MPO, 1984)

2.2 Growth Stages and Flooding Tolerance of Rice Plant

MPO (1984) has divided the development of rice plant into three phases (Figure - 2.2) as given below:

(1) vegetative phase, which runs from germination to panicle initiation;

(2) reproductive phase, which runs from panicle initiation to flowering; and

(3) ripening phase, which runs from flowering to full maturity.

The tolerable limit of the plant to submergence is the depth of standing water under which plant can survive. Drainage is required for removal of excess water which depends on tolerable limit and growth stage of the plant.

2.3 Drainage Design Parameters Used in BWDB Projects

Various design manual of flood control and drainage projects in Bangladesh are in use in the design of drainage coefficient. A detail description of the parameters used in the Third FCD projects, SSFCDI projects and Teesta Barrage Project are given in the Articles 2.1.1, 2.1.4 and 2.4.3 respectively.

Delta Development Project (1985) prepared a design manual for the development of Polders in the south-west region of Bangladesh (DDP, 1985). Part 1 of the manual deals with four volumes containing the drainage design procedure and the design criteria for drainage.

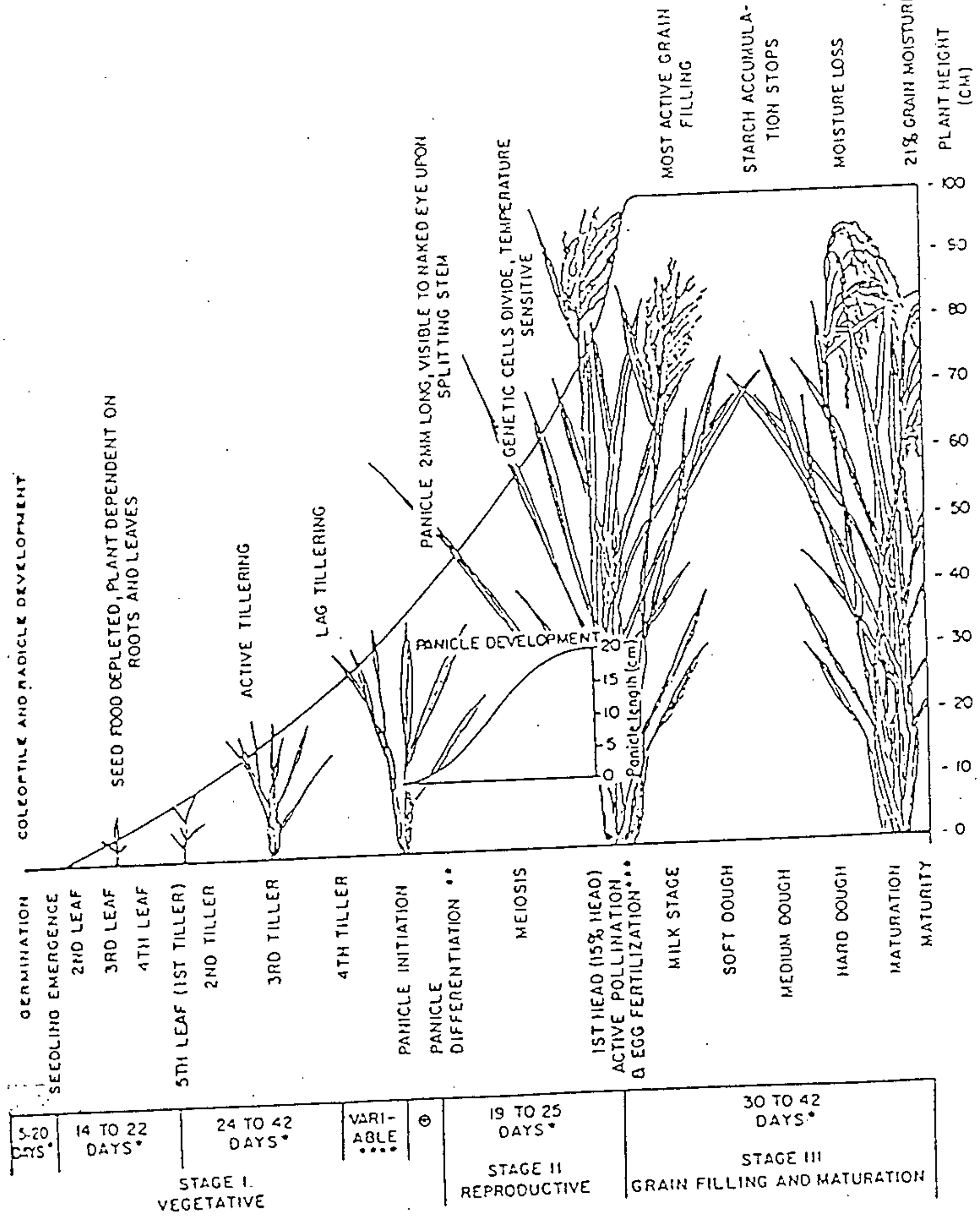


Figure - 2.2 : Development Stages of the Rice Plant

Drainage design specification has been prepared for the Pabna Irrigation and Rural Development Project (Phase-I) which was briefly described in volume 1 of the feasibility report (PIRDP, 1978). BWDB Small Schemes Project was undertaken by Engineering and Planning Consultants Ltd.(EPC) in association with William Halcrow and Partners, UK and Resources Development Consultants Ltd. (BWDB,1987). Thirty small scale flood control and drainage projects were implemented in different locations of Bangladesh. In the drainage design, 1 in 5 year 10-day rainfall was considered in determining the drainage coefficient.

A number of design manuals have been developed and some are in the process of preparation under different development projects for the design of drainage parameters. Few of these manuals have been reviewed which showed different drainage criteria and compiled together in the Table-2.3 for easy understanding. The Design Directorate of Water Development Board (1978) prepared a design manual drainage structures.

A single design standard may now be developed based on evaluation of effectiveness and performance of the drainage projects. The existing BWDB design manual may be further extended and upgraded containing procedures for computation of drainage coefficient and drainage channels.

Table - 2.3 : Drainage Design Parameters Used in Bangladesh

Projects	Return Period	Duration (days)	Tolerable flood depth	Drainage Period	Initial water depth, mm	
					Pre monsoon	Monsoon
Third Flood Control and Drainage Project	1:10 yr	10	150 mm[1/]	May-June Premonsoon	50 mm	
Delta Development Project	1:5 yr	5	200 mm[2/] 400 mm[3/]	June	100 mm[5/] 150 mm[6/]	
Second Small Scale Flood Control Drainage and Irrigation Project	1:10 yr	10	300 mm	Entire year	50 mm	100 mm
Teesta Barrage Project	1:5 yr	3	200 mm[4/]	entire year	50 mm	
BWDB Small Scheme Projects	1:5 yr	10	200 mm	entire year	100 mm	
Pabna IRD Project	1:10 yr	10		entire year		

Notes: 1/ Crop tolerance to submergence.

2/ 200 mm for short straw varieties.

3/ 400 mm for long straw.

4/ Crop tolerance to submergence.

5/ For short varieties under rainfed condition.

6/ For short varieties under irrigated conditions.

Source : NHCL, 1989.

2.4 Drainage System of Teesta Barrage Project

2.4.1 Description

The Teesta Barrage Project is a major irrigation project with the barrage recently been completed by BWDB. The project location is within the north-west region bounded by two major rivers - the Brahmaputra on the east and Ganges on the south. The other perennial rivers are Atrai, Teesta, Dharla, Dudkumar, Mahananda and Karatoya which originates in India and are draining to the main rivers (Figure - 2.4). The proposed gross area for drainage system is about 748,695 ha of which net area for irrigation is 539,600 ha (MPO, 1985). The command area of the project has a fairly steep slope, and in general most of the area is fairly well drained. The area is traversed by a river network of about 1150 km in length. The rivers along with their tributaries and distributaries meet the existing drainage demand of the area. The network of drainage system over the entire project area has been planned to drain out the excess water.

The entire project area is divided into three hydrological zones (Zone - I, II and III) considering the variation of annual rainfall (BRTC, 1989). The project map showing drainage system of the project is presented in Figure - 2.4.1.

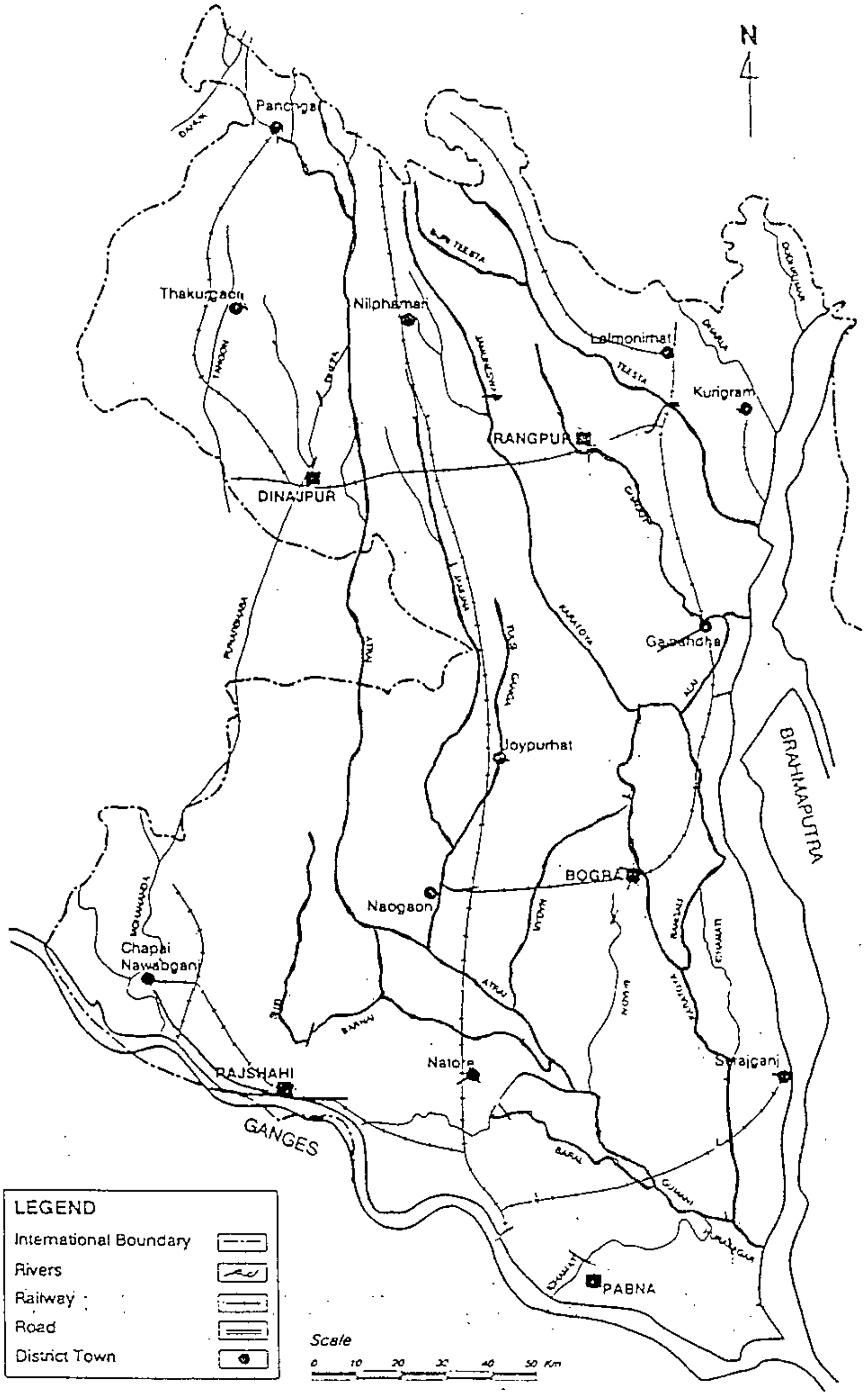


Figure - 2.4 : River System in the Northwest Region

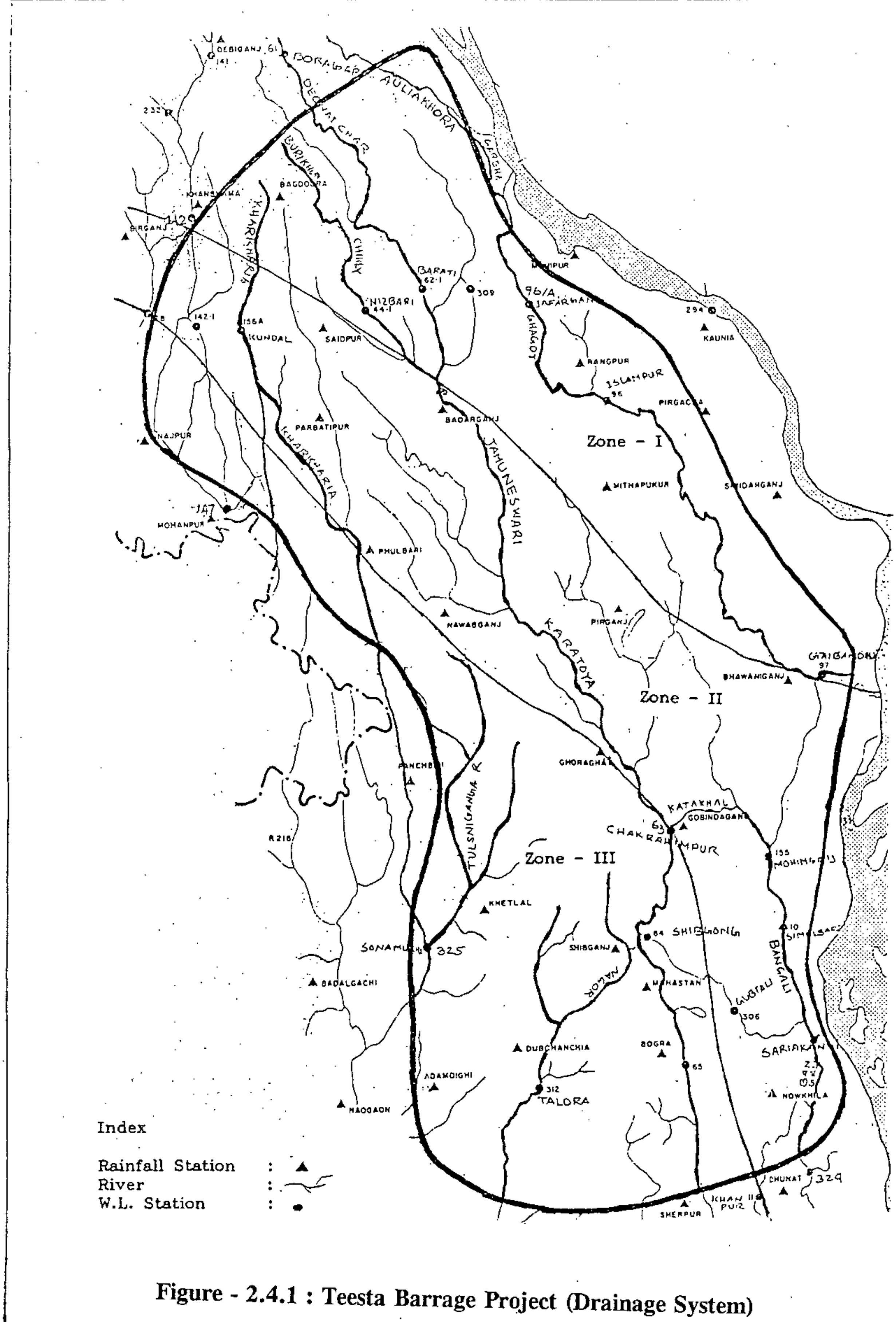


Figure - 2.4.1 : Teesta Barrage Project (Drainage System)

2.4.2 Planning and Design

BWDB (1985) planned for the drainage system of the Teesta Barrage Project utilizing the existing rivers. Seven river systems were planned for this purpose. These are:

i) Buri Teesta Systems with branch channels of Naotra and Dhum

ii) Auliakhora-Garbha-Ghagot System (outfall at Bangali river)

iii) Deonai-Charalkata-Jamuneswari-Karatoya-Katakhali-Bangali System (Outfall at Hurasagar) with branch channels of Panga, Kheroa, Saiki, Dhaizan and Bullai

iv) Burikhora-Chikly System (outfall at Jamuneswari near Badarganj with branch channel of Old Jamuneswari

v) Kharkharia System (outfall at Jamuna Rajarampur)

vi) Ichamati-Jamuna-Atrai System (outfall at Hurasagar)

vii) Tulsiganga-Haraboti-Nangota-Gangnai System

These river systems were planned to be re-excavated as per requirement to drain off excess irrigation and rain water from the project area. A network of major and minor drainage channels would be excavated inside the project area for efficient drainage of the irrigation blocks.

Later on, BRTC (1989) reviewed the works done so far by BWDB on drainage planning of the project. Out of the seven river systems of the project area proposed by BWDB, BRTC observed that two river systems (Burikhora-Chikly system and Ichamati-Jamuna system) were actually sub-systems to other major systems. Moreover, two other independent river systems exist in the project area that were not considered by BWDB. The seven major river systems that were planned by BRTC and utilized as major drains for the computation of drainage coefficient are as given below:

1) Buri Teesta System
2) Auliakhora-Garbha-Ghagot System
3) Deonai-Charalkata-Jamuneswari-Karatoya-Katakhali-Bangali System with Burikhora-Chikly Sub-System
4) Kharkharia-Jamuna System with Ichamati-Jamuna Sub-System
5) Tulsiganga System with Haraboti Sub-System
6) Gangnai-Nagor System with Nungolar Sub-System
7) Karatoya System

2.4.3 Computation of Drainage Coefficient in the Project by BRTC (BUET)

Drainage coefficients for the three hydrological zones of the project area have been calculated using 5-year 3-day accumulated rainfall. The water balance equation used for the determination of drainage coefficient for rice field is as follows:

$$AD = R(T) + ID - (DC + ET + SP) T$$

where AD = allowable depth of water, mm

R(T) = rainfall of 5-years frequency and duration of T days, mm

ID = initial depth of water, mm

DC = drainage coefficient, mm/day

ET = evapotranspiration, mm/day

SP = seepage and percolation, mm/day

T = 3 days

The drainage coefficients obtained by using above parameters for the three zones are 62.5, 40.5 and 35.2 mm per day respectively.

In this analysis, crop specific drainage requirement in different seasons was not taken into the consideration.

CHAPTER - 3

METHODOLOGY

BRTC and BWDB (1989) calculated design drainage coefficient for the three hydrological zones in the project area. The present study has been undertaken to recalculate the drainage coefficient using two recent methods. The steps including detail data analysis are presented in the following sections.

3.1 Rainfall Data Analysis

There are eleven rainfall stations in Zone I, ten in Zone II and eight in Zone III. Four representative rainfall stations from each zone have been selected for the drainage design analysis. Hence this exercise considered a network of twelve raingauge stations in the project area.

A list of selected rainfall stations showing location and period of records are presented in Table - 3.1. Examination of data showed that the extreme event of rainfall could occur at any time within the period from April to October, though highest frequency of occurrence is found in the monsoon months of July, August and September. For this study, the period from April to October is selected as the critical season. The daily rainfall data were extracted for the entire rainy season (April to October) and compiled for analysis using a computer programme.

Table - 3.1 : Rainfall Stations Used in the Study

Zones	Station Name	Station Number	Period of Record	Available Record Length (Year)	Remarks
I	Debiganj	R - 166	1965 - 1990	25	1 year missing
	Kaliganj	R - 177	1962 - 1990		4 year missing
	Rangpur	R - 206	1965 - 1989		no missing
	Sundarganj	R - 218	1963 - 1989		2 year missing
II	Bardarganj	R - 153	1964 - 1989	25	1 year missing
	Bhawaniganj	R - 156	1962 - 1989		3 year missing
	Mithapukur	R - 186	1963 - 1988		1 year missing
	Pirganj	R - 203	1965 - 1989		no missing
III	Bogra	R - 006	1965 - 1989	25	no missing
	Hilli	R - 175	1964 - 1989		1 year missing
	Phulbaria	R - 201	1963 - 1989		2 year missing
	Sibganj	R - 216	1965 - 1989		no missing

Considering the economic viability of the drainage project and studies of rainfall data which occur more or less continuous for periods upto 10 days, a design 10-day rainfall of 1 in 10 year return period was used in the present analysis. To determine the successive 1-day, 2-day, 3-day,...., 10-day maximum rainfall, the software DATMAN.02 was used. This program was developed by Northwest Hydraulic Consultants Ltd. (CIDA and NHCL, 1992).

The design 10-day 10-year cumulative rainfall for each zone for the month of April through October was determined by using Extreme Value Type I distribution. This distribution is the best for estimating design rainfall (Begum, 1985). This is also known as Double Exponential Distribution and introduced for extreme value by R.A Fisher and I. H. Tippet. This distribution is sometimes known as Gumbel Distribution because of Gumbel's various studies using this distribution in the flood frequency analysis.

Firstly, mean ($\bar{x}$) and standard deviation (σ) values were calculated using 25 years successive 1-day, 2-day, ..., 10-day cumulative rainfall for each station. Then two parameters (α and μ) were estimated using the equations $\alpha = \sigma * \sqrt{(6)}/\pi$ and $\mu = (\bar{x} - \alpha * 0.5772)$ for each rainfall depth. Finally, these values are substituted into the Extreme Value Type I distribution equation and calculated design rainfall depth (M) as given below (Haan, 1977):

$$M = \mu + \alpha * [-\ln \{-\ln (1 - 1/T)\}]$$

For this study, the value of T was considered as 10 years. The results of analysis for each zone are presented in the tabular form in Tables - B.1 to B.3. The summery of these results is shown in Table - B.4.

As mentioned in Article 1.1 that, both BWDB (1985) and BRTC (1989) used 1 in 5 year frequency of rainfall in the computation of drainage coefficient for the Teesta Barrage Project. The present study also attempted to carry out the same for the months of July and August for easy comparison. The results are shown in Table - B.4.

3.2 Water Level Data Analysis

To determine the gravity drainage period, river water level data were analyzed for the month of April through October for each of the drainage systems of the Project. For this analysis, recent 10 year data were used to determine 1 in 10 years data of monthly water level. These water levels were compared with the average ground level (MPO and BWDB, 1985) for the respective drainage system in the project area and shown in Table - 3.1.

Table - 3.2 indicates that the design water level for at each of the drainage systems are lower than the average ground level of the drainage basin. Hence it is concluded that gravity drainage is possible from April through October in the project area.

Table - 3.2 : Comparison of Water Level with Average Ground Level of the Drainage System in Teesta Barrage Project

Drainage System	Outfall River Stations & nos.	Avg GL[1]	1 in 10 Year Water Level, M PWD						
			A	M	J	J	A	S	O
ZONE - I									
1. Auliakhora-Garbha-Ghagot	Gaibandha(97)[2], Ghagot River	25.0	17.8	18.4	20.3	21.6	21.3	21.1	20.5
2. Deonai-Charalkata-Burikhora-Chikly	Badarganj (62), Jamuneswari Karatoya River	43.04	Data not available						
			20 year water level = 32.40, [MPO, 1985]						
ZONE - II									
1.Jamuneswari-Karatoya	Chak- Rahimpur(63); Karotoya River	24.5	16.5	17.4	19.5	20.2	20.6	20.3	19.9
2. Bangali	Simulbari (10), Bangali River	18.5	13.6	14.6	16.3	17.6	17.6	17.6	17.2
ZONE - III									
1.Kharkharia, Tulsiganga	Sunamukhi (325), Khakharia River	19.5	11.2	12.1	14.4	15.5	15.9	15.7	15.4
2. Nagor	Tolora Rly. Bridge(312)	16.5	11.5	12.1	13.7	14.4	14.8	14.1	14.7
3. Karatoya	Bogra (65)	18.0	12.1	12.7	14.0	14.7	15.2	15.1	14.7

[1] The average ground level is the weighted average of the mean ground level (MPO, 1985). Mean ground level of a catchment is the arithmetic average of the elevation of all grid points (1 km interval) falling in the Catchment Area.

[2] Values in ( ) indicate Water Level Gauge Station Numbers.

3.3 Drainage Coefficient Computation by Analytical Method

As described in the previous chapter in Article 2.1.4, the following values were taken into the consideration for the computation of drainage coefficient.

a) The percolation loss is assumed as 3 mm per day during premonsoon season (April-June) and 2 mm per day for the months of July and August during monsoon season.

b) For monthly evapotranspiration losses, values were taken from the report prepared by Karim and Akhand (1982) considering Rangpur district for zone I and Dinajpur district for zone II and zone III of the Teesta Barrage Project.

c) The pre-storage water depth was assumed as 50 mm and 100 mm during premonsoon (April - June) and monsoon (July - August) seasons respectively.

d) The allowable period of submergence was considered 3 days for Aus and Aman rice. The permissible submergence depth was assumed as 250 mm and 300 mm for these crops. The tolerance limit for Boro rice was assumed as 200 mm without submergence for a single day.

The computed rainfall values of 10-day 10-year were used for the determination of drainage coefficient. A computer program was used to perform the following computations.

- Net cumulative rainfall
- Residual flooding depths corresponding to assumed drainage coefficient value

Then the process of calculation has been done repeatedly with the assumed value of drainage coefficient until it satisfied the condition. It was usually attempted to limit the residual flooding to within the permissible flood depth. In this way, the analysis for the three zones has been completed for specific drainage period. The computer outputs showing results are presented in Tables - B.5 to B.13.

3.4 Drainage Coefficient Computation by Graphical Method

The procedure for computation of drainage coefficient by this method has already been described in Article 2.1.1. The assumed pre-storage depth, permissible flood depth and allowable duration of flooding were also mentioned. The 10-day 10-year rainfall values (Table - B.4) were used for the computation of drainage coefficient. Then rainfall depth - duration curves were plotted (Figures - A.1 to A.9). Over this curve, a line was drawn from the point of tolerable flood depth with no interceptor for boro crop and with 3 days interceptor for other crops. The value of drainage coefficient was determined from the slope of the line. By adopting the same procedure, depth-duration-frequency curves for 5 and 10 years frequencies were plotted in the same graph for the three zones (Figures - A.10 to A.12) and drainage coefficient was calculated.

CHAPTER - 4

RESULTS AND DISCUSSION

The different procedures adopted to determine the design drainage coefficient of the flood control and drainage projects are reviewed after collecting reports and design manuals from organizations responsible for this purpose in Bangladesh. It reveals that procedures and design criteria are not similar to each other. The results of the present study and their comparison with the results obtained by other organizations are briefly described in the following sections.

4.1 Results of the Present Study

The drainage coefficient has been estimated for this study using the two methods developed by NHCL (graphical) and EPC (analytical), described in articles 2.1.1 and 2.1.4 of this report. The results of these analysis for the three zones in the project area are presented in Table - 4.1.

From Table - 4.1, it is observed that the values of drainage coefficient by graphical method is lower in May but higher in August and almost equal in June. This is due to the provision of 300 mm flood submergence tolerance for Boro crop in graphical method in contrast to 200 mm in analytical method. The variation of drainage coefficient in monsoon seasons is due to provision of deep percolation which may be lower than assumed values. The results of the drainage coefficient considering 5 year frequency were calculated as 40, 34 and 30 mm per day for zone I, zone II and zone III respectively. These values are almost 27 percent lower in comparison to 10 year frequency results due to variation of rainfall depth.

The design drainage discharge of the drainage channels is generally computed from the critical drainage coefficient.

Table - 4.1: Drainage Coefficient of Teesta Barrage Project by Two Different Methods

Drainage Period	April-May			May-Early June			July-August		
Crops	Boro at late stage			T.Aus/B.Aus at vegetative stage			T.Aman at early stage		
Analytical method	Graphical method	Analytical method	Percent Variation	Graphical method	Analytical method	Percent Variation	Graphical method	Analytical method	Percent Variation
Zone-I	11	18	63	23	23.1	0	54.5	39.9	26
Zone-II	6	12	100	17	17	0	49.5	31	37
Zone-III	3	2	33	15.8	17.5	10	40	24.5	38

Note: Drainage Coefficient values are in mm per day.

Hence it is concluded that T. aman is the most critical crop which need significant drainage during transplantation period for the aforesaid three zones in the project area. Therefore, the design drainage coefficients have been found as 54.50, 49.50 and 40.00 mm per day for zone - I, zone - II and zone - III respectively.

4.2 Comparison of the Results

Similar types of analysis were carried out by MPO (1984), BWDB/UNDP (1983) and BRTC/BUET (1989) which have been reviewed during present study. The critical values of drainage coefficients evaluated by two different methods and the values obtained by the aforesaid organizations are compiled together and presented in Table - 4.2. for easy comparison of the results.

Table - 4.2 : Comparison of the Results of Drainage Coefficient of Teesta Barrage Project

Zones	Present Study	BRTC & BUET (1989)	BWDB & UNDP (1983)	MPO (1984)
I	54.5	62.8	34.9	40.0
II	49.5	40.5	25.9	30.0
III	40.0	35.2	22.5	30.0

From the above results, it is observed that the drainage coefficient values obtained by BRTC (BUET) are lower in zone II and zone III compared to the results of present study and higher in zone I. This is due to use of 3-day 5-year cumulative rainfall by BRTC/BUET instead of 10-day 10-year cumulative rainfall used in the present study. The values of the drainage coefficient obtained by BWDB/UNDP and MPO are comparatively lower than the other values.

But the values of drainage coefficient with 5 years frequency are 42 percent lower in zone-I and almost 16 percent lower in zone II and III in contrast to BRTC results and found nearly equal to MPO values. This is also due to variation of rainfall depth.

Before designing a drainage system for agricultural purpose, drainage coefficient should be determined considering the crops for which protection is necessary. Lack of anticipated drainage may cause failure of the project.

CHAPTER - 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

In the light of the present study, the following conclusions can be drawn :

1) From the results of the present study, it was observed that graphical method is more conservative than the analytical method for monsoon drainage and less conservative for premonsoon drainage. The reason behind this may be that crop evapotranspiration and percolation losses have been ignored.

2) From the results, it was also found that T. Aman is the most critical crop which need significant drainage during transplantation period for the three zones in the project area.

3) Consideration of drainage period, return period and duration of rainfall are the dominating variable in the analysis of drainage coefficient. But at present, different projects use different design criteria in Bangladesh.

5.2 Recommendations

Flood control and drainage (FCD) schemes are extensive throughout the study area and there are many existing and on-going projects. Drainage planning should be undertaken including the existing development where appropriate, and best possible use of the existing infrastructures.

Some completed projects may be taken up under a research study to measure the rainfall, actual discharges and crop submergence data.

To make the computation of design drainage coefficient easier, it is recommended to prepare 1-day, 2-days, ..., 10-days isohyetal maps for frequencies of 5 and 10 years for Bangladesh. From available data and computer facilities, these types of rainfall atlas will save a lot of time for computation of drainage coefficient for the projects in Bangladesh.

The concept used in graphical method for the estimation of drainage design in this study area will meet for appropriate drainage design for small drainage system for the northwest region and other locations of Bangladesh.

REFERENCES

1. Agricultural Development Corporation (Korea) and BWDB, PIRDP, Feasibility Report, Volume 1, 1978.

2. BWDB and EPC; Third Flood Control and Drainage Project, Design Manual, Vol. - 1, 1985

3. BWDB, Design Standard for Irrigation and Drainage System, Directorate of Design, Teesta Barrage Project, 1985.

4. Begum, Selina, Drainage Requirement for Selected Crops in the North - Eastern Region of Bangladesh, M. Sc. Engineering Thesis, Department of Water Resources Engineering, BUET, 1985.

5. BWDB and UNDP, Water Balance Studies, Final Report, Report 1 Surface Water, July 1983.

6. BUET and BWDB, Review and Modification of Drainage Planning and Methodology for Drainage Design, June, 1989.

7. Bangladesh - Netherlands Joint Programme, Delta Development Project, Design Manual, 1985.

8. Chow, V.T., Hand-Book of Applied Hydrology, McGraw-Hill Book Company, 1964.

9. CIDA, NHCL, Basic Engineering Planning for Small Flood Control and Drainage Schemes in Bangladesh, 1992.

10. EPC and BWDB, BWDB Small Scheme Project, 1988.

11. FAO, Crop Water Requirements, Irrigation and Drainage Paper Nr. 24, Rome, 1977.

12. Haan, Charles T., Statistical Methods in Hydrology, Iowa St. University Press, America, 1977.

13. ILRI, Drainage Principles and Applications; Publication 16, Vol.- 1, 1979.

14. Karim, Z, and Akhand, N.A., Net Irrigation Requirement of Rice and Evapotranspiration of Wheat and Potato for Different Locations of Bangladesh. BARC, December, 1982.

15. MPO and HARZA, National Water Plan Project; Second Interim Report, Volume VI, Agriculture, June 1984.

16. MPO and HARZA, Technical Report Nr. 10, Surface Water Availability, 1985.

17. MPO and HARZA, Technical Report Nr. 15, Planning Area Analysis, 1985.

18. Shajahan and Hossain, Flood in Bangladesh and Acceptable Policy for Flood Control, 34th Annual Convention, IEB, Dhaka, 1990.

APPENDIX - A : FIGURES

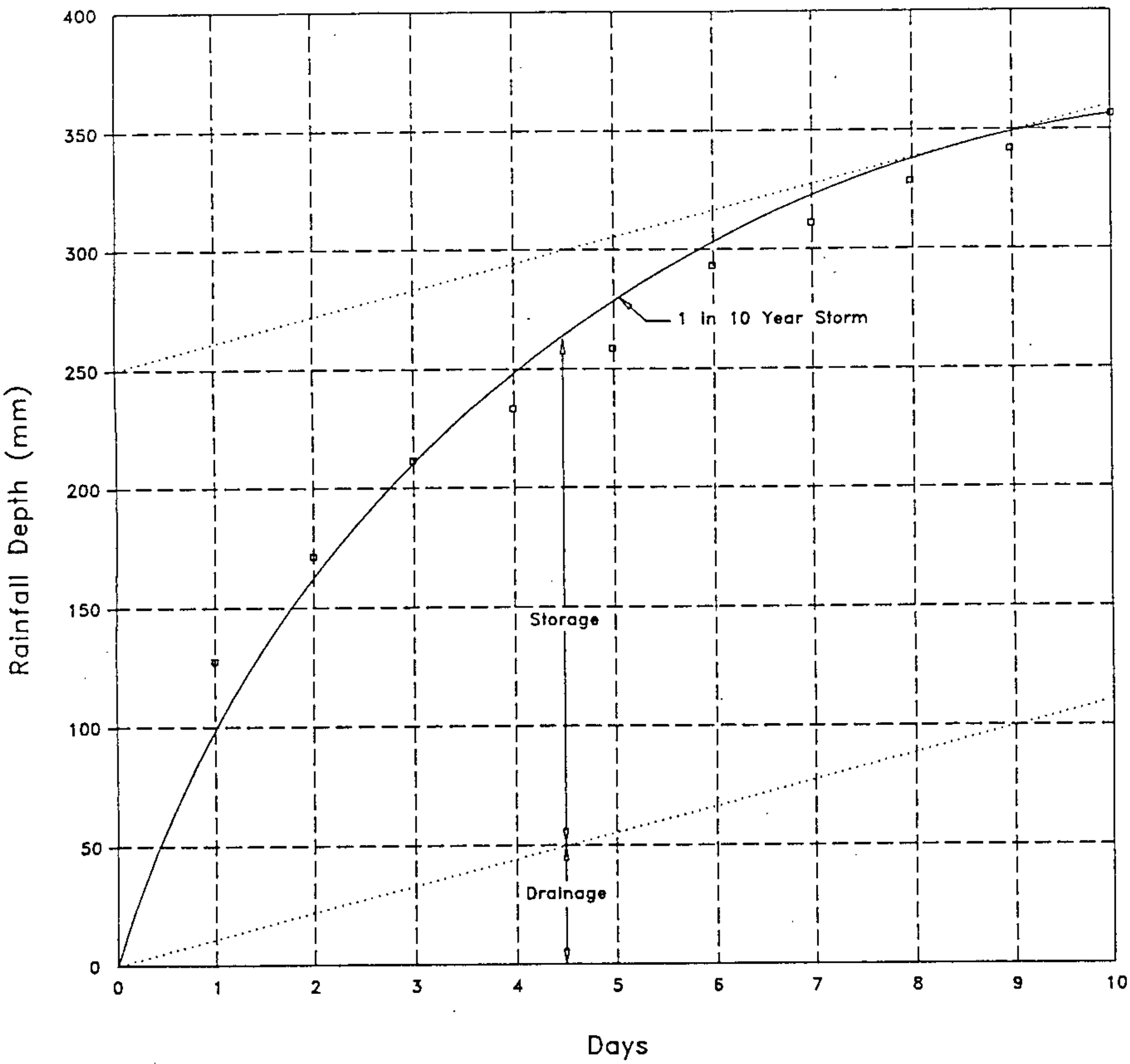


Figure - A.1 : **Depth-Duration-Frequency Relation To Determine Drainage Coefficient for Boro Rice (April-May), Zone-I**

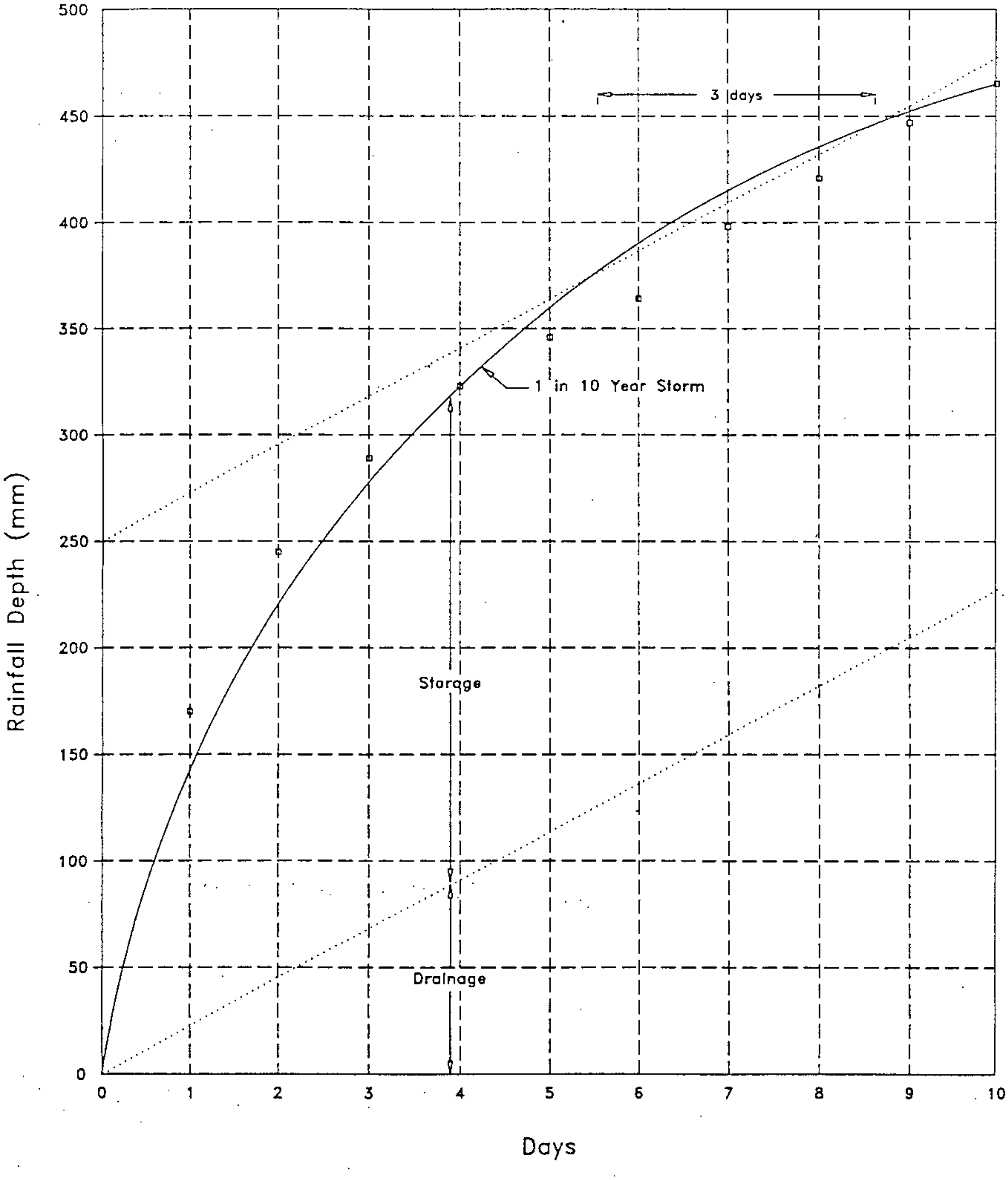


Figure - A.2 : **Depth-Duration-Frequency Relation To Determine Drainage Coefficient for Aus Rice (May-June), Zone-I**

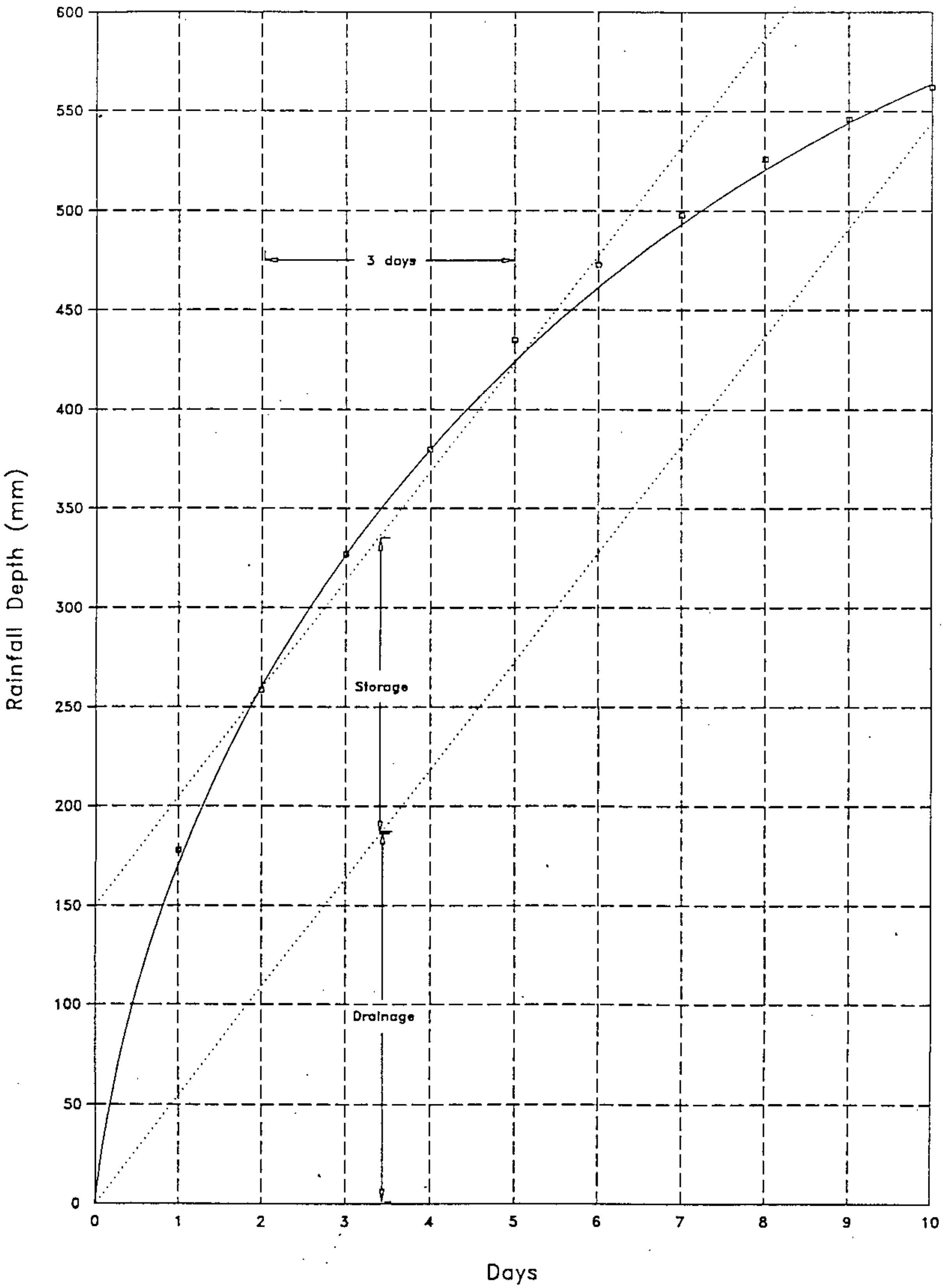


Figure - A.3 : **Depth-Duration-Frequency Relation To Determine Drainage Coefficient for Aman Rice (July-August), Zone-I**

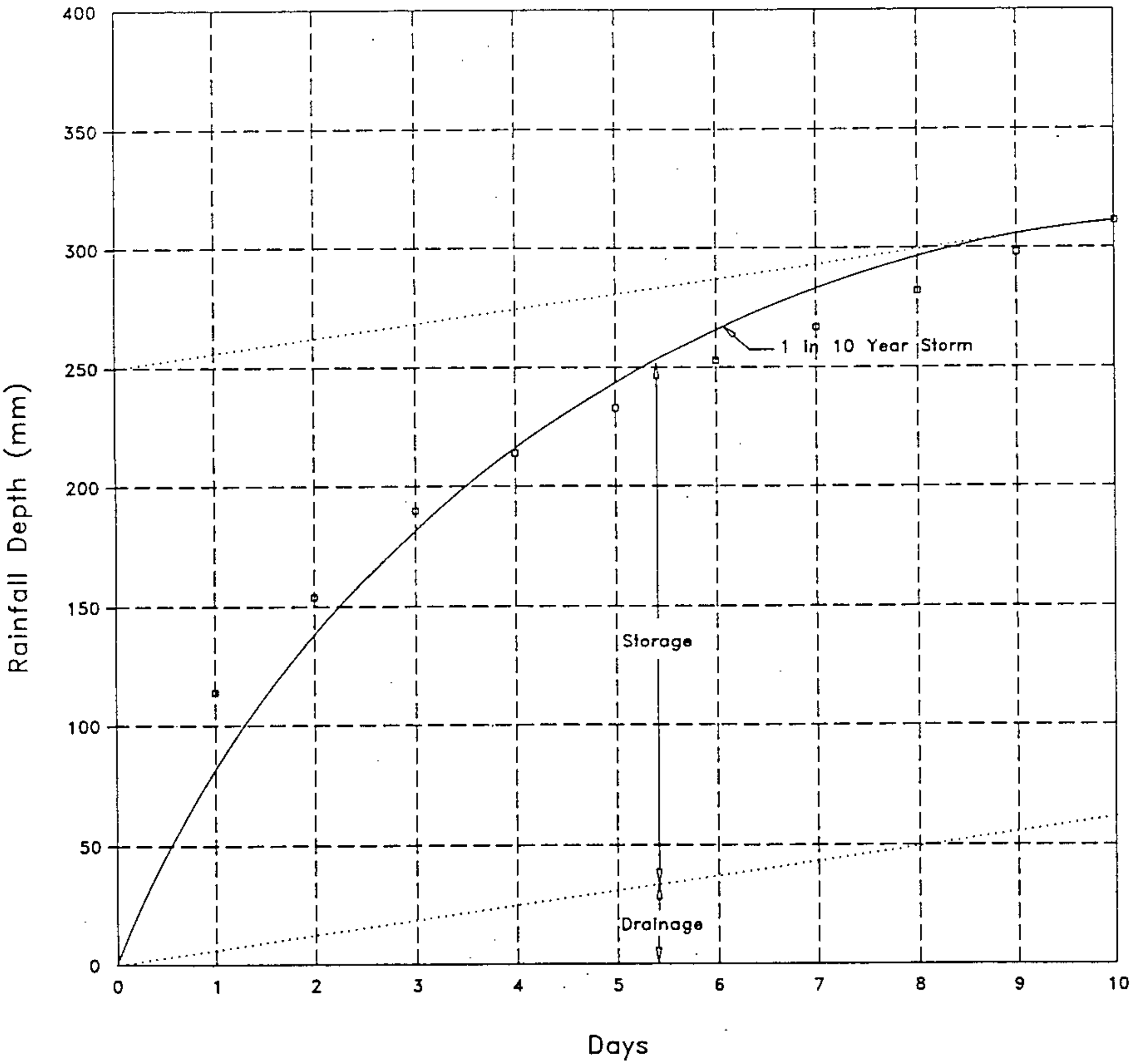


Figure - A.4 : **Depth-Duration-Frequency Relation To Determine Drainage Coefficient for Boro Rice (April-May), Zone-II**

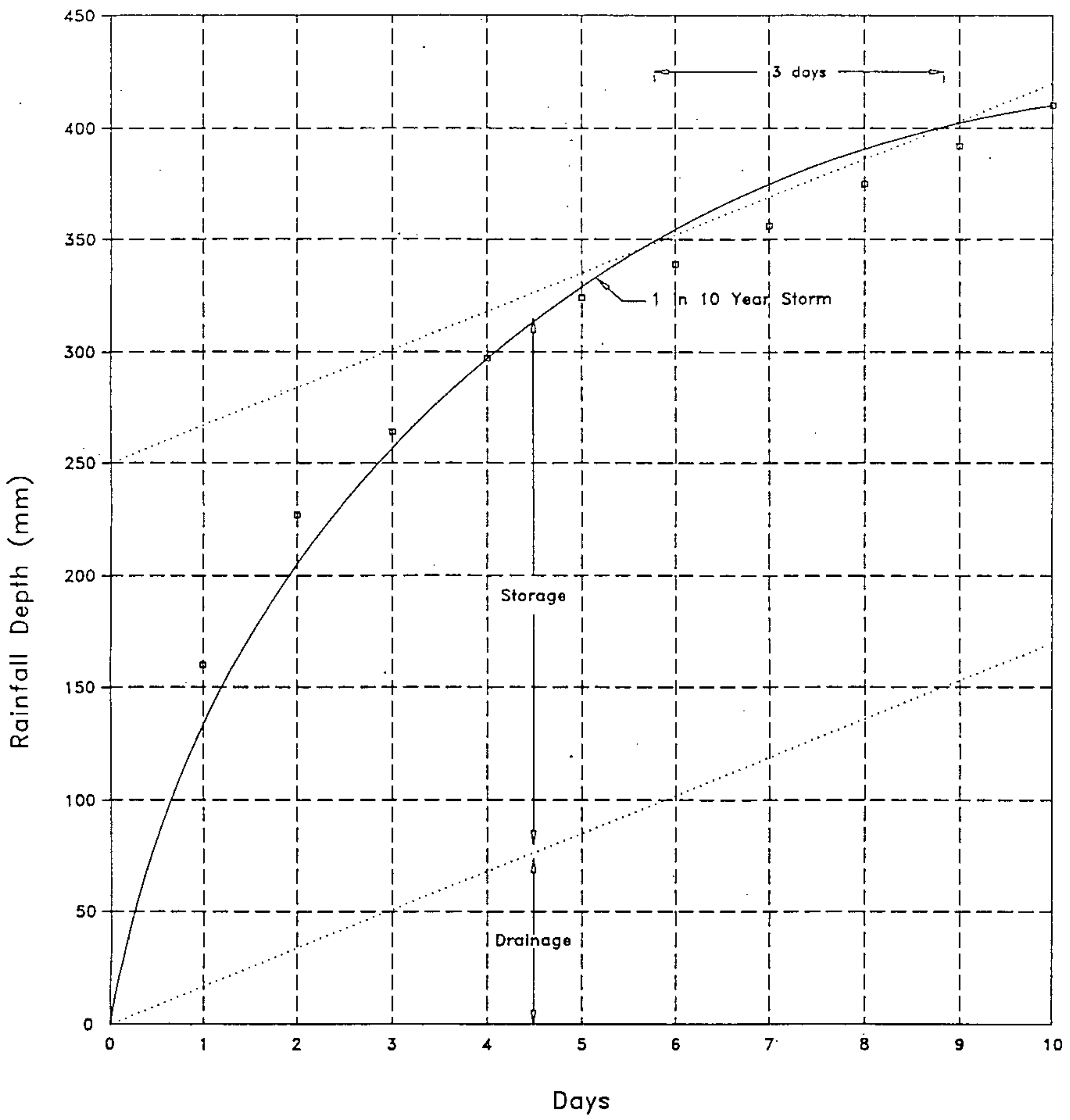


Figure - A.5 : **Depth-Duration-Frequency Relation To Determine Drainage Coefficient for Aus Rice (May-June), Zone-II**

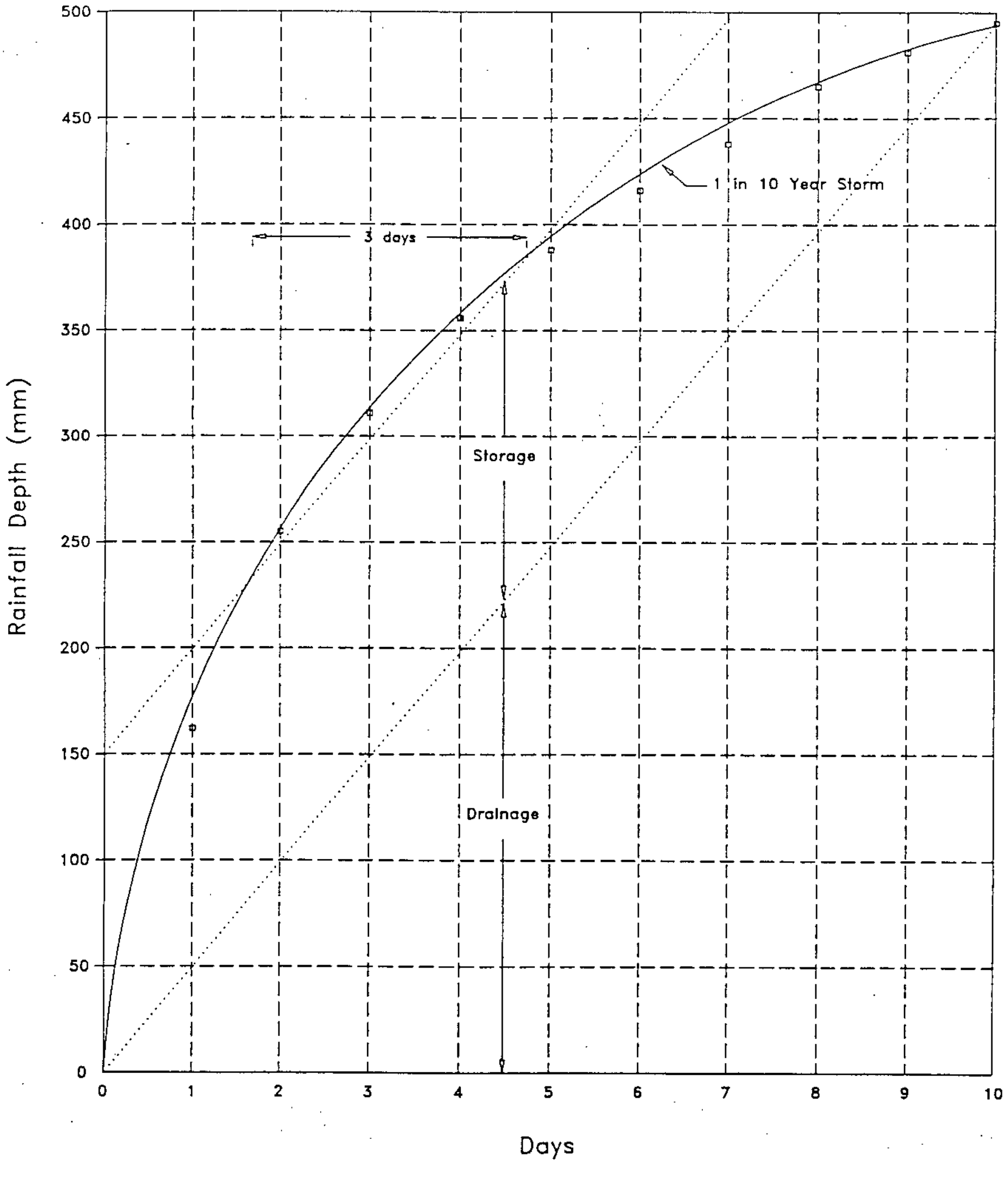


Figure - A.6 : **Depth-Duration-Frequency Relation To Determine Drainage Coefficient for Aman Rice (July-August), Zone-II**

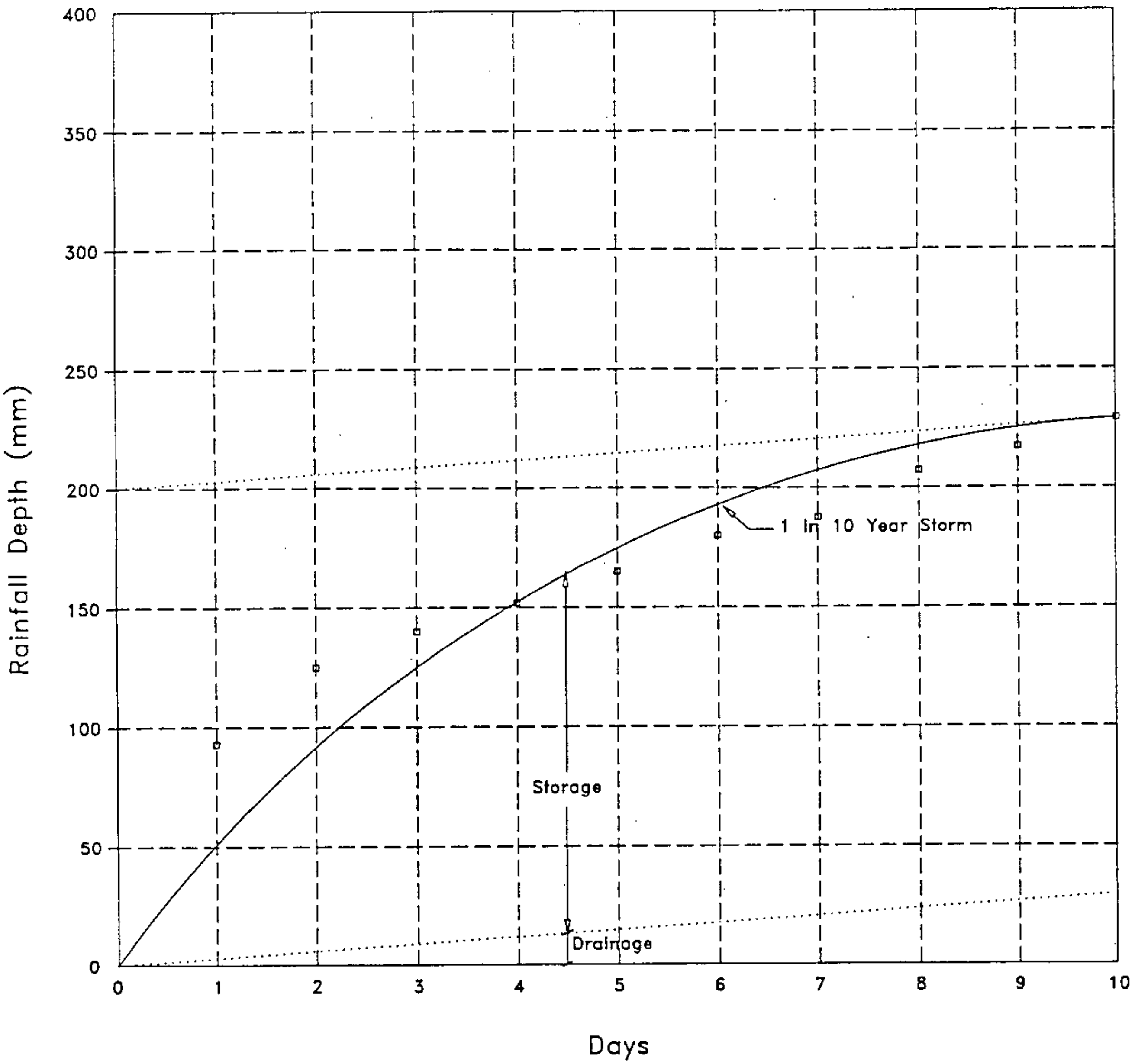


Figure - A.7 : **Depth-Duration-Frequency Relation To Determine Drainage Coefficient for Boro Rice (April-May), Zone-III**

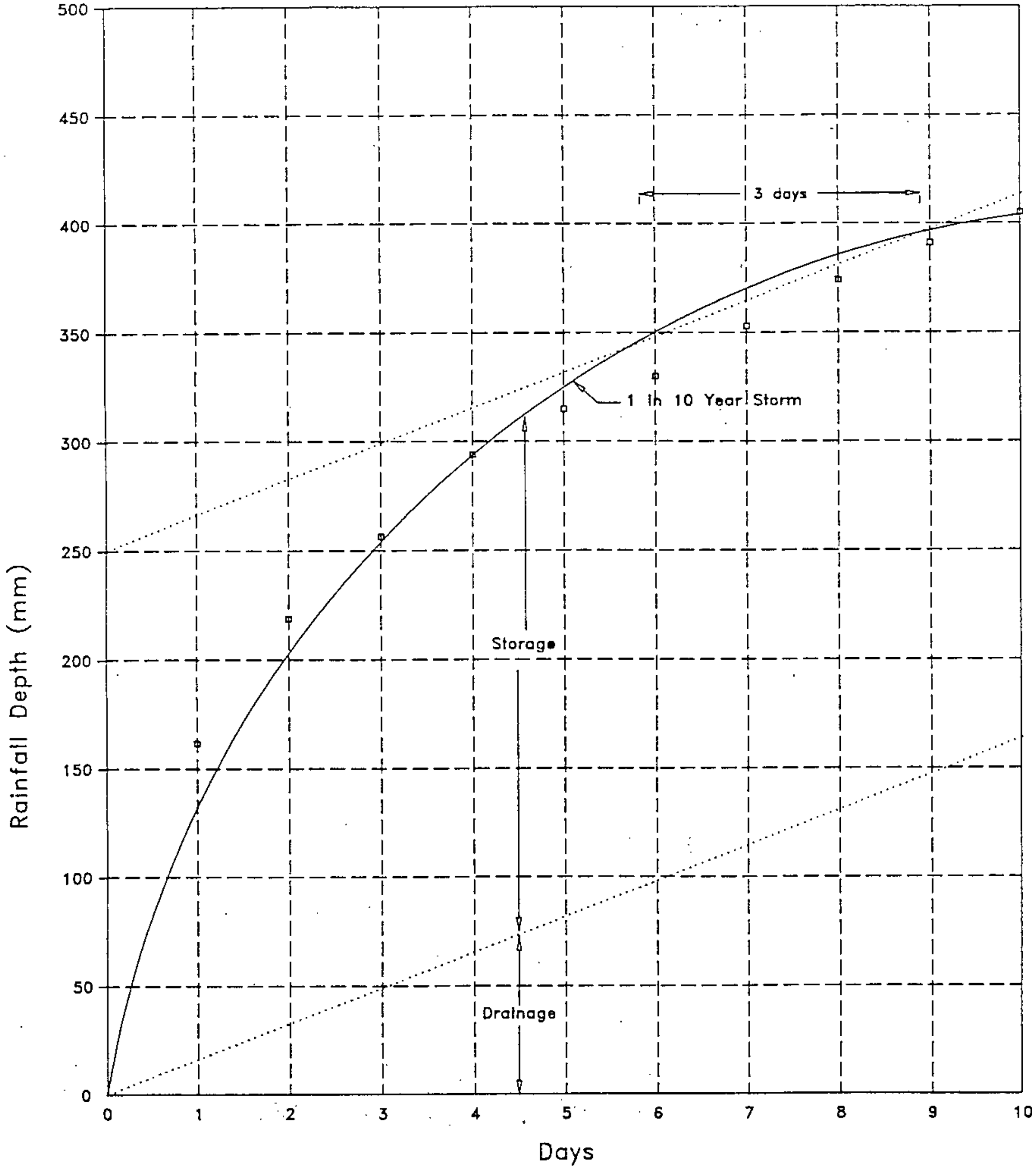


Figure - A.8 : **Depth-Duration-Frequency Relation To Determine Drainage Coefficient for Aus Rice (May-June), Zone-III**

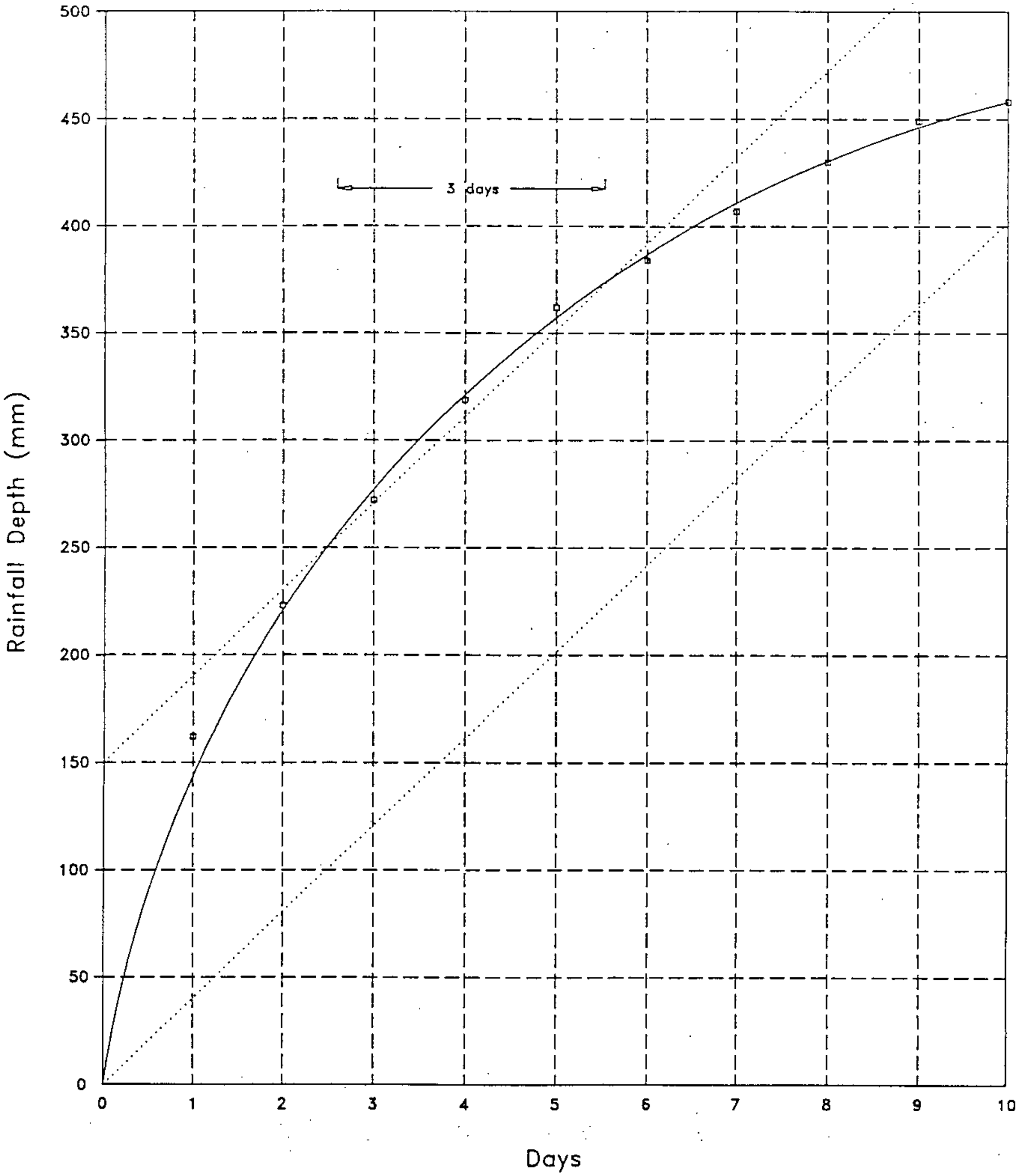


Figure - A.9 : **Depth-Duration-Frequency Relation To Determine Drainage Coefficient for Aman Rice (July-August), Zone-III**

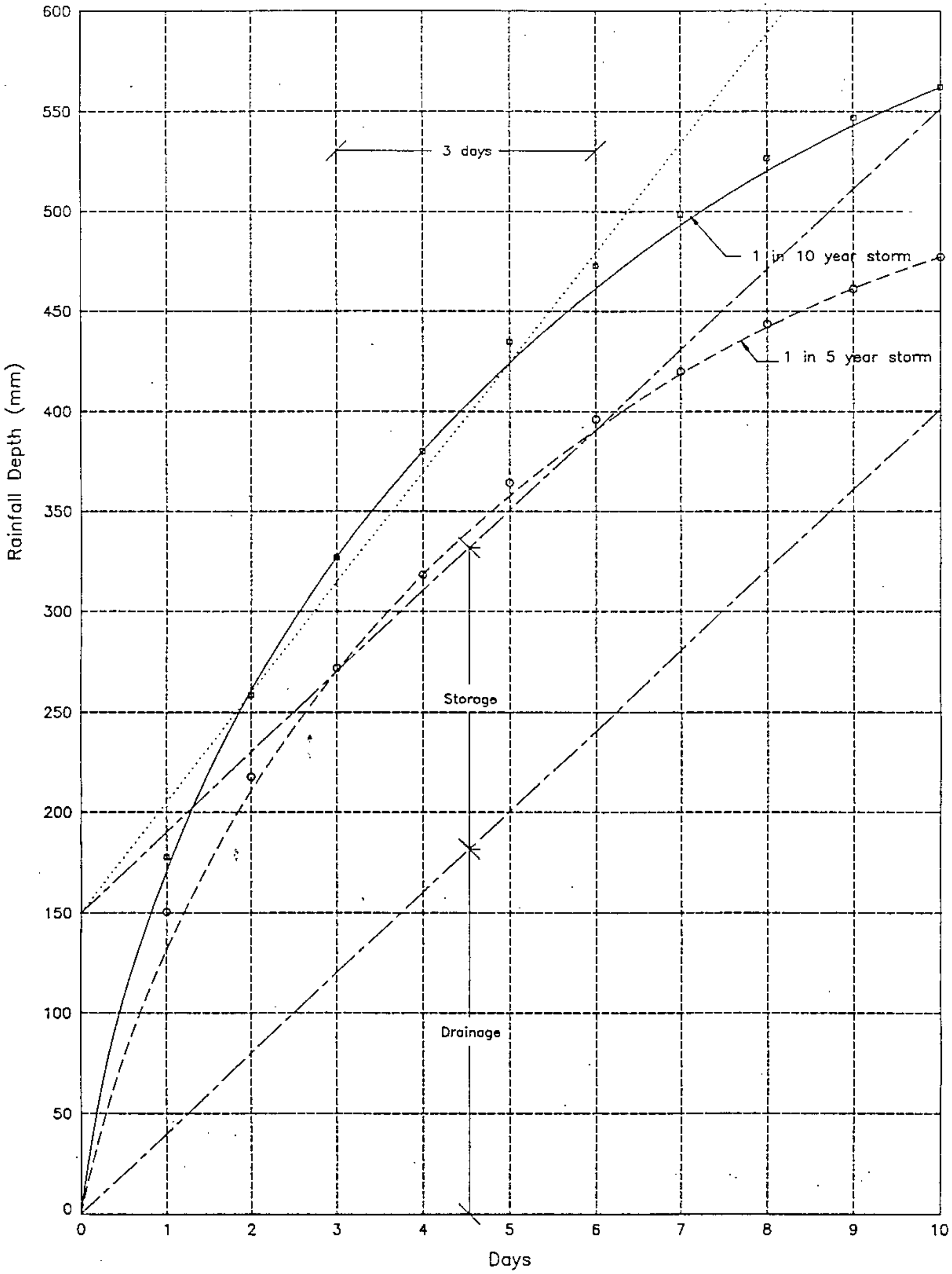


Figure - A.10 : **Depth-Duration-Frequency Relation with 5 and 10 Year Frequencies for Aman Rice (July-August), Zone-I**

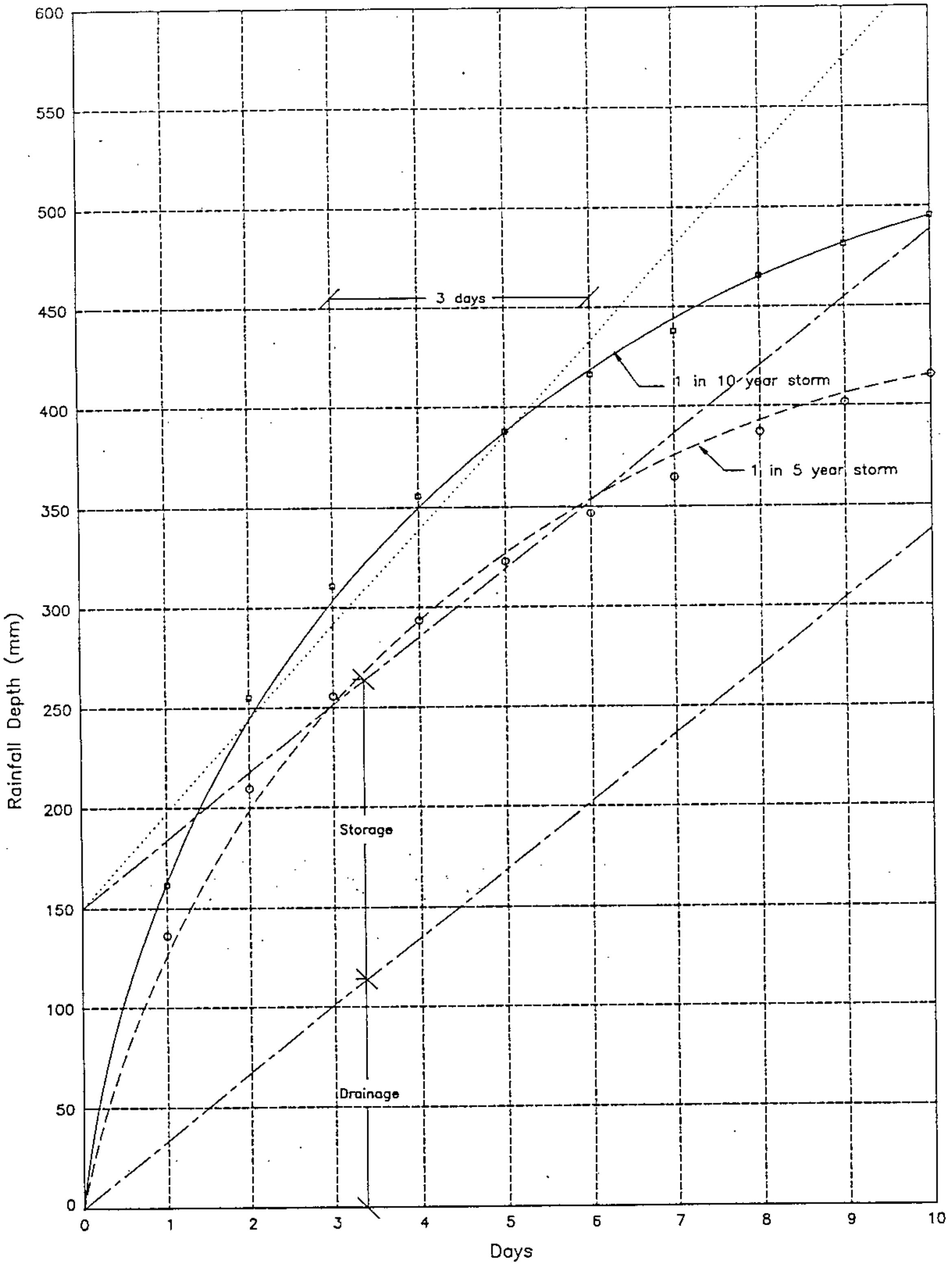


Figure - A.11 : **Depth-Duration-Frequency Relation with 5 and 10 Year Frequencies for Aman Rice (July-August), Zone-II**

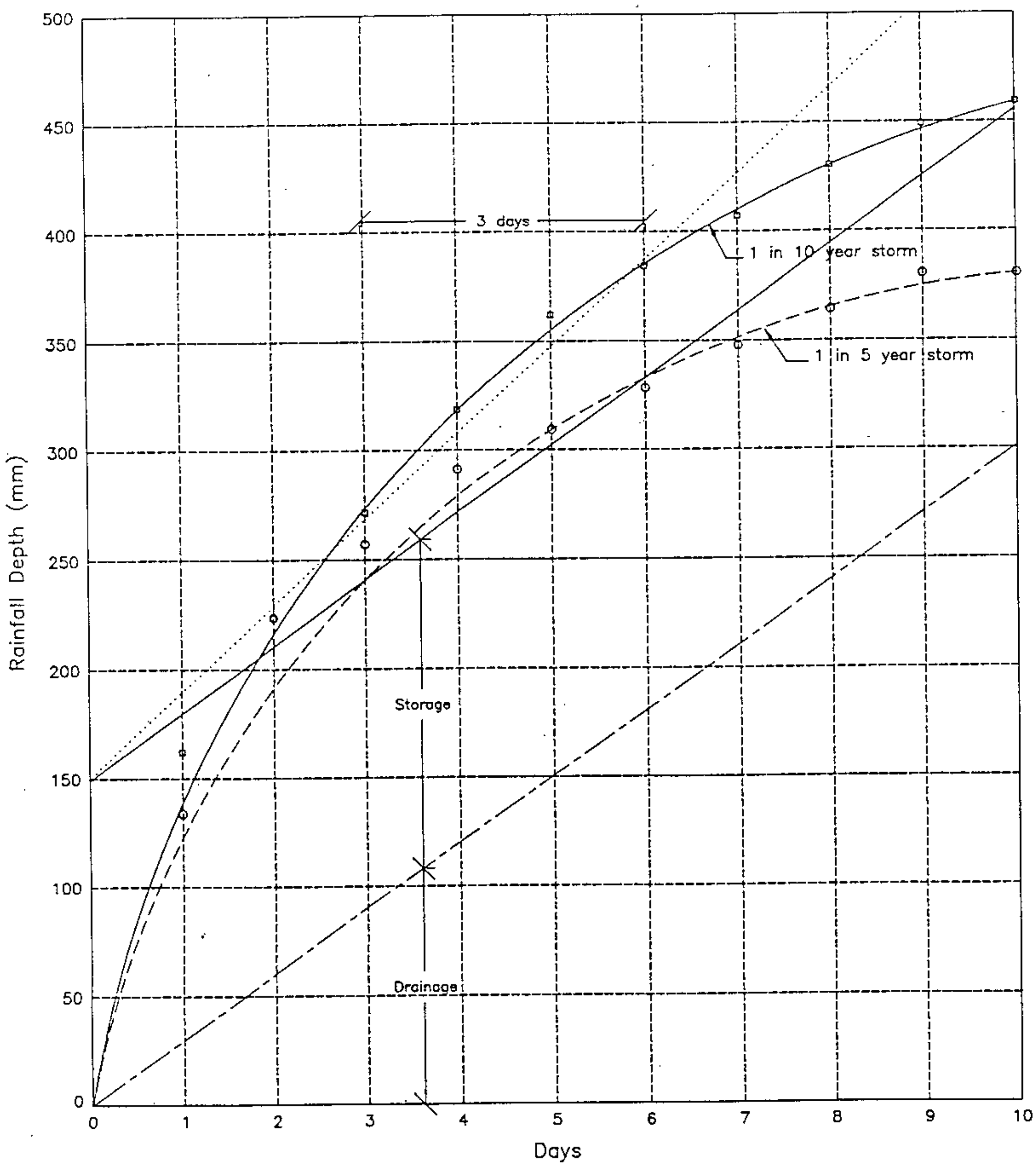


Figure - A.12 : **Depth-Duration-Frequency Relation with 5 and 10 Year Frequencies for Aman Rice (July-August), Zone-III**

APPENDIX - B : TABLES

Table-B.1 : Successive 1-10 Day Maximum Rainfall (mm), 1 in 10 Year (Zone I)

Station	Days	APR	MAY	JUN	JUL	AUG	SEP	OCT
R 166 DEBIGANJ	D01	80.0	128.7	165.9	164.5	176.1	163.4	144.9
	D02	88.7	172.5	228.3	234.2	245.9	236.6	203.0
	D03	103.6	210.7	269.3	333.6	324.6	286.5	236.6
	D04	120.6	243.8	306.9	385.6	381.3	329.2	249.2
	D05	121.4	248.2	332.1	439.9	392.1	349.5	264.5
	D06	122.6	311.9	352.0	490.6	466.6	416.3	270.8
	D07	124.7	332.2	399.9	521.2	494.7	443.0	296.6
	D08	131.9	355.4	413.2	558.0	520.4	463.6	317.0
	D09	135.4	377.8	447.9	575.3	539.3	492.6	321.9
	D10	140.1	398.0	477.0	593.7	556.0	529.4	334.4
R 177 KALIGANJ	D01	66.7	111.3	165.5	187.1	163.1	177.9	164.8
	D02	94.8	177.9	244.9	295.4	218.0	280.3	219.6
	D03	104.5	232.7	295.5	367.8	283.8	299.5	253.6
	D04	106.0	245.5	336.6	421.6	330.1	340.1	268.3
	D05	109.4	285.3	355.5	500.2	345.2	372.6	293.6
	D06	112.7	313.3	379.3	554.4	398.9	442.5	304.0
	D07	116.9	323.0	406.3	591.2	409.2	465.0	326.0
	D08	121.4	334.6	437.4	612.9	500.3	484.1	340.9
	D09	126.4	349.0	464.9	638.3	514.5	497.2	347.3
	D10	130.3	372.9	482.7	661.4	538.7	514.5	358.1
R 206 RANGPUR	D01	55.1	120.4	201.3	187.3	156.9	175.3	138.5
	D02	72.2	153.0	279.0	270.5	215.9	232.1	173.9
	D03	83.4	189.8	317.4	325.0	260.7	262.7	185.7
	D04	94.7	210.4	341.9	376.7	300.5	314.9	194.5
	D05	107.2	235.3	368.9	425.2	313.9	325.3	214.1
	D06	109.0	260.0	385.7	450.0	347.4	341.1	234.8
	D07	112.9	278.0	402.6	464.8	395.7	356.8	243.0
	D08	117.3	297.6	419.9	483.3	441.4	387.6	251.3
	D09	122.4	308.0	445.8	509.4	494.0	407.2	268.7
	D10	130.8	316.9	459.0	522.2	524.3	426.1	291.7
R 218 SUNDARGANJ	D01	57.3	150.5	148.3	172.3	135.7	152.0	104.8
	D02	75.6	182.3	228.2	233.8	201.4	219.0	154.7
	D03	86.7	212.9	273.9	281.1	247.4	255.7	192.3
	D04	94.3	234.4	306.8	336.6	286.1	277.7	222.4
	D05	112.0	266.4	326.9	373.1	311.7	298.0	231.1
	D06	114.1	287.8	340.8	395.3	329.6	313.6	249.8
	D07	116.7	310.8	384.0	415.8	351.0	319.3	258.8
	D08	120.9	326.2	413.1	451.2	363.1	332.8	261.8
	D09	121.6	333.6	428.3	462.6	429.1	348.2	270.1
	D10	125.3	338.0	441.2	471.0	458.5	364.2	283.0

Table–B.2 : Successive 1–10 Day Maximum Rainfall (mm), 1 in 10 Year (Zone II)

Station	Days	APR	MAY	JUN	JUL	AUG	SEP	OCT
R 153 BADARGANJ	D01	64.3	94.8	170.7	173.8	147.8	190.4	124.2
	D02	74.2	128.8	247.8	236.5	190.8	225.3	183.2
	D03	78.4	159.5	280.9	269.5	230.2	271.3	203.4
	D04	83.2	174.7	312.8	321.4	269.0	295.1	210.1
	D05	91.3	193.1	329.7	357.6	278.2	302.0	245.3
	D06	103.2	209.1	346.9	369.9	295.4	311.7	262.9
	D07	109.7	222.4	361.7	400.3	338.4	326.0	272.0
	D08	115.4	236.8	376.0	413.5	383.8	343.4	275.9
	D09	117.0	250.2	390.3	438.0	415.1	358.1	280.4
	D10	120.3	258.3	416.0	446.1	457.6	368.3	293.2
R 156 BHAWANIGANJ	D01	62.0	139.8	144.3	148.9	114.6	135.4	154.4
	D02	70.9	186.7	208.9	251.9	171.3	192.5	190.6
	D03	90.1	225.4	229.6	315.2	203.0	223.8	203.6
	D04	101.4	257.0	251.2	356.4	236.3	253.0	215.7
	D05	106.6	275.1	267.1	386.7	257.6	278.4	218.6
	D06	112.8	300.8	278.1	413.0	275.4	293.8	234.8
	D07	123.8	309.6	307.5	421.9	314.8	297.0	241.3
	D08	128.8	325.7	347.0	446.9	372.5	301.2	256.8
	D09	134.3	341.9	371.8	451.9	417.6	307.8	265.1
	D10	135.7	355.5	393.5	463.2	433.7	320.4	272.8
R 186 MITHAPUKUR	D01	73.8	115.5	190.3	189.2	143.8	188.4	111.7
	D02	88.4	163.0	261.4	310.8	221.3	256.0	192.4
	D03	97.0	212.7	335.4	400.3	280.9	309.0	227.1
	D04	108.6	240.9	385.6	465.3	322.7	331.2	256.4
	D05	113.4	262.5	434.5	496.5	340.6	355.7	283.8
	D06	123.0	282.3	445.6	553.3	368.2	369.4	303.0
	D07	131.3	299.8	458.4	587.8	417.7	388.3	310.4
	D08	139.2	313.5	463.7	644.6	461.0	423.9	313.6
	D09	149.2	339.7	482.5	667.1	535.1	460.1	330.2
	D10	153.0	356.4	498.3	686.5	569.5	485.7	346.4
R 203 PIRGANJ	D01	52.5	104.6	134.4	135.1	127.7	123.4	124.2
	D02	90.9	136.9	188.3	219.0	182.9	178.9	156.9
	D03	104.9	162.6	211.4	257.3	213.6	220.7	168.4
	D04	108.1	184.9	239.5	278.9	234.0	239.3	175.4
	D05	112.9	201.7	264.2	310.4	281.8	254.8	195.5
	D06	117.4	219.5	284.1	328.6	320.4	270.3	211.0
	D07	124.2	235.2	295.3	341.7	338.8	281.9	220.2
	D08	129.2	252.8	313.3	356.4	364.1	299.9	230.5
	D09	135.1	260.5	323.8	367.7	398.9	326.6	238.5
	D10	137.5	272.8	333.7	384.4	418.5	337.6	252.2

Table-B.3 : Successive 1-10 Day Maximum Rainfall (mm), 1 in 10 Year (Zone III)

Station	Days	APR	MAY	JUN	JUL	AUG	SEP	OCT
R 006 BOGRA	D01	80.8	92.0	148.8	149.5	113.4	122.9	119.1
	D02	98.9	130.7	217.0	212.6	188.6	156.7	220.4
	D03	107.7	146.2	258.3	245.8	229.9	230.5	263.2
	D04	119.2	168.3	292.2	284.1	248.7	246.5	274.8
	D05	124.7	178.8	301.7	319.7	258.9	258.9	282.9
	D06	131.8	202.7	319.7	330.8	272.3	274.2	290.9
	D07	136.8	210.1	353.7	356.7	290.0	284.3	297.0
	D08	142.5	229.7	373.2	373.7	325.0	303.5	306.1
	D09	145.8	242.8	386.1	387.8	351.1	342.8	326.0
	D10	150.0	259.0	398.0	399.0	387.7	366.1	339.2
R 175 HILLI	D01	57.7	91.7	142.9	144.1	156.0	140.7	121.0
	D02	71.4	116.9	185.4	185.8	191.9	184.6	149.8
	D03	82.0	127.6	214.3	223.4	277.2	213.8	171.1
	D04	89.6	141.0	237.4	258.8	299.2	245.7	179.8
	D05	93.0	151.1	251.9	285.7	318.2	266.2	197.2
	D06	94.6	162.4	264.9	314.2	339.2	282.7	219.8
	D07	95.7	172.7	288.0	338.2	366.2	294.7	225.7
	D08	102.5	179.2	306.8	356.6	389.7	315.9	233.0
	D09	104.2	188.6	321.2	379.0	430.1	329.5	249.8
	D10	107.2	199.4	341.3	396.9	446.7	353.7	264.2
R 201 PHULBARIA	D01	67.4	95.0	175.8	177.1	178.1	134.0	102.4
	D02	86.8	126.4	236.1	247.3	252.3	197.7	135.3
	D03	96.1	142.5	276.8	308.8	286.2	219.0	164.4
	D04	113.7	148.5	323.4	365.6	313.0	234.5	169.5
	D05	119.5	164.2	353.0	420.9	352.6	244.2	178.5
	D06	126.9	177.8	368.5	445.5	373.0	260.7	204.5
	D07	131.8	187.3	384.9	466.6	404.6	270.5	212.0
	D08	135.7	209.7	407.3	495.2	425.5	288.3	224.5
	D09	140.6	218.0	428.3	514.6	475.5	308.3	230.2
	D10	153.0	228.9	439.7	518.8	519.7	337.5	253.7
R 216 SIBGANJ	D01	60.1	136.5	153.8	161.5	141.4	162.0	190.1
	D02	71.5	164.0	210.8	219.7	180.2	212.4	301.8
	D03	84.1	182.4	258.7	277.8	213.9	275.5	336.7
	D04	100.1	196.2	305.2	302.0	237.1	294.6	341.8
	D05	105.1	202.7	321.3	348.4	262.1	321.0	355.1
	D06	112.3	215.2	364.2	366.8	279.6	329.0	385.5
	D07	118.1	226.9	394.5	388.3	302.3	347.3	391.8
	D08	124.0	242.8	421.8	408.7	336.4	355.9	412.0
	D09	126.3	248.7	443.2	433.0	371.0	380.4	417.4
	D10	131.1	262.9	452.1	462.3	401.7	397.2	423.3

Table–B.4 : 10 Day 10 Year Rainfall (mm) for Twelve Stations

Zone	Days	10 Day – 10 Year							10 Day – 5 Year	
		APR	MAY	JUN	JUL	AUG	SEP	OCT	JUL	AUG
Zone I	D01	64.8	127.7	170.3	177.8	158.0	167.2	138.3	150.6	129.2
	D02	82.8	171.4	245.1	258.5	220.3	242.0	187.8	217.8	180.4
	D03	94.5	211.5	289.0	326.9	279.2	276.1	217.1	272.1	226.3
	D04	103.9	233.5	323.0	380.1	324.5	315.5	233.6	318.4	263.5
	D05	112.5	258.8	345.8	434.6	340.7	336.3	250.8	364.5	279.1
	D06	114.6	293.2	364.4	472.6	385.6	378.4	264.8	396.1	315.4
	D07	117.8	311.0	398.2	498.3	412.6	396.0	281.1	419.9	338.2
	D08	122.9	328.5	420.9	526.3	456.3	417.0	292.7	443.6	370.4
	D09	126.4	342.1	446.7	546.4	494.2	436.3	302.0	461.2	401.2
	D10	131.6	356.4	465.0	562.1	519.4	458.5	316.8	477.1	423.3
Zone II	D01	63.2	113.7	159.9	161.7	133.5	159.4	128.6	136.3	108.9
	D02	81.1	153.8	226.6	254.5	191.6	213.2	180.8	209.6	152.8
	D03	92.6	190.0	264.3	310.6	231.9	256.2	200.6	255.8	186.4
	D04	100.3	214.4	297.3	355.5	265.5	279.7	214.4	293.6	214.3
	D05	106.1	233.1	323.9	387.8	289.6	297.7	235.8	322.9	325.3
	D06	114.1	252.9	338.7	416.2	314.8	311.3	252.9	346.8	256.3
	D07	122.3	266.8	355.7	437.9	352.4	323.3	261.0	364.8	285.3
	D08	128.2	282.2	375.0	465.3	395.4	342.1	269.2	387.7	318.0
	D09	133.9	298.1	392.1	481.2	441.7	363.2	278.6	401.5	354.3
	D10	136.6	310.7	410.4	495.0	469.8	378.0	291.2	415.2	376.7
Zone III	D01	68.3	93.4	160.8	162.0	156.4	132.9	111.3	133.7	118.7
	D02	85.9	125.1	218.6	223.3	221.3	184.2	160.2	183.7	164.2
	D03	95.5	139.7	256.5	271.7	269.9	220.6	190.8	223.8	203.1
	D04	109.1	151.6	294.1	318.5	293.5	240.3	198.4	257.1	222.9
	D05	114.2	164.6	314.9	361.8	320.6	253.3	209.3	291.1	243.4
	D06	120.0	180.2	330.4	384.0	339.4	269.6	229.9	309.3	259.3
	D07	124.0	189.3	352.9	407.0	366.3	280.0	236.7	328.4	286.7
	D08	129.1	207.1	373.7	430.2	391.4	299.0	247.0	347.8	279.7
	D09	132.8	216.9	391.0	449.0	433.1	322.2	259.1	364.0	331.7
	D10	140.8	229.0	404.7	458.4	468.5	348.7	277.7	380.2	334.9

Table - B.5 : Drainage Design for Boro Rice (April-May) for Zone-I

TEESTA BARRAGE PROJECT

Drainage Coefficient Analysis

Location: ZONE - I

Evapotranspiration (mm/d):
April- 5.65
May- 5.43

Percolation(mm/d): 3

Losses (Et*0.5 + Perc.),mm/d: 6

Design Standards:
1. Rainfall: 1 in 10 year 10-day rainfall
2. Pre-storage (mm): 50
3. Permissible flood depth (mm): 200

Assumed drainage coefficient (mm/d): 18

Day	Cum.rain (mm)	Inc.rain (mm)	Cum.loss (mm)	Net rain (mm)	Drainage (mm)	Residual flood (mm)
1	128	128	6	122	18	154
2	171	43	12	159	36	173
3	212	41	18	194	54	190
4	234	22	24	210	72	188
5	259	25	30	229	90	189
6	293	34	36	257	108	199
7	311	18	42	269	126	193
8	328	17	48	280	144	186
9	342	14	54	288	162	176
10	356	14	60	296	180	166

Maximum residual flood (mm) : 199
Res.flood - permissible flood (mm): 0
Res.flood > permissible flood for : 0 days

Table - B.6 : Drainage Design for Aus Rice (May-June) for Zone - I

TEESTA BARRAGE PROJECT

Drainage Coefficient Analysis

Location: ZONE - I

Evapotranspiration (mm/d):
May- 5.5
June- 4.33

Percolation(mm/d): 3

Losses (Et*0.5 + Perc.),mm/d: 6

Design Standards:
1. Rainfall: 1 in 10 year 10-day rainfall
2. Pre-storage (mm): 50
3. Permissible flood depth (mm): 250

Assumed drainage coefficient (mm/d): 23.1

Day	Cum.rain (mm)	Inc.rain (mm)	Cum.loss (mm)	Net rain (mm)	Drainage (mm)	Residual flood (mm)
1	170	170	6	164	23	191
2	245	75	12	233	46	237
3	289	44	18	271	69	252
4	323	34	24	299	92	257
5	346	23	30	316	116	251
6	364	18	36	328	139	239
7	398	34	42	356	162	244
8	421	23	48	373	185	238
9	447	26	54	393	208	235
10	465	18	60	405	231	224

Maximum residual flood(mm) : 257
Res.flood - permissible flood (mm): 7
Res.flood > permissible flood for : 3 days

Table - B.7 : Drainage Design for Aman Rice (July-August) for Zone-I

TEESTA BARRAGE PROJECT

Drainage Coefficient Analysis

Location: ZONE - I

Evapotranspiration (mm/d):
July- 4.32
August- 4.16

Percolation(mm/d): 2

Losses (Et*0.5 + Perc.),mm/d: 5

Design Standards:
1. Rainfall: 1 in 10 year 10-day rainfall
2. Pre-storage (mm): 100
3. Permissible flood depth (mm): 300

Assumed drainage coefficient (mm/d): 39.9

Day	Cum.rain (mm)	Inc.rain (mm)	Cum.loss (mm)	Net rain (mm)	Drainage (mm)	Residual flood (mm)
1	178	178	5	173	40	233
2	259	81	10	249	80	269
3	327	68	15	312	120	292
4	380	53	20	360	160	300
5	435	55	25	410	200	311
6	473	38	30	443	239	304
7	498	25	35	463	279	284
8	526	28	40	486	319	267
9	546	20	45	501	359	242
10	562	16	50	512	399	213

Maximum residual flood(mm) : 311
Res.flood - permissible flood (mm): 11
Res.flood > permissible flood for : 3 days

Table - B.8 : Drainage Design for Boro Rice (April-May) for Zone-II

TEESTA BARRAGE PROJECT

Drainage Coefficient Analysis

Location: ZONE - II

Evapotranspiration (mm/d):
April- 5.13
May- 5.5

Percolation(mm/d): 3

Losses (Et*0.5 + Perc.),mm/d: 6

Design Standards:
1. Rainfall: 1 in 10 year 10-day rainfall
2. Pre-storage (mm): 50
3. Permissible flood depth (mm): 200

Assumed drainage coefficient (mm/d): 12

Day	Cum.rain (mm)	Inc.rain (mm)	Cum.loss (mm)	Net rain (mm)	Drainage (mm)	Residual flood (mm)
1	114	114	6	108	12	146
2	154	40	12	142	24	168
3	190	36	18	172	36	186
4	214	24	24	190	48	192
5	233	19	30	203	60	193
6	253	20	36	217	72	195
7	267	14	42	225	84	191
8	282	15	48	234	96	188
9	298	16	54	244	108	186
10	311	13	60	251	120	181

Maximum residual flood(mm) : 195
Res.flood - permissible flood (mm): 0
Res.flood > permissible flood for : 0 days

Table - B.9 : Drainage Design for Aus Rice (May-June) for Zone-II

TEESTA BARRAGE PROJECT

Drainage Coefficient Analysis

Location: ZONE - II

Evapotranspiration (mm/d):
May- 5.5
June- 4.33

Percolation(mm/d): 3

Losses (Et*0.5 + Perc.),mm/d: 6

Design Standards:
1. Rainfall: 1 in 10 year 10-day rainfall
2. Pre-storage (mm): 50
3. Permissible flood depth (mm): 250

Assumed drainage coefficient ,(mm/d): 17

Day	Cum.rain (mm)	Inc.rain (mm)	Cum.loss (mm)	Net rain (mm)	Drainage (mm)	Residual flood (mm)
1	160	160	6	154	17	187
2	227	67	12	215	34	231
3	264	37	18	246	51	245
4	297	33	24	273	68	255
5	324	27	30	294	85	259
6	339	15	36	303	102	251
7	356	17	42	314	119	245
8	375	19	48	327	136	241
9	392	17	54	338	153	235
10	410	18	60	350	170	230

Maximum residual flood(mm) : 259
Res.flood - permissible flood (mm): 9
Res.flood > permissible flood for : 3 days

Table - B. 10 : Drainage Design for Aman (July-August) for Zone-II

TEESTA BARRAGE PROJECT

Drainage Coefficient Analysis

Location: ZONE - II

Evapotranspiration (mm/d):
July- 4.32
August- 4.16

Percolation(mm/d): 2

Losses (Et*0.5 + Perc.),mm/d: 5

Design Standards:
1. Rainfall: 1 in 10 year 10-day rainfall
2. Pre-storage (mm): 100
3. Permissible flood depth (mm): 300

Assumed drainage module (mm/d): 31

Day	Cum.rain (mm)	Inc.rain (mm)	Cum.loss (mm)	Net rain (mm)	Drainage (mm)	Residual flood (mm)
1	162	162	5	157	31	226
2	255	93	10	245	62	283
3	311	56	15	296	93	303
4	356	45	20	336	124	312
5	388	32	25	363	155	308
6	416	28	30	386	186	300
7	438	22	35	403	217	286
8	465	27	40	425	248	277
9	481	16	45	436	279	257
10	495	14	50	445	310	235

Maximum residual flood(mm) : 312
Res.flood - permissible flood (mm): 12
Res.flood > permissible flood for : 3 days

Table - B. 11 : Drainage Design for Boro Rice (April-May) for Zone-III

TEESTA BARRAGE PROJECT

Drainage Coefficient Analysis

Location: ZONE - III

Evapotranspiration (mm/d):
April- 5.13
May- 5.5

Percolation(mm/d): 3

Losses (Et*0.5 + Perc.),mm/d: 6

Design Standards:
1. Rainfall: 1 in 10 year 10-day rainfall
2. Pre-storage (mm): 50
3. Permissible flood depth (mm): 200

Assumed drainage module (mm/d): 2

Day	Cum.rain (mm)	Inc.rain (mm)	Cum.loss (mm)	Net rain (mm)	Drainage (mm)	Residual flood (mm)
1	93	93	6	87	2	135
2	125	32	12	113	4	159
3	140	15	18	122	6	166
4	152	12	24	128	8	170
5	165	13	30	135	10	175
6	180	15	36	144	12	182
7	189	9	42	147	14	183
8	207	18	48	159	16	193
9	217	10	54	163	18	195
10	229	12	60	169	20	199

Maximum residual flood(mm) : 199
Res.flood - permissible flood (mm): 0
Res.flood > permissible flood for : 0 days

Table - B.12 : Drainage Design for Aus Rice (May-June) for Zone-III

TEESTA BARRAGE PROJECT

Drainage Coefficient Analysis

Location: ZONE - III

Evapotranspiration (mm/d):
May- 5.5
June- 4.33

Percolation(mm/d): 3

Losses (Et*0.5 + Perc.),mm/d: 6

Design Standards:
1. Rainfall: 1 in 10 year 10-day rainfall
2. Pre-storage (mm): 50
3. Permissible flood depth (mm): 250

Assumed drainage coefficient (mm/d): 15.8

Day	Cum.rain (mm)	Inc.rain (mm)	Cum.loss (mm)	Net rain (mm)	Drainage (mm)	Residual flood (mm)
1	161	161	6	155	16	189
2	219	58	12	207	32	225
3	257	38	18	239	47	242
4	294	37	24	270	63	257
5	315	21	30	285	79	256
6	330	15	36	294	95	249
7	353	23	42	311	111	250
8	374	21	48	326	126	250
9	391	17	54	337	142	245
10	405	14	60	345	158	237

Maximum residual flood(mm) : 256.8
Res.flood - permissible flood (mm): 7
Res.flood > permissible flood for : 3 days

Table - B.13 : Drainage Design for Aman Rice (July-August) for Zone-III

TEESTA BARRAGE PROJECT

Drainage Coefficient Analysis

Location: ZONE - III

Evapotranspiration (mm/d):
July- 4.32
August- 4.16

Percolation(mm/d): 2

Losses (Et*0.5 + Perc.),mm/d: 5

Design Standards:
1. Rainfall: 1 in 10 year 10-day rainfall
2. Pre-storage (mm): 100
3. Permissible flood depth (mm): 300

Assumed drainage coefficient (mm/d): 24.5

Day	Cum.rain (mm)	Inc.rain (mm)	Cum.loss (mm)	Net rain (mm)	Drainage (mm)	Residual flood (mm)
1	162	162	5	157	25	233
2	223	61	10	213	49	264
3	272	49	15	257	74	284
4	318	46	20	298	98	300
5	362	44	25	337	123	315
6	384	22	30	354	147	307
7	407	23	35	372	172	301
8	430	23	40	390	196	294
9	449	19	45	404	221	284
10	458	9	50	408	245	263

Maximum residual flood(mm) : 314.5
Res.flood - permissible flood (mm): 15
Res.flood > permissible flood for : 3 days