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UNIT HYDROGRAPH ANALYSIS

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ABSTRACT

This user's manual gives the details of twenty one computer programmes to carry out unit hydrograph analysis. These computer programmes are considered to be in five different categories dealing with:

(i) Processing and analysis of precipitation data,

(ii) Computation of discharge and rating curve analysis,

(iii) Computation of excess rainfall and direct surface runoff,

(iv) Unit hydrograph derivation, and

(v) Reproduction of direct surface runoff and estimation of flood hydrograph.

There are five programmes, GAPF.FOR, DOUBLE.FOR, THIES.FOR, ISO.FOR and DAILY.FOR, for processing and analysis of precipitation data. The programme GAPF.FOR is used for filling up the missing record using Normal ratio method. The programme DOUBLE.FOR performs the computations involved in consistency check using double mass curve analysis. The average rainfall for the storm are computed using Theissen polygon method through the programme THIES.FOR. The programme ISO.FOR calculates the variation of depth with area over the catchment using Isohyet Method. While the programme DAILY.FOR is used for the distribution of daily rainfall at non-recording raingauge stations into hourly rainfall and the computation of average hourly rainfall using Theissen polygon method.

In the second category there are three computer programmes namely VEL.FOR, RATING.FOR and GAUGE.FOR to carry out the computation of discharge and rating curve analysis. The programme

VEL.FOR calculates the discharge from velocity measurement taking number of sections and different number of velocity measurements in each section. The stage-discharge relationship (rating curve) in the form of $Q=a(G-e)^b$ can be developed using the least square method in the programme RATING.FOR where the provision is made to decide the value of e by trial and error method. The programme GAUGE.FOR computes the values of discharge corresponding to the various stages using the stage-discharge relationship developed in the above given form.

There are two-programmes namely EFF.FOR and LOSS.FOR which deal with the computation of excess rainfall and direct surface runoff. The first programme EFF.FOR permits the user to deduct baseflow (constant or non constant) from the discharge hydrograph ordinates in order to get the direct surface runoff hydrograph and computes the area under the direct surface runoff hydrograph using Simpson's rule, which is further divided by the catchment area to give the depth of effective rainfall. The second programme LOSS.FOR separates the baseflow from the discharge hydrograph using straight line baseflow separation technique in order to get the direct surface runoff hydrograph. Furthermore, the losses are also accounted from the computed average rainfall at a particular time interval in the programme LOSS.FOR using the uniform loss rate procedure which provides an estimate for the excess rainfall hyetograph.

In fourth category of the programmes there are nine computer programmes namely UNIT.FOR, UHISO.FOR, CoLUH.FOR, NASHF.FOR, INTNAS.FOR, CLARKF.FOR, SCURVE.FOR, SUPERIM.FOR and NEWD.FOR for the unit hydrograph derivation. The first two computer programmes, UNIT.FOR and UHISO.FOR, are used to derive the unit hydrograph from single-period, individual and isolated storms. The only difference is that the programme UNIT.FOR requires the discharge hydrograph as input and permits the user to supply the constant or non constant baseflow values which are deducted from the discharge hydrograph in order to get the direct surface runoff hydrograph. Then the area under the direct surface runoff hydrograph is computed in the programme UNIT.FOR using Simpson's rule and the runoff volume in depth unit is obtained for further computations. While the runoff volume (in depth unit) and direct surface runoff hydrograph ordinates are input to the programme UHISO.FOR. The programmes CoLUH.FOR, NASHF.FOR, INTNAS.FOR and CLARKF.FOR are used for the derivation of unit hydrograph using Collin's method, Conventional Nash Model, Integer Nash Model and Clark Model respectively. The computer programme SCURVE.FOR computes the S-curve hydrograph from the unit hydrograph of a specified duration. The last two computer programmes, SUPERIM.FOR and NEWD.FOR, are used for changing the duration of Unit hydrograph using superimposition and S-curve methods respectively.

There are two computer programmes REPROD.FOR and SYNTH.FOR in last category of the programmes. These programmes are dealing with the reproduction of observed direct surface runoff and estimation of observed direct surface runoff and estimation of flood hydrograph. The first programme REPROD.FOR computes the direct surface runoff hydrograph using unit hydrograph and also computes the fitting efficiency and various error functions described further in the text. While the second programme SYNTH.FOR is used for the computation of direct surface runoff for flood hydrograph from unit hydrograph and composite storm.

These programmes are developed in FORTRAN-IV language and implemented and tested on VAX-11/780 computer system available at National Institute of Hydrology, Roorkee. All these programmes could also be run on other computer systems including the micro computers having FORTRAN compiler after suitable modifications as per the software requirements of the system. This user's manual provides some useful informations regarding the unit hydrograph analysis which are very much useful to the field engineers involved in hydrologic analysis and design based on unit hydrograph approach. The results obtained from these programmes are subjected to the assumptions and limitations of the respective techniques on which the programmes are based.

1.0 INTRODUCTION

Unit hydrograph analysis technique is one of the most commonly used techniques for design flood estimation and real time flood forecasting. By definition, unit hydrograph is the direct surface runoff hydrograph resulted at the catchment outlet due to unit (1mm/1cm/1inch) rainfall excess falling uniformly over the catchment in time as well as in space for the specified duration. The unit hydrograph is basically a multiplier which converts the excess rainfall to direct surface runoff. Thus it can be said that the unit hydrograph only deals with the direct surface runoff and excess rainfall. Therefore, the baseflow must be separated from the streamflow hydrograph and losses must be accounted from the average rainfall hyetograph in order to get the direct surface runoff hydrograph and excess rainfall hyetograph respectively.

The unit hydrograph can be derived by analysing the excess rainfall and direct surface runoff of various storms for the gauged catchments. Simple conventional method is used to derive the unit hydrograph from single period storms. However, Collin's method based on trial and error procedure is preferred for use in the unit hydrograph derivation from the multiperiod storms. Some times Collin's method does not converge and provides an estimate for unit hydrograph with unrealistic shape and negative ordinates. In such a situation one has to make subjective judgements for preserving the shape of the unit hydrograph with required unit volume. The use of conceptual models for unit hydrograph derivation overcomes these deficiencies associated with the collin's method. Among many otners conceptual models, Nash and Clark models are most simple and popular conceptual models for unit hydrograph derivation. Integer Nash Model is a simplified form of the conventional Nash Model.

The unit hydrograph of T-hour duration is required to convert the T-hour rainfall excess block into the direct surface runoff hydrograph. When the duration of the derived unit hydrograph differs from that of the excess rainfall, the methods are available for the derivation of the unit hydrographs of desired durations from the hydrographs of other available durations.

In this user's manual twenty one computer programmes are discussed dealing with the various aspects such as processing and analysis of precipitation data, computation of discnarge and rating curve analysis, computation of excess rainfall and direct surface runoff, unit hydrogoraph derivation and reproduction of direct surface runoff and estimation of flood hydrograph using unit hydrograph approach

2.0 PURPOSE AND CAPABILITIES

The purpose of this user's manual is to provide guidelines for the users in order to run the unit hydrograph analysis package programme without facing any difficulty. The user's manual gives the details of twenty one computer programmes. These computer programmes are classified in five different categories dealing with different aspects involved in unit hydrograph analysis such as:

(i) Processing and analysis of precipitation data

(ii) Computation of discharge and rating curve analysis

(iii) Computation of excess rainfall and direct surface runoff.

(iv) Unit hydrograph derivation, and

(v) Reproduction of direct surface runoff and estimation of flood hydrograph.

Different computer programmes and their descriptions, input specifications, output specifications and test input and output withthe illustrative examples are given in different Appendices.

3.0 METHODOLOGY

Before going to discuss about the methodologies used in each programme, some of the important terms which have appeared in the text frequently are described.

Terminology:

(i) Unit Hydrograph(UH): It is a hydrograph of direct surface runoff resulting from unit excess rainfall falling uniformly over the catchment in space and time for a specified duration.

(ii) Instantaneous Unit Hydrograph(IUH): It is a unit hydrograph of infinitesimally small duration.

(iii) Excess(or effective) rainfall:- The part of the rainfall which appear over the surface as runoff and later on contributes to the stream of the catchment.

(iv) Base flow: It is that contribution to a stream flow hydrograph which results from releases of water from ground water storage.

(v) Direct surface runoff: It is a that portion of runoff which resulted at the catchment outlet due to excess rainfall.

(vi) Linear reservoir: The reservoir in which the storage is assumed to be directly proportional to the discharge.

(vii) Time of Concentration: It is the travel time of a water particle from the most upstream point in the basin to the outflow location.

3.1 Processing and Analysis of precipitation data

3.1.1 Estimation of Missing Data

While retrieving data for climatological purposes or inputing data in real time, one often comes across missing data situations. Since blank in a data set is read as zero, necessary software for identifying the blanks and marking them appropriately need to be developed.

Data for the period of missing rainfall data could be filled using estimation technique. The length of period upto which the data could be filled is dependent on individual judgement. Rainfall for the missing period is estimated either by using the normal ratio method or the distance power method. Here a computer programme GAPF.FOR for estimation of the missing data by the normal ratio method is described in Appendix I.

In the normal ratio method, the rainfall R_A at station A is estimated as a function of the normal monthly or annual rainfall of the station under question and thos of the neighbouring stations using actual rainfall data recorded at neighbouring stations for the period of missing data at the station under questions.

$$R_A = \frac{\sum_{i=1}^{n} \frac{NR_A}{NR_i} \times R_i}{n} \qquad \ldots(1)$$

where, R_A is the estimated rainfall at station A

R_i is the rainfall at surrounding stations

NR_A is the normal monthly or seasonal rainfall at station A.

NR_i is the normal monthly or seasonal rainfall at station i.

n is the number of surrounding stations whose data are used for estimation.

3.1.2 Consistency check of record using double mass curve technique

The double mass curve may be used to check the consistency of a particular record. It involves plotting the fall at one station against the sum, or the average, of the falls at a number of nearby station. Under normal circumstances, it would be expected that cummulative fall at one station would bear a fairly constant relationship to tne cumulative fall at other nearby gauges. Thus a plot of the accumulated precipitation at one station with the average (or summated) accumulated precipitation at a number of other nearby gauges should result in a straight line. Divergence from a straight line provides an indication of error at the gauge. The time at which the error occured may be indicated on the plot by the point at which the slope of the line changes. Caution must be used in applying the double mass technique because the plotted points always fall about a mean line. Changes in slope should be identified only when these are significant.

A computer programme DOUBLE.FOR given in Appendix-II handles the computational aspects involved in double mass curve technique for the consistency check.

3.1.3 Thiessen Polygon method for the estimation of mean areal precipitation:

The Thiessen Polygon method is used with non-uniform stations spacing and gives weights to stations data according to the area which is closer to that station than to any other station. This area is found by drawing the perpendicular of the lines joining the nearby stations so that polygons are form around stations. The polygons thus formed around each station are the boundaries of the effective area assumed to be controlled by the station. The area governed by each station is planimetered and expressed as a percentage of total area. Weighted average rainfall for the basin is computed by multiplying each station precipitation amount by its assigned percentage of area and totalling.

The weighted rainfall is given by:

$$\bar{P} = \frac{\sum_{i=1}^{n} P_i W_i}{\sum_{i=1}^{n} W_i} \qquad \ldots(2)$$

where, $\bar{P}$ is the average catchment precipitation, P_i is the precipitation at station 1 to n, W_i the respective weights.

If a few observations are missing it is better to estimate the missing data than to construct new set of polygons.

The advantage of this method is stations outside the catchment may also be used for assigning weights of marginal stations within the catchment. The disadvantage, however, is it assumes that precipitation between two stations varies linearly and does not make allowance for variation due to orography.

A computer programme THIES.FOR for the computation of mean areal precipitation using Theissen weights is given in Appendix-III.

3.1.4 Isohyet method for depth-area analysis:

Isohyets are lines on a map joining points of equal rainfall. An isohyetal map is developed from the point recordings of rainfall in exactly the same manner in which a contour map is developed from spot heights. When isohyets have been drawn it may reasonably be assumed that the total volume of rain falling between any two isohyets is given by the product of the area between the isohyets and the average depth of fall. Curves showing the variation of depth with area over the catchment(depth-area curves) may be constructed as part of an isohyetal analysis. These show how the average depth of fall decreases as the area considered increases.

A computer programme ISO.FOR given in Appendix-IV calculates the variation of depth with area over the catchment using Isohyet method.

3.1.5 Distribution of Daily Rainfall Data into Hourly

For hydrological analysis, rainfall data of shorter duration is required. The net work of recording raingauges in India being small in comparison to that of daily (non-recording) raingauge, it becomes necessary to convert the daily rainfall into shorter period intervals either manually or by using appropriate computer routines. The information of short interval rainfall is used together with information of daily rainfall from nearby non-recording (daily gauges).

Mass curve is a graphical display of accumulated rainfall vs time. Mass curves of accumulated rainfall at (non-recording) daily stations and recording stations are prepared by plotting the accumulated rainfall values against time for the storm duration under analysis.

A comparison of the mass curves of the recording rain gauge stations with those of the non-recording stations would help in deciding which recording raingauges or group of gauges could be considered as representative of which of the non-recording raingauge for the purpose of distributing daily rainfall into hourly rainfall.

A computer programme DAILY.FOR for distribution of daily rainfall at non-recording raingauge stations into hourly rainfall and computation of average hourly rainfall using Theissen polygon is explained in Appendix V.

3.2 Computation of discharge and rating curve analysis

3.2.1 Calculation of discharge from velocity measurements

For measuring the discharge on a large river, the river cross section is divided into a number of sections and the area of each section is measured along with velocity traverse in each section. Then the discharge in each section of the river can be calculated by multiplying the area of the section by the average velocity. The total discharge is given by the summation of the discharge in each section.

A computer programme VEL.FOR given in Appendix-VI is developed to handle the general problem in the calculation of discharge from velocity measurement covering different numbers of sections and different numbers of velocity measurements in each section.

3.22 Stage Discharge relationship

Generally a single valued relationship between the stage and the discharge expressed in the following form is developed for those streams and rivers which exhibit permanent control:

$$Q = a(G-e)^b \qquad ...(3)$$

where, Q= storm discharge (m^3/s)

G = Gauge height or stage (m)

and e = a constant which represent the gauge reading corresponding to zero discharge (m)

The best values of a and b in Eq.3 for a given range of stage are obtained by the least square method. Thus by taking logarithms

$$\log Q = b \log (G-e) + \log a \qquad ...(4)$$

or $$\hat{Y} = \alpha + \beta X \qquad ...(5)$$

where $Y = \log Q$

$\beta = b$

$X = \log (G-e)$

$\alpha = \log a$

For the best fit straight line of N observations of X and Y,

$$\beta = \frac{N(\sum_{i=1}^{N} X_iY_i) - (\sum_{i=1}^{N} X_i)(\sum_{i=1}^{N} Y_i)}{N(\sum_{i=1}^{N} X_i^2) - (\sum_{i=1}^{N} X_i)^2} \quad \ldots(6)$$

and $$\alpha = \frac{\sum_{i=1}^{N} Y_i - (\sum_{i=1}^{N} X_i)}{N} \quad \ldots(7)$$

The correlation coefficient , r , is computed using the following equations:

$$r = \sqrt{1 - (F_1/F_o)} \quad \ldots(8)$$

$$F_1 = \sum_{i=1}^{N} (Y_i - Y_i)^2/(N-2) \quad \ldots(9)$$

$$F_1 = \sum_{i=1}^{N} (Y_i - Y)^2/\ (N-1) \quad \ldots(10)$$

where

Y_i = ith observed value of Y

$\overline{Y}$ = Mean of the observed Y values

$\hat{Y}_i$ = ith value of Y computed by Eq.(5)

In the above it should be noted that e is an unknown and its determination poses some difficulties. A number of optimization procedures that are based on the use of computers are available to estimate the best value of e. A trial and error search for e which gives the best value of the correlation coefficient, e, is one of them.

The standard errors of regression coefficients and associated t values are also computed for testing the significance of the coefficients in the regresion equation (Haan(1977)).

A computer programme RATING.FOR given in Appendix-III is used for developing the stage-discharge curve relationship using the least square method and making a trial and error search for the unknown coefficient e.

3.2.3 Conversion of stage values to corresponding discharge Values:

As discussed earlier, the relationship between the stage and the discharge for those streams and rivers which exhibit permanent control is expressed as:

$$Q = a(G-e)^b \qquad ...(11)$$

The coefficients a,b and e of the above equation are determined from the observed stage and corresponding discharge values using Least square method as discussed in section 3.2.2.

If the coefficients a,b and e are known, Eq(11) may be used to compute the values of the discharge corresponding to the various stage values. The use of the Eq (11) for converting the stage into discharge should be avoided in the extrapolation range, as far as possible. Before attempting extrapolation, if required, it is necessary to examine the site and collect relevant data on changes in the river cross-section due to flood plains, roughness and backwater effects. The reliability of the extrapolated values depends on the stability of the gauging section control.

A computer programme GAUGE.FOR given in Appendix-VIII is able to convert the given gauge values into corresponding discharge values using the stage-discharge relationship of the form given by Eq.(11).

3.3 Computation of Excess Rainfall and Direct Surface Runoff

3.3.1 Calculation of effective rainfall from hydrograph

The discharge hydrograph is considered to be a composite of the direct surface runoff and ground water flow (base flow). When these are separated the area under the direct surface runoff hydrograph provides a measure of the volume of the direct surface runoff. This volume is equal to the product of the catchment area and depth of effective rainfall. A computer programme EFF. FOR given in Appendix-IX permits the user to deduct ground water flow (base flow) from the ordinates of the given hydrograph and computes the area of the direct surface runoff hydrograph using Simpson's rule, which is further divided by the catchment area to give the depth of effective rainfall.

3.3.2 Estimation of effective rainfall and direct surface runoff using storm rainfall-runoff data:

The average rainfall for the storm is obtained by Theissen polygon method where the weighted mean of the observed rainfall values at different stations are computed at each time interval. The next step is to separate base flow from discharge hydrograph to get the direct surface runoff. The method used here for base flow separation involves drawing of a line from the rising point of the hydrograph to the recession point on the falling limb of the hydrograph. The recession point can be obtained by the user after plotting the recession limb of the hydrograph on semi-log graph paper taking time on linear scale and discharge values on log scale. The point on the graph at which the straight line changes the slope is known as the recession point. The separation of abstraction from rainfall is done by using the uniform loss rate procedure. A trial and error procedure is adopted to locate the starting point of the effective rainfall and the infiltration rate is adjusted such that the volume of effective rainfall equals the volume of direct surface runoff. If during the trial it is found that the infiltration rate is more than the rainfall depths in initial period of storm, it is assumed that this rainfall is completely lost as initial loss and does not contribute to direct surface runoff.

A computer programme LOSS.FOR given in Appendix-X computes the effective rainfall and direct surface runoff for a storm using the above stated procedure.

3.4 Unit Hydrograph Derivation

3.4.1 Derivation of unit hydrograph from the discharge hydrograph

The unit hydrograph from the flood hydrograph recorded from a specific duration individual, isolated storms of fairly uniform intensity distributed evenly over the catchment, is derived using the principle of proportionality. A computer programme UNIT.FOR given in Appendix-XI is used for the derivation of unit hydrograph from the isolated storms. In the programme the constant or non constant base flows supplied by the user are deducted from the discharge hydrograph in order to obtain the ordinates of the direct surface runoff hydrograph. Then the area under the curve is calculated using Simpson's rule and this provides an estimate for the volume of direct surface runoff. The estimate for the volume of direct surface runoff, thus obtained, are divided by the area of the catchment to provide the depth of effective rain. The ordinates of the direct surface runoff hydrograph are divided by the effective rainfall depth to give the ordinates of the unit hydrograph.

3.4.2 Derivation of unit hydrograph from the direct surface runoff hydrograph of a single period storm.

The following procedure is generally followed to derive the unit hydrograph from the direct surface runoff hydrograph of a single period storm.

(i) Determine the volume of excess rainfall in the single unit period (it also equals the volume of the direct surface runoff hydrograph).

(ii) Calculate the proportionality factor(F) dividing the volume of excess rainfall by the unit volume of the unit hydrograph, both in same unit.

(iii) Divide the ordinates of the surface runoff hydrograph by F and this gives the required unit hydrograph ordinates.

A computer programme UHISO.FOR given in Appendix-XII is used for the derivation of unit hydrograph from the direct surface runoff hydrograph of a single period storm using the above procedure.

3.4.3 Collin's method of UH derivation

This method is based on a trial and error procedure to derive the unit hydrograph. The method is particularly applicable if the number of blocks of effective rainfall is small and/or if one block contains a large part of the effective rainfall for the storm. The steps involved in the method are as follows:

(i) Make a first estimate of the unit hydrograph. Constant value for unit hydrograph ordinates may be used as a first approximation.

(ii) This first estimate UH is next applied to each effective rainfall block except the largest and the runoff are computed.

(iii) The difference between the actual runoff and the runoff obtained in step(ii) is assumed to be due to the omitted period of effective rainfall.

(iv) From this by proportionate adjustment a second estimate UH is obtained and a weighted mean of this and the first estimate is applied in the first step again and so on until the method converges. The weights are the amounts of rainfall in the largest block and the sum of all the others, respectively. Some control may be exercised on the method by smoothing any oscillations which may tend to occur particularly in the later part of the UH as the computation proceeds.

A computer programme CoLUH.FOR given in Appendix-XII is used for the derivation of unit hydrograph using Collin's method.

3.4.4 Conventional Nash Model for Unit hydrograph derivation

The instantaneous unit hydrograph could be obtained by routing the instantaneous inflow through a cascade of linear reservoirs with equal storage coefficient. This is the concept of Nash Model. Here the outflow from the first reservoir is considered as inflow to the second reservoir and so on. The mathematical equation developed for the T-hour unit hydrograph is given as:

$$U(T,t) = \frac{1}{T}[I(n,t/K)-I(n(t-T)/K) \qquad \ldots(12)$$

where $U(T,t)$ = t^{th} ordinate for the unit hydrograph of duration T hours.

$I(n,t/K)$ = incomplete gamma function of order n at (t/k)

$I(n,(t-T)/K)$ = incomplete gamma function of order n at $(t-T)/K$

n & K = the parameters of Nash Model

The following equations are solved to compute the parameters of Nash Model(n and K).

$$nK = {}_1M'_Y - {}_1M'_X \qquad \ldots(13)$$

$$n(n+1)K^2+2nK\,{}_1M'_X = {}_2M'_Y - {}_2M'_X \qquad \ldots(14)$$

where ${}_1M'_Y$ and ${}_2M'_Y$ are first and second moment of the direct surface runoff hydrograph about the origin respectively, and ${}_1M'_X$ and ${}_2M'_X$ are first and second moment of the excess rainfall hyetograph respectively.

The first and second moments of the effective rainfall and direct surface runoff hydrograph about the origin are computed using the following equations:

$$_1M'_Y = \frac{\sum_{i=1}^{N} \frac{Y_i + Y_{i+1}}{2} t_i}{\sum_{i=1}^{N} \frac{Y_i + Y_{i+1}}{2}} \qquad ...(15)$$

$$_2M'_Y = \frac{\sum_{i=1}^{N} \frac{Y_i + Y_{i+1}}{2} (t_i)^2}{\sum_{i=1}^{N} \frac{Y_i + Y_{i+1}}{2}} \qquad ...(16)$$

$$_1M'_X = \frac{\sum_{i=1}^{M} X_i t_i}{\sum_{i=1}^{M} X_i} \qquad ...(17)$$

$$_2M'_X = \frac{\sum_{i=1}^{M} X_2 t_i^2}{\sum_{i=1}^{M} X_i} \qquad ...(18)$$

where

Y_i = ith ordinate of direct surface runoff hydrograph (DSRO) in m^3/s

N = No. of DSRO ordinates

t_i = Time to the mid point of the ith interval from the origin in hours.

M = No. of rainfall blocks

X_i = ith block of excess rainfall in mm

A computer programme NASHF.FOR given in Appendix-XIV uses this procedure to estimate the unit hydrograph for the desired duration by Conventional Nash Model.

3.4.5 Integer Nash Model for Unit Hydrograph derivation

Integer Nash Model is a simplified form of the conventional Nash Model. It takes the parameter 'n' approximated to the nearest integer and computes the incomplete gamma function using a simplified procedure where the user of Pearson table is fully avoided. The unit hydrograph of T-hour duration is derived using the following equations by this method.

$$U(T,t) = \frac{1}{T}[I(n,y) - I(n,y_1)] \qquad \text{...(19)}$$

where,

$$I(n,y) = 1-e^{-y} \sum_{m=0}^{n-1} \frac{y^m}{m!} \qquad \text{...(20)}$$

$$l(n,y_1) = i-e^{-y_1} \sum_{m=0}^{n-1} \frac{y_1^m}{m!} \qquad \text{...(21)}$$

$$y = t/K \qquad \text{...(22)}$$

$$y_1 = (t-T)/K \qquad \text{...(23)}$$

The integer value of n and modified value of K are obtained preserving the first moment of IUH and checking closeness of the second moment of IUH about the centroid. A computer programme INTNAS.FOR is given in Appendix-XV for the computation of T-hour unit hydrograph using Integer Nash Model.

3.4.6 Clark Model for Unit hydrograph Derivation

Clark (1945) suggested that the IUH can be derived by routing the unit inflow in the form of time-area concentration curve, constructed from isochronal map, through a single linear reservoir. The linear reservoir routing is accomplished using the general equation.

$$U_i = C\ I_i + (1-C)\ U_{i-1} \qquad \ldots(24)$$

where C and (1-C) are routing coefficients

U_i is the IUH at the period i

U_{i-1} is the IUH at the period (i-1)

$$e = \frac{\Delta t}{R + 0.5\Delta t} \qquad \ldots.(25)$$

Δt is the computation interval (hours)

The IUH can be converted to a unit hydrograph of unit rainfall duration Δt by simply averaging the two ordinates of IUH spaced an interval Δt apart as follows:

$$UH_i = 0.5\ (U_i + U_{i-1}) \qquad \ldots(26)$$

The IUH can be converted to a unit hydrograph of some unit rainfall duration other than Δt, provided that it is in an exact multiple of Δt by the following equation:

$$UH_i = \frac{1}{n}\ [0.5\ U_{i-n} + U_{i-n+1} + \ldots + U_{i-1} + 0.5U_i] \qquad \ldots(27)$$

where UN_i = ordinate at time i of unit hydrograph of duration D-hour and computational interval Δt hours.

$$n = D/\Delta t \qquad \ldots(28)$$

D = unit hydrograph duration (hours)

A computer programme CLARKF.FOR for the derivation of unit hydrograph using Clark model is given in Appendix-XVI.

3.4.7 Derivation of S-Curve Hydrograph

S-curve is the hydrograph of direct surface runoff that would result from excess rainfall of unit volume occuring per unit period continuously. The S-curve may be derived from T-hour unit hydrograph. The unit hydrograph ordinates are successively lagged by time period T-hours which equals the unit period of unit hydrograph. The s-curve hydrograph ordinates are obtained after summing up the respective ordinates of successively lagged unit hydrograph. Generally at time t_b which is the base length of the first unit hydrograph the S-curve hydrograph ordinates becomes constant. The maximum ordinate of the S-curve corresponds with the equilibrium discharge computed as:

$$Q_{max} = \frac{0.2778\ AU}{T} \qquad \ldots(29)$$

where A is the catchment area (sq.km)

V is the unit volume (mm)

and T is duration of the unit hydrograph

A computer programme SCURVE.FOR for the derivation of S-curve hydrograph is given in Appendix-XVII.

3.4.8 Change of Unit Period of a Unit Hydrograph

Having derived a unit hydrograph for a particular unit period and you want to change the period the following procedure can be used.

(a) Superimposition method:- only suitable when the new duration of unit hydrograph is integer multiple of the original duration.

(b) S-curve method: More general method

(a) Superimposition method:

The unit hydrograph of 2 t_r duration can be derived from a unit hydrograph of t_r duration in the following steps:

(i) Add the ordinates of t_r - hour unit hydrograph to the ordinates of an identical unit hydrograph lagged by t_r hour.

(ii) Divide the ordinates of the resulting hydrograph of step (i) by 2 to obtain a unit hydrograph for a unit duration of 2 t_r.

Note that the unit hydrograph of n t_r duration can be derived by n time successive lagging of the t_r duration unit hydrograph and then dividing the resulting hydrograph by n, where n is an integer (n=1,2..etc.)

A computer programme SUPERIM.FOR for changing the duration of unit hydrograph using superimposition method is given in Appendix XVIII.

(b) S-curve method

The unit hydrograph of t_2 duration can be obtained from the unit hydrograph of t duration as follows:

(i) Derive the S-curve from t_1 hour unit hydrograph. This curve is termed as S_1-curve.

(ii) Shift the S-curve by t_2 hours to get the S_2-curve.

(iii) Subtract the S_2 curve from S_1 curve to give another curve.

(iv) The curve obtained at step (iii) represents the unit hydrograph for t_2 hour duration with a unit volume equal to t_2/t_1 of U, where U is the unit volume of the t_1 hour duration unit hydrograph. Multiply the differences between the S-curves by t_1/t_2 to produce a unit hydrograph for the period t_2 hours with a unit volume U.

A computer programme NEWD.FOR for changing the duration of Unit hydrograph using S-curve method is given in Appendix-XIX.

3.5 Reproduction of Direct Surface Runoff and estimation of flood

3.5.1 Reproduction of observed direct surface runoff:

The direct surface runoff hydrograph ordinates are computed using the following equations of convolution summation:

$$\hat{Y}_i = \sum_{i=1}^{m} \sum_{j=1}^{i} UH_j * X_{i-j+1} \qquad ...(30)$$

where $\hat{Y}_i$ = computed direct surface runoff (m^3/s)

UH_j = jth ordinate of T-hour unit hydrograph ordinates with 1 mm unit volume.

X_i = ith block of excess rainfall of T-hour duration in mm

m = number of rainfall excess ordinate

In order to see the reproduction of observed direct surface runoff using the desired unit hydrograph the fitting efficiency and the values of the various error functions are computed. Those are described as follows:

(i) Fitting efficiency: The fitting efficiency is, mathematically, defined as:

$$EF = ((F_o - F_1)/F_o) *100 \qquad ...(31)$$

$$F_o = \sum_{i=1}^{N} (Y_i - \bar{Y})^2 \qquad ...(32)$$

$$F_1 = \sum_{i=1}^{N} (Y_i - \hat{Y}_i)^2 \qquad ...(33)$$

where Y_i = ith value of the observed DSRO (m^3/s)

$\hat{Y}_i$ = ith value of the computed DSRO (m^3/S)

N = No. of DSRO ordinates

$\bar{Y}$ = mean of the N values of observed DSRO(m^3/s)

EF = Fitting efficiency in percentage

F_o = Sum of the squares of the differences between observed DSRO and mean DSRO values.

F_1 = Sum of the squares of the differences between observed and computed DSRO ordinates.

(ii) Average standard error:- It is the root mean squared sum of the differences between observed and computed DSRO.

(iii) Average absolute error: It is the average of the absolute values of the differences between observed and computed DSRO.

(iv) Average percentage absolute error: It is the average of the absolute values of percentage differences between observed and computed DSRO ordinates.

(v) Percentage absolute error in peak- It is the ratio of the absolute difference in observed and computed DSRO peaks and observed peak.

(vi) Percentage absolute error in time to peak:- It is the ratio of the absolute difference between the observed and computed time in peak and observed time to peak.

A computer programme REPROD.FOR given in Appendix-XX computes the direct surface runoff, fitting efficiency and various error functions described above.

3.5.2 Development of direct surface runoff hydrograph from unit hydrograph and composite storm:

The ordinates of the unit hydrograph must be multiplied by the depth of excess rainfall to provide the different hydrographs of direct surface runoff, one for each of the intensities given in the design storm. These must then be superimposed with the correct time lag and added to give the direct surface runoff hydrograph due to composite storm.

A computer programme SYNTH.FOR given in Appendix-XXI uses the above procedure to compute the direct surface runoff hydrograph from unit hydrograph and composite storm.

4.0 RECOMMENDATIONS

The twenty one computer programmes given in this user's manual are written in FORTRAN-IV language. A computer system with FORTRAN compiler along with simple FORTRAN user's guide are required to run the programmes. The memory requirement depends upon the length of the data which may be modified through the DIMENSION statements in the programmes. The execution time for each programme is different due to different length of the data required for running the different programmes. All these programmes are used for the unit hydrograph analysis of gauged catchments. In case user wants to derive unit hydrographs for ungauged catchments, he may refer to report UM-9 (NIH, 1984-85).

The programmes are developed in FORTRAN IV language and implemented and tested on VAX-11/780 computer system which is a 32 bit machine available at National Institute of Hydrology, Roorkee. The programme may run on other computer systems, having FORTRAN compiler, after suitable modifications as per the software requirements of the system.

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APPENDIX-I

A. COMPUTER PROGRAMME GAPF. FOR

```
C       PROGRAME FOR ESTIMATING MISSING DATA USING NORMAL RATIO METHOD
        DIMENSION RN(100,50),RAIN(100,50),ARAIN(100,50)
        OPEN(UNIT=1,FILE='GAPF.DAT',STATUS='OLD')
        OPEN(UNIT=2,FILE='GAPF.OUT',STATUS='NEW')
        READ (1,*) NEV
        WRITE(2,51)
51      FORMAT(20X,'RAINFALL AT DIFFEREN STATIONS AFTER FILLING THE
        1 MISSING RECORDS')
        WRITE(2,52)
52      FORMAT(10X,120('-'))
        DO 1 I=1,NEV
        READ(1,*) NS
        READ(1,*) NRAIN
        READ(1,*)((RN(J,K),K=1,NRAIN),J=1,NS)
        READ(1,*)((RAIN(J,K),K=1,NRAIN),J=1,NS)
        DO 2 J=1,NS
        DO 3 K=1,NRAIN
        IF(RAIN(J,K).NE.-1)GO TO 100
        RAT=0.
        L=0
        DO 4 K1=1,NS
        IF(J.EQ.K1) GO TO 4
        IF(RAIN(K1,K).EQ.-1) GO TO 4
        L=L+1
        RAT=RAT+RAIN(K1,K)/RN(K1,K)
4       CONTINUE
        IF(L.EQ.0)ARAIN(J,K)=RN(J,K)
        IF(L.NE.0)ARAIN(J,K)=RAT*RN(J,K)/L
        GO TO 101
100     ARAIN(J,K)=RAIN(J,K)
101     CONTINUE
3       CONTINUE
2       CONTINUE
        WRITE(2,30)I
30      FORMAT(4X,'EVENT NO:-',I5)
        WRITE(2,45) ((ARAIN(J,K),K=1,NRAIN),J=1,NS)
45      FORMAT(4X,<NRAIN>F10.3)
1       CONTINUE
50      STOP
        END
```

B. DESCRIPTION OF COMPUTER PROGRAMME GAPF.FOR

The computer programme GAPF.FOR is written in FORTRAN IV language and run on VAX-11/780 digital computer system. The programme is used for estimating the missing station rainfall data using normal ratio method. The important variables used in the main programme are described below:

VARIABLE	DESCRIPTION
NS	No. of raingauge stations
NEV	No. of events
NRAIN	No. of rainfall values
RN	Two dimensional array containing the normal rainfall values at each raingauge stations
RAIN	Two dimensional array containing the observed rainfall values at each raingauge stations for different event
ARAIN	Two dimensional aray containing the observed rainfall values and estimated values of missing rainfall at each raingauge stations for different event

C. INPUT SPECIFICATIONS:

The input lists and their specifications which are to be supplied through an input file GAPF.DAT are:

REC No.	INPUT LISTS	FORMAT	REMARK
1.	NEV	FREE	
2.	NS	FREE	Repeat record no. 2 to 5 for each event
3.	NRAIN	FREE	

4. ((RN(J,K),K=1,NRAIN), FREE
J=1, NS)

5. ((RAIN(J,K),K=1,NRAIN), FREE
J=1, NS)

D. OUTPUT SPECIFICATIONS

The output file GAPF.OUT consists the values of the following output lists in the specified format:

REC No.	OUTPUT LISTS	FORMAT	REMARK
1.	Nil	20X,'RAINFALL AT DIFFERENT STATIONS AFTER FILLING THE MISSING RECORD'	
2.	Nil	10X, 120 ('-')	Repeat record no. 3 and 4 for each event
3.	I	4 X, 'EVENT NO:-', I 5	
4.	((ARAIN(J,K), K=1,NRAIN),J=1,NS)	4 X, <NRAIN> F 10.3	

E. EXAMPLE

The data below provide details of individual storm precipitation at four gauges A, B, C and D togather with normal annual precipitation. Estimate the missing storm precipitation data at station A using normal ratio method.

Gauge	A	B	C	D
Precipitation (mm)	-1	98.9	120.5	110.0
Normal annual (mm)	331.3	290.8	325.9	360.5

where -1 denotes the missing storm precipitation data at the respective station (station A).

(a) <u>Input</u>:

The input data, required to run the programme for estimating the missing precipitation data (station A in the above example), are supplied through the file GAPF.DAT. For the above example, the input file GAPF.DAT contains the following data:

```
1
4
1
331.3   290.8   325.9   360.5
 -1      98.9   120.5   110.0
```

(b) <u>Output</u>

```
        RAINFALL AT DIFFERENT STATIONS AFTER FILLING THE
        MISSING RECORDS

EVENT NO:-  1

112.087
 98.900
120.500
110.000
```

APPENDIX - II

A. COMPUTER PROGRAMME DOUBLE.FOR

```
C       THIS PROGRAMME CHECKS THE CONSISTENCY OF A PARTICULAR
C       RECORD USING DOUBLE MASS CURVE ANALYSIS HERE:
C       NS=NO. OF RAIGAUGE STATIONS
C       N=NO. OF OBSERVATIONS AT EACH STATIONS
C       NT=STATION NO. FOR WHICH ANALYSIS IS REQUIRED
C       R=MATRIX HAVING OBSERVATIONS AT DIFFERENT RAINGAUGE
C       STATIONS WHERE RAINFALL VALUES ARE SUPLIED COLUMN VISE
        DIMENSION R(20,100)
        OPEN(UNIT=1,FILE='DOUBLE.DAT',STATUS='OLD')
        OPEN(UNIT=2,FILE='DOUBLE.OUT',STATUS='NEW')
        READ(1,*) NS,N,NT
        READ(1,*) ((R(J,I),I=1,N),J=1,NS)
        WRITE(2,7)
7       FORMAT(20X,'DOUBLE MASS CURVE ANALYSIS')
        WRITE(2,8)
8       FORMAT(20X,27('_')///)
        WRITE(2,6)NT
6       FORMAT(5X,'STATION NO.',I3,28X,'SUM OF OTHER STATIONS')
        A=0.0
        B=0.0
        DO 1 I=1,N
        DO 2 J=1,NS
        IF(J.EQ.NT) GO TO 3
        A=A+R(J,I)
        X=A/(NS-1)
        GO TO 2
3       B=B+R(J,I)
2       CONTINUE
        WRITE(2,5) B,X
5       FORMAT(5X,F10.2,31X,F12.2)
1       CONTINUE
        CLOSE(UNIT=1)
        CLOSE(UNIT=2)
        STOP
        END
```

B. DESCRIPTION OF COMPUTER PROGRAMME DOUBLE.FOR

The computer programme DOUBLE.FOR checks the consistency of a particular record using double mass curve analysis. The programme is written in FORTRAN IV language and run on VAX-11/780 digital computer system. The important variables used in the main programme are described below:

VARIABLE	DESCRIPTION
NS	No. of raingauge stations
N	No. of observations at each stations
NT	Station no. at which consistency check of the record is required
R	Two dimensional array containing the observed rainfall values at different stations
B	Cummulative fall at the selected raingauge station for the consistency check
X	Average of cummulative falls at other raingauge stations excluding the one selected for consistency check.

C. INPUT SPECIFICATIONS:

The input data file DOUBLE.DAT consists the following input lists in the specified format.

REC No.	INPUT LISTS	FORMAT	REMARK
1.	NS, N, NT	FREE	
2.	((R(J,I), I=1,N), J=1, NS)	FREE	

D. OUTPUT SPECIFICATIONS:

The output file DOUBLE.OUT consists the following output lists in the specified format:

RECNo.	OUTPUT LISTS	FORMAT	REMARK
1.	Nil	20X, 'DOUBLE MASS CURVE ANALYSIS'	
2.	Nil	20X, 27('-')|||	
3.	NT	5X, 'STATION NO.',I3,28X, 'SUM OF OTHER STATIONS'	
4.	B, X	5X, F10.2, 31X, F12.2	

E. EXAMPLE

The annual rainfall values for five stations all in the same catchment area are given below. Develop a programme to check the consistency of different stations using double mass technique.

Year	stn 1	stn 2	stn 3	stn 4	stn 5
1973	43.54	40.10	44.21	39.17	39.91
1974	48.80	47.54	48.41	43.34	45.15
1975	47.57	46.77	47.50	42.28	42.74
1976	43.15	43.26	43.86	35.02	33.12
1977	45.03	44.91	50.95	37.86	48.91
1978	45.99	47.06	43.10	37.36	37.15
1979	40.41	40.16	38.97	35.71	40.77
1980	53.77	61.75	60.57	52.23	54.07

(a) Input :

The input data to check the conistency of records at a station using the double mass curve technique are supplied through the file DOUBLE.DAT. For the above example, the input file DOUBLE.DAT contains the following data to run the programme for checking the consistency of records at station no.1.

```
5 8 1
43.54  48.80  47.57  43.15  45.03  45.99  40.41  63.77
40.10  47.54  46.77  43.26  44.91  47.06  40.16  61.75
44.21  48.41  47.50  43.86  50.96  43.10  38.94  60.57
39.17  43.34  42.28  35.02  37.86  37.36  35.71  52.23
39.91  45.15  42.74  33.12  48.91  37.15  40.77  54.07
```

(b) Output :

DOUBLE MASS CURVE ANALYSIS

STATION NO.1	SUM OF OTHER STATIONS
43.54	40.85
92.34	86.96
139.91	131.78
183.06	170.60
228.09	216.25
274.08	257.42
314.49	296.32
378.26	353.47

APPENDIX - III

A. COMPUTER PROGRAMME THIES.FOR

```
C       THIS PROGRAMME CALCULATES THE AVERAGE RAINFALL FROM GIVEN
C       RAINFALL VALUES AT DIFFERENT RAINGAUGE STATIONS
        DIMENSION RAIN(50,50),WT(50),AVR(50)
        READ(5,*) NST      !NO. OF STATIONS
        READ(5,*) NRN      !NO. OF RAINFALL VALUES AT EACH STATIONS
        READ(5,*)(WT(I),I=1,NST)  !THIESSEN WEIGHT OF EACH STATIONS
        READ(5,*)((RAIN(I,J),J=1,NST),I=1,NRN) !RAINFALL AT EACH STATIONS
        DO 1 I=1,NRN
        AVR(I)=0.0
        DO 2 J=1,NST
2       AVR(I)=AVR(I)+RAIN(I,J)*WT(J)
1       CONTINUE
        WRITE(6,3)
3       FORMAT(20X,'AVERAGE RAINFALL (MM)')
        WRITE(6,4) (AVR(I),I=1,NRN)
4       FORMAT(4X,10F8.2)
        STOP
        END
```

B. DESCRIPTION OF COMPUTER PROGRAMME THIES.FOR

The computer programme THIES.FOR is used for computing the areal average rainfall due to a storm event in the catchment using Theissen polygon method. The programme is written in FORTRAN-IV language and run on VAX- 11/780 digital computer system. The variables used in the main programme are described below:

VARIABLE	DESCRIPTION
NST	No. of raingauge stations
NRN	Maximum no. of rainfall values at any raingauge station
WT	Veetor containing the Thiesen weights for each raingauge stations
RAIN	Two dimensional array containing the rainfall values at each raingauge statins for different time intervals
AVR	Vector containing the average rainfall values at given time intervals

C. INPUT SPECIFICATIONS :

The input file THIES.DAT should contain the values of the following input lists in the specified format:

REC.No.	INPUT LISTS	FORMAT	REMARK
1.	NST	FREE	
2.	NRN	FREE	
3.	(WT(I),I=1,NST)	FREE	
4.	((RAIN(I,J),J=1,NST), I=1, NRN)	FREE	

D. OUTPUT SPECIFICATIONS :

The output file THIES.OUT would be created after running the programme THIES.FOR. The output file consists the values of the following output lists in the specified format:

REC.No.	OUTPUT LISTS	FORMAT	REMARKS
1.	Nil	20X,'AVERAGE RAINFALL(MM)'	
2.	(AVR(I),I=1,NRN)	4X, 10F8.2	

E. EXAMPLE :

Hourly rainfall data observed at five raingauge stations in a catchment during a storm are given below. Find out the average rainfall in the catchment using Theissen Polygon method. Theissen weights for the five raingauge stations are 0.1559, 0.1811, 0.2716, 0.1710 and 0.2203 respectively.

OBSERVED RAINFALL DURING THE STORM

Time(hr)	Rainfall(mm)				
	stn 1	stn 2	stn 3	stn 4	stn 5
1	0	0	2.0	0	0
2	0	11	0	0	0
3	0	13	6	25	14
4	8	9	15	10	21
5	7	0	3	8	5.5
6	10	0	9	0	11
7	0	12	1	0	1.5

(a) Input :

To run the programme for the computation of average rainfall using Theissen polygon method the input data have to be supplied through a file THIES.DAT. For the above example the structure of the input file THIES.DAT would be:

```
5
7
0.1559   0.1811   0.2716   0.1710   0.2203
0   0  2.0     0   0
0  11  0       0   0
0  13  6      25  14
8   9 15      10  21
7   0  3       8   5.5
10  0  9       0  11
0  12  1       0   1.5
```

(b) Output :

AVERAGE RAINFALL (MM)

0.54   1.99   11.34   13.29   4.49   6.43   2.78

APPENDIX-IV

A. COMPUTER PROGRAMME ISO.FOR

```
C       THIS PROGRAMME COMPUTES THE AREAL AVERAGE
C       PRECIPITATION USING ISOHYETAL METHOD
C       N=NO. OF ISOHYETAL AREAS
C       HISO=VECTOR CONTAINING THE AREA AREA ENCLOSED
C       BETWEEN THE TWO ISOHYETS
C       R=VECTOR CONTAINING THE VALUES OF AVERAGE
C       PRECIPITATION(TO BE COMPUTED TAKING THE AVERAGE OF
C       TWO CONSECUTIVE ISOHYETS AND SUPLYING THE UPPER
C       AND LOWER LIMITS FOR AVERAGE PRECIPITATIONS)
        DIMENSION HISO(100),AEN(0:100),R(100),E(100)
        1,P(100),Q(100),D(100)
        OPEN(UNIT=1,FILE='ISO.DAT',STATUS='OLD')
        OPEN(UNIT=2,FILE='ISO.OUT',STATUS='NEW')
        READ(1,*)N
        READ(1,*)(HISO(I),I=1,N)
        READ(1,*)(AEN(I),I=1,N)
        READ(1,*)(R(I),I=1,N)
        WRITE(2,1)
1       FORMAT(30X,'ISOHYETAL METHOD')
        WRITE(2,2)
2       FORMAT(30X,16('_')///)
        A=0.0
        B=0.0
        AEN(0)=0.0
        DO 3 I=1,N
        E(I)=AEN(I)-AEN(I-1)
        P(I)=E(I)*R(I)
        B=B+P(I)
        Q(I)=B
        D(I)=Q(I)/AEN(I)
3       CONTINUE
        WRITE(2,4)
4       FORMAT(1X,'ISOHYET',2X,'AREA',2X,'NET AREA',2X,'AVG. PREC.',2X,
        1'PREC. VOL.',2X,'TOTAL PREC. VOL.',2X,'AVG. DEPTH')
        WRITE(2,5)
5       FORMAT(10X,'(SQ KM)',2X,'(SQ KM)',4X,'(MM)',8X,'(CU M)'
        1,9X,'CU M',9X,'(MM)')
        WRITE(2,6)
6       FORMAT(1X,7('_'),2X,4('_'),2X,8('_'),2X,10('_'),2X,10('_'),2X
        1,15('_'),2X,10('_')/)
        WRITE(2,7)(HISO(I),AEN(I),E(I),R(I),P(I),Q(I),D(I),I=1,N)
7       FORMAT(1X,F7.0,2X,F5.0,2X,F7.2,F10.1,2X,F10.1,F15.1,2X,F10.
        14)
        CLOSE(UNIT=1)
        CLOSE(UNIT=2)
        STOP
        END
```

B. LDESCRIPTION OF COMPUTER PROGRAMME ISO.FOR

The computer programme ISO.FOR computes the variation of depth with area over the catchment using Iso - hyetal method. The programme is written in FORTRAN IV language and run on VAX-11/780 digital computer system. The main variables used in the programme are described below:

VARIABLE	DESCRIPTION
N	No. of Isohyetal areas
HISO	Vector containing the precipitation values associated with each Isohyets
AEN	Vector containing the comulative area enclosed between the two Ischyets
R	Vector containing the average precipitation between the two consecutive isohyets except the first one to be supplied by the user based on the observations at precipitation stations of the neighbouring basin
E	Vector containing the net area enclosed between the two consecutive isohyets
P	Vector containing the precipitation volume between the two consecutive isohyets.
Q	Vector containing the cummulative values of precipitation volume
D	Vector containing the total areal average precipitation over the area enclosed by consecutive isohyets.

C. INPUT SPECIFICATIONS :

The input file ISO.DAT should contain the values for the following input lists in the specified format:

REC.No.	INPUT LISTS	FORMAT	REMARK
1.	N	FREE	
2.	(HISO(I),I=1,N)	FREE	
3.	(AEN(I),I=1,N)	FREE	
4.	(R(I),I=1,N)	FREE	

D. OUTPUT SPECIFICATIONS :

After running the programme ISO.FOR an output file ISO.OUT will be created on disk. This output file will have the values of the following output lists in the specified format:

REC.No.	OUTPUT LISTS	FORMAT	REMARK
1.	Nil	30X,'ISOHYETAL METHOD'	
2.	Nil	30X, 16 ('-')|||	
3.	Nil	IX,'ISOHYET', 2X, 'AREA',2X, 'NET AREA',2X,'AV6.PREC.',2X, 'PREC.VOL',2X,'TOTAL PREC.VOL', 2X, 'AVG.DEPTH'	
4.	Nil	10X,'(SQKM)', 2X,'(SQKM)',4X,'(MM)' 8X,'(CUM)',9X, 'CUM',9X,'(MM)'	
5.	Nil	1X, 7('-'),2X, 4('-'), 2X, 8('-') 2X,10('-'),2X, 10('-'), 2X,15('-'), 2X,10('-')|	

6. (HISO(I),AEN(I), E(I), R(I),P(I) O(I),D(I),I=1,N) — 1X, F7.0, 2X, F5.0, 2X, F7.2, F10.1, 2X, F10.1, F15.1, 2X, F10.4

E. EXAMPLE

Following a storm on a particular catchment an isohyetal map is drawn. The total area enclosed by the isohyets is given below. Calculate the variation of depth with area over the catchment.

Isohyet (mm)	100	75	50	25	<25
Total area enclosed (sq km)	32	224	500	1005	1517

In the area enclosed by the 100 mm isohyet it will be assumed that the average depth is 110 mm. For the area outside the 25 mm isohyet it will be assumed that the average depth is 20 mm.

(a) Input :

For the above example the structure of the input file ISO.DAT would be as given below:

```
5
100     75     50     25     15
 32    224    500   1005   1517
110    87.50  62.50  37.50  20.00
```

(b) <u>Output</u> :

ISOHYETAL METHOD

ISOHYET	AREA (SQ KM)	NET AREA (SQ KM)	AVG. PREC. (MM)	PREC. VOL. (CU M)	TOTAL PREC. VOL. CU M	AVG. D (MM)
100.	32.	32.00	110.0	3520.0	3520.0	110.0000
75.	224.	192.00	87.5	16800.0	20320.0	90.7143
50.	500.	276.00	62.5	17250.0	37570.0	75.1400
25.	1005.	505.00	37.5	18937.5	56507.5	56.2264
15.	1517.	512.00	20.0	10240.0	66747.5	43.9997

APPENDIX - V

A. COMPUTER PROGRAMME DAILY.FOR

```
C       THIS PROGRAMME DISTRIBUTES THE DAILY RAINFALL INTO HOURLY
C       RAINFALL AS PER THE CHOICE OF THE S.R.R.G. AND COMPUTES
C       THE AVERAGE HOURLY RAINFALL
        DIMENSION RORG(50),RSRRG(24,50),WTONS(50),SUM1(24),CHO(50)
        1,S(50),RAIN(24,50)
        OPEN(UNIT=1,FILE='DAILY.DAT',STATUS='OLD')
        OPEN(UNIT=2,FILE='DAILY.OUT',STATUS='NEW')
C       NDAY=NO. OF DAYS
C       NORG=NO. OF O.R.G. STATIONS
C       NSRRG=NO. OF S.R.R.G STATIONS
C       WTONS=VECTOR CONTAINING WEIGHTS OF S.R.R.G. AND O.R.G. STATIONS
C       CHO=VECTOR CONTAINING CHOICE OF S.R.R.G FOR EACH O.R.G.
        READ(1,*)NDAY
        WRITE(2,20)
20      FORMAT(30X,'DAILY TO HOURLY CONVERSION OF RAINFALL AND COMPUTATION
        1 OF AVERAGE HOURLY RAINFALL')
        WRITE(2,21)
21      FORMAT(10X,120('-'))
        DO 1 I=1,NDAY
        READ(1,*)NSRRG
        READ(1,*)NORG
        NTONS=NORG+NSRRG
        READ(1,*)(WTONS(J),J=1,NTONS)
        READ(1,*)(CHO(J),J=1,NORG)
C       RORG=VECTOR CONTAINING ORG STATIONS RAINFALL FOR THE DAY
        READ(1,*)(RORG(J),J=1,NORG)
C       RSRRG=VECTOR CONTAINING RAINFALL AT EACH S.R.R.G. STATIONS
        READ(1,*)((RSRRG(J,K),J=1,24),K=1,NSRRG)
        DO 2 J=1,NSRRG
        S(J)=0.0
        DO 3 K=1,24
        S(J)=S(J)+RSRRG(K,J)
3       CONTINUE
2       CONTINUE
        DO 4 J=1,24
        DO 5 K=1,NORG
        K1=CHO(K)
        RAIN(J,K)=RORG(K)*RSRRG(J,K1)/S(K1)
5       CONTINUE
4       CONTINUE
        DO 6 J=1,24
        L1=0
        L2=NORG+1
        DO 7 K=L2,NTONS
        L1=L1+1
        RAIN(J,K)=RSRRG(J,L1)
7       CONTINUE
6       CONTINUE
        DO 8 J=1,24
        SUM1(J)=0.0
```

```
      DO 9 K=1,NTONS
      SUM1(J)=SUM1(J)+RAIN(J,K)*WTONS(K)
9     CONTINUE
8     CONTINUE
      WRITE(2,12)I
12    FORMAT(4X,'ORG ST.NO.',10X,'RAINFALL OBS. FOR THE DAY(MM)
     1:--',I5)
      WRITE(2,14)(J,RORG(J),J=1,NORG)
14    FORMAT(10X,I4,10X,F15.2)
      DO 15 K=1,NSRRG
      WRITE(2,16) K
16    FORMAT(30X,'RAINFALL OBSERVED AT ',I3,'S.R.R.G. STATIONS(MM)')
      WRITE(2,11)(RSRRG(J,K),J=1,24)
15    CONTINUE
      WRITE(2,23)
23    FORMAT(10X,'THIESSEN WEIGHTS OF ALL THE STATIONS (O.R.G+S.R.R.G)')
      WRITE(2,24)(WTONS(J),J=1,NTONS)
24    FORMAT(4X,10F12.4)
      WRITE(2,10) I
10    FORMAT(30X,'AVERAGE RAINFALL FOR THE DAY(MM):---',I5)
      WRITE(2,11)(SUM1(J),J=1,24)
11    FORMAT(4X,10F12.4)
1     CONTINUE
      STOP
      END
```

B. DESCRIPTION OF COMPUTER PROGRAMME DAILY.FOR

This programme converts the daily rainfall data of O.R.G. Stations into hourly rainfall data in the ratio of the hourly rainfall values of an appropriate S.R.R.G. station for the day. The choice of the S.R.R.G. stations for each O.R.G. station has to be made by the user. Further more the programme computes the average hourly rainfall values in the catchment during the storm using Theissen polygon method. The programme is written in FORTRAN-IV language and run on VAX-11/780 digital computer system. The main variables used in the programme are described below:

VARIABLE	DESCRIPTION
NDAY	No. of days
NSRRG	No. of operational SRRG for the day
NORG	No. of operational ORG for the day
WTONS	Vector containing the Theissen Weights for all the operational raingauge stations (ORG + SRRG)
CHO	Vector containing the SRRG No. chosen for different ORG station for the distribution of daily rainfall
RORG	Vector containing the ORG stations rainfall for the day
RSRRG	Two dimensional array containing 24 values of hourly rainfall at each SRRG stations for the day
SUMI	Vector containing 24 values of average hourly rainfall for the day

C. INPUT SPECIFICATIONS

The input file DAILY.DAT should contain the values for the following input lists in the specified format.

REC.No.	INPUT LISTS	FORMAT	REMARK
1	NDAY	FREE	
2	NSRRG	FREE	Repeat rec.No.
3	NORG	FREE	2 to 7 for
4	(WTONS(J),J=1, NTONS)	FREE	NDAY.NTONS=NORG+
5	(CHO(J),J=1, NORG)	FREE	NSRRG
6	(RORG(J),J=1, NORG)	FREE	
7	((RSRRG(J,K),J=1, 24), K=1, NSRRG)	FREE	

D. OUTPUT SPECIFICATIONS

After successful running of the programme DAILY.FOR an output file DAILY.OUT will be created. This file will have the values of the following output lists including some no list parameters in the specified formats:

REC.No.	OUTPUT LISTS	FORMAT	REMARK
1	Nil	30X,'DAILY TO HOURLY CONVERSION OF RAINFALL AND COMPUTATION OF AVERAGE HOURLY RAINFALL'	Rec.No.3 to 10 are repeated for NDAY.
2	Nil	10X, 120('-')	Rec.No.5 and 6 are repeated
3	I	4X,'ORGST.No.',10X,'RAINFALL OBS.FOR THE DAY(MM):--',I5	for NSRRG times on
4	(J,RORG(J),J=1, NORG)	10X, I4, 10X, F15.2	each day.

5	K	30X,'RAINFALL OBSERVED AT', I3,'SRRG STATIONS (MM)'
6	(RSRRG(J,K),J=1 24)	4X, 10F12.4
7	Nil	10X,'THEISSEN WEIGHTS OF ALL THE STATIONS (O.R.G.+S.R.R.G)'
8	(WTONS(J),J=1, NTONS)	4X, 10F12.4
9	I	30X,'AVERAGE RAINFALL FOR THE DAY (MM): ---',I5
10	(SUMI(J),J=1,24)	4X, 10F12.4

E. EXAMPLE

During a storm the following rainfall values were observed on a day at five O.R.G. stations:

O.R.G. Station No.	Rainfall (mm)
1	65.3
2	23.2
3	171.0
4	42.0
5	30.4

Two S.R.R.G. were recording the rainfall on that day the recorded hourly rainfall values for the two S.R.R.G. are given below:

Hourly rainfall data of S.R.R.G. No.1

0 0 0 0 0 0 0 0 0 0 25.7 0 0.1 1.0 6.0 1.3 0.0 0.0 0.3 05
0.1 1.0 24.4 0.2

Hourly rainfall data of S.R.R.G. No. 2

0 0 0 0 0 0 0 0 0.2 2.1 0.7 0.3 0.1 0.1 4.7 0.0 0 0 0 0 0
0 1.7 9.0

Mass curve analysis was performed for the recorded rainfall of each station. The mass curves of daily rainfall for O.R.G. stations were compared with that of the hourly rainfall for S.R.R.G. stations and the following choice of S.R.R.G. stations were made for different O.R.G. stations:

O.R.G. Station No.	1	2	3	4	5
Chosen S.R.R.G. Station No.	1	2	1	2	1

Theissen Weights for all the raingauge stations are 0.1, 0.2, 0.15, 0.15, 0.10, 0.15 and 0.15 respectively. Here first five values of Theissen Weights correspond to O.R.G. stations while the remaining two to S.R.R.G. stations.

Find out the average hourly rainfall in the catchment on the day.

(a) Input :

For the above example the structure of the input file DAILY.DAT would be as follows:

```
1
2
5
0.1  0.2  0.15  0.15  0.10  0.15  0.15
1  2  1  2  1
65.3  23.2  171.0  42.0  30.4
0 0 0 0 0 0 0 0 0 0 25.7 0 0.1 1.0 6.0 1.3 0.0 0.0
0.3 0.5 0.1 1.0 24.4 0.2
0 0 0 0 0 0 0 0 0.2 2.1 0.7 0.3 0.1 0.1 4.7 0.0
0 0 0 0 0 0 1.7 9.0
```

(b) <u>Output</u> :

```
                 DAILY TO HOURLY CONVERSION OF RAINFALL AND COMPUTATION OF AVERAGE HOURLY RAINFALL
-------------------------------------------------------------------------------------------------------------
ORG ST.NO.        RAINFALL OBS. FOR THE DAY(MM):--    1
     1                  65.30
     2                  23.20
     3                 171.00
     4                  42.00
     5                  30.40
                        RAINFALL OBSERVED AT   1S.R.R.G. STATIONS(MM)
   0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  25.7000    0.0000    0.1000    1.0000    6.0000    1.3000    0.0000    0.0000    0.3000    0.5000
   0.1000    1.0000   24.4000    0.2000
                        RAINFALL OBSERVED AT   2S.R.R.G. STATIONS(MM)
   0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.2000    2.1000
   0.7000    0.3000    0.1000    0.1000    4.7000    0.0000    0.0000    0.0000    0.0000    0.0000
   0.0000    0.0000    1.7000    9.0000
   THIESSEN WEIGHTS OF ALL THE STATIONS (O.R.G+S.R.R.G)
   0.1000    0.2000    0.1500    0.1500    0.1000    0.1500    0.1500
                        AVERAGE RAINFALL FOR THE DAY(MM):---    1
   0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.1458    1.5306
  19.3017    0.2187    0.1460    0.8041    7.8127    0.9505    0.0000    0.0000    0.2194    0.3656
   0.0731    0.7312   19.0800    6.7058
```

APPENDIX- VI

A COMPUTER PROGRAMME VEL.FOR

```
C       THIS PROGRAMME CALCULATES THE DISCHARGE FROM VELOCITY
C       MEASUREMENT
C       N=NO.SECTIONS
C       AR=VECTOR CONTAINING AREA OF SECTIONS IN SQ.METRE
C       NV=NO OF VELOCITY MEASUREMENTS AT A SPECIFIC SECTION
C       VL=VECTOR CONTAINING THE VELOCITY MEASUREMENT AT THE
C       SPECIFIC SECTION
        DIMENSION V(100),VL(100),AR(100)
        OPEN(UNIT=1,FILE='VEL.DAT',STATUS='OLD')
        OPEN(UNIT=2,FILE='VEL.OUT',STATUS='NEW')
        READ (1,*) N
        READ(1,*) (AR(I),I=1,N)
        S=0.00
        AV=0.0
        DO 1  I=1,N
        READ(1,*) NV
        READ(1,*) (VL(J), J=1,NV)
        S=VL(1)
        DO 2 J=2,NV
2       S=S+VL(J)
        AV=S/NV
        V(I)=AV*AR(I)
1        CONTINUE
        T1=V(1)
        DO 3 I=1,(N-1)
3       T1=T1+V(I+1)
        WRITE (2,4)
4       FORMAT(20X,'STAGE DISCHARGE -CALCULATION OF DISCHARGE FROM
        1VELOCITY MEASUREMENTS')
        WRITE (2,5)
5       FORMAT(20X,68('-')//)
        WRITE (2,6)
6       FORMAT(26X,'SECTION',8X,'AREA',10X,'DISCHARGE')
        WRITE (2,7)
7       FORMAT(26X,7('-'),8X,4('-'),10X,9('-'))
        WRITE(2,8) (I,AR(I),V(I),I=1,N)
8       FORMAT(26X,I3,10X,F6.2,10X,F6.4)
        WRITE (2,9) T1
9       FORMAT (//26X,'TOTAL DISCHARGE EQUAL',F7.3,'(CUMECS)')
        CLOSE (UNIT=1)
        CLOSE (UNIT=2)
        STOP
        END
```

B. DESCRIPTION OF COMPUTER PROGRAMME VEL.FOR

The programme VEL.FOR computes the discharge from velocity measurements. The programme is written in FORTRAN-IV language and run on VAX-11/780 Digital Computer System. The variables used in the programme as input and output lists are described below:

VARIABLE	DESCRIPTION
N	No of Sections
AR	Vector containing the area of different sections in Sq.Metre.
NV	No. of Velocity measurements at a specific section
VL	Vector containing the values of velocity measured at that section.
TI	Total computed discharge (m^3/sec)
V	Vector containing the discharge for each section.

C. INPUT SPECIFICATIONS:

The input file VEL.DAT should contain the values of the following input lists in the specified format.

REC No.	INPUT LISTS	FORMAT	REMARK
1	N	Free	
2	(AR(I),I=1,N)	Free	
3	NV	Free	Repeat Rec.
4	(VL(I),J=1,NV)	Free	No.3 & 4 for N times

D. OUTPUT SPECIFICATION

After successful running of the programme an output file VEL.OUT will be created. This output file will consist the following output lists in the specified format:

REC NO.	OUTPUT LISTS	FORMAT	REMARKS
1	Nil	20X,'STAGE DISCHARGE-CALCULATION OF DISCHARGE FROM VELOCITY MEA- SUREMENTS'	
2	Nil	20X, 68 ('-')//	
3	Nil	26X, 'SECTION', 8X,'AREA',10X, 'DISCHARGE'	
4	Nil	26X,7('-'),8X,4('-') ,10X, 9('-')	
5	(I,AR(I),V(I),I=1,N)	26X, I3, 10X,F6.2, 10X,F6.4	
6	TI	//26X, 'TOTAL DISCHARGE EQUAL',F7.3, '(CUMECS)'	

E. EXAMPLE

The data given below were obtained from discharge measurements on a large river. The river was divided into a number of sections and the area of each section was measured. Calculate the total discharge in the river.

Section	1	2	3	4	5	6	7
Area m^2	3.1	5.1	7.1	9.2	6.6	4.8	2.6
Velocities	0.65	0.70	0.70	0.75	0.65	0.60	0.60
(m/sec)	0.80	0.85	0.84	0.89	0.85	0.71	0.70
		0.84	0.82	0.87	0.85	0.70	0.62
			0.80	0.78	0.70		

(a) Input:- For the above example the structure of the input file VEL.DAT would be as given below:

```
7
3.1  5.1  7.1  9.2  6.6  4.8  2.6
2
0.65 0.8
3
0.7 0.85 0.84
4
0.7 0.84 0.82 0.8
4
0.75 0.89 0.87 0.78
4
0.65 0.85 0.85 0.7
3
0.6 0.71 0.70
3
0.6 0.7 0.62
```

(b) Output

STAGE DISCHARGE-CALCULATION OF DISCHARGE FROM VELOCITY MEASUREMENT

SECTION	AREA	DISCHARGE
1	3.10	2.2475
2	5.10	4.0630
3	7.10	5.6090
4	9.20	7.5670
5	6.60	5.0325
6	4.80	3.2160
7	2.60	1.6640

TOTAL DISCHARGES EQUAL 29.399 (CUMECS)

APPENDIX-VII

A COMPUTER PROGRAMME RATING.FOR

```
C      DEVELOPEMENT OF RATING CURVE IN THE FORM OF Q=a*(G-e)**b
       DIMENSION GAUGE(100),DISCH(100),Y(100),X(100),DISCHC(100)
       OPEN(UNIT=1,FILE='RATING.DAT',STATUS='OLD')
       OPEN(UNIT=2,FILE='RATING.OUT',STATUS='NEW')
C      N=NO. OF VALUES OF GAUGE OR DISCHARGE
C      GAUGE=VECTOR CONTAINING GAUGE VALUES(METRE)
C      DISCH=VECTOR CONTAINING DISCHARGE VALUES(CUMEC)
C      E=ZERO LEVEL OF THE GAUGE (METRE)
       WRITE(2,100)
100    FORMAT(20X,'DEVELOPMENT OF RATING CURVE IN THE FORM OF
       1 Q=a*(G-e)**b')
       READ(1,*)N
       READ(1,*)(GAUGE(I),I=1,N)
       READ(1,*)(DISCH(I),I=1,N)
14     WRITE(6,1)
1      FORMAT(4X,'SUPLLY THE ZERO OF THE GAUGE(METRE)?'$)
       READ(5,*)E
       DO 2 I=1,N
       Y(I)=ALOG(DISCH(I))
       X(I)=ALOG(GAUGE(I)-E)
2      CONTINUE
       CALL REG(Y,X,N,A,B)
       WRITE(2,3)
3      FORMAT(20X,'EQUATION OF THE RATING CURVE')
       WRITE(2,4)
4      FORMAT(20X,28('*'))
       A=EXP(A)
       WRITE(2,5)A,E,B
5      FORMAT(26X,'Q =',F12.3,'*(G-',F8.2,')**',F12.3)
       DO 6 I=1,N
       DISCHC(I)=A*(GAUGE(I)-E)**B
6      CONTINUE
       WRITE(2,7)
7      FORMAT(20X,'OBSERVED AND COMPUTED DISCHARGE VALUES')
       WRITE(2,8)
8      FORMAT(20X,38('*'))
       WRITE(2,9)
9      FORMAT(16X,'NO',10X,'OBS. GAUGE',10X,'OBS. DISCH.',10X,
       1'COMP. DISCH')
       WRITE(2,10)
10     FORMAT(30X,'(CUMEC)',11X,'(CUMEC)',18X,'(CUMEC)')
       WRITE(2,11)(I,GAUGE(I),DISCH(I),DISCHC(I),I=1,N)
11     FORMAT(16X,I3,9X,F10.2,5X,F15.2,5X,F15.2)
       WRITE(6,12)
12     FORMAT(4X,'DO YOU WANT TO CHANGE ZERO GAUGE VALUE?(1/0)'$)
       READ(5,*)N1
       IF(N1.EQ.1) GO TO 14
       STOP
       END
C      *****************************************************************
```

```
      SUBROUTINE REG(Y,X,N,A,B)
      DIMENSION X(100),Y(100),YC(100)
      DATA IYES/'YES'/
      AN=N
      SUM1=0.0
      SUM2=0.0
      DO100 I=1,N
      SUM1=SUM1+X(I)
100   SUM2=SUM2+Y(I)
      XM=SUM1/AN
      YM=SUM2/AN
      SUMXY=0.0
      SUMX2=0.0
      DO101 I=1,N
      SUMXY=SUMXY+(X(I)-XM)*(Y(I)-YM)
101   SUMX2=SUMX2+(X(I)-XM)*(X(I)-XM)
      B=SUMXY/SUMX2
      A=YM-B*XM
      WRITE(2,1)
1     FORMAT(4X,120('*'))
      WRITE(2,2)
2     FORMAT(50X,'LEAST SQUARE FITTING OF A STRAIGHT LINE')
      WRITE(2,3)
3     FORMAT(10X,'EQUATION OF THE FITTED LINE')
      WRITE(2,4)A,B
4     FORMAT(5X,'Q=',F10.4,'+',F10.4,'*Y')
      DO102 I=1,N
102   YC(I)=A+B*X(I)
      SUMS=0.0
      DO103 I=1,N
103   SUMS=SUMS+(YC(I)-Y(I))*(YC(I)-Y(I))
      SUMS=SUMS/(AN-2.0)
      S=SQRT(SUMS)
      SUMY=0.0
      DO104 I=1,N
104   SUMY=SUMY+(Y(I)-YM)*(Y(I)-YM)
      SUMY=SUMY/(AN-1.0)
      R=1.0-(SUMS/SUMY)
      R=SQRT(R)
      WRITE(2,25)R
25    FORMAT(4X,'COEFFICIENT OF CORRELATION=',F10.3)
      SEB=S/(SQRT(SUMX2))
      SEA=S*SQRT(1.0/AN+(XM*XM)/SUMX2)
      TB=B/SEB
      TA=A/SEA
      WRITE(2,6)
6     FORMAT(4X,'REGR. COEFF.',10X,'STAND. ERR.',10X,'T-VALUES')
      WRITE(2,7)A,SEA,TA,B,SEB,TB
7     FORMAT(4X,F11.3,10X,F11.3,10X,F11.3/4X,F11.3,10X,F11.3,10X
     1,F11.3)
```

```
      WRITE(2,8)S
8     FORMAT(4X,'STANDARD ERROR OF REGRESSION EQUATION=',F11.2)
      WRITE(2,1)
      RETURN
      END
```

B. DESCRIPTION OF COMPUTER PROGRAMME RATING.FOR

The programme RATING.FOR is used for developing the rating curve in the form of Q=a*(G-e)**b. This programme is written in FORTRAN-IV language and implemented and tested on VAX 11/780 system. The variables used in the programme are described below:

VARIABLE	DESCRIPTION
N	No. of observations for gauge or discharge
GAUGE	Vector containing Gauge Values (metre)
DISCH	Vector containing Discharge values (m^3/sec)
E	Zero level of the gauge(Metre)
A	Co-efficient 'a' in the rating curve equation.
B	Co-efficient 'b' in the rating curve equation
DISCHC	Vector containing the values of discharge corresponding to various stage values

A SUBROUTINE REG (Y,X,N,A,B) is called in the main programme. This SUBROUTINE is used for least square fitting of a straight line. Further more the coefficient of correlation, regression coefficient, standard error of regression co-efficients, T-values for regression coefficients and standard error of regression equations are also computed by this SUBROUTINE. The variables used as arguments of the SUBROUTINE are described below:

VARIABLE	DESCRIPTION
Y	Vector containing the logarithmic of discharge values
X	Vector containing the logarithmic of the stage values obtained after deducting the gauge value corresponding to zero discharge.
N	No. of observed stage or discharge values
A	Regression Co-efficient 'a' in the rating curve equation.
B	Regression co-efficient 'b' in the rating curve equation.

The variables used as the output lists within the above SUBROUTINE are described below:

VARIABLE	DESCRIPTION
A	Same as described for the variables used in the main programme
B	Same as described for the variables used in the main programme
R	Coefficient of correlation.
SEA	Standard error of regression coefficient A

TA	T-value computed for regression coefficient A.
SEB	Standard error of regression coefficient B
TB	T-value computed for regression coefficient B.
S	Standard error of regression equation.

C. INPUT SPECIFICATIONS

The values of the following input lists are required in the specified format for running the programme.

REC No.	INPUT LISTS	FORMAT
1	N	FREE
2	(GAUGE(I),I=1,N)	FREE
3	(DISCH(I),I=1,N)	FREE

The values of the above input lists are supplied through a data file RATING.DAT. In addition to this the value of the gauge corresponding to the zero discharge is supplied through terminal in interactive mode as follows while running the programme:

(i) The following matter will be displayed over the terminal screen during the running session of the programme:

SUPPLY THE ZERO OF THE GAUGE(METRE)?

(ii) The cursor will wait in the end of the above matter untill the value of the zero of the gauge is supplied by the user through terminal.

(iii)Once the step(ii) is over the following matter will be displayed over the terminal.

DO YOU WANT TO CHANGE ZERO GAUGE VALUES?(1/0)

(iv) Again the cursor will wait for input after displaying the above matter over the terminal screen. Either '1' or '0' has to be supplied by the user through terminal in free format. If the user has supplied '1' in the above response, then the control will be repeated with the other value of the gauge corresponding to zero discharge. Otherwise, if use has supplied '0', the further computation will not be performed.

D. OUTPUT SPECIFICATIONS

An output file RATING.OUT will be created after the successful running of the programme. The values of the following output lists in the specified format will be stored in the output file:

REC No.	OUTPUT LISTS	FORMAT
1	Nil	20X,'DEVELOPMENT OF RATING CURVE IN THE FORM OF Q=A*(G-e)**b'
2	Nil	4X,120('*')
3	Nil	50X, 'LEAST SQUARE FITTING OF A STRAIGHT LINE'
4	Nil	10X,'EQUATION OF THE FITTED LINE'
5	A,B	5X,'Q=', F10.4, '+', F10.4,'*Y'
6	R	4X,'COEFFICIENT OF CORRELATION = ', F10.3
7	Nil	4X,'REGR.COEFF.',10X,'STAND. ERR.', 10X, 'T-VALUES'
8	A,SEA,TA,B, SEB,TB	4X,F 11.3,10X,F11.3,10X, F11.3 4X,F11.3, 10X,F11.3,10X, F11.3
9	S	4X,'STANDARD ERROR OF REG-RESSION EQUATION=',F11.2
10	Nil	4X,120('*')
11	Nil	20X,'EQUATION OF THE RATING CURVE'
12.	Nil	20X,28('*')
13	A,E,B,	26X,'Q=',F12.3,'*(G-', F8.2',**)',F12.3
14	Nil	20X,'OBSERVED AND COMPUTED DISCHARGE VALUES'

15	Nil	20X, 38('*')
16	Nil	16X, 'NO', 10X, 'OBS. GAUGE', 10X, 'OBS.DISCH', 10X, 'COMP.DISCH'
17	Nil	30X,'(CUMEC)', 11X, '(CUMEC)', 18X,'(CUMEC)'
18	(I,GUAGE(I), DISCH(I),DISCHC(I), I=1, N)	16X,I3,9X,F10.2,5X,F15.2,5X

Note:

(1) The output lists for rec.no.2 to 10 are in SUBROUTINE REG.

(ii) The output lists for rec.No.1 and rec.No.11 to 18 are in the main programme.

(iii) Rec.No.2 to 18 are repeated with different Values of the gauge corresponding to zero discharge supplied by the user through terminal in interactive mode as discussed in earlier section on 'INPUT SPECIFICATIONS'

E. EXAMPLE

The following values of the gauge and corresponding discharges were observed at a gauging site of a river. Develope rating curves in the form of Q=a*(G-e)**b taking the values of gauge corresponding to zero discharge as 21.0 and 21.50 metre respectively for the first and second trials.

Gauge(m)	21.95	22.45	22.80	23.00	23.40	23.75	23.65
Discharge(m^3/s)	100	220	295	400	490	500	640
Gauge (m)	24.05	24.55	24.85	25.40	25.15	25.55	25.90
Discharge(m^3/s)	780	1010	1220	1300	1420	1550	1760

(a) Input: For the above example the structure of the input file RATING.DAT would be as given below:

```
14
21.95  22.45  22.80  23.00  23.40  23.75  23.65  24.05  24.55
24.85  25.40  25.15  25.55  25.90
100    220    295    400    490    500    640    780    1010   1220
1300   1420   1550   1760
```

The value of the gauge corresponding to zero discharge.

(e) is to be supplied by the user through terminal in interactive mode as given below:

```
SUPPLY THE ZERO OF THE GAUGE (METRE)? 21.00
DO YOU WANT TO CHANGE ZERO GAUGE VALUE?(1/0)1
SUPPLY THE ZERO OF THE GAUGE(METRE)? 21.50
DO YOU WANT TO CHANGE ZERO GAUGE VALUE?(1/0)0
```

b) Output

DEVELOPMENT OF RATING CURVE IN THE FORM OF Q=a*(G-e)**b

****

LEAST SQUARE FITTING OF A STRAIGHT LINE

EQUATION OF THE FITTED LINE

Q= 4.7032+ 1.7346*Y

COEFFICIENT OF CORRELATION= 0.994

REGR. COEFF.	STAND. ERR.	T-VALUES
4.703	0.058	80.539
1.735	0.052	33.128

STANDARD ERROR OF REGRESSION EQUATION= 0.09

****

EQUATION OF THE RATING CURVE

****

Q = 110.296*(G- 21.00)** 1.735

OBSERVED AND COMPUTED DISCHARGE VALUES

****

NO	OBS. GAUGE (CUMEC)	OBS. DISCH. (CUMEC)	COMP. DISCH (CUMEC)
1	21.95	100.00	100.91
2	22.45	220.00	210.12
3	22.80	295.00	305.74
4	23.00	400.00	367.04
5	23.40	490.00	503.58
6	23.75	500.00	637.70
7	23.65	640.00	598.02
8	24.05	780.00	763.16
9	24.55	1010.00	993.06
10	24.85	1220.00	1143.11
11	25.40	1300.00	1441.05
12	25.15	1420.00	1302.00
13	25.55	1550.00	1527.33
14	25.90	1760.00	1736.84

****

LEAST SQUARE FITTING OF A STRAIGHT LINE

EQUATION OF THE FITTED LINE

Q= 5.4666+ 1.2874*Y

COEFFICIENT OF CORRELATION= 0.989

REGR. COEFF.	STAND. ERR.	T-VALUES
5.467	0.052	104.491
1.287	0.053	24.424

STANDARD ERROR OF REGRESSION EQUATION= 0.12

****

EQUATION OF THE RATING CURVE

****

Q = 236.659*(G- 21.50)** 1.287

OBSERVED AND COMPUTED DISCHARGE VALUES

****

NO	OBS. GAUGE (CUMEC)	OBS. DISCH. (CUMEC)	COMP. DISCH (CUMEC)
1	21.95	100.00	84.66

2	22.45	220.00	221.54
3	22.80	295.00	331.76
4	23.00	400.00	398.87
5	23.40	490.00	540.76
6	23.75	500.00	672.26
7	23.65	640.00	634.04
8	24.05	780.00	789.81
9	24.55	1010.00	994.56
10	24.85	1220.00	1122.25
11	25.40	1300.00	1364.85
12	25.15	1420.00	1253.27
13	25.55	1550.00	1432.81
14	25.90	1760.00	1594.16

APPENDIX VIII

A. COMPUTER PROGRAMME GAUGE.FOR

```
C       THIS PROGRAMME CONVERTS GIVEN GAUGE VALUES TO DISCHARGE VALUES
C       FOR A GIVEN RATING CURVE OF THE FORM: Q=a*(H-H0)**b
        DIMENSION GAUGE(100),DISCH(100)
        READ(5,*) NG     !NO. OF GAUGE VALUES TO BE SUPLIED
        READ(5,*)(GAUGE(I),I=1,NG) !GAUGE VALUES
        READ(5,*)A,B  !COEFFICIENTS a & b OF RATING CURVE
        DO 10 I=1,NG
C       DISCH(I)=A*GAUGE(I)**B
        DISCH(I)=A+B*ALOG(GAUGE(I))
        DISCH(I)=EXP(DISCH(I))
10      CONTINUE
        WRITE(6,2)
2       FORMAT(10X,'DISCHARGE VALUES CORRESPONDING TO EACH GAUGE')
        WRITE(6,3) (DISCH(I),I=1,NG)
3       FORMAT(4X,10F8.2)
        STOP
        END
```

DESCRIPTION OF COMPUTER PROGRAMME GAUGE.FOR

The computer programme GAUGE.FOR is used for converting the given stage values into corresponding discharge values using a given rating curve in the form: $Q = a* (H-H_o)**b$. The programme is written in FORTRAN IV language and run on VAX-11/780 Digital Computer system. The variables used in the programme as input and output lists are described below:

VARIABLE	DESCRIPTION
NG	No of observed gauge values
GAUGE	Vector containing the stage values relative to the gauge corresponding to zero discharge (H-Ho)
A	Coefficient 'a' in the rating curve equation.
B	Coefficient 'b' in the rating curve equation
DISCH	Vector containing the discharge values corresponding to the given stage values.

C. INPUT SPECIFICATIONS

The input file GAUGE.DAT contains the values of the following input lists in the specified format:

REC NO.	INPUT LISTS	FORMAT
1	NG	FREE
2	(GAUGE(I),I=1,NG)	FREE
3	A,B	FREE

D.OUTPUT SPECIFICATIONS

An output file GAUGE.OUT will be created after the successful running of the programme . This file contains the values of the following output lists including some no list parameters in the specified format:

REC.No.	OUTPUT LISTS	FORMAT
1	Nil	10X, 'DISCHARGE VALUES CORRESPONDING TO EACH GAUGE'
2.	DISCH(I),I=1,NG)	4X, 10F8.2

E.EXAMPLE

The hourly stage values above the zero gauge level at a river gauging site are given below. The rating curve equation for the gauging site is in the form of Q=a*(H-Ho)**b where a=5.09 and b=1.60. Find out the discharge values corresponding to given stage values.

Time (hrs)	1	2	3	4	5	6	7	8	9	10	11	12
Stage($H-H_o$) (metre)	0.35	0.35	0.35	0.35	0.61	0.89	1.79	1.97	1.75	1.35	1.35	1.11

Time(hrs)	13	14	15	16	17	18	19	20	21	21	23	24
Stage(H-Ho) (metre)	1.03	0.95	0.83	0.71	0.61	0.57	0.55	0.55	0.55	0.51	0.51	0.51

(a) Input: For the above example the structure of the input file GAUGE.DAT would be as given below :

```
24
0.35 0.35 0.35 0.35 0.61 0.89 1.79 1.97 1.75 1.35 1.35 1.11
1.03 0.95 0.83 0.71 0.61 0.57 0.55 0.55 0.55 0.51 0.51 0.51
5.09 1.60
```

(b) Output

DISCHARGE VALUES CORRESPONDING TO EACH GAUGE

30.27 30.27 30.27 30.27 73.64 134.77 412.21 480.51 397.58 262.48

262.48 191.90 170.25 149.59 120.53 93.88 73.64 66.06 62.39 62.39

62.39 55.29 55.29 55.29

APPENDIX IX

A.COMPUTER PROGRAMME EFF.FOR

```
C       THIS PROGRAMME CALCULATES THE EFFECTIVE RAINFALL FROM DISCHARGE
C       HYDROGRAPH
C       N=NO.OF OBSERVATIONS
C       A1=VECTOR CONTAINING THE DISCHARGE HYDROGRAPH ORDINATES
C       NOPT=AN INTEGER CONSTANT WHICH ALLOW USER TO CHOOSE OPTION
C       FOR BASE FLOW
C       IF NOPT=1 USER SHOULD SUPPLY CONSTANT BASE FLOW
C       IF NOPT=2 USER MAY SUPPLY NON-CONSTANT BASE FLOW
C       A2=VECTOR CONTAINING THE ORDINATES OF DIRECT SURFACE RUNOFF
C       HYDROGRAPH OBTAINED  BY SUBTRACTING THE BASE FLOW FROM
C       DISCHARGE HYDROGRAPH
C       AR=CATCHMENT AREA (SQ.METERS)
C       HR=DATA INTERVAL IN HOURS
        DIMENSION A1(0:100),A2(0:100),CBN(0:100)
        OPEN(UNIT=1,FILE='EFF.DAT', STATUS='OLD')
        OPEN(UNIT=2,FILE='EFF.OUT',STATUS='NEW')
        READ(1,*) N
        READ (1,*) (A1(I),I=0,(N-1))
        READ (1,*) HR
        READ(1,*) AR
        READ(1,*) NOPT
        GO TO (100,200),NOPT
100     WRITE (2,1)
1       FORMAT (20X,'EFFECTIVE RAIN FALL FROM HYDROGRAPH -CONSTANT
        1BASE FLOW')
        WRITE(2,2)
2       FORMAT (20X,53('_'))
C       THIS PART OF THE PROGRAMME COMPUTES THE EFFECTIVE RAIN
C       FALL SUBTRACTING THE CONSTANT BASE FLOW FROM DISCHARGE
C       HYDROGRAPH
C       CB=CONSTANT BASE FLOW
        READ (1,*) CB
        K=0
        DO 3 I=0,(N-1)
        T=A1(I)-CB
        IF(T.LT.0.0) GO TO 3
        A2(K)=T
        K=K+1
3       CONTINUE
400             CALL SIMP (K,A2,HR,VL)
        DP=VL/AR
        DC=DP*100.0
        WRITE (2,4) VL
4       FORMAT(4X,'VOLUME OF RAIN FALL(M**3)=',F14.2)
        WRITE (2,5) AR
5       FORMAT(4X,'CATCHMENT AREA (M**2)=',E8.2)
        WRITE (2,6) DC
6       FORMAT (4X,'EFFECTIVE RAIN FALL IN CM IS=',F8.6)
        GO TO 300
200     WRITE (2,7)
```

```
7       FORMAT (20X,'EFFECTIVE RAIN FALL FROM HYDROGRAPH -NON
       1CONSTANT BASE FLOW')
        WRITE (2,8)
8       FORMAT (20X,57('_'))
C       THIS PART OF PROGRAMME COMPUTES THE EFFECTIVE RAIN FALL
C       SUBTRCTING NON CONSTANT BASE FLOW FROM DISCHARGE
C       HYDROGRAPH
        READ (1,*) (CBN(I),I=0,(N-1))
        K=0
        DO 9 I=0,(N-1)
        T=A1(I)-CBN(I)
        IF (T.LT.0) GO TO 9
        A2(K)=T
        K=K+1
9       CONTINUE
        GO TO 400
300     CLOSE (UNIT=1)
        CLOSE(UNIT=2)
        STOP
        END
        SUBROUTINE SIMP (K,A2,HR,VL)
        DIMENSION A2(0:100),A3(100)
        T=0
        NC=1
        X1=A2(0)
        X2=A2(K)
        DO 1 I=1,(2*K-1)
        ITP=MOD(I,2)
        IF (ITP) 2,3,2
3       A3(I)=A2(I/2)
        GO TO 1
2       A3(I)=(A2(NC)+A2(NC-1))/2.0
        NC=NC+1
1       CONTINUE
        DO 4 I=1,(2*K-1)
        ITP=MOD(I,2)
        IF(ITP)5,6,5
6       T=T+(2.*A3(I))
        GO TO 4
5       T=T+(4.*A3(I))
4       CONTINUE
        S=((HR/2.0)/3.0)*(X1+T+X2)
        TS=(K-1)*HR*(60.*60.)
        VL=S*TS
        RETURN
        END
```

B. DESCRIPTION OF THE COMPUTER PROGRAMME EEF.FOR

The computer programme EFF.FOR computes the effective rainfall from discharge hydrographs after seperating the constant or non-constant base flow ordinates supplied by the user as input to the programme. The programme is written in FORTRAN-IV language and run on VAX-11/780 Digital computer system. The variables used in the programme as input and output lists are described below.

VARIABLE	DESCRIPTION
N	No of discharge hydrograph ordinates
A1	Vector containing the discharge hydrograph ordinates
NOPT	An integer constant for choosing the base flow options NOPT=1 For constant base flow NOPT=2 For non-constant base flow
HR	Data interval (hours)
AR	Catchment area (sq metres)
CB	Constant base flow (m^3/sec)
VL	Volume of rainfall (M**3)
DC	Effective rainfall (cm)
CBN	Vector containing the non-constant baseflow (m^3/sec)

A SUBROUTINE SIMP(K,A2,HR,VL) is called in the main programme using the following statement:

CALL SIMP(K,A2,HR,VL)

This subroutine is used for computing the area under the direct surface runoff hydrograph using Simpson rule. The variables used in the arguments of the subroutine are described below:

VARIABLE	DESCRIPTION
K	Ordinate no. for direct surface runoff hydrograph.
A2	Vector containing the direct surface runoff hydrograph ordinates
HR	Same as described earlier in this section.
VL	Same as described earlier in this section.

C. INPUT SPECIFICATIONS

The input file EFF.DAT consists the values of the following input lists in the specified format:

REC No.	INPUT LISTS	FORMAT
1	N	Free
2	(A1(I),I=0,(N-1))	Free
3	HR	Free
4	AR	Free
5	NOPT	Free

6	CB	Free
7	(CBN(I),I=0(N-1))	Free

Note:-

(i) If NOPT=1, the input list/lists at rec.No.7 will be sbipped from input file.

(ii) If NOPT=2, the input list/lists at rec.No.6 will be skipped from input file.

D. OUTPUT SPECIFICATIONS

The values of the following output lists including some no list parameters will be stored in an output file EFF.OUT with the specified format

REC.NO.	OUTPUT LISTS	FORMAT
1	Nil	20 X,'EFFECTIVE RAINFALL FROM HYDROGRAPH-CONSTANT BASE FLOW'
2	Nil	20X, 53('-')
3	VL	4X,'VOLUME OF RAINFALL (M**3)=',F14.2)
4	AR	4X,'CATCHMENT AREA(M**2)=', F8.2)
5	DC	4 X, 'EFFECTIVE RAINFALL IN CMIS=', F8.6
6	Nil	20X,'EFFECTIVE RAINFALL FROM HYDROGRAPH-NON CONSTANT BASE FLOW'

7	Nil	20X, 57('-')

Note:-

(i) If NOPT=1, rec. no.6 and 7 will be skipped.

(ii) If NOPT=2, rec no.1, and 2 will be skipped and rec. no.6 and 7 will be written in the beginning of the output file followed by rec.no.3 to 5.

E EXAMPLE

The ordinates of discharge hydrograph in a river following a storm, which covered the entire catchment are given below at 2-hourly interval. The catchment area is 1250 km^2. Calculate the depth of effective rainfall assuming the constant base flow equal to 10 m^3/s

(a) Input: The structure of the input file EFF.DAT for the above example would be as given below:

```
12
10  57  133  136  102  76  56  41  28  18  12  10
2
1250000000
1
10
```

(b) Output

```
        EFFECTIVE RAINFALL FROM HYDROGRAPH-CONSTANT BASE FLOW

VOLUME OF RAINFALL(M**3) = 88545600.00
CATCHMENT AREA (M**2)=0.13E+10
EFFECTIVE RAINFALL IN CM IS=7.083648
```

APPENDIX -X

A.COMPUTER PROGRAMME LOSS.FOR

```
C       THIS PROGRAMME SEPERATE UNIFORM LOSS FROM RAINFALL
C       HYETOGRAPH AND BASEFLO FORM DISCHARGE HYDROGRAPH
        DIMENSION EXR(50),ODSRO(50),BFLO(50),OBD(50),WT(10),ABFLO(50)
        DIMENSION TITLE(50),TIME(50), EFR(50),REXR(50),RAIN(50,50)
        OPEN(UNIT=1,FILE='LOSS.DAT',STATUS='OLD')
        OPEN(UNIT=2,FILE='LOSS.OUT',STATUS='NEW')
C       CA=CATCHMENT AREA
        READ(1,*) CA
C       DLT=SAMPLING INTERVAL
        READ(1,*) DLT
C       NST=NO. OF  STORMS HAS TO BE ANALYSED
        READ(1,*) NST
        DO 112 II=1,NST
C       READ NO OF STATIONS
        READ(1,*) NSTAT
C       READ THIES. WEIGHTS
        READ(1,*) (WT(I),I=1,NSTAT)
C       READ NO. OF RAIN FALL BLOCKS
        READ(1,*) NRAIN
C       READ RAIN FALL AT EACH STATIONS
        READ (1,*) ((RAIN(I,J),I=1,NRAIN),J=1,NSTAT)
        DO 1003 I=1,NRAIN
        EFR(I)=0.0
        DO 1003 J=1,NSTAT
1003    EFR(I)=EFR(I)+RAIN(I,J)*WT(J)
C       READ NO.  OF RUNOFF BLOCKS
        READ(1,*) NRUN
C       READ RUNOFF BLOCKS
        READ(1,*)(OBD(I),I=1,NRUN)
C       CB=RECESSION FLOW
        READ(1,*)CB
12      FORMAT(4X,128('*'))
13      FORMAT(///)
        WRITE(2,16)CA
16      FORMAT(4X,'C..TCHMENT AREA-',4X,F8.3)
        WRITE(2,3451) NSTAT
3451    FORMAT(4X,'NO. OF RAINGAUGE STATIONS=',2X,I3)
        WRITE(2,3452)
3452    FORMAT(30X,'WEIGHT OF EACH RAINGAUGE STATIONS')
        WRITE(2,3453)(WT(I),I=1,NSTAT)
3453    FORMAT(10F8.4)
        WRITE(2,3454) NRAIN
3454    FORMAT(4X,'NO. OF RAINFALL VALUES=',2X,I3)
        WRITE(2,4454)
4454    FORMAT(30X,'RAINFALL AT EACH STATIONS')
        DO 3455 J=1,NSTAT
        K=J
        WRITE(2,3456) K
3456    FORMAT(4X,'STATION NO.=',2X,I3)
        WRITE(2,3457) (RAIN(I,J),I=1,NRAIN)
```

```
3457    FORMAT(10F8.2)
3455    CONTINUE
        WRITE(2,3458) NRUN
3458    FORMAT(4X,'NO. OF RUNOFF VALUES=',2X,I3)
        WRITE(2,3459)
3459    FORMAT(30X,'OBSERVED DISCHARGE HYDROGRAPH')
        WRITE(2,3460) (OBD(I),I=1,NRUN)
3460    FORMAT(10F8.2)
        WRITE(2,12)
        WRITE(2,3461)
3461    FORMAT(30X,'WEIGHTED RAINFALL VALUES')
        WRITE(2,3462) (EFR(I),I=1,NRAIN)
3462    FORMAT(10F8.2)
        TIME(1)=0.0
        DO 18 I=2,NRUN
        K=I-1
        TIME(I)=TIME(K)+DLT
18      CONTINUE
        NBEG=1
202     CALL RUNSEP(OBD,BFLO,ODSRO,NRUN,NBEG,TIME,CB)
        SDSRO=0.0
        DO 200I=NBEG,NRUN
200     SDSRO=SDSRO+ODSRO(I)
        SDSRO=SDSRO*DLT
        SDSRO=SDSRO*3.6/CA
        CALL RAINSP(EFR,SDSRO,DLT,EXR,NBEG,NRAIN,AINFR,SRX)
        IF(EXR(NBEG).GT. 0.0) GO TO 201
        NBEG=NBEG+1
        GO TO 202
201     WRITE(2,203)
203     FORMAT(20X,'DIRECT SURFACE RUNOFF (CUMECS)')
        WRITE(2,204) (ODSRO(I),I=NBEG,NRUN)
204     FORMAT(4X,10F8.3)
        WRITE(2,205)
205     FORMAT(20X,'BASE FLOW (CUMECS)')
        WRITE(2,204) (BFLO(I),I=NBEG,NRUN)
        WRITE(2,350) AINFR,SRX
350     FORMAT(4X,'INFILTRATION CAPACITY(MM/HR)-',4X,F8.3/4X,'TOTAL
        1 RAINFALL EXCESS(MM)-',4X,F8.3)
        NR=NRUN-NBEG+1
        NRN=NRAIN-NBEG+1
        DO 206 I=1,NRN
206     REXR(I)=EXR(I+NBEG-1)
        DO 207 I=1,NR
207     ABFLO(I)=BFLO(I+NBEG-1)
        WRITE(2,3569) NBEG
3569    FORMAT(4X,'NBEG=',I3)
        WRITE(2,208)
208     FORMAT(20X,'SEPERATED RAINFALL VALUES (MM)')
        WRITE(2,209) (REXR(I),I=1,NRN)
```

```
209     FORMAT(4X,10F10.3)
112     CONTINUE
        CLOSE(UNIT=1)
        CLOSE(UNIT=2)
        STOP
        END
C       ***************************************************************
        SUBROUTINE RAINSP(EEFR,SSDSRO,DDLT,EEXR,NNBEG,NNRAIN,AAINFR
       1,SSRX)
        DIMENSION EEFR(50),EEXR(50),RXS(50)
        AAINFR=0.0
15      NN=0
        SSRX=0.0
        DO 150 I=NNBEG,NNRAIN
        RXS(I)=EEFR(I)-AAINFR*DDLT
        IF(RXS(I).LE.0.0) GO TO 140
        EEXR(I)=RXS(I)
        NN=NN+DDLT
        GO TO145
140     EEXR(I)=0.0
145     SSRX=SSRX+EEXR(I)
150     CONTINUE
        IF((ABS(SSDSRO-SSRX))/(SSDSRO)-0.0001)20,20,35
35      AINF1=(SSRX-SSDSRO)/NN
        AAINFR=AAINFR+AINF1
        GO TO 15
20      CONTINUE
        RETURN
        END
C       ***************************************************************
        SUBROUTINE RUNSEP(Q,BF,DRO,NNRUN,NNBEG,TTIME,CB)
        DIMENSION Q(50),BF(50),DRO(50),TTIME(50)
        DO 50 I=NNBEG,NNRUN
        IF(Q(I).EQ.CB.AND.Q(I+1).LT.CB) GO TO 60
        IF(Q(I).EQ.CB.AND.Q(I+1).EQ.CB) GO TO 60
50      CONTINUE
60      MRUN=I
        Q(MRUN)=CB
        TTIME(MRUN)=TTIME(I)
        DO 10 I=NNBEG,MRUN
        DLT=TTIME(I)-TTIME(NNBEG)
        BF(I)=Q(NNBEG)+(Q(MRUN)-Q(NNBEG))*DLT/(TTIME(MRUN)-TTIME(NNBE
       1G))
        IF(Q(I)-BF(I)) 20,20,15
20      DRO(I)=0.0
        GO TO 10
15      DRO(I)=Q(I)-BF(I)
10      CONTINUE
        IF(MRUN.EQ.NNRUN) GO TO 80
        DO 70 I=(MRUN+1),NNRUN
        BF(I)=Q(I)
70      DRO(I)=0.0
80      RETURN
        END
```

B. DESCRIPTION OF THE COMPUTER PROGRAMME LOSS.FOR

The computer programme LOSS.FOR separates the base flow from discharge hydrograph using straight line technique and also computes the excess rainfall hyetograph after accounting for the hydrologic abstractions using ϕ-index method. The programme is written in FORTRAN IV language and run on VAX-11/780 computer system. Variables used in the programme are described below:

VARIABLE	DESCRIPTION
CA	Catchment area (Km^2)
DLT	Computational interval (hours)
NST	No. of storms to be analysed in single run
NSTAT	No. of raingauge stations
WT	Vector containing the values of Thiessen weights for each station
NRAIN	No. of rainfall blocks (maximum from all the stations)
RAIN	Two dimensional array containing the values of rainfall for different raingauge stations at different computational intervals (mm)

NRUN	No. of discharge hydrograph ordinates
OBD	Vector containing the discharge hydrograph ordinates(m^3/s)
CB	Discharge at Recession point on the recession limb of the discharge hydrograph

The following subroutines are called in the main programme for intermediate computations:

(i) SUBROUTINE RUNSEP(Q,BF,DRO,NNRUN,NNBEG,TTIME,CB)

This subroutine separates the base flow and computes the direct surface runoff hydrograph. The variables used as arguments of the subroutine are described below:

VARIABLE	DESCRIPTION
Q	A vector containing the discharge hydrograph ordinates
BF	A vector of base flow ordinates
DRO	A vector of direct surface runoff hydrograph ordinates
NNRUN	Number of discharge hydrograph ordinates
NNBEG	The ordinate number at which the effective rainfall starts contributing the direct surface runoff after satisfying the requirement for the initial losses.
TTIME	Vector of time period

CB	Flow at recession point on the falling limb.

(ii) SUBROUTINE RAINSP(EEPR,SSDSRO,DDLT,EEXR,NNBEG,NNRAIN, AAINFR, SSRX)

This subroutine accounts for the hydrologic abstractions (abstractions due to infiltration is predominant during the period of floods) using ϕ – index method and computes the effective rainfall hyetograph. The variables used in the arguments of the subroutine are described below:-

VARIABLE	DESCRIPTION
EEPR	A vector of average rainfall hyetograph (mm)
SSDSRO	Volume of direct surface runoff hydrograph expressed in equivalent depth unit (mm)
DDLT	Computational interval (hours)
EEXR	A vector of effective rainfall hyetograph (mm)
NNBEG	Same as described for subroutine RUNSEP
NNRAIN	Number of average rainfall blocks
AAINFR	Uniform loss rate (ϕ -index) (mm./hr)
SSRX	Total volume of excess rainfall(mm)

C. INPUT SPECIFICATIONS

The input file LOSS.DAT consists the values of the following input lists in the specified format

REC.No.	INPUT LISTS	FORMAT
1	CA	Free
2	DLT	Free
3	NST	Free
4	NSTAT	Free
5	(WT(I),I=1,NSTAT)	Free
6	NRAIN	Free
7	((RAIN(I ,J)=I=1,NRAIN), J=1,NSTAT)	Free
8	NRUN	Free
9	(OBD(I),I=1,NRUN	Free
10	CB	Free

Note: Rec. no. 4 to 10 should be repeated for NST times

D. OUTPUT SPECIFICATIONS

After successful running of the programme a file LOSS.OUT will be created which consists the following output lists in the specified format:

REC.No.	OUTPUT LISTS	FORMAT
1	CA	4X,'CATCHMENT AREA',F8.3
2	NSTAT	4X,'NO. OF RAINGAUGE STATION =',2X,I3
3	Nil	30X,'WEIGHT OF EACH RAIN GAUGE STATIONS'

4	(WT(I),I=1,NSTAT)	10 F8.4
5	NRAIN	4X,'NO OF RAINFALL VALUES=',2X,I3
6	Nil	30X,'RAINFALL AT EACH STATIONS'
7	K	4X,'STATION No.=',2X,I3
8	(RAIN(I,J),I=1, NRAIN)	10F8.2
9	NRUN	4X,'NO OF RUNOFF VALUES=', 2X,I3
10	Nil	30X,'OBSERVED DISCHARGE HYDROGRAPH'
11	(OBD(I),I=1, NRUN)	10F8.2
12	Nil	4X,128 ('*')
13	Nil	30X,'WEIGHTED RAINFALL VALUES'
14	(EFR(I),I=1, NRAIN)	10F8.2
15	Nil	20X,'DIRECT SURFACE RUNOFF (CUMECS)'
16	(ODSRO(I),I= NBEG,NRUN)	4X, 10F8.3
17	Nil	20X,'BASE FLOW (CUMECS)'
18	(BFLO(I),I= NBEG,NRUN	4X, 10F8.3
19	AINFR,SRX	4X,'INFILTRATION CAPACITY (MM/HR)-',4X,F8.3/4X, 'TOTAL RAINFALL EXCESS(MM) - ',4X, F8.3

20 MBEG 4X,'MBEG=', I3

21 Nil 20X, 'SEPARATED RAINFALL VALUES (mm)'
22 (REXR(I),I=1,NRN) 4X,10F10.3

Note: The output lists from rec. No.1 to 22 are repeates for each storm (NST times)

E. EXAMPLE

During a storm in a catchment an average hourly rainfall values are given below. The discharge hydrograph observed at the catchment outlet during the storm event are also given below. If the catchment area is 823.62 sq.km and flow at recession point of the recession limb is 105 m^3/s, calculate the direct surface runoff hydrograph and the excess rainfall hyetograph ordinates.

Time(hrs)	1	2	3	4	5	6	7	8	9
Average Rainfall(mm)	0.544	1.991	11.34	13.287	4.486	6.428	2.774	0	0
Discharge (m^3/s)	55	55	60	65	142	285	355	370	430

Time(hrs)	10	11	12	13	14	15	16	
Average Rainfall(mm)	0	0	0	0	0	0	0	
Discharge (m^3/s)	440	285	260	210	170	150	132	120

Time(hrs)	18	19	20
Average Rainfall(mm)	0	0	0
Discharge Discharge(m^3/s)	115	105	100

(a) Input: The structure of the input file LOSS.DAT for the above example is given below:

823.62

7

0.544 1.1991 11.34 13.287 4.486 6.428 2.777

20

55 55 60 65 142 285 355 370 430 440

285 260 210 170 150 132 120 115 105 100

105

(b) Output:

```
   CATCHMENT AREA-     823.620
   NO. OF RAINGAUGE STATIONS=    1
                                   WEIGHT OF EACH RAINGAUGE STATIONS
 1.0000
   NO. OF RAINFALL VALUES=     7
                                   RAINFALL AT EACH STATIONS
   STATION NO.=     1
   0.54    1.99    11.34   13.29    4.49    6.43    2.77
   NO. OF RUNOFF VALUES=   20
                                   OBSERVED DISCHARGE HYDROGRAPH
  55.00  55.00  60.00  65.00 142.00 285.00 355.00 370.0 430.00 440.00
 285.00 260.00 210.00 170.00 150.00 132.00 120.00 115.00 105.00 100.00
   *************************************************************
                                   WEIGHTED RAINFALL VALUES
   0.54    1.99    11.34   13.29    4.49    6.43    2.77
                          DIRECT SURFACE RUNOFF (CUMECS)
0. 2.188 76.375 216.563 283.750 295.938 353.125 360.313 202.500 174.688
    121.875  79.063  56.250  35.438  20.625  12.813   0.000    0.000
                          BASE FLOW (CUMECS)
60.0 62.813 65.625 68.438 71.250 74.063 76.875 79.688 82.50  85.313
     88.125  90.938  93.750  96.563  99.375 102.188 105.000 100.000
    INFILTRATION CAPACITY(MM/HR)-        7.305
    TOTAL RAINFALL EXCESS(MM)-       10.016
    NBEG=  3
                          SEPERATED RAINFALL VALUES (MM)
         4.035      5.982      0.000      0.000      0.000
```

APPENDIX-XI

A. COMPUTER PROGRAMME UNIT.FOR

```
C       THIS PROGRAMME COMPUTES THE UNIT  HYDROGRAPH  FROM A
C       SPECIFIC DURATION INDIVIDUAL,ISOLATED STROME AFTER
C       SUBTRACTTING THE BASE FROM THE DISCHARGE HYDROGRAPH HERE:
C       N=NO. OF OBSERVATIONS
C       A1=VVCTOR CONTIAINING THE DISCHARGE HYDROGRAPH ORDINATES
C       NOPT=AN INTEGER CONSTANT WHICH ALLOWS
C       USER TO CHOOSE BASE FLOW OPTION WHERE :
C       NOPT=1 FOR CONSTANT BASE FLOW OPTION
C       NOPT=2 FOR NON-CONSTANT BASE FLOW OPTION
C       A2=VECTOR CONTAINING DIRECT SURFACE RUNOFF ORDINATES
C       OBTAINED BY SUBRACTING THE BASE FLOW DISCHARGE HYDROGRAPH
C       AR=CATCHMENT AREA (SQ.METRES)
C       HR=DATA INTERVAL IN HOURS
        DIMENSION A1(0:100),A2(0:100),A4(0:100),CBN(0:100)
        OPEN(UNIT=1,FILE='UNIT.DAT',STATUS='OLD')
        OPEN(UNIT=2,FILE='UNIT.OUT',STATUS='NEW')
        READ(1,*) N
        READ (1,*) (A1(I),I=0,(N-1))
        READ (1,*) HR
        READ(1,*) AR
        READ(1,*) NOPT
        WRITE (2,1)
1       FORMAT(20X,'UNIT HYDROGRAPH')
        WRITE (2,2)
2       FORMAT(20X,15('-'))
        GO TO (100,200),NOPT
100     WRITE (2,101)
101     FORMAT (10X,'EFFECTIVE RAIN FALL FROM HYDROGRAPH -CONSTANT
        1BASE FLOW')
        WRITE(2,201)
201     FORMAT (10X,53('_'))
C       THIS PART OF THE PROGRAMME COMPUTES THE EFFECTIVE RAIN
C       FALL SUBTRACTING THE CONSTANT BASE FLOW FROM DISCHARGE
C       HYDROGRAPH
C       CB=CONSTANT BASE FLOW
        READ (1,*) CB
        K=0
        DO 3 I=0,(N-1)
        T=A1(I)-CB
        IF(T.LT.0.0) GO TO 3
        A2(K)=T
        K=K+1
3       CONTINUE
400             CALL SIMP (K,A2,HR,VL)
        DP=VL/AR
        DC=DP*100.0
        WRITE (2,4) VL
4       FORMAT(4X,'VOLUME OF RAIN FALL(M**3)=',F14.2)
        WRITE (2,5) AR
5       FORMAT(4X,'CATCHMENT AREA (M**2)=',E8.2)
```

```
      WRITE (2,6) DC
6     FORMAT (4X,'EFFECTIVE RAIN FALL IN CM IS=',F8.6)
      DO 60 I=0,K
      A4(I)=A2(I)/DC
60    CONTINUE
      WRITE (2,61)
61    FORMAT(10X,'TIME',15X,'UNIT HYDROGRAPH ORDINATE')
      WRITE(2,62)
62    FORMAT(10X,4('-'),15X,24('-'))
      WRITE(2,63) (HR*I,A4(I),I=1,K)
63    FORMAT(10X,F4.0,15X,F13.6)
      GO TO 300
200   WRITE (2,7)
7     FORMAT (10X,'EFFECTIVE RAIN FALL FROM HYDROGRAPH -NON
      1CONSTANT BASE FLOW')
      WRITE (2,8)
8     FORMAT (10X,57('_'))
C     THIS PART OF PROGRAMME COMPUTES THE EFFECTIVE RAIN FALL
C     SUBTRCTING NON CONSTANT BASE FLOW FROM DISCHARGE
C     HYDROGRAPH
      READ (1,*) (CBN(I),I=0,(N-1))
      K=0
      DO 9 I=0,(N-1)
      T=A1(I)-CBN(I)
      IF (T.LT.0) GO TO 9
      A2(K)=T
      K=K+1
9     CONTINUE
      GO TO 400
300   CLOSE (UNIT=1)
      CLOSE(UNIT=2)
      STOP
      END
      SUBROUTINE SIMP (K,A2,HR,VL)
      DIMENSION A2(0:100),A3(100)
      T=0
      NC=1
      X1=A2(0)
      X2=A2(K)
      DO 1 I=1,(2*K-1)
      ITP=MOD(I,2)
      IF (ITP) 2,3,2
3     A3(I)=A2(I/2)
      GO TO 1
2     A3(I)=(A2(NC)+A2(NC-1))/2.0
      NC=NC+1
1     CONTINUE
      DO 4 I=1,(2*K-1)
      ITP=MOD(I,2)
      IF(ITP)5,6,5
```

```
6       T=T+(2.*A3(I))
        GO TO 4
5       T=T+(4.*A3(I))
4       CONTINUE
        S=((HR/2.0)/3.0)*(X1+T+X2)
        TS=(K-1)*HR*(60.*60.)
        VL=S*TS
        RETURN
        END
```

B.DESCRIPTION OF COMPUTER PROGRAMME UNIT.FOR

The computer programme UNIT.FOR computes the unit hydrograph of a specified duration from the direct surface runoff hydrograph obtained by separating the base flow (constant or nonconstant), supplied by the user, from the discharge hydrograph of an isolated event. This programme is written in FORTRAN IV language and run on VAX-11/780 Digital computer system. The variables used in input and output lists are described below:

VARIABLE	DESCRIPTION
N	No. of observations
A1	Vector containing the values of the discharge hydrograph ordinates (m^3/s)
HR	Data interval in hours
AR	Catchment area (Sq.metres)
NOPT	An integer constant which provides options for baseflow, constant or nonconstant base flow, to the user. NOPT=1 for constant baseflow NOPT=2 for non-constant baseflow.
CB	Constant baseflow (m^3/sec)
CBN	Vector containing non-constant base flow values.(m^3/sec)
VL	Volume of rainfall (m^3)
DC	Effective rainfall (cm)

A4 Vector containing the unit hydrograph ordinates (m^3/s)

This programme requires a subroutine for the computation of the area under the direct surface runoff hydrograph. This SUBROUTINE SIMP(K,A2,HR,VL) is already described in Appendix-IX.

C. INPUT SPECIFICATIONS

The values of the following input lists are required to be supplied through an input file UNIT.DAT in the specified format:

Rec.No.	INPUT LISTS	FORMAT
1	N	Free
2	(A1(I),I=0,(N-1))	Free
3	HR	Free
4	AR	Free
5	NOPT	Free
6	CB	Free
7	(CBN(I),I=0,(N-1))	Free

Note:-

(i) If NOPT=1, rec. no.7 should be skipped.

(ii) If NOPT=2, rec. no.6 should be skipped.

D. OUTPUT SPECIFICATIONS

The output file UNIT.OUT consists the values of the following output lists.

Rec.No.	OUTPUT LISTS	FORMAT
1	Nil	20X,'UNIT HYDROGRAPH'
2	Nil	20X, 15('-')

3	Nil	10X,'EFFECTIVE RAINFALL FROM HYDROGRAPH-CONSTANT BASEFLOW
4	Nil	10X,53('-')
5	VL	4X,'VOLUME OF RAINFALL(M**3)=', F14.2
6	AR	4X,'CATCHMENT AREA(M**2)=', E8.2
7	DC	4X,'EFFECTIVE RAINFALL IN CM IS=',F8.6
8	Nil	10X,'TIME', 15X,'UNIT HYDRO-GRAPH ORDINATE'
9	Nil	10X,4('-'),15X,24('-')
10	(HR*I,A4(I),I=1,K)	10X,F4.0, 15X, F13.6
11	Nil	10X,'EFFECTIVE RAINFALL FROM HYDROGRAPH-NON CONSTANT BASE FLOW'
12	Nil	10X, 57('-')

Note:

(i) If NOPT=1, the output lists of rec.No.1 to 10 will be written in the output file.

(ii) If NOPT=2, the output lists of rec.no.1, 11 and 12 followed by the output lists of rec.no.5 to 10 will be written in the output file.

E. EXAMPLE

The data given below provide details of the flood hydrograph recorded from a four-hour duration individual, isolated storm of the fairly uniform intensity which was distributed uniformly over the catchment. Calculate the ordinates of the unit hydrograph. The catchment area is 1250 km^2 and baseflow is 10 m^3/s throughout the storm.

Time(h)	0	2	4	6	8	10	12	14	16	18	20	22
Flow(m^3/s)	10	57	133	136	102	76	56	41	28	18	12	10

(a) Input: - The structure of the input file UNIT.DAT for the above example is given below:

```
12
10   57   133 136 102   76   56   41   28   18   12   10
1250000000
1
10
```

(b) Output

```
                 UNIT HYDROGRAPH
                 ---------------
       EFFECTIVE RAIN FALL FROM HYDROGRAPH -CONSTANTBASE FLOW
       -----------------------------------------------------
VOLUME OF RAIN FALL(M**3)=   88545600.00
CATCHMENT AREA (M**2)=0.13E+10
EFFECTIVE RAIN FALL IN CM IS=7.083648
      TIME              UNIT HYDROGRAPH ORDINATE
      ----              ------------------------
        2.                     6.635000
        4.                    17.363935
        6.                    17.787445
        8.                    12.987659
       10.                     9.317233
       12.                     6.493829
       14.                     4.376276
       16.                     2.541064
       18.                     1.129362
       20.                     0.282340
       22.                     0.000000
       24.                     0.000000
```

APPENDIX -XII

A COMPUTER PROGRAMME UHISO.FOR

```
C       THIS PROGRAMME IS USED FOR DERIVATION OF UNIT HYDROGRAPH
C       FROM ISOLATED STORM EVENT
        DIMENSION UH(100),TIME(100),DSRO(100)
        OPEN(UNIT=1,FILE='UHISO.DAT',STATUS='OLD')
        OPEN(UNIT=2,FILE='UHISO.OUT',STATUS='NEW')
C       D=DURATION OF UNIT HYDROGAPH (HOURS)
        READ(1,*)D
C       VOL=UNIT VOLUME OF UH(MM)
        READ(1,*)VOL
C       DLT=COMPUTATIONAL INTERVAL (HOURS)
        READ(1,*)DLT
C       EXE=EXCESS RAINFALL BLOCK(MM)
        READ(1,*)EXE
C       NRUN=NO OF DSRO BLOCKS
        READ(1,*)NRUN
C       DSRO=VECTOR CONTAINING DSRO ORDINATES (M**/SEC)
        READ(1,*)(DSRO(I),I=1,NRUN)
        FAC=EXE/VOL
        DO 1 I=1,NRUN
        UH(I)=DSRO(I)/FAC
1       CONTINUE
        WRITE(2,2)
2       FORMAT(10X,'DERVATION OF UNIT HYDROGRAPH FROM ISOLATED STORM')
        WRITE(2,3)
3       FORMAT(10X,45('-')/)
        TIME(1)=0.0
        DO 4 I=2,NRUN
        TIME(I)=TIME(I-1)+DLT
4       CONTINUE
        WRITE(2,5)D
5       FORMAT(15X,'TIME',5X,F5.0,'-HOUR UNIT HYDROGRAPH')
        WRITE(2,6)
6       FORMAT(15X,'(HRS)',20X,'(M**3/SEC)'/)
        WRITE(2,7)(TIME(I),UH(I),I=1,NRUN)
7       FORMAT(15X,F5.1,19X,F12.3)
        STOP
        END
```

B. COMPUTER PROGRAMME UHISO.FOR

The computer programme UHISO.FOR provides an estimate for the unit hydrograph from the direct surface runoff of an isolated storm event. The programme is written in FORTRAN-IV language and run on VAX-11/780 Digital Computer system. The variables used as input and output lists are described below:

VARIABLE	DESCRIPTION
D	Duration of Unit hydrograph (hours)
VOL	Unit volume of UH(mm)
DLT	Computational interval(hours)
EXE	Excess rainfall block(mm)
NRUN	No. of Direct surface runoff ordinates.
DSRO	Vector of direct surface runoff hydrograph ordinates (hrs)
UH	Vector of unit hydrograph ordinates.

C. INPUT SPECIFICATIONS

The values of the following input lists are to be supplied through an input file UHISO.DAT in the specified format.

REC.No.	INPUT LISTS	FORMAT
1	D	Free
2	VOL	Free
3	DLT	Free
4	EXE	Free

5	NRUN	Free
6	(DSRO(I),I=1,NRUN)	Free

D. OUTPUT SPECIFICATIONS

An output file UHISO .OUT will be created after the successful running of the programme. The output file consists the values of the following output lists in the specified format.

Rec.No.	OUTPUT LISTS	FORMAT
1	Nil	10X,'DERIVATION OF UNIT HYDROGRAPH FROM ISOLATED STORM'
2.	Nil	10X,45('-')/
3	D	15X,'TIME',5X,F5.0,'-HOUR UNIT HYDROGRAPH'
4	Nil	15X,'(HRS)', 20X,'(M**3/SEC)'/
5	(TIME(I),UH(I), I=1,NRUN)	15X,F5.1,19X,F12.3

E. EXAMPLE

The ordinates of direct surfac runoff hydrograph from a six-hour duration individual, isolated storm of the fairly uniform intensity with excess rainfall volume equal to 154 mm are given below. Calculate the ordinates of 6 hour unit hydrograph with unit volume 100 mm.

Time (hour)	0	6	12	18	24	30	36	42	48	54	60
DSRO(m /s)	0	10	500	1600	3500	5200	3100	1500	650	250	0

(a) Input :

The structure of the input file UHISO.DAT for the above example will be as given below:

```
6
100
6
154
10
10  500  1600  3500 5200  3100  1500  650  250  0
```

(b) Output

DERVATION OF UNIT HYDROGRAPH FROM ISOLATED STORM

TIME (HRS)	6.-HOUR UNIT HYDROGRAPH (M**3/SEC)
0.0	6.494
6.0	324.675
12.0	1038.961
18.0	2272.727
24.0	3376.624
30.0	2012.987
36.0	974.026
42.0	422.078
48.0	162.338
54.0	0.000

APPENDIX-XIII

A COMPUTER PROGRAMME COLUH.FOR

```
C       UNIT HYDROGRAPH DERIVATION USING COLLIN'S METHOD
        DIMENSION TIME(100),EXE(100),DSRO(100),UH(100),UHS(100)
        1,UR(100),CDSRO(100)
        OPEN(UNIT=1,FILE='COLUH.DAT',STATUS='OLD')
        OPEN(UNIT=2,FILE='COLUH.OUT',STATUS='NEW')
C       CA=CATCHMENT AREA (SQ.KM)
        READ(1,*)CA
C       DLT=COMPUTATIONAL INTERVAL (HOURS)
        READ(1,*)DLT
C       D=DURATION OF UNIT HYDROGRAPH (HOUR)
        READ(1,*)D
C       VOL=UNIT VOLUME (MM)
        READ(1,*)VOL
C       NRUN=NO OF DSRO ORDINATES
        READ(1,*)NRUN
        DO 1 I=1,NRUN
        DSRO(I)=0.0
        CDSRO(I)=0.0
        EXE(I)=0.0
        TIME(I)=0.0
        UH(I)=0.0
        UHS(I)=0.0
        UR(I)=0.0
1       CONTINUE
        DO 500 I=2,NRUN
500     TIME(I)=TIME(I-1)+DLT
C       DSRO=VECTOR CONTAINING THE DSRO ORDINATES (M**3/SEC)
        READ(1,*)(DSRO(I),I=1,NRUN)
C       NRAIN=NO. OF EXCESS RAINFALL BLOCKS
        READ(1,*)NRAIN
C       EXE=VECTOR CONTAINING THE EXCESS RAINFALL VALUES(MM)
        READ(1,*)(EXE(I),I=1,NRAIN)
        WRITE(2,400)
400     FORMAT(30X,'UNIT HYDROGRAPH DERIVATION USING COLLIN''S
        1 METHOD')
        WRITE(2,401)
401     FORMAT(10X,120('-')/)
        WRITE(2,402)
402     FORMAT(30X,'DIRECT SURFACE RUNOFF(M**3/SEC)'/)
        WRITE(2,403)(DSRO(I),I=1,NRUN)
403     FORMAT(4X,10F12.3)
        WRITE(2,404)
404     FORMAT(/30X,'EXCESS RAINFALL (MM)'/)
        WRITE(2,405)(EXE(I),I=1,NRAIN)
405     FORMAT(4X,10F12.2)
        K=0
        DO 800 I=2,NRUN
        K=K+1
        CDSRO(K)=DSRO(I)
800     CONTINUE
```

```
      NRUN=NRUN-1
      NDUH=NRUN-NRAIN+1
      CALL COL(CDSRO,EXE,NRUN,UH,DLT,NDUH,CA,VOL,D)
      SUMI=0.0
      DO 17 I=1,NDUH
      UR(I)=UH(I)*DLT
      SUMI=SUMI+UR(I)
17    CONTINUE
      SUMI=SUMI*3.6/CA
      WRITE(2,23)SUMI
23    FORMAT(10X,'AREA OF UH=',F12.5)
      K=1
      UHS(1)=0.0
      DO 18 I=1,NDUH
      K=K+1
      UHS(K)=UH(I)
18    CONTINUE
      WRITE(2,345)
345   FORMAT(20X,'UNIT HYDROGRAPH ORDINATES (M**3/SEC)')
      WRITE(2,410)D
410   FORMAT(/4X,'TIME',10X,F5.0,'-HOUR U.H. ORDINATES')
      NDUH=NDUH+2
      WRITE(2,411)
411   FORMAT(4X,'(HRS)',21X,'(CUMEC)')
      WRITE(2,346)(TIME(I), UHS(I),I=1,NDUH)
346   FORMAT(4X,F5.0,21X,F12.3)
      STOP
      END
C     *****************************************************
      SUBROUTINE COL(DSRO,EXR,N,DUH,DLT,NDUH,CA,VOL,DH)
      DIMENSION DSRO(200),EXR(200),DUH(200),C(200),D(200),EST(200)
     1,DD(200),CC(200)
      DO 10 I=1,N
      DO 11 J=1,N
      IF(EXR(I).LT.EXR(J)) GO TO 10
11    CONTINUE
      NM=I
      EXMAX=EXR(I)
      GO TO 20
10    CONTINUE
20    CONTINUE
      DO 21 I=1,NDUH
      C(I)=CA*1000.*VOL/(NDUH*DLT*3600)
21    CONTINUE
      NTR=1
100   CONTINUE
      WRITE(2,250)DH,VOL,NTR
250   FORMAT(10X,F3.0,'-HOUR UNIT HYDROGRAPH OF VOLUME',F4.0,
     1 'MM',' AT TRIAL NO.-',I4)
      WRITE(2,251)
```

```
251     FORMAT(10X,60('-'))
        WRITE(2,252)(C(I),I=1,NDUH)
252     FORMAT(2X,10F12.5)
        PEAK1=C(1)
        TPEAK1=1
        DO 240 I=2,NDUH
        IF(PEAK1.LT.C(I))TPEAK1=I
        IF(PEAK1.LT.C(I))PEAK1=C(I)
240     CONTINUE
        DO 23 I=1,N
        EST(I)=0.0
        DO 24 J=1,I
        KK=I-J+1
        IF(EXR(KK).EQ.EXMAX) GO TO 24
        EST(I)=EST(I)+EXR(KK)*C(J)
24      CONTINUE
23      CONTINUE
        J=0
        DO 25 I=NM,(NM+NDUH-1)
        J=J+1
        D(J)=(DSRO(I)-EST(I))/EXMAX
25      CONTINUE
        S2=0.0
        S3=0.0
        DO 28 I=1,N
        S2=S2+EXR(I)
        IF(I.EQ.NM) GO TO 28
        S3=S3+EXR(I)
28      CONTINUE
        A=S3/S2
        B=EXMAX/S2
        DO 29 I=1,NDUH
29      D(I)=A*C(I)+B*D(I)
        FAC=CA*1000*VOL/(DLT*3600)
        S1=0.0
        DO 26 I=1,NDUH
26      S1=S1+D(I)
        FACT=S1/FAC
        DO 27 I=1,NDUH
27      D(I)=D(I)/FACT
        TYPE *,(D(J),J=1,N)
        PEAK2=D(1)
        TPEAK2=1
        DO 340 I=2,NDUH
        IF(PEAK2.LT.D(I))TPEAK2=I
        IF(PEAK2.LT.D(I))PEAK2=D(I)
340     CONTINUE
        NTR=NTR+1
        IF(NTR.GT.100) GO TO 150
        IF((ABS(PEAK1-PEAK2)/PEAK2).LT.0.1.AND.ABS(TPEAK1-TPEAK2).EQ.
```

```
      1GO TO 150
       DO 30 I=1,NDUH
30     C(I)=D(I)
       GO TO 100
150    DO 31 I=1,NDUH
31     DUH(I)=D(I)
       RETURN
       END
```

B. DESCRIPTION OF COMPUTER PROGRAMME COLUH.FOR

The computer programme COLUH.FOR derives the unit hydrograph from multiperiod storm using Collin's Method. The programme is written in FORTRAN-IV language and run on VAX-11/780 Digital computer system. The variables used in the main programme are described below:

VARIABLE	DESCRIPTION
CA	Catchment area (sq.km)
DLT	Computational interval (hours)
D	Duration of unit hydrograph (hours)
VoL	Unit volume (mm)
NRUN	No. of DSRO ordinates
DSRO	Vector of DSRO ordinates (m^3/s)
NRAIN	No. of Excess rainfall blocks
EXE	Vector of Excess rainfall hyetograph (mm)
SUMI	Area of UH
TIME	Vector of time ordinates (hour)
UHS	Vector of D-hour unit hydrograph ordinates (m^3/s)

A SUBROUTINE COL (DSRO, EXR, N, DUH, DLT, NDUH, CA, VOL, DH) is called in the main programme. This subroutine performs the trial and error computation involved in unit hydrograph derivation using collin's method. The variables used as arguments of the subroutine are described below:

VARIABLE	DESCRIPTION
DSRO	Vector of direct surface runoff hydrograph ordinates (m^3/s)
EXR	Vector of excess rainfall hyetograph ordinates (mm)
N	No. of direct surface runoff
DUH	Vector of unit hydrograph ordinates with volume equal to one mm.
DLT	Computational interval (hours)
NDUH	No. of unit hydrograph ordinates
CA	Catchment area (sq.km.)
VOL	Unit volume (mm)
DH	Duration of unit hydrograph

C. INPUT SPECIFICATIONS

The values of the following input lists are to be supplied in sequence through an input file COLUH.DAT in specified format:

REC.No.	INPUT LISTS	FORMAT
1	CA	Free
2	DLT	Free
3	D	Free
4	VOL	Free
5	NRUN	Free
6	(DSRO(I),I=1,NRUN)	Free
7	NRAIN	Free
8	(EXE(I),I=1,NRAIN)	Free

D. OUTPUT SPECIFICATIONS

An output file COLUH.OUT will be created after the successfull completion of the programme. The output file consists the values of the following output lists in the specified format:

REC.NO.	OUTPUT LISTS	FORMAT
1	Nil	30X,'UNIT HYDROGRAPH DERIVATION USING COLLIN'S METHOD'
2	Nil	10X, 120 ('-')/
3	Nil	30X, 'DIRECT SURFACE RUNOFF (M**3/SEC)'/
4	(DSRO(I),I=1, NRUN)	4X, 10F12.3
5	Nil	/30X,'EXCESS RAINFALL (MM)'/
6	(EXE(I),I=1, NRAIN)	4X, 10F12.2
7	DH,VOL,NTR	10X,F3.0, '-HOUR UNIT HYDROGRAPH of VOLUME',F4.0,'MM' 'AT TRIAL NO.-', I4
8	Nil	10X, 60 ('-')
9	(C(I),I=1,NDUH)	2X, 10F12.5
10	SUMI	10X,'AREA OF UH=', F12.5
11	Nil	20X, 'UNIT HYDROGRAPH ORDINATES (M**3/SEC)'
12	D	/4X, 'TIME', 10X, F5.0, '-HOUR U.H. ORDINATES'
13	Nil	4X, '(HRS)', 21X, '(CUMEC)'
14	(TIME(I), UHS(I), I=1, NDUH)	4X, F5.0, 21X, F12.3

Note: (i) The output lists at rec. no.7 to 9 are in SUBROUTINES COL

(ii) Rec.no. 7 to 9 are repeated for each trial made during the computation

E. EXAMPLE

The ordinates of direct surface runoff hydrograph and the excess rainfall hyetograph resulting due to a storm over a catchment of 1700 sq.km. in size are given below, compute the 6 hour unit hydrograph ordinates with 1 mm unit volume using the collin's method

Time (hrs)	Excess Rainfall (mm)	Direct surface runoff ordinates (m^3/s)
0	0	0
6	40.209	250
12	100.209	1050
18	60.209	2050
24	-	4350
30	-	4150
36		2300
42	-	1070
48	-	450
54	-	120

(a) Input :

The structure of the input file COLUH.DAT for the above example would be as given below :

```
1700
6
6
10
0  250 1050 2050  4350  4150  2300  1070  450  120
3
40.209  100.209  60.209
```

(b) Output

UNIT HYDROGRAPH DERIVATION USING COLLIN'S METHOD

DIRECT SURFACE RUNOFF(M**3/SEC)

0.000 250.000 1050.000 2050.000 4350.000 4150.000 2300.000 1070.000 450.000 120.000

EXCESS RAINFALL (MM)

40.21 100.21 60.21

6.-HOUR UNIT HYDROGRAPH OF VOLUME 1.MM AT TRIAL NO.- 1

11.24339 11.24339 11.24339 11.24339 11.24339 11.24339 11.24339

6.-HOUR UNIT HYDROGRAPH OF VOLUME 1.MM AT TRIAL NO.- 2

8.21302 9.74936 20.68768 19.73652 10.93831 5.08869 4.29013

6.-HOUR UNIT HYDROGRAPH OF VOLUME 1.MM AT TRIAL NO.- 3

7.28960 8.37100 24.81202 21.86057 9.85964 3.68682 2.82406

AREA OF UH= 1.00000

UNIT HYDROGRAPH ORDINATES (M**3/SEC)

TIME (HRS)	6.-HOUR U.H. ORDINATES (CUMEC)
0.	0.000
6.	7.162
12.	7.205
18.	27.048
24.	22.075
30.	9.046
36.	3.632
42.	2.535
48.	0.000

APPENDIX-XIV

A COMPUTER PROGRAMME NASHF.FOR

```
C       UNIT HYDROGRAPH DERIVATION USING CONVENTIONAL NASH MODEL
        DIMENSION TIME(100),EXE(100),DSRO(100),UIR(100),UH(100),UR(100)
        1,UHS(100)
        OPEN(UNIT=1,FILE='NASHF.DAT',STATUS='OLD')
        OPEN(UNIT=2,FILE='NASHF.OUT',STATUS='NEW')
C       CA=CATCHMENT AREA (SQ.KM)
        READ(1,*)CA
C       DLT=COMPUTATIONAL INTERVAL (HOURS)
        READ(1,*)DLT
C       D=DURATION OF UNIT HYDROGRAPH(HOURS)
        READ(1,*)D
C       VOL=UNIT VOLUME OF UH(MM)
        READ(1,*)VOL
C       NRUN=NO OF DSRO ORDINATES
        READ(1,*)NRUN
        DO 1 I=1,NRUN
        DSRO(I)=0.0
        EXE(I)=0.0
        TIME(I)=0.0
        UIR(I)=0.0
        UR(I)=0.0
        UH(I)=0.0
        UHS(I)=0.0
1       CONTINUE
        DO 500 I=2,NRUN
500     TIME(I)=TIME(I-1)+DLT
C       DSRO=VECTOR CONTAINING THE DSRO ORDINATES (M**3/SEC)
        READ(1,*)(DSRO(I),I=1,NRUN)
C       NRAIN=NO. OF EXCESS RAINFALL BLOCKS
        READ(1,*)NRAIN
C       EXE=VECTOR CONTAINING THE EXCESS RAINFALL VALUES(MM)
        READ(1,*)(EXE(I),I=1,NRAIN)
        WRITE(2,400)
400     FORMAT(30X,'UNIT HYDROGRAPH DERIVATION USING CONVENTIONAL NASH
        1 MODEL')
        WRITE(2,401)
401     FORMAT(10X,120('-')/)
        WRITE(2,402)
402     FORMAT(30X,'DIRECT SURFACE RUNOFF(M**3/SEC)'/)
        WRITE(2,403)(DSRO(I),I=1,NRUN)
403     FORMAT(4X,10F12.3)
        WRITE(2,404)
404     FORMAT(/30X,'EXCESS RAINFALL (MM)'/)
        WRITE(2,405)(EXE(I),I=1,NRAIN)
405     FORMAT(4X,10F12.2)
        CALL MRUN(DSRO,NRUN,DLT,QM1,QM2)
        CALL MRAIN(EXE,NRAIN,DLT,RM1,RM2)
        WRITE(2,2) QM1,QM2,RM1,RM2
2       FORMAT(4X,'FIRST MOMENT OF DSRO (HRS)-',2X,F10.3/4X,
        1'SECON. MOMENT OF DSRO (HRS**2)-',2X,F10.3/4X,
```

```
        2'FIRST MOMENT OF ERH (HRS)-',2X,F10.3/4X,'SEC
        3OND MOMENT OF ERH (HRS**2)-',2X,F10.3)
        ANK=QM1-RM1
        AK=((QM2-RM2-2*ANK*RM1)-ANK**2)/ANK
        AN=ANK/AK
        BNK=ANK*AK
        WRITE(2,3)AN,AK
3       FORMAT(4X,'VALUE OF N-',2X,F8.3/4X,'VALUE OF K(HRS)-',2X,F8.3
        WRITE(2,4) ANK,BNK
4       FORMAT(4X,'FIRST MOMENT OF IUH (HRS)=',F5.2/4X,'SECOND
        1MOMENT OF IUH ABOUT THE CENTROID (HRS**2)=',F10.2)
        CALL DUHGAM(UH,NRUN,AN,AK,D,IER)
        CALL GAMMA(AN,GAMN,IER)
        DTIME=0.0
        DO 5 I=1,NRUN
        DTIME=DTIME+DLT
        EXP1=EXP(-DTIME/AK)
        EXP2=(DTIME/AK)**(AN-1.0)
        EXP3=1.0/(AK*GAMN)
5       UIR(I)=EXP3*EXP1*EXP2
        S7=0.0
        DO 6 I=1,NRUN
        S7=S7+UIR(I)
6       CONTINUE
        WRITE(2,7)
7       FORMAT(10X,'I.U.H. ORDINATES')
        WRITE(2,8) (UIR(I),I=1,NRUN)
8       FORMAT(4X,10F8.3)
        WRITE(2,10) S7
10      FORMAT(4X,'SUM OF IUH=',F12.5)
        SUMI=0.0
        DO 17 I=1,NRUN
        UR(I)=UH(I)*DLT
        SUMI=SUMI+UR(I)
17      CONTINUE
        WRITE(2,23)SUMI
23      FORMAT(10X,'AREA OF UH=',F12.5)
        K=1
        DO 24 I=1,NRUN
        K=K+1
24      UHS(K)=.277*CA*UH(I)*VOL
        WRITE(2,345)
345     FORMAT(20X,'UNIT HYDROGRAPH ORDINATES (M**3/SEC)')
        WRITE(2,410)D
410     FORMAT(/4X,'TIME',10X,F5.0,'-HOUR U.H. ORDINATES')
        WRITE(2,411)
411     FORMAT(4X,'(HRS)',21X,'(CUMEC)')
        WRITE(2,346)(TIME(I), UHS(I),I=1,NRUN)
346     FORMAT(4X,F5.0,21X,F12.3)
        STOP
```

```
      END
C     ******************************************************************
      SUBROUTINE GAMMA(X,GAM,IER)
      IER=999
      IF(X.LT.0.0) RETURN
      IER=0.0
      IF(X.LE.20.0) GO TO 10
      Y=1./(X*X)
      P=(0.77783067E-3*Y-0.277765545E-2)*Y+0.8333333309E-1
      P=P/X
      GAM=(X-0.5)*ALOG(X)-X+0.9189385+P
      GAM=EXP(GAM)
      RETURN
10    Y=AINT(X)
      N=Y-2.
      Y=X-Y
      GAM=(((0.1082985985E-1*Y-0.3427052255E-2)*Y+0.77549276E-1)
     1*Y)
      GAM=(((GAM+0.8017824769E-1)*Y+0.4121029027)*Y+0.4227663678)*Y
      GAM=GAM+1.000000199
      T1=1.0
      YP2=Y+2.0
      IF(N) 40,70,60
40    CONTINUE
C  NEGATIVE N
      N=IABS(N)
      DO 45 I=1,N
45    T1=T1*(YP2-I)
      T1=1.0/T1
      GO TO 70
60    CONTINUE
C  POSITIVE N
      N=N-1
      DO 65 I=0,N
65    T1=T1*(YP2+I)
70    GAM=GAM*T1
      RETURN
      END
C     ***************************************************************
C     THIS SUBROUTINE GIVES FIRST AND SECOND MOMENTS OF DSRO
      SUBROUTINE MRUN(DSRO,N,DELT,DM1,DM2)
      DIMENSION DSRO(50),SUM(50),TIME(50)
      DO 10 I=1,N
10    SUM(I)=(DSRO(I)+DSRO(I+1))/2.0
      AK=0.0
      DO 11 I=1,N
      TIME(I)=AK+DELT/2
      AK=AK+DELT
11    CONTINUE
      S1=0.0
```

```
      S2=0.0
      S3=0.0
      DO 12 I=1,N
      S1=S1+SUM(I)
      S2=S2+SUM(I)*TIME(I)
      S3=S3+SUM(I)*TIME(I)*TIME(I)
12    CONTINUE
      DM1=S2/S1
      DM2=S3/S1
      RETURN
      END
C     ****************************************************************
C     THIS SUBROUTINE GIVES FIRST AND SECOND MOMENT OF EX. RAIN
      SUBROUTINE MRAIN(REX,N,DELT,DR1,DR2)
      DIMENSION REX(50),TIME(50)
      AK=0.0
      DO 10 I=1,N
      TIME(I)=AK+DELT/2
      AK=AK+DELT
10    CONTINUE
      S1=0.0
      S2=0.0
      S3=0.0
      DO 11 I=1,N
      S1=S1+REX(I)
      S2=S2+REX(I)*TIME(I)
      S3=S3+REX(I)*TIME(I)*TIME(I)
11    CONTINUE
      DR1=S2/S1
      DR2=S3/S1
      RETURN
      END
C     ****************************************************************
      SUBROUTINE DUHGAM(DUH,NDUH,PN,PK,D,IER)
C     CALCULATE A D- PERIOD UNIT HYDROGRAPH FOR A GAMMA FUNCTION IUH
      DIMENSION DUH(NDUH)
      CALL GAMMA(PN,GAM,IER)
      IF(IER.NE.0) STOP 770
      T1=1.0/GAM
      IF(D.GT.0.0) GO TO 100
      T1=T1/PK
      DUH(1)=0.0
      DELTA=D/PK
      T2=DELTA
      PN1=PN-1.0
      DO 10 I=2,NDUH
      DUH(I)=T1*EXP(T2)*ABS(T2)**(PN1)
10    T2=T2+DELTA
      GO TO 200
100   DELTA=D/PK
```

```
      DUH1=0.0
      T2=DELTA
      DO 20 I=1,NDUH
      CALL ICGAMA(PN,T2,GAMI,IER)
      DUH2=GAMI
      DUH(I)=(DUH2-DUH1)/D
      DUH1=DUH2
20    T2=T2+DELTA
200   RETURN
      END
C     ****************************************************************
      SUBROUTINE ICGAMA(A,X,GAMI,IER)
C     CALCULATES THE INCOMPLETE GAMMA FUNCTION
      IER=999
      IF(X.LE.0.0) RETURN
      NEND=10
      T=0.0
      J=NEND
      DO 10 I=1,NEND
      AJ=J
      T=(AJ-A)/(1.0+AJ/(X+T))
      J=J-1
10    CONTINUE
      T=1.0/(X+T)
      GAMI=EXP(-X)*X**A*T
      CALL GAMMA(A,GAM,IER)
      IF(IER.NE.0) STOP 777
      GAMI=1.0-GAMI/GAM
      IER=0
      RETURN
      END
```

B. DESCRIPTION OF COMPUTER PROGRAMME NASHF. FOR

The programme NASHF.FOR is used for the derivation of unit hydrograph using conventional Nash model from the direct surface runoff hydrograph and excess rainfall hyetograph of an event. The programme is written in FORTRAN-IV language and run on VAX-11/780 computer system. The variables used in the main programme are described below :

VARIABLE	DESCRIPTION
CA	Catchment area (sq.km)
DLT	Computational interval (hours)
D	Duration of unit hydrograph (hours)
VOL	Unit Volume of UH(mm)
NRUN	No. of DSRO ordinates
DSRO	Vector of direct surface runoff ordinates (m^3/s)
NRAIN	No. of excess rainfall blocks
EXE	Vector of excess rainfall hyetograph ordinates (mm)
QM1	First moment of DSRO about the origin (hours)
QM2	Second moment of DSRO about the origin ($hours^2$)
RM1	First moment of excess rainfall hyetograph (ERH) about the origin (hours)
RM2	Second moment of ERH about the origin ($hour^2$)
AN	Parameter 'n' for conventional Nash Model
AK	Parameter 'K' for conventional Nash Model

ANK	First moment of IUH about the origin (hours)
BNK	Second moment of IUH about the centroid ($hours^2$)
UIR	Vector of IUH ordinates
S7	Sum of IUH
SUMI	Area of UH
TIME	Vector of time ordinates (hours)
UHS	Vector of UH ordinates (m^3/s)

The main programme calls various subroutines for different intermediate computations involved in the methodology. The purpose of each subroutines and the description of the variables used as arguments of the subroutinesare given below :

(i) SUBROUTINE MRUN (DSRO, N, DELT, DM1, DM2)

This subroutine calculates the first and second moment of direct surface runoff about the origin. The variables used as arguments of the subroutine are :

VARIABLE	DESCRIPTION
DSRO	A vector of DSR O (M^3/s)
N	Number of DSRO ordinates
DELT	Computational interval (hours)
DM1	First moment of DSRO about the origin (hour)
DM2	Second moment of DSRO about the origin ($hour^2$)

(ii) SUBROUTINE MRAIN (REX, N, DELT, DR1, DR2)

This subroutine estimates the first and second moments of effective rainfall about the origin. The variables used in the arguments are :

VARIABLE	DESCRIPTION
REX	A vector of excess rainfall hyetograph ordinates (mm)
N	No. of excess rainfall blocks
DELT	Computational interval (hours)
DR1	First moment of ERH about the origin (hour)
DR2	Second moment of ERH about the origin (hour^2)

(iii) SUBROUTINE DUHGAM (DUH, NDUH, PN, PK, D, IER)

This subroutine calculates D-hour unit hydrograph from a gamma function IUH. The variables used as arguments are described as follows :

VARIABLE	DESCRIPTION
DUH	A vector of D-hour unit hydrograph ordinates
NDUH	Number of unit hydrograph ordinates
PN	Parameter 'n' for the Nash Model
PK	Parameter 'K' for the Nash Model
D	Duration of unit hydrograph
IER	An integer which value on return indicates whether the solution for unit hydrograph is acceptable or not. If IER=0 on return, then it indicates that the solution is acceptable otherwise some error condition occurs.

The SUBROUTINE DUHGAM calls another SUBROUTINE ICGAMA which calculates the values of incomplete gamma function as required by the SUBROUTINE DUHGAM to derive D-hour unit hydrograph. The form of the subroutine ICGAMA and the variables used as its arguments are described below :

SUBROUTINE ICGAMA (A,X,GAMI, IER)

VARIABLE	DESCRIPTION
A	Parameter for which the incomplete gamma function is required.
X	Upper limit of the integration
GAMI	the computed approximation to the incomplete gamma function.
IER	same as described in the SUBROUTINE DUHGAM

The SUBROUTINE ICGAMA calls the SUBROUTINE GAMMA for computing the gamma function value. The subroutine GAMMA is described as :

SUBROUTINE GAMMA (X, GAM, IER)

VARIABLE	DESCRIPTION
X	The real positive argument for which the gamma function is to be evaluated
GAM	The computed approximation to the gamma function value
IER	same as described in the SUBROUTINE DUHGAM.

e) INPUT SPECIFICATIONS

The input file NASHF.DAT should consist the values of the following input lists in the specified format.

REC. NO.	INPUT LISTS	FORMAT
1	CA	Free
2	DLT	Free
3	D	Free
4	VOL	Free
5	NRUN	Free
6	(DSRO(I),I=1, NRUN)	Free
7	NRAIN	Free
8	(EXE(I),I=1,NRAIN)	Free

D. OUTPUT SPECIFICATIONS

The created output file NASHF.OUT contains the values of the following output lists in the specified format :

REC.NO.	OUTPUT LISTS	FORMAT
1	Nil	30X,'UNIT HYDROGRAPH DERIVATION USING CONVENTIONAL NASH MODEL'
2	Nil	10X, 120('-')/
3	Nil	30X, 'DIRECT SURFACE RUNOFF (M**3/SEC)'/
4	(DSRO(I), I=1,NRUN)	4X, 10F12.3
5	Nil	/30X,'EXCESS RAINFALL (MM)'/
6	(EXE(I),I=1,NRAIN)	4X, 10F12.2
7	QM1, QM2, RM1, RM2	4X,'FIRST MOMENT OF DSRO (HRS) -',2X,F10.3/4X,'SECON. MOMENT OF DSRO (HRS**2)-', 2X,F10.3/ 4X, 'FIRST MOMENT OF ERH(HRS) -', 2X,F10.3/4X,'SECOND MOMENT OF ERH (HRS**2)-',2X,F10.3
8	AN, AK	4X,'VALUE OF N-', 2X,F8.3/4X, 'VALUE OF K(HRS)-',2X, F8.3
9	ANK, BNK	4X,'FIRST MOMENT OF IUH (HRS)

		=',F5.2/4X,'SECOND MOMENT OF IUH ABOUT THE CENTROID (HRS**2)=',F10.2
10	Nil	10X, 'I.U.H. ORDINATES'
11	(UIR(I),I=1,NRUN)	4X, 10 F 8.3
12	S7	4X, 'SUM OF IUH =', F12.5
13	SUMI	10X,'AREA OF UH='. F12.5
14	Nil	20X,'UNIT HYDROGRAPH ORDINATES (M**3/sec)'
15	D	14X,'TIME',10X,F5.0,'-HOUR U.H. ORDINATES'
16	Nil	4X,'(HRS)', 21X, '(CUMEC)'
17	(TIME(I),UHS(I), I=1, NRUN)	4X, F5.0, 21X, F12.3

E EXAMPLE

The direct surface runoff hydrograph and excess rainfall hyetograph ordinates for a typical storm in a catchment of size 1700 sq km. are given below. Find out 6-hour unit hydrograph with volume 1mm using conventional Nash Model procedure :

Time (hrs)	Excess rainfall hyetograph (mm)	Direct surface runoff hydrograph (m^3/s)
0	0	0
6	40.209	250
12	100.209	1050
18	60.209	2050
24		4350
30		4150
36		2300
42		1070

48	450
54	120

(a) Input - The structure of the input file NASHF.DAT for the above example would be as given below :

```
1700
  6
  6
  1
 10
  0   250  1050  2050  4350  4150  2300  1070  450  120
  3
40.209   100.209   60.209
```

(b) Output

UNIT HYDROGRAPH DERIVATION USING CONVENTIONAL NASH MODEL

DIRECT SURFACE RUNOFF(M**3/SEC)

0.000 250.000 1050.000 2050.000 4350.000 4150.000 2300.000 1070.000 450.000 120.000

EXCESS RAINFALL (MM)

40.21 100.21 60.21
FIRST MOMENT OF DSRO (HRS)- 27.595
SECON. MOMENT OF DSRO (HRS**2)- 852.572
FIRST MOMENT OF ERH (HRS)- 9.598
SECOND MOMENT OF ERH (HRS**2)- 109.785
VALUE OF N- 4.410
VALUE OF K(HRS)- 4.081
FIRST MOMENT OF IUH (HRS)=18.00
SECOND MOMENT OF IUH ABOUT THE CENTROID (HRS**2)= 73.44
I.U.H. ORDINATES
0.020 0.050 0.046 0.028 0.014 0.006 0.002 0.001 0.000 0.000
SUM OF IUH= 0.16711
AREA OF UH= 0.99951
UNIT HYDROGRAPH ORDINATES (M**3/SEC)

TIME (HRS)	6.-HOUR U.H. ORDINATES (CUMEC)
0.	0.000
6.	2.939
12.	17.732
18.	23.556
24.	17.414
30.	9.578
36.	4.414
42.	1.809
48.	0.682
54.	0.241

APPENDIX-XV

A. COMPUTER PROGRAMME INTNAS.FOR

```
C       UNIT HYDROGRAPH DERIVATION USING INTEGER NASH MODEL
        DIMENSION TIME(100),EXE(100),DSRO(100),UH(100),UR(100)
        1,UHS(100)
        DATA IYES/'YES'/
        OPEN(UNIT=1,FILE='INTNAS.DAT',STATUS='OLD')
        OPEN(UNIT=2,FILE='INTNAS.OUT',STATUS='NEW')
C       CA=CATCHMENT AREA (SQ.KM)
        READ(1,*)CA
C       DLT=COMPUTATIONAL INTERVAL (HOURS)
        READ(1,*)DLT
C       D=DURATION OF UNIT HYDROGRAPH(HOURS)
        READ(1,*)D
C       VOL=UNIT VOLUME OF UH (MM)
        READ(1,*)VOL
C       NRUN=NO OF DSRO ORDINATES
        READ(1,*)NRUN
        DO 1 I=1,NRUN
        DSRO(I)=0.0
        EXE(I)=0.0
        TIME(I)=0.0
        UH(I)=0.0
        UHS(I)=0.0
1       CONTINUE
        DO 500 I=2,NRUN
500     TIME(I)=TIME(I-1)+DLT
C       DSRO=VECTOR CONTAINING THE DSRO ORDINATES (M**3/SEC)
        READ(1,*)(DSRO(I),I=1,NRUN)
C       NRAIN=NO. OF EXCESS RAINFALL BLOCKS
        READ(1,*)NRAIN
C       EXE=VECTOR CONTAINING THE EXCESS RAINFALL VALUES(MM)
        READ(1,*)(EXE(I),I=1,NRAIN)
        WRITE(2,400)
400     FORMAT(30X,'UNIT HYDROGRAPH DERIVATION USING INTEGER NASH
        1 MODEL')
        WRITE(2,401)
401     FORMAT(10X,120('-')/)
        WRITE(2,402)
402     FORMAT(30X,'DIRECT SURFACE RUNOFF(M**3/SEC)'/)
        WRITE(2,403)(DSRO(I),I=1,NRUN)
403     FORMAT(4X,10F12.3)
        WRITE(2,404)
404     FORMAT(/30X,'EXCESS RAINFALL (MM)'/)
        WRITE(2,405)(EXE(I),I=1,NRAIN)
405     FORMAT(4X,10F12.2)
        CALL MRUN(DSRO,NRUN,DLT,QM1,QM2)
        CALL MRAIN(EXE,NRAIN,DLT,RM1,RM2)
        WRITE(2,2) QM1,QM2,RM1,RM2
2       FORMAT(4X,'FIRST MOMENT OF DSRO (HRS)-',2X,F10.3/4X,
        1'SECON. MOMENT OF DSRO (HRS**2)-',2X,F10.3/4X,
        2'FIRST MOMENT OF ERH (HRS)-',2X,F10.3/4X,
```

```
        3'SECOND MOMENT OF ERH(HRS**2)-',2X,F10.3)
        ANK=QM1-RM1
        AK=((QM2-RM2-2*ANK*RM1)-ANK**2)/ANK
        AN=ANK/AK
        BNK=ANK*AK
        WRITE(6,2345)AN,AK
2345    FORMAT(4X,'ACTUAL VALUE OF N=',F5.3/4X,'ACTUAL VALUE OF
        1K(HRS)=',F6.3)
        WRITE(2,4781) ANK,BNK
        WRITE(6,4781) ANK,BNK
680     WRITE(6,3703)
3703    FORMAT(4X,'SUPPLY INTEGER VALUE OF N?'$)
        READ(5,*) N
        AN=N
        AK=ANK/AN
        WRITE(6,3805) AK
3805    FORMAT(4X,'MODIFIED VALUE OF K=',F5.3)
        ANK=AN*AK
3807    BNK=ANK*AK
        CALL INTR(N,AK,DLT,D,NRUN,UH)
3706    WRITE(2,1007)AN,AK
1007    FORMAT(4X,'VALUE OF N-',2X,F8.3/4X,'VALUE OF K(HRS)-',2X,F8.3)
        WRITE(2,4781) ANK,BNK
4781    FORMAT(4X,'FIRST MOMENT OF IUH(HRS)=',F5.2/4X,'SECOND MOMENT OF
        1IUH ABOUT THE CENTROID(HRS**2)=',F10.2)
        SUMI=0.0
        DO 1700 I=1,NRUN
        UR(I)=UH(I)*DLT
        SUMI=SUMI+UR(I)
1700    CONTINUE
        WRITE(2,23)SUMI
23      FORMAT(10X,'AREA OF UH=',F12.5)
        DO 24 I=1,NRUN
24      UHS(I)=.277*CA*UH(I)*VOL
        WRITE(2,345)
345     FORMAT(20X,'UNIT HYDROGRAPH ORDINATES (M**3/SEC)')
        WRITE(2,410)D
410     FORMAT(/4X,'TIME',10X,F5.0,'-HOUR U.H. ORDINATES')
        WRITE(2,411)
411     FORMAT(4X,'(HRS)',21X,'(CUMEC)')
        WRITE(2,346)(TIME(I), UHS(I),I=1,NRUN)
346     FORMAT(4X,F5.0,21X,F12.3)
        WRITE(6,4781) ANK,BNK
        WRITE(6,678)
678     FORMAT(4X,'DO YOU WANT TO TRY WITH OTHER INTEGER VALUE OF N?'$)
        READ(5,679)IANS
679     FORMAT(A4)
        IF(IANS.EQ.IYES) GO TO 680
        STOP
        END
```

```
C       ************************************************************
C       THIS SUBROUTINE GIVES FIRST AND SECOND MOMENTS OF DSRO
        SUBROUTINE MRUN(DSRO,N,DELT,DM1,DM2)
        DIMENSION DSRO(50),SUM(50),TIME(50)
        DO 10 I=1,N
10      SUM(I)=(DSRO(I)+DSRO(I+1))/2.0
        AK=0.0
        DO 11 I=1,N
        TIME(I)=AK+DELT/2
        AK=AK+DELT
11      CONTINUE
        S1=0.0
        S2=0.0
        S3=0.0
        DO 12 I=1,N
        S1=S1+SUM(I)
        S2=S2+SUM(I)*TIME(I)
        S3=S3+SUM(I)*TIME(I)*TIME(I)
12      CONTINUE
        DM1=S2/S1
        DM2=S3/S1
        RETURN
        END
C       *************************************************************
C       THIS SUBROUTINE GIVES FIRST AND SECOND MOMENT OF EX. RAIN
        SUBROUTINE MRAIN(REX,N,DELT,DR1,DR2)
        DIMENSION REX(50),TIME(50)
        AK=0.0
        DO 10 I=1,N
        TIME(I)=AK+DELT/2
        AK=AK+DELT
10      CONTINUE
        S1=0.0
        S2=0.0
        S3=0.0
        DO 11 I=1,N
        S1=S1+REX(I)
        S2=S2+REX(I)*TIME(I)
        S3=S3+REX(I)*TIME(I)*TIME(I)
11      CONTINUE
        DR1=S2/S1
        DR2=S3/S1
        RETURN
        END
C       ***********************************************************
        SUBROUTINE INTR(N,AK,DT,D,NO,UH)
        DIMENSION G(100),UH(100),Y(100)
        G(1)=0.
        NO1=NO+1
        DO 20 I=2,NO1
```

```
      SUM=1.
      Y(I)=FLOAT(I-1)*DT
      Y(I)=Y(I)/AK
      DO 30 J=1,(N-1)
      IF(J.EQ.1)GO TO 10
      FAC=1.
      DO 15 K=1,J
15    FAC=FAC*FLOAT(K)
      GO TO 22
10    FAC=1.
22    SUM=SUM+Y(I)**J/FAC
30    CONTINUE
      G(I)=1.-EXP(-Y(I))*SUM
20    CONTINUE
      UH(1)=0.
      DO 40 I=2,N01
      UH(I)=(G(I)-G(I-1))/D
40    CONTINUE
      RETURN
      END
```

B. DESCRIPTION OF COMPUTER PROGRAMME INTNAS.FOR

The programme INTNAS.FOR is used for the derivation of unit hydrograph using Integer Nash Model. The programme is written in FORTRAN-IV language and run on VAX-11/780 computer system. The variables used in the programme as input and output lists are having the same meaning as that of the conventional Nash model programme described in Appendix -XIV. The main programme calls the following subroutines

(i) SUBROUTINT MRUN(DSRO,N,DELT,DM1,DM2)

(ii) SUBROUTING MRAIN (REX,N,DELT,DR1, DR2)

(iii) SUBROUTINE INTR(N,AK,DT,D,NO,UH)

The subroutines given at (i) and (ii) are already described in Appendix-XIV. The variables used as the auguments of the SUBROUTINE INTR are described below:

VARIABLE	DESCRIPTION
N	Integer value of Nash model parameter 'n'
AK	Parameter 'K' for the model(hrs)
D T	Computational interval (hours)
D	Duration of unit hydrograph (hours)
NRUN	No. of direct surface runoff
UH	Vector of unit hydrograph

C. INPUT SPECIFICATIONS

The values of the same input lists as described in

Appendix-XIV for conventional Nash model are required to be supplied through a data file INTNAS.DAT. In addition to this integer value of the parameter 'n' is to be supplied through terminal in interactive mode at the time of running the programme as follows:

(i) The following matter will be displayed over the terminal screen during the execution of the programme.

ACTUAL VALUE OF N=X

ACTUAL VALUE OF K(HRS)=Y

FIRST MOMENT OF IUH(HRS)=A

SECOND MOMENT OF IUH ABOUT THE CONTROID (HRS**2)=B

SUPPLY INTEGER VALUE OF N?

(ii) The cursor will wait for an input to be supplied by the user through terminal in free format. At step (1), X,Y,A and B are real constants computed by the programme.

(iii) Once the required input are supplied, the modified values of parameter K, first and second moment of IUH will be displayed over the terminal as:

MODIFIED VALUE OF K=C'

FIRST MOMENT OF IUH(HRS)=A'

SECOND MOMENT OF IUH ABOUT THE CENTROID (HRS ** 2)=B'

where A',B' and C' are the real constants.

(iv) Further, the cursor will wait after displaying the matter given below:

DO YOU WANT TO TRY WITH OTHER INTEGER VALUE OF N?

(v) Now user may supply either 'YES' or 'NO' depending upon his requirement. If the response is 'YES' then the control will be transferred to the statement asking for another integer value of parameter 'n' as follows and step (ii) onward will be repeated:

SUPPLY INTEGER VALUE OF N?

Otherwise, the execution will stop.

(D) OUTPUT SPECIFICATIONS

The output file INTNAS.OUT consists the values of the following output lists in the specified format:

REC.No.	OUTPUT LISTS	FORMAT
1	Nil	30X,'UNIT HYDROGRAPH DERIVATION USING INTEGER NASH MODEL'
2	Nil	10X,120('-')/
3	Nil	30X,'DIRECT SURFACE RUNOFF (M**3/SEC)'/
4	(DSRO(I),I=1, NRUN)	4X,10F 12.3
5	Nil	/30X,'EXCESS RAINFALL(MM)'/
6	(EXE(I),I=1,NRAIN)	4X,10F12.2

7	QM1, QM2,RM1,RM2	4X,'FIRST MOMENT OF DSRO(HRS)-', 2X,F10.3/4X,'SECON. MOMENT OF DSRO (HRS**2)-',2X,F10.3/ 4X, 'FIRST MOMENT OF ERH (HRS)-',2X,F10.3/4X,'SECOND MOMENT OF ERH(HRS**2)-', 2X,F10.3
8	ANK, BNK	4X,'FIRST MOMENT OF IUH(HRS) =', F5.2/4X,'SECOND MOMENT OF IUH ABOUT THE CENTROID (HRS**2)=',F10.2
9	AN,AK	4X,'VALUE OF N-',2X,F8.3/4X, 'VALUE OF K(HRS)-',2X, F8.3
10	ANK, BNK	Same format as for the output lists at rec.no.8
11	SUMK	10X,'AREA AOF UH=', F12.5
12	Nil	20X,'UNIT HYDROGRAPH ORDI NATES (M**3/SEC)'
13	D	17X, 'TIME', 10X,F5.0,'-HOUR UH ORDINATES'
14	Nil	4X,'(HRS)', 21X,'(CUMEC)'
15	(TIME(I),UHS(I), I=1, NRUN)	4X,F5.0,21X,F12.3

Note:

Rec.no. 9 to 15 will be repeated for each integer values of N.

E. EXAMPLE

Derive 6-hour unit hydrograph using Integer Nash Model. Use the data of a storm given in Appendix XIV as an example for the derivation of unit hydrograph using conventional Nash Model

(a) Input: The structure of the input file INTNAS.DAT would be as given below for the above example

```
1700
6
6
1
10
0   250   1050   2050   4350   4150   2300   1070   450   120
3
40.209   100.209   60.209
```

Additional informations supplied by the user through terminal and displayed on the terminal during execution are given below:

ACTUAL VALUE OF N=4.410 (displayed)

ACTUAL VALUE OF K=4.081 (displayed)

FIRST MOMENT OF IUH(HRS)=18.00 (displayed)

SECOND MOMENT OF IUH ABOUT THE CENTROID=73.44(displayed)

SUPPLY INTEGER VALUE OF N? 4 (supplied).

MODIFIED VALUE OF K=7.499 (displayed)

FIRST MOMENT OF IUH (HRS)=18.00 (displayed)

SECOND MOMENT OF IUH ABOUT THE CENTROID=80.97(displayed)

DO YOU WANT TO TRY WITH OTHER INTEGER VALUE OF N? YES (Supplied)

SUPPLY INTEGER VALUE OF N?5 (Supplied)

MODIFIED VALUE OF K=3.599 (displayed)

FIRST MOMENT OF IUH (HRS)=18.00(displayed)

SECOND MOMENT OF IUH ABOUT THE CENTROID (HRS**2)=64.78(displayed)

DO YOU WANT TO TRY WITH OTHER INTEGER

VALUE OF N? NO (supplied)

FORTRAN STOP (displayed)

(b) output

```
                    UNIT HYDROGRAPH DERIVATION USING INTEGER NASH MODEL
------------------------------------------------------------------------------------------------

                    DIRECT SURFACE RUNOFF(M**3/SEC)

   0.000    250.000   1050.000   2050.000   4350.000   4150.000   2300.000   1070.000    450.000    120.000

                    EXCESS RAINFALL (MM)

   40.21     100.21      60.21
FIRST MOMENT OF DSRO (HRS)-      27.595
SECON. MOMENT OF DSRO (HRS**2)-     852.572
FIRST MOMENT OF ERH (HRS)-       9.598
SECOND MOMENT OF ERH(HRS**2)-     109.785
FIRST MOMENT OF IUH(HRS)=18.00
SECOND MOMENT OFIUH ABOUT THE CENTROID(HRS**2)=      73.44
VALUE OF N-     4.000
VALUE OF K(HRS)-     4.499
FIRST MOMENT OF IUH(HRS)=18.00
SECOND MOMENT OFIUH ABOUT THE CENTROID(HRS**2)=      80.97
     AREA OF UH=     0.99771
             UNIT HYDROGRAPH ORDINATES (M**3/SEC)

TIME            6.-HOUR U.H. ORDINATES
(HRS)                    (CUMEC)
  0.                          0.000
  6.                          3.651
 12.                         18.221
 18.                         22.603
 24.                         16.649
 30.                          9.448
 36.                          4.589
 42.                          2.010
 48.                          0.818
 54.                          0.315
VALUE OF N-     5.000
VALUE OF K(HRS)-     3.599
FIRST MOMENT OF IUH(HRS)=18.00
SECOND MOMENT OFIUH ABOUT THE CENTROID(HRS**2)=      64.78
     AREA OF UH=     0.99915
             UNIT HYDROGRAPH ORDINATES (M**3/SEC)

TIME            6.-HOUR U.H. ORDINATES
(HRS)                    (CUMEC)
  0.                          0.000
  6.                          2.163
 12.                         16.957
 18.                         24.805
 24.                         18.430
 30.                          9.693
```

36.	4.142
42.	1.542
48.	0.520
54.	0.163

APPENDIX XVI

A.COMPUTER PROGRAMME CLARKF.FOR

```
C       THIS PROGRAMME IS USED FOR UNIT HYDROGRAPH DERIVATION
C       USING CLARK MODEL
        DIMENSION TAREA(100),FLOWIN(100),CUMAR(100),PTIME(100),
        1TIME(100),CUMA(100),UH(100),U(100)
        DATA IYES/'YES'/
        OPEN(UNIT=1,FILE='CLARKF.DAT',STATUS='OLD')
        OPEN(UNIT=2,FILE='CLARKF.OUT',STATUS='NEW')
C       CA=CATCHMENT AREA (SQ.KM)
        READ(1,*)CA
C       DLT=COMPUTATIONAL INTERVAL (HOURS)
        READ(1,*)DLT
C       D=DURATION OF UNIT HYDROGRAPH (HOURS)
        READ(1,*)D
C       NDUH=NO OF UNIT HYDROGRAPH ORDINATES
        READ(1,*)NDUH
C       VOL=UNIT VOLUME OF UH (MM)
        READ(1,*)VOL
C       TC=TIME OF CONCENTRATION (HOURS)
        READ(1,*)TC
C       R=STORAGE COEFFICIENT (HOURS)
        READ(1,*)R
C       NT=NO. OF ORDINATES OF TIME AREA DIAGRAMME
        READ(1,*)NT
C       TAREA=VECTOR CONTAINING TIME AREA DIAGRAMME ORDINATES
        READ(1,*)(TAREA(I),I=1,NT)
        TIME(1)=0.0
        DO 1 I=2,NDUH
        TIME(I)=TIME(I-1)+DLT
1       CONTINUE
        CUMAR(1)=0.0
        DO 2 I=2,NT
        CUMAR(I)=CUMAR(I-1)+TAREA(I)
2       CONTINUE
        DO 30 I=1,NT
        PTIME(I)=(TIME(I)/TC)*100.0
30      CONTINUE
        DLT1=DLT
        NTR=0
21      NTIME=TC/DLT
        WRITE(2,500)
500     FORMAT(30X,'CLARK MODEL COMPUTATIONS')
        WRITE(2,510)
510     FORMAT(10X,120('-'))
        N1=DLT1/DLT
        NDUH=NDUH*N1
        TIME(1)=0.0
        DO 100 I=2,NDUH
        TIME(I)=TIME(I-1)+DLT
100     CONTINUE
        NTIME=NTIME+1
```

```
      DO 4 I=1,NTIME
      DF=(TIME(I)/TC)*100
      IF(DF.GT.100)CUMA(I)=CA
      IF(DF.GT.100)GO TO 4
      CALL INTER(DF,DL,PTIME,CUMAR,NT)
      CUMA(I)=DL
4     CONTINUE
      FLOWIN(1)=0.0
      DO 5 I=2,NTIME
      FLOWIN(I)=CUMA(I)-CUMA(I-1)
5     CONTINUE
      DO 6 I=1,NDUH
      FLOWIN(I)=0.2778*VOL*FLOWIN(I)/DLT
6     CONTINUE
      N=D/DLT
      AN=N
22    CO=DLT/(R+0.5*DLT)
      C1=1.-CO
      U(1)=0.0
      UH(1)=0.0
      NTR=NTR+1
      WRITE(2,501)NTR
501   FORMAT(10X,'TRIAL NO.',2X,I3)
      WRITE(2,502)TC,R
502   FORMAT(4X,'TC (HOURS)=',F10.2/4X,'R(HOURS)=',F10.2)
      DO 7 I=2,NDUH
      U(I)=CO*FLOWIN(I)+C1*U(I-1)
      UH(I)=0.0
      DO 8 J=0,N
      K=I-J
      IF(K.LE.0)GO TO 8
      IF(J.EQ.0.OR.J.EQ.N)GO TO 9
      UH(I)=UH(I)+U(K)
      GO TO 8
9     UH(I)=UH(I)+0.5*U(K)
8     CONTINUE
      UH(I)=UH(I)/AN
7     CONTINUE
      WRITE(2,10)D
10    FORMAT(4X,'TIME',10X,'IUH ORDINATE',5X,F5.0,
     1'-HOUR UH ORDINATE')
      WRITE(2,11)
11    FORMAT(3X,'(HOUR)',11X,'(M**3/SEC)',11X,'(M**3/SEC)')
      WRITE(2,12)(TIME(I),U(I),UH(I),I=1,NDUH)
12    FORMAT(2X,F6.2,10X,F12.3,10X,F12.3)
      WRITE(6,14)NTR
14    FORMAT(4X,'DO YOU WANT TO REVISE TC FOR TRIAL NO.?',I3,2X,$)
      READ(5,15)IANS
15    FORMAT(A4)
      IF(IANS.NE.IYES)GO TO 170
```

```
        WRITE(6,16)
16      FORMAT(4X,'SUPPLY VALUE OF TC?'$)
        READ(5,*)TC
170     WRITE(6,220)NTR
220     FORMAT(4X,'DO YOU WANT TO REVISE THE COMPUTATIONAL
        1 INTERVAL FOR TRIAL NO.?',I3,2X,$)
        READ(5,15)ICNS
        IF(ICNS.NE.IYES) GO TO 17
        WRITE(6,23)
23      FORMAT(4X,'SUPPLY REVISED VALUE OF COMPUT. INTERVAL?'$)
        READ(5,*)DLT
17      WRITE(6,18)NTR
18      FORMAT(4X,'DO YOU WANT TO REVISE R FOR TRIAL NO.?',I3,2X,$)
        READ(5,15)IBNS
        IF(IBNS.NE.IYES)GO TO 20
        WRITE(6,19)
19      FORMAT(4X,'SUPPLY VALUE OF R?'$)
        READ(5,*)R
20      CONTINUE
        IF(IANS.NE.IYES.AND.IBNS.NE.IYES.AND.ICNS.NE.IYES) GO TO 511
        WRITE(2,503)
503     FORMAT('1')
        IF(IANS.EQ.IYES.OR.ICNS.EQ.IYES)GO TO 21
        IF(IANS.NE.IYES.AND.ICNS.NE.IYES.AND.IBNS.EQ.IYES)GO TO 22
511     STOP
        END
C       ****************************************************************
        SUBROUTINE INTER(A,B,C,D,M)
        DIMENSION C(100),D(200)
        DO 1 I=1,M
        IF(A.GE.C(I))GO TO 1
        NI=I
        GO TO 2
1       CONTINUE
2       NI1=NI-1
        D1=D(NI)-D(NI1)
        D2=C(NI)-C(NI1)
        DF=A-C(NI1)
        B=(D1/D2)*DF+D(NI1)
        RETURN
        END
```

B. DESCRIPTION OF COMPUTER PROGRAMME CLARKF.FOR

The programme CLARKF.FOR is used for unit hydrograph derivation using Clark model. The programme is written in FORTRAN-IV language and run on VAX-11/780 system. The variables used in the programme are described below:

VARIABLE	DESCRIPTION
CA	Catchment area (Sq Km)
DLT	Computational interval (hours)
D	Duration of unit hydrograph (hours)
NDUH	No. of unit hydrograph ordinates
VOL	Unit Volume of UH (mm)
TC	Time of concentration (hours)
R	Storage co-efficient (hours)
NT	No.of ordinates of time area diagramme
TAREA	Vector of time-area diagramme ordinates
NTR	Trial no.
U	Vector of IUH ordinate (m^3/s)
UH	Vector of UH ordinate (m^3/s)
TIME	Vector of time ordinates (hour)

The main programme calls the SUBROUTINE INTER (A,B,C,D,M). This subroutine inter polates the time area diagramme ordinates corresponding to any time interval less than or equal to time of concentration. The variables used in the arguments of the SUBROUTINE are described as follows:

VARIABLE	DESCRIPTION
A	Ratio of cumulative time periods to time of concentration in percentage for interpolation.
B	Interpolated value of cumulative time area diagramme ordinate corresponding to A.
C	Vector containing the ordinates of the cumulative time periods as a percentage of time of concentration.
D	Vector containing the cumulative time-area diagramme ordinates.
M	No. of the time-area diagramme ordinates.

C. INPUT SPECIFICATIONS

The input file CLARKF.DAT consists the values of the following input lists in the specified format:

Rec. No.	INPUT LISTS	FORMAT
1	CA	Free
2	DLT	Free
3	D	Free
4	NDUH	Free
5	VoL	Free
6	TC	Free
7	R	Free
8	NT	Free
9	(TAREA(I),I=1,NT)	Free

The values of the model parameters TC and R and the computational interval DLT may be changed by the user through the terminal in interactive made as given below and the unit hydrograph may be derived accordingly for each trial run:

(i) Matter displayed during the execution:

DO YOU WANT TO REVISE TC FOR TRIAL NO.? N1 YES/NO. Here N1 is an integer constant displayed on the terminal and 'YES' or 'NO' has to be supplied by the user through the terminal. If the user response is YES the following informations are required to be feeded interactively otherwise the control will be transferr ed to step (ii).

SUPPLY VALUE OF TC? A

Here A is a real constant to be supplied by the user to revise the value of Tc for the next trial run.

(ii) DO YOU WANT TO REVISE THE COMPUTATIONAL INTERVAL FOR TRIAL NO.? N2 YES/NO

Here N2 is an integer constant displayed on the terminal sereen in I3 format. Either 'YES' or 'NO' is supplied by the user through terminal. If user has supplied 'YES' then the control will be transferred to the write statement which displays the following:

SUPPLY REVISED VALUE OF COMPUT.INTEVAL?

Now the cursor will wait for the revised value of computational interval. Once this is supplied the computation will proceed to step (iii).

However, if user has supplied 'No', then the control will be transferred to step (iii) without asking for the value of revised computational interval.

(iii) DO YOU WANT TO REVISE R. FOR TRIAL NO? N3 YES/NO

Here N3 is an integer constant which represents the trial no. and displays on the terminal in I3 format. Either 'YES' or

'NO' is supplied through terminal by the user depending upon the requirement. If user want to revise the value of R in the next trial, then 'YES' may be supplied in response of the above querry and the revised value of R may be supplied in response of the querry made as below:

SUPPLY VALUE OF R? B

Here B is a real constant which repesents the revised value of R.

From here the control will be transferred to an appropriate statement in the programme to compute the unit hydrograph using revised parameters in case user has supplied 'YES' in response to any one of the querries listed above. More over, the above querries will be repeated again for the next trial. If the user response in all the querries made is 'NO' then the control will be transferred to the stop statement and execution will be over.

D. OUTPUT SPECIFICATIONS

The output file CLARKF.OUT consists the values of the following output lists in the specified format:

Rec.No.	OUTPUT LISTS	FORMAT
1	Nil	30X, 'CLARK MODEL COMPUTATIONS'
2	Nil	10X, 120 ('-')
3	NTR	10X, 'TRIAL NO.', 2X,I3
4	TC,R	4X, 'TC(HOURS)=', F10.2/4X, 'R (HOURS)=', F10.2
5	D	4X,'TIME', 10X, 'IUH ORDINATE', 5X, F5.0, '- HOUR UH ORDINATE'

6	Nil	3X,'(HOUR)', 11X, '(M**3/SEC)', 11X, '(M**3/SEC)'
7	(TIME (I), U(I), UH(I), I=1,NDUH)	2X, F6.2, 10X, F12.3, 10X,F12.3

Note : The above output lists are repeated for revised values of the parameters Tc or R or computational interval DLT.

E. EXAMPLE

The time-area diagramme ordinates for a typical catchment are given below. If clark model parameters derived from the direct surface runoff hydrograph and excess rainfall hyetograph of a storm in the catchment are 8 hours (Tc) and 7.5 hours (R) respectively, derive 20 ordinates of 2 hour unit hydrograph with volume 10 mm. The catchent area is 250 sq.km.

Time (hrs)	0	1	2	3	4	5	6	7	8
Area (Km^2)	0	10	23	39	43	42	40	35	18

If clark model parameters, Tc and R are 7.0 and 7.5 hours respectively, derive 2 hour unit hydrograph with unit volume 10mm.

(a) Input :

The structure of the input file CLARKF.DAT for the above example would be as given below:

```
250
  1
  2
 20
 10
  8
  7.5
  9
  0  10  23  39  43  42  40  35  18
```

The values of the parameters are revised interactively as given below while running the programme:

```
DO YOU WANT TO REVISE TC FOR TRIAL NO? 1 YES
SUPPLY  VALUE OFTC? 7.0

DO YOU WANT TO REVISE THE COMPUTATIONAL INTERVAL FOR TRIAL
No. ? 1 NO

DO YOU WANT TO REVISE R FOR TRIAL NO.? 1 NO.

DO YOU WANT TO REVISE TC FOR TRIAL NO. ? 2 NO

DO YOU WANT TO REVISE THE COMPUTATIONAL INTERVAL FOR TRIAL
NO. ? 2 NO

DO YOU WANT TO REVISE R FOR TRIAL NO.? 2 NO
FORTRAN STOP
```

(b) Output

CLARK MODEL COMPUTATIONS

TRIAL NO. 1
TC (HOURS)= 8.00
R(HOURS)= 7.50

TIME (HOUR)	IUH ORDINATE (M**3/SEC)	2.-HOUR UH ORDINATE (M**3/SEC)
0.00	0.000	0.000
1.00	3.472	0.868
2.00	11.025	4.493
3.00	23.190	12.178
4.00	35.223	23.157
5.00	45.404	34.760
6.00	53.619	44.913
7.00	59.070	52.928
8.00	57.937	57.424
9.00	50.695	56.410
10.00	44.358	50.921
11.00	38.813	44.556
12.00	33.962	38.987
13.00	29.716	34.113
14.00	26.002	29.849
15.00	22.752	26.118
16.00	19.908	22.853
17.00	17.419	19.997
18.00	15.242	17.497
19.00	13.337	15.310

CLARK MODEL COMPUTATIONS

TRIAL NO. 2
TC (HOURS)= 7.00
R(HOURS)= 7.50

TIME (HOUR)	IUH ORDINATE (M**3/SEC)	2.-HOUR UH ORDINATE (M**3/SEC)
0.00	0.000	0.000
1.00	4.613	1.153
2.00	14.752	5.995
3.00	28.981	15.774
4.00	42.225	28.734
5.00	53.118	41.637
6.00	60.865	52.331
7.00	67.147	60.499
8.00	76.117	67.819
9.00	66.602	71.496
10.00	58.277	66.900
11.00	50.993	58.537
12.00	44.618	51.220
13.00	39.041	44.818
14.00	34.161	39.215

15.00	29.871	34.314
16.00	26.155	30.024
17.00	22.885	26.271
18.00	20.025	22.987
19.00	17.521	20.114

Appendix-XVII

A.COMPUTER PROGRAMME S-CURVE.FOR

```
C       THIS PROGRAMME IS USED FOR S-CURVE DEVELOPMENT HERE:
C       N=NO. OF UNIT HYDROGRAPH ORDINATES
C       VH=VECTOR CONTAINING THE VALUE OF UNIT HYDROGRAPH
C       ORDINATES
C       HR=DATA INTERVAL IN HOURS
C       DO =DURATION OF UNIT HYDROGRAPH
        DIMENSION UH(100),S(100),T(100)
        OPEN(UNIT=1,FILE='SCURVE.DAT',STATUS='OLD')
        OPEN(UNIT=2,FILE='SCURVE.OUT',STATUS='NEW')
        READ (1,*) N
        READ (1,*) (UH(I),I=1,N)
        READ(1,*) HR,DO
        T(1)=0.0
        DO 1 I=2,N
1       T(I)=T(I-1)+HR
        NB=DO/HR
        DO 20 I=1,NB
20      S(I)=UH(I)
        DO 2 I=(NB+1),N
2       S(I)=S(I-1)+UH(I)
        WRITE (2,3)
3       FORMAT(20X,'DEVELOPMENT OF S-CURVE')
        WRITE (2,4)
4       FORMAT (20X,22('_'))
        WRITE (2,5)
5       FORMAT(10X,'TIME',5X,'UNIT HYDROGRAPH',10X,'S-VALUE')
        WRITE (2,6)
6       FORMAT(10X,4('_'),5X,15('_'),10X,7('_'))
        WRITE(2,7) (T(I),UH(I),S(I),I=1,N)
7       FORMAT (10X,F4.0,10X,F6.2,14X,F6.2)
        CLOSE(UNIT=1)
        CLOSE(UNIT=2)
        STOP
        END
```

B. DESCRIPTION OF COMPUTER PROGRAMME SCURVE.FOR

The programme SCURVE.FOR is used for the development of S-curve hydrograph from T-hour unit hydrograph. The programme is written in FORTRAN-IV language and run on VAX-11/780 Digital Computer System. The variables used as the input and output lists in the programme are described below:

VARIABLE	DESCRIPTION
N	No. of unit hydrograph ordinates
UH	A vector of unit hydrograph ordinates (m^3/s)
HR	Data interval (hrs)
DO	Unit hydrograph duration (hrs)
T	A vector of time period (hrs)
S	A vector of S-curve hydrograph ordinates (m^3/s)

C. INPUT SPECIFICATIONS

The input file SCURVE.DAT consists the values of the following input lists in the specified format:

REC. NO.	INPUT LISTS	FORMAT
1	N	Free
2	(UH(I),I=1,N)	Free
3	HR, DO	Free

D OUTPUT SPECIFICATIONS

The values of the following output lists will be written in the output file SCURVE.OUT in the specified format:

REC.NO.	OUTPUT LISTS	FORMAT
	Nil	20X, 'DEVELOPMENT OF S-CURVE'
2	Nil	20X, 22 ('-')
3	Nil	10X, 'TIME', 5X,'UNIT HYDROGRAPH' 10X, 'S-VALUE'
4	Nil	10X, 4('-'), 5X, 15('-'), 10X, 7('-')
5	(T(I),UH(I), S(I), I=1,N)	10X, F4.0, 10X, F6.2, 14X, F6.2

E. EXAMPLE

The unit hydrograph shown below resulted from a 4-hour duration storm. Determine the ordinates of the associated S-curve hydrograph.

Time (hrs)	0	4	8	12	16	20	24	28
UH ordinates(m^3/s)	0	20	50	70	65	60	40	0

(a) Input :

The structure of the input file SCURVE.DAT for the above example would be as given below:

```
8
0   20   50   70   65   60   40   0
4   4
```

(b) Output

DEVELOPMENT OF S-CURVE

TIME	UNIT HYDROGRAPH	S-VALUE
0.	0.00	0.00
4.	20.00	20.00
8.	50.00	70.00
12.	70.00	140.00
16.	65.00	205.00
20.	60.00	265.00
24.	40.00	305.00
28.	0.00	305.00

APPENDIX-XVIII

A.COMPUTER PROGRAMME SUPERIM.FOR

```
C       THIS PROGRAMME IS USED FOR CHANGING THE DURATION OF
C       UNIT HYDROGRAPH BY SUPERIMPOSITION METHOD
C       APPLICABLE WHEN NEW DURATION OF UH IS INTEGER MULTIPLE
C       OF OLD DURATION OF UH
        DIMENSION UOLD(100),UNEW(100),SUM(100),TIME(100)
        OPEN(UNIT=1,FILE='SUPERIM.DAT',STATUS='OLD')
        OPEN(UNIT=2,FILE='SUPERIM.OUT',STATUS='NEW')
C       DO=ORGINAL DURATION OF UNIT HYDROGRAPH (HRS)
        READ(1,*)DO
C       DN=NEW DUATION OF UNIT HYDROGRAPH (HRS)
        READ(1,*)DN
C       DLT=COMPUTATIONAL INTERVAL (HRS)
        READ(1,*)DLT
C       NDUH=NO OF ORDINATES OF DO-DURATION UNIT HYDROGRAPH
        READ(1,*)NDUH
C       UOLD=VECTOR CONTAINING DO-HOUR UNIT HYDROGRAPH (M**3/SEC)
        READ(1,*)(UOLD(I),I=1,NDUH)
        TIME(1)=0.0
        M=DN-DO
        M1=M/DLT
        NRUN=NDUH+M1
        DO 1 I=2,NRUN
        TIME(I)=TIME(I-1)+DLT
1       CONTINUE
        N=DO/DLT
        N1=DN/DO
        DO 2 I=1,NRUN
        SUM(I)=0.0
        L=0
        DO 3 J=1,I,N
        K=I-J+1
        L=L+1
        IF(L.GT.N1)GO TO 2
        SUM(I)=SUM(I)+UOLD(K)
3       CONTINUE
2       CONTINUE
        DIV=DN/DO
        DO 4 I=1,NRUN
        UNEW(I)=SUM(I)/DIV
4       CONTINUE
        WRITE(2,5)
5       FORMAT(30X,'CHANGE IN UNIT HYDROGRAPH DURATION USING SUPERIM
        1POSITION METHOD')
        WRITE(2,6)
6       FORMAT(10X,120('-')/)
        WRITE(2,7)DO
7       FORMAT(4X,'TIME',10X,F6.0,'-HOUR DURATION UNIT HYDROGRAPH')
        WRITE(2,8)
8       FORMAT(4X,'(HRS)',25X,'(CUMEC)'/)
        WRITE(2,9)(TIME(I),UOLD(I),I=1,NDUH)
```

```
9       FORMAT(3X,F5.0,25X,F12.2)
        WRITE(2,10)DN
10      FORMAT(4X,'TIME',10X,F6.0,'-HOUR DURATION UNIT HYDROGRAPH')
        WRITE(2,8)
        WRITE(2,9)(TIME(I),UNEW(I),I=1,NRUN)
        STOP
        END
```

B. DESCRIPTION OF COMPUTER PROGRAMME SUPERIM.FOR

The programme SUPERIM.FOR is used for changing the duration of unit hydrograph by superimposition method. The programme is written in FORTRAN-IV language and run on VAX-11/780 computer system. The variables used in the programme are described below:

VARIABLE	DESCRIPTION
DO	Original duration of unit hydrograph (hour)
DN	New duration of unit hydrograph (hour)
DLT	Computational interval (hours)
NDUH	No. of ordinates of DO-duration unit hydrograph
UOLD	Vector of DO-hour unit hydrograph (m^3/s)
UNEW	Vector of DN-hour unit hydrograph (m^3/s)

C. INPUT SPECIFICATIONS

The input file SUPERIM.DAT consists the values of the following input lists in the specified format:

REC.No.	INPUT LISTS	FORMAT
1	DO	Free
2	DN	Free
3	DLT	Free
4	NDUH	Free
5	(UOLD(I),I=1,NDUH)	Free

D. OUTPUT SPECIFICATIONS

The output file SUPERIM.OUT consists the values of the following output lists in the specified format:

REC.NO.	OUTPUT LISTS	FORMAT
1	Nil	30X,'CHANGE IN UNIT HYDROGRAPH DURATION USING SUPERIMPOSITION METHOD'
2	Nil	10X, 120 ('-')/
3	DO	4X, 'TIME', 10X, F6.0, '-HOUR DURATION UNIT HYDROGRAPH'
4	Nil	4X, '(HRS)', 25X, '(CUMEC)'/
5	(TIME(I),UOLD (I),I=1,NDUH)	3X, F5.0, 25X, F12.2
6	DN	4X,'TIME', 10X, F6.0, '-HOUR DURATION UNIT HYDROGRAPH
7	Nil	4X, '(HRS)', 25X, '(CUMEC)'/
8	(TIME(I),UNEW(I), I=1, NDUH)	3X, F5.0, 25X, F12.2

E. EXAMPLE

Using the data for the example given in APPENDIX-XVII, obtain the unit hydrograph of 12 hour duration using superimposition method.

(a) The structure of the input file SUPERIM.DAT would be as given below for the above example.

```
4
12
4
8
0   20   50   70   65   60   40   0
```

(b) Output

CHANGE IN UNIT HYDROGRAPH DURATION USING SUPERIMPOSITION METHOD

TIME (HRS)	4.-HOUR DURATION UNIT HYDROGRAPH (CUMEC)
0.	0.00
4.	20.00
8.	50.00
12.	70.00
16.	65.00
20.	60.00
24.	40.00
28.	0.00

TIME (HRS)	12.-HOUR DURATION UNIT HYDROGRAPH (CUMEC)
0.	0.00
4.	6.67
8.	23.33
12.	46.67
16.	61.67
20.	65.00
24.	55.00
28.	33.33
32.	13.33
36.	0.00

APPENDIX-XIX

A.COMPUTER PROGRAMME NEWD.FOR

```
C       THIS PROGRAMME COMPUTES THE UNIT HYDROGRAPH ORDINATE OF
C       NEW DURATION USING S-CURVE TECHNIQUE HERE:
C       N=NO.OF UNIT HYDROGRAPH ORDINATE OF ORGINAL DURATION
C       UH=VECTOR CONTAINING THE VALUES OF UNIT HYDROGHAPH
C       ORDINATES OF ORIGNAL DURATION
C       HR= DATA INTERVAL IN HOURS
C       DO=ORIGNAL DURATION OF UNIT HYDROGRAPH
C       DN=NEW DURATION OF UNIT HYDROGRAPH
C       RATIO DN/HR SHOULD BE AN INTEGER NO.
        DIMENSION UH(100),S(100),T(100),DC(100),DS(100)
        OPEN (UNIT=1,FILE='NEWD.DAT',STATUS='OLD')
        OPEN (UNIT=2,FILE='NEWD.OUT',STATUS='NEW')
        READ (1,*) N
        READ (1,*)  (UH(I), I=1,N)
        READ (1,*) HR,DO,DN
        T(1)=0.0
        DO 1 I=2,N
1       T(I)=T(I-1)+HR
        NBEG=DO/HR
        DO 2 I=1,NBEG
2       S(I)=UH(I)
        DO 30 I=(NBEG+1),N
30      S(I)=S(I-1)+UH(I)
        WRITE (2,3)
3       FORMAT(20X,'DEVELOPMENT OF S-CURVE')
        WRITE (2,4)
4       FORMAT (20X,22('_'))
        WRITE (2,5)
5       FORMAT(10X,'TIME',5X,'UNIT HYDROGRAPH',10X,'S-VALUE')
        WRITE (2,6)
6       FORMAT(10X,4('_'),5X,15('_'),10X,7('_'))
        WRITE(2,7) (T(I),UH(I),S(I),I=1,N)
7       FORMAT (10X,F4.0,10X,F6.2,14X,F6.2)
        NB=DN/HR
        DO 8 I=1,NB
8       DS(I)=S(I)
        DO 9 I=(NB+1),N
9       DS(I)=S(I)-S(I-NB)
        NEND=N+NB-1
        DO 10 I=(N+1),NEND
10      DS(I)=S(N)-S(I-NB)
        WRITE(2,11)
11      FORMAT(20X,'NEW UNIT GRAPH')
        WRITE (2,12)
12      FORMAT(20X,14('_'))
        WRITE (2,14)
14      FORMAT(10X,'TIME',10X,'NEW U H  ORDINATES')
        WRITE (2,15)
15      FORMAT(10X,4('_'),10X,18('_'))
        DO 16 I=(N+1),NEND
```

```
16      T(I)=T(I-1)+HR
        DO 18 I=1,NEND
        DS(I)=DS(I)*DO/DN
        DS(I)=AINT(DS(I)*100+0.5)/100
18      CONTINUE
        WRITE (2,17)(T(I),DS(I),I=1,NEND)
17      FORMAT(10X,F4.0,10X,F12.2)
        NDO=DO
        NDN=DN
        WRITE (2,19) NDO,NDN
19      FORMAT (10X,'ORIGNAL DURATION OF UH=',I5,'HOUR'
        1/10X,'NEW DURATION OF UH=',I5,'HOUR')
        CLOSE(UNIT=1)
        CLOSE(UNIT=2)
        STOP
        END
```

B. DESCRIPTION OF COMPUTER PROGRAMME NEWD.FOR

The programme NEWD.FOR computes the unit hydrograph ordinate of new duration using S-curve technique. The programme is written in FORTRAN-IV language and run on VAX-11/780 computer system. The variables used as input lists and output lists are described below:

VARIABLE	DESCRIPTION
N	No. of unit hydrograph ordinate of original duration
UH	Vector of unit hydrograph ordinates of original duration (m^3/s)
HR	Data interval (hour)
DO	Original duration of UH (hour)
DN	New duration of UH (hour)
S	Vector of associate s-curve hydrograph ordinates (m^3/s)
DS	Vector of DN-hour unit hydrograph ordinates (m^3/s)
T	Vector of time period (hours)
NDO, NDN	Same as DO and DN respectively

C. INPUT SPECIFICATIONS

The input file NEWD.DAT consists the values of the following input lists in the specified format.

REC.NO.	INPUT LISTS	FORMAT
1	N	Free
2	(UH(I),I=1,N)	Free
3	HR, DO, DN	Free

D. OUTPUT SPECIFICATIONS

The output file NEWD.OUT will be created after the execution of the programme. The output file NEWD.OUT consists the values of the following output lists in the specified format:

REC.NO.	OUTPUT LISTS	FORMAT
1	Nil	20X,'DEVELOPMENT OF S-CURVE'
2	Nil	20X, 22 ('-')
3	Nil	10X, 'TIME', 5X, 'UNIT HYDROGRAPH', 10X, 4('-'),'S-VALUE'
4	Nil	10X, 4('-'), 5X, 15('-'), 10X, 7('-')
5	(T(I),UH(I),S(I), I=1, N)	10X, F4.0, 10X, F6.2, 14X, F6.2
6	Nil	20X, 'NEW UNIT GRAPH'
7	Nil	20X, 14('-')
8	Nil	10X, 'TIME', 10X, 'NEW UH ORDINATES'
9	Nil	10X, 4('-'), 10X, 18('-')
10	(T(I),DS(I),I=1 NEND)	10X, F4.0, 10X, F12.2
11	NDO, NDN	10X, 'ORIGINAL DURATION OF UH = ', I5, 'HOUR'/10X, 'NEW DURATION OF UH=', I5, 'HOUR'

E. EXAMPLE

Using the data for the example given in APPENDIX-XVII, obtain the unit hydrograph of 12 hour duration using s-curve method.

(a) Input :

The structure of the input file NEWD.DAT would be as given below for the above example:

```
8
0  20  50  70  65  60  40  0
4   4  12
```

(b) Output

DEVELOPMENT OF S-CURVE

TIME	UNIT HYDROGRAPH	S-VALUE
0.	0.00	0.00
4.	20.00	20.00
8.	50.00	70.00
12.	70.00	140.00
16.	65.00	205.00
20.	60.00	265.00
24.	40.00	305.00
28.	0.00	305.00

NEW UNIT GRAPH

TIME	NEW U H ORDINATES
0.	0.00
4.	6.67
8.	23.33
12.	46.67
16.	61.67
20.	65.00
24.	55.00
28.	33.33
32.	13.33
36.	0.00

ORIGNAL DURATION OF UH= 4HOUR
NEW DURATION OF UH= 12HOUR

APPENDIX-XX

A.COMPUTER PROGRAMME REPROD.FOR

```
C       THIS PROGRAMME IS USED FOR REPRODUCING THE OBSERVED DSRO
        DIMENSION TIME(100),DSRO(100),CDSRO(100),UH(100),EXE(100)
        OPEN(UNIT=1,FILE='REPROD.DAT',STATUS='OLD')
        OPEN(UNIT=2,FILE='REPROD.OUT',STATUS='NEW')
C       CA=CATCHMENT AREA (SQ.KM)
        READ(1,*)CA
C       DLT=COMPUTATIONAL INTERVAL (HOURS)
        READ(1,*)DLT
C       NRUN=NO OF DSRO ORDINATES
        READ(1,*)NRUN
        DO 1 I=1,NRUN
        DSRO(I)=0.0
        CDSRO(I)=0.0
        EXE(I)=0.0
        TIME(I)=0.0
        UH(I)=0.0
1       CONTINUE
        DO 500 I=2,NRUN
500     TIME(I)=TIME(I-1)+DLT
C       DSRO=VECTOR CONTAINING THE DSRO ORDINATES (M**3/SEC)
        READ(1,*)(DSRO(I),I=1,NRUN)
C       NRAIN=NO. OF EXCESS RAINFALL BLOCKS
        READ(1,*)NRAIN
C       EXE=VECTOR CONTAINING THE EXCESS RAINFALL VALUES(MM)
        READ(1,*)(EXE(I),I=1,NRAIN)
C       D=DURATION OF UNIT HYDROGRAPH(HOURS)
        READ(1,*)D
C       VOL=UNIT VOLUME OF UH (MM)
        READ(1,*)VOL
C       NDUH=NO. OF UNIT HYDROGRAPH ORDINATES
        READ(1,*)NDUH
C       UH=VECTOR CONTAINING U.H. ORDINATES (M**3/SEC)
        READ(1,*)(UH(I),I=1,NDUH)
        WRITE(2,400)
400     FORMAT(30X,'REPRODUCTION OF OBSREVED DSRO USING UNIT HYDROGRAPH')
        WRITE(2,401)
401     FORMAT(10X,120('-')/)
        WRITE(2,402)
402     FORMAT(30X,'DIRECT SURFACE RUNOFF(M**3/SEC)'/)
        WRITE(2,403)(DSRO(I),I=1,NRUN)
403     FORMAT(4X,10F12.3)
        WRITE(2,404)
404     FORMAT(/30X,'EXCESS RAINFALL (MM)'/)
        WRITE(2,405)(EXE(I),I=1,NRAIN)
405     FORMAT(4X,10F12.2)
        WRITE(2,406)D
406     FORMAT(/30X,F5.0,'-HOUR U.H. ORDINATES(M**3/SEC)')
        WRITE(2,407)(UH(I),I=1,NDUH)
407     FORMAT(4X,10F12.3)
        SUM=0.0
        DO 865 I=1,NDUH
865     SUM=SUM+UH(I)*DLT
```

```
      UVOLUM=0.2778*CA*VOL
      DO 866 I=1,NDUH
866   UH(I)=UH(I)*(UVOLUM/SUM)
      CALL CONVOL(CDSRO,UH,EXE,NRUN)
      PEAK1=0.0
      PEAK2=0.0
      TPEAK1=0.0
      TPEAK2=0.0
      DO 867 I=1,NRUN
      IF(PEAK1.GE.DSRO(I))GO TO 898
      PEAK1=DSRO(I)
      TPEAK1=TIME(I)
898   IF(PEAK2.GE.CDSRO(I)) GO TO 867
      PEAK2=CDSRO(I)
      TPEAK2=TIME(I)
867   CONTINUE
      UHP=0.0
      UHTP=0.0
      DO 868 I=1,NDUH
      IF(UHP.GE.UH(I))GO TO 868
      UHP=UH(I)
      UHTP=TIME(I)
868   CONTINUE
      WRITE(2,602)UHP,UHTP
602   FORMAT(4X,'U.H. PEAK(M**3/S)=',2X,F5.0/
      14X,'U.H. TIME TO PEAK  (HRS)=',2X,F5.0)
      WRITE(2,1119)
1119  FORMAT(4X,'COMPARISON OF OBSERVED AND COMPUTED HYDROGRAPHS
      1 USING UNIT HYDROGRAPH')
      WRITE(2,401)
      WRITE(2,27)
27    FORMAT(4X,'TIME',4X,'OBSERVED D. S. R. O. ',4X,'COMP
      1UTED D. S. R. O. ')
      WRITE(2,1120)
1120  FORMAT(4X,'(HRS)',15X,'(CUMEC)',15X,'(CUMEC)')
      DO 28 I=1,NRUN
      WRITE(2,29)TIME(I),DSRO(I),CDSRO(I)
29    FORMAT(4X,F5.0,15X,F7.1,15X,F7.1)
28    CONTINUE
      S2=0.0
      DO 6835 I=1,NRUN
6835  S2=S2+DSRO(I)
      ANRUN=NRUN
      SMEAN=S2/ANRUN
      S3=0.0
      S4=0.0
      DO 6836 I=1,NRUN
      S3=S3+(DSRO(I)-SMEAN)**2
6836  S4=S4+(DSRO(I)-CDSRO(I))**2
      EFF=((S3-S4)/S3)*100.0
```

```
      WRITE(2,6837) EFF
6837  FORMAT(4X,'EFFICIENCY OF THE MODEL=',F10.2)
      WRITE(2,605)PEAK1,TPEAK1
605   FORMAT(4X,'OBS. PEAK (M**3/S)=',2X,F7.1/4X,
     1'OBSERVED TIME TO PEAK (HRS)=',2X,F5.0)
      WRITE(2,607)PEAK2,TPEAK2
607   FORMAT(4X,'COMPUTED PEAK (M**3/S)=',2X,F7.1/4X,
     1'COMPUTED TIME TO PEAK (HRS)=',2X,F5.0)
      CALL ERROR(DSRO,CDSRO,NRUN,STE,ABE,ABPE)
      WRITE(2,30) STE,ABE,ABPE
30    FORMAT(4X,'AVERAGE STANDARD ERROR=',2X,F8.3/4X,'AVREAGE AB
     1SOLUTE ERROR=',2X,F8.3/4X,'AVERAGE PERCENTAGE ABSOLUTE ERROR
     2=',2X,F8.3)
      PEP=(ABS(PEAK1-PEAK2)/PEAK1)*100
      PET=(ABS(TPEAK1-TPEAK2)/TPEAK1)*100.0
      WRITE(2,6838) PEP,PET
6838  FORMAT(4X,'PERCENTAGE ABSOLUTE ERROR IN PEAK=',F10.2,/,
     14X,'PECENTAGE ABSOLUTE ERROR IN TIME TO PEAK=',F10.2)
      STOP
      END
C     ******************************************************************
      SUBROUTINE CONVOL(QEST,UHH,REX,NRR)
      DIMENSION QEST(50),UHH(50),REX(50)
      DO 20 I=1,NRR
      SUM=0.0
      DO 10 J=1,I
      KK=I-J+1
10    SUM=SUM+UHH(J)*REX(KK)
20    QEST(I)=SUM
      RETURN
      END
C     ******************************************************************
      SUBROUTINE ERROR(OBSQ,COMPQ,N,SE,AE,APE)
      DIMENSION OBSQ(50),COMPQ(50)
      SUM1=0.0
      AN=N
      DO 10 I=1,N
10    SUM1=SUM1+(COMPQ(I)-OBSQ(I))**2
      SUM1=SUM1/AN
      SE=SQRT(SUM1)
      SUM2=0.0
      SUM3=0.0
      DO 20 I=1,N
      SUM2=SUM2+ABS(COMPQ(I)-OBSQ(I))
      IF(OBSQ(I).EQ.0)GO TO 20
      SUM3=SUM3+(ABS(COMPQ(I)-OBSQ(I))/OBSQ(I))
20    CONTINUE
      SUM2=SUM2/AN
      AE=SUM2
      SUM3=(SUM3/AN)*100
```

```
APE=SUM3
RETURN
END
```

B. DESCRIPTION OF COMPUTER PROGRAMME REPROD.FOR

The programme REPROD.FOR is used for reproducing the observed direct surface runoff hydrograph and computes the various error functions based on the observed and computed direct surface runoff hydrographs. The programme is written in FORTRAN-IV language and run on VAX-11/780 computer system. The variables used in the programme as input and output lists are described below:

VARIABLE	DESCRIPTION
CA	Catchment area (sq.km)
DLT	Computational interval (hours)
NRUN	No.of DSRO ordinates
TIME	Vector of time period (hours)
DSRO	Vector of observed DSRO ordinates (m^3/s)
NRAIN	No. of excess rainfall blacks
EXE	Vector of the excess rainfall values (mm)
D	Duration of unit hydrograph (hour)
VOL	Unit Volume of UH (mm)
NDUH	No. of UH ordinates
UH	Vector of UH ordinates (m^3/s)
UHP	UH peak (m^3/s)
UHTP	UH time to peak (hours)
CDSRO	Vector of computed DSRO ordinates (m^3/s)
EFF	Efficiency of the model used for UH derivation (%)
PEAK1	Peak ordinate of observed DSRO (m^3/s)
TPEAK1	Time to peak of observed DSRO (hrs)

PEAK2	Peak ordinate of computed DSRO (m^3/s)
TPEAK2	Time to peak of computed DSRO (hour)
STE	Average standard error
ABE	Average Absolute error
ABPE	Average percentage absolute error
PEP	Percentage absolute error in peak
PET	Percentage absolute error in time to peak.

The main programme calls the following SUBROUTINES

(i) SUBROUTINE ERROR (OBSQ, COMPQ, N, SE, AE, APE)

(ii) SUBROUTINE CONVOL (QEST, UHH, REX, NRR)

The purposeof the above subroutines and the descriptions of the variables used as arguments of the subroutines are given below:

(i) SUBROUTINE ERROR (OBSQ, COMPQ, N, SE, AE, APE)

This subroutine calculates three eror functions from observed and computed direct surface runoff hydrographs. The variables used as arguments are described below:

VARIABLE	DESCRIPTION
OBSQ	A vector of observed DSRO (m^3/s)
COMPQ	A vector of computed DSRO (m^3/s)
AE	Average standard error
AE	Average absolute error
APE	Average percentage absolute error
N	No. of DSRO ordinates

(ii) SUBROUTINE CONVOL (QEST, UHH, REX, NRR)

This subroutine computes the direct surface runoff convoluting the excess rainfall with unit hydrograph. The variables used as arguments are:

VARIABLE	DESCRIPTION
QEST	Vector of computed direct surface runoff (m^3/s)
UHH	Vector of D-hour unit hydrograph (m^3/DLT hour)
REX	Vector of excess rainfall (mm)
NRR	Number of DSRO to be computed

C. INPUT SPECIFICATIONS

The values of the following input lists are to be supplied through the input file REPROD.DAT in the specified format:

REC.No.	INPUT LISTS	FORMAT
1	CA	Free
2	DLT	Free
3	NRUN	Free
4	(DSRO(I),I=1,NRUN)	Free
5	NRAIN	Free
6	(EXE(I),I=1,NRAIN)	Free
7	D	Free
8	VoL	Free
9	NDUH	Free
10	(UH(I),I=1,NDUH)	Free

D. OUTPUT SPECIFICATIONS

The output file REPROD.OUT consists the values of the following output lists in the specified format:

REC.No.	OUTPUT LISTS	FORMAT
1	Nil	30X,'REPRODUCTION OF OBSERVED DSRO USING UNIT HYDROGRAPH'
2	Nil	10X, 120 ('-')/
3	Nil	30X,'DIRECT SURFACE RUNOFF (M**3/SEC)'/
4	(DSRO(I),I=1,NRUN)	4X, 10 F 12.3
5	Nil	/30X,'EXCESS RAINFALL (MM)'/
6	(EXE(I),I=1, NRAIN)	4X, 10 F12.2
7	D	/ 30X,F5.0,'-HOUR U.H.ORDINATES (M**3/SEC)'
8	(UH(I),I=1,NDUH)	4X, 10 F12.3
9	UHP, UHTP	4X,'U.H. PEAK (M**3/S)=',2X,F5.0/4X, 'U.H.TIME TO PEAK (HRS)=', 2X,F5.0
10	Nil	4X,'COMPARISON OF OBSERVED AND COMPUTED HYDROGRAPHS USING UNIT HYDROGRAPH'
11	Nil	10X, 120 ('-')/
12	Nil	4X,'TIME', 4X,'OBSERVED D.S.R.O.', 4X,'COMPUTED D.S.R.O.'
13	Nil	4X, '(HRS)',15X, '(CUMEC)',15X,'(CUMEC)'
14	TIME(I),DSRO (I),CDSRO(I)	4X, F5.0, 15X, F7.1, 15X, F7.1
15	EFF	4X,'EFFICIENCY OF THE MODEL=', F10.2
16	PEAK1,TPEAK1	4X,'OBS.PEAK (M**3/S)=',2X,F7.1/4X,'OBSERVED TIME TO PEAK (HRS)=', 2X, F5.0
17	PEAK2,TPEAK2	4X,'COMPUTED PEAK (M**3/S)=',2X,F7.1/ 4X,'COMPUTED TIME TO PEAK (HRS)=',2X,F5.0
18	STE,ABE,ABPE	4X,'AVERAGE STANDARD ERROR=',2X,F8.3/ 4C,'AVERAGE ABSOLUTE ERROR=',2X,

		F8.3/4X,'AVERAGE RECENTAGE ABSOLUTE ERROR=', 2X, F8.3
19	PEP,PET	4X,'PERCENTAGE ABSOLUTE ERROR IN PEAK=', F10.2,/,4X,'PERCENTAGE ABSOLUTE ERROR IN TIME TO PEAK=', F10.2

Note : Rec. no. 14 will be repeated for NRUN times.

E. EXAMPLE

The direct surface runoff hydrograph and excess rainfall hydrograph ordinates for a storm in a catchment are given below. 6-hour representative unit hydrograph ordinates with volume 1mm are also given below. Compute the direct surface runoff using the given unit hydrograph. Also compute the various error functions from observed DSRO and computed DSRO ordinates.

The catchment area is 1700 sq.km.

Time (hrs)	Excess Rainfall (mm)	Observed DSRO (m^3/s)
0	0	0
6	40.209	250
12	100.209	1050
18	60.209	4350
24	-	4150
30	-	2300
36	-	1070
42	-	450
48	-	120
54	-	0

6-hour unit hydrograph data

Time (hrs)	6-hour unit hydrograph with 1 mm unit volume (m^3/s)
0	0
6	2.97
12	17.83
18	23.61
24	17.43
30	9.59
36	4.44
42	1.790
48	0.0

(a) Input :

The structure of the input file REPROD.DAT would be as given below for the above example:

```
1700
6
10
0  250  1050  2050  4350  4150  2300  1070  450  120
3
40.209  100.209  60.209
6
1
8
0  2.97  17.83  23.61  17.43  9.59  4.44  1.79  0
```

(b) Output

REPRODUCTION OF OBSREVED DSRO USING UNIT HYDROGRAPH

DIRECT SURFACE RUNOFF(M**3/SEC)

0.000	250.000	1050.000	2050.000	4350.000	4150.000	2300.000	1070.000	450.000	120.000

EXCESS RAINFALL (MM)

40.21	100.21	60.21

6.-HOUR U.H. ORDINATES(M**3/SEC)

0.000	2.970	17.830	23.610	17.430	9.590	4.440	1.790

U.H. PEAK(M**3/S)= 24.
U.H. TIME TO PEAK (HRS)= 18.
COMPARISON OF OBSERVED AND COMPUTED HYDROGRAPHS USING UNIT HYDROGRAPH

TIME (HRS)	OBSERVED D. S. R. O. (CUMEC)	COMPUTED D. S. R. O. (CUMEC)
0.	0.0	0.0
6.	250.0	121.0
12.	1050.0	1028.3
18.	2050.0	2954.3
24.	4350.0	4196.3
30.	4150.0	3601.8
36.	2300.0	2218.6
42.	1070.0	1109.1
48.	450.0	452.7
54.	120.0	109.2

EFFICIENCY OF THE MODEL= 94.98
OBS. PEAK (M**3/S)= 4350.0
OBSERVED TIME TO PEAK (HRS)= 24.
COMPUTED PEAK (M**3/S)= 4196.3
COMPUTED TIME TO PEAK (HRS)= 24.
AVERAGE STANDARD ERROR= 341.651
AVREAGE ABSOLUTE ERROR= 189.092
AVERAGE PERCENTAGE ABSOLUTE ERROR= 13.129
PERCENTAGE ABSOLUTE ERROR IN PEAK= 3.53
PECENTAGE ABSOLUTE ERROR IN TIME TO PEAK= 0.00

APPENDIX -XXI

A.COMPUTER PROGRAMME SYNTH.FOR

```
C       THIS PROGRAMM IS USED TO DEVELOP SURFACE RUN OFF
C       HYDROGRAPH FROM UNIT HYDROGRAPH AND COMPOSITE STROM HERE
C       N=NO.OF ORDINATES OF UNIT HYDROGRAPH
C       DT=DATA INTERVAL
C       D=DURATION OF UNIT HYDROGRAPH
C       NR=NO. OF ORDINATES OF RAIN  FALL
C       R=VECTOR CONTAINING THE RAIN FALL VALUES
C       UH= VECTOR CONTAINING THE UNIT HYDROGRAPH ORDINATES
        DIMENSION UH(100),R(100),P(100,100),T(100),TIME(100)
        OPEN(UNIT=1,FILE='SYNTH.DAT',STATUS='OLD')
        OPEN (UNIT=2,FILE='SYNTH.OUT',STATUS='NEW')
        READ(1,*) N
        READ(1,*) (UH(I),I=1,N)
        READ(1,*) DT,D
        READ(1,*) NR
        READ(1,*) (R(I),I=1,NR)
        NB=1
        NEND=N
        NM=D/DT
        DO 1 I=1,NR
        K=0
        DO 2 J=NB,NEND
        K=K+1
2       P(I,J)=UH(K)*R(I)
        NB=NB+NM
        NEND=NEND+NM
1       CONTINUE
        NEND=NEND-NM
        DO 3 J=1,NEND
        T(J)=0.0
        DO 4 I=1,NR
4       T(J)=T(J)+P(I,J)
3       CONTINUE
        WRITE (2,5)
5       FORMAT(20X,'DEVELOPMENT OF COMPOSITE HYDROGRAPH ')
        WRITE (2,6)
6       FORMAT(20X,35('-'))
        WRITE (2,7) N,D
7       FORMAT(10X,'NO.OF UNIT HYDROGRAPH ORDINATES',I3/10X,
        1'DURATION OF UNIT HYDROGRAPH',F5.0)
        TIME (1)=0.0
        DO 8 I=2, NEND
8       TIME(I)=TIME(I-1)+DT
        WRITE (2,9)
9       FORMAT(15X,'UNIT HYDROGRAPH DATA')
        WRITE (2,10)
10      FORMAT(15X,20('-'))
        WRITE(2,11)
11      FORMAT(10X,'TIME',10X,'UNIT HYDROGRAPH ORDINATE')
        WRITE(2,12)
```

```
12      FORMAT (10X,4('-'),10X,23('-'))
        WRITE (2,14) (TIME(I),UH(I),I=1,N)
14      FORMAT(10X,F3.0,20X,F10.2)
        WRITE(2,15)
15      FORMAT(20X,'COMPOSITE HYDROGRAPH DETAILS')
        WRITE(2,16)
16      FORMAT(20X,28('-'))
        WRITE(2,17)
17      FORMAT(10X,'TIME',10X,'DISCHARGE')
        WRITE(2,18)
18      FORMAT(10X,4('-'),10X,9('-'))
        WRITE (2,19) (TIME(I),T(I),I=1,NEND)
19      FORMAT(10X,F3.0,11X,F9.2)
        CLOSE(UNIT=1)
        CLOSE(UNIT=2)
        STOP
        END
```

B. DESCRIPTION OF COMPUTER PROGRAMME SYNTH.FOR

The programme SYNTH.FOR is used for computing the direct surface runoff hydrograph from the excess rainfall of the multi-period storm and unit hydrograph. The programme is written in FORTRAN-IV language and run on VAX-11/780 computer. The variables used in the programme are described below:

VARIABLE	DESCRIPTION
N	No.of unit hydrograph ordinates
UH	Vector of UH ordinates (m^3/s)
DT	Data interval (hours)
D	Duration of unit hydrograph (hour) with one cm unit volume
NR	No. of excess rainfall blocks
R	Vector of excess rainfall blocks (cm). Each block of excess rainfall is of D-hour duration
TIME	Vector of time period (hours)
T	Vector of computed DSRO ordinates (m^3/s)

C. INPUT SPECIFICATIONS

The input file SYNTH.DAT consists the values of the following input lists in the specified format.

REC.NO.	INPUT LISTS	FORMAMT
1	N	Free
2	(UH(I),I=1,N)	Free
3	DT,D	Free
4	NR	Free
5	(R(I),I=1,NR)	Free

D. OUTPUT SPECIFICATIONS

The output file SYNTH.OUT consists the values of the following output lists in the specified format.

REC.NO.	OUTPUT LISTS	FORMAT
1	Nil	20X,'DEVELOPMENT OF COMPOSITE HYDROGRAPH'
2	Nil	20X, 35('-')
3	N,D	10X,'NO. OF UNIT HYDROGRAPH ORDINATES',I3/10X,'DURATION OF UNIT HYDROGRAPH', F5.0
4	Nil	15X, 'UNIT HYDROGRAPH DATA'
5	Nil	15X, 20('-')
6	Nil	10X, 'TIME', 10X, 'UNIT HYDROGRAPH ORDINATE'
7	Nil	10X, 4('-'), 10X, 23('-')
8	(TIME(I),UH(I), I=1,N)	10X, F3.0, 20X, F10.2
9	Nil	20X,'COMPOSITE HYDROGRAPH DETAILS'
10	Nil	20X, 28('-')
11	Nil	10X, 'TIME', 10X, 'DISCHARGE'
12	Nil	10X, 4('-'), 10X, 9('-')
13	(TIME(I),T(I), I=1,NEND)	10X, F3.0, 11X, F9.2

E. EXAMPLE

The data provided below give details of a 4 hr. unit hydrograph and of a design storm from which all losses have been abstracted (design excess rainfall). Determine the design hydrograph of direct surface runoff which will result from this composite design storm.

4-hr. unit hydrograph data

Time (hr)	0	2	4	6	8	10	12	14	16
Discharge(m /s)	0	40	90	135	130	120	80	40	0

Storm data

Time (hr)	0-4	4-8	8-12
Design Excess rainfall (cm)	0.4	1.2	0.5

(a) Input :

The structure of the input file SYNTH.DAT would be as given below for the above example :

```
9
0   40   90   135   130   120   80   40   0
2   4
3
0.4   1.2   0.5
```

(b) Output

DEVELOPMENT OF COMPOSITE HYDROGRAPH

NO.OF UNIT HYDROGRAPH ORDINATES 9
DURATION OF UNIT HYDROGRAPH 4.

UNIT HYDROGRAPH DATA

TIME	UNIT HYDROGRAPH ORDINATE
0.	0.00
2.	40.00
4.	90.00
6.	135.00
8.	130.00
10.	120.00
12.	80.00
14.	40.00
16.	0.00

COMPOSITE HYDROGRAPH DETAILS

TIME	DISCHARGE
0.	0.00
2.	16.00
4.	36.00
6.	102.00
8.	160.00
10.	230.00
12.	233.00
14.	227.50
16.	161.00
18.	108.00
20.	40.00
22.	20.00
24.	0.00