HYDROLOGICAL DESIGN ASPECTS OF SMALL SCALE DRAINAGE PROJECT IN BANGLADESH

by

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C E R T I F I C A T E

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

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We hereby recommend that the project presented by Mr. Amal Chandra Adhikary entitled "Hydrological Design Aspects of Small Scale Drainage Project in Bangladesh" be accepted as fulfilling this part of the requirements for the Post Graduate Diploma in Water resources Engineering.

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ABSTRACT

The procedures and assumptions used for hydrological design for small scale project in Bangladesh by differenrt agencies have been reviewed. The design discharge calculation for a selected project have been studied by three different methods and compared with existing project situation.

For the purpose of this study manuals and design reports were collected from the organizations such as BWDB, LGEB and their Consultants. A particular subproject "Bannyar Khal" at Muktagacha Upazilla has been selected to apply Unit Hydrograph method, Soil Conservation Service(SCS) method and Richard's method for calculating inflow during premonsoon taking rainfall data used in original design. Again a unit hydrograph has been derived using recent rainfall data. The unit hydrographs thus obained were compared with inflow used in original design.

It is found that most of the organization used unit hydrograph method for calculation of inflow. The existing 2 vent regulator in the subproject area was found quite adequate compared to discharge calculated by the three methods. It is revealed that S.C.S and Richard's method require less time to calculate inflow hydrograph provided rainfall frequency intensity and duration curves are available for the area concerned. On the other hand unit hydrograph hydrograph method is scientific method but it needs long time to complete the calculation.

Chapter 1

INTRODUCTION

1.1 Background

Hydrology means the science of water; deals with the occurrence, circulation and distribution of water on the earth and earth's atmosphere. Basically this applied science is classified as (i) scientific hydrology - the study which is concerned chiefly with academic aspects (ii) applied hydrology - a study concerned with engineering applications. Engineering applications of the knowledge of the hydrologic cycle, and hence of the subjects of hydrology are found in the design and operation of projects dealing with water supply, irrigation and drainage, water power, flood control, navigation, coastal works, salinity control and recreational uses of water. The main purpose of hydrologic design of a drainage system is to drain off the excess water so that the water level in the paddy field drops back to the original level within predetermined time period.

Two types of drainage project normally exit in Bangladesh, large and small. The broad strategy of Master Plan (IECO, 1964) was to reduce damage of crops by implementing large scale drainage projects. But it has been changed in the recent years and a large number of small scale projects are being undertaken and completed by the BWDB and LGEB. The aim of small scale project is to complete the construction works within shortest possible time, mostly one or two years and to add GNP by agricultural development. Area of a small scale project so far completed ranged from 800 ha to 4000 ha (MPO, 1990). About 380 small scale projects have been completed which are providing drainage facilities to about 2 million hectare (MPO, 1990).

Drainage system design includes selection of suitable ventage of drainage regulator and section of drainage channel. Adequate ventage is provided to permit proper drainage of internal runoff by gravity flow during premonsoon and postmonsoon period when river water level is low. The drainage channel should have adequate capacity to provide effective drainage during the premonsoon period.

In Bangladesh, organizations that are mainly involved in designing small scale project are BWDB and LGEB and the consulting companies appointed by these two major organization. Among the consultants EPC ltd. associated with Sir William Halcrow and Partners and Northwest Hydraulic Consultants Ltd. are mainly involved in hydrologic design of small scale projects. They have different appoaches and assumptions in calculating design storm, design discharge and selection of ventage for drainage regulator. So a study is necessary to review critically the various methods, procedures and assumptions considered for determining design discharge.

1.2 Objectives

The objectives of this study are:

a) to review the different procedures for determining the design discharge of small scale drainage projects in Bangladesh; and

b) to evaluate the various methods of estimating design discharge of a selected subproject by using the actual data.

Chapter 2

HYDROLOGICAL DESIGN OF DRAINAGE PROJECTS IN BANGLADESH

Hydrological design of drainage systems of Bangladesh is still based on the method and analysis adopted in Master Plan (IECO, 1964). IECO (1964), developed series of charts and figures showing the relationship between probable rainfall intensity, frequency and duration. The basis of the IECO (1964) studies is the total mean rainfall that may be expected to fall during the four calender month period of maximum rainfall. This four month rainfall index is recommended for studying a pre monsoon, monsoon or postmonsoon period. IECO(1964) also developed two other charts in their study (i) to convert the total four month rainfall to total rainfall over a selected number of days (ii) to convert the index frequency to a selected frequency. On the basis of IECO(1964) study, BWDB(1966) prepared a design manual describing methods to select design storm, rainfall excess and routing to decide drainage discharge of the basin. In the recent years the consultants involved in the design of water development projects developed computer based model in BASIC for runoff hydrograph using Snyder method and pre and post monsoon routing program (EPC, 1986). Among others Northwest hydraulic consultant Ltd. developed LOTUS work-sheet model following the BWDB manual for their use. So hydrology in Bangladesh still cann't create broad base for general practitioner. Description of different methods are given in the following sections.

2.1 Simple Methods for Design Discharge for Small Basins

Some of the simple methods for computing peak flows for small basins used by BWDB (1966) are reviewed in this section.

2.1.1 IECO Method

IECO(1964), developed Figs.1, 2 and 3 for estimating flood flows in small basins of Bangladesh corresponding to return periods of 2 to 500 years. Computational procedures are explained as below:

(i) The total annual precipitation for the project area is obtained and entered in Fig.1 to obtain the Q_{100} unit peak flow. This value is multiplied by the coefficient given in the table of the figure to obtain the peak unit flow for the selected return period. The ten year frequency is taken for sluices and water retention structures.

(ii) The basin characterstic $(L^2/S)^{0.3}$ is computed using length(L) of the main watercourse and slope(S). The value is then entered in Fig.2 to obtain the percentage adjustment to be applied to the peak flood flow rate.

(iii) The basin area is entered to the Fig. 3 and the percentage error is obtained as a function of basin area.

(iv) The unit peak flow is multiplied by the values obtained in (ii) and (iii) to arrive at the unit peak flow rate.

(v) The value obtained in (iv) is multiplied by the basin area to obtain an estimate of the peak flood flow for the basin.

In Karnafulli Irrigation project WBDB used this method.

2.1.2 The Rational Formula

Lack of records for rainfall intensity, runoff and stream flow have led to the development of empirical formula for estimating flood flow. One of the leading formula for estimating peak runoff as used by BWDB(1966)is:

$$Q = CIA \tag{1}$$

Where, Q = Peak runoff in cfs

I = Rainfall intensity in inches/hours

$$= \frac{68.2}{t_c^{0.73}}$$

t_c = time of concentration of the basin in minutes.

$$t_c = 31 \left[\frac{L^2 n^2}{S}\right]^{0.30} \text{ in hour.}$$

C = a runoff coefficient

$$= 0.7 \left[\frac{Tp}{100}\right]^{0.18}$$

T_p = Recurrence period (hour),
A = Basin area in acres.
L = Length of dainage channel (km)
n = Roughness co-efficient

Using the commonly used SI unit, rational formula described above can be written as:

$$Q_p = CIA / 3.6 \qquad (2)$$

Where, Q_p = peak discharge (m^3/sec)

C = coefficient of runoff

I = the mean intensity of precipitation (mm/h) for a duration equal to t_c and an exceedance probability of P.

A = drainage area in km^2

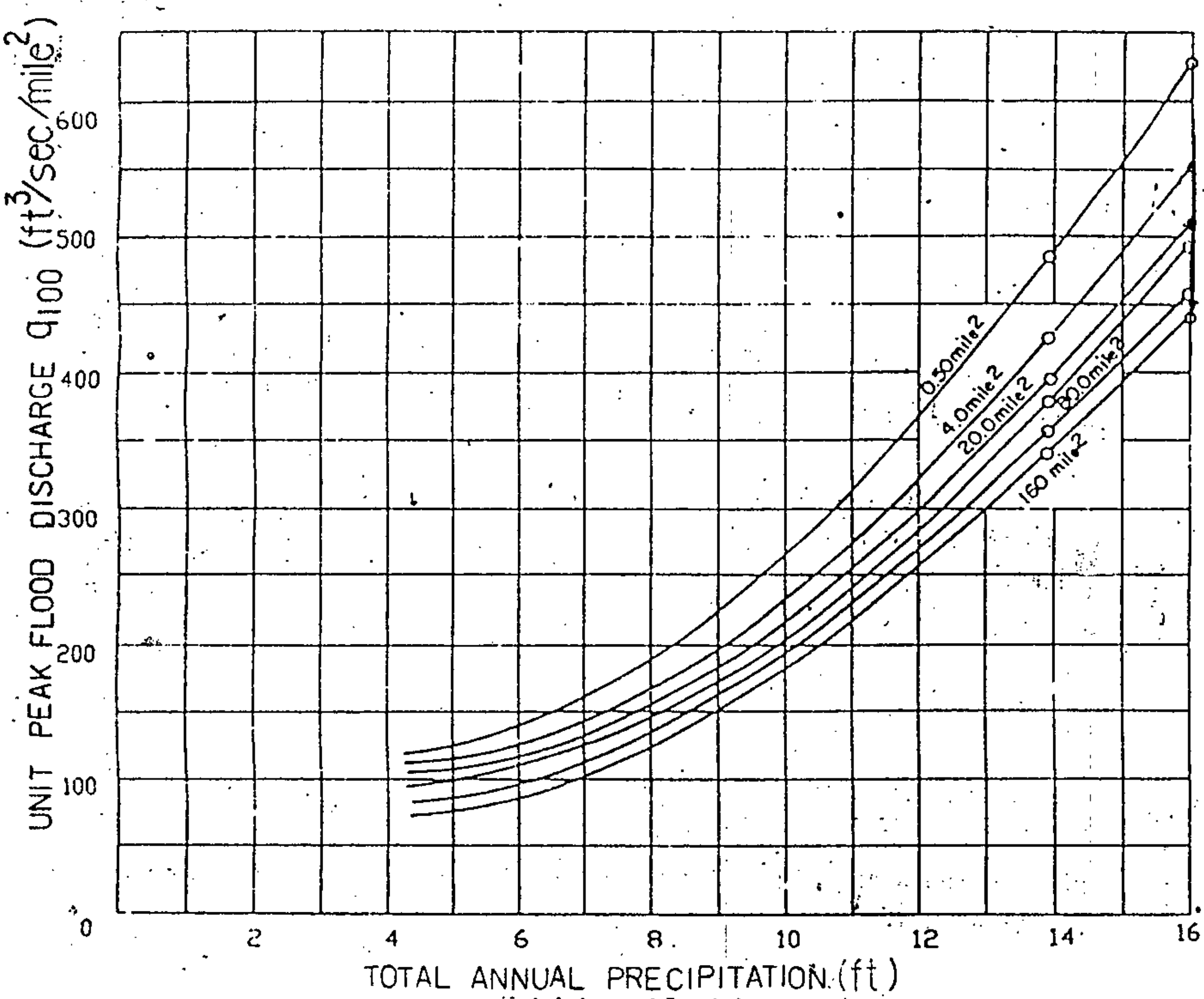
Time of concentration for small drainage basins is taken approximately equal to the lag time of the peak flow:

$$t_c = t_p = C \left(\frac{L.L_c}{S^{1/2}}\right)^n \qquad (3)$$

Where, L = Length of drainage channel (km).

L_c = Distance from outlet point to the point nearest the centroid of basin (km).

S = slope of the drainage area.



Factor for Other Flood Frequencies

$q_{500} / q_{100} = 1.14$
$q_{200} / q_{100} = 1.06$
$q_{50} / q_{100} = 0.93$
$q_{25} / q_{100} = 0.85$
$q_{15} / q_{100} = 0.79$
$q_{10} / q_{100} = 0.73$
$q_{5} / q_{100} = 0.62$
$q_{2} / q_{100} = 0.40$

Region	Rainfall
Rangpur	7.5 Feet
Kurigram	7.5 "
Chittagong	9.2 "
Cox's Bazar	12.5 "
Dhaka	6.7 "
Khulna	5.8 "
Sylhet	9.2 to 16.7 ft.
Mymensingh	8.0 "
Barisal	7.5 "
Jessore	6.0 "

FIG. 1 UNIT PEAK DISCHARGE 100 YEAR RETURN PERIOD

Sorce: IECO (1964)

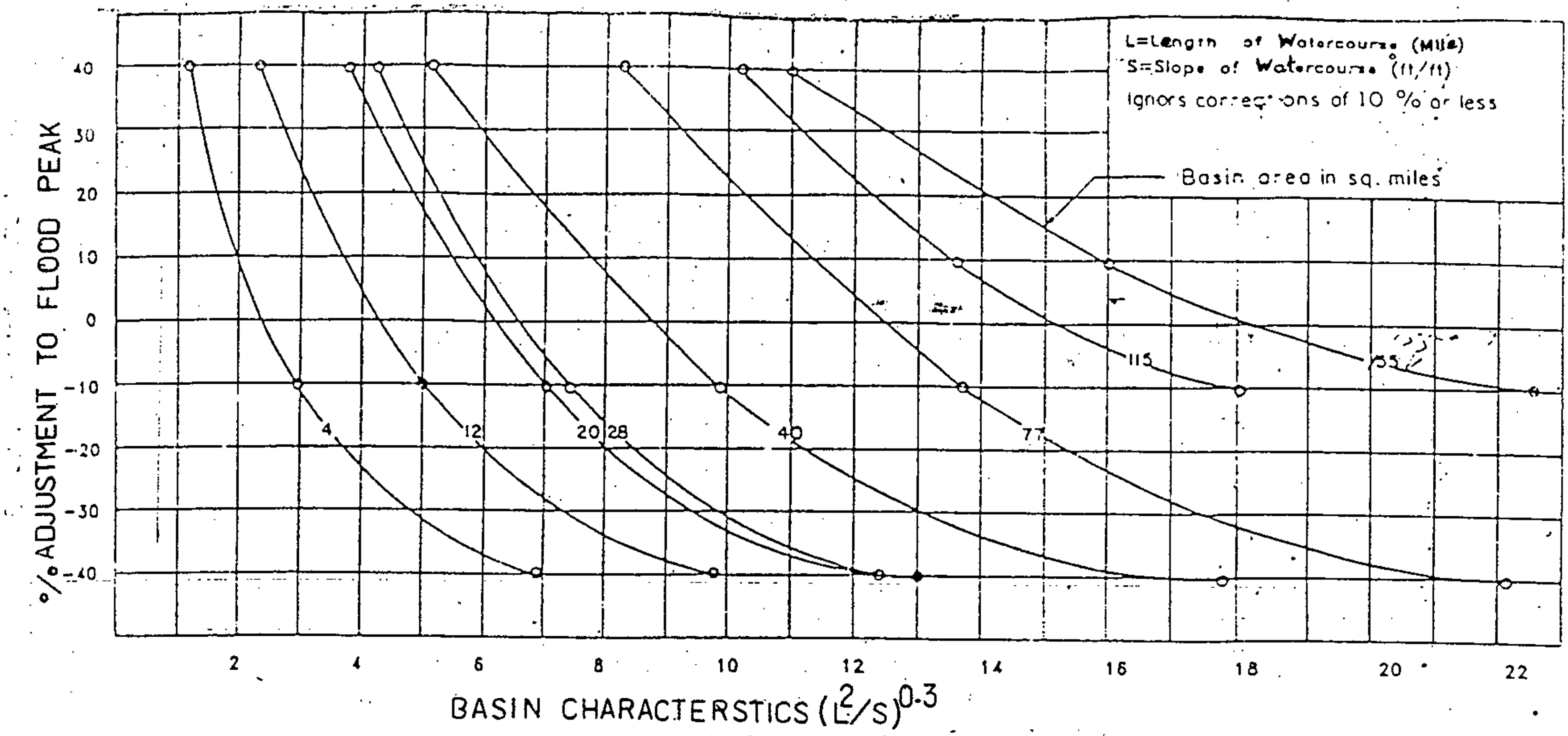
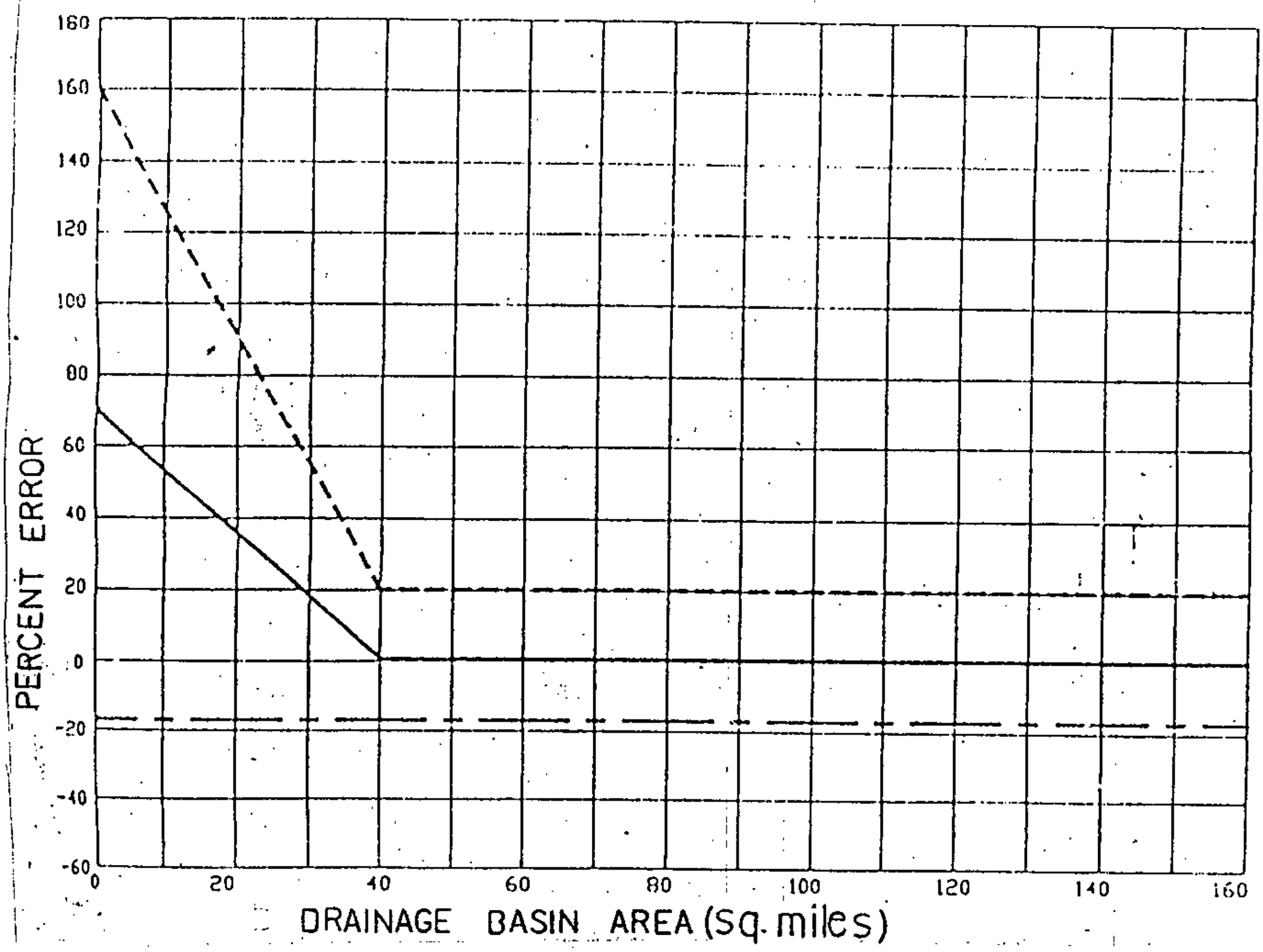


FIG. 2 ESTMATED PEAK FOR BASIN SHAPE AND SLOPE CHARACTERSTICS

source: IECO(1964)



$$\text{Percent Error} = \frac{Q_{25} \text{ from stream Records} - Q_{25} \text{ Regional analysis}}{Q_{25} \text{ Regional analysis}} \times 100$$

- - - - - - Use for high Coefficients of runoff
———— Use for average existing Conditions
— — — Use for low Coefficients of runoff

FIG.3 ERROR AS A FUNCTION OF DRAINAGE AREA

source: IECO (1964)

C and n are taken as 0.5 and 0.38 respectively for foothill drainage area and 0.24 and 0.38 respectively for valley drainage area.

Runoff coefficient for agriculture area are (Mutreja,1986):

Flat land:	Tight clay, cultivated	0.5
	Woodland	0.4
	Sandy loam, cultivated	0.2
	Woodland	0.1
Hilly land:	Tight clay, cultivated	0.7
	Woodland	0.6
	Sandy loam, cultivated	0.4
	Woodland	0.3

Intensity of rainfall for small scale project for a given return period, (T years) and intensity of rainfall (mm/hr) is found from the rainfall frequency duration relationship (Subramanya, 1984):

$$I = \frac{kT^{x}}{(t_c+a)^{m}} \qquad (4)$$

Where, k, x, and m are constant.

The desired intensity is also read from a locally derived Intensity Duration Frequency (IDF) curve corresponding to the desired frequency and computed value of time of concentration, t_c.

2.1.3 Method of Drainage Module

To determine the drainage channel section, the drainage module or the rate of removal of excess water per day is used. During pre-monsoon period (May and June) the low stage of the outfall river permits gravity drainage and the drainage is considered effective through main and secondary drains. As such the premonsoon storm is used to determine the drainage modulus of a basin to design drainage channel section.

Delta Development Project, BWDB(1985), used drainage module concept to estimate the design discharge of a small drainage basin. In this method rainfall duration frequency curves are plotted. The return period of 5-year and duration of 1,2,3,5,10, and 15 days are recommended. Different allowable water level in the field are recommended for different varieties of crops and different growing stages. To find the required drainage module(mm/day) a tangent line is drawn from the allowable point of water level on the rainfall axis to the curve. The slope of the tangent line represents the drainage module.

2.2 Elaborate Method of Hydrologic Design for small Basins

Elaborate method for computing the runoff and ventage selection for small basin involve the following steps:

(i) Computation of design storm;

(ii) Computation of rainfall excess considering losses;

(iii) Computation of runoff hydrograph;

(iv) Determination of allowable basin water level by routing the runoff hydrograph through an assumed size of sluice and selection of suitable size of the sluice.

2.2.1 The Design Storm

Monsoon rainfall is not continuous rather intermittent showers and may occur several times during a day. Downpours of heavy rain are generally localized with normal rainfall intensity occurring a short distance away. Premonsoon rain occurs during April and May have the characteristics of strong northwest wind with heavy thunder storms, usually of short duration. It is uneconomical to design hydraulic structures for the maximum storm that may ever occur. The structures are designed instead with the expectation that those will be subjected to flow greater than design flow once in 10, 15 or 25 years on the average. Therefore, for flood and drainage studies it is necessary to know the frequency of intense rainfall for varying periods of time.In consideration of design storm BWDB use either four month rainfall index IECO (1964) or conduct frequency analysis using recent rainfall data.

IECO (1964), developed several graphs for the computation of design storm. Fig.4 presents the total mean maximum rainfall that may be expected to occur during four calender month period. Fig.5 is used to convert the total four-month rainfall to total rainfall over a selected number of days. Fig.6 is used to convert index frequency to a selected frequency. The rainfall duration of 5 days and frequency of 10 or 25 years are recommended for small scale projects. Table 1 gives the combined rainfall index for the selected frequencies.

Table 1 Combined Rainfall Index for Selected Frequencies

Days	Storms Frequencies	
	10 years	25 years
1	0.128	0.153
2	0.192	0.228
3	0.230	0.272
4	0.257	0.303
5	0.276	0.326

Point rainfall, the amount of rain falling at a specific point, is usually measured at a rain gauging station. In this case point rainfall is defined as the volume of rainfall, at the center of the storm, equal to the product of the four month rainfall index and the combined rainfall index (Table 1).

If point rainfall is used as the basis for designing a structure, the computed runoff will be high resulting in increased project costs. Rainfall intensity is decreased as the distance from the storm center increased and it becomes zero at the edge of the storm. The rate of decrease of a storm intensity away from its centre is given in Table 2.

Table 2 Rainfall Variability

Av. distance from Storm centre (km)	5-day storm percent of point rainfall
0.25	100.00
1.00	94.06
2.00	86.47
3.00	82.56
4.00	79.66
5.00	77.15
6.00	75.09
7.00	73.43
8.00	72.06
9.00	70.69
10.00	69.37

The equivalent uniform depth of rainfall is defined as the depth of water which results from spreading the total volume of basin rainfall uniformly over the total basin area. The procedure for determining uniform equivalent depth of rainfall is described below:

(i) For locating geographical centre (centroid) of the basin a card board is cut to the shape of the basin. The card board is suspended vertically from three or more points by threads. After holding the free ends of the threads together by hand, the length of threads are adjusted to make the board horizontal. The centroid is located on the card board vertically below the point of intersection of the threads for a horizontal position of the board. The centroid location may be determined by suspending a plumb-bob from the intersection point of all the threads.

(ii) Concentric circles, or isohyetals are drawn at one km, intervals around the center starting one-half km from the centre.

(iii) The areas between the respective isohyetals within the basin area are measured by planimeter.

(iv) The area is multiplied by the proper percentage from table 2.

(v) Summation of the values from step (iv) is divided by the total basin area.

(vi) The result is a percentage which is applied to point rainfall yields the equivalent uniform depth of rainfall.

The daily rainfall increment may occur in any order. An arbitrary sequence of 3,2,1,4,5 is considered in order to satisfy the losses that will take place early in the strom (BWDB, 1966).

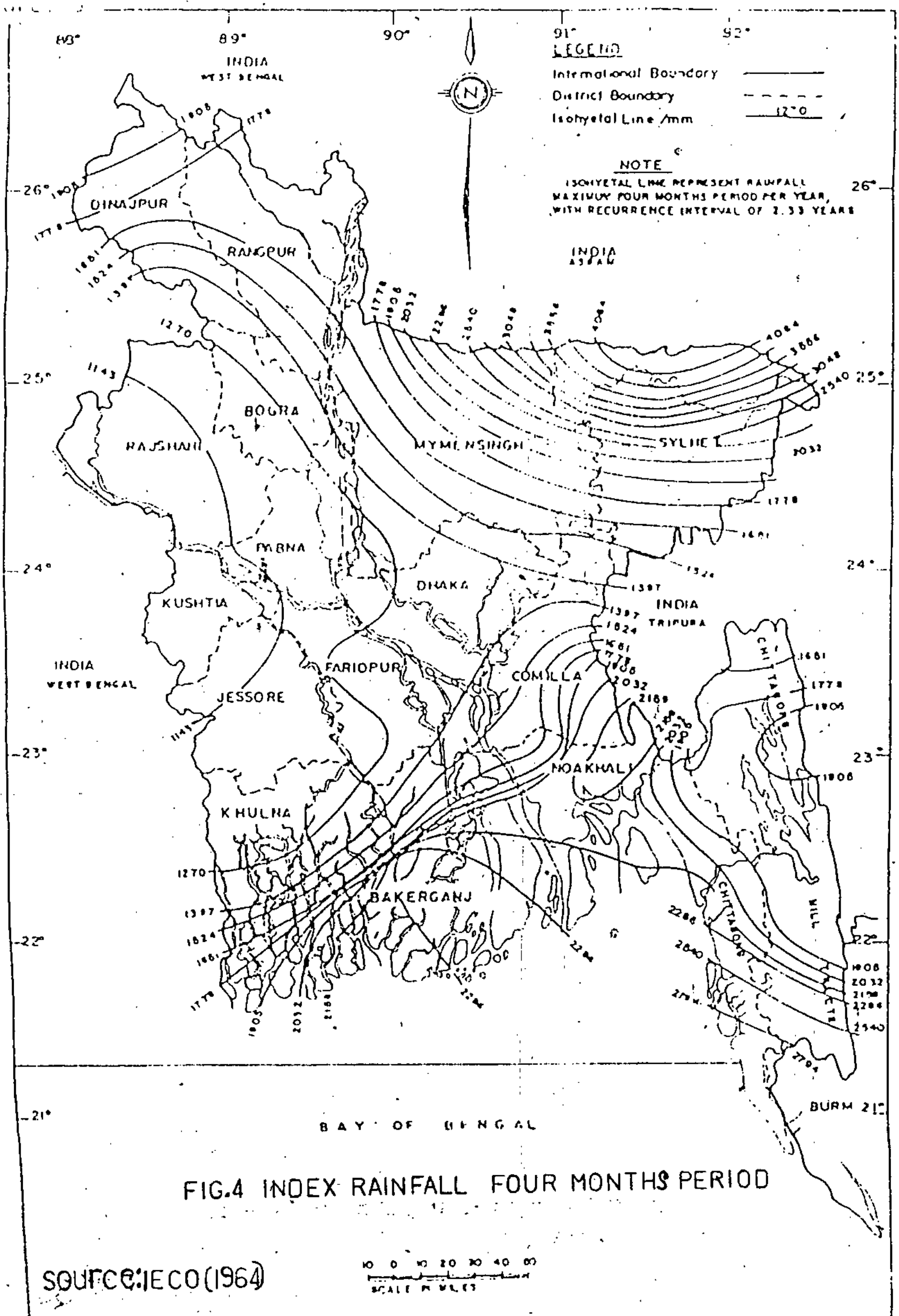


FIG.4 INDEX RAINFALL FOUR MONTHS PERIOD

Source: IECO (1964)

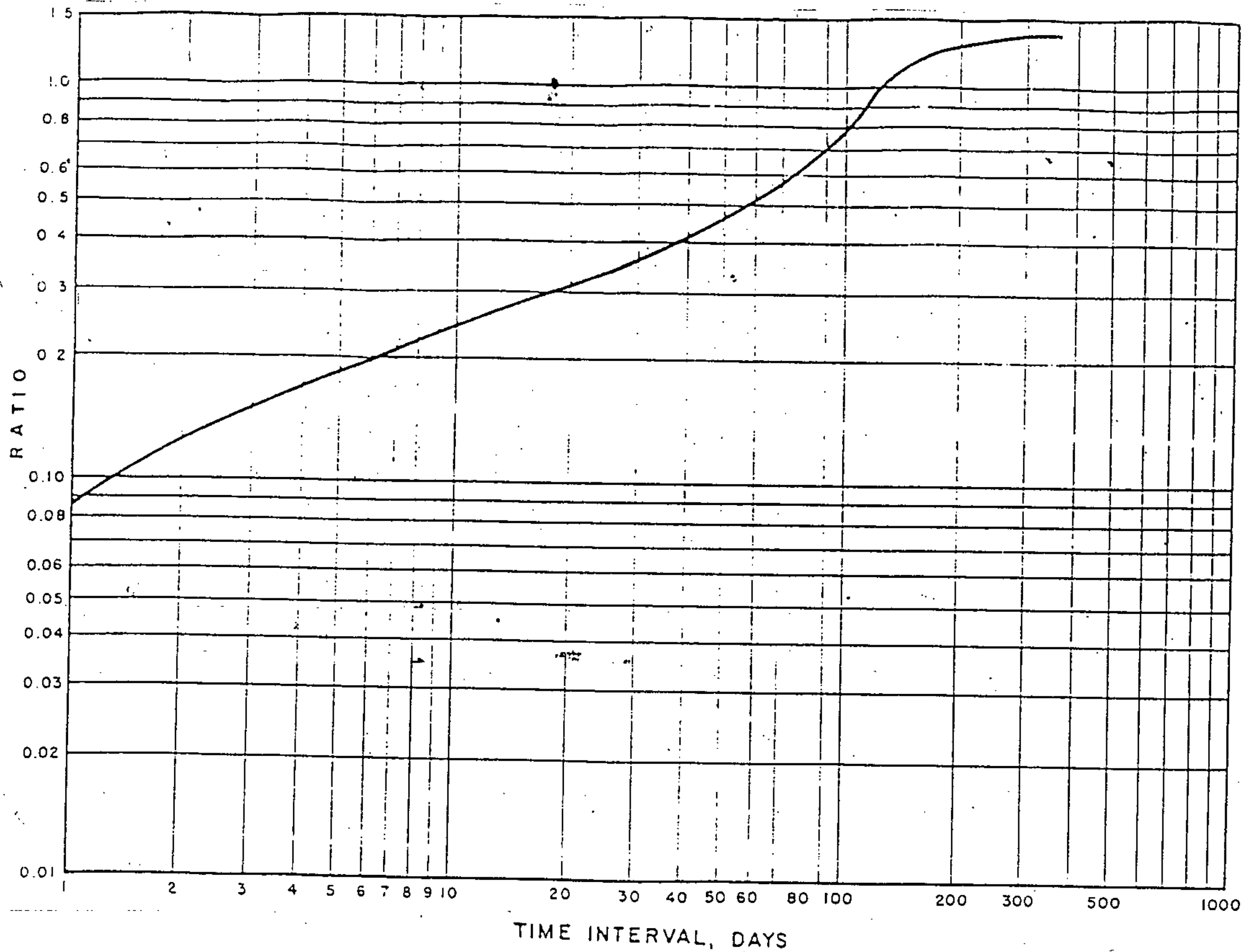


FIG. 5 RATIO OF INDEX RAINFALL FOR A GIVEN TIME INTERVAL TO INDEX RAINFALL FOR FOUR MONTHS

source : IECO (1964)

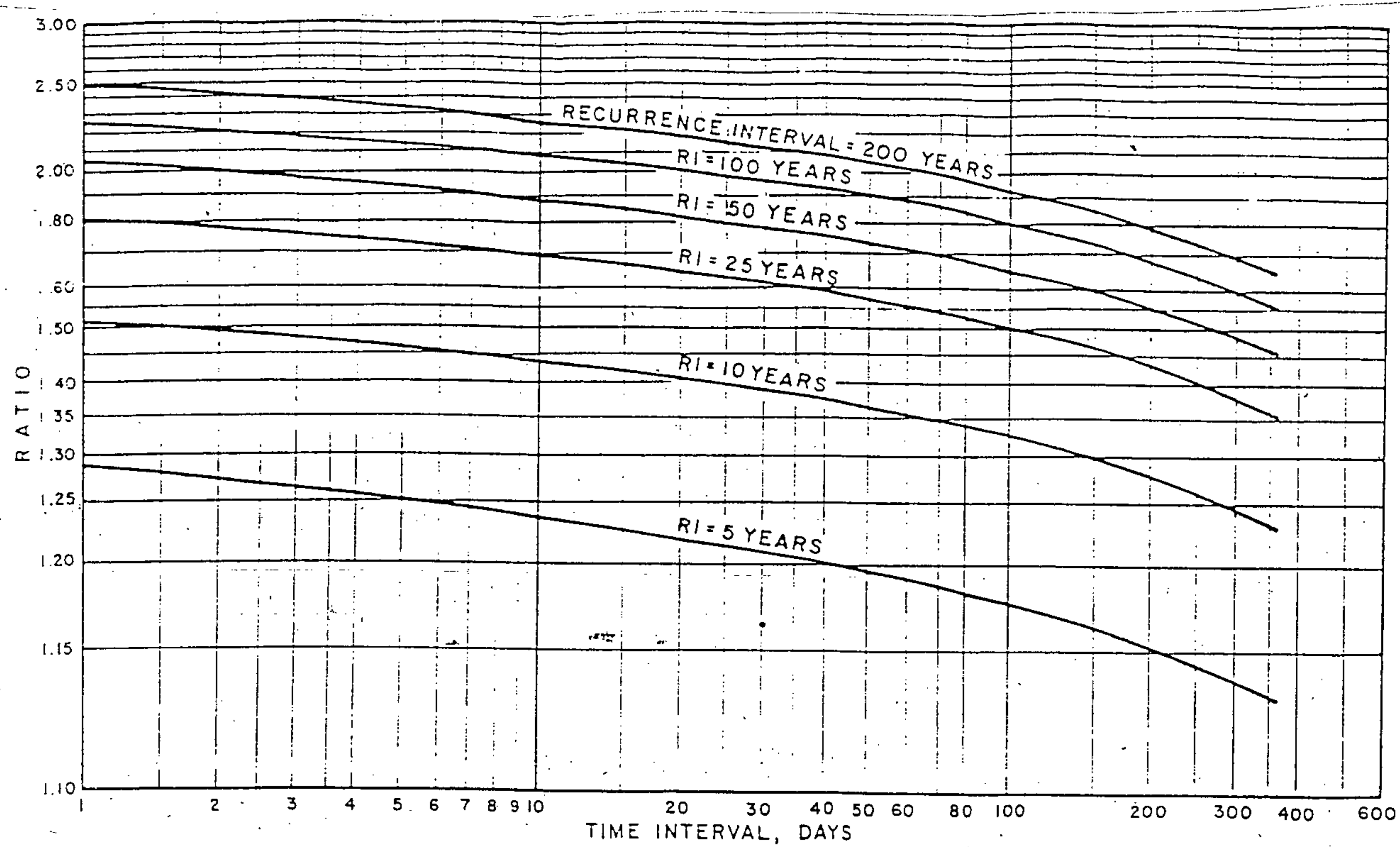


FIG.6 RATIO OF RAINFALL FOR SELECTED RECURRENCE INTERVALS TO INDEX RAINFALL FOR INDICATED TIME INTERVAL

source: IECO (1964)

For breaking down rainfall time distribution into intervals less than 24 hours, Table 3 is prepared from Fig.8 by IECO. A reasonable 24 hours rainfall time distribution is made for any basin by using the particular rainfall data closest in distance to the basin being studied and adjusting it to fit the calculated 24 hours basin rainfall. The smallest time interval to be used depend on the length of the main drainage course within the basin. The intervals recommended are: (i) one hour for less than 3 km ; (ii) 3 hours 3 to 10 km (iii) and 6 hours for over 10 km.

Table 3 24 Hour Point Rainfall time Distribution

Accumulative Rainfall in mm

Location	Four Months Rainfall Index (mm)	Storm Duration in Hours						
		1	2	3	6	12	18	24
Barisal	1651	59	70	79	97	136	174	212
Jessore	1168	60	76	84	97	113	131	150
Cox's Bazar	2921	59	73	84	112	169	267	358
Chittagong	2184	61	78	94	116	169	229	274
Dhaka	1397	79	102	140	133	155	168	179
Bogra	1473	86	107	119	139	160	175	188
Sylhet	3048	72	105	127	156	208	305	389

2.2.2 Rainfall Excess

The U.S. soil conservation service (SCS) has recommended an initial abstraction of Ia = 0.2S to be made to cover initial interception, infiltration and surface storage losses, where S is the difference between storm rainfall and direct runoff. Utilizing the SCS rainfall runoff curves for land use classification and soil groups similar to those in Bangladesh S has been found to equal 2.5 and Ia = 13mm. For paddy land no initial loss is used. For non-paddy land an initial soil moisture loss of 13 mm is considered.During the storm period infiltration continues to take place at a slower rate than the initial soil moisture repletion. Infiltration studies show that all but impervious clay soils has a maximum constant infiltration rate after saturation, ranging from 1.27 mm/hour to greater than 25 mm/hr. Mostly an average infiltration rate of 25 mm/day or 1 mm/hour for relatively impervious soils are assumed.

Paddy land bounded by small earthen bund to retain water. This may be as high as 150mm. It is assumed that the first 100 mm of rain falling upon paddy land serves to fill up the paddy basin. Rainfall in excess of 100 mm becomes runoff. For nonpaddy land, the constant rate of retention is approximately 0.8382 mm/hour during periods of rainfall until a maximum of 25 mm stored.

The rainfall losses from the rainfall time distribution is separately determined by assuming that the entire basin area consists of paddy land. It is again determined by assuming that the entire basin area consists of non-paddy land. The weighted basin runoff distribution is computed by multiplying the net runoff determined separately by the respective land classification percentage. Whenever possible the percentages of paddy and nonpaddy land is determined by field survey. This is particularly important for small basins where the proportion of paddy land may be very high.

2.2.3 Runoff Hydrograph

The runoff(inflow) hydrograph represents the time-discharge relationship of total design storm runoff at the basin outlet. The following three methods are used for runoff calculation.

2.2.3.1 Unit Hydrograph Method

The unit hydrograph of a drainage basin is defined as a hydrograph of direct runoff resulting from one millimeter of rainfall excess of a specified duration generated uniformly over the basin area at a uniform rate. The rainfall excess is that part of the total storm that enters the stream as direct runoff. In surface flow phenomena rainfall excess (Pe):

$$Pe = P - Li - E - (F + Sd) \qquad (5)$$

Where, P = total rainfall, mm

Li = interception, mm

E = evaporation from land and from depression storage, mm

F = infiltration, mm

Sd = depression storage, mm

The runoff hydrograph is developed on the basis of the following unit hydrograph principles:

(i) Hydrograph of the same basin with the same unit rainfall duration, have vertical ordinates qx, directly proportional to the depth of rainfall excess.

(ii) Hydrograph of the same basin with the same unit rainfall duration have the same time base, Tb regardless of intensity of rainfall.

(iii) Several of the above hydrographs can be combined to form one composite hydrograph by the simple addition of their vertical ordinates.

Most of the basins in Bangladesh is unguaged with scanty of available hydrological data. Therfore, rather than using the more complicated and classical curvilinear hydrograph shape, the simpler traingular approximation shape is used. The shape of the hydrograph is shown in Fig.7 and its nomenclature was as follows:

q_p = peak rate of runoff in cumec

T_p = Time of rise from beginning of rainfall excess to peak rate in hours

T_r = Time of recession from peak rate to end of hydrograph in hours

T_b = Time base of hydrograph in hours

t_r = Duration of rainfall in hours

t_p = Lag time in hours from centre of rainfall to peak

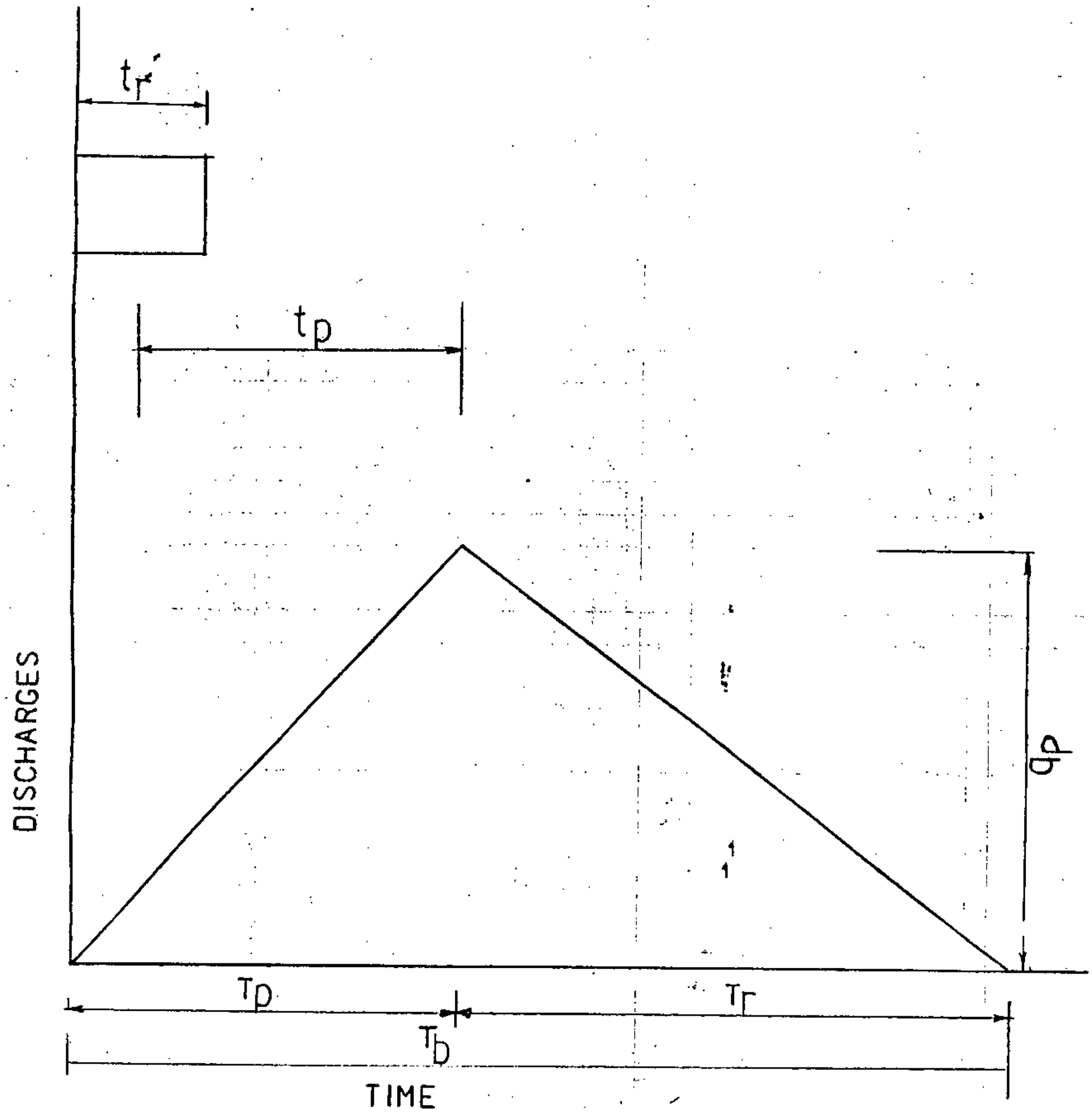
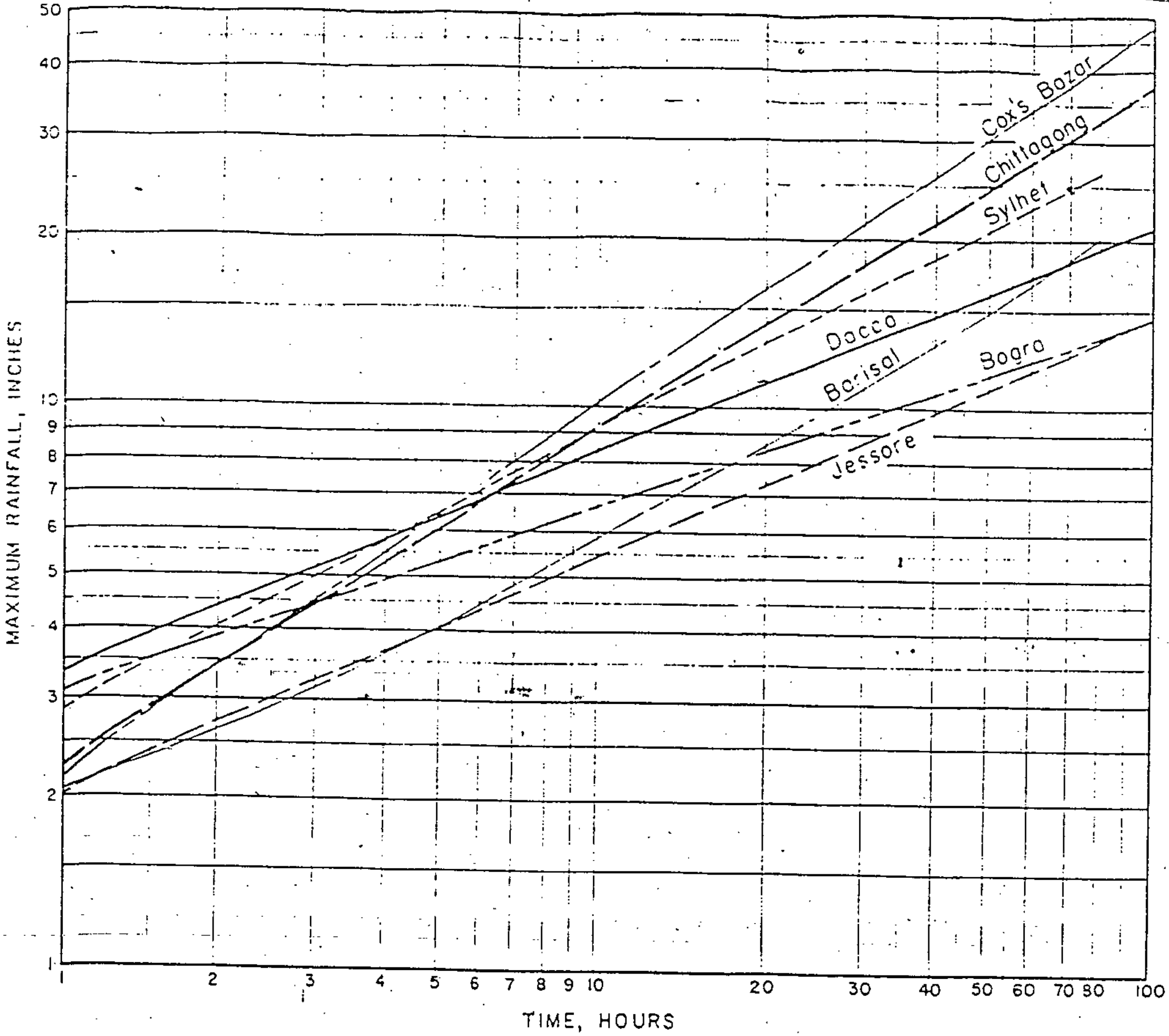


FIG.7 SIMPLIFIED HYDROGRAPH SHAPE

source: BWDB (1966)



source: IECO (1964)

FIG. 8 MAXIMUM RAINFALL

Synthetic unit hydrographs based on known physical characterstics are developed and Snyder method is followed (BWDB, 1966).

The elements of the unit Hydrograph:

Time of concentration, $T_c = 14.15 [L^2 n^2]^{0.3}$ hours (6)

Lag time to peak, $t_p = 0.6 T_c$ hours (7)

Time of rise, $T_p = t_p + 0.5t_r$ hours (8)

Coefficient , $C_t = 1.331 t_p / (L L_c)^{0.3}$ (9)

Coefficient C_p. obtained from the relation;

$$C_p = 0.7527 - 0.2056 \ln (C_t) \quad (10)$$

Unit graph base length, $T_b = 1.2 Tc / C_p$ hours (11)

Peak discharge, $q_p = 0.56 A / T_b$ cumec (12)

Where, A = Basin area, in Sq km.

L = Length of the principle drainage channel in Km.

L_c = Distance from the outlet to a point on the channel nearest to the centroid of the basin in Km.

S_0 = Average overland slope of basin measured between contour, in m/km

L_s= Straight line length of basin in Km.

$S = S_0 L_s / L$ Average channel slope;

n = Channel roughness factor,

A check on the computation can be made as follows:

Total volume of water under the hydrograph;

$$V = 3.6 I t / 1000 \text{ in } Mm^3 \quad (13)$$

Where, I = Total volume a runoff hydrograph m^3/sec

t = time interval in hour

Total rainfall excess; i = 1000 V / A in mm. (14)

2.2.3.2 Soil Conservation Service (SCS) Method

The method developed by the Soil Conservation Service is based on a dimentionless hydrograph (Table 4), the result of an analysis of a large number of natural unit hydrographs obtained from different geographics location of varying sizes. The method needs to know the peak time and the peak discharge computed by the following equation:

(i) Time of concentration, $T_c = 14.15 \left[\frac{L^2 n^2}{S}\right]^{0.385}$ in hrs. (15)

Where, L = Length of the principle drainage channel in Km.

S = Average channel slope, m/Km.

n = Channel roughness factor.

ii) Duration of rainfall, $t_R = 0.133\ T_c$ in hour. (16)

iii) Time from centroid of rainfall to the peak discharge,

$$t_p = 0.6\ T_c \text{ in hour.} \quad (17)$$

iv) Time from the beginning of rainfall to the peak discharge,

$$T_p = t_R/2 + 0.6T_c \text{ in hour.} \quad (18)$$

v) Peak discharge for a direct runoff of one milimeter,

$$q_p = \frac{0.208\ A}{T_p} \text{ cumec} \quad (19)$$

Where, A is drainage area in sq km.

vi) Direct runoff is calculated using equation

$$Q = \frac{(P - 0.2\ S)^2}{P + 0.8\ S} \text{ mm} \quad (20)$$

Where, P = Potential maximum rainfall for the duration, T_R in in inch (Fig. 8)

$$S = \frac{254000}{CN} - 254$$

Where, CN was curve number according to hydrologic soil group and soil complexes (Table 5).

Total actual hydrograph is obtained from SCS dimensionless unit hydrograph (Table 4).

Table 4 Ratios For Dimensionaless Unit Hydrograph

Time Ratios (t/Tp)	Discharge Ratios (q/qp)
0.0	.000
0.1	.030
0.2	.100
0.3	.190
0.4	.310
0.5	.470
0.6	.660
0.7	.820
0.8	.930
0.9	.990
1.0	1.000
1.1	.990
1.2	.930
1.3	.860
1.4	.780
1.5	.680
1.6	.560
1.7	.460
1.8	.390
1.9	.330
2.0	.280
2.2	.207
2.4	.147
2.6	.107
2.8	.077
3.0	.055
3.2	.040
3.4	.029
3.6	.021
3.8	.015
4.0	.011
4.5	.005
5.0	.000

Table 5 Runoff Curve Numbers for Selected Agricultural and Urban Land Use (All Antecedant Moisture Condition, Ia = 0.2S)

Land Use Description		_*/ Hydrological Soil Group			
		A	B	C	D
Cultivable land	: Without conservation treatment	72	81	88	91
	With conservation treatment	62	71	78	81
Pasture or range land	: Poor condition	68	79	86	89
	Good condition	39	61	74	80
Meadow	: Good condition	30	58	71	78
Wood of forest land	: Thin scant, poor cover, no mulch	45	66	77	83
	Good cover	25	55	70	77
Open spaces, lawns, course, cemeteries,	parks, golf, etc.				
good condition	: grass cover on 75% or more of the area	39	61	74	80
faif condition	: grass cover on 50% or 75% of the area	49	69	79	84
Commercial and business areas (85% impervious)		89	92	94	95
Industrial districts (72% imprevious)		81	88	91	93
Residential					
Average lot size	Average % imprevious				
1/8 acre or less	65	71	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
Paved parking lots, roofs, driveway etc.		98	98	98	98
Streets and roads: paved with carbs and storm sewers		98	98	98	98
	gravel	75	85	89	91
	dirt	72	82	87	89

Source: SCS Technical Release No. 55, P.2-5
Notes on Hydrologic Soil Grops of Table 4,
Hydrological Soil Group

_*/ Hydrological Soil Group

A. (Low runoff potential). Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sands or gravels. These soils have a high rate of water transmission.

B. Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately will to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

C. Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate or water transmission.

D. (High runoff potential). Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

2.2.3.3 Richard's Runoff Hydrograph Mehtod

The assumptions made by Richard are that the storm cover the catchment and its duration is equal to the period of concentration of the flood. These assumptions implied that the whole catchment contributed to produce the maximum intensity of flood.

On that basis, the following principal equations were deduced:

i) $$i = \frac{R.f(a)}{t+1} \quad \text{or,} \quad R = \frac{i\ (t+1)}{f(a)} \qquad (21)$$

ii) $$\frac{t^3}{t+1} = \frac{N\ C\ L^2}{K.S.R.f(a)} \qquad (22)$$

iii) $$Q = K\ i\ a \qquad (23)$$

Where,

t = the period of concentration in hours.

Q = maximum intensity of flood in cusec

N = storm shape factor with range of value from 0.27 to 1.72 (usually 1.1)

i = the average intensity of rainfall over the catchment in inches per hour

a = the area of the catchment in acres

L = the distance in miles from the point of concentration to the furthest point on the catchment

S = the slope of the catchment

K = the runoff coefficient, (Table 6)

f(a), a function of the area for the adjustment of the average intensity of the rainfall (Fig.9)

C = a coefficient (Fig.10)

R = a coefficient of rainfall

The intermediate points on the curve of rising flood were given by:

$$Q_1 = Qm\ a_1/a \tag{24}$$

$$t_1 = t\ \left[\frac{r^2}{L}\right]^{1/3} \tag{25}$$

Where, a_1 = any area of catchment;

Qm = maximum flood intensity.

Where, r is the radius from the point of concentration along L for the area, a, bounded by the catchment boundary.

The falling flood curve is the reverse of the rising flood curve.

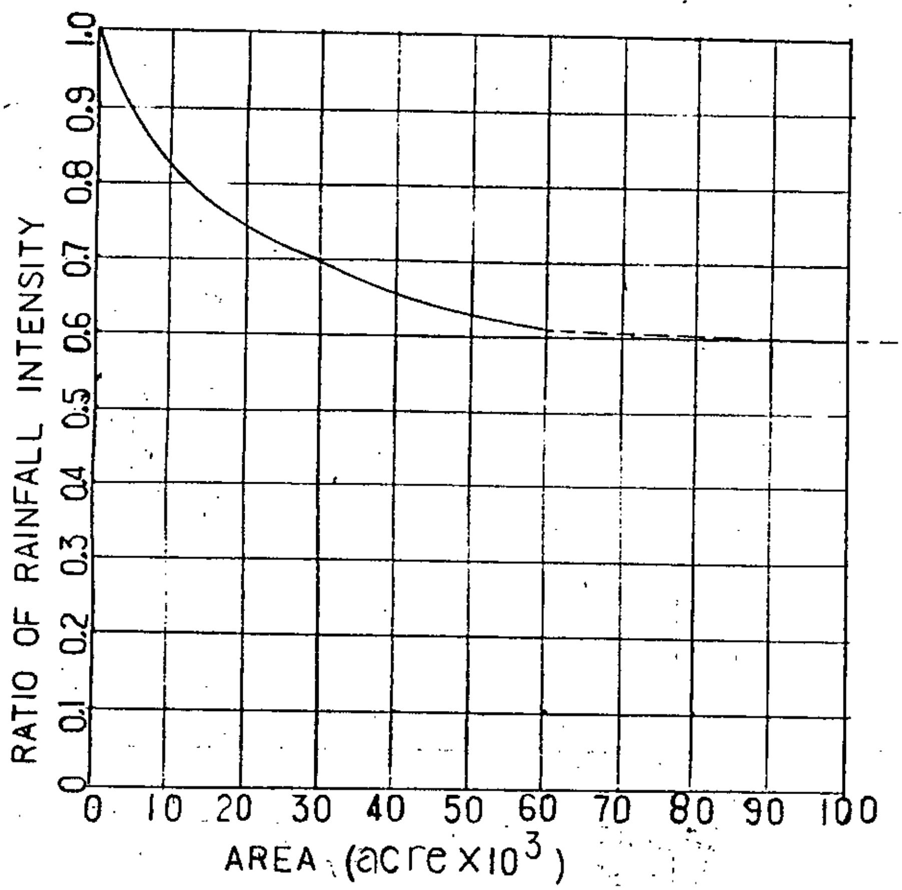


FIG. 9 RATIO OF RAINFALL INTENSITY, $f(a) = \frac{\text{AVERAGE}}{\text{MAXIMUM}}$

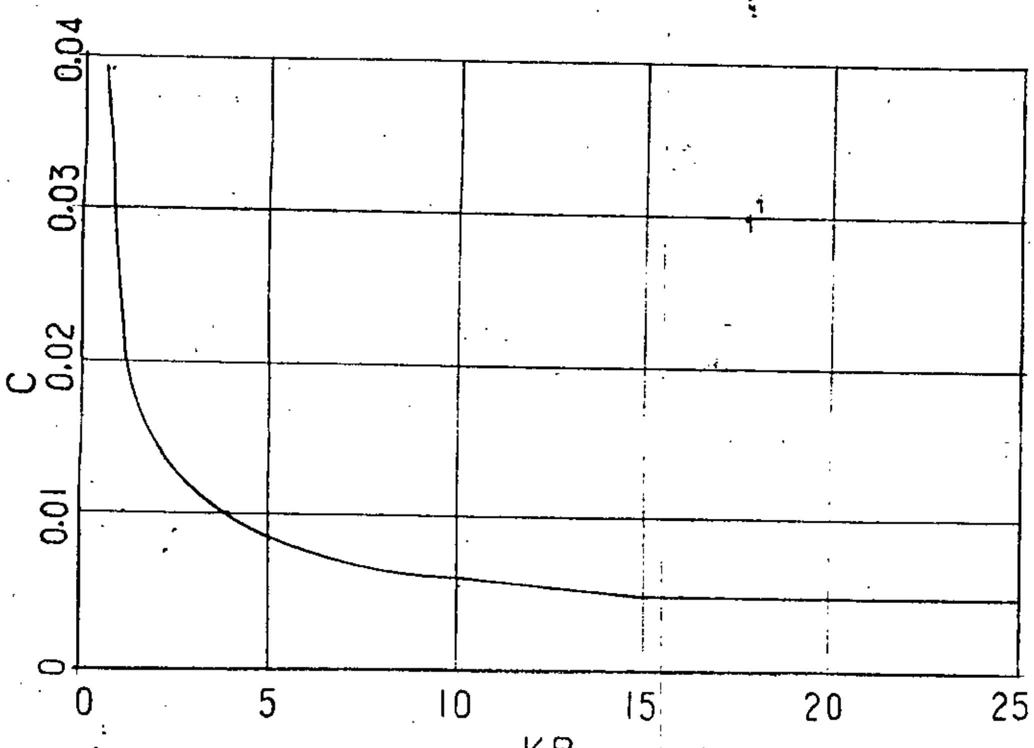


FIG. 10 COEFFICIENT, C VERSUS KR

source: Richard's B.D. (1955)

The computation procedure is given below:

i) 24-hours point rainfall with required frequency is used and i is determined;

ii) Topo-map is used to determine a, L and S;

iii) f(a) is determined from Fig.9 for the area of the catchments;

iv) R is computed from Equation (21);

v) K is selected for the catchment (Table 6) and computed KR;

vi) C is determined from Fig.10 using computed value KR;

vii) t is found out by Equation (22);

ix) Using t in nearest days, point rainfall is taken for this this duration ; necessary step is repeated to obtain t at the end of the operation as same as in the beginning of the operation;

x) i is computed using this determined t;

xi) Arcs with 'o' as center is drawn from the point of concentration along L with equal intervals 1,2,3,4,..miles;

xii) Area of the catchment intercepted by each arc is computed;

xiii) Intermediate points on the hydrograph is computed by Equation (24) and (25) for intermadiate points.

Table 6 Value of Runoff Co-efficient, K

Type of Catchment	Large	Small & Steep
Rocky and impermeable	0.8	1.0
Slightly permeable, bare	0.6	0.8
Slightly permeable, partly cultivated or covered with vegetation	0.4	0.6
Cultivated absorbent soil	0.3	0.4
Sandy absorbent soil	0.2	0.3
Heavy forest	0.1	0.2

2.2.4 Flood Routing

The flood wave moving through a short reach of channel of regular section will undergo little change in its configuration. However, if the flow obstructed by any way the flood wave configuration may be modified appreciably. The determination of this modification is called flood routing. Flood routing in that case consisted of predicting an outflow hydrograph below a drainage structure from a known inflow hydrograph above the structure. The purposes of flood routing are:

i) The maximum discharge under the outflow hydrograph is used as a basis for designing the size of the structure.

ii) Because the inflow discharge during the flood peak is greater than the outflow discharge, a portion of runoff becomes storage. Flood routing will determine the accumulated storage volume. The storage water surface elevation can be found out by using the basin area - capacity curve. This information is used to compute crop damages due to flooding.

iii)The structure is designed for percolation and uplift using the head differential across the structure measured from the storage level to the tail water level as determined by the outflow hydrograph.

Generally a routing is made for a pre-monsoon storm, when the river stage is low, as criteria for designing the structural elements. Before the flood routing process begins, the designer assumes a preliminary size of the structure. In a non-tidal area roughly for each 1200 ha to 1500 ha of the catchment area a single vent of size 1.52 m x 1.83 m is assumed. The routing procedure determines whether the assumed structure is adequate after computing the extent of flood damage. Additional routing may be required through an enlarged or reduced size of hte structure depending upon the results of flood damage computed from the first routing. The range of tolerable submergence of area may be as high as 10 percent or even more of the gross project area depending on the topograpy of the basin. The designer applies his judgement after studying the basin topography and importance of land, how great an area can be flooded and to what depth. In general the tolerable range of submergence of area for not more than 30 cm for a period of 72 hours may be considered upto an incremental area of 5 percent of the total project area in addition to the existing low lands that can not be drained by gravity.

A post monsoon routing, when the discharge is controlled by the tail water level due to high river stage, is required to check the size of the structure selected by pre- monsoon routing. The criteria for checking the adequacy of the size is to observe that the difference of water level between river side and country side cannot be visually identified. This difference of water level is considered to be 15 cm to 23 cm which is not easily detectable in the field to a maximum of 30 cm for three consecutive days.

2.2.4.1 Premonsoon Flood Routing

Flood routing is basically a system of book keeping involving inflow, outflow and storage. During a definite time interval:

$$I_v - D_v = S \qquad (26)$$

Where, I_v = Total volume of inflow during the period

D_v = Total volume of outflow during the period

S = Total volume going to storage during the period

The equation written for a definite time period and expressing inflow and outflow in m^3/sec is:

$$S/t = I - D \qquad (27)$$

Where, t = Time of period in sec

I = Average inflow during the period, m^3/sec

D = Average outflow during the period, m^3/sec

S = Total volume going to storage during the period, m^3

This equation forms the basis for a hydrological procedure in routing in which 't' is known as the routing period.

Let $S_2 - S_1 = S$, Storage differential during period

$\frac{I_1+I_2}{2} = I$, Average inflow during the period

$\frac{D_1+D_2}{2} = D$, Average outflow during the period

Substituting the terms in Equation(27),

$$\left[\frac{I_1+I_2}{2} - \frac{D_1 + D_2}{2} \right] t = S_2 - S_1 \qquad (28)$$

$$I_1 + I_2 - D_1 - D_2 = 2S_2/t - 2S_1/t$$

$$(I_1+I_2) + 2S_1/t - D_1) = (2S_2/t + D_2) \qquad (29)$$

To solve Equation (28) the following curves are required:

i) The inflow hydrograph

ii) Area-capacity curve

iii) The stage discharge relation for flow types 3 and 5

iv) The 2S/t + D curve

To draw an area-capacity curve a contour map of the project area is collected and the area between each contour level is planimetered. The curve is plotted as ground elevation versus total accumulated area at any elevation. Capacity between two contour intervals is calculated as the average of the area at the two levels multiplied by the contour interval.

For premonsoon routing the flow condition changes between 5 to 3. Flow condition 5 occurs when the head water depth is less than 1.5 times the vent height the entrance is not sealed by water and the regulator acts as a broad crested weir. A hydraulic jump usually occurs at downstream. The control is at the outlet. The discharge per meter of width is given by:

$$q = C\,H^{3/2} \quad \text{where } C = 1.49 \qquad (30)$$

Flow type 3 occurs when the head water depth is greater than 1.5 times the vent height. The control is at entrance and is similar to orifice discharge.

$$q = Cq\ D\ (\ 2\ g\ H\ )^{1/2} \text{ per meter width} \qquad (31)$$

C_q is obtained from Fig.11 for the corresponding value of D/H.

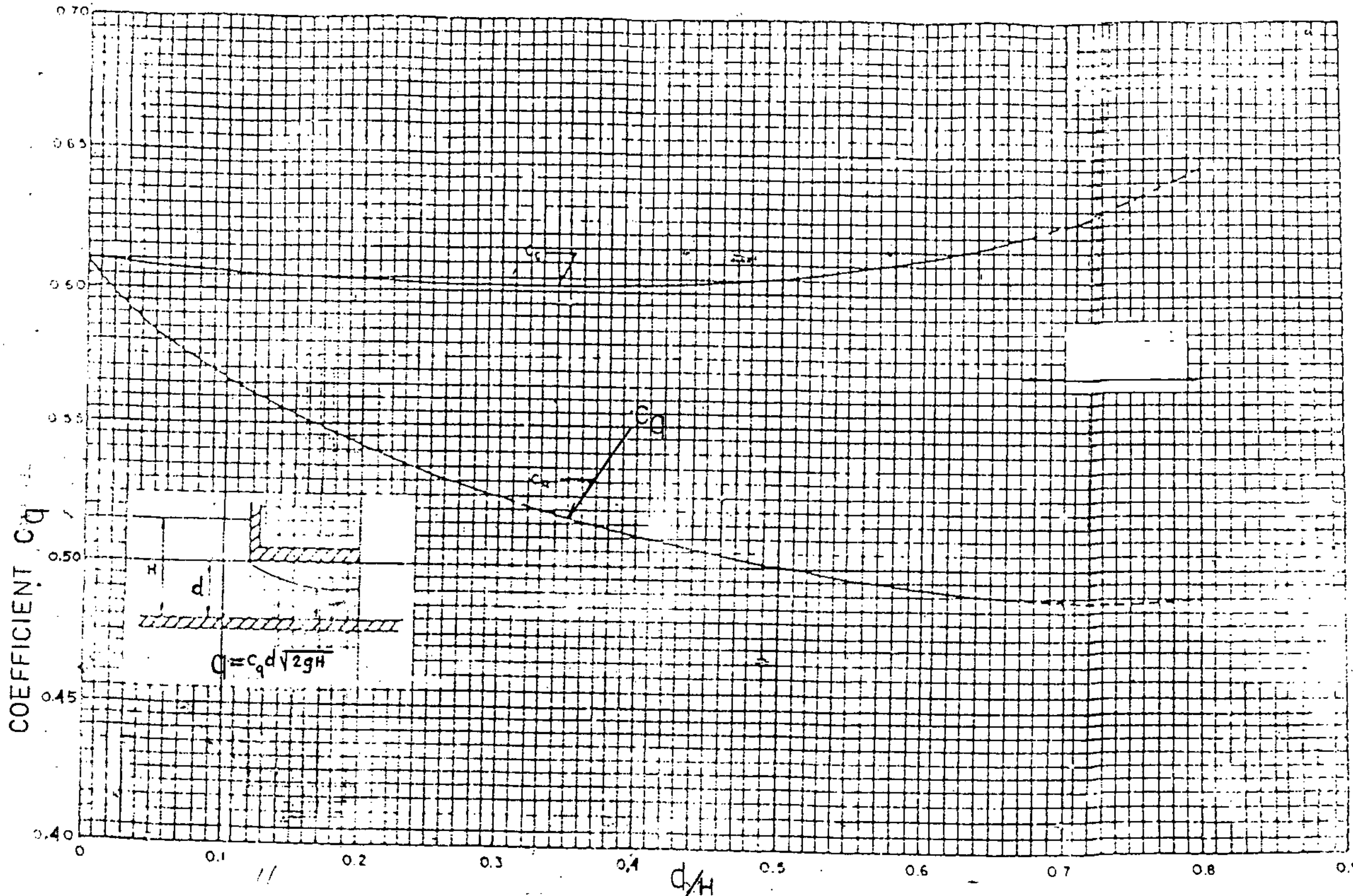


FIG.11 DISCHARGE COEFFICIENT FOR FLOW TYPE 3

Source: BWDB (1966)

Invert level of the structure is normally fixed at channel bed level. The discharges under conditions 5 and 3 are computed for different elevation and entered in the stage discharge curve.

2.2.4.2 Postmonsoon Flood Routing

As the river stage starts rising the gates of the regulator are closed before the flooding inside the project area exceeds the tolerable inundation level. During the flood period the gates remain close and flood water cannot enter into the project area provided the project area is completely empoldered, but the excess rainfall runoff will be accumulated inside the basin. The rainfall runoff volumes for non-paddy land, paddy land and weighted basin average for different months are computed. The basin water surface elevation after each day is computed considering head difference. It may be observed that the basin water level always remains below the level in the peripheral rivers. The difference is the benefit accured out of the project by reclaiming land which were subjected to annual flooding during the pre-project condition.

2.3 Discussion

Until recently the small scale drainage projects have been designed without going into detailed hydrologcal analysis. In the recent years, however, efforts are given for hydrological analysis to obtain economic design.

The unit hydrograph method has been widely used. But different organization useed different values of duration and frequency of design storm. BWDB and Northwest Hydraulic Consultants Limited use 5-day rainfall with 10-year return period while EPC(1985) uses 10-day rainfall with 5-year return period.

Although the design storm is recently determined by frequency analysis of rainfall data, the time distribution of the design storm is still obtained by IECO (1964) method.

Chapter - 3

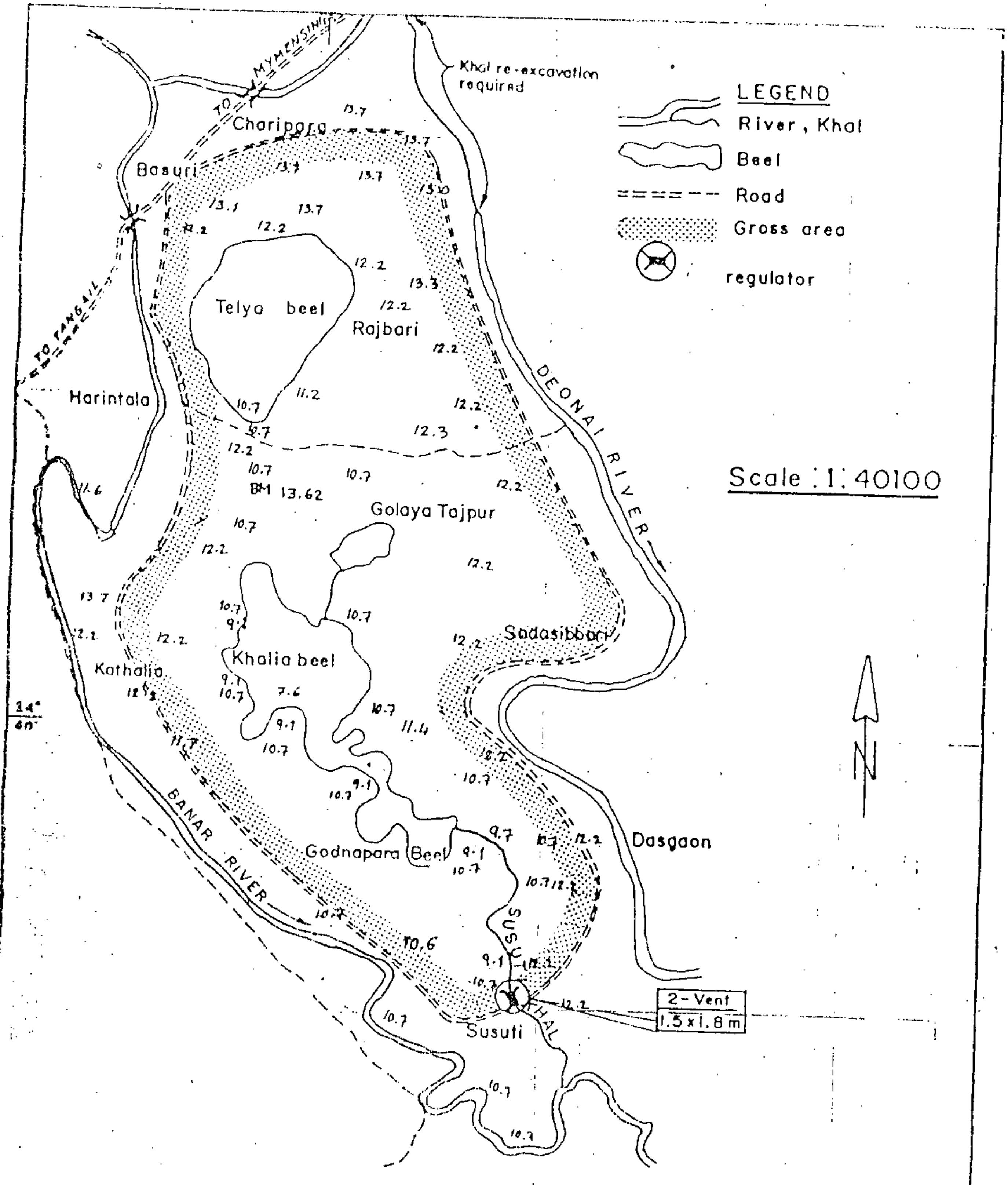
A CASE STUDY OF BANNYAR KHAL SUBPROJECT

3.1 Subproject Description

The Bannyar Khal is a small scale flood control and drainage subproject. It is located at Muktagacha Upazila in the district of Mymensingh. It is under Catchment No.43 of Planning Area No. 18 in the National Water Plan Map. The area is within the oldest part of the Brahmaputra flood plain, a shallow flooded land as per MPO land classification. The soil is principally silty loam. Ground surface elevation ranged from 16.0 m to 7.2m (PWD). The project area drains into two large beels and then to the Sisuti Khal which drains the catchment area into Banar river.

The subproject was undertaken by the BWDB to protect the crops of the area from the flush flood of river Banar. A regulator of 2 vents ([illegible] 3mx1.52m) has bee[illegible]nstructed 1200m upstream of the Banar ri[illegible] confluence as shown in subproject map (Fig.12). A 6.10 km embankment was also constructed to protect the area from flood and a 4.0 km channel was reexcavated to facilitate drainage.

The subproject was selected for this study of hydrological design, ventage selection and runoff calculation procedure.



BANNYAR KHAL
Sub-Project

Source: BWDB FIG. 12 PROJECT MAP

The criteria of selecting this sub-project were (i) the sub-project is in operation since 1987 (ii) there is no drainage problem so far reported (iii) all hydrological data were available (iv) the area is nearer to Dhaka and easy for field investigation.

3.2 Hydrologic Design of Subproject

All available reports and design data were collected from the BWDB planning office and also from Northwest Hydraulic Consultants Ltd. which is responsible for the design and implementation of the subproject. The characteristics of subproject data were obtained as follows:

Basin area, A = 15.42 Sqkm.

Principal channel length, L = 8.1 Km.

Length from outlet to nearest to basin centroid,= 4.0 Km.

Straight basin length, L_s = 7.1 Km.

Roughness, n = 0.055

Percent paddy land = 52

Number of vents used = 2

Size of vent = 1.52 m x 1.83 m

Area-elevation and water level data were also collected from design file and used in calculation. The temperature data used are those for Mymensingh the potential evapotranspiration data are regional estimates and the rainfall data are adopted from Sherpur rain gauge. The climatic data were collected as shown in Table 7.

Table 7 Subproject Climatic Data

Month	Temperature Min. (^0C)	Max (^0C)	Evaporatranspiration (mm)	Rainfall Average (mm)
Jan	11.6	25.2	88.9	25.4
Feb	13.8	27.6	125.5	30.6
Mar	18.2	32	172.7	70.6
Apr	22.1	33.8	149.9	154.4
May	23.5	32.4	157.5	400.8
Jun	24.9	31.2	144.8	535.4
Jul	25.7	31.3	144.8	512.8
Aug	25.7	31.3	142.2	500.1
Sep	25.4	31.5	127	389.5
Oct	23.8	30.7	116.9	210.5
Nov	18.2	28.7	294	42.6
Dec	13.6	26.4	86.4	11.6

3.2.1 Inflow Hydrograph Adopted in Design

Northwest hydraulic Consultant Ltd. derived the design inflow hydrograph by using unit hydrograph method. The design storm was obtained by using 4-month rainfall index. For verification the design inflow hydrograph was compared with the inflow hydrograph obtained the following methods:

i) Inflow hydrograph by unit hydrograph method using recent rainfall Data;

ii) Inflow hydrograph using soil conservation service method;

iii) Inflow hydrograph using Richard's method.

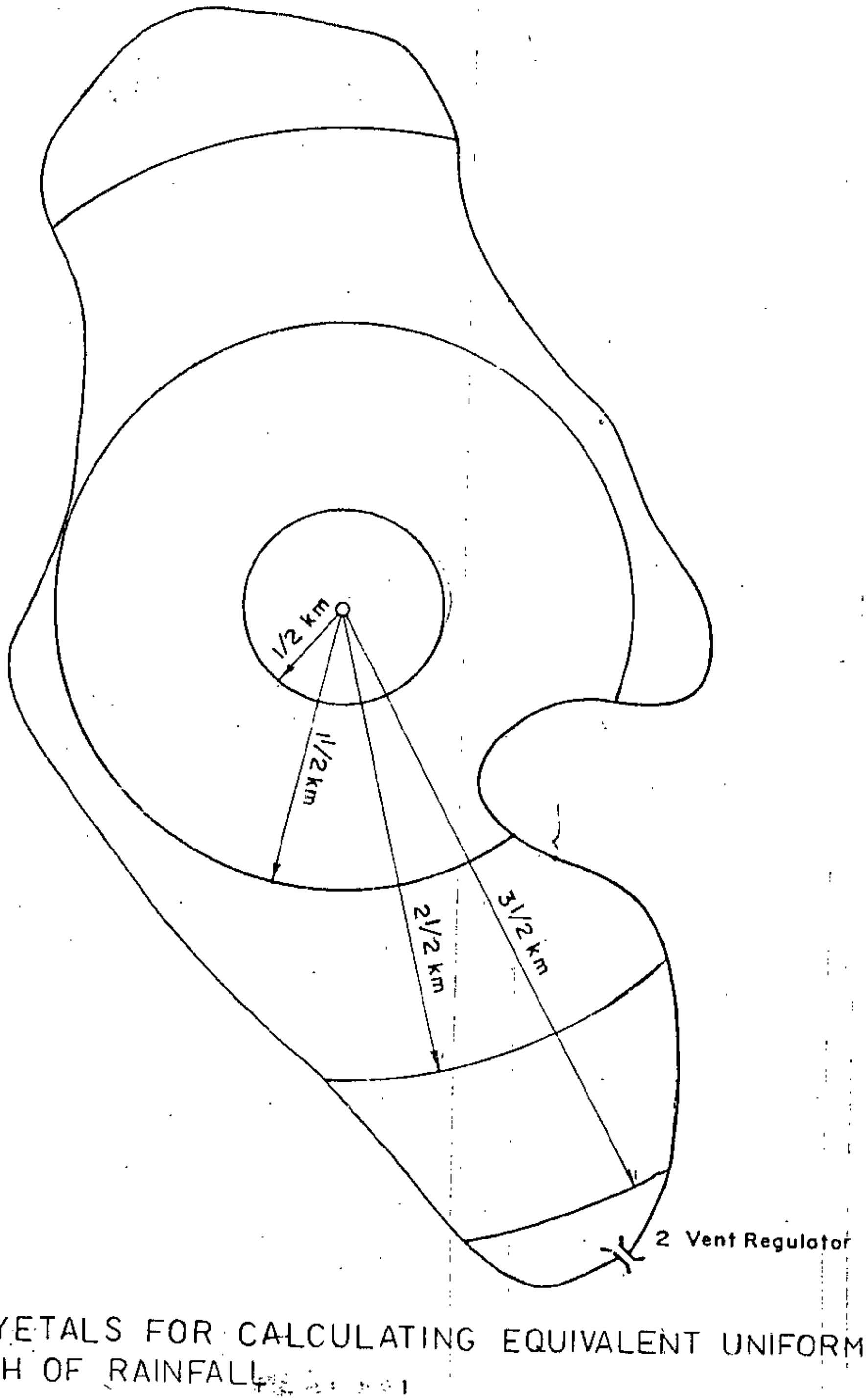


FIG.13 ISOHYETALS FOR CALCULATING EQUIVALENT UNIFORM DEPTH OF RAINFALL

The geographical center of the basin was located and isohyetals were drawn at one kilometer intervals starting from one half kilometer from the center (Fig. 13). The areas were planimetered and multiplied by the rainfall variability percent from Table 2 to get percent of point rainfall that forms the equivalent uniform depth of rainfall as given in Table 8.

Table 8 Subproject Percent of Point Rainfall

Distance Km.	Area Sqkm.	Area times Percentage
0.25	0.95	0.95
1.0	6.35	5.97
2.0	5.77	4.99
3.0	1.80	1.49
4.0	0.55	0.44
5.0	0.00	0.00
Total	15.42	13.84

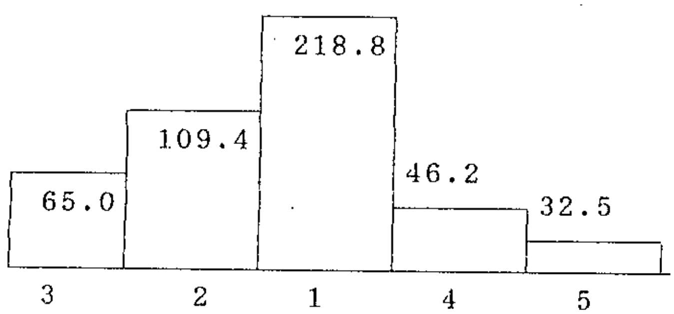
Now the percentage of point rainfall that forms the equivalent uniform depth of rainfall = 13.84/15.42 = 90%.
Four month rainfall index for the subproject area was taken as 1905 mm and Table 9 was prepared taking 10 year storm frequency from Table 1.

Table 9 Subproject Accumulated Point Rainfall

(10 year storm frequency)

Days	10 year storm frequency	Accumulated point rainfall	Equivalent uniform depth	Daily increment
1	0.128	243.8	218.8	218.8
2	0.192	365.8	328.2	109.4
3	0.230	438.2	393.2	65.0
4	0.257	489.6	439.3	46.2
5	0.276	525.8	471.8	32.5

The daily increment of rainfall may occur in any order and an arbitrary sequence of 3,2,1,4,5 was considered in order to satisfy the losses that would take place early in the storm.



For breaking down rainfall time distribution into intervals less than 24 hours nearest rainfall station of Bogra has been considered because IECO(1964) gave a time distribution of rainfall for that station. Four month rainfall index for Bogra station is 1473 mm and Table 10 was prepared to obtain time distribution of rainfall for this subproject.

Table 10 Subproject 24 Hour Rainfall Time Distribution

	Hour	6	12	18	24
i	Bogra point rainfall max.(mm)	138.9	160.0	175.3	187.9
ii	Project area point rainfall max.(mm) (row(i)x1905/1473)	179.6	206.9	226.7	243.0
iii	Project area incremental point rainfall	179.6	27.3	19.8	16.3
iv	Project area uniform rainfall (row(iii)x13.84/15.42)	161.2	24.5	17.8	14.6

Now considering the sequence of maximum day rainfall 218.8 mm distributed 6 hourly according to Table 10 in the middle of 5 days; Table 11 was prepared. The same sequence of total rainfall for the other days was followed.

The rainfall excess was calculated for paddy land and nonpaddy land considering (i) initial soil moisture loss of o and 13mm for paddy land and nonpaddy land respectively, (ii) subsequent soil moisture loss of 1mm/hr for impervious soil, (iii) depression storage of 100 mm for paddy land and 5 mm per 6 hours until a maximum of 25 mm for nonpaddy land. The calculations are presented in Table 12 and Table13.Subproject area consists of 52% paddy land and 48% nonpaddy land. Excess rainfall for the subproject is given in Table 14.

Table 11 Subproject 5 Day Design Storm

Days	6 hour incremental rainfall
1	17.8
	14.6
	8.1
	24.5
2	17.8
	14.6
	52.5
	24.5
3	17.8
	14.6
	161.2
	24.5
4	17.8
	3.9
	0.0
	24.5
5	17.8
	0.0
	0.0
	14.7

Table 12 Rainfall Excess for Paddy Land

Days	Hours	Rain Fall (mm)	Losses(mm) Soil Moisture Init.	Subseq.	Depression Storage	Available Paddy Storage	Net Runoff (mm)
1	00-06	17.8	0.0	-6	-100	-88.2	0.0
	06-12	14.6		-6		-79.6	0.0
	12-18	8.1		-6		-77.5	0.0
	18-24	24.5		-6		-59.0	0.0
2	00-06	17.8		-6		-47.3	0.0
	06-12	14.6		-6		-38.7	0.0
	12-18	52.5		-6		0.0	7.8
	18-24	24.5		-6		0.0	18.5
3	00-06	17.8		-6		0.0	11.8
	06-12	14.6		-6		0.0	8.6
	12-18	161.2		-6		0.0	155.2
	18-24	24.5		-6		0.0	18.5
4	00-06	17.8		-6		0.0	11.8
	06-12	3.9		-6		-2.1	0.0
	12-18	0.0		-6		-8.1	0.0
	18-24	24.5		-6		0.0	10.4
5	00-06	17.8		-6		0.0	11.8
	06-12	0.0		-6		-6.0	0.0
	12-18	0.0		-6		-12.0	0.0
	18-24	14.7		-6		-3.3	0.0

Table 13 Rainfall Excess for Nonpaddy Land

Day	Hours	Rain (mm)	Losses(mm) Soil Moisture Init.	Subseq.	Depression Storage	Available Available Storage	Net Runoff
1	00-06	17.8	-13.0	0.0	-4.8	0.0	0.0
	06-12	14.6		-6	-5.0	0.0	3.6
	12-18	8.1		-6	-2.1	0.0	0.0
	18-24	24.5		-6	-5.0	0.0	13.5
2	00-06	17.8		-6	-5.0	0.0	6.8
	06-12	14.6		-6	-3.2	0.0	5.5
	12-18	52.5		-6	0.0	0.0	46.5
	18-24	24.5		-6	0.0	0.0	18.5
3	00-06	17.8		-6	0.0	0.0	11.8
	06-12	14.6		-6	0.0	0.0	8.6
	12-18	161.2		-6	0.0	0.0	155.2
	18-24	24.5		-6	0.0	0.0	18.5
4	00-06	17.8		-6	0.0	0.0	11.8
	06-12	3.9		-6	0.0	-2.1	0.0
	12-18	0.0		-6	0.0	-8.1	0.0
	18-24	24.5		-6	0.0	0.0	10.4
5	00-06	17.8		-6	0.0	0.0	11.8
	06-12	0.0		-6	0.0	-6.0	0.0
	12-18	0.0		-6	0.0	-12.0	0.0
	18-24	14.7		-6	0.0	-3.3	0.0

Table 14 Rainfall Excess - Weighted Basin Average

Day	Hour	52% Paddy Weighted runoff	Land Net runoff	48% Nonpaddy Weighted runoff	Land Net runoff	Weighted Basin runoff
1	00-06	0.0	0.0	0.0	0.0	0.0
	06-12	0.0	0.0	3.6	1.7	1.7
	12-18	0.0	0.0	0.0	0.0	0.0
	18-24	0.0	0.0	13.5	6.5	6.5
2	00-06	0.0	0.0	6.8	3.2	3.2
	06-12	0.0	0.0	5.5	2.6	2.6
	12-18	7.9	4.1	46.5	22.3	26.4
	18-24	18.5	9.6	18.5	8.9	18.5
3	00-06	11.8	6.1	11.8	5.6	11.8
	06-12	8.6	4.5	8.6	4.1	8.6
	12-18	155.2	80.7	155.2	74.5	155.2
	18-24	18.5	9.6	18.5	8.9	18.5
4	00-06	11.8	6.1	11.8	5.6	11.8
	06-12	0.0	0.0	0.0	0.0	0.0
	12-18	0.0	0.0	0.0	0.0	0.0
	18-24	10.4	5.4	10.4	5.0	10.4
5	00-06	11.8	6.6	11.8	5.6	11.8
	06-12	0.0	0.0	0.0	0.0	0.0
	12-18	0.0	0.0	0.0	0.0	0.0
	18-24	0.0	0.0	0.0	0.0	0.0
					Total Rainfall Excess =	287.0

The elements of the unit Hydrograph were calculated as follows:

Time of concentration, $T_c = 14.15 [L^2 n^2 / S]^{0.3} = 11.6$ hours

Lag time to peak, $t_p = 0.6 T_c = 6.96$ hours

Time of rise, $T_p = t_p + 0.5 t_r = 10$ hours ($t_r = 6$ hour)

Coefficient , $C_t = 1.331 t_p / (L L_c)^{0.3} = 3.27$

Coefficient C_p obtained from Figure 12 or from the relation;

$$C_p = 0.7527 - 0.2056 \ln(C_t) = 0.51$$

Unit graph base length, $T_b = 1.2 Tc / C_p = 27$ hours

Peak discharge, $q_p = 0.56 A / T_b = 0.322$ cumec

Recession time $= 27 - 10 = 17$ hour

Table 15 Runoff Hydrograph Computation

(Unit Hydrograph Method)

Days	Rainfall Excess 6-hour Duration(mm)																				Runnoff Hydrograph (m3/s)
	0.0	1.7	0.0	6.5	3.2	2.6	26.4	18.5	11.8	8.6	155.2	18.5	11.8	0.0	0.0	10.4	11.8	0.0	0.0	0.0	
1	0.0																				0.0
	0.0	0.0																			0.0
	0.0	0.2	0.0																		0.2
	0.0	0.6	0.0	0.0																	0.6
2	0.0	0.4	0.0	0.8	0.0																1.2
	0.0	0.2	0.0	2.1	0.4	0.0															2.7
	0.0	0.0	0.0	1.3	1.0	0.3	0.0														2.7
	0.0	0.0	0.0	0.6	0.7	0.8	3.4	0.0													5.5
3	0.0	0.0	0.0	0.0	0.3	0.5	8.5	2.4	0.0												11.7
	0.0	0.0	0.0	0.0	0.0	0.2	5.4	6.0	1.5	0.0											13.1
	0.0	0.0	0.0	0.0	0.0	0.0	2.3	3.8	3.8	1.1	0.0										11.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	2.4	2.8	19.9	0.0									26.7
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.8	50.0	2.4	0.0								55.1
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	31.7	6.0	1.5	0.0							39.9
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.4	3.8	3.8	0.0	0.0						21.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	2.4	0.0	0.0	0.0					4.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	1.3	0.0				2.4
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	1.5	0.0			4.9
			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	3.8	0.0	0.0		5.9
				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	2.4	0.0	0.0	0.0	3.3
6					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0
						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
											0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
												0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
													0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
														0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
															0.0	0.0	0.0	0.0	0.0	0.0	0.0
																0.0	0.0	0.0	0.0	0.0	0.0
																	0.0	0.0	0.0	0.0	0.0
																		0.0	0.0	0.0	0.0
																			0.0	0.0	0.0

ays	Rainfall Excess 6-hour Duration(mm)																				Runnoff Hydrograph
	0.0	1.7	0.0	6.5	3.2	2.6	26.4	18.5	11.8	8.6	155.2	18.5	11.8	0.0	0.0	10.4	11.8	0.0	0.0	0.0	(m3/s)
1	0.0																				0.0
	0.0	0.0																			0.0
	0.0	0.2	0.0																		0.2
	0.0	0.6	0.0	0.0																	0.6
2	0.0	0.4	0.0	0.8	0.0																1.2
	0.0	0.2	0.0	2.1	0.4	0.0															2.7
	0.0	0.0	0.0	1.3	1.0	0.3	0.0														2.7
	0.0	0.0	0.0	0.6	0.7	0.8	3.4	0.0													5.5
3	0.0	0.0	0.0	0.0	0.3	0.5	8.5	2.4	0.0												11.7
	0.0	0.0	0.0	0.0	0.0	0.2	5.4	6.0	1.5	0.0											13.1
	0.0	0.0	0.0	0.0	0.0	0.0	2.3	3.8	3.8	1.1	0.0										11.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	2.4	2.8	19.9	0.0									26.7
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.8	50.0	2.4	0.0								55.1
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	31.7	6.0	1.5	0.0							39.9
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.4	3.8	3.8	0.0	0.0						21.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	2.4	0.0	0.0	0.0					4.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	1.3	0.0				2.4
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	1.5	0.0			4.9
			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	3.8	0.0	0.0		5.9
				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	2.4	0.0	0.0	0.0	3.3
6					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0
						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
										0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
											0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
												0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
													0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
														0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
															0.0	0.0	0.0	0.0	0.0	0.0	0.0
																0.0	0.0	0.0	0.0	0.0	0.0
																	0.0	0.0	0.0	0.0	0.0
																		0.0	0.0	0.0	0.0
																			0.0	0.0	0.0
																				0.0	0.0
																				T0tal, I=	212.7

A unit hydrograph for the subproject is shown in Fig.14. The ordinates were taken to compute the inflow hydrograph and presented in Table 15.

3.2.2 Inflow Hydrograph by Unit Hydrograph Method Using Recent Rainfall Data

Rainfall data from 1961 - 1988 were collected from MPO. Five - day 10-year rainfall was obtained by frequency analysis (Pearson's type iii distribution). The equivalent uniform depth of rainfall was determined as presented in Table 16.

Table 16 5 Day 10 Year Rainfall from Recorded Recent Data

Day	Rainfall (1:10 year)	Equivalent uniform depth	Daily increment
1	266	239	239
2	358	322	83
3	388	349	27
4	422	380	31
5	441	397	17

This rainfall data were used to calculate inflow hydrograph given in Table 17.

Table 17 Runoff Hydrograph from Recorded Recent Data

Hour	Runoff
0	0
6	0
12	0
18	0
24	0
30	0
36	0.307
42	1.448
48	3.112
54	4.338
60	25.23
66	59.096
72	43.6
78	24.24
84	6.173
90	2.476
96	0.516
102	0
Total = 174.89 mm	

3.2.3 Inflow Hydrograph Using Soil Conservation Service Method

The calculation is given as follows:

i) Time of concentration, $T_c = 14.15 [L^2 n^2 / S]^{0.385}$ hour

For L = 8.1 Km. S = 0.381 m/Km. and n=0.055, T_c = 11.01 hour

ii) Duration of rainfall, $t_R = 0.133\ Tc = 1.46$ hours.

iii) Time from centroid of rainfall to the peak discharge,

$$t_p = 0.6\ T_c = 0.876 \text{ hour.}$$

iv) Time from the beginning of rainfall to the peak discharge,

$$T_p = t_R/2 + 0.6T_c = 7.34 \text{ hours.}$$

v) Peak discharge for a direct runoff of one millimeter,

$$q_p = 0.208\ A / Tp \text{ cumec}$$

For $A = 15.42$ sq km. $T_p = 7.34$, $q_p = 0.4369$ cumec

Where, A is drainage area in sq km.

vi) Now direct runoff is calculated using equation

$$Q = (P-0.2S)^2 / (P + 0.8S) \text{ mm}$$

From Fig.8 for Bogra, potential maximum rainfall, P for the duration, T_R of 1.46 hours is 3.5". Correction for four month rainfall index (Fig.4) for subproject location at Sherpur , P= 3.5 x 1905/1270 =4.52 " = 114.8 mm. Considering the type of soil and land of the project area, CN = 91.

So, $S = 254000 / CN - 254 = 254000/91 - 254 = 25.1$ mm

And $Q = (114.8 - 0.2 \times 25.1) / (114.8 + 0.8 \times 25.1) = 127$ mm

For 127 mm, $q_p = 0.4369 \times 127 = 55.5$ cumec

From the above data and SCS dimensionless unit hydrograph (Table 6), the ordinates of the inflow hydrograph were calculated and presented in Table 18.

Where, q = Discharge at any time, t

t = a selected time

Table 18 Runoff Hydrograph by SCS method

Time Ratios (t/Tp)	Time in hour	Discharge Ratios (q/qp)	Discharge, q cumec
0.0	0	.000	0.0
0.1	0.7	.030	1.67
0.2	1.5	.100	5.55
0.3	2.2	.190	10.55
0.4	2.9	.310	17.21
0.5	3.7	.470	26.08
0.6	4.4	.660	36.63
0.7	5.1	.820	45.51
0.8	5.9	.930	51.62
0.9	6.6	.990	54.94
1.0	7.3	1.000	55.5
1.1	8.1	.990	54.84
1.2	8.8	.930	51.62
1.3	9.5	.860	47.73
1.4	10.3	.780	43.29
1.5	11.0	.680	37.74
1.6	11.7	.560	31.08
1.7	12.5	.460	25.53
1.8	13.2	.390	21.65
1.9	13.9	.330	18.32
2.0	14.7	.280	15.54
2.2	15.1	.207	11.49
2.4	17.6	.147	8.16
2.6	19.1	.107	5.94
2.8	20.6	.077	4.27
3.0	22.0	.055	3.05
3.2	23.5	.040	2.22
3.4	25.0	.029	1.61
3.6	26.4	.021	1.17
3.8	27.9	.015	0.83
4.0	29.4	.011	0.61
4.5	33.0	.005	0.28
5.0	36.7	.000	0.0

3.2.4 Inflow Hydrograph Using Richard's Method

Calculation of Runoff Hydrograph by Richard's Method is given below:

Basin area, a = 15.42 x 2.47 = 3808.74 acre

Average channel slope s = 0.435 m/km = 0.000435

Length of principal drainage channel, L = 8.1 km = 5.0 miles.

24 hour rainfall = 243.8 mm =9.6 inch from Table 10

Average intensity of rainfall, i = 9.6/24 = 0.4 "/hr

f(a) = a function of the area for the adjustment of the averageintensity of the rainfall =0.91 from Fig.11

Coefficient of rainfall , R = i(t + 1) / f(a) = 0.4 x25 /0.91 = 10.99 inch

K , runoff coefficient = 0.6 from Table

KR = 6.6 and C = 0.008 fro Fig.12

Storm shape factor, N = 1.1

$$t^3 / (t+1) = (NxCxL^2) / (KxSxRxf(a)) = 84.28$$

By trial , T =10 hrs , say 0.5 day

12 hour rainfall from Table 10 is 207 mm = 8.1 inch

i = 8/12 = 0.66, R = 0.66 x 13/0.91 =9.5

KR = 5.7 , C=0.0085

$t^3 / (t+1) = (NxCxL^2) / (KxSxRxf(a)) = 103.6$

Trial for t =11 hrs , say 0.5 day

So i = 0.66 inch/hr

Q = Kia = 0.6x 0.66x 3808.74 =1508 cfs = 42.74 cumec

The runoff hydrograph from the above data are given in Table 19.

Table 19 Runoff Hydrograph by Richard's Method

Distance to outlet	a_1/a	$((r/L)^2)^{1/3}$	Rising flood Q_r (cumec)	t_R (hour)	Falling flood Q_f (cumec)	t_f (hour)
miles	2	3	4	5	6	7
0	0	0	0	0	42.74	12.0
1	0.15	0.34	6.24	4.1	36.5	16.1
2	0.34	0.54	14.7	6.51	28.04	18.51
3	0.69	0.71	29.45	8.54	13.29	20.54
4	0.92	0.86	39.32	10.34	3.42	22.34
5	1.0	1.0	42.74	12.0	0	24.0

3.2.5 Comparison of Inflow Hydrographs

The four inflow hydrographs thus obtained were plotted in Fig.16 for comparison. It is seen that peak discharge obtained by using recent rainfall data is 7 percent higher than the value obtained by using four months rainfall index. But the time to peak discharge is same for both the cases. Unit hydrograph method and SCS method have been found to give more or less same value of peak discharge. The peak discharge obtained by Richards method is 23 percent less than the value obtained by unit hydrograph method. But in case of SCS and Richard's method the peak discharge is found to occur very quickly.

3.2.6 Flood Routing

The inflow hydrograph obtained by (i) unit hydrograph method (ii) SCS method and (iii) Richard's method are routed for the selected vent size of the regulator. The required (i) area-capacity curve (ii) stage-discharge curve and (iii) 2S/t + D curve were obtained design file and reproduced in Figs. 17,18 and 19. The outflow hydrographs and the basin water level versus time curves are presented in Figs.22 to 25.

The outflow hydrograph peak obtained by unit hydrograph method and Richard's method are about same(9.2 cumec) but larger in SCS method(20.4 cumec). The percentage of area submerged for more than 72 hours is negligible for all the outflow hydrograph. Therefore it can be concluded that the size of the regulator is quite adequate.

3.2.7 Questionnaire Survey

A questionnaire survey was conducted with a view to assess the drainage condition of the subproject. Twenty farmers were selected in the project area and interviewed in this survey. The results are given in Table 20. A sample questionnaire is shown in Annex - 1.

Table 20 Result of Questionnaire Survey in Project Area

Ques. No.	Beneficiaries View/Opinion	Respond/Percent			
4(i)	Objective of Project	Flood Control 0%	Flood Control Drainage 5%	Drainage and Irrig. 10%	FCDI 85%
4(ii)	Achievement of the Project	Ful-filled 100%	Partial fulfilled 0%	Not fulfilled 0%	
4(iii)	Benefits obtained	Communi-cation 10%	Crop Production 60%	Employment 40%	
5	Does drainage Congestion occur?	Yes 10%	No 90%		

From this and after visiting the site, it is evident that there is no drainage congestion in the project area. So the size of the regulator is quite adequate for this project area. 85% farmers reported that the achievement of the project is fulfilled. They obtained benefits in communication,crop production and also in employment.

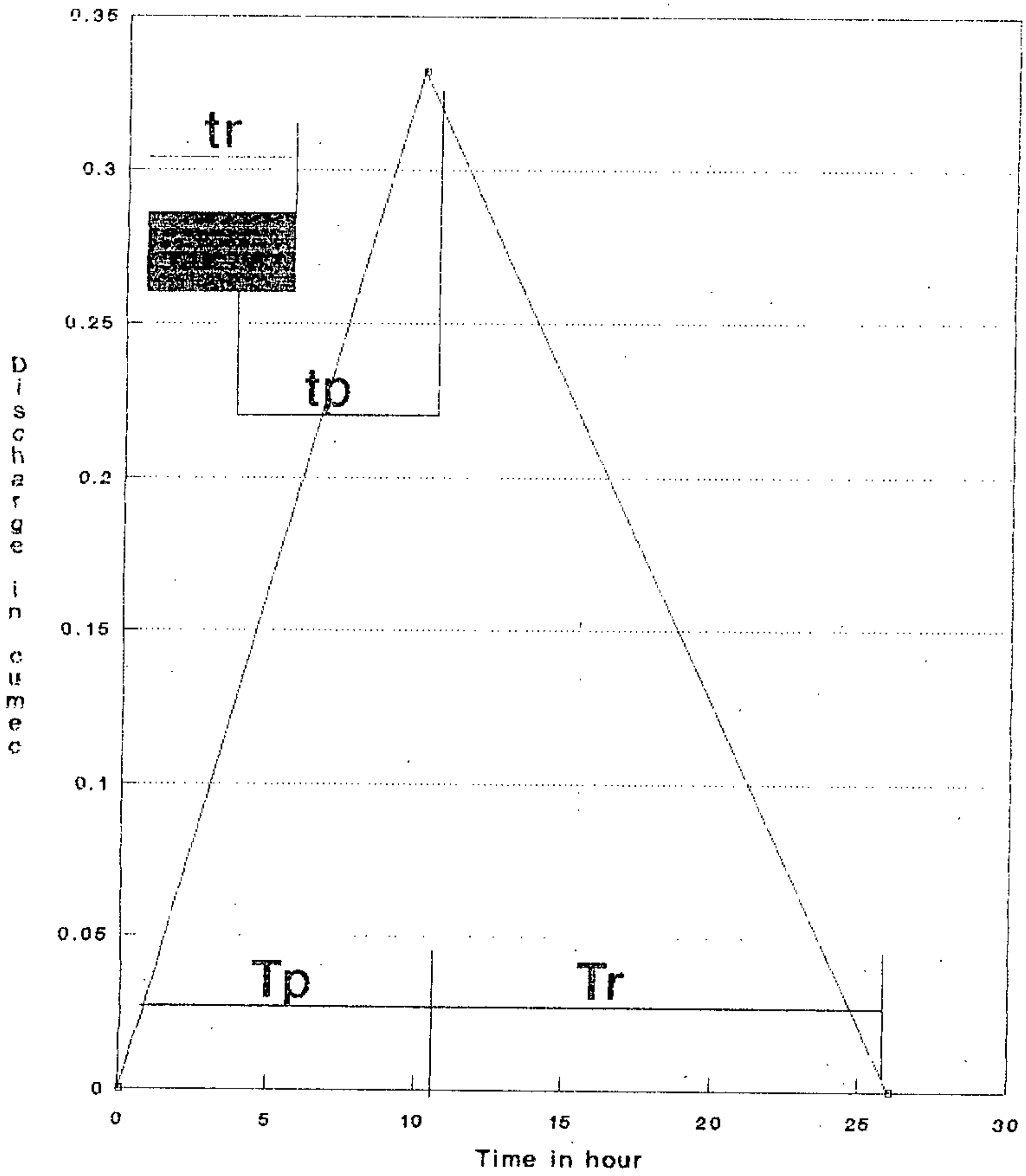


FIG.14 UNIT HYDROGRAPH FOR THE PROJECT

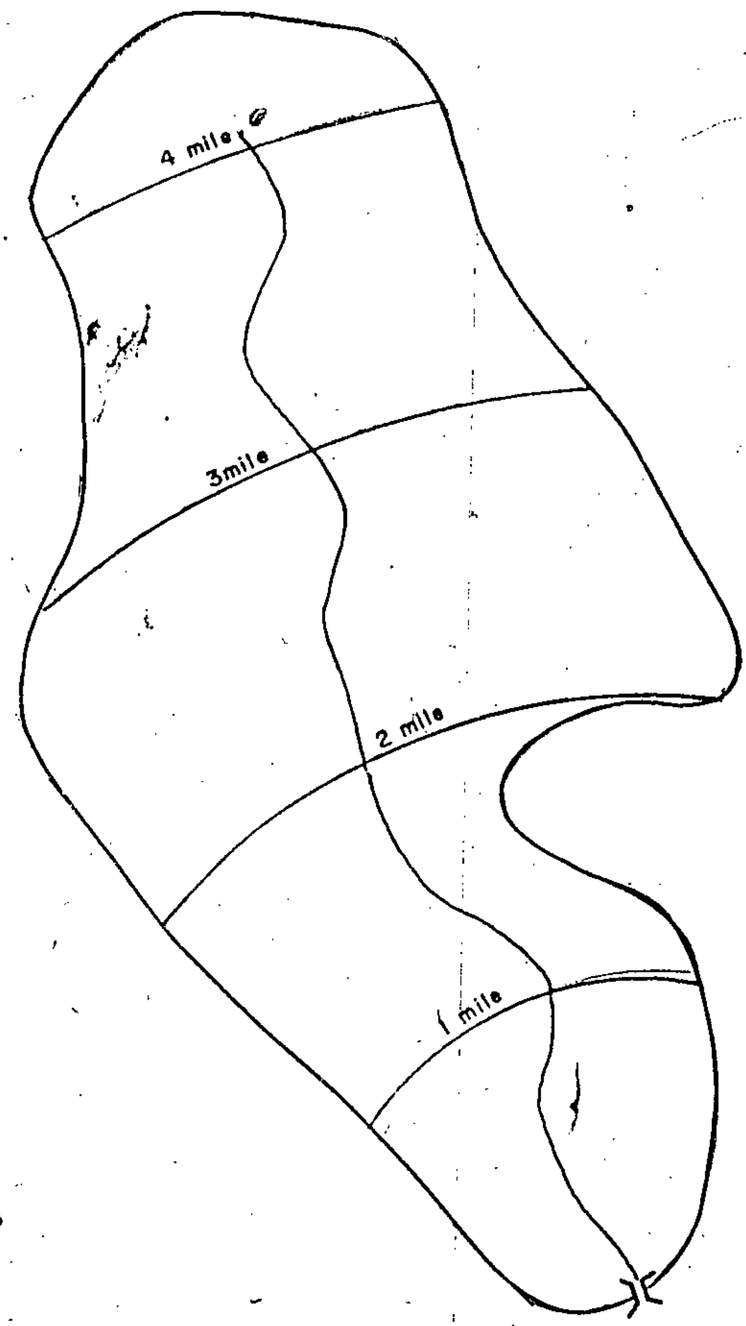


FIG.15 RICHARD'S BASIN CHARACTERSTICS

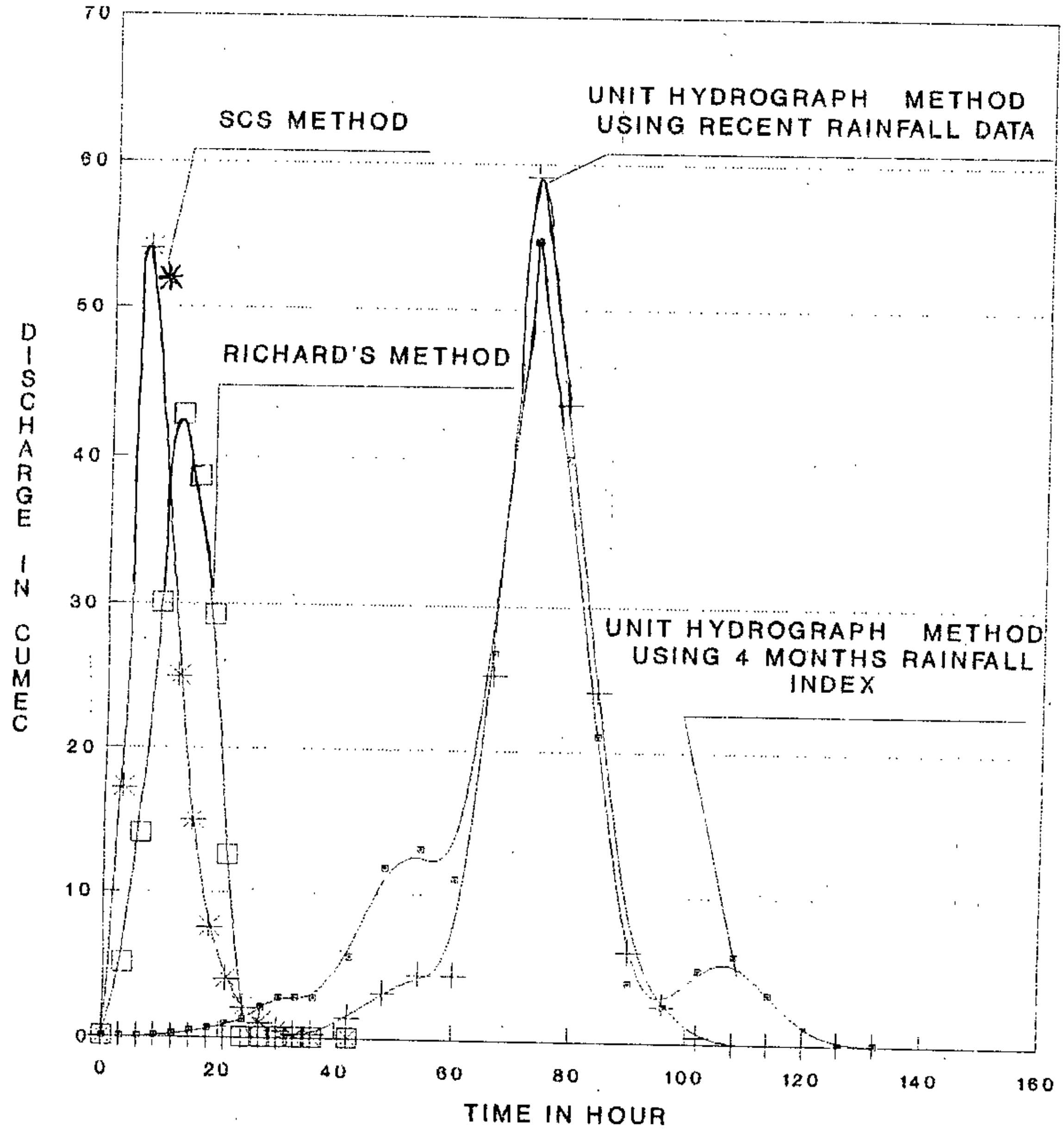


FIG.16 COMPARISON OF INFLOW HYDROGRAPHS OBTAINED BY DIFFERENT METHODS

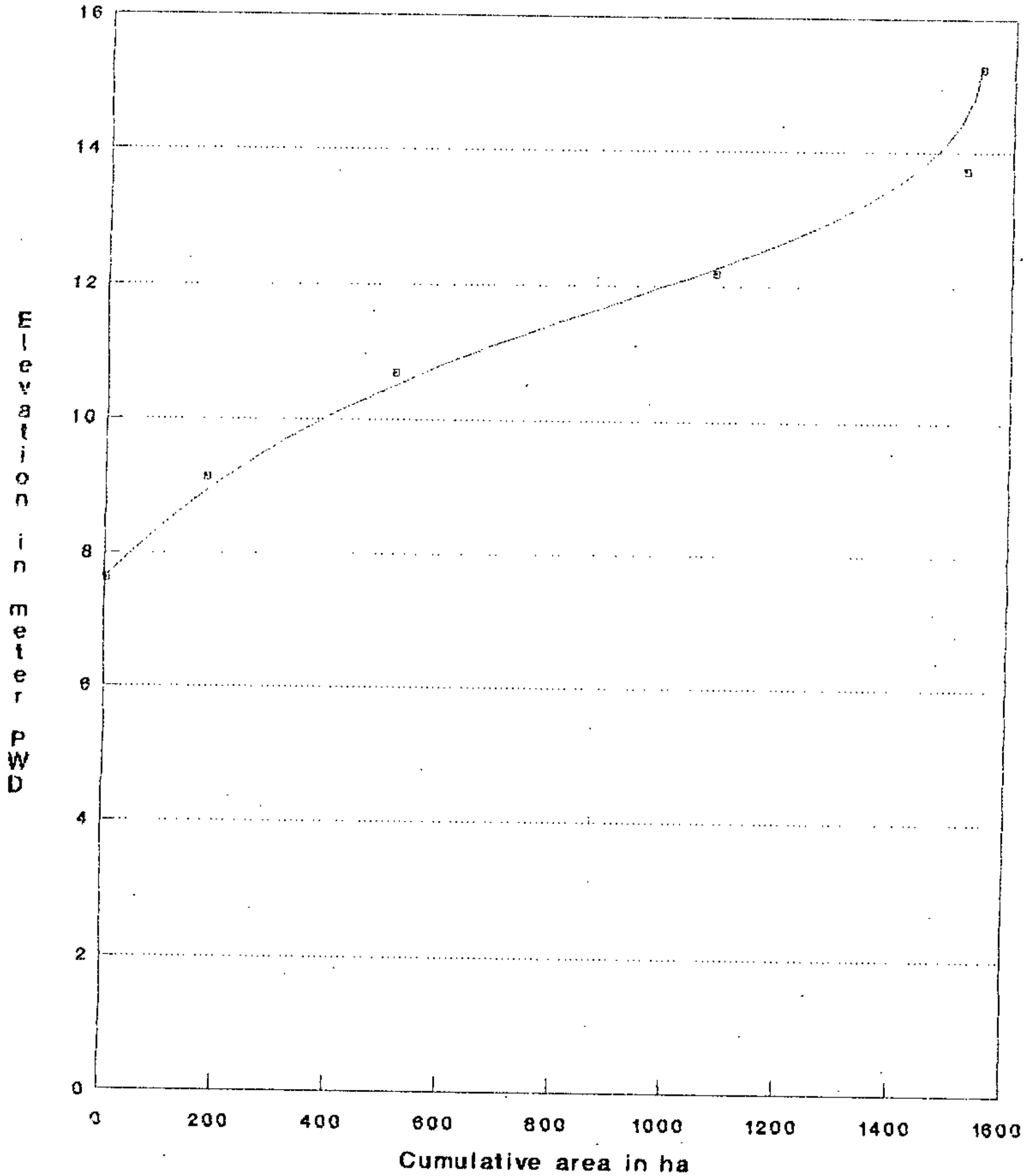


FIG.17. CUMULATIVE AREA VS. ELEVATION CURVE

80274

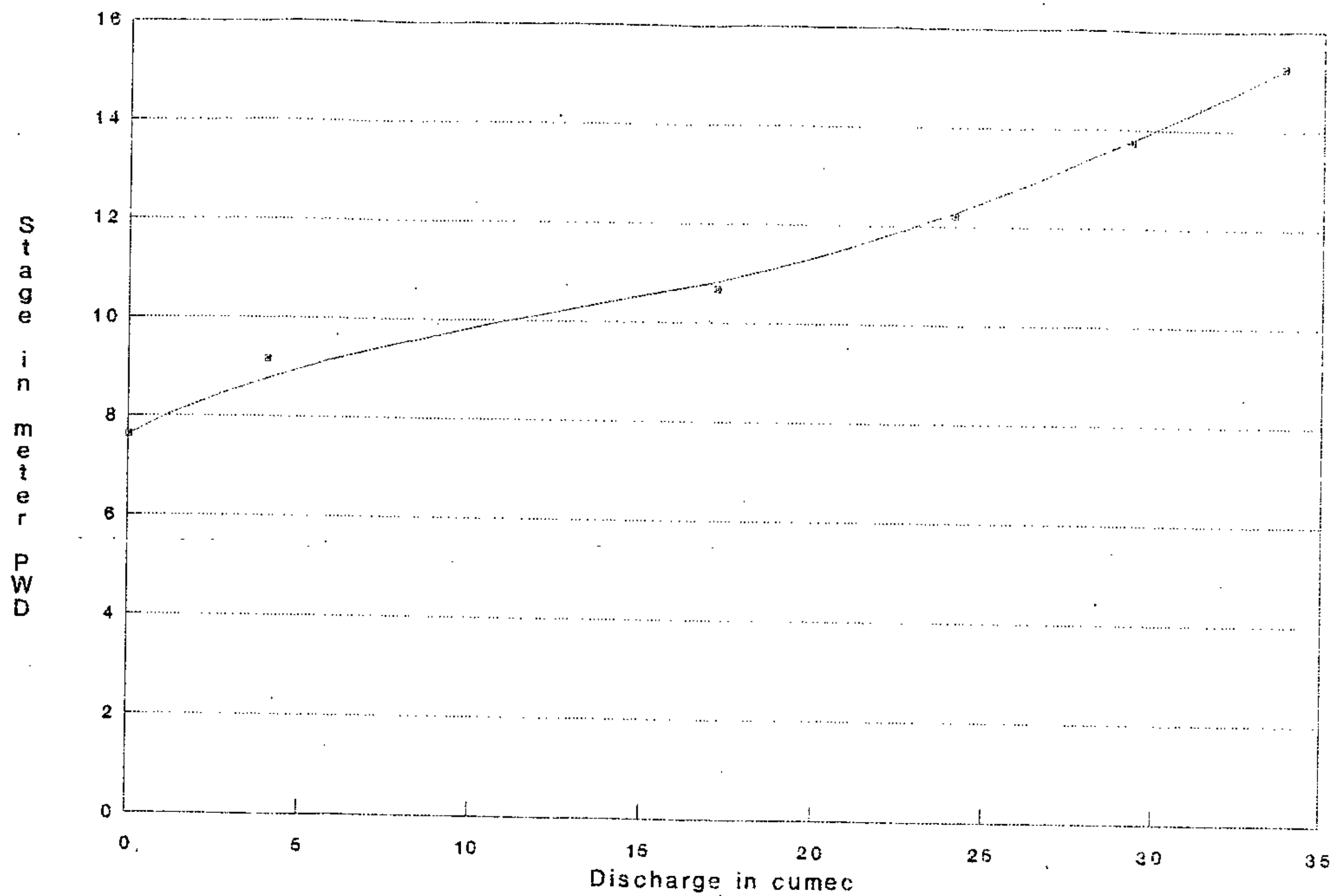


FIG.18 STAGE-DISCHARGE CURVE
OF THE PROJECT

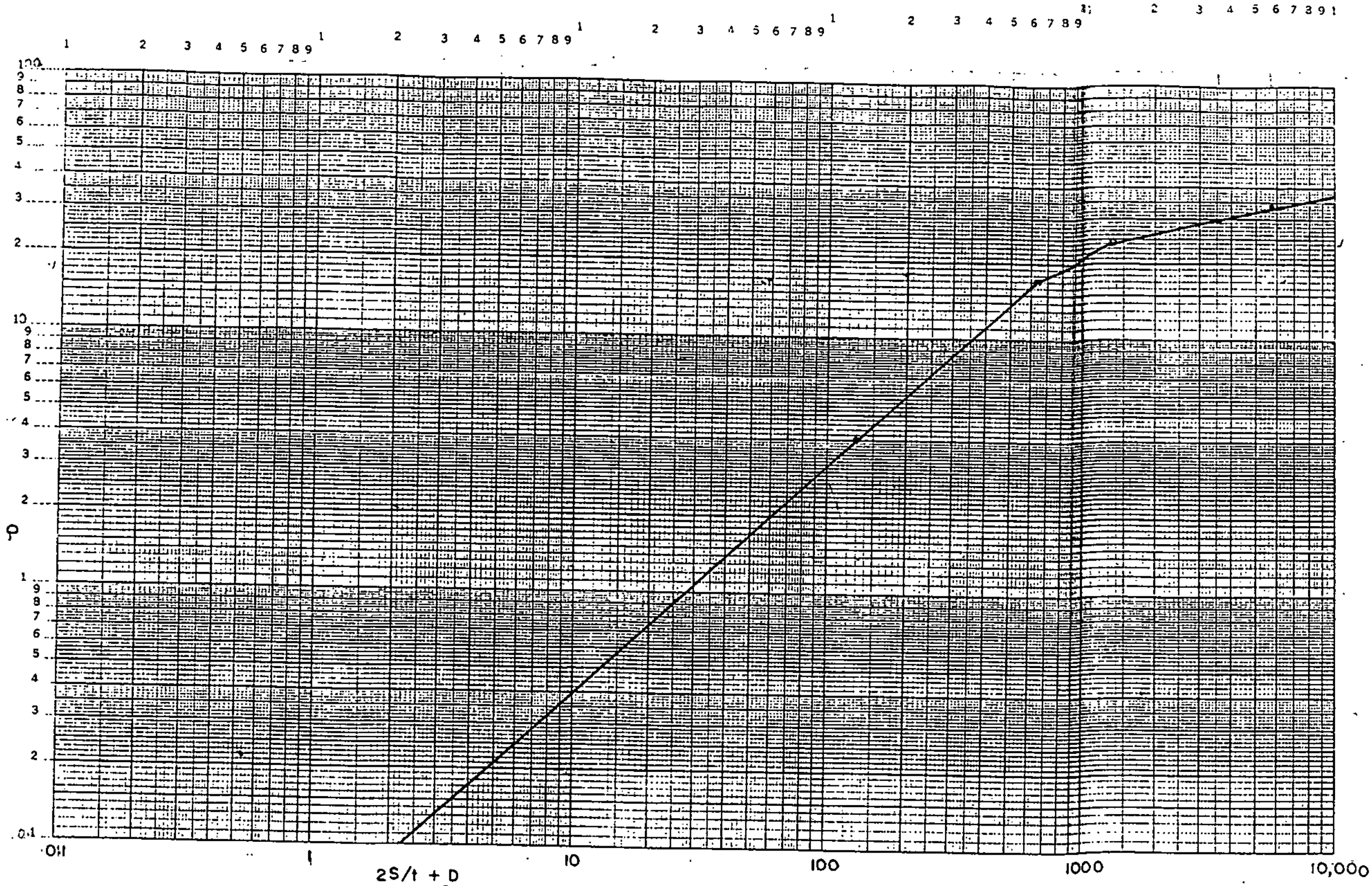


FIG.19 2S/t + D VS D Curve

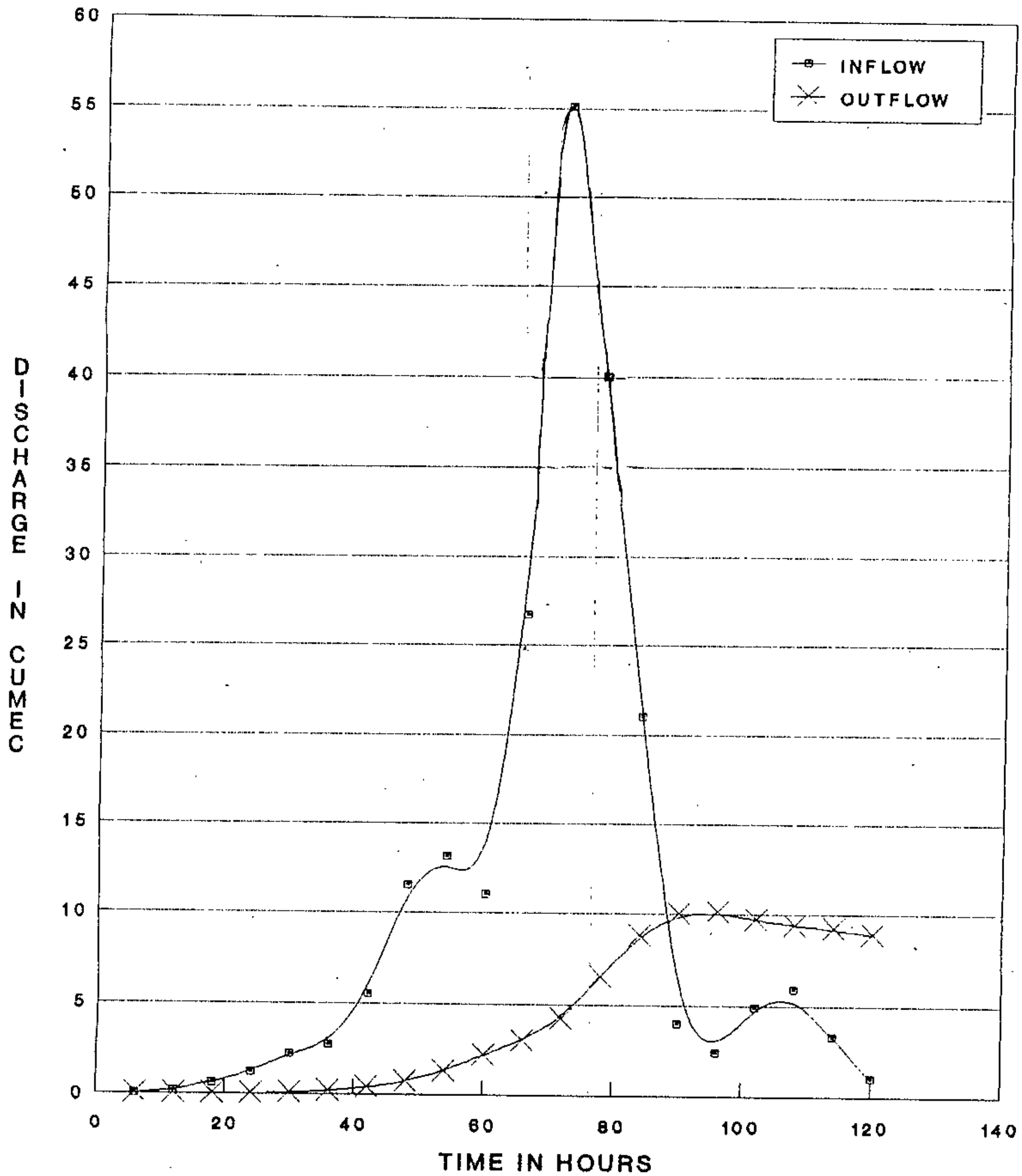


FIG.20 INFLOW AND OUTFLOW HYDROGRAPH (UNIT HYDROGRAPH METHOD)

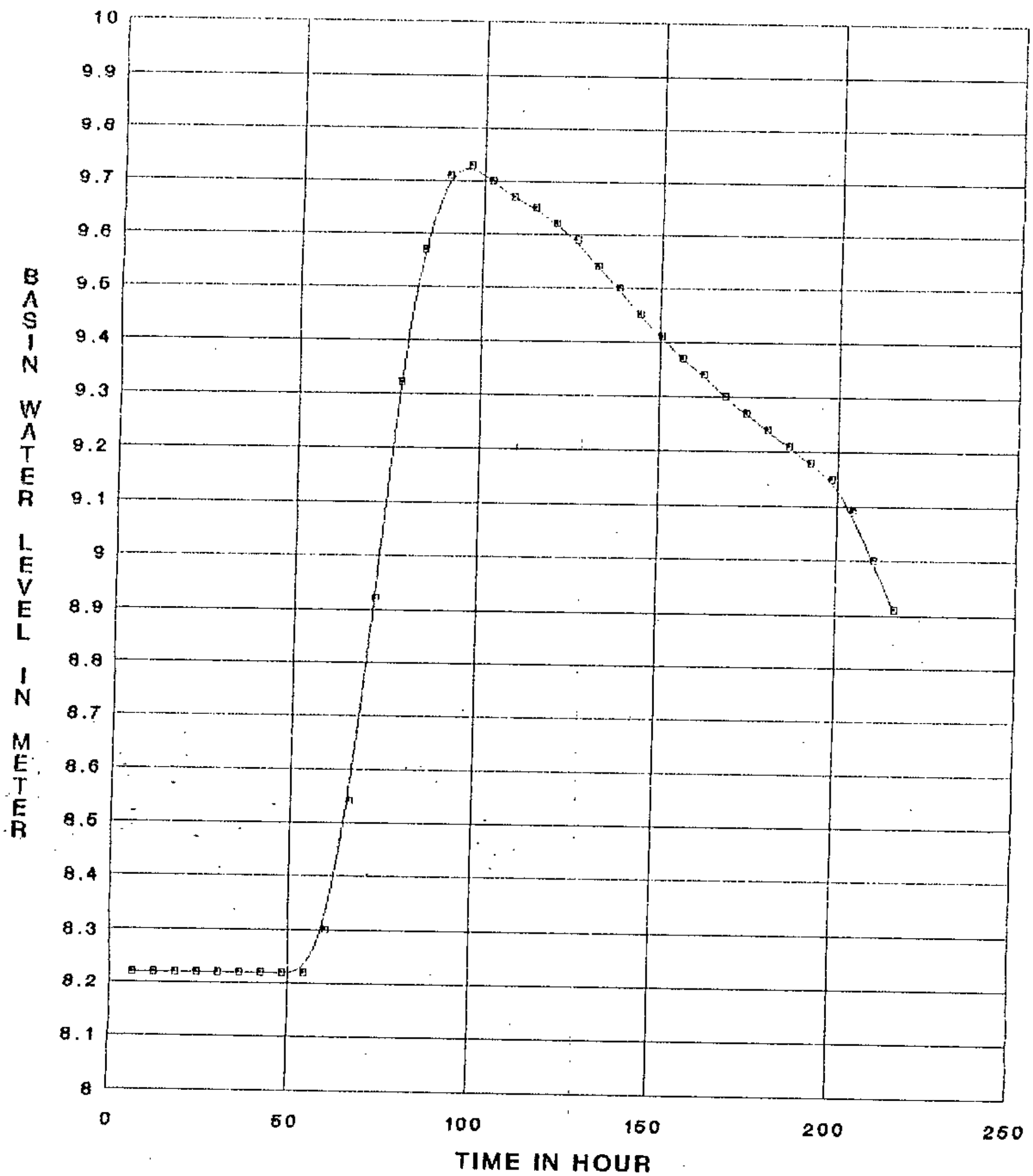


FIG.21 TIME VS BASIN WATER LEVEL CURVE
(UNIT HYDROGRAPH METHOD)

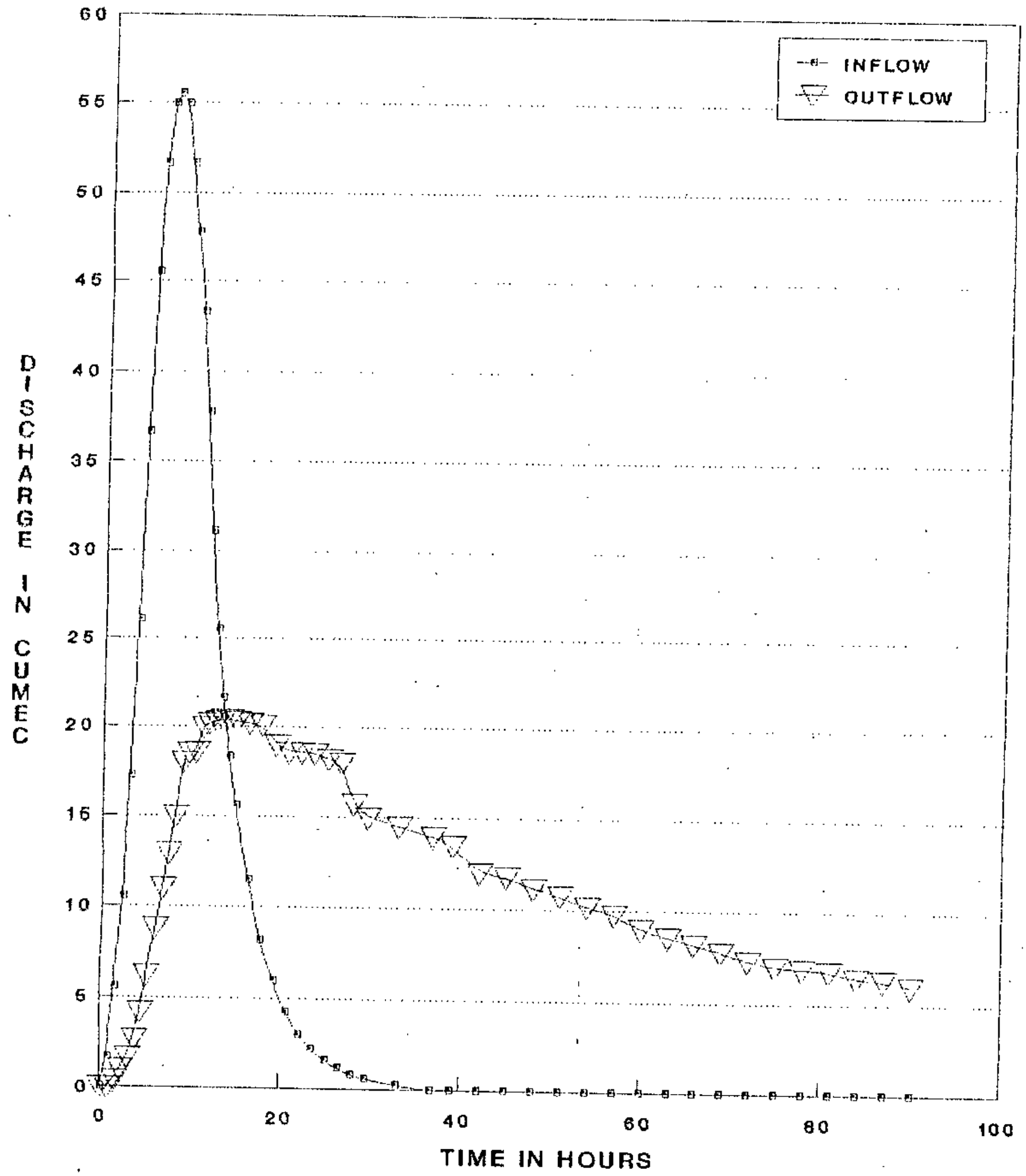


FIG.22 INFLOW-OUTFLOW HYDROGRAPHS
(SCS METHOD)

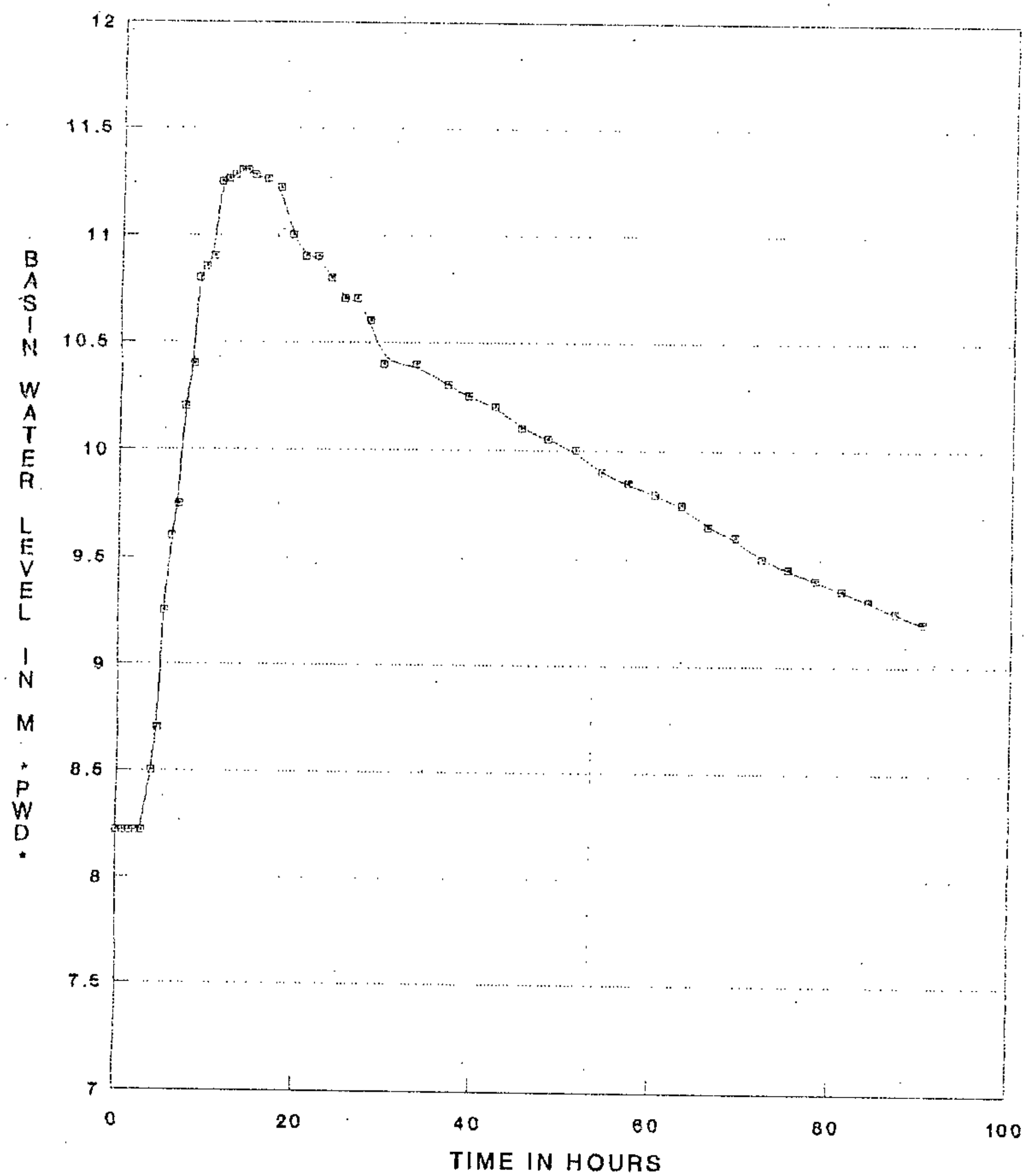


FIG.23 BASIN WATER LEVEL VURSES TIME CURVE (SCS METHOD)

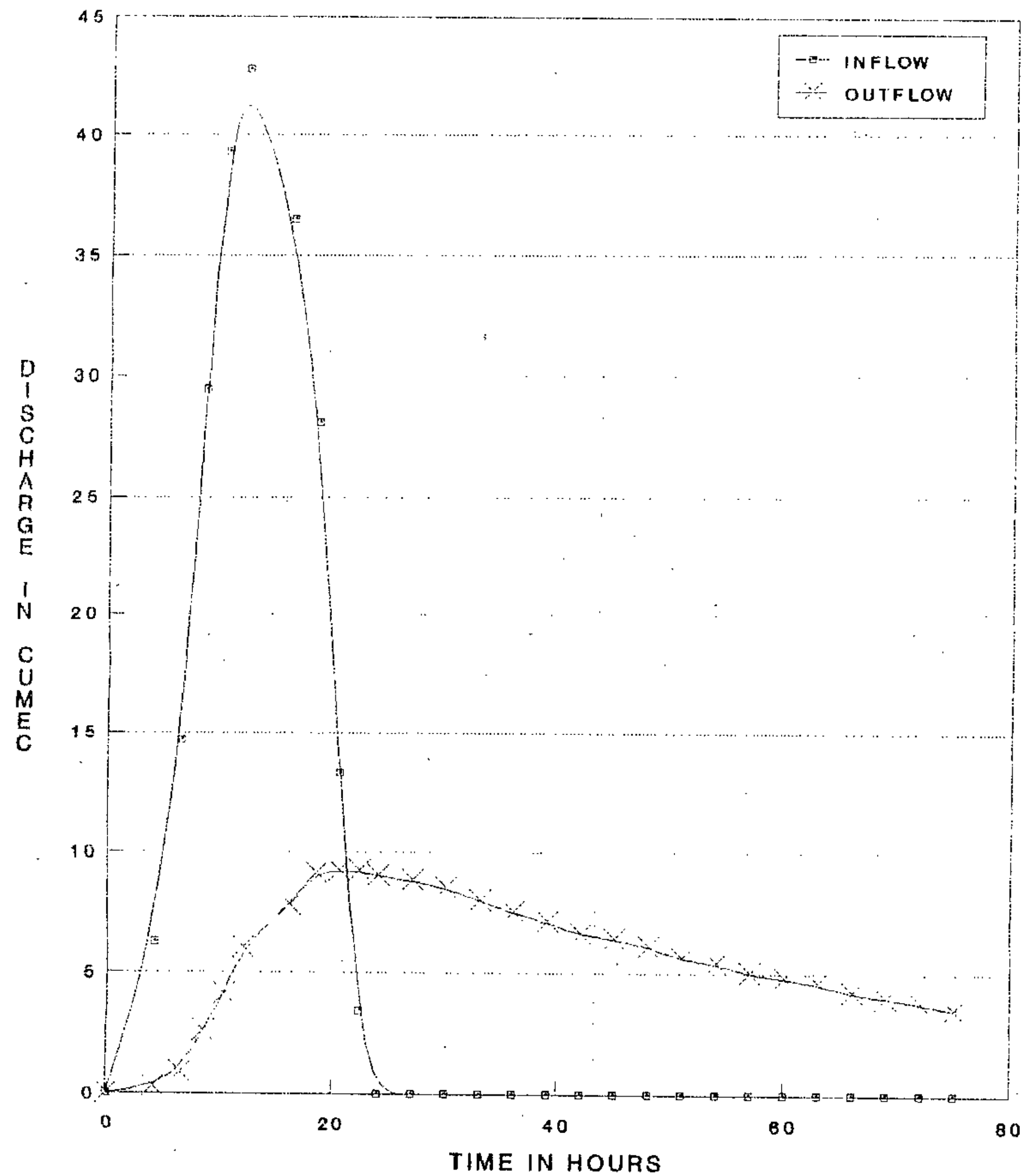


FIG.24 INFLOW AND OUTFLOW HYDROGRAPH
(RECHARD'S METHOD)

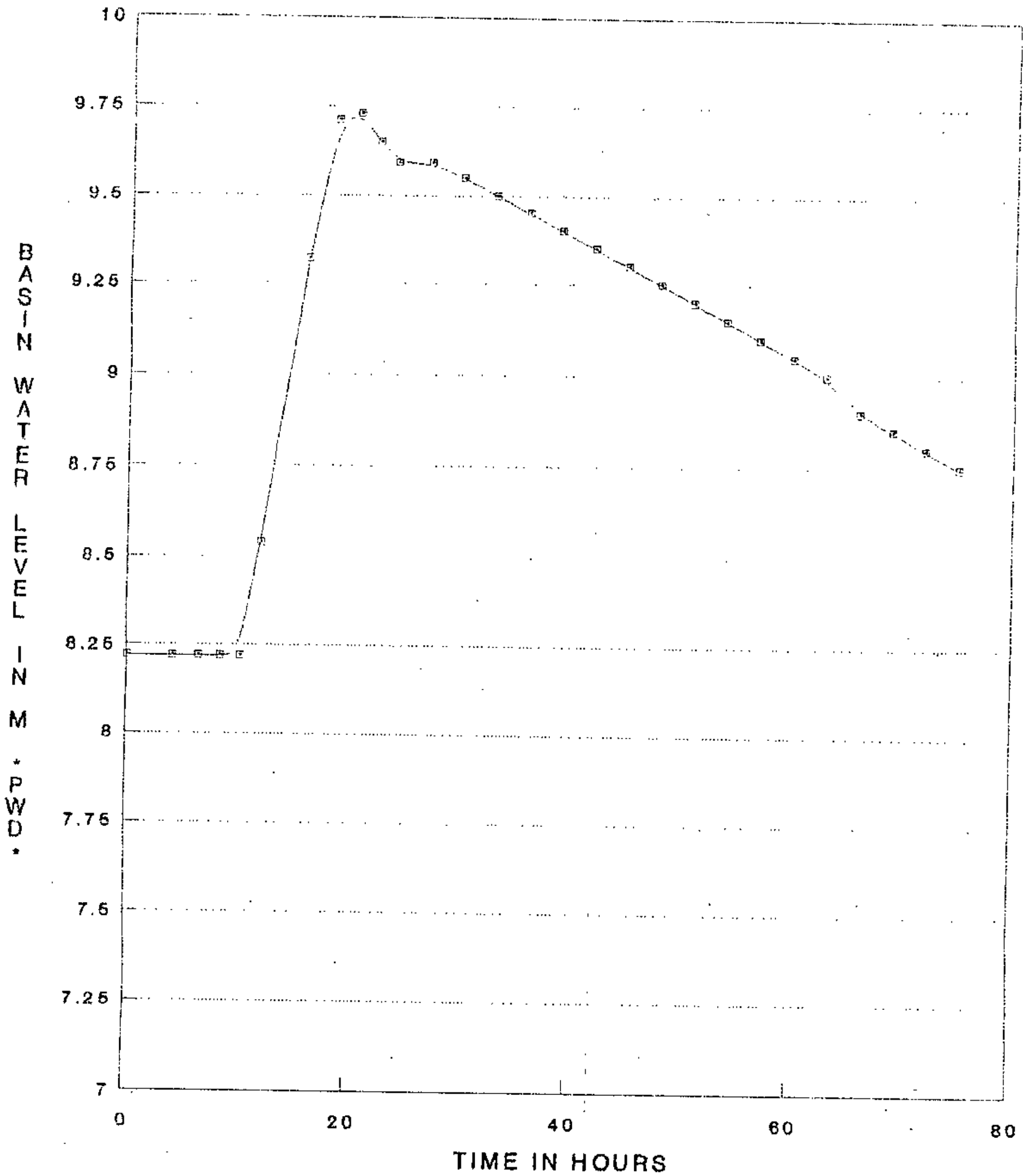


FIG.25 BASIN WATER LEVEL VURSES TIME CURVE (RECHARD'S METHOD)

Chapter - 4

CONCLUSIONS

From this study the following conclusion can be drawn:

(i)The unit hydrograph method is a satisfactory method for runoff calculation for a catchment. But it involves detailed calculation which is time consuming .

(ii) Snyder method as used in Bangladesh to calculate unit hydrograph is still dependent on studies in USA. No efforts have been made in Bangladesh to fit Snyder coefficients and no post project studies are taken to get suitable values for different location of Bangladesh.

(iii) There are no rainfall-duration curve and average intensity rainfall curve available in Bangladesh so that other synthetic method like SCS and Richard's method may use to get inflow hydrogrtaph quickly.

(iv) To save time and to avoid detailed calculation by unit hydrograph method; SCS and Richard's method may be used for runoff computation for small scale projects. But further study is necessary find the constant used in Richard's and SCS method to use in Bangladesh.

(v)To make hydrological analysis and computation of design discharge easier one day, two day ...... ten days isohyetals maps for frequency of five and ten years are necessary for Bangladesh. From available data and computer facilities these type of map will save a lot of time for computation of design discharge for a small scale sub-project.

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ANNEX-1

Sample Questionnaire

STUDY ON POST PROJECT DRAINAGE CODITION

Bannyar Khal Subproject

Date of interview:

1. Name of interview:

2.(i) Name of beneficiary:

(ii) Land holding within the Subproject:

Landless(<0.5 ha)   Small farmer(0.5 to 1.0 ha)

Medium farmer(1.0 to 2.0 ha)

Large farmer (>2.0 ha)

3. Education level:

Nil   Primary   S.S.C.

H.S.C.   Graguate   Higher

4.(i) Beneficiary's view about the objective of the project:

Flood Control   Drainage and Flood Control

Irrigation and Drainage

Flood Control, Drainage and Irrigation

(ii) Beneficiary's opinion to the achievement of the project

Fulfilled   Partial fulfilled

Not fulfilled

(iii) Benefit obtained from the subproject:

Communication   Crop production

Employment

5. Does drainage congestion occur under present condition?

Yes No

If yes,

(i) Period of drainage congestion

Premonsoon Monsoon

Post monsoon

(ii) Project area inundated

10% 20% 30%

50% 60% 75%

(iii) Stage of crop growth at which congestion occur

Planting Growing

Ripening

(iv) Duration of submersence

3 days 7 days 15 days

30 days

(v) Extent of crop damage

10% 20% 30%

50% 60% 75%

6. What are the reasons of water logging or drainage congestion?

Inadequate capacity of regulator

Inadequate drainage channel section

Siltation of drainage channel

Untimely gate operation

Difficulty in gate operation

ABREVIATION

BWDB : Bangladesh Water Development Board

IECO : International Engineering Company, U.S.A

EPC : Engineering and Planning Consultant Limited

NHCL : Northwest Hydraulic Consultant Limited

MPO : Master Plan Organization

LGEB : Local Goverment and Engineering Bureau

GNP : Gross National Product