UM 48

SOFTWARE PACKAGE NO. - 1

UNIT HYDROGRAPH APPLICATIONS FOR FLOOD ESTIMATION

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1.0 INTRODUCTION

1.1 About the Unit Hydrograph Analysis

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 (1 mm/1 cm/1 inch) 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 others 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.

Whenever adequate records of rainfall and runoff are available the unit hydrograph may be derived by analysing those records. However, for many small catchments the streamflow data are either limited or not at all available (i.e. the catchments are ungauged). Therefore the unit hydrograph for such catchment can only be derived using their physiographic characteristics. The procedure used for this purpose involves the development of suitable regional relationship between the unit hydrograph parameters and physiographic characteristics for the gauged catchments which are considered to be similar in hydrological and meteorological characteristics. Snyder method of unit hydrograph derivation is widely applied for the derivation of unit hydrograph for ungauged catchments. CWC derived the synthetic unit hydrograph relationship for the various sub-zones of India and these relationships are being used to estimate the characteristics of unit hydrograph for the ungauged catchments located in the respective regions.

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 seven options are included which deals with the various aspects such as processing and analysis of rainfall data, rating curve analysis and computation of discharge, computation of excess rainfall and direct surface runoff, unit hydrograph derivation and reproduction of direct surface runoff and estimation of design flood hydrograph using unit hydrograph approach. For all the options examples, sample input and output files are given in appendices I to VII. Last appendix contains the names of input and output files for various options.

1.2 Computer Requirements

The Unit hydrograph package would run on any PC. It requires a graphic adapter such as Hercules in the case of monochrome monitor or a EGA/VGA graphic card, in the case of a coloured monitor.

1.3 Programme Installation

Unit hydrograph package may be installed on the hard disk using the step by step procedure as follows:

To install the software on the hard disk do the following:

1. Switch on the computer.
2. After getting the prompt, insert the package diskette in the A: drive.
3. Type A:INSTALL and press <ENTER> key.
4. Package will create UH directory in the hard disk (C:\UH) and also a sub directory (C:\UH\MISC). A message to this effect will be displayed on the screen.
5. C:\UH directory contains the main programme files used by the package while C:\UH\MISC contains the data, plot and result files.
6. Files are zipped files. File transfer will take some time depending upon the speed of the computer.
7. After copying the files, control will be shifted to hard disk and pakage will be executed. Now Diskette can be taken out from the A: drive.

1.4 Contents of the package Diskette

The Diskette contains the following files:

UHP1.ZIP UHP2.ZIP INSTALL.BAT PKUZJR.COM

UHP1.ZIP contains the following files :

PREFACE	UH.BAT	EDIT.COM	CLARKF.EXE	CLARKH.EXE	COLUH.EXE
CWC.EXE	DAILY.EXE	DESIGN.EXE	DOUBLE.EXE	EFF.EXE	GAPF.EXE
GAUGE.EXE	INTNAS.EXE	ISO.EXE	LOSS.EXE	MAIN.EXE	NASHF.EXE
NASHG.EXE	NASHH.EXE	NASHM.EXE	NEWD.EXE	PPLOT.EXE	RATING.EXE
REPROD.EXE	SCURVE.EXE	SNYD.EXE	SUPERIM.EXE	SYNTH.EXE	THIES.EXE
UHG.EXE	UHISO.EXE	UNIT.EXE	VEL.EXE	CLARKF.HDT	CLARKH.HDT
COLUH.HDT	CWC.HDT	DAILY.HDT	DESIGN.HDT	DOUBLE.HDT	EFF.HDT
GAPF.HDT	GAUGE.HDT	INTNAS.HDT	ISO.HDT	LOSS.HDT	NASHF.HDT
NASHG.HDT	NASHH.HDT	NEWD.HDT	RATING.HDT	REPROD.HDT	SCURVE.HDT
SNYD.HDT	SUPERIM.HDT	SYNTH.HDT	THIES.HDT	UHISO.HDT	UNIT.HDT
VEL.HDT	CLARKF.HLP	CLARKH.HLP	COL.HLP	COLUH.HLP	CWC.HLP
DAILY.HLP	DATA.HLP	DEL.HLP	DRH.HLP	EDIT.HLP	EFF.HLP
GAPF.HLP	GAUGE.HLP	GEN.HLP	INTNAS.HLP	ISO.HLP	LEAVE.HLP
LOSS.HLP	MON.HLP	MONO.HLP	NASHF.HLP	NASHG.HLP	NASHH.HLP
NEWD.HLP	PLOT.HLP	POS.SET	PRO.HLP	RATE.HLP	RATING.HLP
REP.HLP	REPROD.HLP	RETURN.HLP	SCURVE.HLP	SNYD.HLP	SUPERIM.HLP
SYNTH.HLP	THIES.HLP	UH.HLP	UHISO.HLP	UHT.HLP	UHUNG.HLP
UNIT.HLP	VEL.HLP	WORK.HLP			

UHP2.ZIP contains the following files:

UHCLARKH.DAT	UHCLRKF.DAT	UHCOLUH.DAT	UHCWC.DAT
UHDAILY.DAT	UHDESIGN.DAT	UHDOUBLE.DAT	UHEFF.DAT
UHGAPF.DAT	UHGAUGE.DAT	UHINTNAS.DAT	UHISO.DAT
UHLOSS.DAT	UHNASHF.DAT	UHNASHG.DAT	UHNASHH.DAT
UHNEWD.DAT	UHRATING.DAT	UHREPROD.DAT	UHSCURVE.DAT
UHSNYD.DAT	UHSUPERI.DAT	UHSYNTH.DAT	UHTHIES.DAT
UHUHISO.DAT	UHUNIT.DAT	UHVEL.DAT	CLARKF.OUT
CLARKH.OUT	COLUH.OUT	CWC.OUT	DAILY.OUT
DESIGN.OUT	DOUBLE.OUT	EFF.OUT	GAPF.OUT
GAUGE.OUT	INTNAS.OUT	ISO.OUT	LOSS.OUT
NASHF.OUT	NASHG.OUT	NASHH.OUT	NEWD.OUT
RATING.OUT	REPROD.OUT	SCURVE.OUT	SNYD.OUT
SUPERIM.OUT	SYNTH.OUT	THIES.OUT	UHISO.OUT
UNIT.OUT	VEL.OUT	PPLT1.PLT	PPLT2.PLT

INSTALL.BAT is used for installing tha package on the hard disk while, PKUNZJR.COM is used for unzipping the UHP1.ZIP and UHP2.ZIP files.

1.5 Units

Units used in the programme are matric units and are specified in the help available about the programme and data file. Units used are as follows:

Rainfall	mm or cm
Runoff	m^3/sec (Cumec)
Area	Km^2 or m^2
Volume	mm/unit area

1.6 Limitations

The package provides some information 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 various options are subjected to the assumptions and limitations of the respective techniques on which the programmes are based.

2. THE UNIT HYDROGRAPH PACKAGE

This package gives the details of various options for carrying out unit hydrograph analysis. These options are considered to be in six main categories dealing with:

(i) Processing and analysis of rainfall data,
(ii) Rating curve analysis and computation of discharge,
(iii) Excess rainfall and direct surface runoff computations,
(iv) Unit hydrograph derivation,
(v) Reproduction and estimation of direct surface runoff hydrograph and,
(vi) Design flood estimation.

Under each main categories there are sub categories for different options. These are discussed in details in the following sections.

2.1 Processing and Analysis of Rainfall Data

In this category, there are five options for processing and analysis of rainfall data.

First option is used for filling up the missing record using Normal ratio method. Second option 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 third option. The fourth option calculates the variation of depth with area over the catchment using Isohyet Method. The last option calculates the distribution of daily rainfall at non-recording raingauge stations into hourly rainfall and the computation of average hourly rainfall using Theissen polygon method.

2.2 Rating Curve Analysis and Computation of Discharge

In this category there are three options to carry out the computation of discharge and rating curve analysis.

The first option 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 $Q=a\ (G-e)^h$ can be developed using the least square method in the second option where the provision is made to decide the value of e by trial and error method. This option also computes the discharge corresponding to the observed discharge supplied by the user for developing the rating curve. The last option computes the values of discharge corresponding to the various stages using the stage-discharge relationship developed in the above given form.

2.3 Excess Rainfall and Direct Surface Runoff Computation

There are two-options in this category which deal with the computation of excess rainfall and direct surface runoff.

The first option permits the user to deduct base flow (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 option separates the base flow from the discharge hydrograph using straight line base flow 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 another programme using the uniform loss rate procedure which provides an estimate for the excess rainfall hyetograph.

2.4 Unit Hydrograph Derivation

In this category there are five different options for unit hydrograph computations.

The first option is used to derive the unit hydrograph for gauged catchments using different methodologies.

The second option is used to derive the unit hydrograph parameters for ungauged catchments using Snyder and CWC approaches.

The third option computes the S-curve hydrograph from the unit hydrograph of a specified duration.

The last two options are used for changing the duration of Unit hydrograph using superimposition and S-curve methods respectively.

2.4.1 Unit Hydrograph Derivation for Gauged Catchments

In this sub-category there are nine different options for unit hydrograph derivation.

The first two options are used to derive the unit hydrograph from single-period, individual and isolated storms. The only difference is that the first option 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 first option using Simpson's rule. The runoff volume in depth unit thus obtained is used for further computations.

The runoff volume (in depth unit) and direct surface runoff hydrograph ordinates are input to the second option for the derivation of unit hydrograph.

Third to ninth options are used for the derivation of unit hydrograph using Collin's, Nash Model and Clark Model Approaches.

2.4.2 Unit hydrograph Derivation for Ungauged Catchments

In this sub-category there are two different options for unit hydrograph derivation.

The first option derives unit hydrograph for a catchment using Snyder's approach while second option is used to derive the unit hydrograph for ungauged catchments using the regional unit hydrograph relationships developed by CWC for the respective regions.

2.5 Reproduction and Estimation of Direct Surface Runoff

There are two options in this category. These options deal with the reproduction of observed direct surface runoff and estimation of direct surface runoff using unit hydrograph technique.

The first option computes the direct surface runoff hydrograph together with the fitting efficiency and various error functions described further in the User's Manual.

The second option is used for the computation of direct surface runoff hydrograph from unit hydrograph and excess rainfall hyetograph of a composite storm.

2.6 Design Flood Estimation

This option of the package calculates design flood using unit hydrograph approach and methodology as suggested by CWC (1972) using critical sequencing of design rainfall considering single bell.

2.7 Other Features

One of the main feature of the package is availability of online help on any option selected at any stage.

Any particular option selected leads to execution of that option. The option can be executed either by selecting the data file from the list of data files which are displayed on the VDU or can be executed directly. In the later option data and result file's name are to be supplied by the user.

Provision is also made for creating, editing, viewing, deleting, renaming or plotting of a file. For the options where it is appropriate to create a plot file, it has been created bearing the name UH.PLT and is displayed during the execution of the programme. It can be viewed under the plot option of the package.

Option for either color or monochrome monitor selection, depending on the facility available in a computer is also been made. Also provision for naming a working directory is also provided to facilitate smooth working and keeping the result and data files in a seperate directory. All these options along with input file specifications, and techniques used are described in details in the section on software components.

Details of examples, sample input and output files for various options are given in appendices I to VII. List of sample input and output file names are given in appendix VII.

3.0 METHODOLOGY

Before going to discuss about the methodologies used in each option, some of the important terms which have appeared frequently in the package, 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 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 Rainfall Data

3.1.1 Filling up of Missing Data

While retrieving data for climatological purposes or inputting data in real time, one often comes across missing data situations. Data for the period of missing rainfall could be filled using estimation technique. The length of period up to which the data could be filled is dependent on individual judgement. Normal ratio method is one of the available popular techniques for estimation of rainfall for the missing period.

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

$$R_A = \frac{\sum_{i=1}^{N} \frac{NR_A}{NR_i} * R_i}{N} \qquad \ldots.(1)$$

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 Records 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 cumulative fall at one station would bear a fairly constant relationship to the cumulative fall at other nearby gauges. Thus a plot of the accumulated rainfall at one station with the average (or summated) accumulated rainfall 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 occurred 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.

3.1.3 Computation of Areal Average Rainfall

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 formed 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 rainfall amount by its assigned percentage of area and totalling.

The weighted rainfall is given by:

$$\bar{A} = \frac{\sum_{i=1}^{N} A_i W_i}{\sum_{i=1}^{N} W_i} \qquad \ldots. (2)$$

where, $\bar{A}$ is the average catchment precipitation, A_i is the precipitation at i^{th} station and W_i are the respective weights.

If a few observations are missing it is better to estimate the missing data first and then estimate the mean areal rainfall.

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 that rainfall between two stations is presumed to vary linearly and it does not make any allowance for variation due to orography.

3.1.4 Computation of Variation of Depth with Area

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.

The option in the package calculates the variation of depth with area over the catchment using Isohyet method.

3.1.5 Distribution of Daily Rainfall Data into Hourly Rainfall

For hydrological analysis, rainfall data of shorter duration is required. The network 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) rain 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 rain gauge could be considered as representative of which of the non-recording raingauge for the purpose of distributing daily rainfall into hourly rainfall.

The option in the package distributes the daily rainfall at non-recording raingauge stations into hourly rainfall based on the rainfall data of the selected recording stations to be specified by the user and computes the average hourly rainfall using Theissen polygon.

3.2 Rating Curve Analysis and Computation of Discharge

3.2.1 Computation 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.

The option handles 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.

3.2.2 Development of Rating Curve

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

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

where,

Q = Discharge (m^3/s)

G = Gauge height on stage corresponding to Q (m)

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

The best fit values of a and b in the above equation for a given range of stage are obtained by the least square method. Thus by taking logarithms of eq. (3)

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

or

$$Y = \alpha + \beta X \qquad \ldots . (5)$$

where, $Y = \log Q$,

$\beta = b$,

$X = \log (G-e)$ and,

$\alpha = \log a$

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

$$\beta = \frac{N(\sum_{i=1}^{N} X_i Y_i) - (\sum_{i=1}^{N} X_i)(\sum_{i=1}^{N} Y_i)}{N(\sum_{i=1}^{N} X^2_i) - (\sum_{i=1}^{N} X_i)^2} \qquad \ldots . (6)$$

and,

$$\alpha = \frac{\sum_{i=1}^{N} Y_i - \beta(\sum_{i=1}^{N} X_i)}{N} \qquad \ldots . (7)$$

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

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

$$F_1 = \frac{\sum_{i=1}^{N} (Y_i - \hat{Y}_i)^2}{(N - 2)} \qquad \ldots . (9)$$

$$F_1 = \frac{\sum_{i=1}^{N} (Y_i - \bar{Y})^2}{(N - 1)} \qquad \ldots . (10)$$

where, Y_i = ith observed value of Y

$\bar{Y}$ = 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, r, 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 regression equation (Haan, 1977).

The option is used for developing the rating curve 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 (rating curve) for those streams and rivers which exhibit permanent control is expressed as :

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

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.

The option available is able to convert the given gauge values into corresponding discharge values using the stage-discharge relationship of the form given by Eq.(11) as explained above.

3.3 Excess Rainfall and Direct Surface Runoff Computations

3.3.1 Computation of Excess Rainfall from Discharge 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 excess rainfall. This option permits the user to deduct either constant or non-constant 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 Excess Rainfall and Direct Surface Runoff for a Storm Event

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 excess rainfall and the infiltration rate is adjusted such that the volume of excess 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.

The option provided in the package computes the excess rainfall and direct surface runoff for a storm using the above stated procedure.

3.4 Unit Hydrograph Derivation

3.4.1 Unit Hydrograph for Gauged Catchment

3.4.1.1 Conventional Method (With Base Flow Option)

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. This option is used for the derivation of unit hydrograph from the isolated single period 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 excess rain. The ordinates of the direct surface runoff hydrograph are divided by the excess rainfall depth to give the ordinates of the unit hydrograph.

3.4.1.2 Conventional Method (Without Base Flow Option)

In this option the following procedure is 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.

The option is used for the derivation of unit hydrograph from the direct surface runoff hydrograph of a single period storm. Here base flow separation option is not included.

3.4.1.3 Unit Hydrograph Derivation Using Collin's Method

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 excess rainfall block.

(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 second 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.

The option provided in the package calculates the unit hydrograph ordinates using Collin's method.

3.4.1.4 Unit Hydrograph Using Conventional Nash Model

The instantaneous unit hydrograph may 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 to be as inflow to the second reservoir and so on. The mathematical equation developed for the T-hour unit hydrograph is given as:

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

where,

U(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

(a) Unit Hydrograph using Given Parameters of Nash Model

This option derives the unit hydrographs corresponding to the different sets of parameter values supplied by the user interactively.

(b) Unit Hydrograph using Conventional Nash Model (Method of Moments)

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

$$nK = 1\,M'_Y - 1\,M'_X \qquad \ldots.(13)$$

$$n(n+1)\,K^2 + 2nK\,1\,M'_X = 2\,M'_Y - 2\,M'_X \qquad \ldots.(14)$$

where, $1M'_Y$ and $2\,M'_Y$ 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 direct surface runoff hydrograph and the excess rainfall about the origin are computed using the following equations :

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

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

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

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

where,

Y_i = ith ordinate of direct surface runoff hydrograph (DRH) in m^3 /s
N = No. of DRH 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.

The option "*UH using Nash Model (Method of Moments)*" uses the above procedure to estimate the parameters of Nash Model and the unit hydrograph for the desired duration by Conventional Nash Model.

(c) Unit Hydrograph using Conventional Nash Model (Optimisation)

The parameters of Nash Model n & K may also be estimated using the optmisation procedure. In this package an option has been included to estimate the parameters n & K using Marquerdt Algerithm, which is a non-linear optimisation technique, to minimise the objective function F given as:

$$F = \sum_{i=1}^{N} (Y_i - \hat{Y}_i)^2 \qquad \ldots.(19)$$

$$\hat{Y}_i = \sum_{j=1}^{i} X_j \, U_{i-j+1} \qquad \ldots.(20)$$

where,

$\hat{Y}_i$ = ith ordinate of computed direct surface runoff hydrograph in (m^3/S) for an event.

Detailed description about the Marquerdt Algarithm may be found else where.

3.4.1.5 Unit Hydrograph Derivation Using Integer Nash Model

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 use of Pearson table is fully avoided. The unit hydrograph of T-hour duration is derived using the following equations by this method.

$$U(T,t) = \frac{1}{T} [I(n,y) - I(n,y_1)] \qquad \ldots.(21)$$

where,

$$I(n, y) = 1 - e^{-y} \sum_{m=0}^{n-1} \frac{y^m}{m!} \qquad \ldots.(22)$$

$$I(n, y_1) = 1 - e^{-y_1} \sum_{m=0}^{n-1} \frac{y_1^m}{m!} \qquad \ldots.(23)$$

$$y = t/K \qquad \ldots.(24)$$

$$y_1 = (t-T)/K \qquad \ldots.(25)$$

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.

The option in the package computes T-hour unit hydrograph using Integer Nash Model.

3.4.1.6 Unit Hydrograph Derivation Using Clark Model

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.

$$U_i = C\, I_i + (1 - C)\, U_{i-1} \qquad \ldots . (26)$$

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), and

$$C = \frac{\Delta t}{R + 0.5\, \Delta t} \qquad \ldots . (27)$$

where, 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 :

$$UH_i = 0.5\, (U_i + U_{i-1}) \qquad \ldots . (28)$$

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:

$$UH_i = 1/n\, [\, 0.5\, U_{i-n} + U_{i-n+1} + \ldots\ldots + U_{i-1} + 0.5\, U_i\,] \qquad \ldots . (29)$$

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

$$n = D/\, \Delta t \qquad \ldots . (30)$$

(a) Unit Hydrograph using Given Parameters of Clark Model

The option "*UH using Given Parameters of Clark Model*" may provide the unit hydrograph of desired duration corresponding to the parameters supplied by the user interactively.

(b) Unit Hydrograph using Clark Model (Optimisation)

Another option regarding the estimation of Clark Model parameters and corresponding unit hydrograph using optimisation technique is also provided in the package.

In this option Marquerdt Algorithm is used to minimise the sum of the squares of the differences between observed and computed direct surface runoff hydrograph ordinates for an event.

3.4.2 Unit Hydrograph Derivation for Ungauged Catchments

3.4.2.1 Unit Hydrograph Using Snyder's Approach

Snyder's gave some empirical relationships for synthetic UH based on his studies carried out in USA for several catchments in the Appalachian Highlands. Those relationships were originally developed in FPS system.

The relationships in metric unit to be used to derive t_r' - hour unit hydrograph characteristics using this approach are given below :

Time Lag (hrs) or Basin Lag (hrs)

$$t_p = C_t \, (LL_{ca})^{0.30} \qquad \ldots. (31)$$

where,

t_p = Basin Lag (or time lag) in hours
L = Length of main stream in Km.
L_{ca} = distance from outlet to centre of area of catchment along the stream in Km.
C_t = a coefficient varying from 0.3 to 0.6 for different regions

Peak of UH (cumec)

$$Q_p = (\, 2.78 \, C_p \, CA \,)/t_p \qquad \ldots. (32)$$

where,

Q_p = peak of UH in cumec
CA = catchment area in sq Km
C_p = a coefficient varying from 0.31 to 0.93

Unit Hydrograph Duration (hrs)

$$t_r = t_p \,/\, 5.5 \qquad \ldots. (33)$$

where, t_r = unit hydrograph duration

Modified time lag or basin lag (hrs) (t_r')

Basin lag may be modified for the desired duration of UH, t_r' using the relationship:

$$t_p' = t_p + 0.25 \, (t_r' - t_r) \qquad \ldots. (34)$$

Peak of UH for desired duration, t_r'

$$Q_p' = (2.78\ C_p\ CA) / t_p' \quad \ldots. (35)$$

Width of UH in hour at 50% peak discharge (W_{50})

$$W_{50} = a / q^{1.08} \quad \ldots. (36)$$

where, $q = Q_p' / CA$ & a is a coefficient for the region

Width of UH in hour at 75% peak discharge (W_{75})

$$W_{75} = W_{50} / b \quad \ldots. (37)$$

where, b is a coefficient for the region

Base width of UH (t_b)

For large catchments

$$t_b = 3 + 3\ (t_p'/24) \quad \text{(in days)} \quad \ldots. (38)$$

For small catchments

$$t_b = 5\ (t_p' + t_r' / 2) \quad \text{(in hours)} \quad \ldots. (39)$$

The UH peak, basin lag time, W_{50}, W_{75} and t_b are used to define the shape of UH preserving the unit volume equal to one cm.

3.4.2.2 Unit Hydrograph Derivation Using the Regional Relationships Developed by CWC.

CWC derived the regional unit hydrograph relationships for different sub-zones of India relating to the various unit hydrograph parameters with some prominent physiographic characteristics. The general forms of the relationships are as given below:

$$t_p = a_1\ (LL_{ca}/\sqrt{S})^{b_1} \quad \ldots. (40)$$

$$q_p = a_2\ (t_p)^{b_2} \quad \ldots. (41)$$

$$W_{50} = a_3\ (q_p)^{b_3} \quad \ldots. (42)$$

$$W_{75} = a_4\ (q_p)^{b_4} \quad \ldots. (43)$$

$$WR_{50} = a_5\ (q_p)^{b_5} \quad \ldots. (44)$$

$$WR_{75} = a_6\ (q_p)^{b_6} \quad \ldots. (45)$$

$$t_b = a_7\ (t_p)^{b_7} \quad \ldots. (46)$$

where, L & L_{ca} have the same meaning as for the Snyder method;
S is stream slope in metre/kilometre

t_p is time from the centre of unit rainfall duration to the peak of unit hydrograph in hours

q_p is peak discharge of UH in cumec/sq.km.

t_b, W_{50} & W_{75} have the same meaning as given for Snyder's method

WR_{50} is the width of the rising side of UH in hours at ordinate equal to 50% of UH peak, and

WR_{75} is the width of the rising side of UH in hours at ordinate equal to 75% of UH peak.

3.4.3 S-Hydrograph Computation

S-curve is the hydrograph of direct surface runoff that would result from excess rainfall of unit volume occurring 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:

$$Q_{max} = (0.2778\ AV) / T$$

where, A is the catchment area (sq.km)
V is the unit volume (mm), and
T is duration of the unit hydrograph

The option of the package derives S-curve hydrograph using this approach.

3.4.4 Change of Unit Duration of a Unit Hydrograph Using Superimposition Method

The unit hydrograph of desired duration can be obtained using superimposition method, provided the new duration of unit hydrograph is integer multiple of the original duration.

Using this option 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 hour.

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.)

The option given in the package can be used for changing the duration of unit hydrograph using this method.

3.4.5 Change of Unit Duration of a Unit Hydrograph Using S-Curve Method

The unit hydrograph of t_2 duration can be obtained from the unit hydrograph of t_1 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.

The option provided in the package can be used for changing the derivation of unit hydrograph using this approach.

3.5 Reproduction and Estimation of Direct Surface Runoff Hydrograph

3.5.1 Computation of Direct Surface Runoff Hydrograph

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 storm. These must then be superimposed with the correct time lag and added to give the direct surface runoff hydrograph due to composite storm.

The option provided in the package uses the above procedure to compute the direct surface runoff hydrograph from unit hydrograph and composite storm.

3.5.2 Computations of Direct Surface Runoff (DRH) and Error Functions

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

$$\hat{Y}_i = \sum_{i=1}^{m} \sum_{j=1}^{i} UHj * X_{i-j+1} \qquad \ldots. \quad (48)$$

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 derived 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:

$$EF = ((F_0 - F_1) / F_0) * 100 \qquad \ldots.(49)$$

$$F_0 = \sum_{i=1}^{N} (Y_i - \overline{Y})^2 \qquad \ldots.(50)$$

$$F_1 = \sum_{i=1}^{N} (Y_i - \hat{Y}_i)^2 \qquad \ldots.(51)$$

where,

- Y_i = ith value of the observed DRH (m^3/s)
- $\hat{Y}_i$ = ith value of the computed DRH (m^3/S)
- N = No. of DRH ordinates
- $\overline{Y}$ = Mean of the N values of observed DRH (m^3/s)
- EF = Fitting efficiency in percentage
- F_0 = Sum of the squares of the differences between observed DRH and mean DRH values
- F_1 = Sum of the squares of the differences between observed and computed DRH ordinates

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

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

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

(v) Percentage absolute error in peak : It is the ratio of the absolute difference in observed and computed DRH 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.

In the package provision is made to compute the direct surface runoff, fitting efficiency and various error functions described above, under this option.

3.6 Design Flood Estimation

Various design parameters are required to be specified for the estimation of design flood using unit hydrograph approach. These include design storm, design unit hydrograph, design loss and design base flow. For the derivation of design storm, the probable maximum precipitation (PMP) or Standard Project Storm (SPS) or rainfall for a specific frequency depending upon the type of project, may be estimated following the guidelines given by India Meteorological Department (IMD). Alternatively, these extreme rainfall values (PMP, SPS, etc.) for project catchments may be obtained from IMD also. The total depth of extreme rainfall may be distributed in time in order to get the cumulative rainfall at each of the increments of time used in computing the design flood hydrograph. For such a temporal distribution, the distribution coefficients may be obtained based on the rainfall records of severe storms at self recording raingauge stations located in the project catchment (or the region). IMD also provides the temporal distribution coefficients along with the extreme rainfall values (PMP, SPS, etc.) for the study area. Other design parameters such as design unit hydrograph, design loss and design base flow etc. may be decided as per the guidelines given by Central Water Commission (1972) in its manual on: '*Design Flood Estimation*'. However, the following steps are involved in the derivation of design storm sequence from the cumulative values of the extreme rainfall (PMP, SPS, etc.), distributed at different increments of time:

(i) Compute the incremental rainfall values subtracting the two consecutive values of the cumulative rainfall.

(ii) Align the incremental rainfall values, obtained from the previous step, matching the ordinates of design unit hydrograph so that the position of the maximum rainfall depth increment is matched with the maximum unit hydrograph ordinate, the position of second largest rainfall depth increment is matched with the second largest unit hydrograph ordinate and so on.

(iii) Reverse the sequence of the rainfall increments, obtained from step (ii), in order to get the design sequence of the rainfall increments. Such a sequence is also known as design storm.

Now the design initial loss and design loss rate may be used to compute the effective rainfall increments from the design storm sequence. For this the initial losses must be subtracted first from the design rainfall increments and thereafter a uniform design loss rate may be applied. The design effective rainfall increments, thus obtained, may be convoluted with the design unit hydrograph to estimate the design direct surface runoff hydrograph using linearity principle of unit hydrograph. Finally, the design base flow values may be added to each ordinate of the design direct surface runoff hydrograph for computing the design flood hydrograph.

SECTION 4 PACKAGE COMPONENTS

4.0 INTRODUCTION

The use and details about the various options used in the package are described here under in order of their appearance in the package. Data file selection / modification / creation option being common to all the options is discussed at the end of all options.

4.1 Processing and Analysis of Rainfall Data

In this category, there are five options for processing and analysis of rainfall data.

First option is used for filling up the missing record using Normal ratio method.

Second option 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 third option.

The fourth option calculates the variation of depth with area over the catchment using Isohyet Method.

The last option calculates the distribution of daily rainfall at non-recording raingauge stations into hourly rainfall and the computation of average hourly rainfall using Theissen polygon method.

For all the options examples, sample input and output files are given in Appendix-I.

4.1.1 Estimation of Missing Data

This option is used for estimating the missing station rainfall data using normal ratio method.

The input variables which are required to be supplied in free format through a file are described below:

REC. NO.	INPUT LISTS	DESCRIPTION
1	NEV	No. of events
2	NS	No. of raingauge stations
3	NRAIN	No. of rainfall values
4	((RN(J,K),K=1,NRAIN), J=1,NS)	Two dimensional array containing the normal rainfall values at each raingauge stations

Note:- Repeat record no. 2 to 5 for each event

The output shall be the rainfall of the different raingauge stations including the estimated rainfall corresponding to the missing station rainfall data, which has to be supplied as -1 in the input file by the user.

4.1.2 Checking the Consistency of a Record Using Double Mass Curve Technique

This option is used for checking the consistency of the records of a raingauge station.

The input data file contains the following input variables in the free format.

REC No.	INPUT LISTS	REMARK
1.	NS, N, NT	NS = No. of raingauge stations N = No. of observations at each station NT = Station no. at which consistency check of the record is required
2.	((R(J,I),I=1,N), J=1,NS)	Two dimensional array containing the observed rainfall values at different stations

The output obtained from this option include the cumulative rainfall at the selected rain gauge station and average of cumulative rainfall at other raingauge stations excluding the one selected for consistency check. The consistency of the rainfall records for the selected station may be checked by plotting these at linear scale over VDU.

4.1.3 Computation of Areal Average Rainfall

This option is used for computing the areal average rainfall for a storm event in the catchment using Theissen polygon method.

The values of the following input variables are required to be supplied in free format through a data file.

REC. NO.	INPUT LISTS	DESCRIPTION
1	NST	No. of raingauge stations
2	NRN	Maximum no. of rainfall values at any raingauge station
3	(WT(I),I=1,NST)	Vector containing the Thiessen weights for each raingauge stations
4	((RAIN(I,J),J=1,NST), I=1,NRN)	Two dimensional array containing the rainfall values at each raingauge stations for different time intervals

The main output of this option shall be the average rainfall values at any given time interval.

4.1.4 Computation of Variation of Depth with Area

This option computes the variation of depth with area over the catchment using Iso -hyetal method.

The values of the following input variables is required to be supplied in free format through a file:

REC. NO.	INPUT LISTS	DESCRIPTION
1	N	No. of Isohyetal areas.
2	(HISO(I),I=1,N)	Vector containing the rainfall values associated with each Isohyets.
3	(AEN(I),I=1,N)	Vector containing the cumulative area enclosed between the two Isohyets.
4	R	Vector containing the average rainfall between the two consecutive isohyets except the first one to be supplied by the user based on the observations at rainfall stations of the neighbouring basin.

The main output file shall consists the following:

(i) The rainfall values associated with each isohyets.
(ii) The cumulative area enclosed between two consecutive isohyets.
(iii) The average rainfall between the two consecutive isohyets except the first one supplied by the user based on the

observations at rain gauge stations of the neighbouring basin.

(iv) Net area enclosed between the two consecutive isohyets.

(v) Rainfall volume between the two consecutive isohyets.

(vi) The cumulative values of the rainfall volumes.

(vii) The total areal average rainfall over the area enclosed by consecutive isohyets.

4.1.5 Distribution of Daily to Hourly Rainfall

This option may be used to convert 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 input file shall contain the values of the following input variables in free format:

REC. NO.	INPUT LISTS	DESCRIPTION
1	NDAY	No. of days
2	NSRRG	No. of operational SRRG
3	NORG	No. of operational ORG
4	(WTONS(J),J=1,NTONS)	Vector containing the Theissen Weights for all the operational raingauge stations (NORG + NSRRG)
5	(CHO(J),J=1,NROG)	Vector containing the SRRG No. chosen for different ORG station for the distribution of daily rainfall
6	(RORG(J),J=1,NROG)	Vector containing the ORG stations rainfall for the day
7	((RSRRG(J,K),J=1,24), K=1,NSRRG)	Two dimensional array containing values of hourly rainfall at each SRRG stations for the day.

Note - (i) Repeat record no. 2 to 7 for NDAY.
(ii) NTONS = NORG + NSRRG

The main output of this option shall be hourly areal rainfall over the catchment for the event.

4.2 Rating Curve Analysis and Computation of Discharge

In this category there are three options to carry out the computation of discharge and rating curve analysis.

The first option calculates the discharge from velocity measurement taking number of sections and different number of velocity measurements in each section.

The rating curve (stage-discharge relationship) in the form of Q=a(G-e)**b may be developed using the least square method in the second option where the provision is made to decide the value of e by trial and error method.

The last option computes the values of discharge corresponding to the various stages using the stage-discharge relationship developed in the above given form.

For all the options examples, sample input and output files are given in appendix-II.

4.2.1 Computation of Discharge from Velocity

This option is used for computing the discharge from velocity measurements.

The values of the following input variables are required to be supplied in free format:

REC. NO.	INPUT LISTS	DESCRIPTION
1	N	No. of Sections
2	(AR(I),I=1,N)	Vector containing the area of different sections in Sq.Metre.
3	NV	No. of Velocity measurements at a specific section
4	(VL(I),I=1,NV)	Vector containing the values of velocity measured at that section.

NOTE:- Repeat Rec. no. 3 & 4 for N times.

The main output shall be the total discharge passing through a river cross section.

4.2.2 Development of Rating Curve and Discharge Computation

This option is used for developing the rating curve in the form of Q=a*(G-e)**b.

The value of the following input variables through a file are required in free format for running this option of the package :

REC. NO.	INPUT LISTS	DESCRIPTION
1	N	No. of observations for gauge or discharge (m^3/sec)
2	(GAUGE(I),I=1,N)	Vector containing Gauge Values (metre)
3	(DISCH(I),I=1,N)	Vector containing Discharge values

The values of the above input lists are supplied through a data file. 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 until the value of the zero of the gauge is supplied by the user through terminal.

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

DO YOU WANT TO CHANGE ZERO GAUGE VALUES (Y/N) :

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

The following main output shall be obtained from this option:

(i) Rating curve equation using least square approach corresponding to each zero of the gauge supplied by the user interactively.
(ii) Coefficient of correlation, standard error, T- values etc. for different rating curve equations.
(iii) Observed and computed discharge values.

4.2.3 Discharge from Stages

This option is used for converting the given stage values into corresponding discharge values using a given rating curve in the form : $Q = a^* (G-e)^b$.

The values of the following input variables are required to be specified in free format through a file:

REC. NO.	INPUT LISTS	DESCRIPTION
1	NG	No. of observed gauge values
2	(GAUGE(I),I=1,NG)	Vector containing the stage values relative to the gauge corresponding to zero discharge, i.e. (G-e) values
3	A, B	A = Coefficient 'a' in the rating curve equation B = Coefficient 'b' in the rating curve equation.

The output of this option shall consists the discharge values corresponding to each gauge values.

4.3 Excess Rainfall and Direct Surface Runoff Computations

There are two-options available in the this category which deal with the computation of excess rainfall and direct surface runoff.

The first option 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 excess rainfall.

The second option 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 using the uniform loss rate procedure which provides an estimate for the excess rainfall hyetograph.

For all the options examples, sample input and output files are given in appendix- III.

4.3.1 Baseflow Separation and Computation of ERH Volume

This option computes the effective rainfall from discharge hydrographs after separating the constant or non-constant base flow ordinates supplied by the user as input to the programme.

The input file contains the values of the following input variables in free format:

REC. NO.	INPUT LISTS	DESCRIPTION
1	N	No. of discharge hydrograph ordinates
2	(A1(I),I=0,N)	Vector containing the discharge hydrograph ordinates (m^3/sec)
3	HR	Data interval (hours)
4	AR	Catchment area (sq metres)
5	NOPT	An integer constant for choosing the base flow options: NOPT=1 For constant base flow NOPT=2 For non-constant base flow
6	CB	Constant base flow (m^3/sec)
7	(CBN(I),I=0,N-1)	Vector containing the non-constant baseflow (m^3/sec)

Note :-

(i) If NOPT=1, the input list/lists at rec. No. 7 will be shipped from input file.
(ii) If NOPT=2, the input list/lists at rec. No. 6 will be skipped from input file.

The main output of this option is the volume of direct surface runoff hydrograph in depth which is same as the effective rainfall.

4.3.2 Separation of Baseflow using Straight line Technique

This option may be used to separate the base flow from discharge hydrograph using straight line technique in order to get direct surface runoff hydrograph and also to compute the excess rainfall hyetograph after accounting for the hydrologic abstractions using ϕ(phi) -index method.

The following input variables are required to be supplied in free format through a file for running this option :

REC. NO.	INPUT LISTS	DESCRIPTION
1	CA	Catchment area (Sq Km)
2	DLT	Computational interval (hours)
3	NST	No. of storms to be analysed in single run
4	NSTAT	No. of raingauge stations
5	(WT(I),I=1,NSTAT)	Vector containing the values of Thiessen weights for each station
6	NRAIN	No. of rainfall blocks (maximum from all the stations)
7	((RAIN(I,J),I=1,NRAIN), J=1,NSTAT)	Two dimensional array containing the values of rainfall for different raingauge stations at different computational intervals (mm).
8	NRUN	No. of discharge hydrograph ordinates
9	(OBD(I),I=1,NRUN)	Vector containing the discharge hydrograph ordinates (m^3/sec)
10	CB	Discharge at Recession point on the recession limb of the discharge hydrograph (m^3/sec).

The main output shall consists of the following :

(i) Weighted rainfall values (mm).
(ii) Uniform loss rate (mm/hr) and total rainfall excess (mm).
(iii) Excess (or separated) rainfall values (mm).
(iv) Base flow (cumec).
(v) Direct surface runoff hydrograph (cumec).

4.4 Unit Hydrograph Derivation

In this category there are five different options for unit hydrograph computations.

The first option is used to derive the unit hydrograph for gauged catchments only using different methodologies.

The second option is used to derive the unit hydrograph parameters for ungauged catchments using Snyder and CWC approaches.

The third option computes the S-curve hydrograph from the unit hydrograph of a specified duration.

The last two options are used for changing the duration of Unit hydrograph using superimposition and S-curve methods respectively.

For all the options examples, sample input and output files are given in appendix- IV.

4.4.1 Unit Hydrograph for Gauged Catchments

In this sub-category there are six different options for unit hydrograph derivation.

The first two options are used to derive the unit hydrograph from single-period, individual and isolated storms. The only difference is that the first option 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 first option using Simpson's rule. 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 second option.

Third to sixth options are used for the derivation of unit hydrograph using Collin's method, Conventional Nash Model, Integer Nash Model and Clark Model respectively.

4.4.1.1 Conventional Method (With Base Flow Option)

This option computes the unit hydrograph of a specified duration from the direct surface runoff hydrograph obtained by separating the base flow (constant or non constant), supplied by the user, from the discharge hydrograph of an isolated event.

The values of the following input variables are required to be supplied in free format through a data file:

REC. NO.	INPUT LISTS	DESCRIPTION
1	N	No. of observations
2	(A1(I),I=0,N-1)	Vector containing the values of the discharge hydrograph ordinates (m^3/sec)
3	HR	Data interval in hours
4	AR	Catchment area (sq. mtrs.)
5	NOPT	An integer constant which provides options for baseflow, constant or non constant base flow, to the user. NOPT=1 for constant baseflow NOPT=2 for non-constant baseflow.
6	CB	Constant baseflow (m^3/sec)
7	(CBN(I),I=0,N-1)	Vector containing non-constant base flow values (m^3/sec)

The main output of this option shall include :

(i) Volume of excess rainfall from hydrograph separating the constant base flow or non-constant base flow.

(ii) Unit hydrograph ordinates.

4.4.1.2 Conventional Method (Without Base Flow Option)

This option provides an estimate for the unit hydrograph from the direct surface runoff of an isolated single period storm event.

The values of the following input variables are required to be supplied in free format through a data file.

REC. NO.	INPUT LISTS	DESCRIPTION
1	D	Duration of Unit hydrograph (hours)
2	VOL	Unit volume of UH (mm)
3	DLT	Computation interval (hours)
4	EXE	Excess rainfall block (mm)
5	NRUN	No. of Direct surface runoff ordinates
6	(DSRO(I),I=1,NRUN)	Vector of direct surface runoff hydrograph ordinates (m^3/sec)

The main output from this option shall be D-hour unit hydrograph derived from an isolated single period storm event of D-hour duration.

4.4.1.3 Unit Hydrograph Using Collin's Method

This option may be used to derive the unit hydrograph of desired duration and unit volume from multi-period storm using Collin's Method. The duration of unit hydrograph (in hours) must be same as the computational interval (in hours).

The values of the following input variables shall be required in sequence through an input file in free format:

REC NO.	INPUT LISTS	DESCRIPTION
1	CA	Catchment area (sq.km)
2	DLT	Computation interval (hours)
3	D	Duration of unit hydrograph (hours)
4	VOL	Unit volume (mm)
5	NRUN	No. of DRH ordinates
6	(DSRO(I),I=1,NRAIN)	Vector of DRH ordinates (m^3/sec)
7	NRAIN	No. of Excess rainfall blocks

The main output file of this option shall be D hour unit hydrograph of VOL unit volume at DLT hour computational interval.

The duration of unit hydrograph shall be same as the computational interval.

4.4.1.4 Unit Hydrograph Using Conventional Nash Model (Method of Moments)

This option 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 using the method of moments.

The values of the following input variables are required to be supplied in free format through a file:

REC. NO	INPUT LISTS	DESCRIPTION
1	CA	Catchment area (sq.km)
2	DLT	Computational interval (hours)
3	D	Duration of unit hydrograph (hours)
4	VOL	Unit Volume of UH (mm)
5	NRUN	No. of DRH ordinates
6	(DSRO(I),I=1,NRUN)	Vector of direct surface runoff ordinates (m^3/sec)
7	NRAIN	No. of excess rainfall blocks
8	(EXE(I),I=1,NRAIN)	Vector of excess rainfall hyetograph ordinates (mm)

The main output from this option shall be :

(i) First and second moment of excess rainfall hyetograph about the origin.
(ii) First and second moments of direct surface runoff hydrograph about the origin.
(iii) Estimated parameter values, n and K.
(iv) First moment of IUH about the origin (nK) and second moment of IUH about the centroid (nK^2).
(v) Instantaneous unit hydrograph (IUH).
(vi) D- hour and VOL mm unit hydrograph (cumec).

4.4.1.5 Unit Hydrograph Using Conventional Nash Model (Optimisation)

In this option Marquardt Algorithm of non-linear optimisation is used to derive the parameters of conventional Nash Model and corresponding unit hydrograph from the direct surface runoff hydrograph and excess rainfall hyetograph of an event.

The values of the following input variables are required to be supplied in free format through a file:

REC. NO	INPUT LISTS	DESCRIPTION
1	CA	Catchment area (sq.km)
2	DLT	Computational interval (hours)
3	D	Duration of unit hydrograph (hours)
4	NRAIN	No. of excess rainfall blocks
5	(EXE(I),I=1,NRAIN)	Vector of excess rainfall hyetograph ordinates (mm)
6	NRUN	No. of DRH ordinates
7	(Y(I),I=1,NRUN)	Vector of direct surface runoff ordinates (m^3/sec)
8	KK	No. of parameters to be optimised
9	(B(J),J=1,KK)	Initial values of the parameters
10	(BMIN(J),J=1,KK)	Minimum values which the parameters may take during optimisation
11	(BMAX(J),J=1,KK)	Maximum values which the parameters may take during optimisation

The main output from this option shall be the optimum values of Nash Model parameters and D-hour 1 mm volume unit hydrograph. In addition to these, the computed direct surface runoff hydrograph ordinates and model efficiency are also obtained as output of this option.

4.4.1.6 Unit Hydrograph Using Given parameters of Conventional Nash Model

This option is used to derive the unit hydrograph from the direct surface runoff hydrograph and excess rainfall hyetograph of an event using the parameters of Nash model supplied by the user interactively.

The values of the following input variables are required to be supplied in free format through a file:

REC. NO	INPUT LISTS	DESCRIPTION
1	CA	Catchment area (sq.km)
2	DLT	Computational interval (hours)
3	D	Duration of unit hydrograph (hours)
4	VOL	Unit volume of UH (mm)
5	NUH	No. of unit hydrograph ordinates

The values of the parameters n & K are required to be supplied by the user during the execution of this option in response of the following :

Please supply the value of N :
Please supply the value of K :

There is a provision in this option to supply different sets of parameter values and to derive unit hydrograph corresponding to each set of parameter values. In this regard the user has to supply either 'Y' or 'y' in response to the following :

Do you want to supply other set of parameter values :

The main output from this option shall be the D-hour 1 mm volume unit hydrograph corresponding to each set of parameter values.

4.4.1.7 Unit Hydrograph Using Integer Nash Model

This option is used for the derivation of unit hydrograph using Integer Nash Model.

The values of the same input variables as described for conventional Nash model are required to be supplied in free format through a file. 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 VDU 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 CENTROID (HRS^2)=B
SUPPLY INTEGER VALUE OF N :

(ii) The cursor will wait for an input as an integer value of N to be supplied by the user 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 VDU 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 'Y' or 'N' depending upon his requirement. If the response is 'Y' 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.

The main output shall consists of D hour and VOL mm unit hydrograph for different trial values of n as integer.

4.4.1.8 Unit Hydrograph using Clark Model (Optimisation)

This option of the package may be used to derive the optimum parameters of Clark model from the direct surface runoff hydrograph and the excess rainfall hyetograph of an event using Marquardt Algorithm.

The values of different variables required to be supplied in free format through a file as described below:

REC NO.	INPUT LISTS	DESCRIPTION
1	nt,dlt,tcfic,duh	nt - No of ordinates of time area diagram at dlt hour interval dlt - Computational interval (hrs) tcfic - Any fictitious value of T_c duh - Duration of unit hydrograph (hrs)
2	(cumfica(i),i=1,nt)	A vector containing ordinates of time area diagram (Sq Km)
3	NRAIN	No. of excess rainfall blocks
4	(EXE(I),I=1,NRAIN)	Vector of excess rainfall hyetograph ordinates (mm).
5	NRUN	No. of DRH ordinates

6	(ODSRO(I),I=1,NRUN)	Vector of direct surface runoff hydrograph ordinates (m^3/sec)
7	KK	No. of parameters to be optimised
8	(B(J),J=1,KK)	Initial values of the parameters
9	(BMIN(J),J=1,KK)	Minimum values which the parameters may take during optimisation
10	(BMAX(J),J=1,KK)	Maximum values which the parameters may take during optimisation

The main output from this option shall be the optimum values of Clark Model parameters and DUH-hour 1 mm volume unit hydrograph.

4.4.1.9 Unit Hydrograph Using Given Parameters of Clark Model

This option may be used to derive unit hydrograph of desired duration and unit volume using Clark model. The input file shall consist of the values of the following input variables in free format:

REC NO.	INPUT LISTS	DESCRIPTION
1	CA	Catchment area (Sq Km)
2	DLT	Computational interval (hours)
3	D	Duration of unit hydrograph (hours)
4	NDUH	No. of unit hydrograph ordinates
5	VOL	Unit Volume of UH (mm)
6	NT	No. of ordinates of time area diagram
7	(TAREA(I),I=1,NT)	Vector of time-area diagram ordinates (Km^2)

Clark model parameters T_c and R may be supplied by the user interactively.

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 mode as given below and the unit hydrograph may be derived accordingly for each trial run:

(i) Matter displayed during the execution:

SUPPLY VALUE OF TC :
SUPPLY VALUE OF R :

DO YOU WANT TO REVISE TC FOR TRIAL NO. N1 (Y/N):

Here N1 is an integer constant displayed on the terminal and 'Y' or 'N' has to be supplied by the user through the terminal. If the user response is Y the following information are required to be supplied interactively otherwise the control will be transferred 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 (Y/N) :

Here N2 is an integer constant displayed on the terminal screen in I3 format. Either 'Y' or 'N' is supplied by the user through terminal. If user has supplied 'Y' then the control will be transferred to the write statement which displays the following :

SUPPLY REVISED VALUE OF COMPUT.INTERVAL :

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 'N', 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 (Y/N) :

Here N3 is an integer constant which represents the trial no. and displays on the terminal in I3 format. Either 'Y' OR 'N' 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 'Y' may be supplied in response of the above quarry and the revised value of R may be supplied in response of the quarry made as below:

SUPPLY VALUE OF R : B

Here B is a real constant which represents 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 'Y' in response to any one of the quarries listed above. Moreover, the above quarries will be repeated again for the next trial. If the user response in all the quarries made is 'N' then the control will be transferred to the stop statement and execution will be over.

The main output file shall be D- hour unit hydrograph at DLT hour interval corresponding to TC and R values.

4.4.2 Unit Hydrograph for Ungauged Catchments

In this sub-category there are two different options for unit hydrograph derivation.

The first option derives unit hydrograph for a catchment using Snyder's approach while second option is used to derive the unit hydrograph for ungauged catchments using the regional unit hydrograph relationships developed by CWC for the respective regions.

4.4.2.1 Unit hydrograph Using Snyder's Method

This option of the package may be used to derive unit hydrograph for ungauged catchments using Snyder's approach. Various input variables required to be supplied in free format are described below:

REC. NO.	INPUT LIST	DESCRIPTION
1.	Ca, al, alc, duh	Ca - Catchment area (sq Km) al - Length of main stream (Km) alc - Distance from outlet to centre of area of catchment along the stream (Km) duh-Duration of Unit hydrograph (hrs)
2.	Ct, Cp, a, b	Ct - a coefficient used in the relationship for lag. It normally varies from 0.3 to 0.6 for different regions. Cp - a coefficient used in the relationship of peak. It normally varies from 0.31 to 0.93. a - a coefficient used in the relationship of W_{50}. b - a coefficient used in the relationship of W_{75}.

The main output shall be the important characteristics of DUH-hr unit hydrograph for ungauged catchment. These include the peak of Uh (cumec), time lag (hrs.), width of unit hydrograph at 50% of UH peak (W_{50}) (hrs.), width of unit hydrograph at 75% of UH peak (W_{75}) (hrs.) and base width of unit hydrograph (hrs.). The user may draw the shape of the unit hydrograph using these characteristics after preserving the unit volume equal to one cm by trial and error.

4.4.2.2 Unit Hydrograph Using CWC Method

This option of the package may be used to derive the unit hydrograph with unit volume 1cm for an ungauged catchment using the regional unit hydrograph relationships developed by CWC for the respective region. The following input variables are required to be supplied in free format :

REC. NO.	INPUT LISTS	DESCRIPTION
1.	Ca, al, alc, s, duh	Ca - Catchment area(sq Km) al - length of main stream (Km) alc - distance from outlet to centre of area of catchment along the main stream (Km). S - Slope of main stream (m/Km) duh - duration of unit hydrograph for which regional UH relationships are developed.
2.	a_1 , b_1	Regional coefficients in the relationship: $t_p = a_1$ (al*alc/$\sqrt{}$S)**b_1
3.	a_2 , b_2	regional coefficients in the relationship : q_p= $a_2(t_p)$**b_2 where, q_p (cumec/sq Km) =QP/Ca
4.	a_3 , b_3	regional coefficients in the relationship W_{50} = $a_3(q_p)$**b_3
5.	a_4 , b_4	regional coefficients in the relationship W_{75} = $a_4(q_p)$**b_4
6.	a_5 , b_5	regional coefficients in the relationship WR_{50} = $a_5(q_p)$**b_5
7.	a_6 , b_6	regional coefficients in the relationship WR_{75} = $a_6(q_p)$**b_6
8.	a_7 , b_7	regional coefficients in the relationship t_b= $a_7(t_p)$**b_7

The main output of this option shall be the important characteristics of UH such as peak (m^3 /s), time to peak (hrs), width of UH at 50% of UH peak (W_{50}) (hrs), width of UH at 75% of UH peak (W_{75}) (hrs), width of rising side of UH at 50% of UH peak (WR_{50}) (hrs), width of rising side of UH at 75% of UH peak (WR_{75}) (hrs) and base width of unit hydrograph (hrs) for an ungauged catchment of the region. User may develop duh-hour unit hydrograph with the help of these characteristics preserving the shape of UH for 1cm unit volume.

4.4.3 S Hydrograph Computation

This option is used for the development of S-curve hydrograph from T-hour unit hydrograph.

The input variables whose values are required to be supplied in free format in a data file are described below :

REC. NO.	INPUT LISTS	DESCRIPTION
1	N	No. of unit hydrograph ordinates
2	(UH(I),I=1,N)	A vector of unit hydrograph ordinates (m^3/sec)
3	HR, DO	HR = Data interval (hrs) DO = Unit hydrograph duration (hrs)

The main output shall be S-curve hydrograph.

4.4.4 Unit Hydrograph of Changed Duration Using Superimposition Method

This option is used for changing the duration of unit hydrograph by superimposition method. The new duration of UH should be the integer multiple of the old duration.

The value of the following input variables are required to be supplied in free format in a data file.

REC. NO.	INPUT LISTS	DESCRIPTION
1	DO	Original duration of unit hydrograph (hour)
2	DN	New duration of unit hydrograph (hour)
3	DLT	Computational interval (hours)
4	NDUH	No. of ordinates of DO-duration unit hydrograph
5	(UOLD(I),I=1,NDUH)	Vector of DO-hour unit hydrograph (m^3/sec)

The main output of this option shall be DN-hour unit hydrograph.

4.4.5 Unit Hydrograph of Changed Duration Using S-Curve Method

This option computes the unit hydrograph ordinate of new duration using S-curve technique.

The values of the following input variables are required to be supplied in free format through a file:

REC. NO	INPUT LISTS	DESCRIPTION
1	N	No. of unit hydrograph ordinate of original duration
2	(UH(I),I=1,N)	Vector of unit hydrograph ordinates of original duration (m^3/sec)
3	HR, DO, DN	HR = Data interval (hour) DO = Original duration of UH (hour) DN = New duration of UH (hour)

The main output obtained from running this option of the package include:

(i) Original duration UH and S-curve.
(ii) UH for new duration (or desired duration).

4.5 Reproduction and Estimation of Direct Surface Runoff

There are two options available in this category. These options deal with the reproduction of observed direct surface runoff and estimation of direct surface runoff.

The first option is used for the computation of direct surface runoff hydrograph from unit hydrograph and composite storm.

The second option computes the direct surface runoff hydrograph using unit hydrograph and also computes the fitting efficiency and various error functions described further in the User's Manual.

For all the options examples, sample input and output files are given in appendix- V.

4.5.1 Computation of Direct Surface Runoff Hydrograph

This option is used for computing the direct surface runoff hydrograph from the excess rainfall of the multi-period storm and unit hydrograph.

The values of the following input variables are required to be supplied in free format in a file:

REC. NO.	INPUT LISTS	DESCRIPTION
1	N	No. of unit hydrograph ordinates
2	(UH(I),I=1,N)	Vector of UH ordinates (m^3/s)
3	DT, D	DT = Data interval (hours) D = Duration of unit hydrograph (hour) with one cm unit volume
4	NR	No. of excess rainfall blocks
5	(R(I),I=1,NR)	Vector of excess rainfall blocks (cm). Each block of excess rainfall is of D-hour duration

The main output of the programme shall be the direct surface runoff hydrograph.

4.5.2 Computation of Direct Surface Runoff and Error Functions

This option 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 values of the following input variables are to be supplied in the free format through a file :

REC. NO.	INPUT LISTS	DESCRIPTION
1	CA	Catchment area (sq.km)
2	DLT	Computational interval (hours)
3	NRUN	No. of DRH ordinates
4	(DSRO(I),I=1,NRUN)	Vector of observed DRH ordinates (m^3/s)
5	NRAIN	No. of excess rainfall blocks
6	(EXE(I),I=1,NRAIN)	Vector of the excess rainfall values (mm)
7	D	Duration of unit hydrograph (hour)
8	VOL	Unit Volume of UH (mm)
9	NDUH	No. of UH ordinates
10	(UH(I),I=1,NDUH)	Vector of UH ordinates (m^3/s)

The main output shall be :

(i) Observed and computed direct surface runoff hydrograph (cumec).
(ii) Observed and computed peak of direct surface runoff hydrograph (cumec).
(iii) Observed and computed time to peak of direct surface runoff hydrograph (hrs).
(iv) Efficiency of the method used for unit hydrograph derivation (%).
(v) Average absolute error and average percentage absolute error.
(vi) Percentage absolute error in peak and time to peak.

4.6 Design Flood Estimation

This option of the package may be used to estimate the design flood using unit hydrograph approach. Critical sequencing for the design excess rainfall is performed using the procedure given by CWC (1972).

For all the options examples, sample input and output files are given in appendix- VI.

The values of the following input variables are required to be supplied in the free format through a data file:

REC. NO.	INPUT LISTS	DESCRIPTION
1	DLT	Computational interval (Hrs)
2	NRAIN	No. of rainfall values
3	(CUMR(I),I=1,NRAIN)	Vector containing the cumulative rainfall values (c.m.)
4	NDUH	No. of unit hydrograph ordinates
5	(UH(I),I=1,NDUH)	Vector containing the ordinates of design unit hydrograph (Cumec)
6	TWLOSS , ULOSS	TWLOSS - Initial loss (c.m.) ULOSS - Uniform loss rate (c.m./hr)
7	BFLOW	Design base flow (Cumec)

The main output of this option shall be the design flood hydrograph.

4.7 Plotting/Editing/Viewing of Files

This option helps in plotting, viewing, editing of the files.

1. Plotting of a file

Computer will ask for the name of the plot file to be plotted. It may be noted here that for some of the options plot file UH.PLT is automatically created which can be viewed here. If TAB kay is pressed here than computer will ask for the file extension so that files with that extension only can be displayed. Here default extension is PLT. After it all the files available in the current directory with a particular extension will be displayed on the terminal by moving the arrow keys any file can be selected and enter key can be pressed to view or to plot that file.

For this option sample input file is given in Appendix-VII.

A plot file can also be created as follows:

First line contains no of variables on Y axis and no of observation points (N) to be plotted. Second line contains the main heading of the graph. Third line contains legend for first variable and if there is second variable also then fourth line will contain legend for that variable. Next two lines contain headings for X axis and Y axis. Thus it can plot only two variables at a time.

Next N lines will have two or three values in each line in free format of x and y1 variables of there is only one variable for Y axis and x, y1 and y2 if there are two variables for Y axis.

Two sample plot files are reproduced below here one with one Y axis variable and other with two Y axis variables.

For one variable (pplt1.plt)

```
1       9
Collin's UH
```

UH
Ord m**3/sec
Time in hrs

0.	.000
6.	7.162
12.	7.205
18.	27.048
24.	22.075
30.	9.046
36.	3.632
42.	2.535
48.	.000

For two variables (pplt2.plt)

2 10
Superimposition method
Old UH
new UH
Ord m**3/sec
Time in hrs

0.00	0.00	0.00
4.00	20.00	6.67
8.00	50.00	23.33
12.00	70.00	46.67
16.00	65.00	61.66
20.00	60.00	65.00
24.00	40.00	55.00
28.00	0.00	33.33
32.00	0.00	13.33
36.00	0.00	0.00

2. Editing/Creation of a File

If desired a file can be edited or created here using the EDIT editor of DOS.

3. Viewing of a File

This option helps in viewing of the contents of a file. Page Up, Page Down and Up and Down arrow keys can be used to see the contents of whole file. ESC key can be used to go back.

4. Delete a File

Option permits deletion of a file if desired. Any file selected will be first checked by the package for its existance in the directory and then package will confirm again before deletion.

5. Rename a File

This option renames a file selected to the new name. First the file will be checked for its existance in the directory. Package will again ask before renaming for confirmation.

4.8 Selection of Monochrome or Color Monitor

This option enables the selection of either monochrome or color monitor. Option selected will be stored in the POS.SET file. Option once selected will continue to be in use until a change is made.

4.9 Assignment of a Working Directory for Result and Data Files

Provision is made in the package for redirecting the output of the package in a working directory so as to avoid unnecessary mixing up of result files with original package files. It also desirable that first a working directory may be created prior to the operation of the apckage and all the data files may be stored in this directory. Working directory first selected will continue to be operation until another directory is specifed through this option.

4.10 Creation/Modification/Selection of a Data File and Execution of a Programme

This option is displayed after selection of a particular option or category is over, prior to its execution for selection of data file/ or naming of data and result files.

Under this category following options are available:

1. List/Selection of a data file(s)

This option helps in selection of a data file for execution of programme. List of data file(s) available (with extension DAT) in the current directory/ sub-directory can also be displayed by pressing the <TAB> key. Programme will ask for extension of files to be displayed. Default extension is DAT which can be changed here. For all the files a * has to be entered. With the help of the arrow keys any file can be highlighted and by pressing enter can be selected. ESC key is used to leave the current menu and go back to previous menu.

Selected file can be viewed / modified in next option.

2. View/Modification in selected file

Selected file can be viewed / modified under this option.

It may be mentioned here that for modification or viewing file MUST be selected first, using the first option. With the help of upward or downward arrow keys or Page Up or Page Down button lines can be viewed and by pressing enter key highlighted line can be entered for modification.

For moving within the line side arrow keys can be used. HOME and END keys can also be used for going to first and last character of the line. TO add character(s) INS key can be used and DEL key is for deleting the character. Enter key creates the new line.

After all the changes are over TAB key may be pressed. Like wise changes in all the lines can be performed.

When changes are over ESC can be pressed. Computer will ask whether changes done are to be saved or not? Any key other than ESC key will enable the changes to be saved. ESC key will leave the changes as such.

On line help for modification in the data file for a particular option is available which can be invoked by pressing the F1 key.

3. Creation of a new file

Here a new file can be created using the arrow and other keys as mentioned in section 2.

Help on the data file to be created for the selected option is available by pressing the F1 key. When all the lines are created and ESC key is pressed user will be asked to supply the data file name in which data will be saved for further use.

4. Execution of a programme

Package permits execution of a programme by either selection of a data file through the package or directly executing the programme. In the first case programme asks for the result file before execution. If programme is executed directly then user has to supply the data and result files name at the time of execution. If result file supplied, already exists in the directory then programme will confirm before going ahead so as to avoid any accediental supplying of name for result file.

If the particualr option selected also creates the plot file, same will be displayed over the terminal that a plot file UH.PLT has been created which can be plotted under the PLOT option of the package.

5. Delete a file

Package permits deletion of a file within the programme if desired. Any file selected will be first checked by the package for its existance in the directory and then package will confirm again before deletion.

REFERENCES

1. NIH (1984-85). *Unit Hydrograph Derivation*. Report No. UM-8, Roorkee

2. NIH (1984-85). *Model parameter Evaluation using catchment characteristics*. Report No. UM-9, Roorkee

3. NIH (1986-87). *Unit Hydrograph Analysis*. Report No. UM-25, Roorkee

4. Sharp, J.J. (1984). *Basic Hydrology*. Butterworth & Co. Ltd.

APPENDICES

Examples of all the options along with sample input and output files

OPTION: Processing and Analysis of Rainfall Data

1. Filling up of Missing Data

(a) Example

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

Gauge	A	B	C	D
Rainfall (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 rainfall data at the respective station (station A).

(b) Input

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

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

(c) Output

A output file GAPF.OUT created by the above input file contains the fillowing:

RAINFALL AT DIFFERENT STATIONS AFTER FILLING THE MISSING RECORDS

```
EVENT NO:-   1
112.087
 98.900
120.500
110.000
```

2. Consistency Check

(a) 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	63.77	61.75	60.57	52.23	54.07

(b) Input

The input data to check the consistency of records at a station using the double mass curve technique are supplied through the input file. For the above example, the input file UHDOUBLE.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
```

(c) Output

A output file DOUBLE.OUT created by the above input file contains the fillowing:

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

3. Computation of Areal Average Rainfall

(a) 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) stn1	stn2	stn3	stn4	stn5
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

(b) Input

To run the programme for the computation of average rainfall using Theissen polygon method the input data have to be supplied through input file. For the above example the structure of the input file UHTHIES.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
```

(c) Output

An output file THIES.OUT created by the above input file contains the following:

AVERAGE RAINFALL (MM)

0.54 1.99 11.34 13.29 4.49 6.43 2.78

4. Computation of Variation of Depth with Area

(a) Example

Following a storm on a particular catchment an iso-hyetal 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	24	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.

(b) Input

For the above example the structure of the input file UHISO.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
```

(c) Output

A output file ISO.OUT created by the above input file contains the fillowing :

ISOHYETAL METHOD

ISOHYET	AREA (SQ KM)	NET AREA (SQ KM)	AVG.PREC. (MM)	PREC. VOL. (CU M)	TOTAL PREC. CU. M	VOL AVG.DEPTH (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

5. Distribution of Daily to Hourly Rainfall

(a) 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 0.5
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.

(b) Input

For the above example the structure of the input file UHDAILY.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
```

(c) Output

A output file DAILY.OUT created by the above input file contains the fillowing :

```
-------------------------------------------------------------------------------
 DAILY TO HOURLY CONVERSION OF RAINFALL & 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  1 S.R.R.G. STATIONS (MM)
     .0000     .0000     .0000     .0000     .0000     .0000
     .0000     .0000     .0000     .0000   25.7000     .0000
     .1000    1.0000    6.0000    1.3000     .0000     .0000
     .3000     .5000     .1000    1.0000   24.4000     .2000

RAINFALL OBSERVED AT  2 S.R.R.G. STATIONS (MM)
     .0000     .0000     .0000     .0000     .0000     .0000
     .0000     .0000     .2000    2.1000     .7000     .3000
     .1000     .1000    4.7000     .0000     .0000     .0000
     .0000     .0000     .0000     .0000    1.7000    9.0000
```

DISTRIBUTED HOURLY RAINFALL AT 1 O.R.G. STATION (MM)

.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	.0000	.0000	27.6932	.0000
.1078	1.0776	6.4653	1.4008	.0000	.0000
.3233	.5388	.1078	1.0776	26.2924	.2155

DISTRIBUTED HOURLY RAINFALL AT 2 O.R.G. STATION (MM)

.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	.2455	2.5778	.8593	.3683
.1228	.1228	5.7693	.0000	.0000	.0000
.0000	.0000	.0000	.0000	2.0868	11.0476

DISTRIBUTED HOURLY RAINFALL AT 3 O.R.G. STATION (MM)

.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	.0000	.0000	72.5198	.0000
.2822	2.8218	16.9307	3.6683	.0000	.0000
.8465	1.4109	.2822	2.8218	68.8515	.5644

DISTRIBUTED HOURLY RAINFALL AT 4 O.R.G. STATION (MM)

.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	.4444	4.6667	1.5556	.6667
.2222	.2222	10.4444	.0000	.0000	.0000
.0000	.0000	.0000	.0000	3.7778	20.0000

DISTRIBUTED HOURLY RAINFALL AT 5 O.R.G. STATION (MM)

.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	.0000	.0000	12.8924	.0000
.0502	.5017	3.0099	.6521	.0000	.0000
.1505	.2508	.0502	.5017	12.2403	.1003

THIESSEN WEIGHTS OF ALL THE STATIONS

.1000	.2000	.1500	.1500	.1000	.1500
.1500					

AVERAGE RAINFALL FOR THE DAY (MM): --- 1

.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	.1458	1.5306	19.3017	.2187
.1460	.8041	7.8127	.9505	.0000	.0000
.2194	.3656	.0731	.7312	19.0800	6.7058

OPTION: Rating Curve Analysis and Computation of Discharge

1. Discharge from Velocity

(a) 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)	3.1	5.1	7.1	9.2	6.6	4.8	2.6
Velocities (m/sec)	0.65	0.70	0.70	0.75	0.65	0.60	0.60
	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		

(b) Input

For the above example the structure of the input file UHVEL.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
```

(c) Output

An output file VEL.OUT created by the above input file contains the fillowing:

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)

2. Development of Rating Curve and Discharge computation

(a) 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 at 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

(b) Input

For the above example the structure of the input file UHRATING.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 (Y/N) :Y

SUPPLY THE ZERO OF THE GAUGE (METRE) : 21.50

DO YOU WANT TO CHANGE ZERO GAUGE VALUE (Y/N) :N

(c) Output

A output file RATING.OUT created by the above input file contains the fillowing :

```
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=      .994
REGR. COEFF.   STAND. ERR.  T-VALUES
   4.703          .058        80.539
   1.735          .052        33.128
STANDARD ERROR OF REGRESSION EQUATION=      .09
*******************************************************
EQUATION OF THE RATING CURVE
***********************************************
 Q=    110.296*(G-  21.00)**      1.735
OBSERVED AND COMPUTED DISCHARGE VALUES
*********************************************************
 NO    OBS. GAUGE  OBS. DISCH  COMP. DISCH
        (CUMEC)     (CUMEC)      (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=      .989
REGR. COEFF.        STAND. ERR.        T-VALUES
   5.467          .052        104.491
   1.287          .053         24.424
STANDARD ERROR OF REGRESSION EQUATION=      .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

3. Discharge from Stages

(a) 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-Ho) (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	22	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

(b) Input

For the above example the structure of the input file UHGAUGE.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
```

(c) Output

A output file GAUGE.OUT created by the above input file contains the fillowing :

```
   DISCHARGE VALUES CORRESPONDING TO EACH GAUGE
 30.27   30.27   30.27   30.27   73.64  134.77  412.22  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
```

OPTION: Excess Rainfall and Direct Surface Runoff Computations

1. Base Flow Separation and Computation of ERH Volume

(a) 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 sq. km. Calculate the depth of excess rainfall assuming the constant base flow equal to 10 m^3 /s.

(b) Input

The structure of the input file UHEFF.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
```

(c) Output

A output file EFF.OUT created by the above input file contains the fillowing :

```
EXCESS RAIN FALL FROM HYDROGRAPH-CONSTANT BASE FLOW
------------------------------------------------------------------------
VOLUME OF RAINFALL(M**3)=   88545600.00
CATCHMENT AREA (M**2)= .13E+10
EXCESS RAINFALL IN CM IS=7.083648
```

2. Separation base flow using straight line technique

(a) 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	10
Average Rainfall (mm)	0.544	1.991	11.34	13.287	4.486	6.428	2.774	0	0	0
Discharge (m^3/s)	55	55	60	65	142	285	355	370	430	440

Time (hrs)	11	12	13	14	15	16	17	18	19	20
Average Rainfall (mm)	0	0	0	0	0	0	0	0	0	0
Discharge (m^3/s)	285	260	210	170	150	132	120	115	105	100

(b) Input

The structure of the input file UHLOSS.DAT for the above example is given below

```
823.62
1
1
1
1
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
```

(c) Output

A output file LOSS.OUT created by the above input file contains the fillowing :

```
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
 .54    1.20   11.34   13.29    4.49    6.43    2.78
NO. OF RUNOFF VALUES=   20
     OBSERVED DISCHARGE HYDROGRAPH
 55.00   55.00   60.00   65.00  142.00  285.00  355.00  370.00
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
 .54    1.20   11.34   13.29    4.49    6.43    2.78
     DIRECT SURFACE RUNOFF (CUMECS)
   .000   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
   .000    .000
     BASE FLOW (CUMECS)
  60.000  62.813  65.625  68.438  71.250  74.063  76.875  79.688
  82.500  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      .000      .000      .000
```

OPTION: Unit Hydrograph Derivation

1. Unit Hydrograph for Gauged Catchments

(i) Conventional Method (With Base Flow Option)

(a) 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 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

(b) Input

The structure of the input file UHUNIT.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
```

(c) Output

A output file UNIT.OUT created by the above input file contains the fillowing :

UNIT HYDROGRAPH

EFFECTIVE RAINFALL FROM HYDROGRAPH-CONSTANT

VOLUME OF RAINFALL (M**3)= 88545600.00
CATCHMENT AREA (M**2)= .13E+10
EFFECTIVE RAINFALL IN CM IS=7.083648

TIME	UNIT HYDROGRAPH ORDINATE
2.	6.634999
4.	17.36393
6.	17.78745
8.	12.98766
10.	9.31723
12.	6.49382
14.	4.37627
16.	2.54106
18.	1.12936
20.	.282340
22.	.000000
24.	.000000

(ii) Conventional Method (Without Base Flow Option)

(a) Example

The ordinates of direct surface 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
DRH (m^3/s)	0	10	500	1600	3500	5200	3100	1500	650	250	0

(b) Input

The structure of the input file UHUHISO.DAT for the above example would be as follows:

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

(c) Output

A output file UHISO.OUT created by the above input file contains the fillowing :

DERIVATION OF UNIT HYDROGRAPH FROM ISOLATED STORM

TIME (HRS.)	6.-HOUR UNIT HYDROGRAPH (M**3/SEC)
.0	324.675
6.0	1038.961
12.0	2272.727
18.0	3376.624
24.0	2012.987
30.0	974.026
36.0	422.078
42.0	162.338
48.0	.000

(iii) Unit Hydrograph Using Collin's Method

(a) 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, comput 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

(b) Input

The structure of the input file UHCOLUH.DAT for the above option would be as follows :

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

(c) Output

A output file COLUH.OUT created by the above input file contains the fillowing :

```
UNIT HYDROGRAPH DERIVATION USING COLLINS METHOD
--------------------------------------------------------------------------------

   DIRECT SURFACE RUNOFF (M**3/SEC)

       .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.
    ------------------------------------------------------------
 11.24339   11.24339   11.24339   11.24339   11.24339   11.24339   11.24339
4.565177E-01       2.000000
    6.-HOUR UNIT HYDROGRAPH OF VOLUME  1.
    ------------------------------------------------------------
  8.21302    9.74936   20.68768   19.73652   10.93831    5.08869    4.29013
1.662235E-01    0.000000E+00
    6.-HOUR UNIT HYDROGRAPH OF VOLUME  1.
    ------------------------------------------------------------
  7.28960    8.37100   24.81202   21.86057    9.85964    3.68682    2.82406
8.267298E-02    0.000000E+00
   AREA OF UH=     1.00000
                 UNIT HYDROGRAPH ORDINATES (M**3/SEC)
```

0.	.000
6.	7.162
12.	7.205
18.	27.048
24.	22.075
30.	9.046
36.	3.632
42.	2.535
48.	.000

(iv) Unit Hydrograph Using Conventional Nash Model (Method of Moments)

(a) 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 1 mm using conventional Nash Model procedure based on method of moments:

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

(b) Input

The structure of the input file UHNASHF.DAT for the above example would be as follows:

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

(c) Output

A output file NASHF.OUT created by the above input file contains the fillowing :

```
UNIT HYDROGRAPH DERIVATION USING CONVENTIONALNASH MODEL
-----------------------------------------------------------------------

    DIRECT SURFACE RUNOFF (M**3/SEC)
     .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
SECOND 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
  .020   .050   .046   .028   .014   .006   .002   .001
  .000   .000
SUM OF IUH=     .16711
    AREA OF UH=     .99951
          UNIT HYDROGRAPH ORDINATES (M**3/SEC)
```

TIME (HRS)	6.-HOUR U.H. ORDINATES (CUMEC)
0.	.000
6.	2.939
12.	17.731
18.	23.556
24.	17.414
30.	9.576
36.	4.414
42.	1.809
48.	.682
54.	.241

(v) Unit Hydrograph using Conventional Nash Model (Optimisation)

(a) Example

The direct surface runoff hydrograph and excess rainfall hyetograph ordinates for a typical storm in a catchment of size 824 sq.km. are given below. Find out 1-hour unit hydrograph with volume 1 mm using Conventional Nash Model based on optimisation technique.

Time (hrs)	Excess rainfall hyetograph (mm)	Direct surface runoff hydrograph (m^3/s)
1	4.07	2.06
2	6.02	4.12
3		78.18
4		218.24
5		285.29
6		297.35
7		354.41
8		361.47
9		203.53
10		175.59
11		122.65
12		79.71
13		56.76
14		35.82
15		20.88
16		12.94
17		0.00

Take initial values of the parameters n & K as 4 and 4 hrs. respectively. The lower limits of the parameters n & K are 0.1 and 0.1 hrs. and upper limits are 10 and 10 hrs. respectively.

(b) Input

The structure of the test input file UHNASHH.DAT for the above example would be as follows:

```
824
1
1
2
4.07    6.02
17
   2.06    4.12   78.18  218.24  285.29  297.35  354.41  361.47  203.53  175.59
 122.65   79.71   56.76   35.82   20.88   12.94     .00
2
4.0 4.0
0.1 0.1
10 10
```

(c) Output

A output file NASHH.OUT created by the above input file contains the fillowing :

CATCHMENT AREA(SQ.KM)- 824.000

Value of N= 5.32
Value of K= 1.22

UNIT HYDROGRAPH ORDINATES

Time (hrs)	UH Ordinates (Cumec)
.00	.00
1.00	.52
2.00	3.44
3.00	13.81
4.00	25.65
5.00	33.39
6.00	35.02
7.00	31.79
8.00	26.01
9.00	19.70
10.00	14.04
11.00	9.53
12.00	6.22
13.00	3.93
14.00	2.41
15.00	1.45
16.00	.85
17.00	.49

Observed and Computed Direct Surface Runoff Values

Time (hrs)	Obs. DRH (Cumec)	Comp. DRH (Cumec)
0.	.00	.00
1.	2.06	2.11
2.	4.12	17.13
3.	78.18	76.96
4.	218.24	187.56
5.	285.29	290.32
6.	297.35	343.54
7.	354.41	340.19
8.	361.47	297.22
9.	203.53	236.76
10.	175.59	175.71
11.	122.65	123.32
12.	79.71	82.73
13.	56.76	53.47
14.	35.82	33.50
15.	20.88	20.43
16.	12.94	12.18
17.	.00	7.12

SUM OF ERROR SQUARES= 8782.407

EFFICIENCY = 96.686

(vi) Unit Hydrograph using Given Parameters of Conventional Nash Model

(a) Example

Find out thirty ordinates of 6-hour (and 1mm unit volume) unit hydrograph at 6 hr. interval for a catchment of size 1700 sq. km. if (i) n = 5, K = 2.5 hrs., and (ii) n = 6, K = 1.5 hrs.

(b) Input

The structure of the input file UHNASHG.DAT for the above example would be as follows:

```
1700
   6
   6
   1
  30
```

Note: The values of the parameters n & K are supplied at the time of execution of this option in interactive mode.

(c) Output

A output file NASHG.OUT created by the above input file contains the fillowing :

CATCHMENT AREA(SQ.KM) - 824.000

Value of N = 5.32
Value of K = 1.22

UNIT HYDROGRAPH ORDINATES

Time (hrs)	UH Ordinates (Cumec)
.00	.00
1.00	.52
2.00	3.44
3.00	13.81
4.00	25.65
5.00	33.39
6.00	35.02
7.00	31.79

8.00	26.01
9.00	19.70
10.00	14.04
11.00	9.53
12.00	6.22
13.00	3.93
14.00	2.41
15.00	1.45
16.00	.85
17.00	.49

Observed and Computed Direct Surface Runoff Values

Time (hrs)	Obs. DRH (Cumec)	Comp. DRH (Cumec)
0.	.00	.00
1.	2.06	2.11
2.	4.12	17.13
3.	78.18	76.96
4.	218.24	187.56
5.	285.29	290.32
6.	297.35	343.54
7.	354.41	340.19
8.	361.47	297.22
9.	203.53	236.76
10.	175.59	175.71
11.	122.65	123.32
12.	79.71	82.73
13.	56.76	53.47
14.	35.82	33.50
15.	20.88	20.43
16.	12.94	12.18
17.	.00	7.12

SUM OF ERROR SQUARES = 8782.407

EFFICIENCY = 96.686

(vii) Unit Hydrograph Using Integer Nash Model

(a) Example

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

(b) Input

The structure of the input file UHINTNAS.DAT for the above example would be as follows:

```
1700
6
6
1
10
0 250 1050 2050 4350 4150 2300 1070 450 120
3
40.209 100.209 60.209
4
1
5
0
```

(c) Output

A output file INTNAS.OUT created by the above input file contains the fillowing :

```
UNIT HYDROGRAPH DERIVATION USING INTEGER NASH MODEL
-------------------------------------------------------------------------------
DIRECT SURFACE RUNOFF (M**3/SEC)

     .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
SECOND MOMENT OF DSRO (HRS**2)-        852.572
FIRST MOMENT OF ERH        (HRS)-        9.598
SECON.MOMENT OF ERH(HRS**2)-           109.785
```

FIRST MOMENT OF IUH(HRS)=18.00
SECOND MOMENT OF IUH 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 OF IUH ABOUT THE CENTROID(HRS**2) = 80.97
AREA OF UH = .99771

UNIT HYDROGRAPH ORDINATE (M**3/SEC)

TIME (HOURS)	6.-HOUR U.H. ORDINATES (CUMEC)
0.	.000
6.	3.651
12.	18.221
18.	22.603
24.	16.649
30.	9.448
36.	4.589
42.	2.010
48.	.818
54.	.315

VALUE OF N 5.000
VALUE OF K(HRS)- 3.599
FIRST MOMENT OF IUH(HRS)=18.00
SECOND MOMENT OF IUH ABOUT THE CENTROID(HRS**2) = 64.78
AREA OF UH = .99915

UNIT HYDROGRAPH ORDINATE (M**3/SEC)

TIME (HOURS)	6.-HOUR U.H. ORDINATES (CUMEC)
0.	.000
6.	2.163
12.	16.957
18.	24.805
24.	18.430
30.	9.693
36.	4.142
42.	1.542
48.	.520
54.	.163

(viii) Unit Hydrograph using Clark Model (Optimisation)

(a) Example

For a catchment of size 114.22 sq.km. the ordinates of the cummulative time-area diagramme are given as follows :

Time (hrs)	1	2	3	4	5
cummulative Time-area ordinates (km^2)	16	45	61	84	114.22

The direct surface runoff hydrograph and excess rainfall hyetograph ordinates for a typical storm in the catchment are given as follows :

Find out 1-hour unit hydrograph with volume 1 mm using Clark Model whose parameters are estimated using Marquerdt Algorithm.

(b) Input

The structure of the input file UHCLARKH.DAT for the above example would be as follows:

```
5  1.0 5.0 1.
16.0 45.0 61.0 84.0 114.22
3
7.3 4.3 3.3
15
0. 1. 3. 15. 78. 120. 82. 54. 36. 26. 21. 15. 11. 7. 3. 0.
2
6 4
1 1
12 12
```

(c) Output

A output file CLARKH.OUT created by the above input file contains the fillowing :

NO FUNCTION IMPROVEMENT POSSIBLE

Value of tc=   4.494
Value of r =   2.482

UH ordinates

Time (Hrs)	UH Ordinates (Cumec)
.00	.00
1.00	.90
2.00	2.86
3.00	4.21
4.00	5.85
5.00	6.01
6.00	3.99
7.00	2.65
8.00	1.76
9.00	1.17
10.00	.78
11.00	.52
12.00	.34
13.00	.23
14.00	.15
15.00	.10
16.00	.07
17.00	.04

UH peak = 6.01 cumec
UH time to peak= 5.00 hours

Observed and Computed direct surface runoff values

Time (Hrs)	Observed (Cumec)	Computed (Cumec)
0.	.00	.00
1.	1.00	6.55
2.	3.00	24.74
3.	15.00	45.97
4.	78.00	70.25
5.	120.00	82.90
6.	82.00	74.29
7.	54.00	56.36
8.	36.00	37.46
9.	26.00	24.90
10.	21.00	16.55
11.	15.00	11.00
12.	11.00	7.31
13.	7.00	4.86
14.	3.00	3.23
15.	.00	2.15

Efficiency of the model = 83.486.

(ix) Unit Hydrograph Using Given Parameters of Clark Model

(a) 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 catchment area is 250 sq.km.

Time (hrs)	0	1	2	3	4	5	6	7	8
Area (Km)	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 10 mm.

(b) Input

The structure of the input file UHCLARKF.DAT for the above example would be as follows:

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

(c) Output

A output file CLARKF.OUT created by the above input file contains the fillowing :

CLARK MODEL COMPUTATIONS

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

TIME (HOUR)	IUH ORDINATE (M**3/SEC.)	2.HR.UH ORDINATE (M**3/SEC)
.00	.000	.000
1.00	3.472	.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.HR.UH ORDINATE (M**3/SEC)
.00	.000	.000
1.00	4.613	1.153
2.00	14.752	5.995
3.00	28.981	15.774
4.00	42.224	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	29.891	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

2. Unit Hydrograph for Ungauged Catchments

(i) Unit Hydrograph Using Snyder's Method

(a) Example

Snyder's formula for sub zone 3-c and catchment no 12345 are given as follows :

$$t_p = C_t\,(LL_{ca})^{0.3C}$$

where t_p = Basin Lag (or time lag) in hours
L = Length of main stream in Km.
L_{ca} = distance from outlet to centre of area of catchment along the stream in Km.
C_t = a coefficient varying from 0.3 to 0.6 for different regions

Peak of UH (cumec)

$$Q_p = (\,2.78\ C_p\ CA\,)\ /\ t_p$$

where Q_p = peak of UH in cumec
CA = catchment area in sq km
C_p = a coefficient varying from 0.31 to 0.93

Width of UH in hour at 50% peak discharge (W_{50})

$$W_{50} = a\ /\ q^{1.08}$$

where $q = Q_p / CA$ & a is a coefficient for the region

Width of UH in hour at 75% peak discharge (W_{75})

$$W_{75} = W_{50}\ /\ b$$

where b is a coefficient for the region

The UH peak, basin lag time, W_{50}, W_{75} and t_b are used to define the shape of UH preserving the unit volume equal to one cm.

Derive 1 hour unit hydrograph (unit volume = 1 cm) characteristics for an ungauged catchment whose catchment area (CA) is 35 sq km, length of the main stream (L) = 10.10 km and length of the main stream from the centroid to the outlet (L_{ca}) = 7.4 km.

Other characteristics may be taken as follows :

C_t = 0.62,
C_p = 0.92,
a = 2.15 and,
b = 1.71

(b) Input

The structure of input file UHSNYD.DAT for the above example would be as follows :

35 10.10 7.4 1
0.62 0.92 2.15 1.71

The no./name of the ungauged catchment and subzone no if any, are to be supplied by the user through terminal in interactive mode as given below :

Please input the sub-zone no. (maximum upto 10 characters) : 3-c

Please input the ungauged catchment no./name (maximum upto 10 characters) : 12345

(c) Output

A output file SNYD.OUT created by the above input file contains the fillowing :

```
CHARACTERISTICS OF 1.- HOUR UH FOR
UNGAUGED CATHMENT NO. : 12345 OF SUBZONE : 3-c
UH peak (cumec)              = 37.16
Lag time of UH (hrs)         =  2.41

Width of UH at 50% of qp (hrs) =  2.02
Width of  UH at 75% of qp (hrs)=  1.18

Base width of UH (hrs)         = 14.55

Unit volume of UH (cm)         =  1
```

(ii) Unit Hydrograph Using CWC Method

(a) Example

The characteristics of 1 -hour unit hydrograph (unit volume = 1 cm) for sub zone 3-c and catchment no 12345 for an ungauged catchment are given below in the form of the following relationships developed by CWC :

$t_p = a_1 (LL_c/\sqrt{S})^{b1}$

$q_p = a_2 (t_p)^{b2}$

where, $q_p = Q_p / CA$

$W_{50} = a_3 (q_p)^{b3}$

$W_{75} = a_4 (q_p)^{b4}$

$WR_{50} = a_5 (q_p)^{b5}$

$WR_{75} = a_6 (q_p)^{b6}$

$t_b = a_7 (t_p)^{b7}$

where,
- L = Length of main stream in Km.
- L_{ca} = distance from outlet to centre of area of catchment along the stream in Km.
- S = Stream slope in metre/kilometre
- t_p = Time from the centre of unit rainfall duration to the peak of unit hydrograph in hours
- q_p = Peak discharge of UH in cumec/sq.km.

W_{50}, W_{75} and t_b are used to define the shape of UH preserving the unit volume equal to one cm.

WR_{50} = The width of the rising side of UH in hours at ordinate equal to 50% of UH peak, and

WR_{75} = The width of the rising side of UH in hours at ordinate equal to 75% of UH peak.

Values of constants $a_1 \ldots a_7$, $b_1 \ldots b_7$ for the above example are as follows :

a_1	=	0.258	b_1	=	0.49
a_2	=	1.017	b_2	=	0.52
a_3	=	2.396	b_3	=	1.08
a_4	=	1.427	b_4	=	1.08
a_5	=	0.750	b_5	=	1.25
a_6	=	0.557	b_6	=	1.12
a_7	=	7.193	b_7	=	0.53

Estimate the characteristics of 1-hour unit hydrograph (unit volume = 1 cm) for an ungauged catchment whose area (CA) is 100.98 sq km, length of the main stream (L) is 16.49 km, length of main stream to the centroid (L_{ca}) is 8.05 km and slope (S) is 6.38 m / km.

(b) Input

The structure of the input file UHCWC.DAT for the above example would be as follows :

```
100.98 16.49 8.05 6.38 1
0.258 0.49
1.017 -0.520
2.396 -1.080
1.427 -1.080
0.750 -1.250
0.557 -1.120
7.193 0.53
```

The no./name of the ungauged catchment and subzone no if any, are to be supplied by the user through terminal in interactive mode as given below :

Please input the sub-zone no. (maximum upto 10 characters) : 3-c

Please input the ungauged catchment no./name (maximum upto 10 characters) : 12345

(c) Output

A output file CWC.OUT created by the above input file contains the fillowing :

```
CHARACTERISTICS OF   1.-HOUR UH FOR
UNGAUGED CATCHMENT NO. : 12345     OF SUBZONE : 3-c
UH peak (cumec)             =   75.70
Time to peak of UH  (hrs)   =    2.00
```

Width of UH at 50% of qp (hrs) = 3.27
Width of UH at 75% of qp (hrs)= 1.95

Width of rising side of UH at 50% of qp (hrs)= 1.08
Width of rising side of UH at 75% of qp (hrs)= .77

Base width of UH (hrs)= 9.82

Unit volume of UH (cm) = 1

3. S - Hydrograph Computation

(a) 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 /s)	0	20	50	70	65	60	40	0

(b) Input

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

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

(c) Output

A output file SCURVE.OUT created by the above input file contains the fillowing :

DEVELOPMENT OF S-CURVE

TIME	UNIT HYDROGRAPH	S-CURVE
0.	.00	.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.	.00	305.00

4. UH of Changed Duration Using Superimposition Method

(a) Example

Using the data for the example given as above, obtain the unit hydrograph of 12 hour duration using superimposition method.

(b) Input

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

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

(c) Output

A output file SUPERIM.OUT created by the above input file contains the fillowing:

CHANGE IN UNIT HYDROGRAPH DURATION USING SUPERIMPOSITION METHOD

TIME (HRS)	4-HOUR DURATION UNIT HYDROGRAPH (CUMEC)
0.	.00
4.	20.00
8.	50.00
12.	70.00
16.	65.00
20.	60.00
24.	40.00
28.	.00

TIME (HRS)	12-HOUR DURATION UNIT HYDROGRAPH (CUMEC)
0.	.00
4.	20.00
8.	50.00
12.	70.00
16.	65.00
20.	60.00
24.	40.00
28.	.00

5. UH of Changed Duration Using S-Curve Method

(a) Example

Using the data for the example given as above, obtain the unit hydrograph of 12 hour duration using S-curve method.

(b) Input

The structure of the input file UHNEWD.DAT for the above example would be as follows:

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

(c) Output

A output file NEWD.OUT created by the above input file contains the fillowing :

DEVELOPMENT OF S-CURVE

TIME	UNIT HYDROGRAPH	S-CURVE
0.	.00	.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.	.00	305.00

NEW UNIT GRAPH

TIME	NEW U H ORDINATES
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.	.00

ORIG.DUR.UH= 4HR.
NEW DUR.UH= 12HR

OPTION: Reproduction of DRH and Estimation of DSR Hydrograph

1. Computation of Direct Surface Runoff (DRH)

(a) 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^3/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

(b) Input

The structure of input file UHSYNTH.DAT for the above example would be as follows :

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

(c) Output

A output file SYNTH.OUT created by the above input file contains the fillowing :

```
DEVELOPMENT OF COMPOSITE HYDROGRAPH
-----------------------------------------------------------------
NO.OF UNIT HYD.ORD.  9
DURATION             4.
```

UNIT HTDROGRAPH DATA

TIME	UNIT HYDROGRAPH ORDINATES
0.	.00
2.	40.00
4.	90.00
6.	135.00
8.	130.00
10.	120.00
12.	80.00
14.	40.00
16.	.00

COMPOSITE HYDROGRAPH DETAILS

TIME	DISCHARGE
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.	.00

2. Computation of Direct Surface Runoff and Error Functions

(a) 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 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

(b) Input

The structure of input file UHREPROD.DAT for the above example would be as follows:

```
1700
6
10
0  250  1050  2050  4350  4150  2300  1070  450  120
3
40.209  100.209  60.209
6
1
11
0 2.939 17.731 23.556 17.414 9.578 4.414 1.809 0.682 0.241 0.0
```

(c) Output

A output file REPROD.OUT created by the above input file contains the fillowing :

```
REPRODUCTION OF OBSERVED DSRO USING UNIT HYDROGRAPH
---------------------------------------------------

DIRECT SURFACE RUNOFF(M**3/SEC)
   .000    250.000    1050.000

   EXCESS RAINFALL (MM)
   40.21      100.21      60.21

   6.-HOUR U.H. ORDINATES(M**3/SEC)
     .000      2.939     17.731     23.556     17.414     9.578
    4.414      1.809       .682       .241       .000
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
6.	250.0	118.7
12.	1050.0	1011.9
18.	2050.0	2913.7
24.	4350.0	4146.5
30.	4150.0	3564.1
36.	2300.0	2195.4
42	1070.0	1096.6
48.	450.0	476.6
54.	120.0	187.8

EFFICIENCY OF THE MODEL = 94.98
OBS. PEAK (M**3/S) = 4350.0
OBSERVED TIME TO PEAK (HRS) = 24.
COMPUTED PEAK (M**3/S) = 4146.5
COMPUTED TIME TO PEAK (HRS) = 24.
AVERAGE STANDARD ERROR = 341.517
AVERAGE ABSOLUTE ERROR = 204.798
AVERAGE PERCENTAGE ABSOLUTE ERROR = 18.649
PERCENTAGE ABSOLUTE ERROR IN PEAK = 4.68
PERCENTAGE ABSOLUTE ERROR IN TIME TO PEAK= .00

OPTION: Design Flood Estimation

(a) Example

The cumulative rainfall ordinates for a severe storm in a catchment alongwith the ordinates of 6-hour representative unit hydrographfor the catchment are given below. Estimate the resulting design flood hydrograph. Take initial loss = 1.2 cm, ϕ -index = 0.15 cm / hour and base flow = 300 m^3 / sec.

Time (hour)	Cumulative rainfall (cm)	6-hour unit hydrograph ordinates m^3/sec
0	0.0	0
6	16.5	30
12	24.5	190
18	30.0	540
24	34.2	700
30	37.2	590
36	39.3	330
42	40.8	200
48	42.0	140
54		100
60		75
66		56
72		40
78		22
84		12
90		4
96		0

(b) Input

The structure of the input file UHDESIGN.DAT for the above example would be as follows :

6
8
16.5 24.5 30.0 34.2 37.2 39.3 40.8 42.0
16
30 190 540 700 590 330 200 140 100 75 56 40 22 12 4 0
1.2 0.15
300

(c) Output

A output file DESIGN.OUT created by the above input file contains the fillowing :

DESIGN FLOOD COMPUTATIONS USING UNIT HYDROGRAPH BASED APPROACH

T	CR	RI	UHO.	RA	DR	EXR	DSRO	DFLH.
HR	CM	CM	CUM	CM	CM	CM	CUM	CUM
0.	16.50	16.50	30.00	.00	1.20	.00	.00	300.00
6.	24.50	8.00	190.00	2.10	1.50	.60	18.00	318.00
12.	30.00	5.50	540.00	5.50	3.00	2.10	177.00	477.00
18.	34.20	4.20	700.00	16.50	4.20	3.30	822.00	1122.00
24.	37.20	3.00	590.00	8.00	8.00	7.10	2394.00	2694.00
30.	39.30	2.10	330.00	4.20	16.50	15.60	5423.00	5723.00
36.	40.80	1.50	200.00	3.00	5.50	4.60	10683.00	10983.00
42.	42.00	1.20	140.00	1.50	2.10	1.20	17064.00	17364.00
48.	.00	.00	100.00	1.20	.00	.00	19414.00	19714.00
54.	.00	.00	75.00	.00	.00	.00	16429.00	16729.00
60.	.00	.00	56.00	.00	.00	.00	10839.00	11139.00
66.	.00	.00	40.00	.00	.00	.00	6861.10	7161.10
72.	.00	.00	22.00	.00	.00	.00	4599.10	4899.10
78.	.00	.00	12.00	.00	.00	.00	3258.50	3558.50
84.	.00	.00	4.00	.00	.00	.00	2381.00	2681.00
90.	.00	.00	.00	.00	.00	.00	1722.80	2022.80
96.	.00	.00	.00	.00	.00	.00	1175.80	1475.80
102.	.00	.00	.00	.00	.00	.00	692.80	992.80
108.	.00	.00	.00	.00	.00	.00	364.80	664.80
114.	.00	.00	.00	.00	.00	.00	144.00	444.00
120.	.00	.00	.00	.00	.00	.00	32.80	332.80
126.	.00	.00	.00	.00	.00	.00	4.80	304.80
132.	.00	.00	.00	.00	.00	.00	.00	300.00

NOTE:-

T IS TIME IN HOURS
CR IS CUMMULATIVE RAINFALL IN CM
RI IS RAINFALL INCREMENT IN CM
UHO. IS DESIGN UNIT HYDROGRAPH ORDINATES IN CUMEC
RA IS RAINFALL ARRANGED IN CM
DR IS DESIGN RAINFALL IN CM
EXR IS DESIGN EXCESS RAINFALL IN CM
DSRO IS DESIGN DIRECT SURFACE RUNOFF IN CUMEC
DFLH. IS DESIGN FLOOD HYDROGRAPH IN CUMEC

OPTION: Plot /View / Edit a File

A typical plot file PPLT1.PLT for single variable may be as follows :

```
1         9
Collin`s UH
UH
Ord m**3/sec
Time in hrs
     0.            .000
     6.           7.162
    12.           7.205
    18.          27.048
    24.          22.075
    30.           9.046
    36.           3.632
    42.           2.535
    48.            .000
```

Similarly, a typical plot file PPLT2.PLT for double variables may be as follows :

```
2          10
Superimposition method
Old UH
new UH
Ord m**3/sec
Time in hrs
  0.000000E+00   0.000000E+00   0.000000E+00
      4.000000      20.000000       6.666667
      8.000000      50.000000      23.333330
     12.000000      70.000000      46.666670
     16.000000      65.000000      61.666670
     20.000000      60.000000      65.000000
     24.000000      40.000000      55.000000
     28.000000   0.000000E+00      33.333330
     32.000000   0.000000E+00      13.333330
     36.000000   0.000000E+00   0.000000E+00
```

These plot files which are created by a particular option can be viewd under plot of the package.

List of names of sample input and output files for various options

OPTION NO.	DETAILS	INPUT FILE	OUTPUT FILE
1	Processing and analysis of rainfall data		
	1.1 Filling up of missing data	UHGAPF.DAT	GAPF.OUT
	1.2 Consistency check of a record	UHDOUBLE.DAT	DOUBLE.OUT
	1.3 Computation of areal average rainfall	UHTHIES.DAT	THIES.OUT
	1.4 Computation of variation of depth with area	UHISO.DAT	ISO.OUT
	1.5 Conversion of daily to hourly rainfall	UHDAILY.DAT	DAILY.OUT
2	Computation of discharge and rating curve analysis		
	2.1 Discharge from velocity	UHVEL.DAT	VEL.OUT
	2.2 Development of rating curve & discharge computation	UHRATING.DAT	RATING.OUT
	2.3 Discharge from stages	UHGAUGE.DAT	GAUGE.OUT
3	Excess rainfall and direct surface runoff Computations		
	3.1 Baseflow separation & computation of ERH volume	UHEFF.DAT	EFF.OUT
	3.2 Separation of baseflow using straight line technique	UHLOSS.DAT	LOSS.OUT
4	Unit hydrograph derivation		
	4.1 Unit hydrograph for gauged catchments		
	4.1.1 Conventional method (with basflow option)	UHUNIT.DAT	UNIT.OUT
	4.1.2 Conventional method (without base flow option)	UHUHISO.DAT	UHISO.OUT
	4.1.3 Unit hydrograph using Collin's method	UHCOLUH.DAT	COLUH.OUT
	4.1.4 Unit hydrograph using conventional Nash model (Method of moments)	UHNASHF.DAT	NASHF.OUT
	4.1.5 Unit hydrograph using Conventional Nash model (Optimisation)	UHNASHH.DAT	NASHH.OUT

OPTION NO.	DETAILS	INPUT FILE	OUTPUT FILE
	4.1.6 Unit hydrograph using given parameters of Conventional Nash model	UHNASHG.DAT	NASHG.OUT
	4.1.7 Unit hydrograph using integer Nash model	UHINTNAS.DAT	INTNAS.OUT
	4.1.8 Unit hydrograph using Clark model (Optimisation)	UHCLARKH.DAT	CLARKH.OUT
	4.1.9 Unit hydrograph using given parameters of Clark model	UHCLARKF.DAT	CHARKF.OUT
	4.2 Unit hydrograph derivation for ungauged catchments		
	4.2.1 Unit hydrograph using Snyder's method	UHSNYD.DAT	SNYD.OUT
	4.2.3 Unit hydrograph CWC method	UHCWC.DAT	CWC.OUT
	4.3 Development of S hydrograph	UHSCURVE.DAT	SCURVE.OUT
	4.4 Unit hydrograph of changed duration using Superimposition method	UHSUPERIM.DAT	SUPERIM.OUT
	4.5 Unit hydrograph of changed duration using S-curve method	UHNEWD.DAT	NEWD.OUT
5	Reproduction of direct surface runoff and estimation of flood hydrograph		
	5.1 Computation of direct surface runoff	UHSYNTH.DAT	SYNTH.OUT
	5.2 Computation of direct surface runoff and error functions	UHREPROD.DAT	REPROD.OUT
6	Design flood estimation	UHDESIGN.DAT	DESIGN.OUT
7	Plotting / editing / viewing of a file		
	7.1 Plotting of a file	PPLT1.PLT PPLT2.PLT	
8	Monitor selection		
9	Creation / modification / selection of a data file and execution of a programme		

Software package
No. - 1

UNIT HYDROGRAPH APPLICATIONS FOR FLOOD ESTIMATION

USER'S MANUAL

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