DEVELOPMENT OF UNIT HYDROGRAPH FOR THE HALDA RIVER BASIN

By

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED BY MD. BADIUZZAMAN ENTITLED DEVELOPMENT OF UNIT HYDROGRAPH FOR THE HALDA RIVER BASIN BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ENGINEERING (WATER RESOURCES)

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ABSTRACT

DEVELOPMENT OF UNIT HYDROGRAPH FOR THE HALDA RIVER BASIN

An extensive study in developing unit hydrographs at Narayan Hat, South Sunderpur and Panch Pukuria stations in the Halda river, in the districts of Chittagong and Chittagong Hill Tracts,was conducted and finally drawn. In doing so,fund-amental principles, basic knowledge, practical data have been utilised.

The exact information of rainfall intensity, as well as, its duration of a storm is compulsory for drawing a unit hydrograph. This particular information was taken from auto rain gage charts maintained by the Bangladesh Meteorological Department, which installed an automatic rain gage at Patenga, near Chittagong. Hundreds of storms have been vigorously studied, verified in the region for no less than fifteen rainfall stations, (whose daily rainfall records are maintained by the Bangladesh Water Develop-Ment Board), scattered in the whole basin area. Only few storms have been isolated and identified whose intensities were equal or very nearly equal to those recorded at Patanga. The rainfall periods for those selected storms have been taken from the actual rainfall charts of the Patenga Meteorological station.

Rainfall reliability test for some stations have been justified in Double Mass Curve Analysis.

Several unit hydrographs, for each station, have been developed at Narayan Hat, South Sunderpur and Panch Pukuria and one average unit hydrograph for each station has been drawn for which some 'S' Curves had also to be developed.

The validity of the unit hydrographs have been justified in finding final hydrographs (synthesized) and thus comparing them with the actual ones, by using effective rainfall runoff relation curves(developed in this study). These were done for South Sunderpur and Narayan Hat Stations.

Following the unit hydrographs, synthetic unit hydrographs at South Sunderpur and Narayan Hat, by Snyder's method, have been developed.

One formula for peak flood discharge at South Sunderpur has been developed and verified with success and some physical basin characteristics like C_t, C_p and a physical constant have been found out in this study which are important results.

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CHAPTER I

INTRODUCTION

Floods in Bangladesh

Bangladesh consists of the flood plains of the Ganges, the Brahmaputra, the Meghna, their tributaries and distributaries. These river systems have their catchment area approximately 6,00,000 sq. miles of which only 7.5 per cent lies in Bangladesh. A seperate system of comparatively small rivers namely, the Karnafuli, the Halda, the Sangu, the Matamuhuri drain, generally, the hilly and forest areas in the districts of Chittagong and Chittagong Hill Tracts. Most of the rivers of Bangladesh are characterised by limited depths, flat slopes, fine sandy bottom, substantial meandering, erodible banks and shifting channels. All the rivers are tidal near the sea with a maximum tide range of 22' feet.

Flood invariably occurs during the monsoon or rainy season. The rivers begin to rise steadily at the onset of the monsoon and reach their peak levels in August or September when flooded area covers about 9800 sq. miles, with a flooding depth of 3'-0" to 12'-0", in normal years. Flash floods occur in the small rivers of steep gradient in high intensity rainfall areas. The maximum flooded area may rise to 19,500 sq. miles as occured in the year 1955 due to synchronisation of flood peaks of several rivers with simultaneous heavy rainfall in their catchment areas.

In this country, the "flood vulnerable areas" that which has been flooded in one year or another comes to nearly 26,000 sq. miles, out of which about 21,900 sq. miles are cultivated. Although the annual flood affected area varies between about 9200 sq. miles to 15,000 sq. miles the area subjected to floods over a period of years is much larger.

Bangladesh Water Development Board has shown in a study that during the 10 years, 1954 to 1956 and 1962 to 1968 the area flooded had ranged from 9.9 thousand to 15.0 thousand sq. miles. Direct annual losses, as estimated by the International Bank of Reconstruction and Development, from an extensive study from 1962 to 1970 in Bangladesh, claimed to be between 600 and 700 million rupees (1969 prices).

River Halda

The river Halda originates in the hilly ranges of Ram garh, in the district of Chittagong Hill Tracts. Durung Khal, Sarta Khal, Talpari Khal, Sua Khal, are its principal tributaries. It falls into the Karnafuli river at Enayet Hat, one mile upstream of Kalurghat railway bridge. Its total length is about 50 miles and total catchment area is about 645 square miles. It is a flashy river and remains perennial and navigable throughout the year. This river frequently crosses the danger lavel almost each year in the monsoon period causing wide spread regional flooding due to high intensity of rainfall in the hilly catchment area.

The head waters of all the tributary streams of the Halda rise in the adjacent hill areas. The hills, west of the river, known as the Sitakund Range, are not very high, reaching elevation of 150 to 500 feet. This escarpment is the western rampant of the Chittagong Hills in this locality and it's western front faces the Bay of Bengal. The westward drainage from this ridge consists of numerous small short streams which debauch from west east oriented ravines and flow eastward to the Halda. To the east of the Halda the ridges are much higher, reaching elevation of 1000 to 1800 feet and the terrain is more rugged and broken. The tributary streams are larger and longer and flow in a, generally, southwesterly direction to the Halda. The three main tributaries, Sarta Khal, Talpari Khal, and Dhurung Khal all arise in the eastern hills.

The main branch of the Halda emarges from the hills near Narayan Hat and the valley floor then becomes quite flat, gently sloping from about elevation 50 in the north to elevation 8 in the south, but there are several hilly areas as low as elevation 5.

The Halda is a meandering stream where it flows through the valley with a number of ox-bow bends, at several of these cutoffs have been made by excavations. The river has a very flat gradient and the valley is subject to flooding by overflows from the Halda and from poor drainage of surface water during the monsoons.

Geology of the Basin Area

The Chittagong and Chittagong Hill Tracts districts,however,are sharply differentiated topographically from the rest of the country as the terrain in these districts is hilly and mountainous. The hill slopes are forested or bear cutover scrub, while the lower stream valleys are generally cultivated. On the perimeter of the basin the Chittagong Hills form the south eastern barrier. The Chittagong Hills comprise a series of steeply folded parallel ridges having a,generally, north south axis. The formation consists of shales and firm grained sandstones of early tertiary (probably Eocen) age. The sand stones are poorly consolidated, weak and friable. Both shales and sandstones weather radially upon exposure. As a result , the hills erode easily, forming deeply eroded transverse ravines and the weathered debris, and is carried to the lower valleys. The valley floor is built up of recently deposited sediments. The present floor of the lower valleys is probably composed of mixed deposits of marine and alluvial origin from the adjacent hills. Along the meandering streams flood banks have been built up.

Floods in the proposed region

In the annual reports on flood, published by Bangladesh Water Development Board in 1975, it showed that the river Halda at South Sunderpur is flasly in nature with sharp rise and fall in stage. The river crossed the danger level for 5 times with a remarkable peak in late July, 1975. The highest peak attained was 41.18 feet on the 28th July, 1975, against the danger level of 27.00 feet at South Sunderpur. From the stage duration curve of this station, it could be seen that high stage of the river above the danger level was for a period of more than 7.1% per cent of the total time (data computed from January to October, 1975).

The following comparative statement of flood level of South Sunderpur station in the river Halda from 1970 to 1975 and damages caused by flood in the district of Chittagong is given to show the gravity of situation for flood forecast or flood control in the region.

TABLE I

Flood Level of South Sunderpur Station in the River Halda From 1970 to 1975

Danger Level ft.	Highest Flood Level ft.	1970	1971	1972	1973	1974	1975	Remarks
27.00	41.18	36.40	33.05	30.20	27.50	36.45	41.18	Stages in ft. PWD

Sources: "Annual Reports on Flood" in Bangladesh: Bangladesh Water Development Board Publication in 1975

TABLE II

Damages Caused By Flood In the District of Chittagong In 1966

Submerged Areas sq. miles	Human Lives Lost	Live Stock Dead	Damage, Crop Crop Area sq. miles	Value Rs (1966 price)	Private Houses Completely Damaged	Partially Damaged	Estimated Value RS (1966 price)
1207	468	43,273	364	3,17,65,500	34,600	99,564	272,56,400

Sources: Relief and Agriculture Department of the then East Pakistan

The above reports are undoubtedly alarming and happen almost every year. Efficient flood forecasting and successful evacution and relief operation by responsible authority can be believed to minimise the havoc of damages and destruction in the region.

Flood control encompasses many possible measures, The commonly accepted ones are (a) Reduction of peak flow by constructing reservoirs, (b) confinement of flow within a predetermined channel (c) channel improvement ,(d) diversion of flood waters through by passes or flood ways ,(e) flood fore casting,warning and evacution ,(f) flood plain zoning ,(g) flood proofing ,(h) land management etc. Structural or non-structural, whatever measures may be thought for implementation —— the respective river, its hydrologic behaviour, its basin characteristics must be known.

Besides floods, we are entangled with many other problems or projects like irrigation, communication, land reclamation, construction of important structures etc. in which the river system, here, plays a vital role. In reality, the river system has become the part and parcel of our traditional, social, economicial, environmental, geological and political life.

The main tool of any river and its basin study is its hydrograph in general, and unit hydrograph in particular. How much extensive is the utility in applying the respective unit hydrograph in the problems and projects of a related river, knows no bounds. To know the unit hydrograph of every river of this country is essential.

Objectives

The principal objectives of this research work were

1) To develop average unit hydrograph at Narayan Hat, South Sunderpur, and Panch Pukuria on the river Halda

2) To develop synthetic unit hydrographs at Narayan Hat and South Sunderpur on the Halda river

3) To find the values of some physical characteristics like C_t, C_p of the basin area

4) To develop a flood formula by which approximate peak discharge at South Sunderpur can be ascertained.

CHAPTER II

BASIC CONSIDERATIONS

Defination of Unit Hydrograph

Detail discussion on hydrographs lead to the hypothesis that identical storms with the same antecedent conditions produce identical hydrographs. This principle was expressed by Sherman, L.K. He pointed out that all hydrographs resulting from rainfalls of a given duration have the same time base.

"The unit hydrograph (originally named unit-graph) of a drainage basin is defined as a hydrograph of direct run-off resulting from 1 in. of effective rainfall generated uniformly over the basin area at a unit rate during a specified period of time or duration".

If the theory is sound, the hydrograph for any other similar storm of the same duration will be established by multiplying the ordinates of the unit graph by the storm run-off.

Assumptions

For the unit hydrograph theory the following basic assumptions are necessary.

1. The effective rainfall is distributed within its duration: For this assumption, the storm in question should be such that it should be intense, and nearly effective rainfall over a short duration.

2. The effective rainfall is distributed uniformly throughout the whole basin area: This assumption requires the drainage area to be of limited aize to be covered by the effective storm uniformly. The Halda river basin is neither too big nor too small for its application.

3. The base of the hydrograph of direct runoff due to an effective rainfall of unit duration is constant. The base of the hydrograph of direct runoff usually depends upon the method of base flow seperation. Theoretically, the recession limb of a hydrograph decreases exponentially with time. Hence this assumption does not hold good always.

4. The ordinates of a direct runoff hydrograph of a common base time are directly proportional to the total amount of direct runoff represented by each hydrograph. Since the ordinates of the direct runoff hydrographs are also mutually proportional and thus can be added or superimposed numerically in proportion to the total amount of direct runoff.

5. The hydrograph of a runoff due to a given period of storm reflects all the combined physical characteristics of the given drainage basin.

Under natural conditions, the above assumptions cannot be satisfied perfectly. Ideal storms are very rare in nature. For this research work care has been taken to select storms so that they meet the above assumptions as close as possible.

Keen observations have been taken in regards of total daily rainfall in all the rain gage stations of the basin area individually, as well as, their daily averages. These records were compared with those of the Patenga Meteorological Department office. Patenga is very near to the Halda river basin and herean auto rain gauge instrument was installed by that department which has been maintaining records. The comparison was made to take storm duration from the Patenga office. Average rainfalls in the basin for the selected storms were taken as the real intensity for the development of unit hydrographs.

Derivation of Unit Hydrograph

Unit Hydrographs from Isolated Storms The unit hydrographs were most easily derived from the hydrographs of isolated storms The steps in the derivation were as follows.

1. Base flow was seperated and the volume of direct runoff from the storm was measured.

2. The ordinates of the direct runoff were divided by the runoff volume (expressed in inches over the drainage area).

The resulting hydrograph was a unit hydrograph for the basin.

3. The effective duration of runoff producing rain for which the unit hydrograph was applicable was determined by a study of the rainfall records.

4. Unit hydrographs for several suitable storms were determined and averaged to obtain a mean unit hydrograph for the basin. The mean unit hydrographs have areas equal to 1 in. of runoff each and resembled the individual unit graphs as much as possible.

Unit Hydrographs from Complex Storms

Whenever ideal storms were not available, unit hydrographs were developed from the records of complex storms. Care was taken to see the seperation of storms and distinct peaks of the hydrographs. The complex storm hydrographs were seperated into individual ones by means of respective composite recession curves. The unit hydrographs were then developed from each seperated storm using the procedure outlined before for isolated storms.

Usefulness and Limitations of a Unit Hydrograph

The unit hydrograph is a technique of determining time distribution of flow from small and moderate areas. The unit hydrograph has proved to be a highly effective and simple tool for hydrologic work. Within the limitation of a fixed duration and similar rate and areal distribution of rainfall, the hydrographs of various storms will be substantially similar in shape with ordinates approximately proportional to the runoff volumes. This simple but very important tool may be easily applied to different problems with success.

This country is frequently visited by floods. In the structural design works, in the case of a standard project flood or a design flood for a flood control project, unit hydrograph can essily be applied. To find flood volumes, flood routing and forecasting of flood a unit hydrograph is extremely used. An early forecast of flood will allow evacuation of residents and removal of goods from a flood threatened area. In the field of this research work the unit hydrographs can be used for flood forecasting where flush of floods occur regularly and in the proposed flood control measures, embankments and dam for multipurpose projects.

There are limitations to the use of unit hydrographs which must be recognised. Unit graphs are best suited to areas under about 2000 sq. miles although they have been applied to fairly large areas with varying success. Oddshaped basin, particularly those which are long and narrow, commonly have very uneven rainfall distribution and hence unit hydrographs are not well adopted to such basins. In mountainous areas, subject to orographic rainfall the areal distribution of rainfall is very uneven, but the pattern tends to remain the same from storm to storm and unit hydrographs may successfully be applied.

Synthetic Unit Hydrographs

Development of some hydrologic relations become, in many design problems, very necessary where inadequecy of data do not permit them. Development of such a technique, i.e., the synthesis of a unit hydrograph requires the determination of equations for the unit peak-flow and time to peak curves in terms of the physical features of the basin under study. With the available data, in this case, the unit hydrographs were drawn. It was then desirable to find some coefficients relating to the Halda river basin characteristics. To find these, Snyder's method of analysing and his developed emperical equations were used. This method is a correlation between three unit hydrograph parameters (peak discharge, time lag from beginning of rain to peak flow and total base time) and three basin characteristics namely, size of the basin area, slope of the basin area elevation curve, and number of major streams in the basin.

Snyder's equations are:

$$t_p = C_t \, (LL_c)^{0.3} \quad \ldots. \quad \ldots.. \quad \ldots...(2\text{-}1)$$

$$q_p = \frac{640 \;\; C_p}{t_p} \quad \ldots. \quad \ldots.. \quad \ldots...(2\text{-}2)$$

$$q_{PR} = \frac{640 \;\; C_p}{t_{PR}} \quad \ldots. \quad \ldots.. \quad \ldots...(2\text{-}3)$$

$$t_r = \frac{t_p}{5.5} \quad \ldots. \quad \ldots.. \quad \ldots...(2\text{-}4)$$

$$t_{PR} = t_p + 0.25 \, (t_R - t_r) \quad \ldots.. \quad \ldots...(2\text{-}5)$$

$$q_{PR} = q_p \, \frac{t_p}{t_{PR}} \quad \ldots.. \quad \ldots.. \quad \ldots...(2\text{-}6)$$

where,

t_p = time lag from midpoint of effective rainfall duration t_r to peak of a unit hydrograph, hr.

t_r = duration of effective rainfall equal to $t_p/5.5$

t_R = duration of effective rainfall other than standard duration t_r, adopted in specific study, hr.

t_{PR} = time lag from midpoint of duration t_R to peak of unit hydrograph, hr.

q_p = peak discharge per unit drainage area of unit hydrograph for standard duration t_r, cfs/sq.mile

q_{PR} = peak discharge per unit drainage area of unit hydrograph for duration t_R, cfs/sq.mile

L_c = river milage from station to centre of gravity of the drainage area

C_t & C_p = Coefficients depending upon units and basin characteristics.

In this research work C_p', C_t and base time T were found for the South Sunderpur and Narayan Hat basins in the Halda river basin. Values were used from developed corresponding average unit hydrographs. The calculation in finding the physical characteristics and constant, using the Snyder's method is shown in Appendix - B.

CHAPTER III

DATA COLLECTION

In developing unit hydrographs in the Halda river basin the following maps, informations, data become necessary which were collected, studied and applied in this work.

Hydrological and Geological Maps: The main source of collection is Bangladesh Water Development Board. These are shown in Figure 27 and Figure 28. From these maps the position of the Halda river, its tributaries, location of necessary rain gages, discharge stations were found out. Drainage areas for different discharge stations, Narayan Hat, South Sunderpur and Panch Pukuria on the Halda river and also those for different tributaries were traced out.

Rainfall and Evaporation: Bangladesh Water Development Board maintains the rainfall, eveporation and discharge records for various places and rivers of this country and publishes them in the Hydrological Year Books for Bangladesh every year. In these publications there are details of stations, their locations, bench marks, elevations, apperatus used, date of installation, availbility of records, extreme records,danger levels, drainage areas, maximum channel width etc.

The figures and quantities shown in data sheets are normally those actually recorded, measured or computed.

Both rainfall and everporation quantities are recorded in inches at 0900 hours each day and entered against the day on which they are read. The Board claims that the figures entered in data sheets are the figures as received from the record observers.

The rain gage, in use, is the standard 5" diameter manual gage and is so placed that its rim is one foot above the ground level.

Daily precipitation data in and around the basin area of this river are available for 15 locations. They were collected from this Bangladesh Water Development Board's Publications, compiled and compared with each station, as well as, with that of Patenga automatic rain gage station. These are shown in Table IV and Table V.

The stations are noted below:

Stations	Period of Records Available From
Amtali	1961
Chanderkhil	1961
Dolu	1961
Fatikchari	1961
Hia Khun	1961
Manik Chari	1960(daily)and monthly since 1902
Mirza Hat	1961
Marayan Hat	1961
Nazir Hat	1961
Rajbari Tilla	1961
Ranga Pani	1961
Sikder Hat	1961
Tenturi	1961
Chittagong	1961(daily) and monthly since 1902

Records from Meteorological Department of Bangladesh: This department installed one automatic rainfall recording instrument at Patenga, near Chittagong. It records continuously the rainfall intensity for each day over a period of 24 hours. Raincharts for the years 1970, 1972, 1973 and 1974 were collected from the aforesaid department and counted to hourly rainfall and shown in Table V.

Records of all rainfall stations for 1969-70, 1972-73, 1973-74 were taken for hydrograph analysisis and from 1962-1976 for rainfall study and Double Mass Curve Analysis.

Records which were used for the development of unit hydrographs, only are shown in data sheets. The others are omitted.

<u>Discharge Records</u>

Bangladesh Water Development Board maintains observed stage-discharge records of various stations of different rivers of Bangladesh. From daily stage records the Board computes discharge data from best fit stage-discharge curves and publishes them in Hydrologic Year Books for Bangladesh.

The station descriptions furnished in those published volumes include the location of the stations, Bangladesh Water Development Board Bench mark no. and their elevation above PWD datum, are recorded as well as annual extremes of both observed and computed discharge and, of course, availability of records, drainage areas etc.

Both Watt's Bucket Type and Ott's propellor type water current meters are used in measuring river discharge, Generally velocities are observed at 0.2 and 0.8 of the total depth of flow (i.e. two point method). On big rivers especially equipped launch, catamarans, are used as gaging crafts which include depth sounding equipment like echo-sounder also. On smaller streams, however, observations were taken from bridges, from boats or by Wading rods or lines.

The discharges are shown along side the corresponding waterstage observed from where stage discharge curves (rating curve) are developed and published in the Hydrological Year Books).

The principal stations for determining discharge in the Halda are (a) Narayan Hat (b) South Sunderpur (Fatikchari) (c) Panch Pukuria. There are no other reliable discharge records on the Halda or it's tributaries.

Daily discharge data of the Halda at Narayan Hat, South Sunderpur and Panch Pukuria were collected and compiled for the years 1970-71, 1972-73 and 1973-74 in this study. These are shown in Tanle VI. The discharge hydrographs were drawn for analysis, for the above stations and years.

From the discharge hydrographs, sometimes it is seen that peak floods of the Halda river at Narayan Hat and at Fatikchari are not closely related because of the difference in drainage area characteristics. The high short duration peaks at Narayan Hat sometimes exceed those at Fatikchari because of channel storage between the two stations.

CHAPTER IV

PROCEDURE

Hydrographic Analysis

A graph which shows the relationship of discharge, stage, velocity, or other properties of water flow with respect to time is known as a hydrograph of a section of a river. The phisiographic and climatic characteristics of any particular drainage basin usually govern the rainfall and runoff relationship of that basin. The hydrograph expresses the characteristics of that basin with its own language. A single peaked hydrograph is produced due to a concentrated storm while a multiple peaked hydrograph indicates, generally, abrupt variation in rainfall intensity, a succession of storms, abnormal ground water recession, non-synchronisation of flow in different tributaries in the upstream or other causes.

The daily rainfall records of different rain gauge stations of the proposed basin have been collected for the years 1970-71, 1972-73 and 1973-74 and also the daily computed discharge records of Narayan Hat, South Sunderpur, and Panch Pukuria were collected for the same period. The discharge hydrographs for those discharge stations were drawn for those three years. From these hydrographs it is seen that the hydrograph achieves its peak only within a couple of hours after the rain fall ceases. Some times if the storm prolongs for hours, the hydragraph shows its peak flow within the duration of the storm.

In developing unit hydrographs, these hydrographs became useful in selecting the unique peaks of the hydrographs developed by isolated or complex storms.

To seperate the complex hydrographs into a number of single peaked hydrographs, it required to develop a composite recession curve for each station of Narayan Hat, South Sunderpur and Panch Pukuria. This became possible after the availability of a good number of smooth, reliable recession limbs from the hydrographs. The selected hydrographs were then analysed with the help of these composite recession curves, Figure 1,2 and 3, for the development of unit hydrographs. The analysis of hydrographs are shown in seperate figures, Figure 4 to Figure 15.

Base Flow Seperation

This is a common practice to divide a hydrograph into direct and groundwater runoff for developing a unit hydrograph. There are several methods to seperate the base flow from the observed hydrograph. Base flow seperation should be such that the time base of direct runoff remains relatively constant from storm to storm. This is one of the assumptions as previously noted keeping in mind that the total time base should not be excessively long and the rise of the ground water should not be too great. The most practical method for the seperation of base flow from the hydrograph the following thumb rule, as given by Linsley, Kohler, and Paulhus in their "Hydrology for Engineers", has been utilised here.

The rule is

$$N = A^{0.2}$$

where,- N = Number of days after the peak of the hydrograph to the point of termination of the direct flow. A = Drainage area in square miles.

<u>Complex Hydrograph Seperation by Composite Reoession Curves</u>

Analysis of complex hydrographs resulting from two or more closely spaced bursts of rainfall often cannot be avoided. In those cases it is necessary to seperate the runoff caused by individual bursts of rainfall. The division between bursts of rain is usually accomplished by projecting the small segment of recession between peaks using a total flow recession curve for the basin. The base flow recession curve is most frequently used, and the method adopted here, for developing such a curve is to piece together sections of recessions from various storms until a composite curve is obtained which covers the necessary flow rates.

Three composite recession curves, each for Narayan Hat South Sunderpur, Panch Pukuria have been developed and shown in the Figures 1,2 and 3. These recession curves were used in seperating the complex hydrographs into single hydrographs which again were analysed for the development of unit hydrographs.

Unit Hydrograph: Calculation

The selected storm hydrographs were plotted elaborately to find the ordinates at an interval of 6 hours. The complex hydrographs were seperated as discussed before. After this step, the hydrographs were taken for base flow seperation. The method adopted was also discussed before. The ordinates of the direct runoff hydrographs equal to the ordinate of the observed hydrographs minus base flow. Total volumes of the direct runoff hydrographs were computed to inches of runoff. The unit hydrographs ordinates were obtained by dividing the ordinates of the direct runoff hydrographs by the runoff in inches as found from the total volumes of flow.

The duration of the effective rainfall was found in the following way:

A hyetograph of Patenga auto rain gage station for each selected hydrograph was drawn. In the hyetograph horizontal lines were drawn such that the portion above the horizontal line equals the total runoff volume or in inches. The portion below the horizontal line represents the abstractions. The corresponding unit hydrograph became the unit hydrograph for that effective rainfall period.

Next, the centroid of the mass of effective rainfall was found for further calculation to find basin lag and some physical characteristics of the area.

The sample calculation for developing 1 hour unit hydrograph, Halda river at Narayan Hat is shown in Table VII.

Average Unit Hydrographs

To minimise errors in the unit hydrographs, unit hydrographs for similar storms are determined and averaged to obtain a mean unit hydrograph for the basin. As because similar storms were not available, unit hydrographs for different effective storm periods were drawn 3 unit hydrographs for Narayan Hat, 6 for South Sunderpur, and 3 for Panch Pukuria were obtained, for different storms. Unit hydrographs for uncommon period were then transformed to [illegible] curve, or [illegible] curve calculation, one for a common duration by means of summation curve, or simply 'S' curve method. One sample 'S' curve calculation, 3 hour and 6 hour unit hydrograph ordinates from 1 hour unit hydrograph ordinates for Narayan Hat, is shown in Table VIII.

After achieving the unit hydrographs for one common hour period the unit hydrographs were then averaged to find a mean unit hydrograph for each station. The average unit hydrographs for different station were obtained by locating the average peak height and time. The mean unit hydrographs, found, have areas equal to 1 in. of runoff each and resemble to individual graphs as close as possible, Figures 16,17 and 18.

Next, the mean unit hydrographs of Narayan Hat and South Sunderpur were transformed for different hours by the same 'S' curve method to utilise them in real storms and thus to prove the validity of the unit hydrographs, in finding total and real hydrographs, calculations are given in Table XIV and Table XV which are shown in Figures 19 and 20 respectively.

Validity of the Unit Hydrographs Developed

To prove the validity of the unit hydrographs, developed for different stations, it is necessary to utilise the unit hydrographs to some real storms and to synthesize the storms hydrographs and finally comparing them with real hydrographs.

To perform this objective, rainfall runoff relation is required and for this, three important curves, one for Narayan Hat, the other for South Sunderpur and another for Panch Pukuria stations were developed. These are shown in Figures 23, 24 and 25 respectively.

Rainfall Runoff Relation

The runoff of a basin is dependent on independent variables like amount, intensity and duration of rainfall, initial moisture condition of the basin or antecedent precepitation, date or week of the year, evapotranspiration etc. The correlation between one dependent and three or more independent variables can be adequately represented by coaxial method of graphical correlation. This type of correlation could not be possible to achieve for want of necessary data.

The simplest rainfall runoff correlation two variable plotting of average rainfall versus resulting runoff, have been drawn for each station of Narayan Hat, South Sunderpur and Panch Pukuria.

For illustration, about 30 storms were selected from which average total rainfall and resulting runoff from each storm was found out from available rainfall records and plotted hydrographs. The rainfall runoff correlations are shown in Figures 23, 24 and 25 as discussed before. Few points, in the developed rainfall runoff relation curves, are observed to be markedly away from the average lines (Figures 23, 24 and 25). Scruitization about these points reveal that storms which were within long dry spell periods contributed much low runoff. The points which were much above the average curves, it was found that the storms were in the wet spell periods producing more runoff.

Only a moderate degree of correlation can be expected from these grphs are seen to be typically curved, indicating an increasing percentage of runoff with increasing rainfall. In sketching the curves two point averages have been taken first and then four point averages. The curves pass through the four point average points and also the mean of all the coordinating points.

Taking the runoff coefficients from these curves, effective rainfall have been found out for utilizing them in the unit hydrographs in synthesizing runoff hydrographs for South Sunderpur and Narayan Hat stations, calculation sheets are given in Table XIV and Table XV. As Panch Pukuria is very close to South Sunderpur (less than two miles), test for this station is omitted. Base flow is estimated and used in calculating tables.

The synthesized hydrographs and the actual hydrographs are also compared and shown and the result is quite satisfactory. This proves the validity of the developed unit hydrographs.

CHAPTER V

RESULTS AND DISCUSSIONS

This study relates to the development of unit hydrographs of the Halda River basin. In this study fundamental principles,basic knowledge and assumptions, available practical data have been utilised which are given in respective chapters.

Discharge hydrographs were drawn for Narayan Hat, South Sunderpur and Panch Pukuria stations on the Halda river for the years 1970-71, 1972-73 and 1973-74 to study the hydrographs,shape and behaviour. This study shows that the time lag to attain peak value of the hydrographs in the basin at Narayan Hat ranges from 12 to 15 hours, 18 to 20 hours at South Sunderpur and 20 to 24 hours at Panch Pukuria, generally. This means that time lag increases from upper to downstreams sides of the river.

In this study, it is observed that peak heights in the hydrographs at Narayan Hat and South Sunderpur are not identical. This happens because of the differences in the characteristics of the drainage areas for the individual gaging station. The high short duration peaks at Narayan Hat sometimes exceed those at South Sunderpur because of channel storage between the two stations.

The collected rainfall records for 15 stations in and around the basin area were compiled, compared and their arithmatic mean values were found and compared with that of the Patenga auto raingage station. The duration and intansity of the storms were taken from the Patenga Automatic Rain Gage station which is maintained by the Bangladesh Meteorological Department. This station is located very near to the basin area. There is no auto raingage in the basin. For rainfall recording, automatic rainage, instead of manual gage, should be installed in the basin. This would serve the purpose in a better way. With the daily mean records of rainfall of the basin, the Patenga daily rainfall records were carefully studied and compared. Whenever equal or nearly equal values were found — intense, isolated or suitable complex storms were selected and assumed to be distributed over the basin area for equal time as that of Patenga station with the average rainfall intensity of the basin which was one of the assumptions for the development of unit hydrographs. The selected storms are shown in hydrographs analysis and in calculation sheets. The Patenga raincharts were collected for the years 1970-71, 1972-73 and 1973-74. For the study of consistency of rainfall records for different stations in and around the basin area,Double Mass Curves were developed and studied. Two Double Mass Curves, one for Chittagong station and another for Dolu Station, are shown in Figures 21 and 22.

Rainfall records from 1962 to 1975 were used in 14 different stations in the basin. This test of consistency of the record of rainfall results very good for most of the stations. A few stations like Amtali, Fatikchari, have shown slight change of slopes in the mean lines.The causes may be attributed to faulty record keeping, non recording for a couple of days due to instrumental defects, change of location of stations etc. Some of the stations were marked not recorded for a few months in the liberation year of 1971-72. The figures of these disturbed stations for the missing months were adjusted by taking the rest of 13 years average rainfall of the respective stations for the respective months and finally were justified by the developed Double Mass Curves.

In seperating the complex hydrographs three composite recession curves were developed each one for Narayan Hat, South Sunderpur and Panch Pukuria and utilised in proper places. Some individual storm recessions have been marked to be (Figures 1, 2 and 3) more inclined vertically than the respective composite recession curves indicating the previous small base flow and responsible storms to be of intense type and durable for short period, aftermath the storm discontinued.

For base fow seperation, the formula $N = A^{0.2}$ in days from the peak value to the receesion limb of the hydrographs was used, where A is the drainage area in sq. miles. In the analysis of hydrographs, (Figures 10 and 15) the base flow seperation lines joining the point below the peak point and the recession part of the hydrographs may seem to be slightly away from normal ones as in the other cases. But it was done necessarily to maintain the assumption of keeping base time constant. And the base flows were small enough to cause any serious harm to the analyses of hydrographs.

Finally 3 unit hydrographs for Narayan Hat, 6 for South Sunderpur and 3 for Panch Pukuria were developed. Summation curves had to be developed for unit hydrographs for common periods and then one average unit hydrograph for each station was achieved. The average unit hydrographs reveal that Narayan Hat, South Sunderpur and Panch Pukuria have 13,20 and 22 hours time lag from rise to peak time of the hydrographs respectively.

The relative average unit hydrographs were then utilised at Narayan Hat and South Sunderpur in real storms to synthesize hydrographs which were finally compared with the actual hydrographs. Figure 19 shows two distinct peaks produced by two intense storms. The first peak of the actual hydrograph is seen to be slightly higher and also lagging than the synthesized hydrograph. The reason may be attributed to the facts that the discharge records used are those of computed from the best fit rating curves claimed by the Bangladesh Water Development Board and not actual ones. Hence the possibility of discripency in regards of time and amount of discharge are not dislikely. Moreover the effective unoff, used in the synthesis of total hydrograph are not also supposed to be most accurate, because it was narrated earlier that in developing rainfall runoff correlation curves, the independent factors like antecedent precepitation conditions, evepotranspiration of the basin area, week of the year etc, were not taken into account for want of necessary informations. A comparative study of these synthesized and actual hydrographs of the Halda river at south Sunderpur, gives the percentage of accuracy to be 88 and hence is reliable. As regard to figure 20, the comparative study of the actual and synthesized hydrograph of the Halda river at Narayan Hat gives the value of percentage of accuracy to be 96%. The results are quite satisfactory and thus proves the validity of the developed unit hydrographs.

Taking the values of time lag to peak discharge and peak discharge per unit area from the developed average unit hydrographs of Narayan Hat and South Sunderpur and utilizing Snyder's equations —— coefficients of C_t and C_p which are dependent upon units and basin characteristics have been found out. The values of C_t and C_p for Narayan Hat are found to be 3.30 and 0.47 and those for South Sunderpur 3.94 and 0.478 respectively. The values of these coefficients can be used to derive synthetic unit hydrographs for different tributaries of the river Halda like Dhurung Khal, Sua Khal, Talpari Khal etc. in the region where no record of discharge is maintained or in the ungaged basins of similar characteristics as for example, in the other areas of Chittagong and Chittagong Hill Tracts in Bangladesh.

When the amount of rainfall of the basin area is known the hydrograph pattern can be evaluated utilizing the developed unit hydrographs. Most often the information about peak discharge becomes important. Many formulas have been developed for computing peak discharges but most of them are considered inadequate. The so called rational formula, $Q = C\ 1\ A$, Where Q = Peak discharge in cfs, C = Runoff coefficient, A = Drainage area in acres, I = Uniform rate of rainfall intensity in/hr for a duration equal to the time of concentration. Although the simplicity of the formula has won its popularity the assumptions, which cannot be satisfied readily under actual circumstances, in fact, called attentions of many hydrologists the inadequacy of this method. There are many empirical, semi-empirical methods developed from experience and judgement, statistical analysis of flood records on regional basis. Several methods for determination of peak discharge from small rural drainage basins like the U.S. Bureau of public Roads method (BPR method), the California method, the Cook method, the Chow method etc., which require correlation analysis for developing formulas or charts showing the effect on peak discharge by various hydrologic factors and basin dimensions, limit their application in this basin of the Halda river. For this reason a formula has been developed mathematically to know the approximate peak discharge when the amount of rainfall in the region is known. This formula is valid for South Sunderpur, station. To use effective rainfall in this formula the developed rainfall runoff relation curve of South Sunderpur Station would be used.

The equation is

$$q_p = \frac{KAQ}{T_p}$$

where, q_p = Peak discharge in cfs.

A = Drainage area in sq. miles.

Q = Total runoff in inch.

T_p = Basin lag in hours.

K = 374, a constant, found from this study dependent on the shape of hydrographs.

This equation and the value of $K = 374$ should be used only for rough estimating of peak flow from rainfall data.

The validity of this equation has been judged by comparing the values of 11 different actual cases which are shown in Table III and Figure 26. The result is quite satisfactory.

In Figure 26 the coordinating points (actual q_p vs computed q_p by the formula $q_p = \frac{374\ AQ}{T_p}$) should pass through the dotted 45° line. The average line joining the points is satisfactory and it has a slope of 1.07 slightly greater than unity. For theoretical interest, if the slope of the line is made equal to unity a modified value of $K = 350$ is found. Thus the modified value, $K = 350$ can be used in the above equation.

CHAPTER VI

CONCLUSIONS

The following conclusions can be drawn from this study of deriving unit hydrographs for the Halda river basin.

1) The time lag to attain the peak value of discharge in the upper reach of the river gradually increases in the downstream. Observation on hydrographs show that this time lag ranges from 12 to 15 hours at Narayan Hat, 18 to 20 hours at South Sunderpur and 20 to 24 hours at Panch Pukuria.

2) The typical upward curvature of the ranfall-runoff relation curves for Narayan Hat, South Sunderpur and Panch Pukuria indicate an increasing percentage of runoff with increasing rainfall.

3) The values of physical basin characteristics of the area namely, C_t, C_p which are used in Snyder's equations for synthetic unit hydrograph are found to be C_t = 3.30, C_p = 0.47 for Narayan Hat and C_t = 3.94, C_p = 0.478 for South Sunderpur catchment areas.

These values of C_t and C_p may be utilised in finding Synthetic unit hydrographs for the catchment areas of the tributaries of the Halda river, namely, Dhurung Khal, Talpari Khal, Sua Khal, Sarta Khal etc., where no discharge record is maintained and also in the ungaged area whose hydrological characteristics are same as this study basin area. In observing the discharge hydrograph sometimes it is seen that peak floods of the Halda river in the upstream at Narayan Hat and that at South Sunderpur are not closely related because of the difference in drainage area characteristics. The high short duration peaks at Narayan Hat sometimes exceeds those at South Sunderpur because of channel storage between the two stations and uneven rainfall.

4) The straight lines in the Double Mass Curves Analysis reveal that there is a good coherence among the rainfall records in the basin area. The straight line of the Double Mass Curve Analysis for the station Chittagong approved to a good extent for the assumption of taking the duration of storms from this station for the development of unit hydrographs.

5) To find an approximate peak value of flood discharge at South Sunderpur from the storms a formula has been developed, justified and can be used, which is

$$q_p = \frac{KAQ}{T_p}$$

where,

q_p = Peak discharge in cfs.

A = Area in sq. miles.

Q = Total runoff in inches.

T_p = Basin lag in hours.

and K = A constant equal to 350 found from this study, dependent on the shape of hydrographs.

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FIGURES AND MAPS

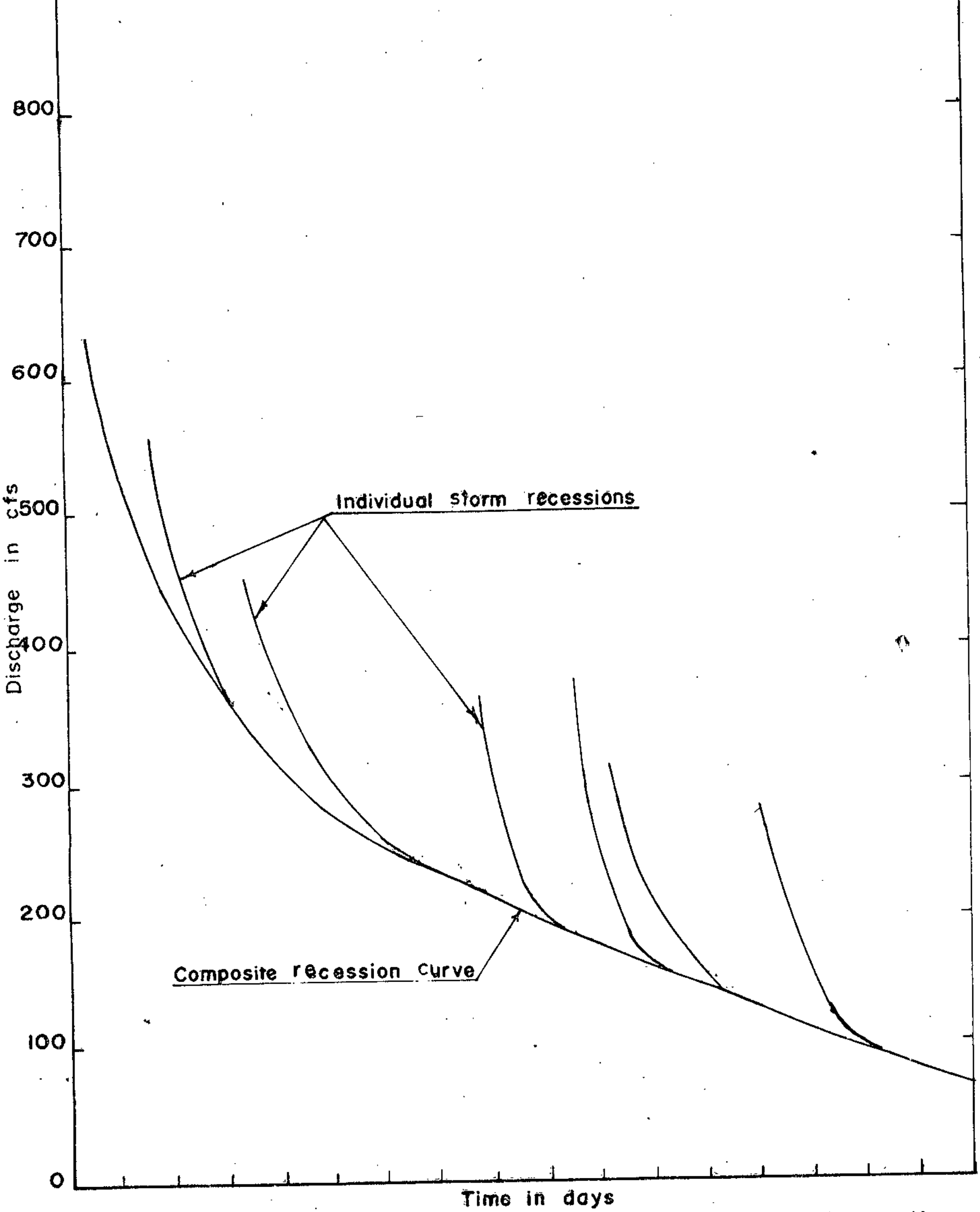


FIG. 1. Construction of composite recession curve, Halda river at Narayan Hat

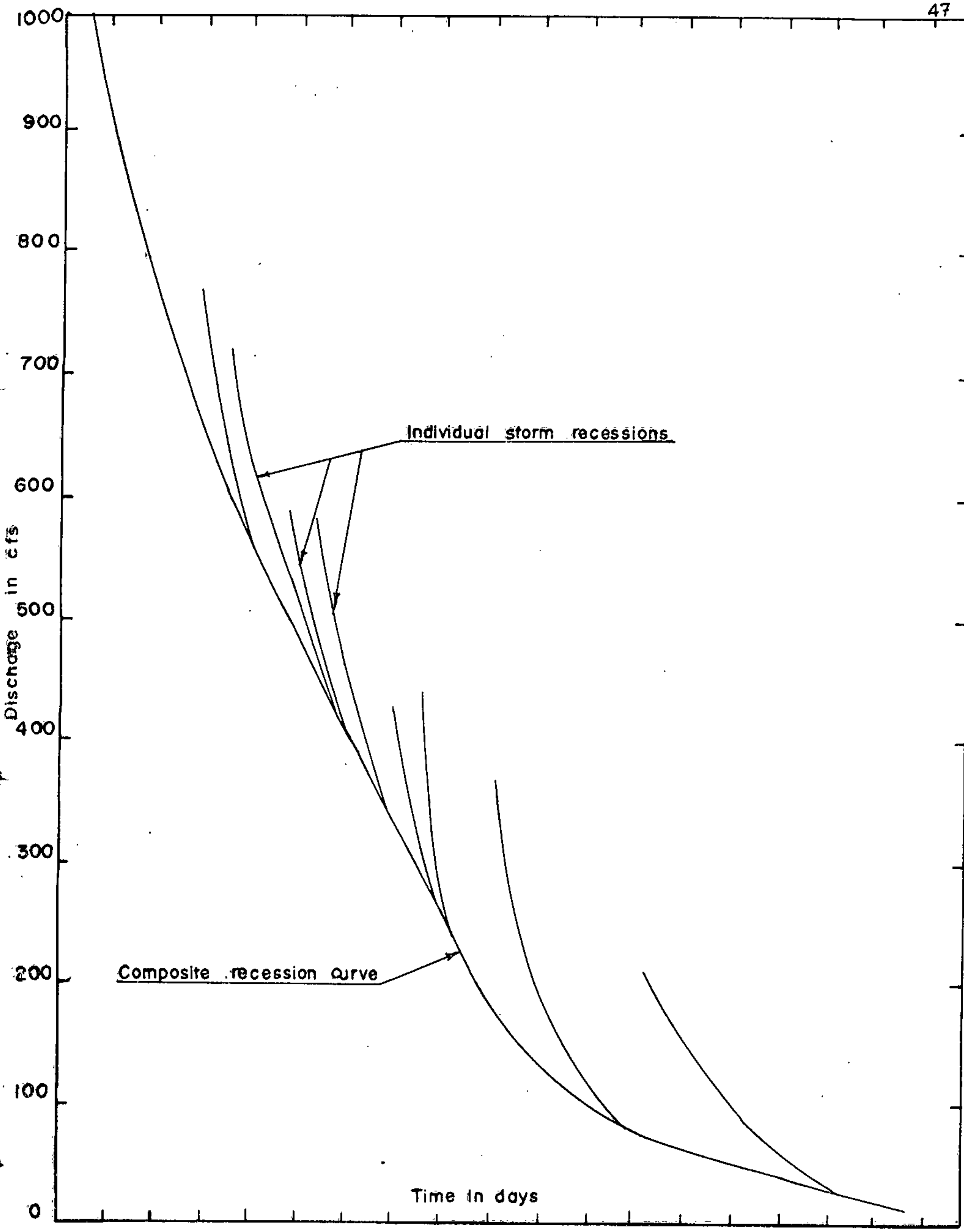


FIG. 2. Construction of Composite recession curve, ··alda river at South Sunderpur discharge station.

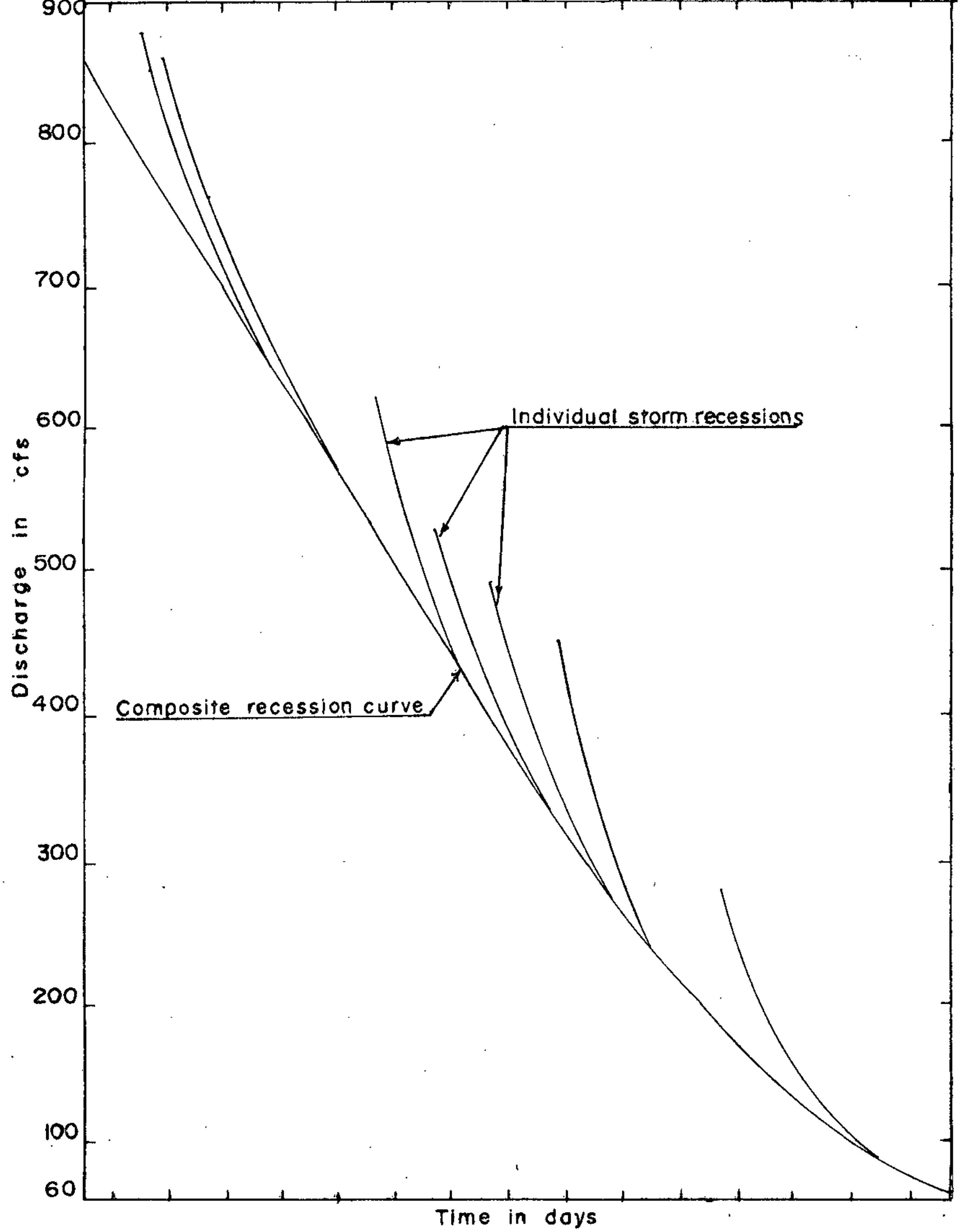


FIG. 3. Construction of composite recession curve, Halda river at Panch Pukuria.

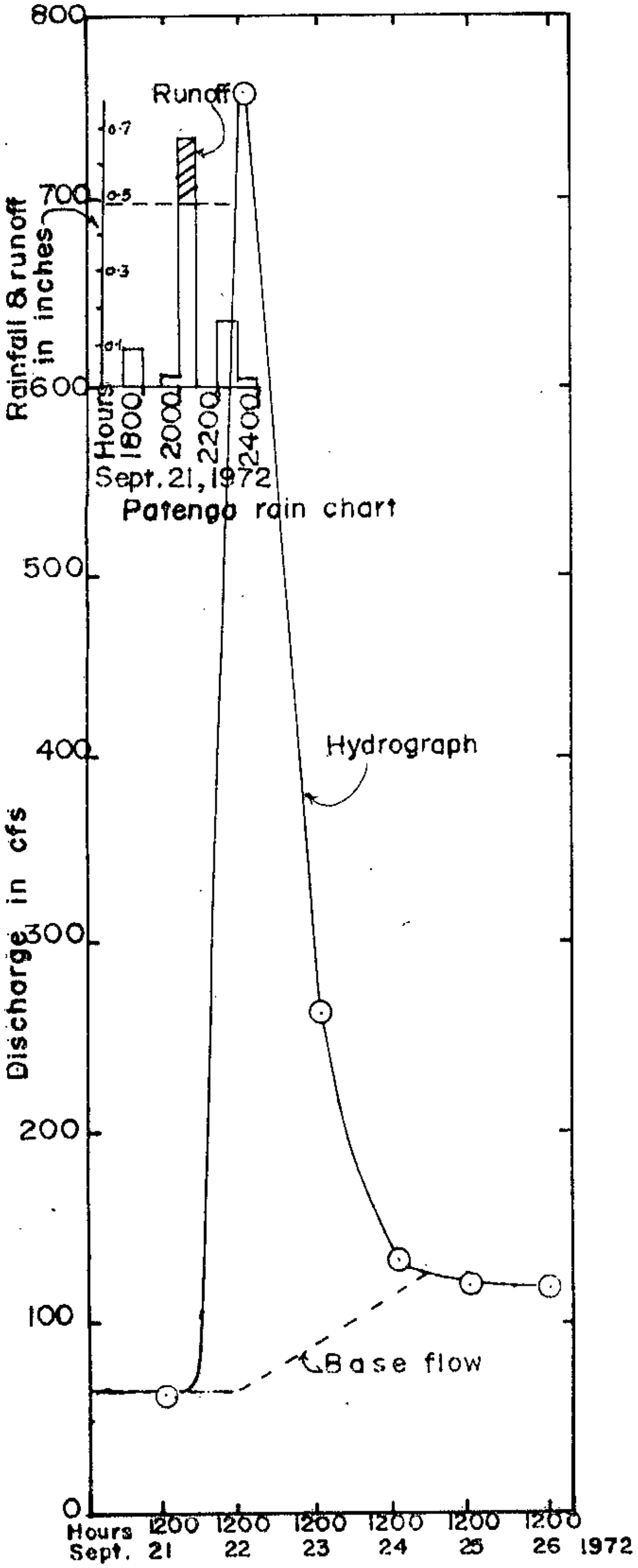


FIG. 4. Development of unit hydrograph
Halda river at Narayan Hat.

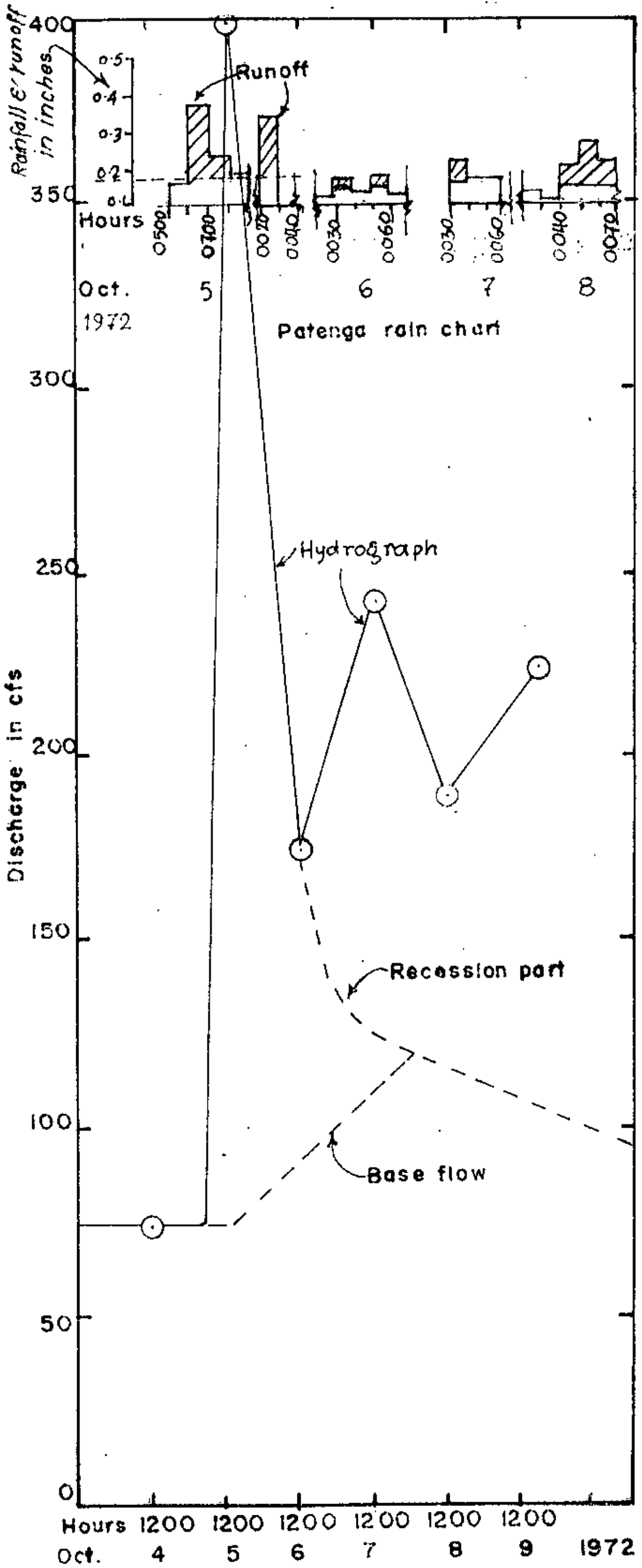


FIG. 5. Development of unit hydrograph
Halda river at Narayan Hat.

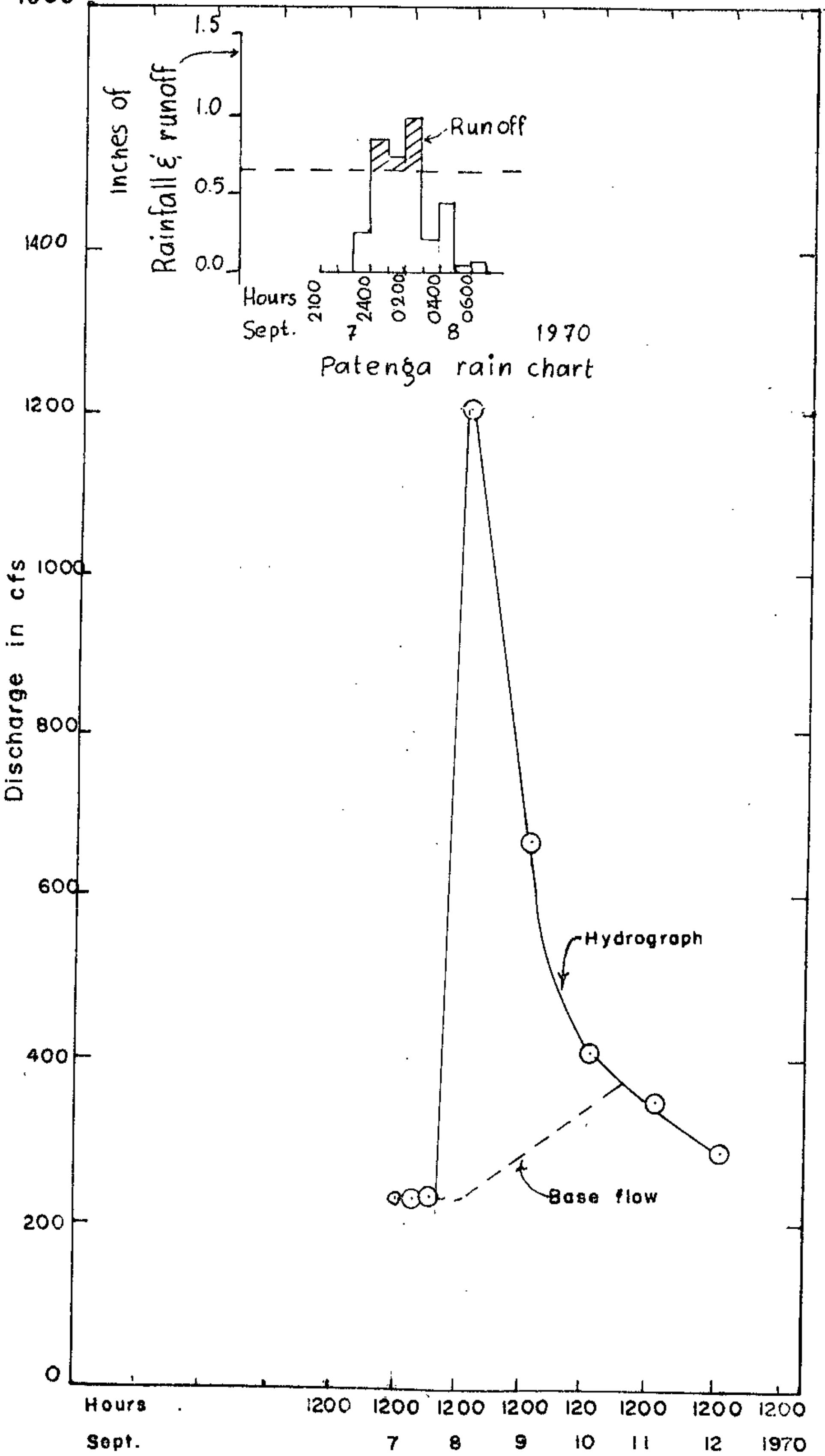


FIG. 6. Development of unit hydrograph
Halda river at Narayan Hat.

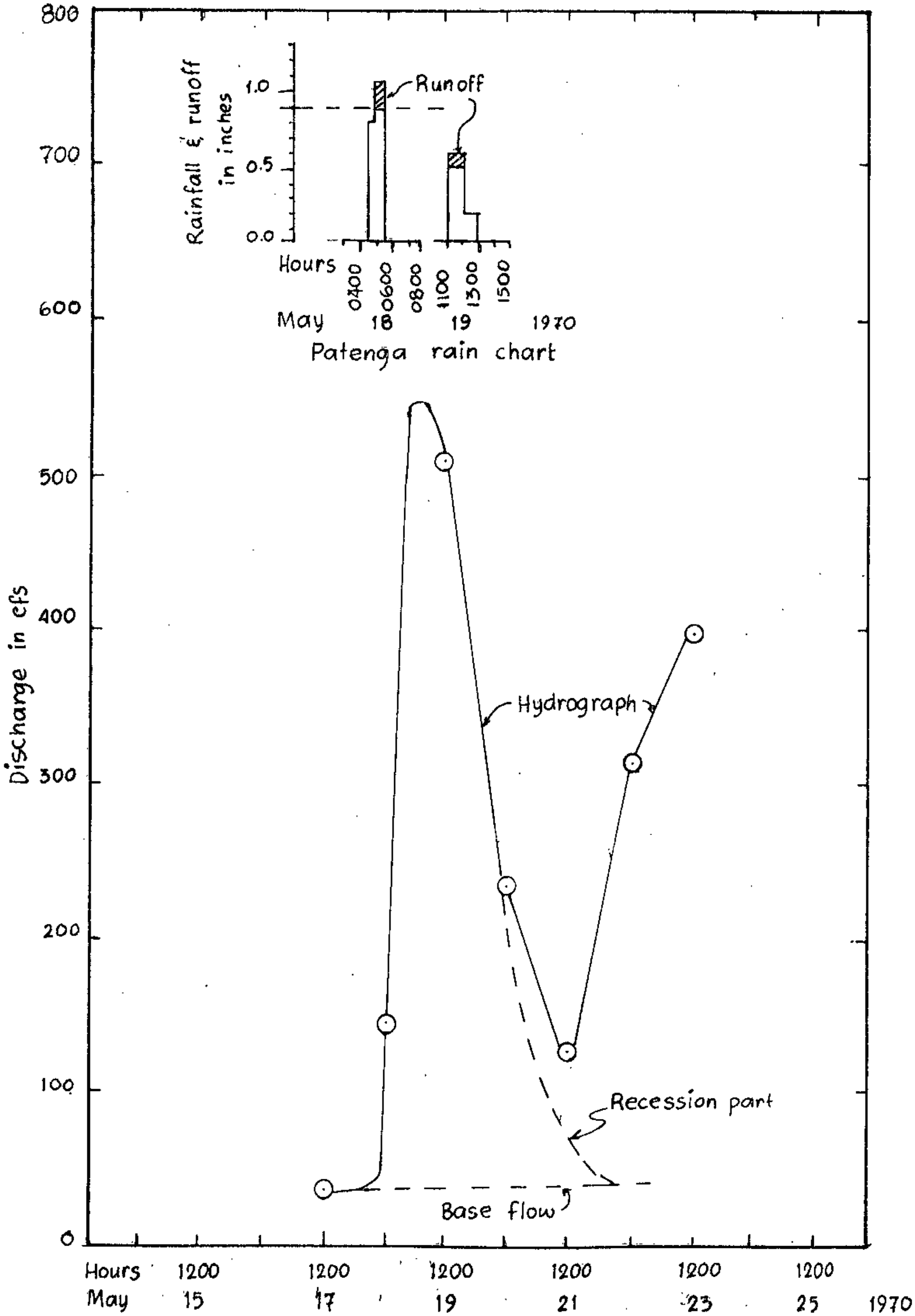


FIG.7. Development of unit hydrograph
Halda river at South Sunderpur

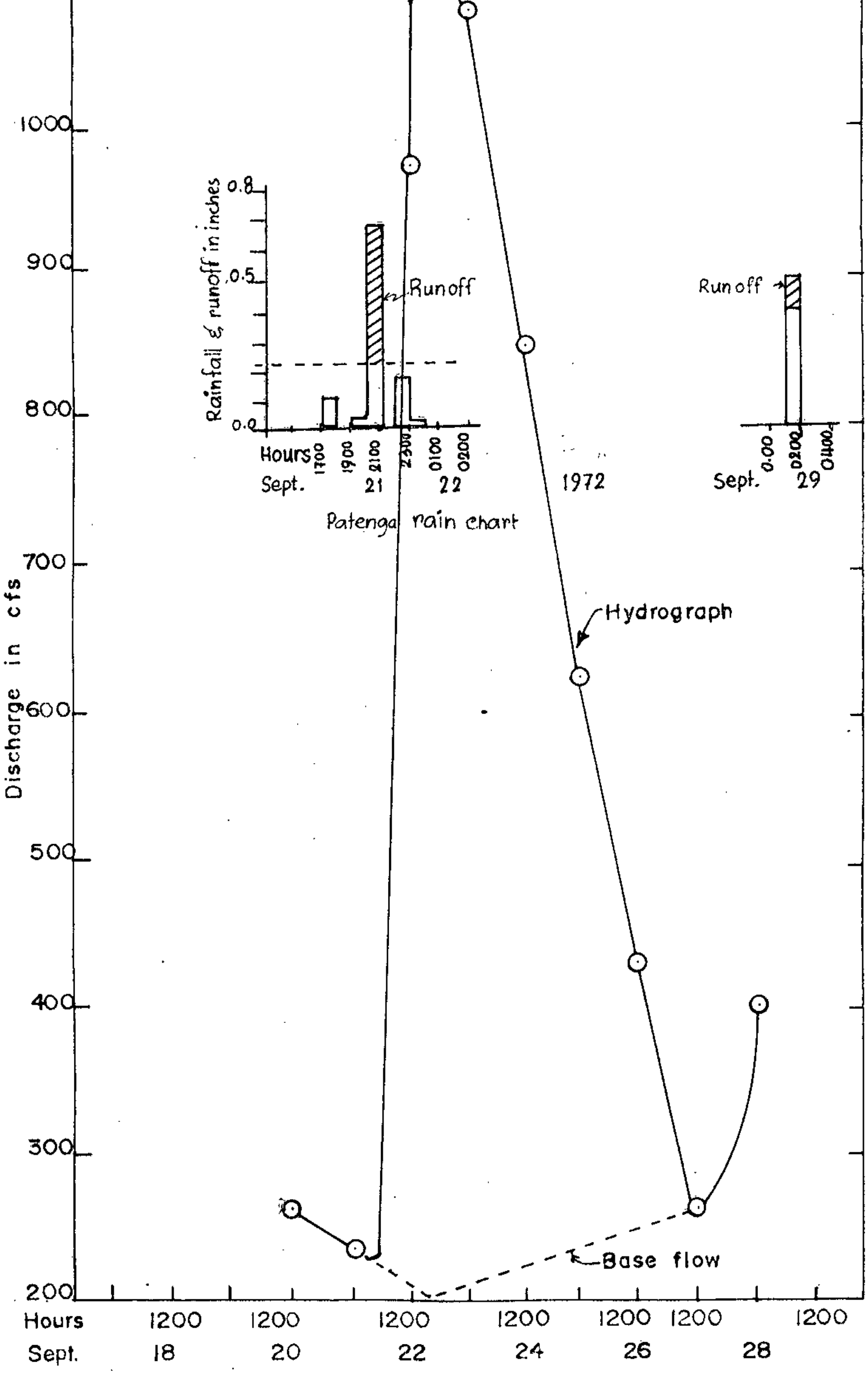


FIG. 8 . Development of unit hydrograph, Halda river at South Sunderpur

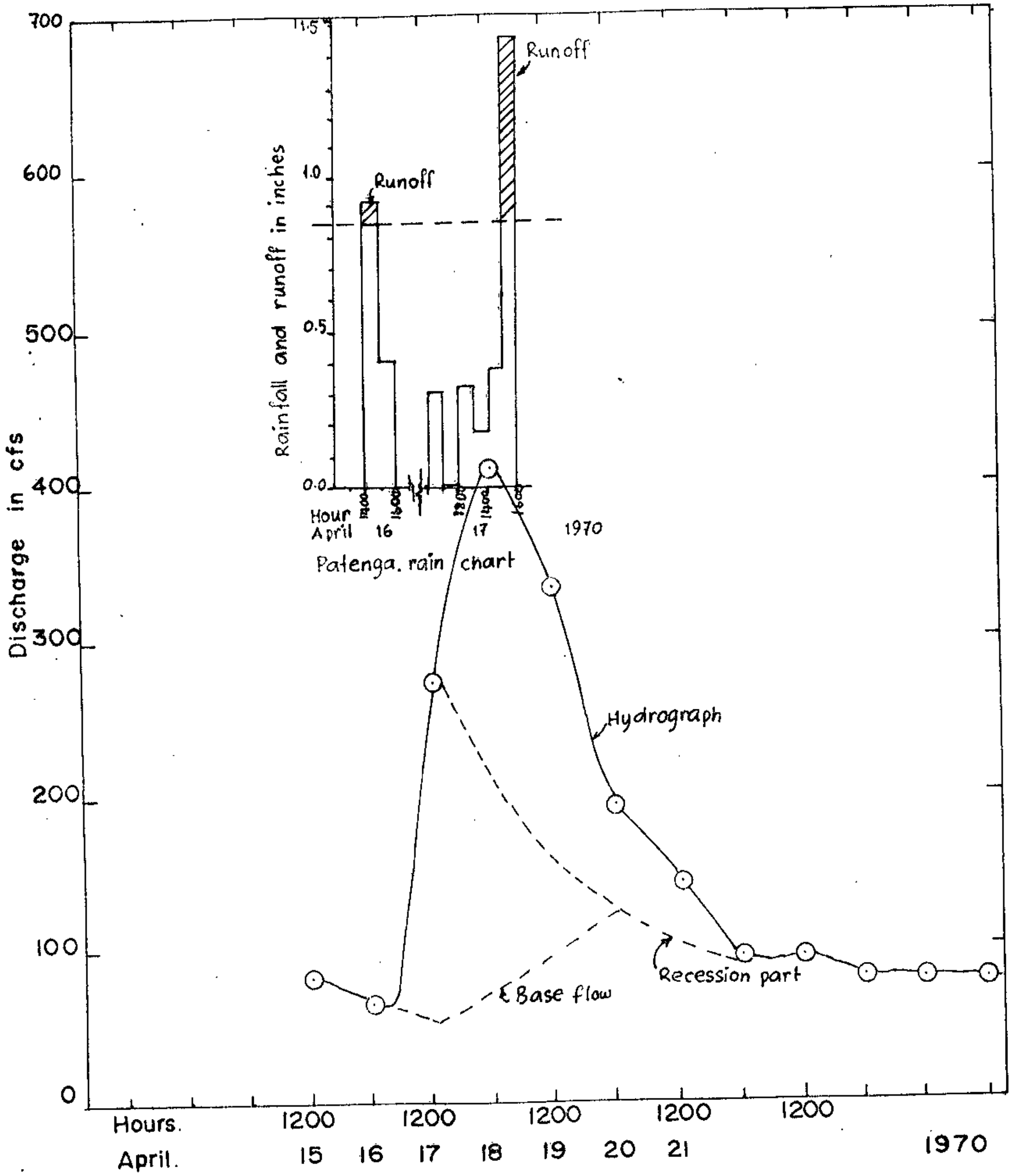


FIG. 9 · Development of unit hydrograph; Halda river, South Sunderpur.

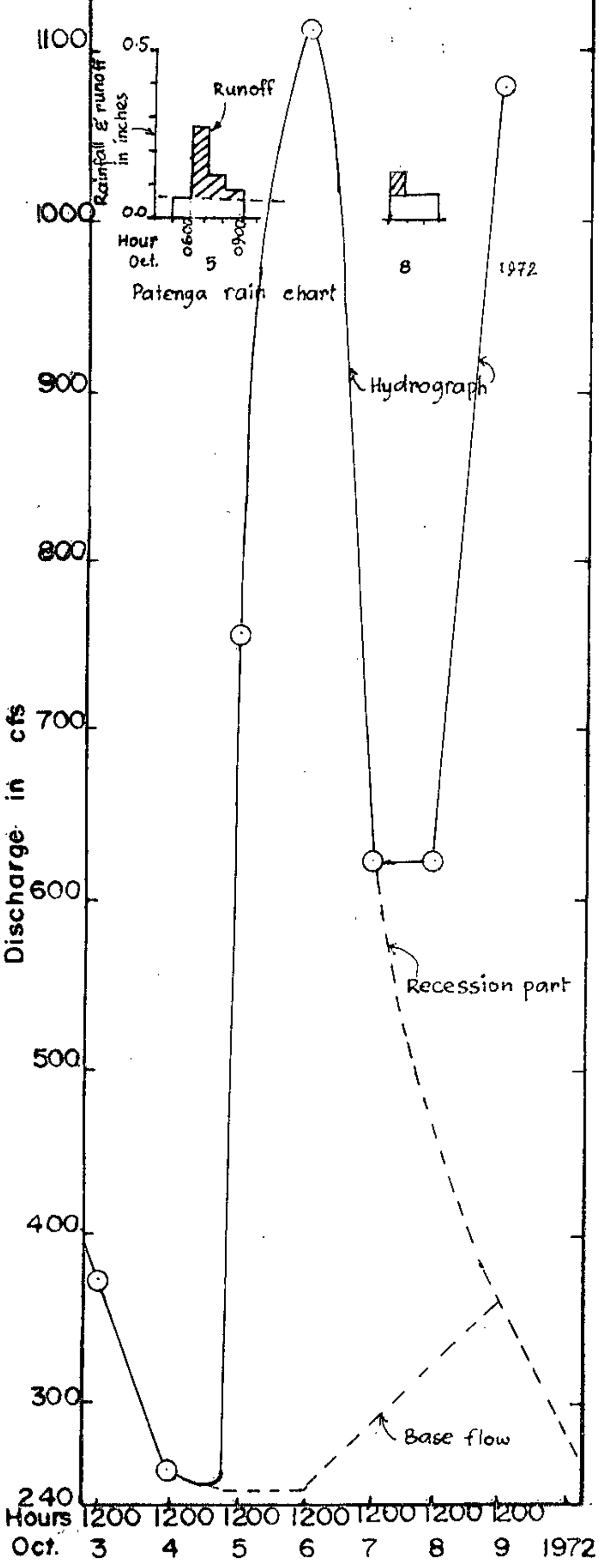


FIG. 10. Development of unit hydrograph Halda river at South Sunderpur.

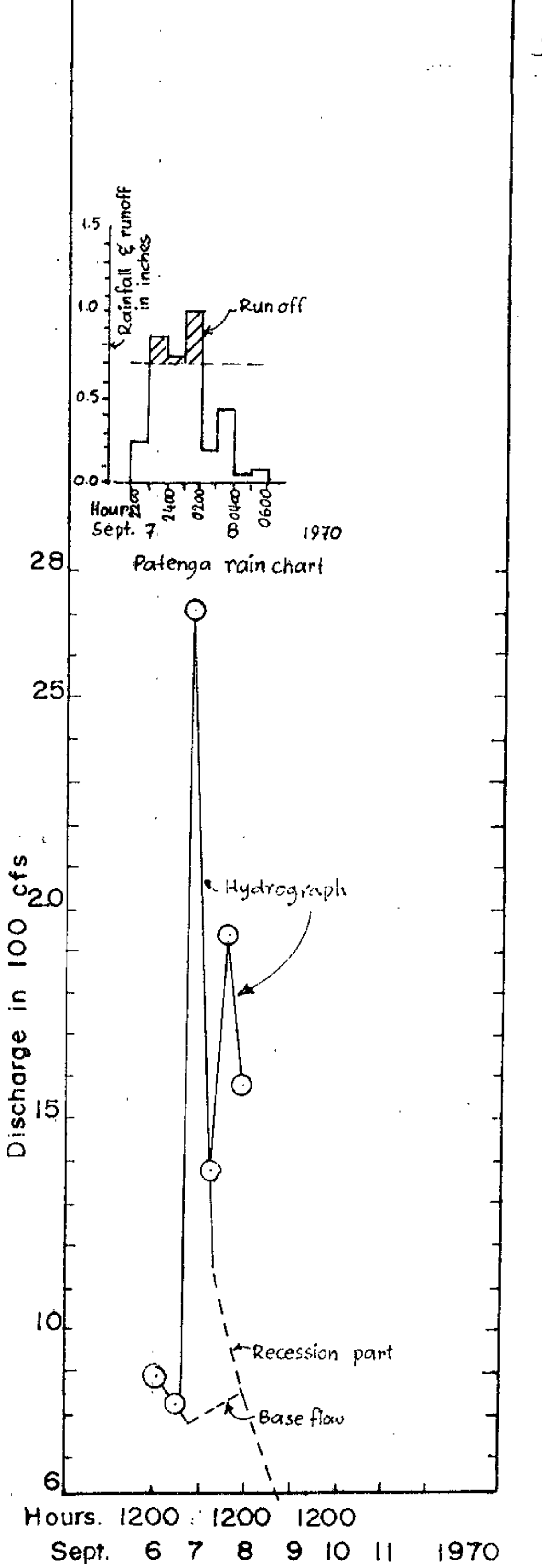


FIG. 11. Development of unit hydrograph Halda river at South Sunderpur.

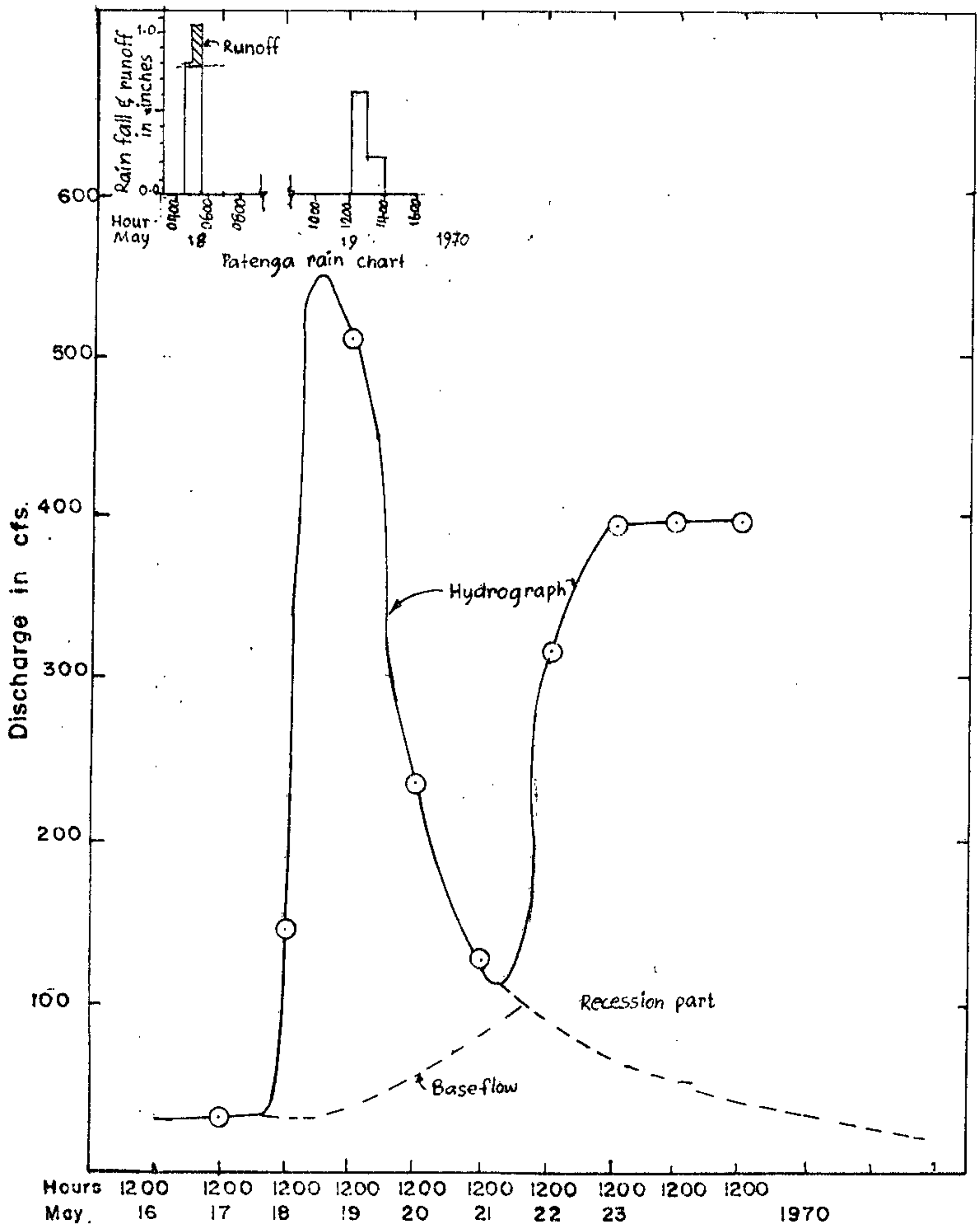


FIG. 12 . Development of unit hydrogrph, Halda river at South Sunderpur.

Hydrograph at P. Pukuria.

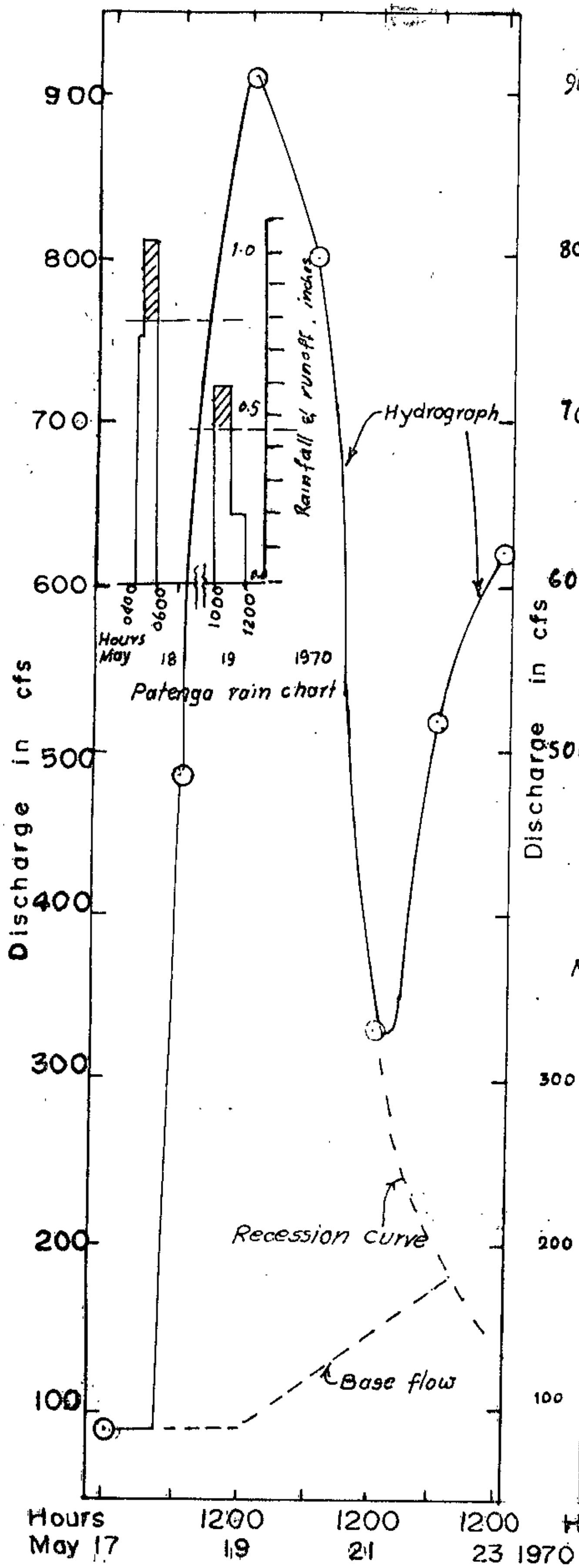


FIG. 13. Development of unit hydrograph

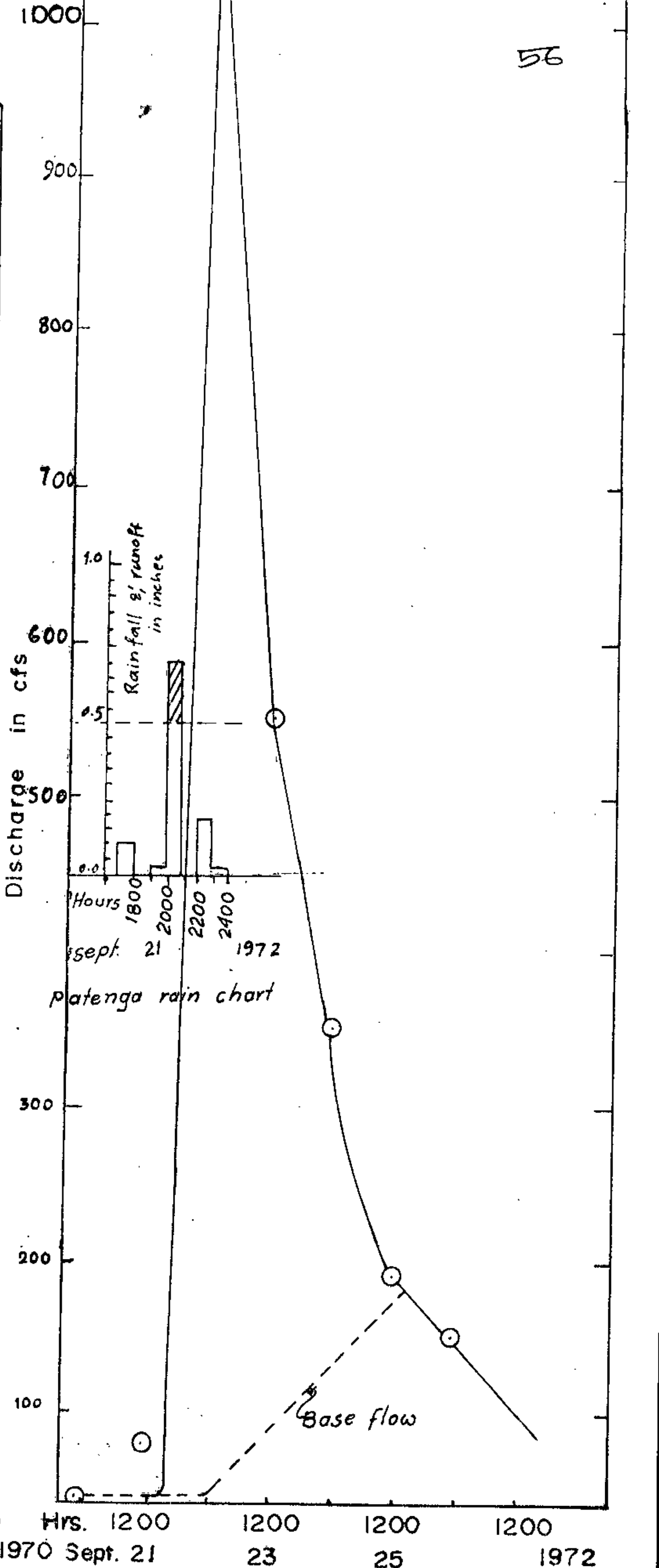


FIG. 15. Development of unit hydrograph P. Pukuria

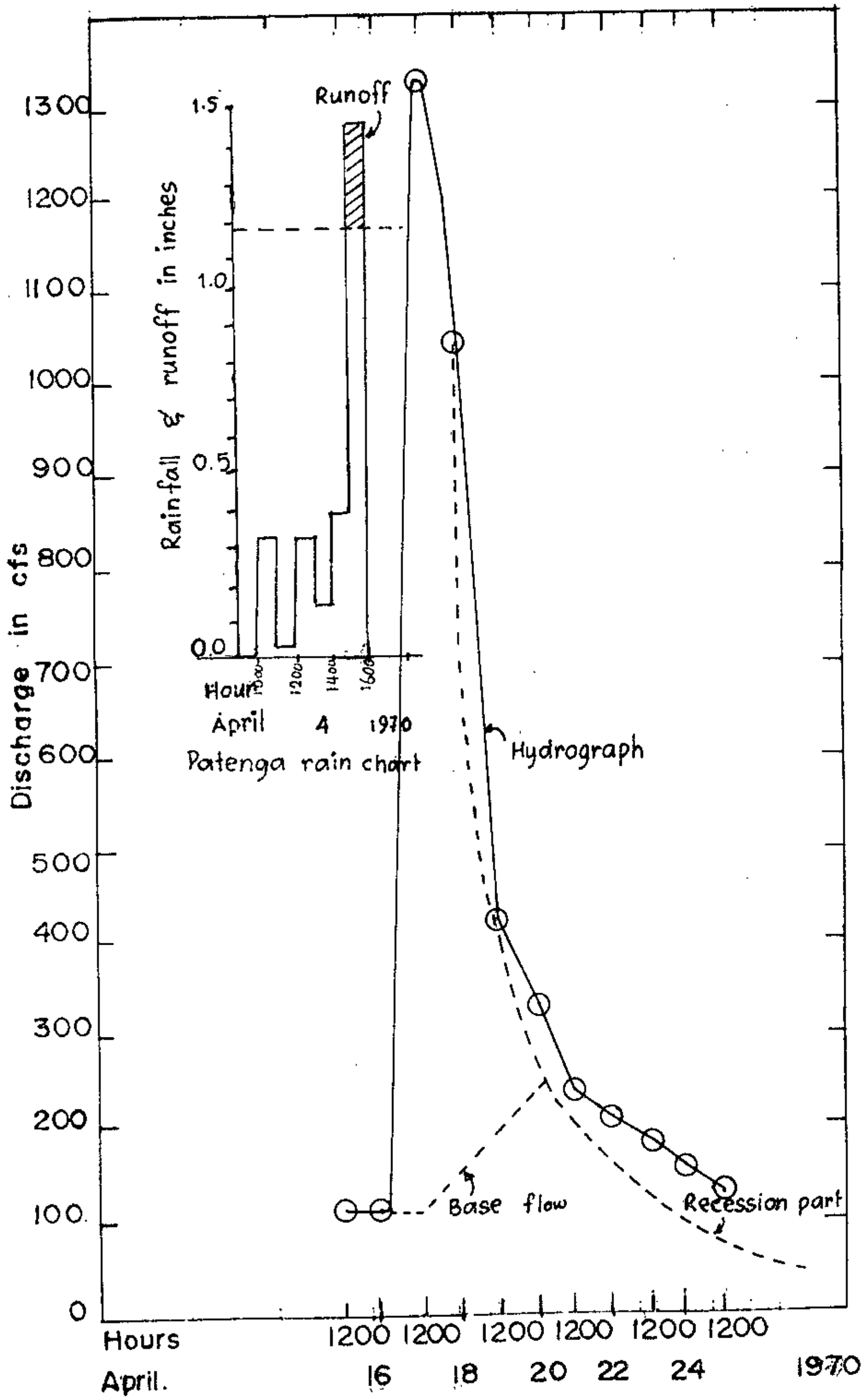


FIG. 14. Development of unit hydrograph, Halda river at Panch Pukuria.

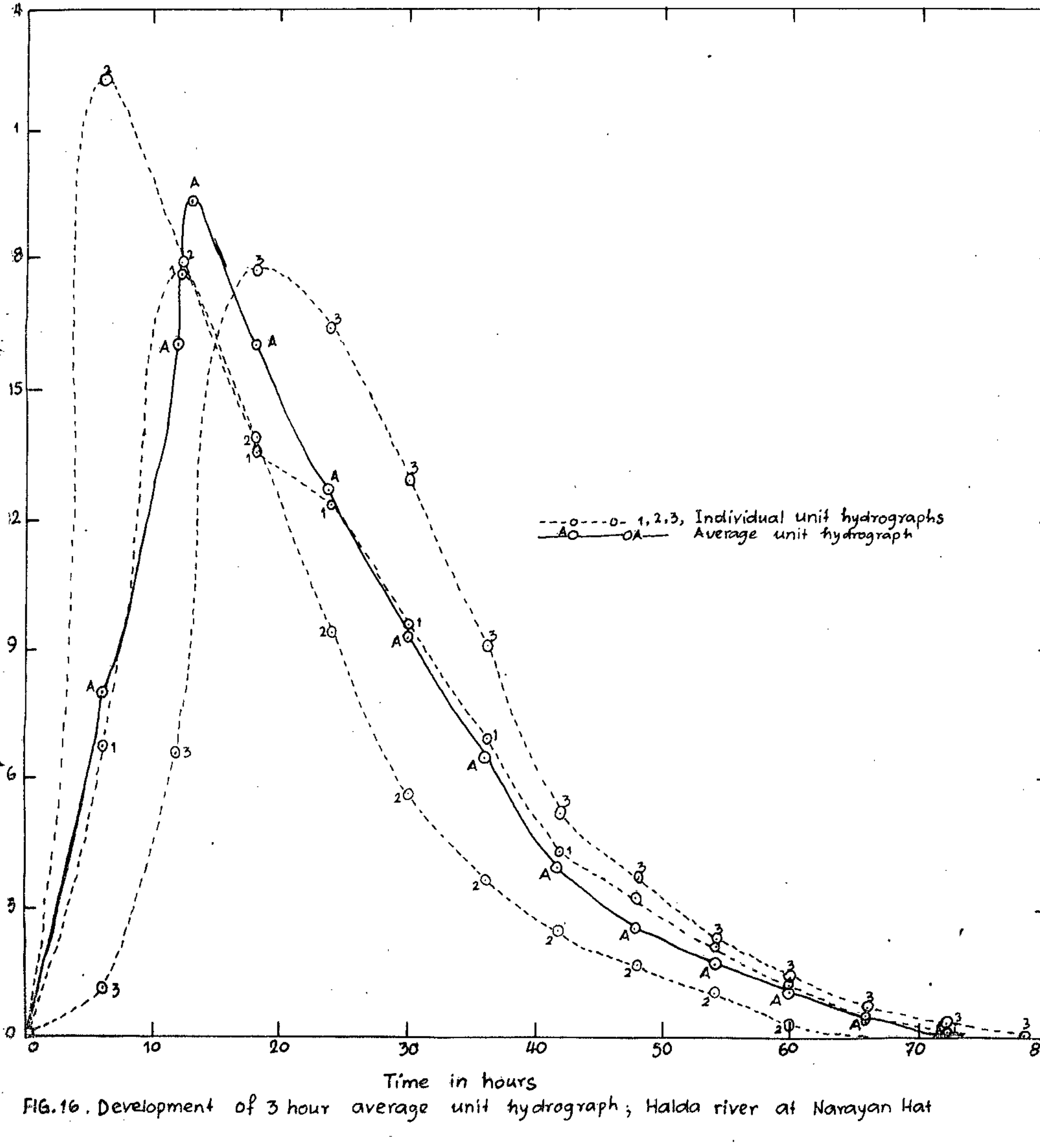


FIG. 16. Development of 3 hour average unit hydrograph; Halda river at Narayan Hat

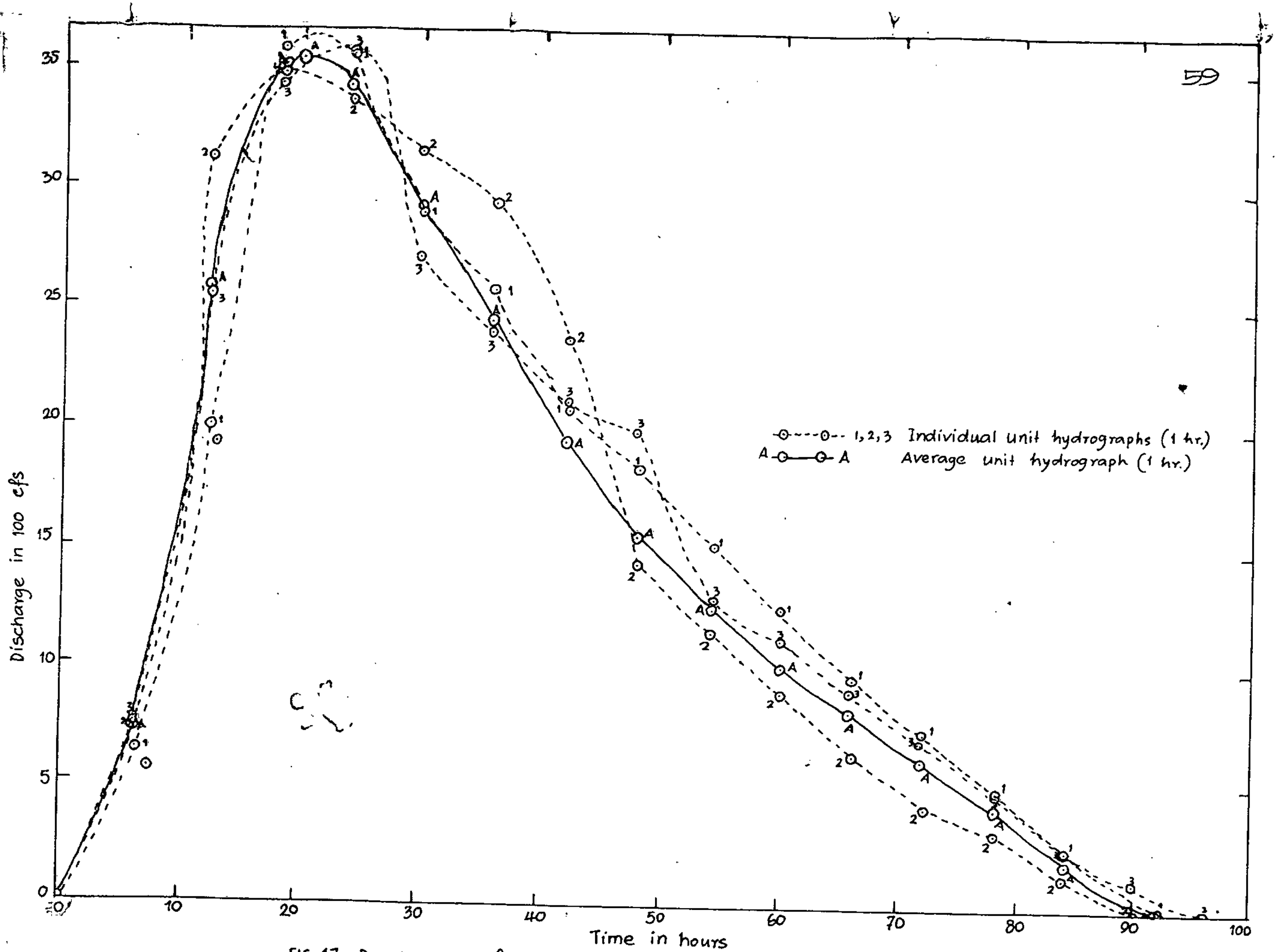


FIG. 17. Development of 1 hour average unit hydrograph; Halda river at South Sunderpur

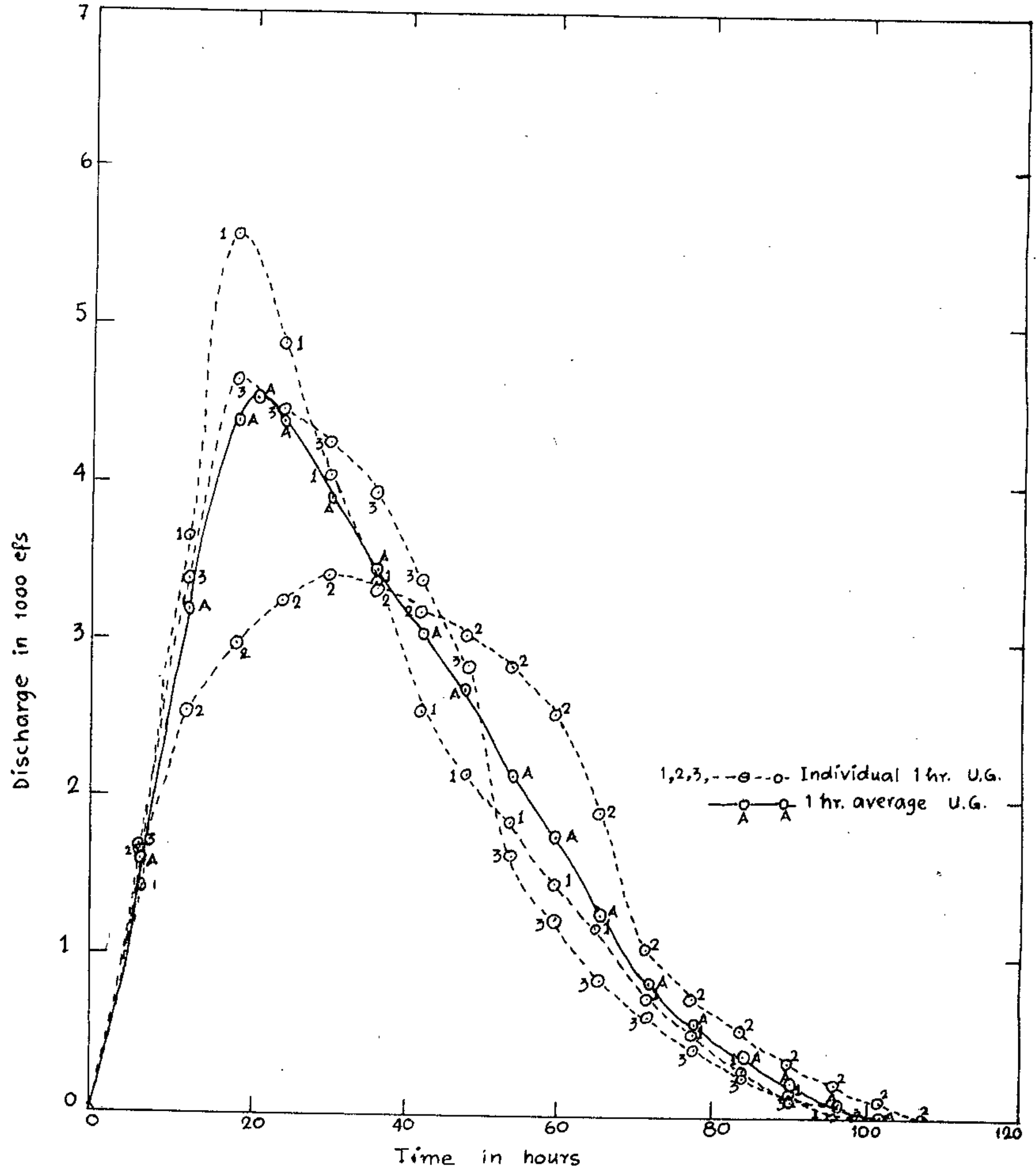


FIG. 18. Development of average (1 hr.) unit hydrograph, Halda river at Panch Pukuria.

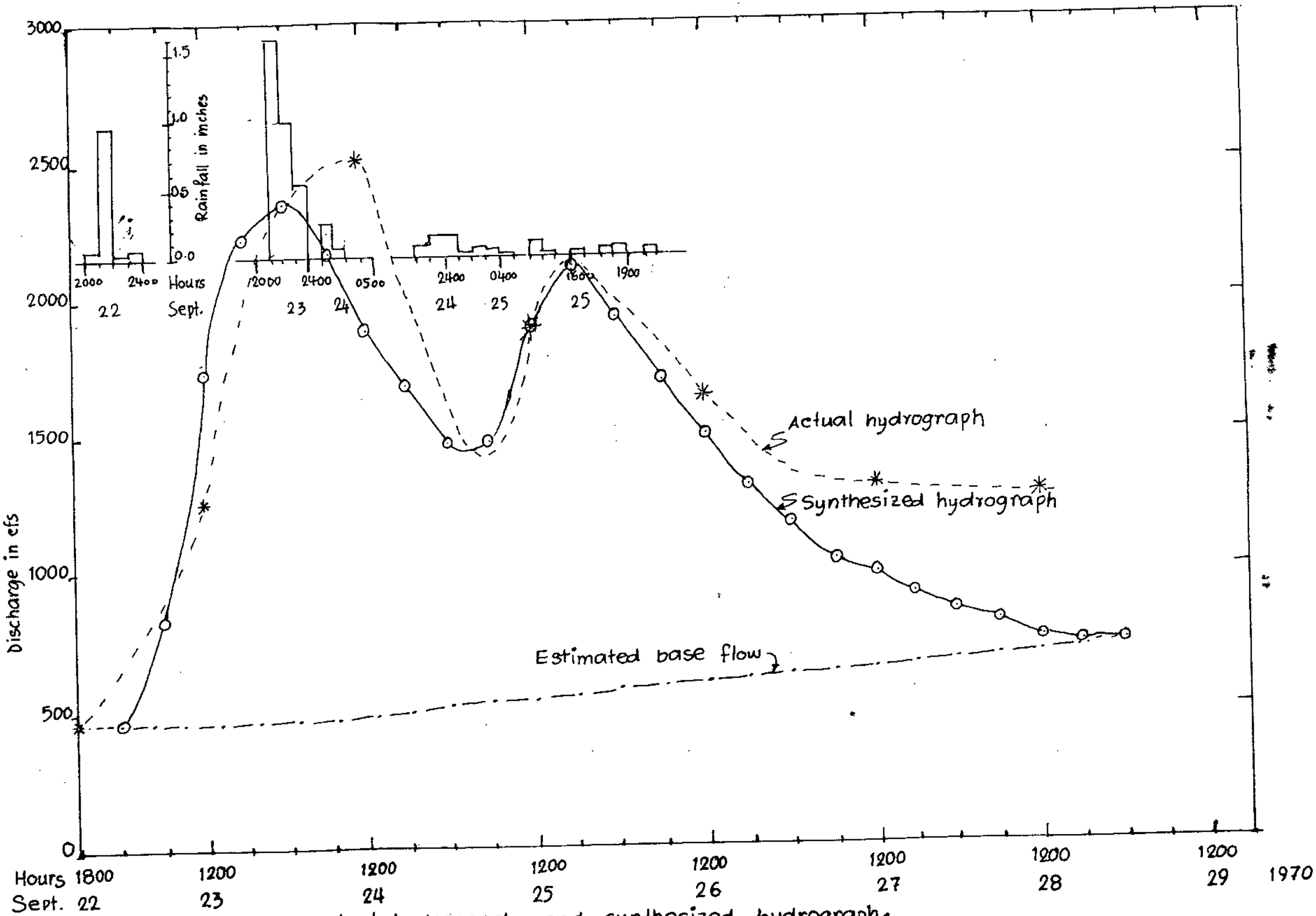


FIG. 19. Comparison of actual hydrograph and synthesized hydrograph; Halda river at South Sunderpur

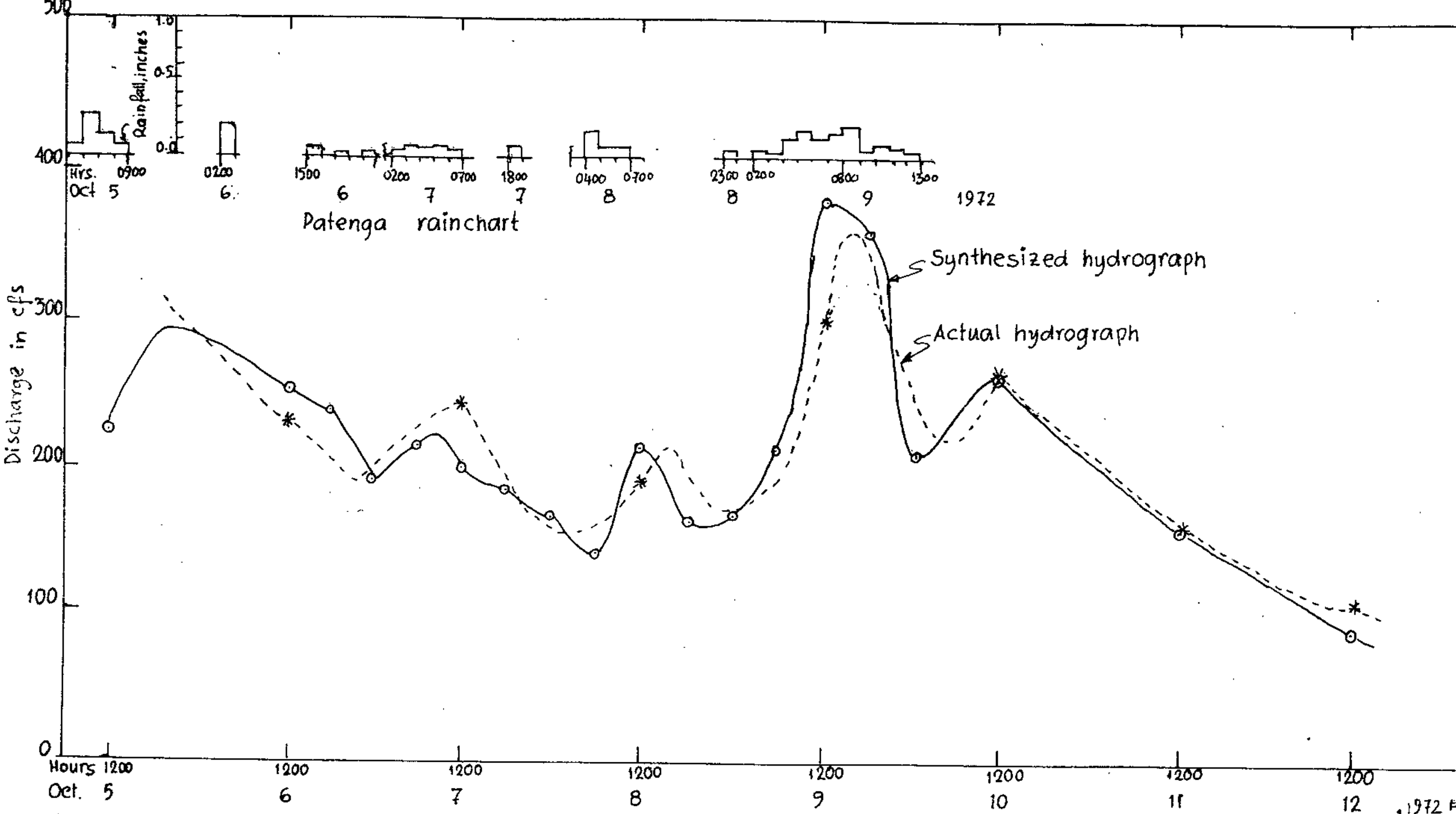


FIG. 20. Comparison of actual hydrograph and synthesized hydrograph ; Halda river at Narayan Hat .

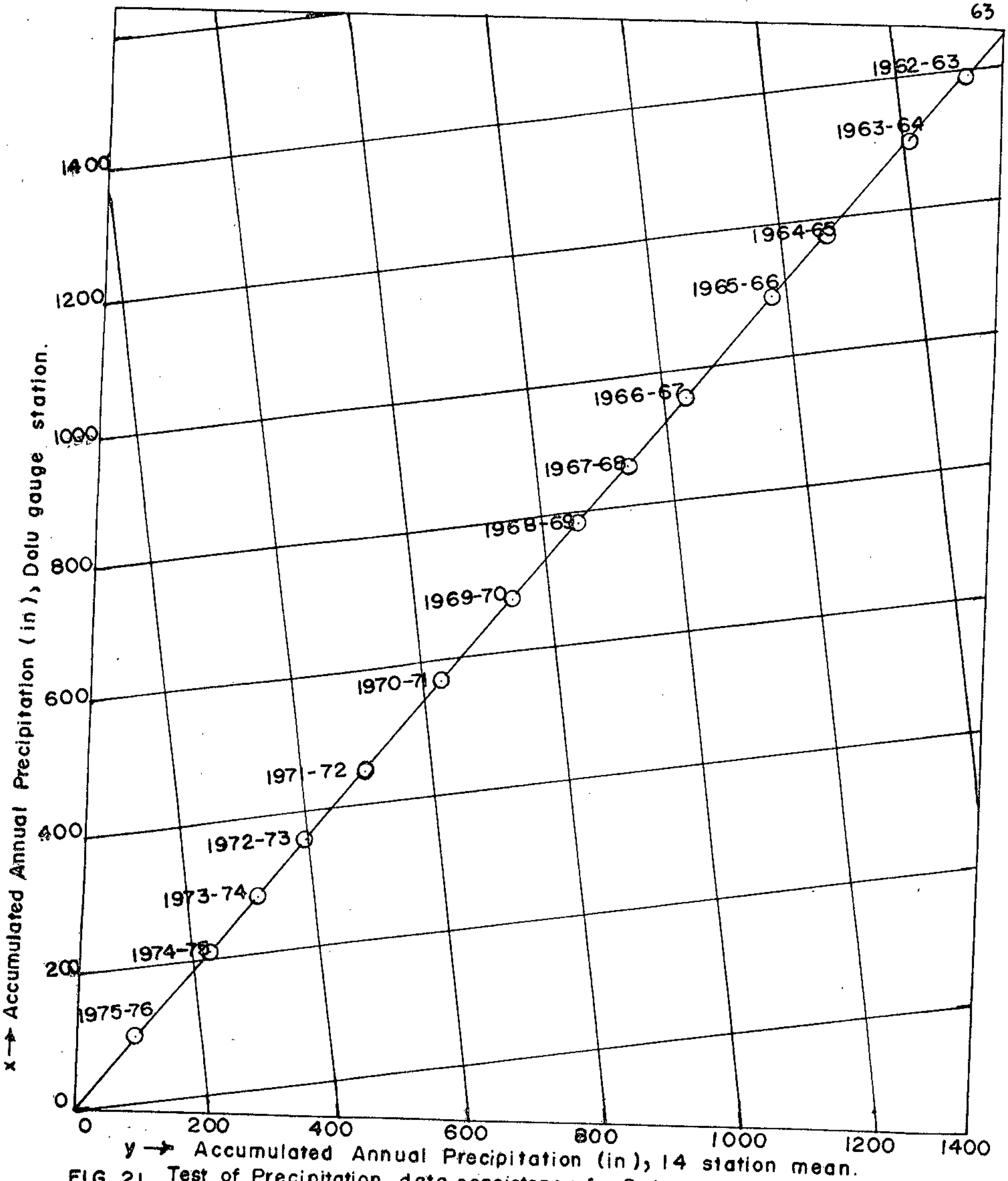


FIG. 21. Test of Precipitation data consistency for Dolu gauge station by double mass curve.

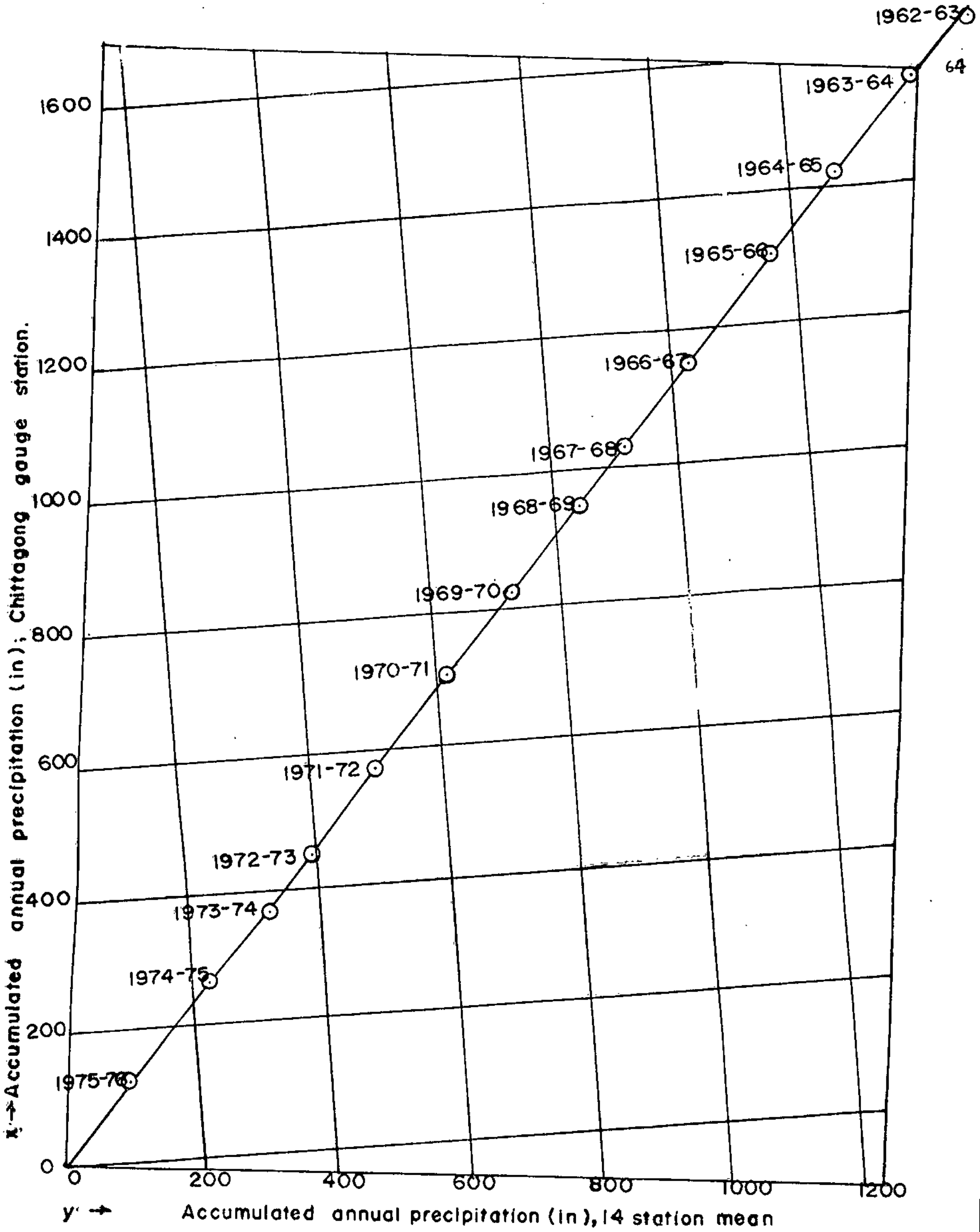


FIG. 22. Test of precipitation consistency for Chittagong gauge station by double mass curve.

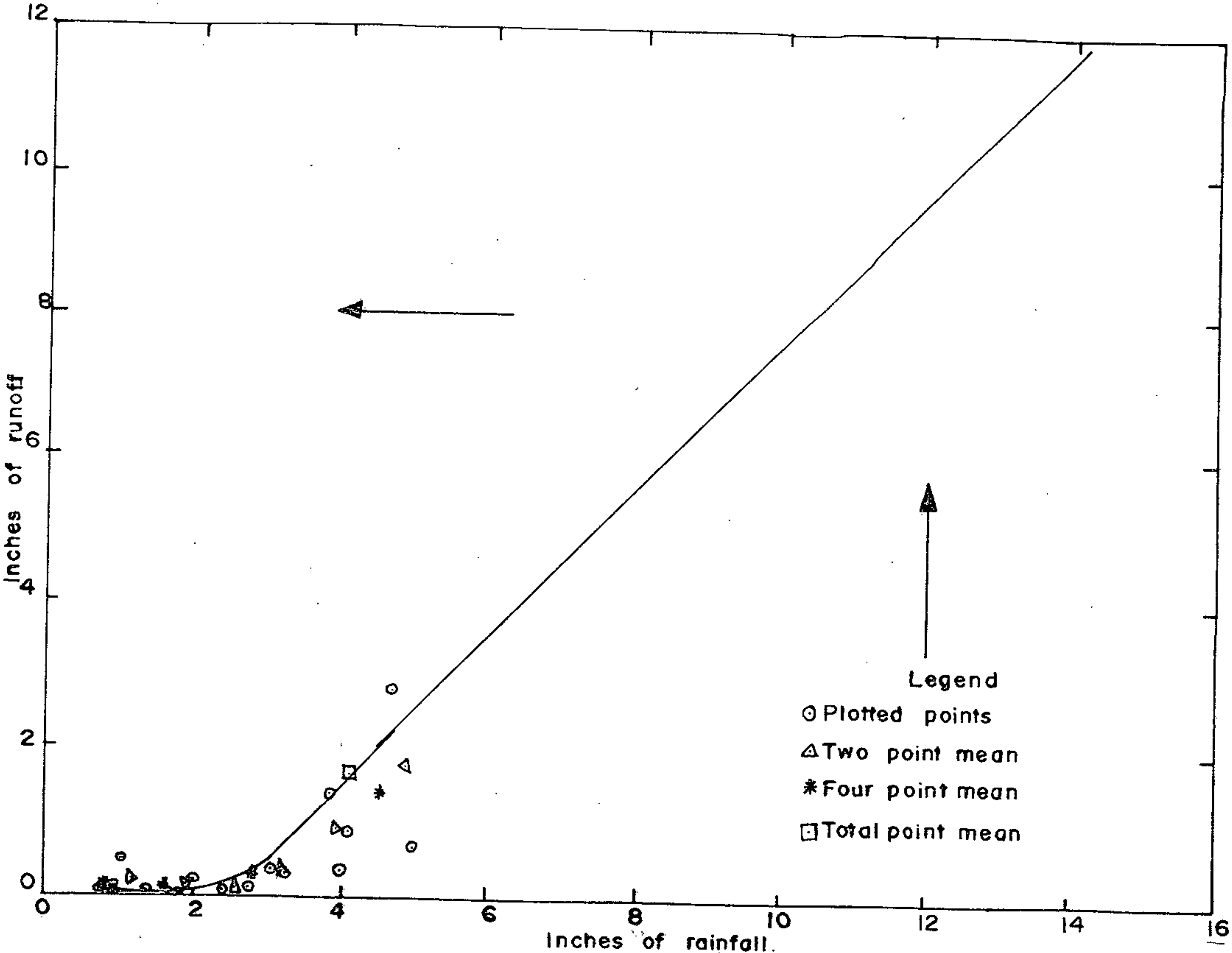


FIG. 23. Rainfall – runoff relation curve, Narayan Hat catchment area, Halda river basin.

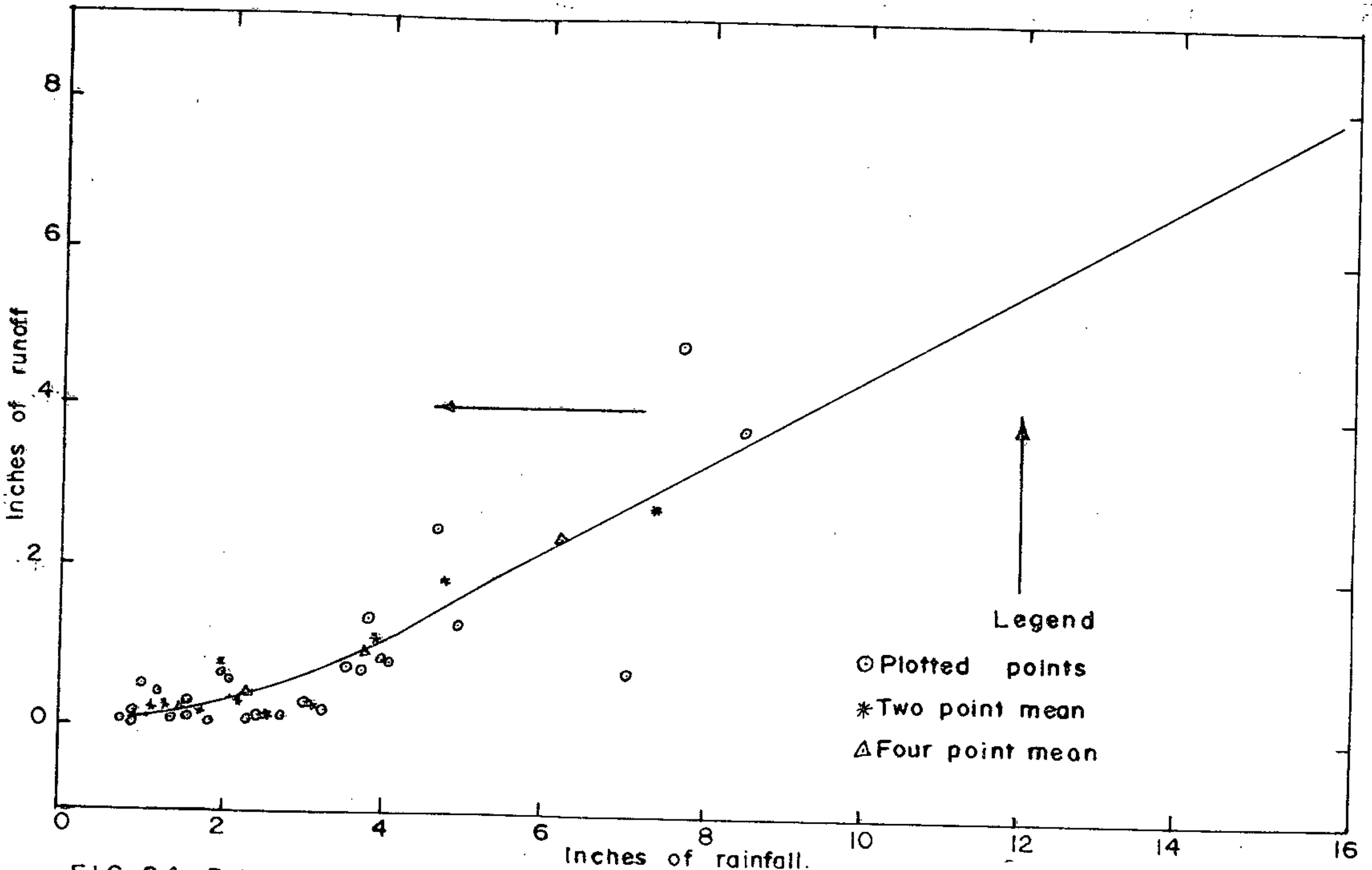


FIG. 24. Rainfall- runoff relation curve, South Sunderpur catchmen area, Halda river basin.

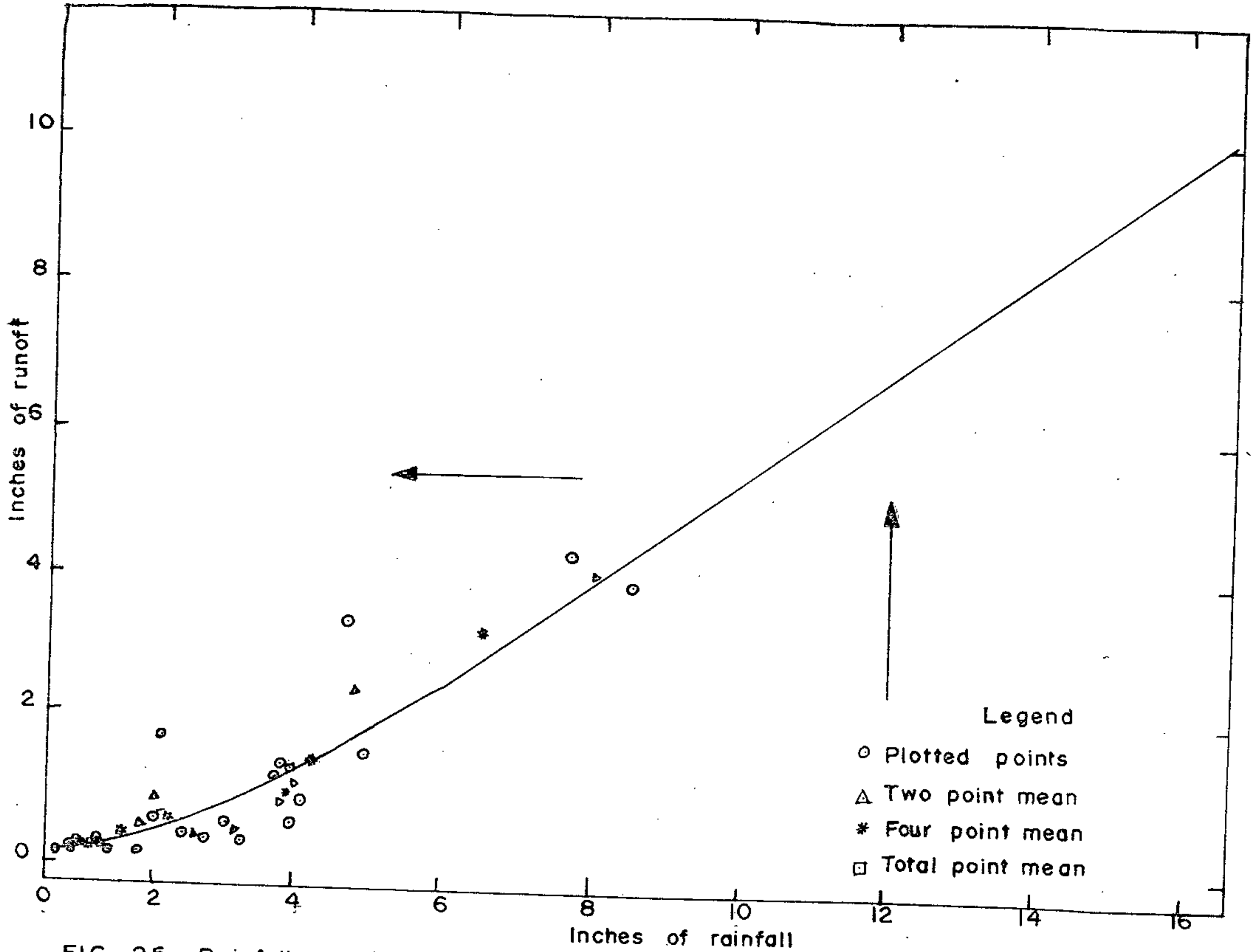


FIG. 25. Rainfall-runoff relation curve, Panch Pukuria catchment area, Halda river basin.

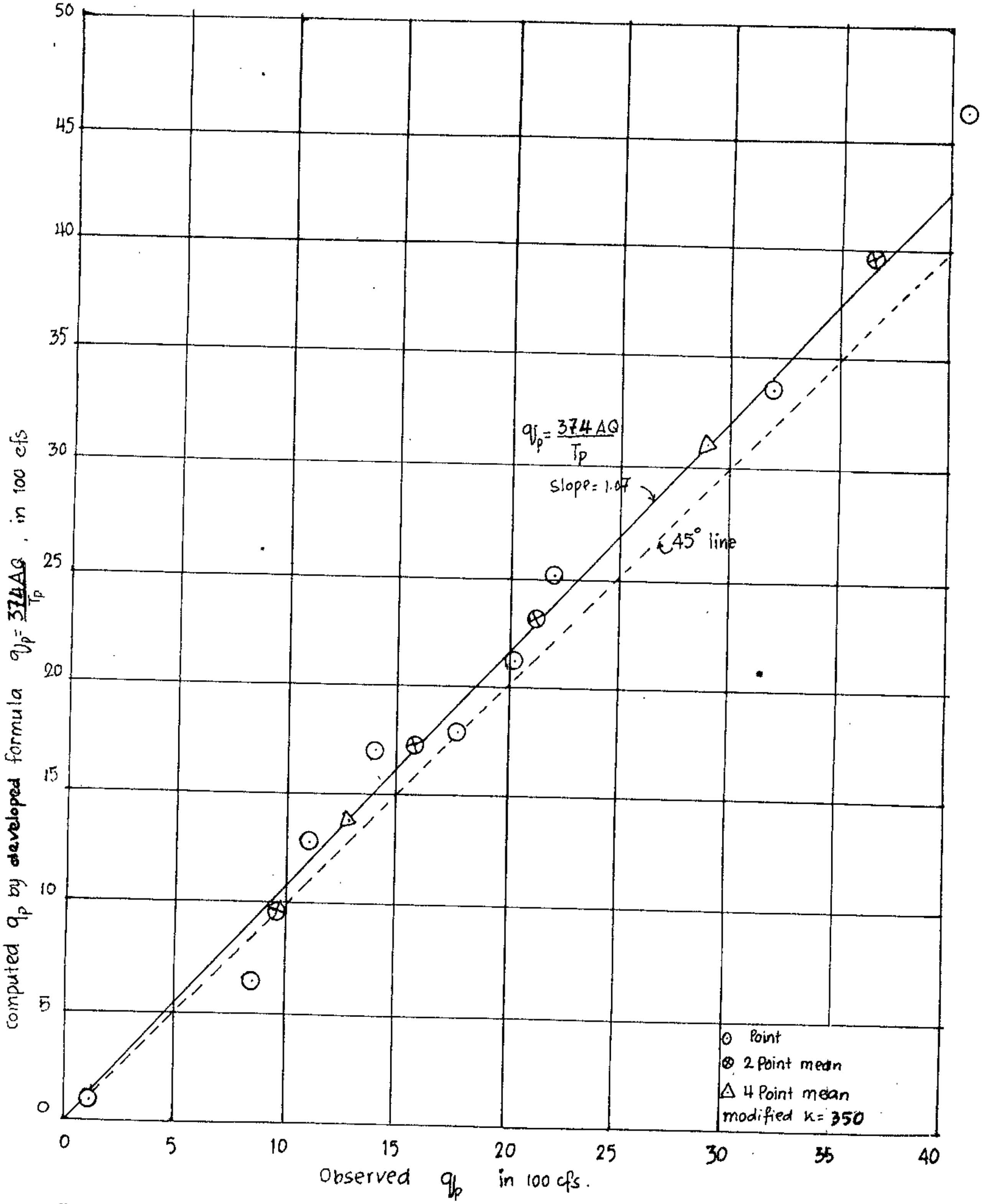


FIG. 26. Graphical relation of peak discharges, observed vs. estimated peaks Halda river at South Sunderpur.

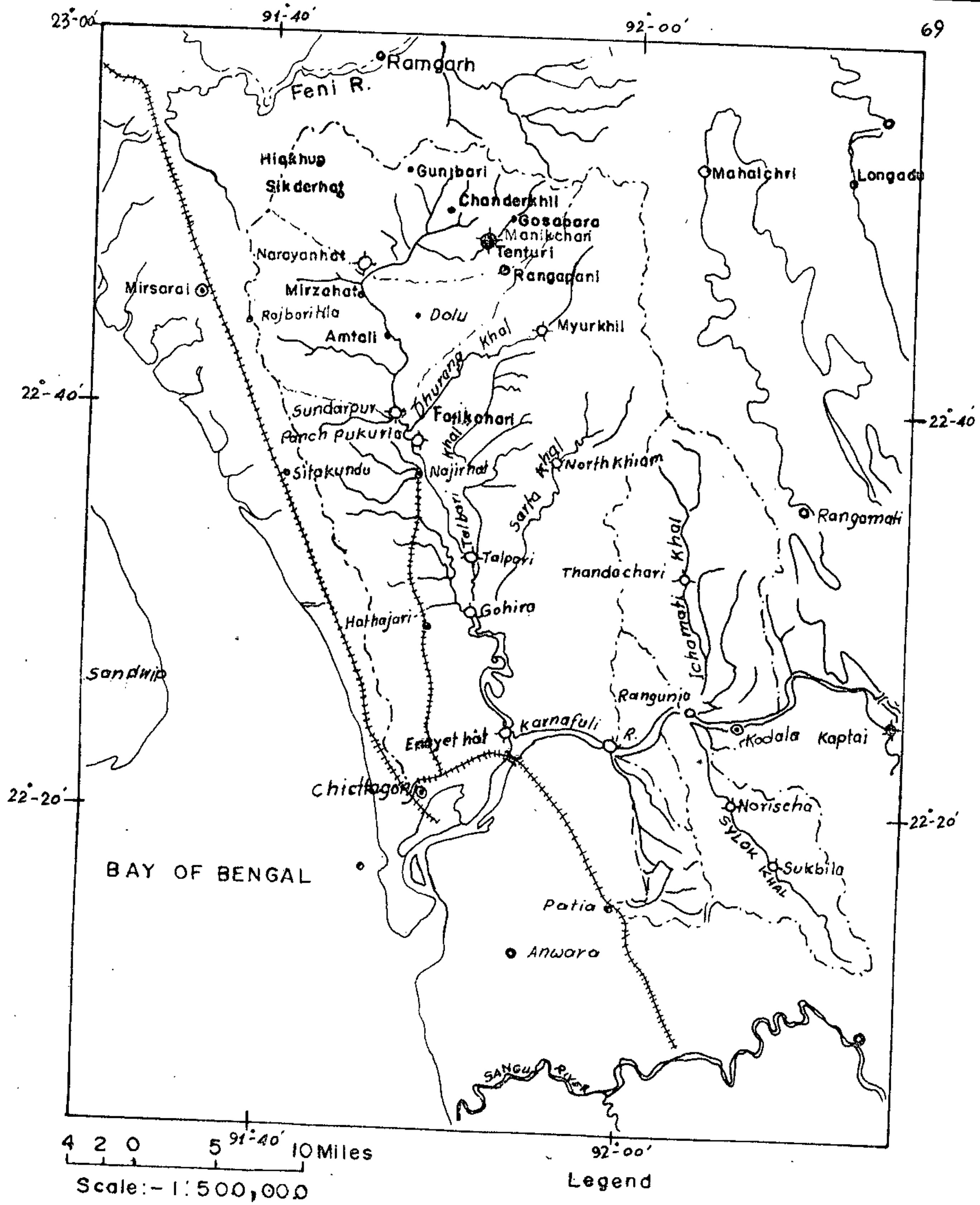


FIG. 27. Map of the Haldariver basin

Legend

New Rainfall station Est. after 1960

Old Rainfall station, Long Record

Gauging station

Water shed

National Boundary

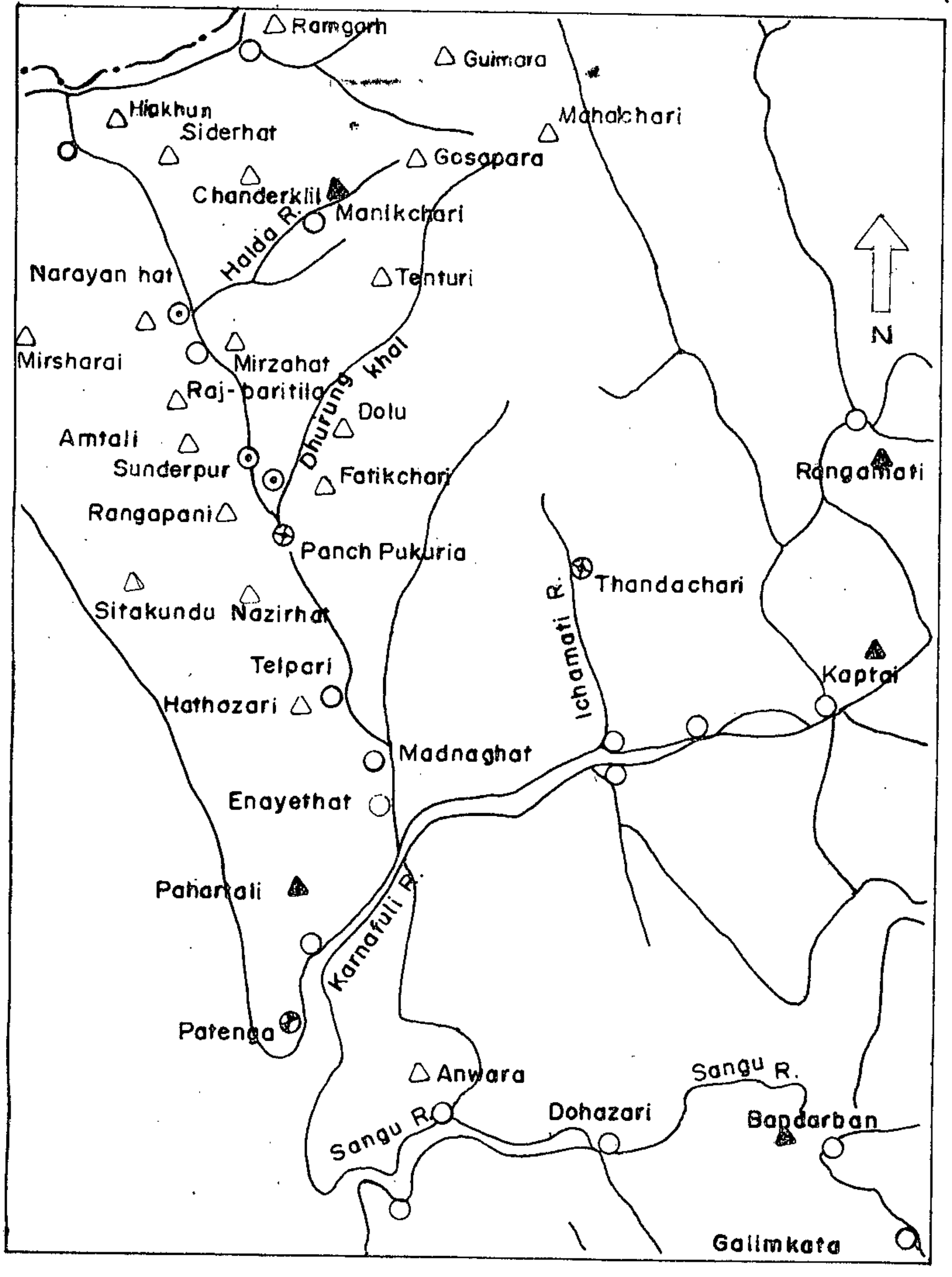


FIG. 28. Locations of rain gauge stations Halda river basin.

Scale: 1" = 8 miles

Legend

○ Gauge station

◎ Gauge & Discharge station

⊕ Gauge, Discharge & Silt station

▲ Raingauge & Evaporation

△ Raingauge station

⊗ Auto rain Gauge

APPENDIX - A

(DATA)

Rainfall data

1970-'71, 1972-'73, 1973-'74.

Precipitation data for the following rain-gage stations were used in this paper.

SL.No.	Name of the Stations
1.	Amtali
2.	Chander Khil
3.	Dolu
4.	Fatikchari
5.	Gui mara *
6.	Hia Khun
7.	Manikchari
8.	Mirza H at
9.	Marayan Hat
10.	Nazir Hat *
11.	Raj Bari Tilla
12.	Ram Garh *
13.	Ranga Pani
14.	Sikder Hat
15.	Tenturi
16.	Patenga Auto Rain Gage *
17.	Average Rainfall of the basin **

* These stations are situated beyond but adjacent the Halda River Basin Area.

** The average is arithematic average of the stations which are only within the boundary of the basin.

Sources:

1) Bangladesh Water Development Board

2) Bangladesh Meteorological Department

TABLE IV

Daily rainfall data (in inches) for 16 rainfall gauge stations in and around the Falda river basin; suitable storms used for Analysis of Hydrographs only are given. Indicates 0.00" of rainfall; Sources: Bangladesh Water Development Board.

Date	Amtali	Chander-Khil	Dolu	Fatik-chari	Gui-mara	Hia-Khun	Manik-chari
16.4.70	-	0.52	1.97	-	-	0.03	-
17.4.70	2.44	0.57	1.39	0.99	-	1.72	1.35
18.4.70	2.20	-	-	0.90	-	-	-
18.5.70	2.90	2.12	-	0.99	1.96	2.14	0.58
19.5.70	0.65	0.45	-	1.80	-	1.03	0.22
8.9.70	2.70	1.49	-	2.10	2.24	1.56	2.08
9.9.70	0.00	0.08	-	-	-	0.07	0.04
10.9.70	0.46	-	-	0.09	0.32	0.31	0.09
11.9.70	0.15	0.75	-	-	0.15	0.04	-
12.9.70	-	0.37	-	-	0.23	-	-
13.9.70	0.76	0.62	-	0.23	0.12	0.59	0.81
22.9.72	1.20	0.78	-	1.60	1.25	0.26	1.65
23.9.72	-	-	-	-	-	0.71	0.28
5.10.72	1.32	3.20	1.30	0.15	1.09	1.51	1.35

TABLE IV (Contd.)

Mirza-Hat	Narayan-Hat	Nazir-Hat	Raj Bari Tilla	Ram Garh	Ranga Pani	Sikder-Hat	Tenturi
-	-	-	0.34	-	-	-	-
4.20	1.80	2.50	0.15	2.32	4.00	-	-
0.55	0.60	0.47	0.04	1.94	-	-	-
-	2.10	2.55	2.86	4.70	3.10	3.65	0.64
-	0.60	0.50	0.21	0.66	2.90	0.55	0.28
-	2.10	3.90	1.25	1.20	4.00	1.34	0.13
0.13	0.10	-	-	0.96	0.15	0.06	-
-	0.15	-	0.54	0.20	-	0.08	-
-	-	0.20	-	0.10	-	0.07	-
-	-	0.50	0.18	-	0.05	-	-
1.26	1.40	1.35	0.67	0.80	0.43	0.10	-
0.25	1.20	0.95	0.23	3.80	0.10	0.33	-
0.50	0.15	0.25	-	0.05	-	0.68	-
0.34	0.30	0.33	0.31	0.78	0.31	1.45	0.04

TABLE IV (Contd.)

Patenga Auto rain gage	Average Rainfall of the basin	Remarks
-	0.02	Antecedent storm on 12.4.70 and next storm on 1.5.70, complex storm
1.36	1.55	
2.67	0.50	
1.85	1.75	Antecedent storm on 1.5.70 & next storm on 24.5.70, complex storm
0.80	0.72	
3.76	1.56	Antecedent storm on 2.9.70 next storm on 13.9.70
0.01	0.05	
0.05	0.14	
0.31	0.08	
0.02	0.05	
0.78	0.57	
0.98	0.76	Antecedent storm on 5.9.72; next storm 29.9.72, complex storm.
0.04	0.23	
0.54	0.96	Antecedent storm on 29.9.72 & next storm on 7.10.72.

TABLE V

Hourly rainfall data (in inches) for Patenga automatic rain gauge station; suitable storms used for Analysis of Hydrographs only are given; —— Indicates 0.00" of rainfall: Bangladesh standard Time from 0.00 hours to 24.00 hours.

Date/Hours	1	2	3	4	5	6	7
16.4.70	—	—	—	—	—	—	—
17.4.70	—	—	—	—	—	—	—
18.5.70	—	—	—	—	0.80	1.05	—
19.5.70	—	—	—	—	—	—	—
20.5.70	0.03	0.03	—	—	—	—	—
8.9.70	—	—	—	—	—	—	—
9.9.70	0.86	0.07	1.00	0.20	0.43	0.05	0.08
21.9.72	—	—	—	—	—	—	—
22.9.72	—	—	—	—	—	—	—
5.10.72	—	—	—	—	—	0.06	0.27
6.10.72	—	—	0.20	—	—	—	—

TABLE V (Contd.)

8	9	10	11	12	13	14	15	16
-	-	-	-	-	-	-	0.94	0.42
-	-	-	0.31	0.01	0.32	0.18	0.38	1.45
-	-	-	-	-	-	-	-	-
-	-	-	0.60	0.20	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	0.16
-	-	-	-	-	-	0.02	0.02	-
0.13	0.03	-	-	-	-	-	-	-
-	-	-	-	-	-	-	0.03	-

TABLE V (Contd.)

17	18	19	20	21	22	23	24	Remarks
-	-	-	-	-	-	-	-	Antecedent storm on 20.2.70 and next storm On 6.5.70
-	-	-	0.01	-	0.01	-	-	
-	-	-	-	-	-	-	-	Antecedent storm on 17.4.70 and next storm on 23.5.70
-	-	-	-	-	-	-	-	
-	-	-	-	-	-	-	-	
-	-	-	-	-	-	-	0.24	Antecedent storm on 1.9.70 & next storm On 10.9.70
-	-	-	-	-	0.01	-	-	
-	0.10	-	0.03	0.67	-	0.16	0.02	Antecedent storm on 31.8.72 & next storm on 29.9.72
-	-	-	-	-	-	-	-	
-	-	-	-	-	-	-	-	Antecedent storm on 30.9.72 & next storm on 7.10.72
0.01	-	0.01	-	-	-	-	-	

DAILY COMPUTED DISCHARGE RECORDS
OF THE HALDA RIVER AT
NARAYAN HAT, SOUTH SUNDERPUR AND PANCH PUKURIA DISCHARGE
STATIONS FOR THE YEARS
1970-'71, 1972-'73 and 1973-'74

SOURCES: BANGLADESH WATER DEVELOPMENT BOARD

TABLE VI

River Halda, Station: Narayan Hat, Average daily discharge for the year 1970-'71.

Date	Apr. '70	May '70	Jun. '70	Jul. '70	Aug. '70	Sept. '70	Oct. '70	Nov. '70	Dec. '70	Jan. '71	Feb. '71	Mar. '71
1	20	31	44	112	580	955	284	502	195	84	44	12
2	31	31	112	98	454	580	338	276	195	84	44	12
3	31	31	84	71	408	438	502	250	195	84	31	12
4	31	31	98	31	352	325	1900	219	183	84	31	12
5	31	31	57	57	338	284	1550	208	183	71	31	12
6	31	31	44	230	305	250	830	195	183	71	31	12
7	20	31	170	230	276	230	454	195	183	71	31	7
8	20	31	122	133	408	1200	338	195	170	71	31	3
9	20	31	184	146	408	665	295	183	157	71	31	3
10	20	31	57	770	378	408	267	183	157	71	12	
11	57	57	44	4640	378	352	240	170	157	71	31	
12	31	57	44	9940	520	284	230	230	146	71	31	Not Recorded
13	31	40	44	8820	770	395	219	8820	146	71	31	
14	31	20	44	6680	438	335	208	7200	146	57	31	
15	31	20	44	5380	325	284	183	2780	146	57	31	
16	31	20	57	1400	990	250	183	1030	146	57	31	
17	84	20	84	3510	640	230	170	580	146	57	20	
18	71	122	98	5380	580	219	133	490	146	57	20	
19	44	84	502	2860	325	208	157	408	146	57	20	
20	44	17	770	990	228	208	157	378	133	57	20	
21	44	84	420	690	1030	195	146	365	122	57	20	
22	31	112	250	2860	740	183	146	338	122	57	20	
23	31	98	170	7330	665	1350	395	315	112	57	20	
24	31	15	183	8240	1450	540	640	284	112	57	12	
25	31	15	146	6940	920	770	338	258	112	44	12	
26	31	84	84	4540	502	560	284	240	98	44	12	
27	31	84	57	1970	378	408	240	230	98	44	12	
28	31	71	57	860	378	267	208	219	98	44	12	
29	31	57	71	1070	1250	240	183	208	98	44	12	
30	31	57	84	1260	2050	230	258	208	84	44	12	
31	–	44	–	800	1840	–	740	–	84	44	12	

TABLE VI (Contd.)

River Halda, Station: Narayan Hat, Average daily discharge for the year 1972-'73

Date	Apr. '72	May '72	Jun. '72	Jul. '72	Aug. '72	Sept. '72	Oct. '72	Nov. '72	Dec. '72	Jan. '73	Feb. '73	Mar. '73
1	29	38	38	79	308	244	85	64	48	33	33	375
2	38	33	33	79	560	206	85	64	48	33	33	206
3	38	33	29	70	485	190	74	64	48	33	33	108
4	38	33	29	63	333	206	74	64	48	33	33	64
5	38	33	29	56	600	225	400	56	48	33	33	56
6	38	33	29	50	1600	176	230	56	48	33	33	56
7	50	33	29	44	1490	134	244	56	48	33	27	48
8	44	33	29	44	600	120	190	56	48	33	27	48
9	44	33	29	44	415	108	300	56	40	33	27	48
10	38	29	63	38	520	96	263	56	40	33	33	48
11	33	29	29	38	285	108	162	56	40	33	33	48
12	33	29	63	33	360	108	148	56	40	33	33	48
13	33	29	108	33	285	96	190	56	48	33	33	48
14	33	29	1380	29	485	96	162	56	48	33	33	48
15	33	29	1050	33	308	85	120	56	40	33	33	40
16	33	29	1210	50	600	85	108	56	40	33	33	40
17	38	29	5080	63	640	74	108	56	40	33	33	33
18	50	29	2260	1860	333	74	96	56	40	33	33	33
19	88	25	1210	3640	224	74	85	56	40	33	33	33
20	70	25	880	4940	173	64	85	48	40	33	33	27
21	63	98	224	3700	132	64	85	48	40	33	27	27
22	50	600	158	1860	188	760	85	48	40	33	27	33
23	44	120	360	780	158	263	74	48	40	33	27	33
24	38	79	450	360	990	134	74	48	40	33	27	27
25	33	63	244	138	680	120	74	48	40	33	27	27
26	29	56	188	205	450	120	74	40	40	33	27	27
27	29	70	145	224	302	108	64	40	40	27	27	27
28	44	264	108	600	263	108	64	40	40	27	27	27
29	38	98	98	2320	206	108	64	48	40	27	27	27
30	38	56	88	830	206	96	64	48	40	27	27	27
31	-	44	-	308	325	-	64	-	40	27	27	27

TABLE VI (Contd.)

River Halda, Station: Narayan Hat, Average daily discharge for the year 1973-'74

Date	Apr. '73	May '73	Jun. '73	Jul. '73	Aug. '73	Sept. '73	Oct. '73	Nov. '73	Dec. '73	Jan. '74	Feb. '74	Mar. '74
1	26	495	213	299	1200	263	1040	174	142	89	49.5	44.5
2	26	35	236	230	616	214	1110	166	142	83	49.5	39.5
3	305	35	201	194	410	192	432	192	136	83	49.5	39.5
4	305	39	188	186	337	289	317	244	130	83	49.5	35
5	305	475	377	161	292	186	261	232	130	77	49.5	35
6	305	89	739	218	286	224	234	878	134	77	49.5	30.5
7	26	866	375	185	1590	398	220	4410	142	77	44.5	39.5
8	26	768	246	164	636	342	197	2620	166	77	44.5	35
9	26	1900	319	147	508	204	188	1160	220	71	44.5	35
10	26	1080	796	120	1270	383	216	720	341	71	44.5	35
11	26	1430	394	990	871	185	188	436	278	71	44.5	35
12	26	866	291	870	480	177	168	376	196	71	39.5	35
13	26	439	246	870	356	161	164	330	148	71	39.5	30.5
14	26	292	918	150	289	173	154	278	142	71	39.5	30.5
15	26	196	796	146	284	192	154	244	140	655	39.5	30.5
16	26	154	397	108	393	228	146	292	130	655	39.5	30.5
17	26	135	1330	890	342	216	142	355	130	60	39.5	30.5
18	26	182	1850	870	460	204	136	442	127	60	39.5	30.5
19	26	142	970	321	426	196	130	390	125	60	39.5	30.5
20	26	122	658	196	331	173	130	341	130	60	39.5	17.2
21	26	99	530	182	285	320	126	299	127	60	39.5	12.2
22	26	99	459	189	226	309	130	238	125	60	35.0	83.0
23	29	87	271	849	278	309	156	208	111	60	35.0	71.0
24	60	306	225	369	424	240	200	190	107	60	35.0	49.5
25	95	520	198	415	359	195	1150	184	107	60	35.0	65.5
26	107	425	414	422	281	253	1190	174	101	54.5	30.5	71.0
27	77	320	317	946	275	209	520	166	95	54.5	30.5	71.0
28	130	292	309	3230	323	368	390	162	95	54.5	44.5	65.5
29	119	214	634	1940	272	516	286	154	95	54.5	-	47.5
30	95	166	403	1140	341	331	236	142	89	54.5	-	44.5
31	-	446	-	833	306	-	200	-	89	49.5	-	12.7

TABLE VI (Contd.)

River Halda, Station: South Sunderpur, Average daily discharge for the year 1970-'71

Date	Apr. '70	May '70	Jun. '70	Jul. '70	Aug. '70	Sept. '70	Oct. '70	Nov. '70	Dec. '70	Jan. '71	Feb. '71	Mar. '71
1	50	50	196	295	2590	3360	1170	1490	543	281	175	35
2	113	50	415	396	2420	3810	1590	990	524	281	161	35
3	113	50	630	375	2650	2050	1680	790	505	281	148	35
4	97	50	955	254	1360	1460	2530	680	462	281	148	35
5	81	50	375	396	1140	1210	2590	655	462	281	148	22
6	81	50	437	1250	1070	900	2240	630	443	266	134	35
7	66	50	655	980	1140	840	2280	630	424	266	134	35
8	66	50	535	735	1170	2720	1850	543	424	266	134	35
9	50	66	375	605	1510	1390	1390	462	424	266	134	35
10	81	50	254	1250	1320	1950	1040	443	405	281	134	23
11	234	50	196	5520	1290	1590	770	483	389	281	121	23
12	128	50	215	10400	1550	1320	655	655	370	281	121	23
13	113	50	145	16000	2000	1430	585	5520	350	266	121	23
14	97	35	215	12700	1360	1630	585	4560	350	234	121	23
15	81	36	274	10130	1210	1100	655	4920	350	204	108	23
16	66	36	196	6900	1210	1100	630	4460	350	204	108	23
17	274	36	335	4740	1430	1140	563	4050	335	204	108	23
18	415	145	295	3360	1720	1030	543	3500	335	204	108	11
19	335	510	735	5730	1320	900	462	2330	335	190	108	11
20	196	234	2000	6040	1030	680	424	1490	317	204	108	23
21	145	128	1590	4920	1550	485	424	1110	317	190	108	11
22	96	315	810	7840	2100	460	630	1020	335	190	108	11
23	97	396	760	14500	2250	1250	990	1020	317	190	96	11
24	81	396	710	16900	2780	2530	2050	945	299	190	84	11
25	81	396	580	14500	2590	1900	1670	790	299	190	72	11
26	81	375	680	10300	2300	1630	1040	655	317	190	59	11
27	81	460	535	6900	2650	1320	655	655	299	405	47	11
28	50	315	355	4470	2480	1290	462	608	281	370	47	11
29	50	196	315	3730	2250	1070	524	585	281	370	47	-
30	50	196	274	3500	3500	810	1790	585	281	190	-	-
31	-	196	-	3210	3580	-	1670	-	-	190	-	-

TABLE VI (Contd.)

River Halda, Station South Sunderpur, Average daily discharge for the year 1972-'73

Date	Apr. '72	May '72	Jun. '72	Jul. '72	Aug. '72	Sept. '72	Oct. '72	Nov. '72	Dec. '72	Jan. '73	Feb. '73	Mar. '73
1	50	50	76	355	2190	692	526	210	113	68	38	262
2	90	50	52	355	2140	632	624	184	113	68	28	318
3	76	50	50	415	2660	975	374	184	113	68	21	318
4	62	50	76	275	2360	889	262	160	113	68	21	210
5	90	40	124	225	2030	889	760	184	113	90	21	136
6	90	40	106	200	3040	975	1115	184	113	90	21	90
7	76	40	76	250	2250	624	624	184	90	90	21	38
8	62	40	62	225	2840	558	624	184	90	90	21	28
9	62	40	62	160	2450	526	1080	160	90	90	21	28
10	50	21	62	180	1700	430	1550	160	113	90	21	28
11	50	21	62	160	1600	402	889	160	113	90	21	28
12	50	21	200	142	2050	494	803	160	113	90	16	21
13	40	21	770	142	2400	462	803	160	113	90	16	21
14	50	21	1830	142	1950	346	803	136	113	90	16	38
15	30	21	3250	142	1650	346	624	136	90	90	16	21
16	30	21	2190	160	3010	318	590	136	113	90	16	21
17	30	21	4030	325	3190	318	494	146	113	90	28	16
18	50	76	6370	3320	2830	318	374	136	113	90	38	16
19	62	62	4750	4840	1900	290	374	113	113	90	28	16
20	62	62	4030	6730	1150	262	346	113	90	90	21	12
21	62	1830	2540	7990	932	236	318	113	90	68	16	9
22	62	1720	2360	6910	1150	975	290	113	90	68	16	9
23	50	690	3110	5440	1050	1080	262	136	90	68	16	9
24	40	275	1460	3880	1800	846	262	160	90	50	16	9
25	40	180	1230	2300	2300	624	262	136	90	50	16	9
26	30	142	1410	1010	2400	430	262	136	90	50	16	9
27	30	104	1280	1230	1950	262	262	136	90	50	[illegible]	9
28	160	545	1010	1880	1550	402	236	160	90	38	16	9
29	124	580	580	4510	1250	374	210	136	90	38	[illegible]	9
30	50	200	300	4930	975	526	210	136	68	38	-	9
31	50	106	[illegible]	4030	1150	[illegible]	210	136	68	38	-	9

TABLE VI (Contd.)

River Halda, Station: South Sunderpur, Average daily discharge for the year 1973-'74

Date	Apr. '73	May '73	Jun. '73	Jul. '73	Aug. '73	Sept. '73	Oct. '73	Nov. '73	Dec. '73	Jan. '74	Feb. '74	Mar. '74
1	19	217	660	1080	2500	895	1910	540	436	246	130	50
2	19	157	660	898	2620	828	2330	540	398	246	122	50
3	23	146	680	714	1840	864	1670	735	386	246	114	50
4	19	122	1110	777	1520	570	1450	903	386	246	114	50
5	19	130	2070	690	1470	600	1140	1350	374	246	119	50
6	19	253	2620	750	1210	1400	913	1590	362	235	114	43
7	19	585	2470	768	1970	1430	770	5410	374	224	106	36
8	19	1080	2450	612	2410	1300	660	4300	410	213	106	36
9	19	2980	2620	511	2090	1300	493	4900	594	206	98	31
10	19	2890	2770	410	1960	1010	462	4070	1120	202	98	31
11	19	3070	2950	386	2450	895	457	2580	735	202	98	26
12	17	2940	1350	386	2640	588	436	1590	519	191	90	26
13	14	2280	1430	374	2170	540	379	1100	436	198	90	26
14	13	1400	4400	386	1300	540	362	878	403	191	87	26
15	13	750	2870	473	549	532	350	630	326	191	82	21
16	13	570	2970	462	1820	672	350	514	314	180	82	19
17	13	488	2830	396	2430	681	374	705	302	180	69	21
18	13	410	5420	362	1940	711	362	1080	290	180	65	18
19	13	436	3680	362	1740	666	374	1120	290	162	62	26
20	13	398	2900	386	1220	561	350	858	290	162	62	26
21	13	374	2630	756	958	690	357	750	290	162	55	162
22	13	360	2000	690	865	1430	362	750	268	154	58	171
23	13	326	1210	1920	780	1430	326	630	268	154	55	154
24	566	345	1060	1640	717	1490	314	540	268	146	55	180
25	555	953	955	2920	1360	1150	1050	540	268	146	55	307
26	527	1740	979	1800	1710	618	1460	488	268	146	53	326
27	410	2060	963	2670	1690	564	1780	475	268	141	55	426
28	398	1830	1300	2190	1520	1440	1260	462	268	141	50	462
29	345	1130	1190	3230	883	1210	1000	454	253	141	50	138
30	336	878	997	3350	910	1660	681	436	246	138	-	114
31	-	720	-	702	1150	-	546	-	246	135	-	283

TABLE VI (Contd.)

River Halda, Station: Panch Pukuria, Average daily discharge for the year 1970-'71

Date	Apr. '70	May '70	Jun. '70	Jul. '70	Aug. '70	Sept. '70	Oct. '70	Nov. '70	Dec. '70	Jan. '71	Feb. '71	Mar. '71
1	47	110	268	420	1390	4520	1800	2520	485	300	208	74
2	208	92	580	450	2460	3980	1950	1850	485	300	185	62
3	185	92	1070	390	1850	2870	2700	1400	450	300	185	62
4	155	92	1480	420	1650	2120	3120	1180	450	300	185	62
5	110	92	940	690	1290	1700	3770	1070	420	300	185	62
6	110	74	730	2170	1440	1290	3620	970	420	300	185	62
7	74	92	1040	1600	1330	1070	3190	875	420	300	155	62
8	74	74	730	1070	1700	3910	2760	910	390	330	155	62
9	74	92	580	730	1900	3480	2280	800	360	300	155	51
10	130	74	485	2870	1800	2700	1290	800	360	330	130	62
11	360	92	330	6780	1700	1750	1070	910	360	300	130	62
12	238	92	600	10800	1900	1360	970	1110	330	268	130	62
13	185	74	268	11700	2700	1520	940	8700	330	300	130	62
14	130	74	485	10000	2280	2000	910	8600	330	238	130	51
15	110	74	390	9100	1850	1650	835	6860	360	268	110	51
16	110	92	360	7290	2400	1250	800	6440	330	268	110	51
17	1330	92	550	5500	2460	1140	730	4520	330	238	110	51
18	1040	485	835	8100	2460	1070	690	2760	360	238	110	41
19	420	910	1750	7830	1560	1000	655	1950	330	238	110	41
20	330	800	3330	6350	1210	1330	655	1480	330	238	92	41
21	238	330	2340	5670	2400	1360	655	1140	330	238	92	62
22	208	520	1210	8300	2870	940	1180	765	300	238	92	62
23	185	620	1110	9700	2580	3330	2000	690	300	238	92	51
24	155	550	1180	10400	3700	3050	3050	690	300	238	74	51
25	130	685	910	8200	3480	2820	2170	655	300	238	62	62
26	130	655	690	8010	2700	2640	1440	620	300	208	62	51
27	110	800	620	6860	2220	2280	1040	580	300	208	62	62
28	92	450	550	5150	1950	1850	875	550	300	208	74	62
29	92	330	450	4450	3480	1210	730	520	300	238	-	51
30	92	238	390	4310	4170	1070	1600	520	300	238	-	62
31	-	208	-	3330	4450	-	3270	-	300	238	-	51

TABLE VI (Contd.)

River Halda, Station: Panch Pukuria, Average daily discharge, for the year 1972-'73

Date	Apr. '72	May '72	Jun. '72	Jul. '72	Aug. '72	Sept. '72	Oct. '72	Nov. '72	Dec. '72	Jan. '73	Feb. '73	Mar. '73
1	85	85	146	306	2900	1300	570	275	163	100	66	345
2	68	68	124	370	2430	1170	530	275	163	100	52	770
3	220	85	104	370	3220	1170	380	275	163	82	52	530
4	85	85	85	277	2620	1080	380	275	140	120	40	215
5	124	68	104	192	2430	1350	1300	275	140	189	40	163
6	84	68	146	169	3620	1260	1210	245	140	140	40	120
7	192	53	124	124	3860	770	940	245	140	120	40	100
8	169	40	104	146	3700	690	1030	245	140	120	40	82
9	124	40	104	146	2900	650	1850	215	120	100	40	52
10	85	29	85	124	2130	610	2250	215	140	100	40	40
11	85	29	85	104	1950	530	1390	215	140	100	40	29
12	68	29	744	104	1600	850	1750	215	140	100	29	29
13	104	19	1250	85	1600	570	1390	189	140	82	29	40
14	85	29	1010	85	1830	490	1030	189	140	100	29	52
15	68	29	3380	85	1770	450	850	189	140	100	29	40
16	53	40	2760	124	3380	415	730	189	120	100	29	29
17	40	40	5800	586	4260	380	650	163	120	82	52	20
18	85	40	8260	4420	3420	380	570	163	120	82	40	20
19	440	85	6800	6000	2350	345	530	189	120	82	52	20
20	306	53	4340	9220	2050	345	490	189	120	82	40	13
21	104	306	2830	9940	1260	380	450	189	120	82	40	13
22	104	2310	1300	7800	1530	1350	415	189	140	100	40	13
23	85	920	1400	5400	1300	850	380	163	140	82	40	13
24	68	405	1400	3540	1850	650	380	189	120	100	29	7
25	53	248	1060	2130	2790	490	345	189	120	100	29	13
26	40	192	966	1350	2790	450	345	215	120	82	29	13
27	40	169	788	1450	1950	650	345	215	120	82	29	13
28	192	744	586	2310	1570	530	310	245	120	82	20	13
29	169	510	510	5600	1620	850	310	189	120	66	-	13
30	85	248	335	4740	1440	650	310	163	100	66	-	7
31	-	220	-	3460	1480	-	275	-	100	66	-	7

TABLE VI (Contd.)

River Halda, Station: Panch Pukuria, Average daily discharge for the year 1973-'74

Date	Apr. '73	May '73	Jun. '73	Jul. '73	Aug. '73	Sept. '73	Oct. '73	Nov. '73	Dec. '73	Jan. '74	Feb. '74	Mar. '74
1	19	106	1610	1240	3300	1230	3430	662	530	338	143	55
2	16	85	864	824	2830	799	4140	612	495	338	156	55
3	19	66	720	670	1940	709	3110	623	495	338	156	63
4	19	62	522	835	1320	684	1660	857	460	325	130	55
5	16	62	3260	655	792	648	1090	706	460	325	122	55
6	13	915	3980	857	644	1410	915	1500	425	325	122	55
7	16	1470	3290	655	2270	1480	817	9280	425	286	122	55
8	16	1230	2510	457	2790	1070	734	7720	495	278	113	47
9	19	3890	1990	393	2550	738	677	6800	760	260	113	47
10	16	3990	3810	356	1810	930	672	6180	1250	247	113	47
11	16	3430	2450	333	3420	812	631	4190	940	247	105	47
12	16	2980	1470	333	3090	770	487	2690	705	247	105	47
13	15	2280	1310	310	1920	706	576	1820	585	260	96	47
14	13	1540	5360	322	1430	706	540	1670	495	260	96	37
15	15	720	4130	450	1100	727	540	1520	351	260	875	37
16	13	471	3530	349	1600	1060	517	1420	460	252	875	37
17	16	648	4980	310	3740	940	517	1570	425	299	875	27
18	16	630	5840	294	3510	1070	529	2480	425	286	71	27
19	13	425	4960	2160	2030	850	517	1960	390	286	71	23
20	10	368	4280	1320	1150	540	554	1730	390	273	71	23
21	10	294	3290	810	1140	910	499	1510	390	247	71	169
22	760	270	2440	893	893	1740	558	1450	390	169	79	234
23	760	238	1250	3260	742	1830	471	1430	364	169	71	122
24	128	278	940	2240	648	1780	540	1260	364	169	71	71
25	414	1890	547	4760	1180	1570	695	1180	338	169	71	195
26	238	2350	900	3000	1090	1240	3510	1160	338	156	71	143
27	117	1650	1790	3390	1040	1240	3230	600	338	156	71	234
28	106	1890	1230	5780	1670	1080	2300	565	338	156	63	47
29	106	1350	1990	6020	1040	2040	1330	565	338	143	-	37
30	262	810	1740	5340	1740	2200	975	630	351	143	-	63
31	-	1510	-	4070	1810	-	770	-	351	143	-	71

A P P E N D I X - B

(Calculation Sheets)

APPENDIX - B

Sample Calculation Sheet for the Development of Unit Hydrograph for Narayan Hat Discharge Station.

Sample Calculation Sheet for the Application of S-Curve Method

Calculation Sheets for the development of Average Unit Hydrographs for Narayan Hat, South Sunderpur and Panch Pukuria Discharge Station.

Calculation Sheet for rainfall and runoff relation for Narayan Hat, South Sunderpur and Panch Pukuria discharge Stations.

Calculation Sheet for the test of consistency of rainfall records for Fatikchari, Chittagong, Amtali, Dolu & Mirza Hat Stations by Double Mass Curve Analysis.

Calculation Sheet for synthesized hydrographs at Narayan Hat and South Sunderpur discharge stations.

TABLE VII

Calculation Sheet for Unit Hydrograph; Halda river at Narayan Hat discharge station, 1 hour unit hydrograph (From Figure 4)

Date	Hour	Total Flow	Base Flow	Direct Runoff	Unit Hydrograph Ordinates	Hours after start	
Sept. 21,'72	1200	64	64	0	0	0	
	1800	64	64	0	0	0	
	2400	120	64	56	149	6	
Sept. 22,'72	0600	450	64	386	1022	12	Drainage Area = 73 sq.miles
	1200	760	64	696	1850	18	Effective Duration = 1 hour.
	1800	660	70	590	1570	24	Av. Basin rainfall = 0.76 "
	2400	530	75	455	1210	30	Total Volume in inches.
Sept. 23,'72	0600	400	80	320	850	36	$= \frac{2961 \times 6}{73 \times 26.9 \times 24}$ = 0.377 inches.
	1200	263	85	178	478	42	
	1800	215	92	123	326	48	Storm on 21,9,'72
	2400	175	100	75	199	54	Patenga Rain chart (Effective Period)
Sept. 24,'72	0600	150	105	45	120	60	Started at 2000 hrs. & Ended at 2100 hrs.
	1200	134	110	24	64	66	
	1800	128	115	13	35	72	on 21,9,1972
	2400	125	125	0	0	78	
			Total	2961 cfs,			

TABLE VIII

Application of 'S'Curve method (a sample calculation sheet) 3 hour and 6 hour unit hydrograph from 1 hour unit hydrograph for Halda river at Narayan Hat Discharge station.(From Figure 4 & Table VII)

Time hour	1 hr. U.G.	S-Curve additions	S-curve Col.(2) +(3)	S-Curve lagged by 6 hr.	Col.(4) -(5)	6 hr. U.G.Col (6) x $\frac{1}{6}$	S-Curve lagged 3 hr.	Col.(4) -(8)	3 hr. U.G. Col.(9)x $\frac{1}{3}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
0	0	0	0	0	0	0	0	0	0
1	10	0	10	0	10	2	0	10	3
2	30	10	40	0	40	7	0	40	13
3	50	40	90	0	90	15	0	90	30
4	80	90	170	0	170	28	10	160	53
5	115	170	285	0	285	48	40	245	82
6	149	285	434	0	434	72	90	344	115
7	200	434	634	10	624	104	170	464	155
8	260	634	894	40	854	142	285	609	203
9	330	894	1224	90	1134	189	434	940	313
10	420	1224	1644	170	1474	246	634	1210	403
11	540	1644	2184	285	1899	317	894	1290	430
12	1020	2184	3204	434	2770	462	1224	1980	660
13	1320	3204	4524	634	3890	648	1644	3500	1166
14	1460	4524	5984	894	5090	448	2184	3800	1266
15	1580	5984	7564	1224	6340	1057	3204	4360	1453
16	1680	7564	9244	1644	7600	1267	4524	4720	1573
17	1780	9244	11024	2184	8840	1307	5984	5040	1680
18	1850	11024	12874	3204	9670	1612	7564	5310	1770
19	1820	12874	14694	4524	10170	1695	9244	5450	1817
20	1780	14694	16474	5984	10490	1748	11024	5450	1817
21	1740	16474	18214	7564	10650	1775	12874	5340	1747
22	1700	18214	19914	9244	10670	1778	14694	5220	1740
23	1640	19914	21554	11024	10530	1755	16474	5080	1693
24	1570	21554	23124	12874	10250	1708	18214	4910	1637
25	1520	23124	24644	14694	9950	1658	19914	4730	1577
26	1480	24644	26124	16474	9650	1608	21554	4570	1523

TABLE VIII

Application of 'S'-Curve method (Contd.)

Time hour (1)	1 hr. U.G. (2)	S-Curve additions (3)	S-Curve Col.(2)+(3) (4)	S-Curve lagged by 6 hr. (5)	Col.(4)-(5) (6)	6 hr. U.G. Col.(6) x $\frac{1}{6}$ (7)	S-Curve lagged 3 hr. (8)	Col.(4)-(8) (9)	3 hr, U.G. Col.(9) x $\frac{1}{3}$ (10)
56	165	45023	45188	43954	1234	206	44644	544	181
57	150	45188	45338	44204	1134	189	44843	495	165
58	140	45338	45478	44434	1044	174	45023	455	152
59	130	45478	45608	44644	0964	161	45188	420	140
60	120	45608	45728	44843	885	147	45338	390	130
61	110	45728	45838	45023	815	136	45478	360	120
62	110	45838	45948	45188	760	127	45608	340	113
63	90	45948	46038	45338	700	117	45728	310	103
64	80	46038	46118	45478	640	107	45838	280	93
65	70	46118	46188	45608	580	97	45948	240	80
66	64	46188	46252	45728	524	87	46038	214	71
67	55	46252	46307	45838	469	78	46118	189	63
68	45	46307	46352	45948	404	66	46188	164	55
69	40	46352	46392	46038	354	56	46252	140	47
70	38	46392	46430	46118	312	55	46307	123	41
71	37	46430	46467	46188	279	47	46352	115	38
72	35	46467	46502	46252	250	42	46392	110	37
73	20	46502	46522	46307	215	36	46430	92	31
74	15	46522	46537	46352	185	30	46467	70	23
75	10	46537	46547	46392	155	26	46502	45	15
76	5	46547	46552	46430	122	20	46522	30	10
77	2	46552	46557	46467	90	15	46537	20	7
78	0	46557	46557	46502	55	9	46547	10	3
79		46557	46557	46522	35	6	46552	5	2
80			46557	46537	20	3	46557	0	0
81			46557	46547	10	2	46557		
82			46557	46555	5	1			
83			46557	46557	0	0			
84									

TABLE VIII

Application of 'S'- Curve method (Contd.)

Time hour	1 hr. U.G.	S-Curve additi-ons	S-Curve Col.(2) +(3)	S-Curve lagged by 6 hr.	Col.(4) -(5)	6 hr. U.G. Col. (6) x $\frac{1}{6}$	S-Curve lagged 3 hr	Col.(4) -(8)	3 hr. U.G. Col.(9) x $\frac{1}{3}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
27	1420	26124	27544	18214	9930	1555	23124	4420	1473
28	1360	27544	28904	19914	8990	1498	24644	4260	1420
29	1300	28904	30204	21554	8650	1442	26124	4080	1360
30	1210	30204	31414	23124	8290	1382	27544	3870	1290
31	1150	31414	32564	24644	7920	1320	28904	53660	1220
32	1100	32564	33664	26124	7540	1257	30204	3460	1153
33	1040	33664	34704	27544	7160	1193	31414	3290	1097
34	980	34704	35684	28904	6780	1230	32564	3120	1040
35	920	35684	36604	30204	6400	1067	33664	2940	980
36	850	36604	37454	31414	6040	1007	34704	2750	917
37	760	37454	38210	32564	5646	941	35684	2526	842
38	680	38210	38890	33664	5226	871	36604	2286	762
39	620	38890	39510	34704	4806	801	37454	2056	689
40	570	39510	40080	35684	4396	733	38210	1870	623
41	520	40080	40600	36604	3996c	666	38890	1710	570
42	478	40600	41078	37454	3624	604	39510	1568	523
43	450	41078	41528	38210	3318	553	40080	1448	483
44	420	41528	41948	38890	3058	510	40600	1348	449
45	400	41948	42348	39510	2838	473	41078	1270	423
46	370	42348	42718	40080	2638	440	41528	1190	397
47	340	42718	43058	40600	2458	410	41948	1110	370
48	326	43058	43384	41078	2306	384	42348	1036	379
49	300	43384	43684	41528	2156	359	42718	966	322
50	270	43684	43954	41948	2006	334	43058	896	299
51	250	43954	44204	42348	1856	309	43384	820	273
52	230	44203	44434	42718	1716	286	43684	750	250
53	210	44434	44644	43058	1586	259	43954	690	230
54	199	44644	44843	43384	1459	243	44204	639	213
55	180	44843	45023	43684	1339	223	44434	589	199

TABLE IX

Calculation Sheet for Average Unit Hydrograph (U.G.); Halda river at Narayan Hat discharge station; 3 hours average unit hydrograph.

Hours after start	3 Hours U.G.No.1 ordinates (From Fig. 6)	3 Hours U.G.No.2 ordinates (From Fig. 5)	3 Hours U.G.No.3 ordinates (From Fig. 4)	Average 3 Hrs. U.G. ordinates 1st Approximation	Average 3 Hrs. U.G. ordinates 2nd Approximation
0	0	0	0	0	
6	674	2230	115	1006	800
12	1762	1790	660	1404	1600
18	1365	1385	1770	1506	1606
24	1238	944	1637	1273	1273
30	965	574	1290	943	943
36	692	362	917	657	657
42	436	239	523	399	399
48	345	171	379	298	260
54	209	103	213	175	175
60	124	55	140	106	106
66	73	0	71	48	48
72	0	0	37	12	12
78	0	0	3	0	0
80	0	0	0	Total: 7827	7879

$$\text{Total Vol.} = \frac{7879 \times 6}{73 \times 24} \times 26.9$$

$= 0.996$ inches,

Drainage Area = 73 sq.miles

U.G.No.	Base Time (hours)	Peak discharge (cfs)	Peak Time (hours)
1	72	1762	12
2	66	2230	6
3	80	1817	20
Total:	218	5809	38
Average:	73	1936	13

TABLE X

Calculation Sheet for 1 hour average unit hydrograph (U.G.) Halda river at South Sunderpur Discharge station

Hours after start	1 hour U.G.No.1 (From Fig. 8)	1 hour U.G.No.2 (From Fig. 9)	1 hour U.G.No.3 (From Fig. 12)	1 hour U.G.No.4 (From Fig. 10)	Average 1 hr.U.G. 1st Approx.	Average 1 hr.U.G. 2nd Approx.
0	0	0	0	0	0	0
6	179	640	737	750	709	709
12	971	1999	3138	2550	2562	2562
18	1708	3582	3476	3435	3498	3498
24	2004	3358	3381	3555	3431	3431
30	1987	2878	3165	2700	2914	2914
36	1969	2559	2935	2400	2631	2450
42	1942	2159	2367	2100	2209	1950
48	1804	1839	1447	1995	1760	1560
54	1663	1519	1163	1314	1332	1300
60	1518	1439	906	1140	1162	1025
66	1393	959	629	909	832	832
72	1239	720	419	708	616	616
78	1098	480	311	480	424	426
84	978	240	135	210	195	195
90	868	0	0	114	38	38
96	759	0	0	36	0	0
					24313	23513
102	643	0	0	0		
108	525					
114	406					
120	297					
126	190					
132	71					
138	0					

$$\text{Total Vol.} = \frac{23513 \times 6}{24 \times 225 \times 26.9} = 0.994 \text{ in.}$$

Drainage Area = 225 sq.miles

	Unit Graph No.	Base Time hour	Peak discharge cfs.	Peak time hour
	2	90	3582	18
	3	90	3476	18
	4	96	3555	24
Total:		276	10613	60
Average:		92	3538	20

TABLE XI

Calculation sheet for 1 hour average unit hydrograph (U.G.) Halda river at Panch Pukuria discharge station.

Hours after start	1 hour U.G.No.1 (Fig.15)	1 hour U.G.No.2 (Fig.13)	1 hour U.G.No.3 (Fig.14)	Average 1 hour U.G.1st Approx.	Average 1 hour U.G. 2nd Approx.
0	0	0	0	0	0
6	1410	1633	1676	1573	1573
12	3622	2569	3389	3193	3193
18	5557	2984	4646	4396	4396
24	4893	3234	4494	4207	4407
30	4064	3400	4265	3910	3910
36	3345	3304	3961	3537	3450
42	2571	3180	3389	3047	3047
48	2184	3034	2818	2679	2640
54	1852	2847	1638	2112	2175
60	1465	2556	1219	1747	1747
66	1244	1912	876	1344	1250
72	746	1143	628	839	839
78	525	769	438	577	577
84	304	582	286	391	391
90	111	395	171	226	226
96	0	229	0	76	76
102	0	125	0	0	0 at 100 hrs.
108	0	0	0		

Total value 33897

$$= \frac{33897 \times 6}{315 \times 26.9 \times 24} = 0.9988 \text{ in.} = 1 \text{ inch}$$

Drainage Area = 315 sq.miles.

U.Graph No.	Base time hr.	Peak time hr.	Peak discharge cfs.
1	96	18	5557
2	108	30	3400
3	96	18	4646
Total:	300	66	13603
Average Value	100 hr.	22hr.	4534 cfs.

TABLE XII

Rainfall & runoff relation for Narayan Hat, South Sunderpur and Punch Pukuria discharge station.

Rainfall records are average rainfall; direct runoff readings taken from actual hydrographs.

Date of storm	Total rain inches	South Sunderpur Statn. Direct run off (cfs.)	South Sunderpur Statn. Direct run off (in.)	Narayan Hat Statn. Direct runoff (cfs.)	Narayan Hat Statn. Direct runoff (in.)	Panch Pukuria Direct runoff (cfs.)	Panch Pukuria Direct runoff (in.)
1.4.70	0.766	100	0.017	60	0.031	460	0.0543
10.4.70	1.399	450	0.074	34	0.017	593	0.070
16.7.70	2.418	968	0.160	84	0.043	3046	0.359
18.5.70	2.721	983	0.162	163	0.083	2445	0.289
22.5.70	3.013	2017	0.333	392	0.200	4286	0.506
12.6.70	7.122	4420	0.730	-	-	-	-
22.6.70	2.338	450	0.074	-	-	-	-
30.6.70	1.606	659	0.109	-	-	-	-
6.7.70	2.071	3570	0.590	400	0.204	4070	0.480
9.7.70	25.713	69570	11.493	4600[illegible]	23.428	71450	8.432
13.9.70	0.915	615	0.102	278	0.142	1550	0.183
23.9.70	3.795	8210	1.356	2748	1.400	11190	1.321
1.10.70	4.745	15258	2.521	5508	2.805	28105	3.317
22.10.70	4.116	4927	0.814	1834	0.934	6840	0.807
29.10.70	3.479	4596	0.759	-	-	-	-
11.11.70	7.714	29384	4.854	-	-	36925	4.358
5.4.72	0.886	70	0.012	50	0.025	230	0.027
18.4.72	1.838	188	0.031	180	0.092	925	0.109
19.5.72	3.966	5000	0.826	775	0.395	3800	0.448
27.5.72	0.920	1149	0.190	304	0.155	891	0.105
22.9.72	0.992	2913	0.481	1009	0.514	1715	0.202
5.10.72	4.988	7785	1.286	1400	0.713	12085	1.426
1.3.73	3.222	1307	0.216	560	0.285	2117	0.250
14.7.73	0.728	149	0.025	-	-	225	0.027
15.8.73	2.075	4089	0.676	-	-	14053	1.658
23.10.73	3.720	4477	0.740	-	-	9321	1.100
17.11.73	1.252	2487	0.411	-	-	2350	0.277
2.11.73	8.480	23030	3.805	-	-	33476	3.951
7.12.73	1.630	1767	0.292	-	-	2800	0.330

Drainage Area: South Sunderpur: 225 sq.miles; Narayan Hat: 73 sq.miles
Panch Pukuria: 315 sq. miles

TABLE XIII

Test of consistency of rainfall records for Fatik Chari, Chittagong, Amtali, Dolu and Mirza Hat raingauge stations by Double Mass Curve Analysis.

Stations	1975-76	1974-75	1973-74	1972-73	1971-72	1970-71
Amtali	163.44	135.35	95.36	94.21+	97.00*	135.27
Chander Khil	37.76	80.53	87.50+	65.54	99.39*	126.49
Chittagong	111.35	160.95	107.59	81.79	117.56*	120.41+
Dolu	109.09	101.20	70.74	77.70	93.72	120.73+
Fatik Chari	108.94	114.91	83.23	85.30	122.65	128.68
Hla Khun	126.78	133.96	99.69+	70.77+	120.92*	132.69+
Manik Chari	36.88	70.24	90.85	46.56	93.56	105.09
Mirza Hat	108.63	130.87	103.82	73.13	114.59*	129.67+
Narayan Hat	116.05	130.58	105.10	61.47	95.32	130.05
Nazir Hat	114.85	141.05	91.80	84.65	128.44	112.15
Raj Bari Tilla	110.30	134.73	119.43	93.50	143.79	146.31
Ranga Pani	102.73	138.32	98.38	97.16	122.54*	152.42
Sikder Hat	103.96	140.01	99.81+	68.16	111.85*	112.74+
Tenturi	37.52	77.61	46.85+	27.47	72.38*	80.59
Total	1388.28	1690.31	1300.05	1027.41	1531.91*	1733.29
Average	99.16	120.74	92.86	73.39	109.57*	123.81
Fatik Chari	$\frac{X}{Y}$ $\frac{109}{99}$	$\frac{224}{220}$	$\frac{307}{313}$	$\frac{392}{386}$	$\frac{515}{496}$	$\frac{644}{620}$
Chittagong	$\frac{X}{Y}$ $\frac{111}{99}$	$\frac{272}{220}$	$\frac{380}{313}$	$\frac{462}{386}$	$\frac{580}{496}$	$\frac{700}{620}$
Amtali	$\frac{X}{Y}$ $\frac{163}{99}$	$\frac{298}{220}$	$\frac{393}{393}$	$\frac{487}{386}$	$\frac{584}{496}$	$\frac{719}{620}$
Dolu	$\frac{X}{Y}$ $\frac{99}{109}$	$\frac{210}{210}$	$\frac{281}{313}$	$\frac{359}{386}$	$\frac{453}{496}$	$\frac{574}{620}$
Mirza Hat	$\frac{X}{Y}$ $\frac{109}{99}$	$\frac{240}{220}$	$\frac{344}{313}$	$\frac{417}{386}$	$\frac{532}{496}$	$\frac{662}{620}$

Contd.

TABLE XIII (Contd.) from previous page

Stations		1969-70	1968-69	1967-68	1966-67	1965-66	1964-65
Amtali		143.53	72.98	50.11	92.13	117.20	107.89
Chandir Khil		106.00	125.62	82.05	112.03	131.61	107.44
Chittagong		119.08	120.70	84.26	119.75	156.17	120.75
Dolu		113.77	102.24	68.08	99.32	121.87	91.84
Fatik Chari		103.85	77.26	80.29	105.95	119.71	96.99
Hia Khun		145.99	124.09	80.05	130.90	142.12	123.75
Manik Chari		98.44	118.36	79.27	115.60	107.95+	107.04
Mirza Hat		135.75	115.05	84.72	122.12	143.34	105.85
Narayan Hat		124.37	105.18	86.03	108.41	132.86	122,35
Nazir Hat		129.55	118.50+	85.36	88.69	102.99	69.99+
Raj Bar Tilla		138.27	170.91	118.36	122.13	149.87	118.03
Ranga Pani		153.57	143.61	82.53	166.04	146.80	124.60
Sikder Hat		118.17	122.53	83.19	106.36	134.52	124.39
Tenturi		80.38	67.68	46.58	115.42	123.83	85.56
Total		1570.22	1584.41	1110.88	1554.85	1830.84	1506.87
Average		112.16	113.17	79.35	111.06	130.77	107.63
Fatik Chari	$\frac{X}{Y}$	$\frac{748}{732}$	$\frac{825}{845}$	$\frac{905}{924}$	$\frac{1011}{1035}$	$\frac{1131}{1166}$	$\frac{1228}{1274}$
Chittagong	$\frac{X}{Y}$	$\frac{819}{732}$	$\frac{940}{845}$	$\frac{1024}{924}$	$\frac{1144}{1035}$	$\frac{1300}{1166}$	$\frac{1421}{1274}$
Amtali	$\frac{X}{Y}$	$\frac{863}{732}$	$\frac{936}{845}$	$\frac{986}{924}$	$\frac{1078}{1035}$	$\frac{1195}{1166}$	$\frac{1303}{1274}$
Dolu	$\frac{X}{Y}$	$\frac{688}{732}$	$\frac{790}{845}$	$\frac{858}{924}$	$\frac{957}{1035}$	$\frac{1078}{1166}$	$\frac{1170}{1274}$
Mirza Har	$\frac{X}{Y}$	$\frac{798}{732}$	$\frac{913}{845}$	$\frac{998}{924}$	$\frac{1120}{1035}$	$\frac{1263}{1166}$	$\frac{1369}{1274}$

Contd.

TABLE XIII (Contd.) from previous page

Stations	1963-64	1962-63
Amtali	134.49	82.50
Chander Khil	147.22+	82.54
Chittagong	127.77+	97.74
Dolu	129.39+	84.14
Fatik Chari	111.17+	90.06
Hla Khun	165.07	96.15
Manik Chari	160.04	79.55
Mirza Hat	153.85	82.86
Narayan Hat	138.02+	83.03
Nazir Hat	113.93+	81.32
Raj Bari Tilla	140.72	100.32
Ranga Pani	155.72	81.09
Sikder Hat	138.59+	101.75
Tenturi	59.77+	91.62
Total	1875.75	1234.67
Average	133.98	88.19
Fatik Chari	$\frac{X}{Y}$ $\frac{1339}{1408}$	$\frac{1429}{1496}$
Chittagong	$\frac{X}{Y}$ $\frac{1549}{1408}$	$\frac{1647}{1496}$
Amtali	$\frac{X}{Y}$ $\frac{1437}{1408}$	$\frac{1520}{1496}$
Dolu	$\frac{X}{Y}$ $\frac{1299}{1408}$	$\frac{1383}{1496}$
Mirza Hat	$\frac{X}{Y}$ $\frac{1523}{1408}$	$\frac{1606}{1496}$

Note: X = Accumulated annual precipitation of the station written (inches).

Y = Accumulated annual precipitation (in.), 14 sts. mean.

\+ = Rainfall record for some couple of days were not recorded

* = Liberation war period, these stations were not recorded for a couple of months and the figures entered were the average of 13 years precipitation records for that period for that station.

TABLE XIV

Use of a developed unit hydrograph in real storms to Synthesize a stream flow hydrograph and its companison with the actual hydrograph:

River Halda at South Sunderpur

Sept/1970 Date	Hours	Hours after start	1 hour (U.G. 4, Table-X)	0.5 x U.G.	0.025 x U.G.	0.30 x U.G.	Estimated base flow	Synthesized Hydrograph Ordinates	Actual Hydrograph ordinates
22	0600	0	0						
	1200	6	750						
	1800	12	2550				460	460	460
	2400	18	3435	0			460	460	460
23	0600	24	3555	355			460	815	
	1200	30	2700	1281			460	1741	1250
	1800	36	2400	1749	0		460	2209	
	2400	42	2100	1716	18		470	2204	
24	0600	48	1995	1457	64		480	2001	
	1200	54	1314	1316	87		490	1893	2530
	1800	60	1140	1105	86		500	1691	
	2400	66	909	880	73	0	520	1473	
25	0600	72	708	666	66	212	530	1474	
	1200	78	480	581	55	769	540	1895	1900
	1800	84	210	416	44	1050	550	2060	
	2400	90	114	308	33	1030	570	1941	
26	0600	96	36	212	29	874	580	1695	
	1200	102	0	98	21	790	590	1499	1630
	1800		0	19	15	662	600	1296	
	2400		0	0	11	528	620	1159	
27	0600				5	400	630	1035	
	1200				1	350	640	991	1320
	1800				0	250	650	900	
	2400					185	660	845	
28	0600					127	670	797	
	1200					59	680	739	1290
	1800					11	700	711	
	2400					0	720	720	
29	0600						740	730	1070
	1200						750	740	

TABLE XV

Use of unit hydrographs developed in real storms to synthesize a streamflow hydrograph and its comparison with the actual hydrograph; River Halda at Narayan Hat discharge station.

Hours after start	1 hr. U.G. (From Fig.4)	3 hrs U.G.	0.15x 3 hrs U.G.	0.03x 1 hr. U.G.	0.05x 3 hrs U.G.	0.10x 3 hrs U.G.	0.15x 3 hrs U.G.	0.05 x 3 hrs. U.G.	Estimated base flow	Synthesized Hydrograph	Actual Hydrograph	October 1972 Date	Hours (noon)
6	149	1006	0										
12	1022	1404	151										
18	1850	1506	211						75	226	400	5	1200
24	1570	1273	226	0									
30	1210	943	191	5									
36	850	657	141	34									
42	478	399	100	62					80	255	176	6	1200
48	326	298	69	52	0								
54	199	175	45	40	50								
60	120	106	26	28	70								
66	64	48	15	16	75				80	204	244	7	1200
72	35	12	13	11	63								
78	0	0	2	7	47	0							
84			0	4	33	100							
				2	20	140			80	217	190	8	1200
				1	15	150							
				0	9	127	0						
					5	144	150						
					2	66	210		80	379	225	9	1200
					1	40	75						
					0	30	189						
						18	141	0					
						11	99	50	100	259	263	10	1200
						5	60	70					
						1	45	75					
						0	27	64					
							15	72	70	161	162	11	1200
							6	33					
							3	20					
							0	15	70	85	108	12	1200

A P P E N D I X - C

Theoretical Approach and Calculation
Sheets for some Basin Characteristics
of the Halda River Basin.

A) Calculation for finding physical characteristics, C_t, C_p, in the South Sunderpur and Narayan Hat Catchment Areas in the Halda river basin using Snyder's Method :

The notation meanings are given in Chapter II, Synthetic Unit hydrograph section.

<u>For South Sunder Pur Basin</u>

$L = 25$ miles (Figure 27)

$L_c = 9$ miles (Figure 27)

Standard duration, $t_r = \dfrac{t_p}{5.5}$ ....(2-4)

$= \dfrac{19.5}{5.5}$

$= 3.54$ hours.

where

$t_p = t_{PR} = (20 - \frac{1}{2}) = 19.5$ hours - (Figure 17)

but t_R = duration of effective rainfall of the average unit hydrograph = 1 hour;

i.e. other than $t_r = 3.54$ hours.

$t_{PR} = t_p + 0.25\ (t_R - t_r)$ ....(2-5)

or, $19.5 = t_p + 0.25\ (1-3.54) = t_p - 0.25 \times 2.54 = t_p - 0.661$

or, $t_p = 20.135$ hrs.

As,, $t_p = C_t\ (LL_c)^{0.3}$ ....(2-1)

$t_p = C_t\ (25 \times 9)^{0.3} = 5.06\ C_t$

or, $20.135 = 5.06\ C_t$

or $C_t = 3.94$

$$q_{PR} = \frac{\text{Peak discharge}}{\text{Basin Area}} = \frac{3558}{225} = 15.7 \text{ cfs/sq.miles}$$

Values of peak discharge are taken from Figure 17 and Figure 27 respectively.

$$q_{PR} = \frac{640 \quad C_p}{t_{PR}} \quad \ldots\ldots \quad \ldots\ldots \quad \ldots\ldots \quad \ldots\ldots(2\text{-}3)$$

or, $15.7 = \dfrac{640 \times C_p}{19.5}$; from where, $C_p = 0.478$

and base time, $T = 3 + 3\dfrac{t_p}{24} = 3 + 3\dfrac{19.5}{24} = 5.44$ days.

For the Narayan Hat Basin.

$L = 10$ miles, $L_c = 6$ miles ...... Figure 27 and $LL_c = 60$ sq.miles.

$t_R = 3$ hours; $t_{PR} = 13 - 1\frac{1}{2} = 11\frac{1}{2}$ hours - from 3 hours average unit graph of Narayan Hat - (Figure 16).

$$t_r = \frac{t_p}{5.5} = \frac{11.5}{5.5} = 2.09 \text{ hours}$$

as $t_r \neq t_R$

$$t_{PR} = t_p + 0.25\,(t_R - t_r) \quad \ldots\ldots \quad \ldots\ldots \quad \ldots\ldots(2\text{-}5)$$

or, $11.5 = t_p + 0.25\,(3 - 2.09)$; or, $t_p = 11.272$

But, $t_p = C_t\,(LL_c)^{0.3} = C_t\,(10 \times 6)^{0.3}$ - $\quad \ldots\ldots(2\text{-}1)$

or, $11.272 = C_t \times 3.41$; from where $C_t = 3.30$

$q_{PR} = \dfrac{\text{Peak discharge}}{\text{Basin area}} = \dfrac{1936}{73} = 26.5\ \dfrac{cfs}{mi^2}$ peak discharge from average unit graph of Narayan Hat, Figure 16.

$q_{PR} = \dfrac{640\ C_p}{t_{PR}}$, or $26.5 = \dfrac{640}{11.272}\,C_p$; from where, $C_p = 0.470$

And base time, $T = 3 + 3 \times \dfrac{T_p}{24} = 3 + 3x\ \dfrac{11.\ \ 2}{24} = 4.41$ days.

The average values of C_p and C_t have been found to be respectively 0.63 and 2.0 in fairly maintainous Appalachian Highlands and the extreme ranges of the values are from 0.94 and 0.40 in the Southern California to 0.61 and 8.0 in sections of states bordering the eastern Gulf of Mexico.

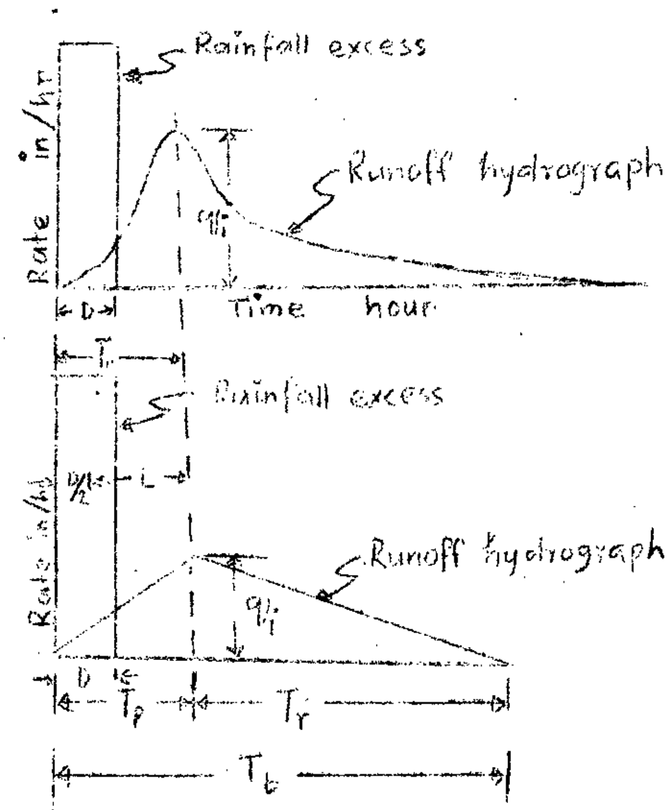
In this research work, the values at a glance are as follows:

<u>South Sunderpur Basin</u>	<u>Narayan Hat Basin</u>
$C_t = 3.94$	$C_t = 3.30$
$C_p = 0.478$	$C_p = 0.47$
$T = 5.44$ days	$T = 4.44$ days
$L = 25$ miles; $L_c = 9$ miles,	$L = 10$ miles $L_c = 6$ miles

It is possible to find three unit hydrograph parameters (q_p, t_p, T) for ungaged stations of similar characteristics basin areas.

B) <u>Theoretical Approach to find a peak Discharge Formula And Its Application In the South Sunderpur Catchment Area</u>

It is an approach to find a relation between peak discharge, basin lag time, drainage area and the resulting runoff. The following diagrams and notations are used. Finally the relation is applied in the South Sunderpur Basin area. The Development of the relation and its application is as follows:



Symbols; Q = Total runoff in inch; q_i = Peak rate in inch/hour, T_p = Time in hour from start of rise to peak rate; T_r = Time in hour from peak rate to end of triangle, T_b = Time base of hydrograph, D = rainfall excess period in hour,

L = Lag time from center of excess rainfall to time of peak, in hour.

Development of Peak Rate Equation.

From the above triangle ,

$$Q = \frac{q_i \; T_p}{2} + \frac{q_i \; T_r}{2}; \text{ and } q_i = \frac{2Q}{T_p + T_r}$$

If $T_r = H \; T_p$ - where H is any factor

then $q_i = \dfrac{2Q}{(1+H) \; T_p}$ - (1)

Converting from inch/hour to cfs by introducing drainage area A in square miles (1 inch/hour = 645.3 cfs/ square miles gives the peak rate q_p:

$$q_p = \frac{K \; A \; Q}{T_p} \text{ cfs. (2)}$$

Utilising the average 1 hour unit hydrograph of South Sunderpur and taking the value of q_i = 3538 cfs., T_p = 20 hours, A = 225 square miles,

$$q_i = \frac{3538}{225} = 15.72 \; \frac{\text{cfs}}{\text{mi}^2} = \frac{15.72}{645.3} = 0.0244 \text{ in/hr.}$$

effective rainfall = 1 inch x 1 hour = 1 in.hr. = the area of traingle. From the above triangle

$\frac{1}{2}$ (20 x 0.0244) + (T_r x 0.0244) = 1 inch hour, the value of T_r is sought.

Solving, T_r = 49 hour.

But $T_r = H \; T_p$

or, 49 = H x 20 ; from where H = 2.45

Using the value of H in equation (1) above,

$$q_i = \frac{2 \times Q}{(1 + 2.45)\, T_p}$$; and introducing the value of inch miles and converting to cfs.

$$q_p \doteq \frac{2 \times 645.3\ A \times Q}{3.45 \times T_p} = \frac{374\ \ AQ}{T_p}$$

Thus $q_p \doteq \frac{K\ A\ Q}{T_p}$, where K = 374 and modified value of K = 350, (as discussed in Chapter V).

This equation and the value of K = 350 should be used only for rough estimating of peak flow at South Sunderpur by using precipitation data.

The validity of this equation has, again, been judged by comparing the values of 11 different actual cases. The result is quite satisfactory. The following table is represented in Figure 26.

TABLE III

Comparative study of actual peak and peak value determined by the formula.

Observation No.	Date of Peak	Effective rain from graph inch (Figure 24).	Observed peak value (Base flow Deducted) cfs.	Peak value determined by the formula, cfs.	Remarks
1	27.4.72	0.02	120	84	In Fig. 26 the line has a slope of 1.07. To make the slope equal to unity K will have a value of 350.
2	21.5.72	0.42	1770	1767	
3	18.6.72	2.20	6200	9240	
4	30.7.72	1.10	4100	4620	
5	6.8.72	0.50	2040	2100	
6	13.8.72	0.40	1400	1680	
7	17.8.72	0.60	2200	2520	
8	23.9.72	0.15	850	630	
9	6.10.72	0.15	850	630	
10	14.6.73	0.80	3200	3360	
11	6.7.70	0.30	1100	1260	