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FLOOD ESTIMATION FOR LARGE CATCHMENTS USING DETERMINISTIC APPROACH

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SECTION 1 INTRODUCTION

1.0 GENERAL

The proper planning of a project needs the proper study of hydrology. The flood problem is not only a concern of the branch of engineering but is important to a number of other branches as well. To avoid destruction, any hydraulic structure constructed must have adequate protection against the maximum flood expected. This maximum flood that any such structure can safely pass is called the design flood.

Design flood estimation is one of the most important aspect of project hydrology. As per the design criteria, if the hydraulic structure has storage capacity more than 60 Mm^3, then probable maximum flood estimate or 1000 year flood is required. However, for the storage structures having capacity less than 60 Mm^3, estimate of standard project flood or 100 year flood is needed. The estimates for return period floods are made by carrying out flood frequency analysis. Such estimates are only peak flood estimate. Probable maximum peak flood or standard project flood estimates are the estimates of flood hydrograph. These estimates not only provide the peak flood but also time to peak, volume and other characteristics of the flood hydrograph.

Unit hydrograph approach is one of the most popular approaches available for estimation of design flood hydrograph. But its applicability is normally limited to small to medium sized catchments (size less than 5000 sq. km.) due to inherent limitation of non-uniform rainfall in large sized catchments. For large size catchments, the flood estimates are carried out applying unit hydrograph techniques together with flood routing through channel and existing or proposed reservoirs if any. The procedure involves sub-dividing the catchment into sub-catchments and preparing the network model for the whole catchment. As the computations involved are tedious and lengthy, therefore the designers are often discouraged for opting the network modelling approach in order to estimate the design flood for large sized catchments. Keeping in mind the requirement of the designer, an interactive software has been developed which may not only provides design flood estimates for large as well as small sized catchments but also helps the users to analyse their historical rainfall-runoff records for calibration and validation of the various techniques for part or whole of the catchment and river reaches.

1.1 FLOOD ESTIMATION FOR LARGE CATCHMENTS USING DETERMINISTIC APPROACH

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. The basic assumption involved is that rainfall is uniformly distributed over the entire catchment in space and time. Therefore, if area of catchment is small it works well but if area is more than 5000 sq. km then principal of unit hydrograph can not be applied as such.

In order to apply the unit hydrograph theory to large catchments, the whole catchment is sub divided into small sub-catchments and then using unit hydrograph theory, design floods for individual sub-catchments are calculated and these are routed through the respective reaches to compute the combined design flood at the main outlet of catchment.

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 (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 relationships 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.

While sub-dividing the large basin into sub-basins, it is required to route the flood hydrograph through river channels, lakes and reservoirs. In other words, one often requires predicting the movement and change in shape of flood wave as it moves downstream to the river reach or passes over the spillways of the dam. The Muskingum method of channel flood routing was first introduced by McCarthy and others in connection with the flood control studies of the Muskingum river channel in Ohio, U.S.A. Since its development, this method has been widely used in river engineering practice. Due to its popularity among field engineers and hydrologists, this method has been extensively researched and from time to time modifications have been suggested. Muskingum- Cunge method is another popularly used method which has been incorporated in this manual.

There are many methods of flood routing through reservoirs, all of which can be classified under three general categories: analytical, semi-graphical and graphical. Most of the methods fall under semi-graphical category. All the methods give reasonable accurate results. In this manual four important and most commonly used are incorporated.

In this user's manual several options are included to deal with the 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, estimation of flood hydrograph for large as well as small catchments, using unit hydrograph approach, reservoir routing and channel routing. For all the options examples, sample input and output files are given in Appendices I to VI. Last Appendix VII, 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. However, Math co-processor may be necessary for most of the programmes.

1.3 PROGRAMME INSTALLATION

The 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 DF directory in the hard disk (C:\DF) and also a sub directory (C:\DF\MISC). A message to this effect will be displayed on the screen. If this directory or sub directory already exists on the computer then all the files will be copied to these directories.
5. C:\DF directory contains the main programme files used by the package while C:\DF\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 package 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:

DFP1.ZIP DFP2.ZIP INSTALL.BAT PKUNZJR.COM

DFP1.ZIP contains the following files (143 FILES):

CLARKF.EXE	CLARKF.HDT	CLARKF.HLP	CLARKH.EXE	CLARKH.HDT	CLARKH.HLP
COL.HLP	COLUH.EXE	COLUH.HDT	COLUH.HLP	CR1.HDT	CR1.HLP
CR2.HLP	CR2.HDT	CR3.HDT	CR3.HLP	CR4.HLP	CR4.HDT
CR5.HLP	CR5.HDT	CWC.EXE	CWC.HDT	CWC.HLP	DAILY.EXE
DAILY.HDT	DAILY.HLP	DATA.HLP	DEL.HLP	DESIGN.EXE	DF.BAT

DFG.EXE	DFL.HDT	DFL.HLP	DFLT.HLP	DFS.HLP	DFS.HDT
DIMLESS.HLP	DIMLESS.EXE	DIMLESS.HDT	DNET.HLP	DOUBLE.EXE	DOUBLE.HDT
DOUBLE.HLP	DRH.HLP	EDIT.HLP	EDIT.COM	EFF.EXE	EFF.HDT
EFF.HLP	FLT.HLP	GAPF.EXE	GAPF.HDT	GAPF.HLP	GAUGE.EXE
GAUGE.HDT	GAUGE.HLP	GEN.HLP	HEAD.EXE	INF.HLP	INTNAS.EXE
INTNAS.HDT	INTNAS.HLP	ISO.EXE	ISO.HDT	ISO.HLP	LEAVE.HLP
LOSS.EXE	LOSS.HDT	LOSS.HLP	MON.HLP	MONO.HLP	MONWOS.HLP
NASHF.EXE	NASHF.HDT	NASHF.HLP	NASHG.EXE	NASHG.HDT	NASHG.HLP
NASHH.EXE	NASHH.HDT	NASHH.HLP	NET.EXE	NEWD.EXE	NEWD.HDT
NEWD.HLP	PLOT.HLP	POS.SET	PPLOT.EXE	PREFACE	PRO.HLP
RATE.HLP	RATING.EXE	RATING.HDT	RATING.HLP	REACH.EXE	REP.HLP
REPROD.EXE	EPROD.HDT	REPROD.HLP	RESR.HLP	RETURN.HLP	ROUTE.EXE
ROUTE.HLP	RSR1.HLP	RSR1.HDT	RSR2.HLP	RSR2.HDT	RSR3.HLP
RSR3.HDT	RSR4.HDT	RSR4.HLP	SCURVE.EXE	SCURVE.HDT	SCURVE.HLP
SDFL.HLP	SFL.HLP	SNYD.EXE	SNYD.HDT	SNYD.HLP	SPEED.HLP
SUPERIM.EXE	SUPERIM.HDT	SUPERIM.HLP	SYNTH.EXE	SYNTH.HDT	SYNTH.HLP
THIES.EXE	THIES.HDT	THIES.HLP	UH.HLP	UHDA.HLP	UHDIM.EXE
UHDIM.HDT	UHDIM.HLP	UHT.HLP	UHUNG.HLP	UNIT.EXE	UNIT.HDT
UNIT.HLP	VEL.EXE	VEL.HDT	VEL.HLP	WORK.HLP	

DFP2.ZIP contains the following files (78 NOS.):

CLARKF.OUT	CLARKH.OUT	COEFF.OUT	COLUH.OUT	CWC.OUT	DAILY.OUT
DESIGN.OUT	DFCLARKH.DAT	DFCLRKF.DAT	DFCOEFF.DAT	DFCOLUH.DAT	DFCWC.DAT
DFDAILY.DAT	DFDESIGN.DAT	DFDIMLS.DAT	DFDOUBLE.DAT	DFEFF.DAT	DFGAPF.DAT
DFGAUGE.DAT	DFGRICH.DAT	DFINTNAS.DAT	DFISO.DAT	DFLOSS.DAT	DFMASS.DAT
DFMKCR.DAT	DFMKG.DAT	DFMKM.DAT	DFMKOP.DAT	DFMKR.DAT	DFNASHF.DAT
DFNASHG.DAT	DFNASHH.DAT	DFNET.DAT	DFNEWD.DAT	DFPULS.DAT	DFRATING.DAT
DFREPROD.DAT	DFSCURVE.DAT	DFSNYD.DAT	DFSUPERI.DAT	DFSYNTH.DAT	DFTHIES.DAT
DFUHDIM.DAT	DFUNIT.DAT	DFVEL.DAT	DIMLESS.OUT	DOUBLE.OUT	EFF.OUT
GAPF.OUT	GAUGE.OUT	GRICH.OUT	INTNAS.OUT	ISO.OUT	LOSS.OUT
MASS.OUT	MKCR.OUT	MKG.OUT	MKM.OUT	MKOP.OUT	MKR.OUT
NASHF.OUT	NASHG.OUT	NASHH.OUT	NET.OUT	NEWD.OUT	PPLT1.PLT
PPLT2.PLT	PULS.OUT	RATING.OUT	REPROD.OUT	SCURVE.OUT	SNYD.OUT
SUPERIM.OUT	SYNTH.OUT	THIES.OUT	UHDIM.OUT	UNIT.OUT	VEL.OUT

INSTALL.BAT is used for installing tha package on the hard disk while, PKUNZJR.COM is used for unzipping the DFP1.ZIP and DFP2.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 flood estimation for small as well as large sized catchment. Options dealing with reservoir routing, channel routing and unit hydrograph analysis are very much useful to the field engineers involved in hydrologic analysis and design where these options are frequently required. The results obtained from various options are subjected to the assumptions and limitations of the respective techniques on which the programmes are based. The Institute is in no way responsible for the results obtained by using the package.

SECTION 2 PACKAGE FOR FLOOD ESTIMATION FOR LARGE CATCHMENT

2.0 THE PACKAGE

This package deals with various options for flood estimation for large as well as small and medium sized catchments using unit hydrograph approach and reservoir and channel routing procedures. It also deals with processing and analysis of rainfall and runoff data and flood estimation for ungauged catchments. These options are categorized in six main groups dealing with:

(i) Channel routing parameters estimation and application,

(ii) Reservoir routing,

(iii) Unit hydrograph development,

(iv) UH application on small catchment for flood estimation,

(v) Flood estimation for large catchment and,

(vi) Plotting and other file related and display operations.

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

2.1 CHANNEL ROUTING PARAMETERS ESTIMATION AND APPLICATION

In this category, there are five options for calibration of channel routing procedures and their application. Muskingum method and Muskingum-Cunge methods of channel routing have been considered here.

First, second and third options deal with estimation of Muskingum parameters using graphical method, method of moments and optimization technique respectively. Fourth option is used for computation of routed outflow hydrograph using Muskingum method and last option computes routed outflow hydrograph using Muskingum - Cunge method of flood routing.

2.2 RESERVOIR ROUTING

The package considers four different options for reservoir routing. These options consider mass curve method, Modified Puls method, Goodrich method and coefficient method of reservoir routing.

2.3 UNIT HYDROGRAPH DEVELOPMENT

This option deals with four main options related to processing of data and derivation of unit hydrograph. First option deals with processing and analysis or rainfall data. It has five different sub-options. Second option deals with rating curve analysis and computation of discharge and has three different sub-options. Third option deals with excess rainfall and direct surface runoff computation from surface runoff and has two different sub-options. Fourth and last option deals with derivation of unit hydrograph for gauged and ungauged catchments, computation and application of S hydrograph, change of unit duration of unit hydrograph using superimposition method, development of dimensionless hydrograph and development of unit hydrograph from a dimensionless hydrograph. Under option for ungauged catchments, there are two different sub-options while under gauged catchment option, there are eight different sub-options for development of unit hydrograph. These different sub-options are discussed further in the following sections.

2.3.1 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.

2.3.2 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 $Q=a(G-e)^b$ 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.

2.3.3 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.

2.3.4 Unit Hydrograph Derivation

In this category there are seven different options related with unit hydrograph related 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 approach and approach based on formula developed by Central Water Commission. The third option computes the S-curve hydrograph from the unit hydrograph of a specified duration. The fourth and fifth options are used for changing the duration of Unit hydrograph using superimposition and S-curve methods respectively. Sixth option derives the dimensionless unit hydrograph from the unit hydrograph for the region and the last option computes the unit hydrograph from the dimensionless unit hydrograph.

2.3.4.1 Unit Hydrograph Derivation for Gauged Catchments

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

The first option is used to derive the unit hydrograph from single-period, individual and isolated storm. The option requires the discharge hydrograph as input and uses 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. The runoff volume in depth unit thus obtained is used for further computations of unit hydrograph. Rainfall details are used to compute the unit duration of unit hydrograph.

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

2.3.4.2 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.

2.4 UH APPLICATION ON SMALL CATCHMENT FOR FLOOD ESTIMATION

This option of the package calculates flood hydrograph using unit hydrograph and storm details available for the small catchment. There are three options available in this category.

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.

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

2.5 FLOOD ESTIMATION FOR LARGE CATCHMENT

This option is used for flood estimation for large catchment using deterministic approach. Unit hydrograph theory may be used to estimate the flood for the small catchments up to the size of 5000 Sq. Km. with reasonable accuracy. However for the catchments having area more than 5000 Sq. Km., the principles of Unit Hydrograph cannot be applied considering catchment as a single unit. A network model is then developed wherein the flood hydrograph is computed for each sub-catchment and the combined contributions from each sub catchment are routed through the respective river reaches or reservoirs using an appropriate flood routing technique to estimate the final flood for this large size catchment. Package has the provision of calculating the flood of each sub-catchment either during the execution or it can be supplied through a file. Similarly, information of individual reach or sub-catchment can be supplied either interactively at the time of execution or through a data file.

2.6 PLOTTING AND OTHER FILE RELATED AND DISPLAY OPERATIONS

Package provides for creating, editing, viewing, deleting, renaming, copying or plotting of a file. For the options where it is appropriate to create a plot file, it has been created bearing the extension PLT and is displayed during the execution of the programme which 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. Speed of graphics display at the time of start of the programme can also be changed by selecting the option and then increasing the number for slowing down the speed and vice versa.

Facility for naming a working directory is also provided to facilitate smooth working and keeping the result and data files in a separate directory.

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.

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 VI. List of sample input and output file names are given in Appendix VII.

3.0 GENERAL

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.

Reservoir: A reservoir or a lake is a relatively large water body wherein the flow velocity is nearly zero. Reservoir with large depth and level surface is usually assumed for developing the methods. It is also assumed that inflowing water wave would be transmitted almost instantaneously to all parts of the reservoir.

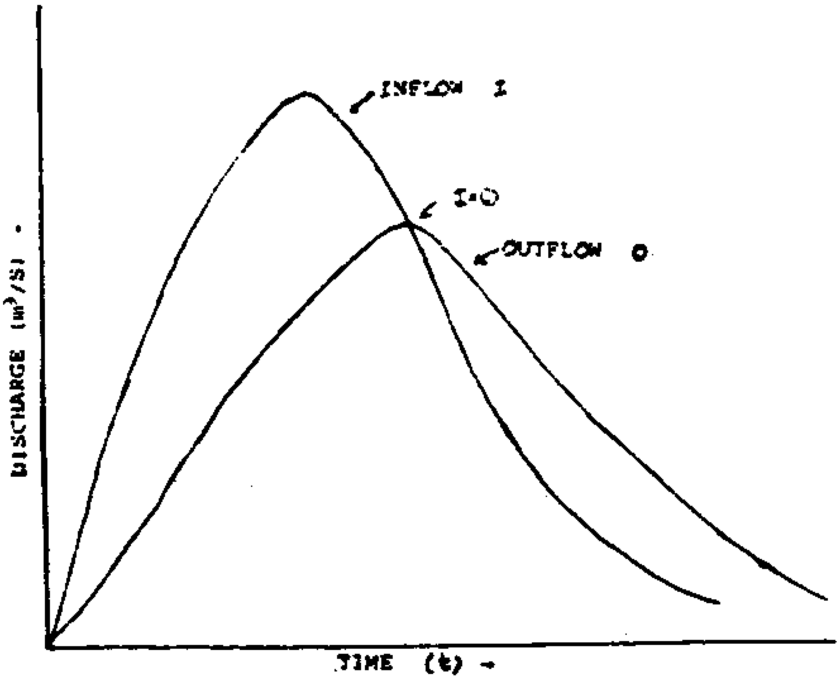

Figure 1: Typical results of reservoir routing

Out flow from these reservoirs may be through regulated or unregulated hydraulic structures. This outflow is directly proportional to the head (reservoir elevation) which increases with inflow. This elevation continues to raise until inflow and outflow are equal. As the outflow is directly proportional to the above elevation, the highest pool elevation and the outflow peak will occur simultaneously when outflow and inflow are equal.

Attenuation and translation: It can easily be seen that the inflow peak is reduced by the reservoir. This reduction of flood peak as it moves downstream is known as attenuation and quantified as the difference in peak discharges. Another common feature that can be observed from this figure is that the occourence of flood peak after passing the reservoir is delayed. This is known as translation effect.

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.

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

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.

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

Direct Surface Runoff : It is that portion of runoff which resulted at the catchment outlet due to excess rainfall.

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

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 CHANNEL ROUTING PARAMETERS ESTIMATION AND APPLICATION

The Muskingum method of flood routing was first introduced by McCarthy and others (U.S. Army Corps of Engineers, 1960) in connection with the flood control studies of the Muskingum river basin in Ohio, U.S.A. Since its development, this method has been widely used in river engineering practice. Due to its popularity among field engineers and hydrologists, this method has been extensively researched (Singh, 1988). This method was introduced as a linear storage routing method and it is termed herein as the classical or conventional Muskingum method to differentiate it with other variations which were introduced in later years.

The classical Muskingum method

The basic equations of this method are the lumped continuity equation and the storage-weighted discharge relationship which are expressed as

$$I - O = dS/dt \qquad \text{....(1)}$$

and $$S = K[XI + (1 - X)\,O] \qquad \text{....(2)}$$

wherein I and O are respectively the inflow into and outflow from the routing reach; S is the storage in the reach corresponding to the flow I and O; and the parameters K denote the travel time of the flood wave in the reach and the parameter X denote the coefficient to weigh the inflow and outflow in order to linearly relate them with the reach storage S.

The rate of change of storage given by Eqn. (1) can be discretized in time at the level of (n+1) Δt and nΔt as:

$$\frac{I_{n+1} + I_n}{2} - \frac{O_{n+1} + O_n}{2} = \frac{S_{n+1} - S_n}{\Delta t} \qquad \text{....(3)}$$

in which Δt is the routing time interval.

Likewise, Eqn. (2) can be discretized at (n+1)Δt and nΔt as:

$$S_{n+1} = K[X\,I_{n+1} + (1 - X)\,O_{n+1}] \qquad \text{....(4)}$$

and $$S_n = K[X\,I_n + (1 - X)\,O_n] \qquad \text{....(5)}$$

Substitution of Eqns.(4) and (5) in Eqn. (3) and rearranging the terms yield.

$$O_{n+1} = C_1\,I_n + C_2\,I_{n+1} + C_3\,O_n \qquad \text{...(6)}$$

in which

$$C_1 = \frac{\Delta t + 2K\theta}{2K(1-\theta) + \Delta t} \quad \text{....(7)}$$

$$C_2 = \frac{\Delta t - 2K\theta}{2K(1-\theta) + \Delta t} \quad \text{....(8)}$$

$$C_3 = \frac{2K(1-\theta) - \Delta t}{2K(1-\theta) + \Delta t} \quad \text{....(9)}$$

Note that $C_1 + C_2 + C_3 = 1$

Determination of K and X :

Parameters K and X of Muskingum method of flood routing can be computed from available inflow and outflow hydrograph of the reach by the following methods which are incorporated in the package.

3.1.1 Estimation of Muskingum Parameters using Graphical Method

The most known method of determination of parameters K and X is by the graphical procedure in which the instantaneous S values are plotted on the X-axis against the corresponding weighted discharge values XI+(1- X)O on the Y-axis. The accepted value of X is that which gives the best linear plot (or the narrowest loop) between S and XI+(1-X) O as characterised by the linear storage-weighted discharge relationship.

In the package computer asks the value of X and then creates the PLT file for linear storage-weighted discharge relationship which can be viewed under the plot option of the package.

Fig. 2 shows some typical form of loop curves obtained during the graphical procedure of estimating the parameters K and X.

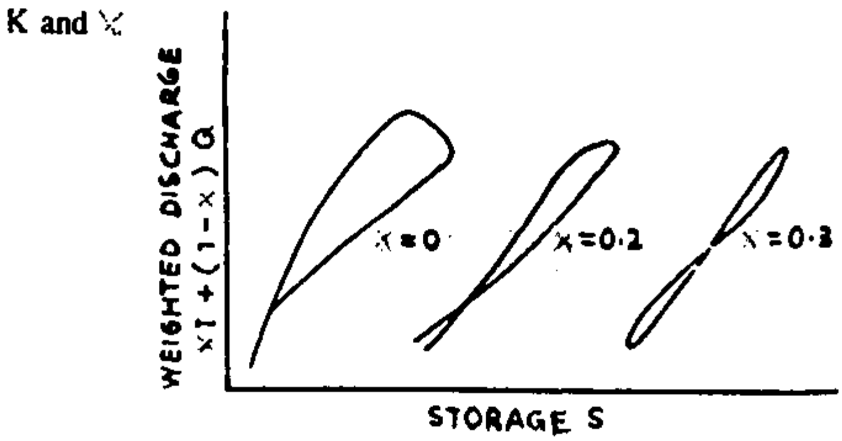

Figure 2: Typical storage Vs Weighted discharge curves

The inverse of the slope of the narrowest loop curve gives the value of K, since from Eqn. (2), one gets

$$K = \frac{S}{XI + (1 - X)O} \quad ....(10)$$

3.1.2 Estimation of Muskingum Parameters using Method of Moments

The following equations are solved to compute the parameters of Muskingum method of flood routing (K and X) using method of moments.

$$K = 1^{M'}{}_O - 1^{M'}{}_I \quad ....(11)$$

$$X = 0.5(1 - (2^{M'}{}_O - 2^{M'}{}_I)/K^2) \quad ....(12)$$

where $1^{M'}{}_O$ and $2^{M'}{}_O$ are first and second moment of the outflow hydrograph about the origin respectively, and $1^{M'}{}_I$ and $2^{M'}{}_I$ are first and second moment of the inflow hydrograph respectively.

The first and second moments of inflow and outflow hydrographs are computed using the following equations:

$$1^{M'o} = \frac{\sum_{i=1}^{N} \frac{(O_i - O_{i+1})}{2} t_i}{\sum_{i=1}^{N} \frac{(O_i - O_{i+1})}{2}} \quad ....(13)$$

$$2^{M'o} = \frac{\sum_{i=1}^{N} \frac{(O_i - O_{i+1})}{2} (t_i)^2}{\sum_{i=1}^{N} \frac{(O_i - O_{i+1})}{2}} \quad ....(14)$$

$$1^{M'_I} = \frac{\sum_{i=1}^{M} I_i\, t_i}{\sum_{i=1}^{M} I_i} \quad ....(15)$$

$$2^{M'_I} = \frac{\sum_{i=1}^{M} I_i \, t_i^2}{\sum_{i=1}^{M} I_i} \qquad ....(16)$$

where

O_i = ith ordinate of outflow runoff hydrograph in m^3 /s

N = No. of ordinates of outflow runoff hydrograph

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

M = No. of ordinates of inflow runoff hydrograph

I_i = ith ordinate of inflow runoff hydrograph in m^3 /s

The option "Estimation of parameters using Method of Moments" uses the above procedure to estimate the parameters of Muskingum method of flood routing.

3.1.3 Estimation of Muskingum Parameters using Optimization Technique

The parameters of Muskingum method of flood routing, K and X may also be estimated using the optimisation procedure. In this package an option has been included to estimate the parameters K and X using Marquerdt Algorithm, which is a non-linear optimisation technique, to minimise the objective function F given as:

$$F = \sum_{i=1}^{N} (O_i - \hat{O}_i)^2 \qquad ....(17)$$

Where,

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

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

Inherent in these procedures is the assumption that the water surface in the reach is uniform unbroken surface profile between upstream and downstream ends of the reach. Additionally, it is presupposed that K and X are constant throughout the range of flow in the stage of investigation. If significant departures from these restrictions are present, it may be necessary to work with shorter reaches of the river, or to employ a more sophisticated approach to the problem. A rule of thumb is that the Muskingum method will fail if the lag of the channel reach defined by K is greater than half the duration of inflow.

Range of X

It is generally recognised that the weighting parameter ranges between zero and 0.5. A critical analysis of the storage-weighted discharge relationship may give further insight into this aspect. Using the storage-weighted discharge relationship, it can be written.

$$O = -\frac{X}{(1-X)}I + \frac{S}{K(1-X)} \qquad \text{....(18)}$$

Differentiating Eqn. (9) with respect to t gives

$$\frac{dO}{dt} = -\frac{X}{(1-X)}\frac{dI}{dt} + \frac{1}{K(1-X)}\frac{dS}{dt} \qquad \text{....(19)}$$

When S is maximum, dS/dt = 0

Then Eqn. (10) reduces to

$$\frac{dO}{dt} = -\frac{X}{(1-X)}\frac{dI}{dt} \qquad \text{....(20)}$$

For a typical flood routing case any one of the situations shown in Fig. 3 is realizable. Fig. 3a corresponds to the case in which X >0. Fig. 3b corresponds to the case when X = 0 and Fig. 3c corresponds to the case when X < 0. The last case is the deviation from the conventional thinking that X ≥ 0. The last case, in which the outflow is less than the synchronous inflow is realised when the reach length is very small. However, the upper value of X is restricted to 0.5 from the point of view of avoiding wave amplification down the channel. Therefore, it is inferred that X has a much broader range defined by θ ≤ 0.5.

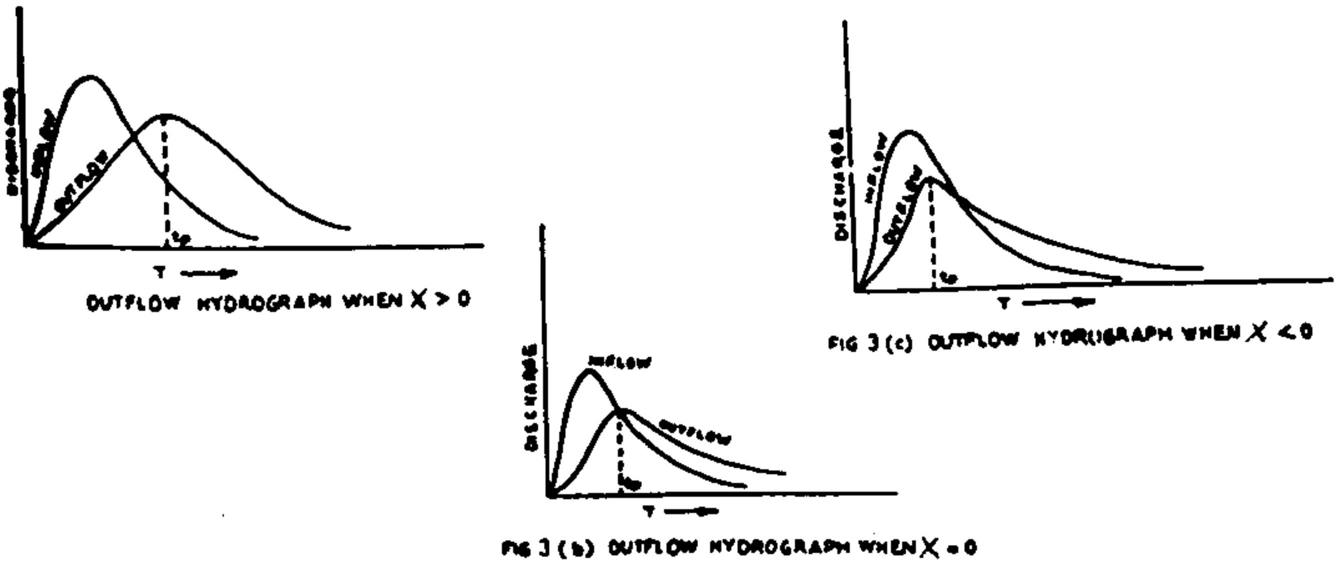

Figure 3: Outflow hydrograph and value of Muskingum parameter X.

3.1.4 Routing of Inflow Hydrograph Using Available Muskingum Parameters

Having known inflow hydrograph and values of constants C0, C1 and C2, equation 6 is used to compute routed outflow hydrograph at the end of the reach or channel.

3.1.5 Routing of Inflow Hydrograph Using Muskingum-Cunge Method

As discussed earlier, the routing equation for conventional Muskingum method is given as:

$$O_{n+1} = C_o I_{n+1} + C_1 I_n + C_2 O_n \qquad ....(21)$$

which, C_o , C_1 and C_2 are routing coefficients defined in terms Δt, K, and X as follows:

$$C_o = \frac{(\Delta t / K) - 2X}{2(1-X) + (\Delta t / K)} \qquad ....(22)$$

$$C_1 = \frac{(\Delta t / K) + 2X}{2(1-X) + (\Delta t / K)} \qquad ....(23)$$

$$C_2 = \frac{2(1-X) - (\Delta t / K)}{2(1-X) + (\Delta t / K)} \qquad ....(24)$$

where, I = Inflow, O = Outflow, K = a time constant or storage coefficient and X = a dimensionless weighting factor.

The Muskingum method can calculate runoff diffusion, ostensibly, by varying the parameter X. A numerical solution of linear kinematic wave equation using a third order - accurate scheme (Courant number C = 1) leads to pure flood hydrograph translation. Other numerical solutions to the linear kinematic wave equation invariably produce a certain amount of numerical diffusion and/or dispersion. The Muskingum and linear kinematic wave routing equation are strikingly similar. Further, unlike the kinematic wave equation, the diffusion wave equation does have the capability to describe the physical diffusion.

From these propositions, Cunge (1969) concluded that the Muskingum method is essentially a linear kinematic wave solution and that the flood wave attenuation shown by the calculation is due to the numerical diffusion of the scheme itself. He discretized the kinematic wave equation on the x-t plane (Fig.4) in such a way that parallels the Muskingum method to prove this assertion and came out with a physically based alternative to the Muskingum method. The alternative method is popularly known as Muskingum Cunge method.

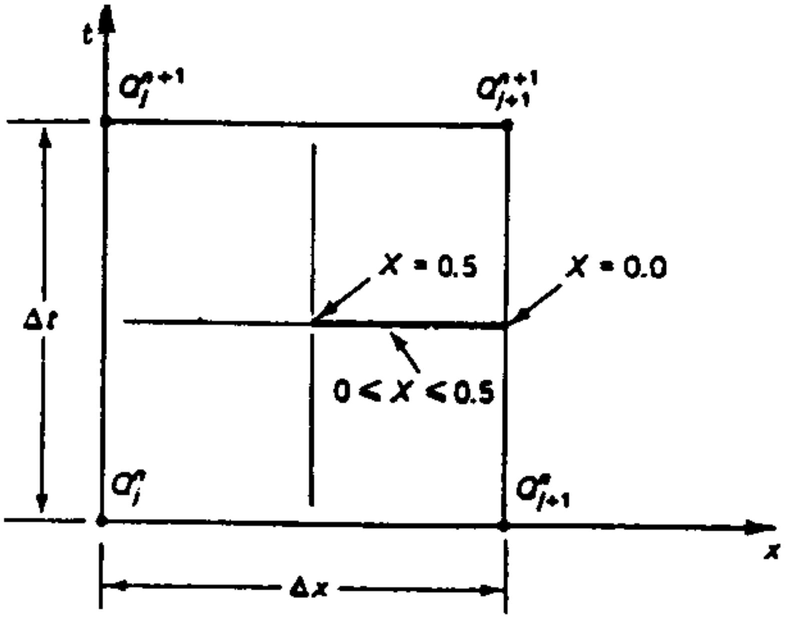

Figure 4: Space-time discretization of Kinematic wave equation paralleling Muskingum Method

MUSKINGUM CUNGE METHOD

The kinematic wave equation is given as:

$$\partial Q/\partial t + c\,\partial Q/\partial x = 0.0 \qquad ...(25)$$

in which, c is the kinematic wave celerity and Q is the discharge.

Eq.(5) was discretized by Cunge (1969) on the x-t plane (Fig. 4) in a way that parallels the Muskingum method, wherein the spatial derivative was centred and the temporal derivative was off-centered by means of a weighting factor X. The resulting equation is given as:

$$\frac{X(Q_j^{n+1} - Q_j^n) + (1-X)\,(Q_{j+1}^{n+1} - Q_{j+1}^n)}{\Delta t} + c\,\frac{(Q_{j+1}^n - Q_j^n) + (Q_{j+1}^{n+1} - Q_j^{n+1})}{2\Delta x} = 0 \qquad ....(26)$$

Solving Eq.(26) for the unknown discharge leads to the following equation:

$$Q_{j+1}^{n+1} = C_o\,Q_j^{n+1} + C_1\,Q_j^n + C_2\,Q_{j+1}^n \qquad ....(27)$$

The routing coefficients are:

$$C_o = \frac{c\,(\Delta t/\Delta x) - 2X}{2(1-X) + c\,(\Delta t/\Delta x)} \qquad ....(28)$$

$$C_1 = \frac{c\,(\Delta t/\Delta x) + 2X}{2(1-X) + c\,(\Delta t/\Delta x)} \qquad ....(29)$$

$$C_2 = \frac{2(1-X) - c\,(\Delta t/\Delta x)}{2(1-X) + c\,(\Delta t/\Delta x)} \quad ....(30)$$

By defining:

$$K = \Delta x/c \quad ....(31)$$

it is seen that the two sets of Eqs.(28) to (30) and (22) to (24) are the same.

Eq.(31) confirms that K is in fact the flood wave travel time, i.e. the time taken for a given discharge to travel the reach length ΔX with the kinematic celerity c. In a linear mode, c is constant and equal to a reference value, and in non-linear mode, it varies with discharge.

It can be seen that for X = 0.5 and C = 1 ($C = c\,\Delta t/\Delta x = \beta v\,\Delta t/\Delta x$, the courant number), the routing equation is third order accurate, i.e. the numerical solution is equal to the analytical solution of the kinematic wave equation. For X = 0.5 and $C \neq 1$, it is second order accurate, exhibiting only numerical dispersion. For $X \neq 0.5$ and $C \neq 1$, it is first order accurate exhibiting both numerical diffusion and dispersion. For $X \neq 0.5$ and C = 1, it is first order accurate, exhibiting only numerical diffusion. These relations are summarized in Table 1.

Table 1 : Numerical Properties of Muskingum-Cunge Method

Parameter X	Parameter C	Order of Accuracy	Numerical Diffusion	Numerical Dispersion
0.5	1	Third	No	No
0.5	≠1	Second	No	Yes
<0.5	≠1	First	Yes	Yes
<0.5	1	First	Yes	No

In practice, the numerical diffusion can be used to simulate the physical diffusion of the coefficient (υ_n) for the scheme can be derived by expanding the discrete function Q (j Δx, n Δt) in Taylor series about grid point (j Δx, n Δt) (Ponce, 1989):

$$\upsilon_n = c\,\Delta X\,(1/2 - X) \quad ....(32)$$

Eq.(32) reveals the following:

(i) For X = 0.5 there is no numerical diffusion, although there is numerical dispersion for $C \neq 1$.

(ii) For X > 0.5, the numerical diffusion coefficient is negative, i.e. numerical amplification which explains the behaviour of the Muskingum method for this range of X values:

(iii) For $\Delta x = 0$, the numerical diffusion coefficient is zero, clearly the trivial case.

The hydraulic diffusivity (υ_h) which is a characteristic of flow and channel is defined as:

$$\upsilon_h = \frac{Q_o}{2TS_o} = \frac{q_o}{2S_o} \qquad ....(33)$$

in which, $q_o = Q_o/T$ is the reference flow per unit channel width.

A predictive equation for X can be obtained by matching the hydraulic diffusivity υ_h (Eq.33) with the numerical diffusion coefficient of the Muskingum scheme (Eq.32). This leads to the following expression for X:

$$X = \frac{1}{2}\left(1 - \frac{q_o}{S_o\, c\Delta x}\right) \qquad ....(34)$$

With X calculated by Eq. (34), the Muskingum method is referred to as Muskingum-Cunge method (NERC, 1975). the routing parameter X can be calculated as a function of the following numerical and physical properties:

(i) Reach length Δx;

(ii) Reference discharge per unit width q_o ;

(iii) Kinematic wave celarity, c; and

(iv) Bottom slope, S_o .

It should be noted that Eq.(34) was derived by matching physical and numerical diffusion (i.e. second order processes) and does not account for dispersion (a third order process). Therefore, in order to simulate flood wave diffusion properly with the Muskingum-Cunge method, it is necessary to optimise numerical diffusion with Eq.(34) while minimizing numerical dispersion (by keeping the value of Courant number as close to 1 as practicable).

A unique feature of the Muskingum method is the grid independence of the calculated outflow hydrograph. If numerical dispersion minimized (keeping Courant number C close to one), the calculated outflow at the downstream end of a channel reach will be essentially the same regardless of how many sub-reaches are used in the computation. This is because X is a function of Δx and the routing co-efficients C_o , C_1 and C_2 vary with reach length.

An improved version of the Muskingum-Cunge method is due to Ponce and Yevjevich (1978). The Courant number, C, is defined as the ratio of wave celerity (C) to grid celerity $\Delta X/\Delta t$ i.e.

$$c = c\ \Delta t/\Delta x \qquad ....(35)$$

The grid diffusivity is defined as the numerical diffusivity for the case of X = 0. From Eq.(32), the grid diffusivity is

$$\upsilon_g = c\Delta x/2 \qquad ....(36)$$

The Cell Reynolds number (Roache, P., 1972) is defined as the ratio of hydraulic diffusivity (Eq.33) to grid diffusivity (Eq.36). This leads to

$$D = q_o/S_o\ c\Delta x \qquad ....(37)$$

in which, D = Cell Reynolds number. Therefore, from Eq.(34) and (37)

$$X = 1/2\ (1-D) \qquad ....(38)$$

Eq.(37) and (38) imply that for very small values of Δx, D may be greater than 1, leading to negative values of X. In fact, for the characteristic reach length

$$\Delta x_c = q_o/S_o c \qquad ....(39)$$

The Cell Reynold number is D = 1, and X = 0. Therefore, in the Muskingum-Cunge method, reach length shorter than the characteristic reach length result in negative values of X. This should be contrasted with the classical Muskingum method, in which X is restricted in the range 0.0 - 0.5. In the classical Muskingum, X is interpreted as a weighting factor. As shown by Eq.(37), and (38) non-negative values of X are associated with long reaches (Δx more than characteristic length Δx_c given by Eq.(39), typical of the manual computation used in the development and early application of the Muskingum method.

In the Muskingum-Cunge method, however, X is interpreted in a moment matching sense (USDA, 1973) or diffusion matching factor. Therefore, negative values of X are entirely possible. This feature allows the use of shorter reaches than would otherwise be possible if X were restricted to non-negative values.

The substitution of Eq.(35) and (38) into Eq.(28) to (30) leads to routing co-efficients expressed in terms of Courant and Cell Reynolds numbers:

$$C_o = \frac{-1 + C + D}{1 + C + D} \qquad ....(40)$$

$$C_1 = \frac{1 + C - D}{1 + C + D} \qquad ....(41)$$

$$C_2 = \frac{1 - C + D}{1 + C + D} \qquad ....(42)$$

Thus C and D are the two routing parameters required to be estimated for Muskingum-Cunge method.

Estimation of Routing Parameters

(a) Estimation of parameter C (Courant number)

The parameter C can be estimated using Eq.(35). It requires an estimate for wave celerity (c) in addition to grid size (Δx, Δt). The wave celerity can be calculated with either

$$c = \beta v \qquad ....(43)$$

or

$$c = 1/T \; dQ/dy \qquad ....(44)$$

Where, v is the average flow velocity; T is the top width; and β is an exponent in the discharge (Q) area (A) rating equation given as

$$Q = \alpha (A)^{\beta} \qquad ....(45)$$

The calculation of β is a function of frictional type and cross sectional shape.

Theoretically, Eq. (43) and (44) are the same. For practical applications, if a stage-discharge rating and cross sectional geometry are available (i.e. stage - discharge - top width tables), Eq.(44) is preferred over Eq.(43) because it accounts directly for cross sectional shape. In the absence of a stage discharge rating and cross sectional data, Eq.(43) can be used to estimate flood wave celerity. The velocity υ in Eq.(43) can be taken as the velocity at reference flow. The choice of reference flow has bearing on the calculated results although the overall effect is likely to be small. The peak flow value has the advantage that it can be readily ascertained, although a better approximation may be obtained by using an average value.

(b) Estimation of parameter D (Cell Reynold Number)

Cell Reynold numbers (D) can be calculated using the reach length (Δx), reference discharge per unit width q_o, kinematic wave celerity (c), and bottom slope (S_o) in Eq.(37).

Resolution Requirements

When using the Muskingum-Cunge method, sufficiently small values of Δx and Δt should be taken in order to approximate closely the actual shape of the hydrograph. For smoothly rising hydrographs, a minimum value of $t_p/\Delta t = 5$ is recommended. This requirement usually results in the hydrograph time base being resolved into at least 15 to 25 discrete points, considered adequate for Muskingum routing.

Unlike temporal resolution, there is no definite criteria for spatial resolution. A criterion borne out by experience is based on the fact that Courant and Cell Reynold numbers are inversely related to reach length Δx. Therefore, to keep Δx sufficiently small, Courant and Cell Reynold numbers should be kept sufficiently large. This leads to the practical Criterions :

$$C + D \geq 1 \qquad \text{....(46)}$$

which can be written as: $-1 + C + D \geq 0$.

This confirms the necessity of avoiding negative values of C_o in Muskingum-Cunge routing (Eq.27). Experience has shown that negative values of either C_1 or C_2 do not adversely effect the methods overall accuracy (Ponce and Theurer, 1982).

Notwithstanding Eq.(46), the Muskingum Cunge method works best when the numerical dispersion is minimized, that is, when C is kept close to 1. Values of C sufficiently different from one are likely to cause the notorious dips, or negative outflows, in portions of the calculated hydrograph. This computational anomaly is attributed to excessive numerical dispersion and should be avoided.

The steps involved in flood routing through a channel reach using the Muskingum-Cunge Method are given as follows:

(i) Estimate the parameter C (Courant number) using the following equation:

$$C = c\ \Delta t/\Delta x \quad ....(47)$$

The wave celerity c is computed using the procedure described earlier. The temporal and spatial resolutions (Δt and Δx) should be such that the routing co-efficient C_o should not be negative as well as the value of Courant number (C) should be close to one in order to minimise the numerical dispersion.

(ii) Estimate the parameter D (Cell Reynold number) using the following equation

$$D = q_o/S_o\ c.\Delta x \quad ....(48)$$

The wave celerity (c) and reference discharge, q_o ($=Q_o/T$) per unit width are used together with channel slope S_o and reach length Δx in the above equation to provide the parameter D (Cell Reynold number). Ensure whether $-1 + C + D > o$ which is the practical criterion to avoid the negative values of C_o in Muskingum Cunge routing.

(iii) Estimate the routing co-efficients C_o, C_1 and C_2 using in following equation:

$$C_0 = \frac{-1 + C + D}{1 + C + D} \quad ....(49)$$

$$C_1 = \frac{1 + C - D}{1 + C + D} \quad ....(50)$$

$$C_2 = \frac{1 - C + D}{1 + C + D} \quad ....(51)$$

(iv) Route the inflow hydrograph (Q) using the following equation in order to have the outflow hydrograph (Q_{j+1}):

$$Q_{j+1}^{n+1} = C_o\ Q_j^{n+1} + C_1\ Q_j^n + C_2\ Q_{j+1}^n \quad ....(52)$$

(v) If the channel is divided into sub-reaches, the steps (i) to (iv) should be repeated for all the sub-reaches considering the outflow from the first sub-reach as inflow to second sub-reach and so on.

3.2 RESERVOIR ROUTING

In most of the hydrological studies, concern with design or forecast it is necessary to find the effect of passing of the generated flood through well-defined geophysical features like channel, lake or reservoirs etc. In other words, one often requires predicting the movement and change in shape of flood wave as it moves downstream. In this section passing of flood through a reservoir is dealt with.

The storage in the reservoir is directly proportional to the elevation. At higher elevation the rate of increase of storage is very high due to large surface area. It may be seen that outflow is also directly proportional to elevation. When combined the storage vs outflow will take the shape shown in Fig.3.

Simplest storage equation is a function of outflow.

$$S = KO \qquad \text{....(53)}$$

Where K is the storage parameter, S is storage (m^3) and O is outflow (m^3/s).
The continuity equation is

$$\begin{aligned} I - O &= dS/dt \qquad \text{....(54)} \\ &= d(KO)/dt \\ &= KdO/dt \end{aligned}$$

Here I is inflow (m^3/s). At the peak do/dt = 0 i.e.

$$I - O = 0 \qquad \text{....(55)}$$

This means the outflow peak occurs when inflow is equal to outflow as shown in Fig. 2. It is also found that this peak occurs generally after inflection point.

Alternatively, in a small time interval Δt, the difference between the total inflow volume and total outflow volume in reach is equal to the change in storage in that reach :

$$\bar{I}\Delta t - \bar{O}\Delta t = \Delta S \qquad \text{....(56)}$$

Where, $\bar{I}$, and $\bar{O}$ denote average inflow and outflow during time Δt, and ΔS denotes change in storage during Δt. Assuming

$$\bar{I} = (I_1 + I_2 /2),\ \bar{O} = (O_1 + O_2 /2) \text{ and } S = S_2 - S_1 \qquad \text{....(57)}$$

Where, suffix 1 and 2 denote the beginning and end of time interval Δ t, equation can also be written as :

$$\frac{I_1 + I_2}{2} \Delta t - \frac{O_1 + O_2}{2} \Delta t = S_2 - S_1 \qquad ....(58)$$

Here the time interval Δ t must be sufficiently small so that the inflow and outflow hydrographs can be assumed to be linear in that time interval. Further, Δ t must be shorter than the time of transit of flood wave through the reservoir.

Large number of techniques have been developed for routing it is impracticable to discuss them herein. Few methods are discussed to provide an idea of the basic principles used. These techniques depend on development of routing curves/storage curves and (or) tables which are site specific(i.e the topography and the dam outlet facilities). Amongst them the equation proposed by Goodrich and Puls (modified) are well known.

3.2.1 Reservoir Routing using Mass Curve Method

This is one of the most commonly used method of reservoir routing, various versions of which include: graphical; direct and trial and error. In the package trial and error method is adopted.

For solution to trial and error the equation can be written as

$$M_2 - (V_1 + \bar{O}\,\Delta t\ ) = S_2 \qquad ....(59)$$

Where, M and V are accumulated mass inflow and outflow respectively.

Based on storage - discharge relationship and the mass curve of inflow spillway discharge is obtained. Following steps are involved in the solution.

(i) A time Δ t is chosen and mass inflow is computed. Mass outflow is assumed. As a guideline, it is a function of accumulated mass inflow. Reservoir storage is computed by deducting the mass outflow from mass inflow. The instantaneous and average spillway discharges are calculated. Outflow for the time period Δ t is computed by multiplying Δ t with average discharge. Then the mass outflow is computed.

(ii) Computed mass outflow is compared with assumed mass outflow. If the two values agree within an acceptable degree of accuracy, then the routing is completed otherwise another mass outflow is assumed and the step (i) is repeated.

3.2.2 Reservoir Routing using Modified Puls Method

Originally developed by L.G. Puls in 1928 (Puls method) is also known as storage-indication method. The modified method is similar to the original one except that the routing curves are simplified to single curve. This is one of the most commonly used methods of reservoir flood routing method.

$$2(S_{j+1}/t) + O_{j+1} = (I_j+I_{j+1}) + 2S_j - O_j \qquad ....(60)$$

The RHS terms are known and the inflow hydrograph is known. The value of LHS terms together can be computed.

Steps for Modified Puls Method also known as Storage Indication Method:

1. Choose routing period: Routing period t should be sufficiently small that the hydrograph shape can be well defined. It may be taken as 1/3 to 1/2 of travel time or 1/5 of time to peak. The routing period is taken to a round off number of hours or days.
2. Discrete the inflow hydrograph and fill in cl.1 to 3 with time, ordinates (J) and I_j
3. Fill in $I_j + I_{j+1}$ in cl.4 of the table 2
4. Compute [(2s/t) + O] LHS of eq. (4) and enter in the cl.6.
5. Interpolate O_{j+1} for the computed [(2s/t) + O] and enter in cl.7.
6. Subtract twice the value of cl.7 from cl.6 and enter in cl.5.
7. Repeat steps 4-6 until the outflow is reduced.

Table 2: Reservoir Routing Table

Time	Ordinates	I_j	$I_j + I_{j+1}$	$(2S_j/t)-O_j$	$(2S_{j+1/t)} + O_{j+1}$	O_{j+1}
hr.	j	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s
1	2	3	4	5	6	7

3.2.3 Reservoir Routing using Goodrich Method

Goodrich (1931) proposed a storage equation in the form

$$I_1 + I_2 + \frac{2S_1}{t} - O_1 = \frac{2S_2}{t} + O_2 \qquad ....(61)$$

Where I, O are inflow and outflow respectively; S is storage; subscripts denote time (beginning and end of time step t). To solve this equation one requires [2S/t + O] as a function of O. They are expressed in the form of curves as shown in Fig.3. The use of different curves for different inflow is optional depending upon the accuracy required.

All quantities on the left hand side of equation (1) are known and hence the value of $[(2S_2/t) + O_2]$ can be determined. Routing curve will give the value of O_2 from which $2S_2/t$ can also be found. The present values with subscript 2 will become the values of the variables with subscript' and computations will be repeated.

3.2.4 Reservoir Routing using Coefficient Method

This method assumes the following storage equation

$$S_2 - S_1 = K(O_2 - O_1) \quad ....(62)$$

$$\frac{I_1 + I_2}{2} t - \frac{O_1 + O_2}{2} = K(O_2 - O_1) \quad ....(63)$$

$$O_2 = O_1 + C(I_1 - O_1) + \frac{1}{2}C(I_2 - I_1) \quad ....(64)$$

where C = t/(K + 0.5t) and K is constant of proportion and equal to the reciprocal of the slope of the storage curve. The value of K, this C can be used either as a constant or as a variable. Adopting appropriate values for C routing can be achieved using eq.(64).

Comments

i) This method produces outflow instantaneously regardless of the length of the reservoir at the same time of incident of an inflow. However, this is not a serious limitation if $[L/(Vt_p)$, 1/2 where L is length of the reservoir V is average velocity, t_p is time to peak.

ii) For a choice of $t > 2S_2/O_2$ the negative outflow will take place during recession. It is also found to distort the raising limit as well. Double log plot O Vs [O + (2s/t)] for a proper choice of t should lie below equal line.

Data requirements

Establishing the routing curves is fundamental requirement of reservoir routing. The following data are needed:

(1) Area - Capacity table for the reservoir;

(2) Outflow as a function of reservoir depth;

(3) Past observation on storage ,inflow and outflow to establish S as a function of (I + O) or to establish a family of curves;

(4) Initial conditions on storage, inflow and outflow;

(5) Inflow hydrograph;

3.3 UNIT HYDROGRAPH DEVELOPMENT

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.

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. 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 (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 following sections some 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 and unit hydrograph derivation.

3.3.1 Processing and Analysis of Rainfall Data

3.3.1.1 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.

$$R_A = \frac{\sum_{i=1}^{N} \frac{NR_A}{NR_i} * R_i}{N} \qquad \text{....(65)}$$

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

3.3.1.2 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.

3.3.1.3 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 :

$$\bar{A} = \frac{\sum_{i=1}^{N} A_i W_i}{\sum_{i=1}^{N} W_i} \qquad \text{....(66)}$$

where, Â 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.

3.3.1.4 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 reasonable 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.

3.3.1.5 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.

3.3.2 Rating Curve Analysis and Computation of Discharge

3.3.2.1 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.

3.3.2.2 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

$$Q = a(G-e)^b \qquad \text{....(67)}$$

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. (67)

$$\log Q = b \log (G-e) + \log a \qquad ....(68)$$

or

$$\hat{Y} = \alpha + \beta X \qquad ....(69)$$

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,

$$\beta = \frac{N\left(\sum_{i=1}^{N} X_i Y_i\right) - \left(\sum_{i=1}^{N} X_i\right)\left(\sum_{i=1}^{N} Y_i\right)}{N\left(\sum_{i=1}^{N} X_i^2\right) - \left(\sum_{i=1}^{N} X_i\right)^2} \qquad ....(70)$$

and

$$\alpha = \frac{\sum_{i=1}^{N} Y_i - \beta\left(\sum_{i=1}^{N} X_i\right)}{N} \qquad ....(71)$$

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

$$r = \sqrt{1 - (F_1 / F_0)} \qquad ....(72)$$

$$F_1 = \frac{\sum_{i=1}^{N} (Y_i - \hat{Y}_i)^2}{(N-2)} \qquad ....(73)$$

$$F_1 = \frac{\sum_{i=1}^{N} (Y_i - \bar{Y})^2}{(N-1)} \qquad ....(74)$$

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. (69)

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.

3.3.2.3 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 :

$$Q = a(G-e)^b \qquad ....(75)$$

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 4.2.2.

If the coefficients a, b and e are known, Eq.(75) may be used to compute the values of the discharge corresponding to the various stage values. The use of the Eq.(75) 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.(75) as explained above.

3.3.3 Excess Rainfall and Direct Surface Runoff Computations

3.3.3.1 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.

3.3.3.2 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.

3.3.4 Unit Hydrograph Derivation

3.3.4.1 Unit Hydrograph for Gauged Catchment

3.3.4.1.1 CONVENTIONAL METHOD

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 base flow supplied by the user is 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 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. Phi- index is applied to rainfall hyetograph to compute the effective rainfall duration to calculate unit duration of unit hydrograph. However this unit duration is to be checked with the S-hydrograph.

3.3.4.1.2 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.

3.3.4.1.3 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 :

$$U(T,t) = \frac{1}{T}\left[I\left(n,\frac{t}{K}\right) - I\left(n,\frac{t-T}{K}\right) \right] \quad \text{....(76)}$$

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.

$$nK = 1\,M'_Y - 1\,M'_X \quad \text{....(77)}$$

$$n(n+1)\,K^2 + 2nK\,1\,M'_X = 2\,M'_Y - 2\,M'_X \quad \text{....(78)}$$

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.

First and second moments of direct surface runoff hydrograph and the excess rainfall about the origin are computed using the following equations :

$$1^{M'Y} = \frac{\sum_{i=1}^{N} \frac{(Y_i - Y_{i+1})}{2} t_i}{\sum_{i=1}^{N} \frac{(Y_i - Y_{i+1})}{2}} \quad \text{....(79)}$$

$$ _2M'_Y = \frac{\sum_{i=1}^{N} \frac{(Y_i - Y_{i+1})}{2} (t_i)^2}{\sum_{i=1}^{N} \frac{(Y_i - Y_{i+1})}{2}} \quad ....(80) $$

$$ _1M'_X = \frac{\sum_{i=1}^{M} X_i \, t_i}{\sum_{i=1}^{M} X_i} \quad ....(81) $$

$$ _2M'_X = \frac{\sum_{i=1}^{M} X_i \, t_i^2}{\sum_{i=1}^{M} X_i} \quad ....(82) $$

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 optimisation procedure. In this package an option has been included to estimate the parameters n & K using Marquerdt Algorithm, which is a non-linear optimisation technique, to minimise the objective function F given as:

$$F = \sum_{i=1}^{N} (Y_i - \hat{Y}_i)^2 \qquad ....(83)$$

$$\hat{Y}_i = \sum_{j=1}^{i} X_j U_{i-j+1} \qquad ....(84)$$

Where,

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

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

3.3.4.1.4 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.

$$U(T,t) = \frac{1}{T} [I(n,y) - I(n,y_1)] \qquad ....(85)$$

Where,

$$I(n, y) = 1 - e^{-y} \sum_{m=0}^{n-1} \frac{y^m}{m!} \qquad ....(86)$$

$$I(n, y_1) = 1 - e^{-y_1} \sum_{m=0}^{n-1} \frac{y_1^m}{m!} \qquad ....(87)$$

$$y = t / K \qquad ....(88)$$

$$y_1 = (t-T) / K \qquad ....(89)$$

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.

3.3.4.1.5 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.

$$U_i = C\, I_i + (1 - C)\, U_{i-1} \qquad \text{....(90)}$$

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

$$C = \frac{\Delta t}{R + 0.5\, \Delta t} \qquad \text{....(91)}$$

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 :

$$UH_i = 0.5\, (U_i + U_{i-1}) \qquad \text{....(92)}$$

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:

$$UH_i = 1/n\, [\, 0.5\, U_{i-n} + U_{i-n+1} + \ldots\ldots + U_{i-1} + 0.5\, U_i\,] \qquad \text{....(93)}$$

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

$$n = D / \Delta t \qquad \text{....(94)}$$

(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.

3.3.4.2 *Unit Hydrograph Derivation for Ungauged Catchments*

3.3.4.2.1 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)

$$t_p = C_t\,(LL_{ca})^{0.30} \qquad \text{....(95)}$$

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)

$$Q_p = (\,2.78\ C_p\ CA\,)\ /\ t_p \qquad \text{....(96)}$$

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)

$$t_r = t_p\ /\ 5.5 \qquad \text{....(97)}$$

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:

$$t_p' = t_p + 0.25\,(t_r' - t_r) \qquad ....(98)$$

Peak of UH for desired duration, t_r'

$$Q_p' = (\,2.78\, C_p\, CA\,) / t_p' \qquad ....(99)$$

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

$$W_{50} = a / q^{1.08} \qquad ....(100)$$

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

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

$$W_{75} = W_{50} / b \qquad ....(101)$$

where b is a coefficient for the region

Base width of UH (t_b)

For large catchments

$$t_b = 3 + 3\,(t_p'/24) \quad \text{(in days)} \qquad ....(102)$$

For small catchments

$$t_b = 5\,(t_p' + t_r' / 2\,) \quad \text{(in hours)} \qquad ....(103)$$

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.

3.3.4.2.2 UNIT HYDROGRAPH DERIVATION BASED ON FLOOD ESTIMATION REPORTS OF 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:

$$t_p = a_1\,(LL_{ca}/\sqrt{S})^{b_1} \qquad ....(104)$$

$$q_p = a_2\,(t_p)^{b_2} \qquad ....(105)$$

$$W_{50} = a_3\,(q_p)^{b_3} \qquad ....(106)$$

$$W_{75} = a_4\,(q_p)^{b_4} \qquad ....(107)$$

$$WR_{50} = a_5 (q_p)^{b_5} \quad ....(108)$$

$$WR_{75} = a_6 (q_p)^{b_6} \quad ....(109)$$

$$t_b = a_7 (t_p)^{b_7} \quad ....(110)$$

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.

3.3.4.3 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 :

$$Q_{max} = (0.2778\ AV) / T \quad ....(111)$$

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.

3.3.4.4 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.

3.3.4.5 *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.

3.3.4.6 *Development of Dimensionless Hydrograph*

The dimensionless unit hydrograph is very handy when comparison of unit hydrographs from basins of different sizes and shapes, or those resulting from different storm patterns is required. This hydrograph can also be used for the transportation of unit hydrograph from a gauged catchment to a ungauged catchment located in the same hydrometeorlogical region. These hydrographs can be constructed in a variety of ways. In the present package, the most commonly used form is used.

To construct a dimensionless unit hydrograph, from a unit hydrograph, first reduce its time scale by dividing it by summation of lag and semi duration time and then multiply it by hundred. The unit hydrograph ordinates are reduced by multiplying them by a factor equal to lag plus semi duration and then dividing by total direct runoff of the unit hydrograph computed in cumec days.

Such double adjustment of both the axes helps in eliminating the effects of the basin size, areal pattern and duration of the rainfall excess.

3.3.4.7 *Development of Unit Hydrograph from a Dimensionless Hydrograph*

The dimensionless unit hydrograph is very useful for transportation of unit hydrograph from a gauged catchment to a ungauged catchment located in the same hydrometeorlogical region. By utilising the catchment information and the dimensionless hydrograph, the unit hydrograph can be easily constructed.

To construct a unit hydrograph, from a dimensionless unit hydrograph, first convert its time scale by multiplying it by summation of lag and semi duration time and then divide it by hundred. The unit hydrograph ordinates are obtained by dividing the ordinates of dimensionless hydrograph by a factor equal to lag plus semi duration and then multiplying by total direct runoff of the unit hydrograph computed in cumec days.

Lag is time in hours starting from the centroid of rainfall excess and ending at half the volume of direct runoff. The lag for the ungauged basin is computed from a generalised relationship such as the Snyder equation as follows:

$$tp = Ct(LK)^{**}0.3 \qquad \text{....(112)}$$

Where, Ct = A coefficient. depending on basin characteristics

L = River distance from the station to the upstream limits of the drainage area (km)

K = River distance from the station to the point nearest the centroid of the drainage area

3.4 UH APPLICATION ON SMALL CATCHMENTS FOR FLOOD ESTIMATION

3.4.1 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.

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

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

$$\hat{Y}_i = \sum_{i=1}^{m} \sum_{j=1}^{i} UH_j * X_{i-j+1} \qquad ....(113)$$

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 :

$$EF = ((F_0 - F_1) / F_0) * 100 \qquad ....(114)$$

$$F_0 = \sum_{i=1}^{N} (Y_i - \bar{Y})^2 \qquad ....(115)$$

$$F_1 = \sum_{i=1}^{N} (Y_i - \hat{Y}_i)^2 \qquad ....(116)$$

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

$\bar{Y}$ = 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.

3.4.3 Computation of Design Flood

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.

3.5 FLOOD ESTIMATION FOR LARGE CATCHMENTS

For the catchments having area more than 5000 Sq. Km., to apply the principles of Unit Hydrograph, the whole catchment is sub-divided into a suitable number of sub-catchments and the flood hydrograph for each sub-catchment is computed and the combined contributions from each sub catchment are routed through the respective river reaches or reservoirs using an appropriate flood routing technique to estimate the final flood for this large size catchment.

The following steps are involved in the derivation of flood hydrograph for the whole catchment:

(i) Divide the whole catchment into suitable number of sub catchments.

(ii) Identify the reaches and calculate individual reach length. For each reach, identify total no of sub-catchments at the start of the reach.

(iii) For each sub-catchment, collect either flood hydrograph or storm (design storm), baseflow and unit hydrograph (design unit hydrograph) details.

(iv) Similarly for the reach, identify routing procedure and routing parameters. If routing parameters are not available then first calculate them using inflow and outflow hydrograph along with other information for that reach.

First step involves the calculation of flood (design flood) hydrograph for a sub-catchment if storm details and Unit Hydrograph details are available. Then, flood hydrograph(s) of sub-catchment(s) at the start of the first reach are routed through the reach to get the routed outflow hydrograph. This outflow hydrograph combined with flood hydrograph of sub-catchment(s) meeting at start of second reach is routed through second reach to get routed flood hydrograph at the end of this reach. Likewise, the routed flood hydrograph may be computed for the last reach which will be the required flood hydrograph for the whole catchment.

4.0 GENERAL

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 CHANNEL ROUTING PARAMETERS ESTIMATION AND APPLICATION

In this category, there are five options for calibration of channel routing procedures and their application. Muskingum method and Muskingum-Cunge methods of channel routing have been considered here. For all the examples, sample input and output files are given in Appendix I.

4.1.1 Estimation of Muskingum Parameters using Graphical Method

Values of the following in the input file in the prescribed sequence, in free format is required.

Line No.	Variable Name			Description
1	dlt	dlt	-	Routing time interval and time interval for input and output hydrograph ordinates in hours.
2	n, bflow			
		n	-	Number of inflow and outflow ordinates.
		bflow	-	Average base flow contribution of this reach in cu. m/sec.

3	in( )	in	- Vector containing n values of inflows in a line, at time interval dlt apart, in cu. m./sec.
4	out( )	out	- Vector containing n values of outflows in a line, at time interval dlt apart, in cu. m./sec.

(i) Information displayed during the execution :

At the time of execution computer asks for trial values of routing parameter X.

Supply trial value of X (0 to 1): X1

Here, X1 value is to be supplied by the user. Based on X1 value another parameter value K is computed and routing is performed. Also, a PLT file is created.

Following is again asked by the computer:

Do you want to try another value of X (y/n)? :

Here, 'YES' or 'NO' or 'Y' or 'N' has to be supplied by the user through the terminal. If the user response is YES, the computer again asks the value of X and above procedure is repeated otherwise the programme ends.

4.1.2 Estimation of Muskingum Parameters using Method of Moments

Values of the following in the input file in the free format and in prescribed sequence is required

Line No.	Variable Name		Description
1	dlt	dlt	- Routing time interval and time interval for input and output hydrograph ordinates in hours.
2	n, bflow	n	- Number of inflow and outflow ordinates.
		bflow	- Average base flow contribution of this reach in cu. m/sec.
3	in( )	in	- Vector containing n values of inflows in a line, at time interval dlt apart, in cu. m./sec.
4	out( )	out	- Vector containing n values of outflows in a line, at time interval dlt apart, in cu. m./sec.

4.1.3 Estimation of Muskingum Parameters using Optimization Technique

Values of the following in the input file in the free format and in prescribed sequence is required

Line No.	Variable Name			Description
1	dlt	dlt	-	Routing time interval and time interval for input and output hydrograph ordinates in hours.
2	k, x	k	-	Initial value of parameter K
		x	-	Initial value of parameter X
3	k1, x1	k1	-	Minimum limit of parameter K
		x1	-	Minimum limit of parameter X
4	k2, x2	k2	-	Maximum limit of parameter K
		x2	-	Maximum limit of parameter X
5	n, bflow			
		n	-	Number of inflow and outflow ordinates.
		bflow	-	Average base flow contribution of this reach in cu. m/sec.
6	in( )	in	-	Vector containing n values of inflows in a line, at time interval dlt apart, in cu. m./sec.
7	out( )	out	-	Vector containing n values of outflows in a line, at time interval dlt apart, in cu. m./sec.

4.1.4 Routing of Inflow Hydrograph using Available Muskingum Parameters

Values of the following in the input file in the free format and in prescribed sequence is required

Line No.	Variable Name			Description
1	dlt	dlt	-	Routing time interval and time interval for input hydrograph ordinates in hours.
2	k, x, bflow	k	-	Value of translation parameter K in hrs.
		x	-	Value of attenuation parameter X
		bflow	-	Average base flow contribution of this reach in cu. m/sec.
3	n	n	-	Number of inflow ordinates.
4	flowin( )	flowin	-	Vector containing n values of inflows in a line, at time interval dlt apart, in cu. m./sec.

4.1.5 Routing of Inflow Hydrograph using Muskingum-Cunge Method

Values of the following in the input file in the prescribed sequence is required

Line No.	Variable Name		Description
1	dlt	dlt -	Routing time interval and time interval for input hydrograph ordinates in hours.
2	dx	dx -	Reach length in kilometres.
3	twqp, bslo, bflow, nopt	twqp -	Top width of the channel corresponding to peak discharge in meter.
		bslo -	Channel bed slope (m/m).
		bflow -	Average base flow contribution of this reach in cu. m/sec.
		nopt -	Option for wave celerity. 1 -Wave celerity based on rating curve. 2 -Wave celerity from average velocity. 3 -Average velocity from Manning's n.
	If nopt = 1		
4	slrat	slrat -	Inverse slope of the rating curve in the vicinity of peak discharge.
	if nopt = 2		
4	fare, beta	fare -	Flow area corresponding to peak discharge in sq. m.
		beta -	Value of rating exponent.
	if nopt = 3		
4	man, beta	man -	Value of Manning's n
		beta -	Value of rating exponent.
5	n	n -	Number of inflow ordinates.
6	flowin( )	flowin-	Vector containing n values of inflows in a line, at time interval dlt apart, in cu. m./sec.

4.2 RESERVOIR ROUTING

The package considers four different options for reservoir routing. These options include mass curve method, Modified Puls method, Goodrich method and coefficient method of reservoir routing. For all the options, sample input and output files are given in Appendix II.

4.2.1 Reservoir Routing using Mass Curve Method

The Mass Curve method of reservoir routing requires the values of following input variables in free format, in the prescribed sequence in an input file:

Line No.	Variable Name		Description
1	nrt, fac, bel, dlt	nrt -	Number of values in storage-elevation-discharge table.

		fac	-	Factor by which inflows are to be multiplied.
		bel	-	Beginning elevation in mt.
		dlt	-	Time interval of computations in hours.
2	table( )		-	Two dimensional vector containing nrt values of elevation storage and outflow respectively in each line.
2+nrt	n	n	-	Number of inflow ordinates.
3+nrt	in( )	in	-	Vector containing n values of inflows in a line, at time interval dlt apart,in cu.m./sec.

4.2.2 Reservoir Routing using Modified Puls Method

The Modified Puls method of reservoir routing requires the values of following input variables in free format, in the prescribed sequence in an input file:

Line No.	Variable Name	Description		
1	nrt, fac, bel, dlt	nr	-	Number of values in storage-elevation-discharge table.
		fac	-	Factor by which inflows are to be multiplied.
		bel	-	Beginning elevation in mt.
		dlt	-	Time interval of computations in hours.
2	table( )		-	Two dimensional vector containing nrt values of elevation storage and outflow respectively in each line.
2+nrt	n	n	-	Number of inflow ordinates.
3+nrt	in( )	in	-	Vector containing n values of inflows in a line, at time interval dlt apart,in cu.m./sec.

4.2.3 Reservoir Routing using Goodrich Method

The Goodrich method of reservoir routing requires the values of following input variables in free format, in the prescribed sequence in an input file:

Line No.	Variable Name	Description		
1	nrt, fac, bel, dlt	nr	-	Number of values in storage-elevation-discharge table.
		fac	-	Factor by which inflows are to be multiplied.
		bel	-	Beginning elevation in mt.
		dlt	-	Time interval of computations in hours.
2	table( )		-	Two dimensional vector containing nrt values of elevation storage and outflow respectively in each line.
2+nrt	n	n	-	Number of inflow ordinates.
3+nrt	in( )	in	-	Vector containing n values of inflows in a line, at time interval dlt apart,in cu.m./sec.

4.2.4 Reservoir Routing using Coefficient Method

The Coefficient method of reservoir routing requires the values of following input variables in free format, in the prescribed sequence in an input file:

Line No.	Variable Name			Description
1	coeff, dlt	coeff	-	Value of coefficient.
		dlt	-	Time interval of computations in hours.
2	n	n	-	Number of inflow ordinates.
3 t	in( )	in	-	Vector containing n values of inflows in a line, at time interval dlt apart,in cu.m./sec.

4.3 UNIT HYDROGRAPH DEVELOPMENT

This option deals with four main options related to processing of data and derivation of unit hydrograph. First option deals with processing and analysis or rainfall data. It has five different sub-options. Second option deals with rating curve analysis and computation of discharge and has three different sub-options. Third option deals with excess rainfall and direct surface runoff computation from surface runoff and has two different sub-options. Fourth and last option deals with derivation of unit hydrograph for gauged and ungauged catchments, computation and application of S hydrograph and change of unit duration of unit hydrograph using superimposition method. Under ungauged category there are two different options and under gauged category there are eight different options. Details of data files for these different sub-options are discussed further in the following sections. For all the options examples, sample input and output files are given in appendix-III.

4.3.1 Processing and Analysis of Rainfall Data

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

4.3.1.1 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:

Line No.	Variable Name	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.

4.3.1.2 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.

Line No.	Variable Name		Description
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.

4.3.1.3 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. It also has the provision of computing Theissen weights. If Thiessen weights are to be computed then coordinates of catchment area as well as raingauge stations are required.

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

Line No.	Variable Name	Description
A	INDX	Index used to define whether Thiessen weights are available or to be

		computed. INDX=0 Theissen weights are available. Otherwise to be computed

If INDX is not zero

****

B=A+1	NGEOM, SCAL	NGEOM - No. of coordinate values for catchment boundary SCAL - Scale of catchment map.
C=B+NGEOM	XC, YC	XC- X coordinate and YC- Y coordinate. Values to given in a line. Thus, there will be NGEOM lines.
D=C+1	NGAGE	No. of stations under consideration
E=D+NGAGE	XCN, YCN	X and Y coordinates of a station in a line. Thus, there will be NGEOM lines.

****

If INDX is zero

B=A+1	NGAGE	No. of raingauge stations
E=B+1	WT	Vector containing the Thiessen weights for each raingauge stations

****

E+1	NRN	Maximum no. of rainfall values at any raingauge station.
E+1+NRN	RAIN	Two dimensional array containing the rainfall values at each raingauge stations (Ngauge values) in a line for a time intervals. Thus there will be NRN lines

The main output of this option shall be the (Computed Theissen weights and) average rainfall values for the catchment at any given time interval.

4.3.1.4 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:

Line No.	Variable Name	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.

4.3.1.5 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:

Line No.	Variable Name	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.

4.3.2 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.

4.3.2.1 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:

Line No.	Variable Name	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.

4.3.2.2 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 :

Line No.	Variable Name	Description
1	N	No. of observations for gauge or discharge.
2	(GAUGE(I),I=1,N)	Vector containing Gauge Values (metre)
3	(DISCH(I),I=1,N)	Vector containing Discharge values (m^3/sec)

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.

(iii) 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 is 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.

4.3.2.3 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:

Line No.	Variable Name	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.

4.3.3 Excess Rainfall and Direct Surface Runoff Computations

This option of the package may be used to estimate the 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.

4.3.3.1 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:

Line No.	Variable Name	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 skipped 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.

4.3.3.2 *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 :

Line No.	Variable Name	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).

4.3.4 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.

4.3.4.1 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.

4.3.4.1.1 CONVENTIONAL METHOD

This option computes the unit hydrograph from the direct surface runoff hydrograph obtained by separating the constant base flow supplied by the user, from the discharge hydrograph of an isolated event. If rainfall details are also available, then programme tries to determine the unit duration also by different methods.

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

Line No.	Variable Name	Description
1	AR	Catchment area in Sq. Km.
2	VOL	Unit volume of Unit Hydrograph in mm.
3	DLT	Data interval in hours.
4	CB	Constant base flow in cumec.
5	N	No. of observations.
6	SRO	Vector containing the values of the discharge hydrograph ordinates in (m**3/sec).
7	NR	Number of rainfall blocks corresponding to discharge hydrograph.
		If information about rainfall is not available then put NR = 0.
		Following information is needed when NR is greater than ZERO.
8	DLR	Data interval of rainfall blocks in hours.
9	RAIN	Vector containing rainfall values in mm.

The main output of this option shall include :

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

(ii) Unit hydrograph ordinates.

(iii) Value of Constant phi-index and rainfall excess details.

(iv) Some guidance for unit duration of computed Unit Hydrograph.

4.3.4.1.2 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:

Line No.	Variable Name	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.

4.3.4.1.3 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:

Line No.	Variable Name	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).

4.3.4.1.4 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:

Line No.	Variable Name	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.

4.3.4.1.5 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:

Line No.	Variable Name	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.

4.3.4.1.6 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 'L' 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.

4.3.4.1.7 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 :

Line No.	Variable Name	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 ord nates (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.

4.3.4.1.8 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:

Line No.	Variable Name	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.

4.3.4.2 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.

4.3.4.2.1 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 :

Line No.	Variable Name	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.

4.3.4.2.2 Unit Hydrograph Using Regional Relationships Developed by CWC

This option of the package may be used to derive the unit hydrograph with unit volume 1 cm 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 :

Line No.	Variable Name		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 1 cm unit volume.

4.3.4.3 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 :

Line No.	Variable Name	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.

4.3.4.4 Unit Hydrograph of Changed Duration Using Superim-position 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.

Line No.	Variable Name	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.

4.3.4.5 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 :

Line No.	Variable Name	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).

4.3.4.6 Development of Dimensionless Hydrograph

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

Line No.	Variable Name	Description
1	N,DR,DLT	N = Number of UH ordinates. DR = Computation interval (hours). DLT = Duration of unit hydrograph.
2	CA	Catchment area (sq.km).
3	(UH(I),I=1,N)	Vector of UH ordinates in (m**3/s).

The main output file of this option shall be dimensionless hydrograph of abscissa as time as percentage of (lag + semi duration) and ordinates in Uh ordinates multiplied by (lag+ semi duration divided by runoff of volume in cumec days).

4.3.4.7 Development of Unit Hydrograph from a Dimensionless Hydrograph

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

Line No.	Variable Name	Description
1	N,LAG,DLT	N = Number of ordinates of dimensionless unit hydrograph.

		LAG= Lag time (hours). DLT= Desired duration of unit hydrograph.
2	CA	Catchment area (sq.km).
3	(DUH(I),I=1,N)	Vector of DUH ordinates in (m**3/s).

The main output file of this option shall be unit hydrograph of abscissa as time in hrs and ordinates in cumecs

4.4 UH APPLICATION ON SMALL CATCHMENTS FOR FLOOD ESTIMATION

This option of the package may be used to estimate the (design) flood hydrograph for small catchments using unit hydrograph approach. Out of three options available in the this category, 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. In the third option, 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- IV.

4.4.1 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 :

Line No.	Variable Name	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.

4.4.2 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 :

Line No.	Variable Name	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.

4.4.3 Computation of Design Flood

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

Line No.	Variable Name	Description
1	DLT	Computational interval (Hrs).

2	NRAIN	No. of rainfall values.
3	(R(I),I=1,NRAIN)	Vector containing the rainfall values (L.).
4	NDUH	No. of unit hydrograph ordinates.
5	(UH(I),I=1,NDUH)	Vector containing the ordinates of design unit hydrograph (Cumec).
6	UVOL	Unit volume of unit hydrograph (L).
7	TWLOSS , ULOSS	TWLOSS - Initial loss (L). ULOSS - Uniform loss rate (L/Hr).
8	BFLOW	Design base flow (Cumec).

Note: Unit of rainfall and loss rate will be same as the unit of unit volume of UH.

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

4.5 FLOOD ESTIMATION FOR LARGE CATCHMENTS

This option of the package may be used to estimate the flood hydrograph for large catchments (area more than 5000 sq. kms.) using flood routing and unit hydrograph approach. An example, sample input and output file for this option is given in Appendix V.

However, the following steps are involved in the derivation of flood hydrograph for the whole catchment:

(i) Divide the whole catchment into suitable number of sub catchments.

(ii) Identify the reaches and calculate individual reach length For each reach, identify total no of sub-catchments at the start of the reach.

(iii) For each sub-catchment, collect either flood hydrograph or storm (design storm), baseflow and unit hydrograph (design unit hydrograph) details.

(iv) Similarly for the reach, identify routing procedure and routing parameters. If routing parameters are not available then first calculate them using inflow and outflow hydrograph along with other information for that reach.

First step involves the calculation of flood (design flood) hydrograph for a sub-catchment if storm details and Unit Hydrograph details are available.

Then, flood hydrograph(s) of sub-catchment(s) at the start of the first reach are routed through the reach to get the routed outflow hydrograph. This outflow hydrograph combined with flood hydrograph of sub-catchment(s) meeting at start of second reach is routed through second reach to get routed flood hydrograph at the end of this reach. Likewise, the routed flood hydrograph may be computed for the last reach which will be the required flood hydrograph for the whole catchment.

It may also be noted here that if number of reaches is given as zero in first line of data file then in the second line only number of sub-catchments are to be given and programme will estimate the total flood of these catchment.

The values of the following input variables are required to be supplied in the free format either through a data file or at the time of creation of data file, as asked by the computer:

Line No.	Variable Name	Description
1	nreach, dlt, ft	nreach - No. of reaches. dlt - Computational time interval (Hrs). ft - Procedure for flood estimation. 1 - Design flood estimation. 2 - Flood estimation.

****

If nreach is greater than zero

2	input, dx, route	input - Number of sub-catchments in this reach. dx - Length of reach in km. route - Type of routing procedure for this reach. 1- Routing method is Muskingum routing method and values of parameters k and x for this reach are known. 2- Channel characteristics of the reach are known and routing procedure is 'Muskingum- Cunge method.
	if route =1 then	
3	k, x, bflow	k - Parameter k of Muskingum routing method in hours. x - Parameter x of Muskingum routing method. bflow - Average base flow contribution of this reach in cu. m/sec.
	if route = 2 then	
3	twqp, bslo, bflow, nopt	twqp - Top width of the channel corresponding to peak discharge in mtr. bslo - Channel bed slope (m/m). bflow - Average base flow contribution of this reach in cu. m/sec. nopt - Option for wave celerity. 1 -Wave celerity based on rating curve. 2 -Wave celerity from average velocity. 3 -Average velocity from Manning's n.
	If nopt = 1	
4	slrat	slrat - Inverse slope of the rating curve in the vicinity of peak discharge.
	if nopt = 2	

4 fare, beta — fare - Flow area corresponding to peak discharge in sq. m.
beta - Value of rating exponent.

if nopt = 3
4 man, beta — man - Value of Manning's n
beta - Value of rating exponent.

****

if nreach is zero then

2 input — input - Number of sub-catchments in this reach

****

if input is greater than zero then following data is required

5 type - Indicator for sub-catchment details:
0 - Flood hydrograph details for this sub-catchment are available.
1 - Storm rainfall and parameters of unit hydrograph for this sub-catchment are available.
2 - Storm rainfall and unit hydrograph details for this sub-catchment are available.

****

if type = 0

6 orno - Number of ordinates of flood hydrograph.

7 ord( ) - Vector containing orno values of flood hydrograph ordinates in a line, in cu.m./sec.

*end of catchment information

****

if type = 1

6 ca, tc, r — ca - Catchment area in sq. km.
tc - Time of concentration in hours.
r - Storage coefficient in hours.

7 nt - No. of ordinates of time area diagram.

8 tarea () - Vector containing time area diagram ordinates in sq. km.

****

if type = 2 then

6 orno - Number of ordinates of unit hydrograph.

7 uh( ) - A vector containing orno values of unit hydrograph. ordinates in a line, in cu.m./sec.

****

***Information common for type =2 and type = 3

d, vol, bflow, nr — d - Duration of unit hydrograph in hrs.
vol - Unit volume of unit hydrograph in mm.
bflow - Uniform baseflow rate in cu.m./sec.
nr - Number of rainfall blocks.

r( )	r	-	Vector containing nr values of rainfall in a line in mm per d hours.
il, fl	il	-	Initial loss rate in mm.
	fl	-	Constant loss rate in mm/hr.

****

**** Reservoir Routing ****

If type = 101 or 102 or 103 then

6	nrt, fac, bel	nrt	-	Number of values in storage-elevation-discharge table.
		fac	-	Factor by which inflows are to be multiplied.
		bel	-	Beginning elevation in mt.
7	table( )		-	Two dimensional vector containing nrt values of elevation storage and outflow respectively in each line.

if type = 104

6	coeff	coeff	-	Value of coefficient.

The main output of this option shall be the final flood hydrograph of the whole catchment.

4.6 PLOT / EDIT / CREATE / AND OTHER OPERATIONS ON A FILE

This option helps in plotting, viewing, creating, copying, deleting and editing of the files.

4.6.1 Plot 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 DF.PLT is automatically created which can be viewed here. If TAB key 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- VI.

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

4.6.2 Edit / Create a file

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

4.6.3 View 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.

4.6.4 Delete a file

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

4.6.5 Rename a file

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

4.6.6 Copy a file

This option copies the contents of a file selected to the new file. First the selected file will be checked for its existence in the directory. Package will again ask before copying the contents.

4.7 MONITOR SELECTION / SPEED OF DISPLAY

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.

Also, speed of graphics, displayed at the start of package can be controlled under this option. To increase the speed reduce the number while to decrease the speed increase the number.

4.8 ASSIGNMENT OF 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 package and all the data files may be stored in this directory. Working directory first selected will continue to be operation until another directory is specified through this option.

4.9 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:

4.9.1 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.

4.9.2 View / Modification in a 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.

4.9.3 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.

4.9.4 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 accidental supplying of name for result file.

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

4.9.5 Plot a File

As mentioned in earlier section, here also the PLT file can be selected and plotted.

4.9.6 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 existence in the directory and then package will confirm again before deletion.

References

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Appendices

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

Channel Routing Parameters Estimation and Application

1. Estimation of Muskingum Parameters Using Graphical Method

(a) Example

For a river reach inflow and outflow hydrograph at time interval of one hour are available. Constant baseflow value may be assumed as 18 cumec. Find out the parameter k of Muskingum channel routing by supplying appropriate value of x from the terminal and the corresponding outflow hydrograph?

Time in hrs.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Inflows in cumec	18	22	35	103	109	86	59	39	28	22	20	19	18	18
Outflows in cumec	18	18	20	34	55	75	85	80	64	44	30	22	20	18

(b) Input file

File name - DFMKG.DAT

```
1.0
14 18
18 22 35 103 109 86 59 39 28 22 20 19 18 18
18 18 20 34 55 75 85 80 64 44 30 22 20 18
```

(c) Output file

File name - MKG.OUT

```
DETERMINATION OF K AND X FOR MUSKINGUM CHANNEL ROUTING
**************************************************************************

VOLUME OF INFLOW HYDROGRAPH (CUMEC-HR)                    =   344.00
VOLUME OF OUTFLOW HYDROGRAPH (CUMEC-HR)                   =   331.00
VOLUME OF INFLOW HYDROGRAPH (CUMEC-HR)                    =   344.00
VOLUME OF ADJUSTED OUTFLOW HYDROGRAPH (CUMEC-HR)          =   344.00
VALUE OF X=  .20
```

TIME (HRS)	INFLOW (CUMEC)	OUTFLOW (CUMEC)	STORAGE (CUM-HR)	X*I+(1.-X)*O (CUMEC)
0.	0.00	0.00	0.00	0.00
1.	4.00	0.00	2.00	0.80
2.	17.00	2.08	11.46	5.06
3.	85.00	16.63	53.11	30.30
4.	91.00	38.45	113.57	48.96
5.	68.00	59.24	144.22	60.99
6.	41.00	69.63	134.29	63.91
7.	21.00	64.44	98.25	55.75
8.	10.00	47.81	57.63	40.25
9.	4.00	27.02	27.22	22.42
10.	2.00	12.47	10.47	10.38
11.	1.00	4.16	3.66	3.53
12.	0.00	2.08	1.04	1.66
13.	0.00	0.00	0.00	0.00

Value of k = 2.1124
Value of x = .30

TIME (HRS)	INFLOW (CUMEC)	OUTFLOW (CUMEC)	STORAGE (CUM-HR)	X*I+(1.-X)*O (CUMEC)
0.	.00	0.00	0.00	0.00
1.	4.00	0.00	2.00	1.20
2.	17.00	2.08	11.46	6.55
3.	85.00	16.63	53.11	37.14
4.	91.00	38.45	113.57	54.22
5.	68.00	59.24	144.22	61.87
6.	41.00	69.63	134.29	61.04
7.	21.00	64.44	98.25	51.40
8.	10.00	47.81	57.63	36.46
9.	4.00	27.02	27.22	20.11
10.	2.00	12.47	10.47	9.33
11.	1.00	4.16	3.66	3.21
12.	.00	2.08	1.04	1.45
13.	.00	0.00	0.00	0.00

Value of k = 2.1404

COMPUTATION OF OUTFLOW HYDROGRAPH USING MUSKINGUM PARAMETERS K AND X

****

TIME (HRS)	INFLOW (CUMEC)	OUTFLOW (CUMEC)	COUTFLOW (CUMEC)
0.	.00	0.00	0.00
1.	4.00	0.00	0.00
2.	17.00	2.08	0.93
3.	85.00	16.63	4.14
4.	91.00	38.45	44.18
5.	68.00	59.24	69.24
6.	41.00	69.63	70.54
7.	21.00	64.44	57.18
8.	10.00	47.81	39.86
9.	4.00	27.02	25.34
10.	2.00	12.47	14.80
11.	1.00	4.16	8.47
12.	0.00	2.08	4.80
13.	0.00	0.00	2.40

****

MUSKINGUM K= 2.14 MUSKINGUM X= .3000

EFFICIENCY (%) = 95.04

2. Estimation of Muskingum Parameters using Method of Moments

(a) Example

Find out the Muskingum parameters k and x for a river reach using the data of example 1.

(b) Input file

Sample data File DFMKM.DAT

```
1.0
14 18
```

18 22 35 103 109 86 59 39 28 22 20 19 18 18
18 18 20 34 55 75 85 80 64 44 30 22 20 18

(c) Output file

Sample output file name :MKM.OUT

ESTIMATION OF PARAMETERS OF MUSKINGUM CHANNEL ROUTING
USING METHOD OF MOMENTS
****

VOLUME OF INFLOW HYDROGRAPH (CUMEC-HR)	=	344.00
VOLUME OF OUTFLOW HYDROGRAPH (CUMEC-HR)	=	331.00
VOLUME OF INFLOW HYDROGRAPH (CUMEC-HR)	=	344.00
VOLUME OF ADJUSTED OUTFLOW HYDROGRAPH (CUMEC-HR)	=	344.00

Values of Parameters are: k = 1.9096 x = .37708

COMPUTATION OF OUTFLOW HYDROGRAPH USING MUSKINGUM PARAMETERS K AND X

****

TIME (HRS)	INFLOW (CUMEC)	OUTFLOW (CUMEC)	COUTFLOW (CUMEC)
0.	.00	0.00	0.00
1.	4.00	0.00	0.00
2.	17.00	2.08	0.46
3.	85.00	16.63	1.39
4.	91.00	38.45	50.10
5.	68.00	59.24	77.30
6.	41.00	69.63	75.31
7.	21.00	64.44	57.61
8.	10.00	47.81	37.37
9.	4.00	27.02	21.95
10.	2.00	12.47	11.59
11.	1.00	4.16	6.04
12.	.00	2.08	3.19
13.	.00	0.00	1.30

****

MUSKINGUM K= 1.91 MUSKINGUM X= .3771

EFFICIENCY (%) = 89.82

3. Estimation of Muskingum Parameters using Optimization Technique

(a) Example

Find out the Muskingum parameters k and x for a river reach using the data of example 1.

(b) Input file

Sample input file for this option :DFMKOP.DAT
1.0
2.0 0.3
0.0 0.0
10 0.8

14 18.0
18 22 35 103 109 86 59 39 28 22 20 19 18 18
18 18 20 34 55 75 85 80 64 44 30 22 20 18

(c) Output file

Sample output file for this input : MKOP.OUT

VOLUME OF INFLOW HYDROGRAPH (CUMEC-HR)	=	344.00
VOLUME OF OUTFLOW HYDROGRAPH (CUMEC-HR)	=	331.00
VOLUME OF INFLOW HYDROGRAPH (CUMEC-HR)	=	344.00
VOLUME OF ADJUSTED OUTFLOW HYDROGRAPH (CUMEC-HR)	=	344.00

COMPUTATION OF OUTFLOW HYDROGRAPH USING MUSKINGUM PARAMETERS K AND X

TIME (HRS)	INFLOW (CUMEC)	OUTFLOW (CUMEC)	COUTFLOW (CUMEC)
0.	.00	0.00	0.00
1.	4.00	0.00	0.00
2.	17.00	2.08	1.62
3.	85.00	16.63	7.72
4.	91.00	38.45	42.19
5.	68.00	59.24	64.26
6.	41.00	69.63	66.23
7.	21.00	64.44	55.18
8.	10.00	47.81	40.03
9.	4.00	27.02	26.68
10.	2.00	12.47	16.57
11.	1.00	4.16	10.07
12.	.00	2.08	6.03
13.	.00	0.00	3.33

MUSKINGUM K= 2.26 MUSKINGUM X= .2321

EFFICIENCY (%) = 96.06

4. Routing of Inflow Hydrograph using Available Muskingum Parameters

(a) Example

For a river reach inflow hydrograph at time interval of one hour is available from example 1. Constant baseflow value may be assumed as 18 cumec. Findout the outflow hydrograph using given parameters k=2.09 and x=.29 of Muskingum channel routing method.

(b) Input file

Sample input file name : DFMKR.DAT
1
2.09 0.29 18
14
18 22 35 103 109 86 59 39 28 22 20 19 18 18

(c) Output file

Output file name : MKR.OUT

COMPUTATION OF OUTFLOW HYDROGRAPH USING MUSKINGUM METHOD

****

Value of k= 2.0900 value of x = .2900 Baseflow = 18.00

Time in Hrs.	Inflow in Cumec	Outflow in Cumec
0.000	18.000	36.000
1.000	22.000	35.786
2.000	35.000	37.215
3.000	103.000	41.535
4.000	109.000	81.269
5.000	86.000	105.550
6.000	59.000	106.213
7.000	39.000	92.557
8.000	28.000	75.223
9.000	22.000	60.814
10.000	20.000	50.429
11.000	19.000	44.218
12.000	18.000	40.633
13.000	18.000	38.298
14.000	0.000	38.102
15.000	0.000	27.970
16.000	0.000	22.944
17.000	0.000	20.452
18.000	0.000	19.216
19.000	0.000	18.603
20.000	0.000	18.299
21.000	0.000	18.148
22.000	0.000	18.074
23.000	0.000	18.036

5. Routing of Inflow Hydrograph using Muskingum-Cunge Method

(a) Example: Use the Muskingum-cunge method to route a flood wave with the following flood and channel characteristics:

Peak flow $Q_p = 1000\ m^3/s$
Base flow $Q_b = 0\ m^3/s$
Channel bottom slope $S_o = 0.000868$
Flow area at peak discharge $A_p = 400\ m^2$
Top width at peak discharge $T_p = 100$ m
Rating exponent $\beta = 1.6$,
Reach Length $\Delta x = 14.4$ Km.
Time interval $\Delta t = 1$ hr.

Time (h)	0	1	2	3	4	5	6	7	8	9	10
Flow (m^3/s)	0	200	400	600	800	1000	800	600	400	200	0

(b) Input file

Sample input file name : DFMKCR.DAT

```
1.
14.4
100 .000868 0.0  2
400 1.60          if nopt=1 then 300 if 2 then 400 1.60 if 3 then 0.035 1.60
10
0 200 400 600 800 1000 800 600 400 200
```

(c) Output file

Description of sample output file: MKCR.OUT

```
************************
CHECKS APPLICATION
************************
(1)RESOLUTION CRITERIA OF C+D>1 CHECKED
(2)MIN. & MAX. REACH LENGTH CRITERIA SATISFIED
(3) DELTA t CRITERIA SATISFIED


COMPUTATION OF OUTFLOW HYDROGRAPH USING MUSKINGUM CUNGE METHOD

**************************************************************************************

!---------------------------------------------------!
!  Time in  !  Inflow in  !  Outflow in  !
!   Hrs.    !  Cumec      !   Cumec      !
!---------------------------------------------------!
!   0.000   !    0.000    !    0.000     !
!   1.000   !  200.000    !   18.183     !
!   2.000   !  400.000    !  201.653     !
!   3.000   !  600.000    !  400.150     !
!   4.000   !  800.000    !  600.014     !
!   5.000   ! 1000.000    !  800.001     !
!   6.000   !  800.000    !  963.634     !
!   7.000   !  600.000    !  796.694     !
!   8.000   !  400.000    !  599.699     !
!   9.000   !  200.000    !  399.973     !
!  10.000   !    0.000    !  199.998     !
!  11.000   !    0.000    !   18.183     !
!---------------------------------------------------!
```

Reservoir Routing

1. Resrevoir Routing using Mass Curve Method

(a) Example

Route the inflows through a reservoir using Mass Curve Method using the following details.
Initial elevation 1071 m.
Inflows values are to be used as such.
Values of elevation-storage and outflow detailsfor the reservoir:

Elevation meter	Storage 10**6 M**3	Outflow Cumecs
1070.	0.0	00.0
1071.	1.0	17.00
1072.	2.0	48.03
1073.	3.0	88.33
1074.	4.0	136.00
1075.	5.0	190.07
1076.	6.0	249.85

Inflow ordinates are as follows

Time (h)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Inlow (m^3/s)	0	20	50	100	130	150	140	110	90	70	50	30	20	17	17	17	17	17

(b) Input file

Sample input file name : DFMASS.DAT

```
7  1. 1071. 1.0
1070.  0.0     0.0
1071.  1.0    17.00
1072.  2.0    48.03
1073.  3.0    88.33
1074.  4.0   136.00
1075.  5.0   190.07
1076.  6.0   249.85
17
0. 20. 50. 100. 130. 150. 140. 110. 90. 70. 50. 30. 20. 17. 17. 17. 17.
```

(c) **output file**

Output file name :MASS.OUT

RESERVOIR ROUTING BY MASS TECHNIQUE

time accumulated (h)	dt (h)	mass inflow m**3/s h	cumulative mass inflow 10**6 m**3	assumed accumulated outflow 10**6 m**3	reservoir volume 10**6 m**3	average spillway discharge m**3/s	outflow for dt 10**6 m**3	cumulative outflow 10**6 m**3
.0	1.0	.00	.00	.00	.00	.00	.00	.00
1.0	1.0	10.00	.04	.04	.00	.00	.00	.00
2.0	1.0	35.00	.16	.16	.00	.00	.00	.00
3.0	1.0	75.00	.43	.43	.00	.00	.00	.00
4.0	1.0	115.00	.85	.45	.40	124.93	.45	.45
5.0	1.0	140.00	1.35	1.11	.24	187.39	.67	1.12
6.0	1.0	145.00	1.87	1.87	.00	218.62	.79	1.91
7.0	1.0	125.00	2.32	2.31	.01	234.23	.84	2.75
8.0	1.0	100.00	2.68	3.16	.00	117.12	.42	3.18
9.0	1.0	80.00	2.97	3.38	.00	58.56	.21	3.39
10.0	1.0	60.00	3.19	3.48	.00	29.28	.11	3.49
11.0	1.0	40.00	3.33	3.52	.00	14.64	.05	3.55
12.0	1.0	25.00	3.42	3.57	.00	7.32	.03	3.57
13.0	1.0	18.50	3.49	3.56	.00	3.66	.01	3.58
14.0	1.0	17.00	3.55	3.58	.00	1.83	.01	3.59
15.0	1.0	17.00	3.61	3.58	.03	125.84	.45	4.04
16.0	1.0	17.00	3.67	4.26	.00	62.92	.23	4.27

2. Resrevoir Routing using Modified Puls Method

(a) **Example**

Using the data of example above, findout the routed outflow hydrograph using modified Puls method.

(b) **Input file**

Input file : DFPULS.DAT

```
7  1.0 1071 1.0
1070.  0.0     0.0
1071.  1.0    17.00
1072.  2.0    48.03
1073.  3.0    88.33
1074.  4.0   136.00
1075.  5.0   190.07
1076.  6.0   249.85
17
0. 20. 50. 100. 130. 150. 140. 110. 90. 70. 50. 30. 20. 17. 17. 17. 17.
```

(c) Output file

Output file name : PULS.OUT

MODIFIED PULS METHOD OF RESRERVOIR ROUTING

S. NO	ELEVATION METER	STORAGE E+06 M**3	OUTFLOW CUMECS
1	1070.000	.000	0.000
2	1071.000	1.000	17.000
3	1072.000	2.000	48.030
4	1073.000	3.000	88.330
5	1074.000	4.000	136.000
6	1075.000	5.000	190.070
7	1076.000	6.000	249.850

THE BEGINNING ELEVATION IS 1071.000 METER

S. N	INFLOW CUMECS	OUTFLOW CUMECS	ELEVATION METER	STORAGE E+06 M**3
1	0.00	17.00	1071.00	1.00
2	20.00	16.58	1070.98	0.98
3	50.00	18.21	1071.04	1.04
4	100.00	24.22	1071.23	1.23
5	130.00	33.82	1071.54	1.54
6	150.00	45.05	1071.90	1.90
7	140.00	57.75	1072.24	2.24
8	110.00	66.84	1072.47	2.47
9	90.00	71.33	1072.58	2.58
10	70.00	72.50	1072.61	2.61
11	50.00	70.81	1072.57	2.57
12	30.00	66.64	1072.46	2.46
13	20.00	61.01	1072.32	2.32
14	17.00	55.26	1072.18	2.18
15	17.00	50.08	1072.05	2.05
16	17.00	46.14	1071.94	1.94
17	17.00	43.05	1071.84	1.84

3. Resrevoir Routing using Goodrich method

(a) Example

Using the data of option 1, findout the outflow hydrograph using Goodrich method of reservoir routing.

(b) Input file

Input file name : DFGRICH.DAT

```
7  1.0 1071 1.0
1070.  0.0     0.0
1071.  1.0     17.00
1072.  2.0     48.03
1073.  3.0     88.33
1074.  4.0     136.00
1075.  5.0     190.07
1076.  6.0     249.85
17
0. 20. 50. 100. 130. 150. 140. 110. 90. 70. 50. 30. 20. 17. 17. 17. 17.
```

(c) **Output file**

Output file name GRICH.OUT

GOODRICH METHOD OF RESERVOIR ROUTING

S. NO	ELEVATION METER	STORAGE E+06 M**3	OUTFLOW CUMECS
1	1070.000	.000	0.000
2	1071.000	1.000	17.000
3	1072.000	2.000	48.030
4	1073.000	3.000	88.330
5	1074.000	4.000	136.000
6	1075.000	5.000	190.070
7	1076.000	6.000	249.850

THE BEGINNING ELEVATION IS 1071.000 METER

S. N	INFLOW CUMECS	OUTFLOW CUMECS	ELEVATION METER	STORAGE E+06 M**3
1	0.00	17.00	1071.00	1.00
2	20.00	16.58	1070.98	0.98
3	50.00	18.21	1071.04	1.04
4	100.00	24.22	1071.23	1.23
5	130.00	33.82	1071.54	1.54
6	150.00	45.05	1071.90	1.90
7	140.00	57.75	1072.24	2.24
8	110.00	66.84	1072.47	2.47
9	90.00	71.33	1072.58	2.58
10	70.00	72.50	1072.61	2.61
11	50.00	70.81	1072.57	2.57
12	30.00	66.64	1072.46	2.46
13	20.00	61.01	1072.32	2.32
14	17.00	55.26	1072.18	2.18
15	17.00	50.08	1072.05	2.05
16	17.00	46.14	1071.94	1.94
17	17.00	43.05	1071.84	1.84

4. Resrevoir Routing using Coefficient Method

(a) Example

Considering the value of coefficient as 1 and using the data of example as given above, find out the outflow hydrograph from the reservior using Coefficient method.

(b) Input file

Input file name : DFCOEFF.DAT

1 1.

17

0. 20. 50. 100. 130. 150. 140. 110. 90. 70. 50. 30. 20. 17. 17. 17. 17.

(c) Output file

Output file name COEFF.OUT

COEFFICIENT METHOD OF RESRERVOIR ROUTING

VALUE OF COEFFICIENT = 1.00

S. NO	INFLOW CUMECS	OUTFLOW CUMECS
1	0.00	0.00
2	20.00	6.67
3	50.00	25.56
4	100.00	58.52
5	130.00	96.17
6	150.00	125.39
7	140.00	138.46
8	110.00	129.49
9	90.00	109.83
10	70.00	89.94
11	50.00	69.98
12	30.00	49.99
13	20.00	33.33
14	17.00	23.44
15	17.00	19.15
16	17.00	17.72
17	17.00	17.24
18	.00	11.41
19	.00	3.80
20	.00	1.27
21	.00	.42
22	.00	.14

Unit Hydrograph Development

(a) 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 file

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 DFGAPF.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 file

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 of a Record using Double Mass Curve Technique

(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 file

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 DFDOUBLE.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 file

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

Yearly rainfall values observed at twelve raingauge stations in a catchment are given below. X and Y Coordinates defining the catchment boundry, coordinates of raingauge stations and scale of map are also given. Find out the average rainfall in the catchment using Theissen Polygon method and theissen weights associated with each station.

No of coordinates values = 78
Scale of catchment map 1 cm = 2.5 Km.
X and Y coordinates defining catchment boundry in cms.

X	Y
0	18.6
1	18.2
2	17.6
2.2	15
2.6	13
3	5.5
3.5	6
4	6.7
5	7.4
5.5	7.6
6	7.5

6.5	7.3
7	6.5
7.5	6
8	6.1
8.3	7.1
9	6.6
10	5
11	3.9
12	3.2
13	2.3
14	1.4
15	0.8
15.5	0.8
16	0.6
17	0
18	0.3
19	0.8
20	1.3
21	1.5
22	1.4
23	8.2
24	8.6
25	9.5
26	10.3
27	10.6
28	12.8
29	13.4
29.5	13.5
29	17
28	18.2
27	18.6
26	18.3
25	17.6
24	17.1
23	17.1
22	17.9
21	18.1
20	18.4
19	18.7
18	19.5
17	19.1
16	19.2
15.5	19.1
15	16.6
14	16.5
13	16.4
12	16.6
11	16.7
10	16.9
9	17.3
8.3	17.2
8	17.2
7.5	17.8
7	18.7
6.5	18.2

6	17.5
5.5	17.6
5	17.8
4	18.2
3.5	18.4
3	18.8
2.6	19.2
2.2	19.6
2	19.8
1	20.4
0	21.0
0	18.6

Number of raingauge stations = 12
X and Y coordinates of raingauge stations

X	Y
23.3	17.2
18.1	2.4
3.2	17.6
21.6	10.6
3.2	15.1
18.4	17.7
0.4	20.7
6.4	11.3
9.7	12.7
7.6	12.4
13	1.1
24.9	3.1

Number of years = 6
Yearly rainfall data in centimeters at each station

36.20	100.30	105.00	.00	.00	.00	29.00	32.00	.00	.00	127.20	.00
157.00	113.00	43.00	56.00	36.80	80.70	56.70	88.40	.00	44.30	147.40	571.80
422.80	473.00	476.00	208.00	419.10	301.20	302.70	358.00	65.80	427.00	745.10	799.30
470.70	419.00	362.00	212.00	328.10	284.10	369.10	328.00	.00	390.40	578.40	840.30
199.90	312.00	205.00	221.00	159.30	487.50	174.70	226.20	.00	235.80	343.00	608.50
165.00	123.00	60.00	164.00	59.00	139.30	86.20	202.80	.00	108.70	337.20	578.60

(b) Input file

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 DFTHIES.DAT would be :

```
 1
    78  2.5
     0   18.6
     1   18.2
     2   17.6
   2.2     15
   2.6     13
     3    5.5
   3.5      6
     4    6.7
     5    7.4
   5.5    7.6
     6    7.5
   6.5    7.3
```

7	6.5
7.5	6
8	6.1
8.3	7.1
9	6.6
10	5
11	3.9
12	3.2
13	2.3
14	1.4
15	0.8
15.5	0.8
16	0.6
17	0
18	0.3
19	0.8
20	1.3
21	1.5
22	1.4
23	8.2
24	8.6
25	9.5
26	10.3
27	10.6
28	12.8
29	13.4
29.5	13.5
29	17
28	18.2
27	18.6
26	18.3
25	17.6
24	17.1
23	17.1
22	17.9
21	18.1
20	18.4
19	18.7
18	19.5
17	19.1
16	19.2
15.5	19.1
15	16.6
14	16.5
13	16.4
12	16.6
11	16.7
10	16.9
9	17.3
8.3	17.2
8	17.2
7.5	17.8
7	18.7
6.5	18.2
6	17.5

5.5	17.6
5	17.8
4	18.2
3.5	18.4
3	18.8
2.6	19.2
2.2	19.6
2	19.8
1	20.4
0	21
0	18.6

12

23.3	17.2
18.1	2.4
3.2	17.6
21.6	10.6
3.2	15.1
18.4	17.7
0.4	20.7
6.4	11.3
9.7	12.7
7.6	12.4
13	1.1
24.9	3.1

6

36.20	100.30	105.00	.00	.00	.00	29.00	32.00	.00	.00	127.20	.00
157.00	113.00	43.00	56.00	36.80	80.70	56.70	88.40	.00	44.30	147.40	571.80
422.80	473.00	476.00	208.00	419.10	301.20	302.70	358.00	65.80	427.00	745.10	799.30
470.70	419.00	362.00	212.00	328.10	284.10	369.10	328.00	.00	390.40	578.40	840.30
199.90	312.00	205.00	221.00	159.30	487.50	174.70	226.20	.00	235.80	343.00	608.50
165.00	123.00	60.00	164.00	59.00	139.30	86.20	202.80	.00	108.70	337.20	578.60

(c) Output file

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

```
The area of the catchment is 2206.96900 sq. km.

********************
Gauge No.   Weight
********************
    1        .088
    2        .105
    3        .053
    4        .140
    5        .026
    6        .096
    7        .009
    8        .123
    9        .211
   10        .053
   11        .070
   12        .026
********************
          AVERAGE RAINFALL (MM)
  32.37  83.62  337.48  297.02  225.22  138.86
```

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 file

For the above example the structure of the input file DFISO.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 file

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. VOL CU. M	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 rainfall into 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 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 file**

For the above example the structure of the input file DFDAILY.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 file**

An 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

(b) Rating Curve Analysis and Computation of Discharge

1. Computation of Discharge from Velocity Measurements

(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**2	3.1	5.1	7.1	9.2	6.6	4.8	2.6
Velocities	0.65	0.70	0.70	0.75	0.65	0.60	0.60
(m/sec)	0.80	0.85	0.84	0.89	0.85	0.71	0.70
		0.84	0.82	0.87	0.85	0.70	0.62
			0.80	0.78	0.70		

(b) Input file

For the above example the structure of the input file DFVEL.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 file**

A 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 file**

For the above example the structure of the input file DFRATING.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 file**

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  OBS. DISCH  COMP. DISCH
        (CUMEC)     (CUMEC)     (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. Conversion of Stage Values to Corresponding Discharge Values

(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 file

For the above example the structure of the input file DFGAUGE.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 file

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
```

(c) Excess Rainfall and Direct Surface Runoff Computations

1. Computation of Excess Rainfall from Discharge Hydrograph

(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 file

The structure of the input file DFEFF.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 file

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. Estimation of Effective Rainfall and Direct Surface Runoff for a Storm Event

(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 file

The structure of the input file DFLOSS.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 file

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
```

(d) Unit Hydrograph Derivation

1. Unit Hydrograph for Gauged Catchments

(i) Conventional Method

(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 425 sq. 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

Storm hyetograph

time (h)	2	4	6
Rainfall (mm)	8	28	16

(b) Input file

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

425
10
2
10
12
10 57 153 236 202 176 116 91 48 22 12 10
3
2
8 28 16

(c) Output file

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

VOLUME OF RAINFALL (M**3) = 7293600.00
CATCHMENT AREA (SQ KM) = 425.00
EFFECTIVE RAINFALL (MM) = 17.16

TIME HRS.	RUOFF ORD. M**3/SEC	D. RUNOFF ORDINATES M**3/SEC	UNIT HYDROGRAPH ORDINATES M**3/SEC
0.	10.000	.000	.000
2.	57.000	47.000	27.387
4.	153.000	143.000	83.326
6.	236.000	226.000	131.691
8.	202.000	192.000	111.879
10.	176.000	166.000	96.729
12.	116.000	106.000	61.766
14.	91.000	81.000	47.199
16.	48.000	38.000	22.143
18.	22.000	12.000	6.992
20.	12.000	2.000	1.165
22.	10.000	.000	.000

UNIFORM PHI INDEX = 13.419 PER 2. HRS.

TIME IN HRS.	RAINFALL IN MM.	PHI INDEX IN MM.	RAINFALL EXCESS IN MM.
0.	8.000	13.419	.000
2.	28.000	13.419	14.581
4.	16.000	13.419	2.581

Determination of Unit duration of Unit Hydrograph

Unit duration from rainfall details: 4. HRS.

Unit duration (one third of time to peak) : 4 Hrs.

Modified unit duration checked with respect to
magnitude of each time block of rainfall excess : 2 Hrs.
Please check the unit duration with S-curve also

(ii) 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 file

The structure of the input file DFCOLUH.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 file

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)

TIME (HRS)	6.-HOUR U.H.ORDINATES (CUMEC)
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

(iii) 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 file

The structure of the input file DFNASHG.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

(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 file

The structure of the input file DFNASHF.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 file

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          6.-HOUR U.H. ORDINATES
(HRS)               (CUMEC)
  0.                  .000
  6.                 2.939
 12.                17.731
 18.                23.556
 24.                17.414
 30.                 9.578
 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 file

The structure of the test input file DFNASHH.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 file

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

(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 file

The structure of the input file DFINTNAS.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 file

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           6.-HOUR U.H. ORDINATES
(HOURS)                (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 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 file

The structure of the input file DFCLARKF.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 file

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

(ix) 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 file

The structure of the input file DFCLARKH.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
4 4
1 1
12 12
```

(c) Output file

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

Value of tc= 4.496
Value of r = 2.472

UH ordinates

Time (Hrs)	UH Ordinates (Cumec)
.00	.00
1.00	.90
2.00	2.87
3.00	4.22
4.00	5.86
5.00	6.02
6.00	3.99

7.00	2.65
8.00	1.76
9.00	1.17
10.00	.77
11.00	.51
12.00	.34
13.00	.23
14.00	.15
15.00	.10
16.00	.07
17.00	.04

UH peak = 6.02 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	6.57
2.	3.00	24.80
3.	15.00	46.07
4.	78.00	70.40
5.	120.00	83.06
6.	82.00	74.38
7.	54.00	56.36
8.	36.00	37.40
9.	26.00	24.81
10.	21.00	16.46
11.	15.00	10.92
12.	11.00	7.25
13.	7.00	4.81
14.	3.00	3.19
15.	.00	2.12

Efficiency of the model = 83.508

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 :

$$t_p = C_t\,(LL_{ca})^{0.30}$$

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 file

The structure of input file DFSNYD.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 file

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 the Regional Relationship developed by CWC*

(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.....a_7, b_1..... 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 file

The structure of the input file DFCWC.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 file

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 file

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

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

(c) Output file

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. Change of Unit Duration of Unit Hydrograph 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 file

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

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

(c) Output file

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.	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

5. Change of Unit Duration of Unit Hydrograph 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 file

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

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

(c) Output file

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

6. Development of Dimensionless Hydrograph

(a) Example

A 3 hour unit hydrograph for a catchment of area 1950 sq. km. is availabl. Construct a dimensionless hydrograph for the catchment.

Time in hrs..	UH ordinates in cumecs
.0	.00
6.0	13.20
12.0	41.60
18.0	83.20
24.0	247.20
30.0	263.00
36.0	204.60
42.0	123.80
48.0	74.90
54.0	45.20
60.0	27.40
66.0	16.60
72.0	10.10
78.0	6.10
84.0	3.60
90.0	2.10
96.0	.00

(b) Input file

For this example structure of input file DFDIMLESS.dat would be as follows:

```
17,6.0,3.0
1950.0
0.0,13.2,41.6,83.2,247.2,263.0,204.6,123.8,74.9,
45.2,27.4,16.6,10.1,6.1,3.6,2.1,0.0
```

(c) Output file

Output file DIMLESS.OUT created by the above input file contains the fillowing :

TIME IN HRS.	UNIT HYDROGRAPH ORDINATE IN CUMECS
.0	.00
6.0	13.20
12.0	41.60
18.0	83.20
24.0	247.20
30.0	263.00
36.0	204.60
42.0	123.80
48.0	74.90
54.0	45.20
60.0	27.40
66.0	16.60
72.0	10.10
78.0	6.10
84.0	3.60
90.0	2.10
96.0	.00

TIME AS % OF(LAG+SEMI DU.)	ORDINATES OF DIMENSIONLESS GRAPH IN CUMECS
.00	.00
17.15	2.05
34.30	6.45
51.45	12.90
68.59	38.32
85.74	40.77
102.89	31.72
120.04	19.19
137.19	11.61
154.34	7.01
171.48	4.25
188.63	2.57
205.78	1.57
222.93	.95
240.08	.56
257.23	.33
274.37	.00

7. Development of Unit Hydrograph from a Dimensionless Hydrograph

(a) Example

Dimensionless hydrograph for a region is available. It is decided to use this hydrograph for the development of a three hour unit hydrograph for a catchment having area 1950 sq. km.Lagtime is 33.49 hrs. find out the UH ordinates.

TIME AS % OF (LAG+SEMI DU.	ORDINATES OF DIMENSIONLESS GRAPH IN CUMECS
.0	.00
17.1	2.05
34.3	6.45
51.4	12.90
68.6	38.32
85.7	40.77
102.9	31.72
120.0	19.19
137.2	11.61
154.3	7.01
171.5	4.25
188.6	2.57
205.8	1.57
222.9	.95
240.1	.56
257.2	.33
274.4	.00

(b) Input file

Structure of input file DFDIM.DAT for this option would be as follows:

```
17  33.49  3.0
1950.0
0.0  17.15  34.30  51.445  68.59  85.742 102.89 120.039  137.187  154.335 171.484 188.632
205.78 222.93  240.077 257.226 274.374
0.0  2.046357  6.449124 12.898250 38.322680 40.772110 31.718530 19.192340
11.611520  7.007221  4.247740  2.573449 1.565773   0.945665  0.558097 0.326  0.0
```

(c) Output file

Output file DIM.OUT created by the above input file contains the fillowing :

TIME AS % OF (LAG+SEMI DU.	ORDINATES OF DIMENSIONLESS GRAPH IN CUMECS
.0	.00
17.1	2.05
34.3	6.45
51.4	12.90
68.6	38.32
85.7	40.77
102.9	31.72
120.0	19.19
137.2	11.61
154.3	7.01
171.5	4.25
188.6	2.57
205.8	1.57
222.9	.95
240.1	.56
257.2	.33
274.4	.00

TIME IN HRS.	UNIT HYDROGRAPH ORDINATE IN CUMECS
.00	.00
6.00	13.20
12.00	41.60
18.00	83.20
24.00	247.19
30.00	262.99
36.00	204.59
42.00	123.80
48.00	74.90
54.00	45.20
60.00	27.40
66.00	16.60
72.00	10.10
78.00	6.10
84.00	3.60
90.00	2.10
96.00	.00

UH Application on Small Catchment for Flood Estimation

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 file

The structure of input file DFSYNTH.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 file

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 file

The structure of input file DFRE?ROD.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 file

An output file REPRODUCT.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   OBS. D. S. R. O.  COMPUTED D. S. R. O.
   (HRS)      (CUMEC)         (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

3. Computation of Design Flood

(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 file

The structure of the input file DFDESIGN.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 file

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

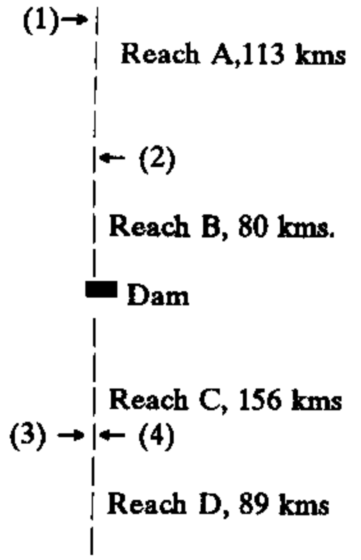
NOTE:-

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

Flood Estimation for Large Catchments

(a) Example

A large size catchment is divided into four sub catchments. There is a dam also on the river channel as shown in the figure below.



For catchment 1, Design flood hydrograph, for catchment 2 design unit hydrograph and storm, for catchment 3 design flood hydrograph and for catchment 4 parameters of Clark unit hydrograph and storm details are available. For reservoir inflow storage and outflow details and begining elevation are available. Based on these details compute the resulting design flood hydrograph at the outlet of the catchment.

Reach A
Value of Muskingum K =2 Value of Muskingum X = 0.2
Constant baseflow in cumec = 8.9 Reach length = 113 kms
Time interval 2 hrs.
Catchment 1
Design flood hydrograph ordinates in cumecs at 2 hr interval
10 118.7 1011.9 2913.7 4146.5 3564.1 2195.4 1096.6 476.6 187.8 56 12

Reach B
Value of Muskingum K =2 Value of Muskingum X = 0.2
Constant baseflow in cumec = 10.0 Reach length = 80 kms
Time interval 2 hrs.
Catchment 2
Design 2 hour unit hydrograph oprdinates at 2 hour interval in cumec
0 47 143 226 192 166 106 81 38 12 2 0
Base flow 12 cumec
Unit depth of UH = 10 mm
Cumulative rainfall in mm per 2 hours
8 36 52
Initial loss rate 10 mm and constant Phi index 7 mm/hr.

Reach C
Value of Muskingum K =2 Value of Muskingum X = 0.2
Constant baseflow in cumec = 10.0 Reach length = 156 kms

Time interval 2 hrs.

Reservoir table

Elevation in mt.	storage in Mm	Outflow in cumec
100	13.345	0
100.5	18.472	100
101	23.88	260
101.5	40.383	460
102	54.882	720
102.5	65.37	1200
102.75	88.527	1936
102	105.856	2930

Begining elevation = 100.5 mt.

Reach D
Value of Muskingum K =2
Value of Muskingum X = 0.2
Constant baseflow in cumec = 10.0
Reach length = 89 kms
Time interval 2 hrs

Catchment 3
Design flood hydrograph ordinates in cumec at 2 hr intervals
20 150 1140 1800 2670 3825 3390 2790 2220 1770 1050 516 351 105

Catchment 4
Catchment area 250 sq. km.
Parameters for Clark unit hydrograph
Value of Tc =8 hrs.
Value of r = 7.5 hrs.
Values of time area diagram in kms. at 2 hr intervals
Unit duration of unit hydrograph to be developed = 2hrs., unit depth = 10 mm
Baseflow = 12 cumec
Number of rainfall blocks = 3
Cumulative rainfall in mm per 2 hours
22 40 62
Initial loss rate 10 mm and constant Phi index 7.5 mm/hr.

(b) Input file

Input file DFNET.DAT for this problem would be as follows:

```
4        2        1
1        113      1
2        .2       8.9
0
12
10 118.7 1011.9 2913.7 4146.5 3564.1 2195.4 1096.6 476.6 187.8 56 12
1        80       1
2        .2       10
2
12
0 47 143 226 192 166 106 81 38 12 2 0
2        10       12       3
8 36 52
10 7
1        156      1
```

2 .2 10
102
8 1 100.5
100 13.345 0
100.5 18.472 100
101 23.88 260
101.5 40.383 460
102 54.882 720
102.5 65.37 1200
102.75 88.527 1936
102 105.856 2930
2 89 1
2 .2 10
0
14
20 150 1140 1800 2670 3825 3390 2790 2220 1770 1050 516 351 105
1
250.0 8. 7.5
5
0 33 82 82 53
2 10 12 3
22 40 62
10 7.5

(c) Output file

Structure of output file NET.OUT created by the above option would be as follows

Reach No. 1 Time interval = 2.0 Hrs.
Sub-catchment No. 1

In CUMEC

S. N	Flow prior to this catchment	Sub catchment Flow	Total Flow
1	.000	10.000	10.000
2	.000	118.700	118.700
3	.000	1011.900	1011.900
4	.000	2913.700	2913.700
5	.000	4146.500	4146.500
6	.000	3564.100	3564.100
7	.000	2195.400	2195.400
8	.000	1096.600	1096.600
9	.000	476.600	476.600
10	.000	187.800	187.800
11	.000	56.000	56.000
12	.000	12.000	12.000

COMPUTATION OF OUTFLOW HYDROGRAPH USING MUSKINGUM METHOD

****

Value of K= 2.0000 value of X = .2000 Baseflow = 8.90

Time in Hrs.	Inflow in Cumec	Outflow in Cumec
.000	10.000	18.900
2.000	118.700	43.985
4.000	1011.900	314.427
6.000	2913.700	1296.668
8.000	4146.500	2831.877
10.000	3564.100	3715.572
12.000	2195.400	3290.047
14.000	1096.600	2201.288
16.000	476.600	1215.297
18.000	187.800	587.269
20.000	56.000	256.416
22.000	12.000	98.942
24.000	.000	36.140

Reach No. 2 Time interval = 2.0 Hrs.

Sub-catchment No. 1

DESIGN FLOOD COMPUTATIONS USING UNIT HYDROGRAPH BASED APPROACH

T	CR	RI	UHO.	RA	DR	EXR	DSRO	DFLH.
0.	8.00	8.00	.00	.00	8.00	.00	.00	.00
2.	36.00	28.00	47.00	.00	16.00	.00	.00	.00
4.	52.00	16.00	143.00	.00	28.00	14.00	.00	12.00
6.	.00	.00	226.00	28.00	.00	.00	65.80	77.80
8.	.00	.00	192.00	16.00	.00	.00	200.20	212.20
10.	.00	.00	166.00	8.00	.00	.00	316.40	328.40
12.	.00	.00	106.00	.00	.00	.00	268.80	280.80
14.	.00	.00	81.00	.00	.00	.00	232.40	244.40
16.	.00	.00	38.00	.00	.00	.00	148.40	160.40
18.	.00	.00	12.00	.00	.00	.00	113.40	125.40
20.	.00	.00	2.00	.00	.00	.00	53.20	65.20
22.	.00	.00	.00	.00	.00	.00	16.80	28.80
24.	.00	.00	.00	.00	.00	.00	2.80	14.80
26.	.00	.00	.00	.00	.00	.00	.00	12.00

NOTE:-

T IS TIME IN HOURS
CR IS CUMMULATIVE RAINFALL
RI IS RAINFALL INCREMENT
UHO. IS (DESIGN) UNIT HYDROGRAPH ORDINATES IN CUMEC
RA IS RAINFALL ARRANGED
DR IS (DESIGN) RAINFALL
EXR IS (DESIGN) EXCESS RAINFALL

DSRO IS (DESIGN) DIRECT SURFACE RUNOFF IN CUMEC
DFLH. IS (DESIGN) FLOOD HYDROGRAPH IN CUMEC
UNIT OF RAINFALL IS SAME AS UNIT OF UH UNIT VOLUME

In CUMEC

S. N	Flow prior to this catchment	Sub catchment Flow	Total Flow
1	18.900	.000	18.900
2	43.985	.000	43.985
3	314.427	12.000	326.427
4	1296.668	77.800	1374.468
5	2831.877	212.200	3044.077
6	3715.572	328.400	4043.972
7	3290.047	280.800	3570.847
8	2201.288	244.400	2445.688
9	1215.297	160.400	1375.697
10	587.269	125.400	712.669
11	256.416	65.200	321.616
12	98.942	28.800	127.742
13	36.140	14.800	50.940
14	.000	12.000	12.000

COMPUTATION OF OUTFLOW HYDROGRAPH USING MUSKINGUM METHOD
****

Value of K= 2.0000 value of X = .2000 Baseflow = 10.00

Time in Hrs.	Inflow in Cumec	Outflow in Cumec
0.000	18.900	28.900
2.000	43.985	34.689
4.000	326.427	114.711
6.000	1374.468	527.117
8.000	3044.077	1571.912
10.000	4043.972	2942.784
12.000	3570.847	3688.361
14.000	2445.688	3346.006
16.000	1375.697	2414.225
18.000	712.669	1470.043
20.000	321.616	804.897
22.000	127.742	396.094
24.000	50.940	179.638
26.000	12.000	79.346
28.000	00.000	32.464
30.000	00.000	15.184
32.000	00.000	11.196
34.000	00.000	10.276
36.000	00.000	10.064
38.000	00.000	10.015

Reach No. 3 Time interval = 2.0 Hrs.

Sub-catchment No. 1 (DAM)

MODIFIED PULS METHOD OF RESRERVOIR ROUTING

S. N	ELEVATION METER	STORAGE E+06 M**3	OUTFLOW CUMECS
1	100.000	13.345	000.000
2	100.500	18.472	100.000
3	101.000	23.880	260.000
4	101.500	40.383	460.000
5	102.000	54.882	720.000
6	102.500	65.370	1200.000
7	102.750	88.527	1936.000
8	102.000	105.856	2930.000

THE BEGINNING ELEVATION IS 100.500 METER

S. N.	INFLOW CUMECS	OUTFLOW CUMECS	ELEVATION METER	STORAGE E+06 M**3
1	28.90	100.00	100.50	18.47
2	34.69	91.05	100.46	18.01
3	114.71	88.90	100.44	17.90
4	527.12	128.39	100.59	19.43
5	1571.91	279.85	101.05	25.52
6	2942.78	445.19	101.46	39.16
7	3688.36	875.46	102.16	58.28
8	3346.01	1506.90	102.60	75.03
9	2414.23	1788.88	102.70	83.90
10	1470.04	1820.35	102.71	84.89
11	804.90	1680.12	102.66	80.48
12	396.09	1458.43	102.59	73.50
13	179.64	1218.06	102.51	65.94
14	79.35	916.92	102.21	59.18
15	32.46	699.99	101.96	53.77
16	15.18	617.99	101.80	49.19
17	11.20	544.63	101.66	45.10
18	10.28	479.88	101.54	41.49
19	10.06	434.43	101.44	38.27
20	10.01	398.95	101.35	35.35

COMPUTATION OF OUTFLOW HYDROGRAPH USING MUSKINGUM METHOD

****

Value of K= 2.0000 value of X = .2000 Baseflow = 10.00

Time in Hrs.	Inflow in Cumec	Outflow in Cumec
.000	100.000	110.000
2.000	91.050	107.935
4.000	88.905	102.144
6.000	128.387	108.763
8.000	279.855	166.505
10.000	445.191	299.544
12.000	875.461	518.566
14.000	1506.899	946.510
16.000	1788.879	1450.343
18.000	1820.349	1725.710
20.000	1680.124	1773.842
22.000	1458.430	1658.284
24.000	1218.063	1456.773
26.000	916.921	1211.348
28.000	699.994	942.498
30.000	617.986	744.724
32.000	544.635	637.998
34.000	479.882	558.930
36.000	434.434	495.328
38.000	398.951	447.990
40.000	.000	325.894
42.000	.000	82.899
44.000	.000	26.823
46.000	.000	13.882
48.000	.000	10.896
50.000	.000	10.207
52.000	.000	10.048

Reach No. 4 Time interval = 2.0 Hrs.
Sub-catchment No. 1

In CUMEC

S. N	Flow prior to this catchment	Sub catchment Flow	Total Flow
1	110.000	20.000	130.000
2	107.935	150.000	257.935
3	102.144	1140.000	1242.144
4	108.763	1800.000	1908.763
5	166.505	2670.000	2836.505
6	299.544	3825.000	4124.544
7	518.566	3390.000	3908.566
8	946.510	2790.000	3736.510
9	1450.343	2220.000	3670.343
10	1725.710	1770.000	3495.710
11	1773.842	1050.000	2823.842

12	1658.284	516.000	2174.284
13	1456.773	351.000	1807.773
14	1211.348	105.000	1316.348
15	942.498	.000	942.498
16	744.724	.000	744.724
17	637.998	.000	637.998
18	558.930	.000	558.930
19	495.328	.000	495.328
20	447.990	.000	447.990
21	325.894	.000	325.894
22	82.899	.000	82.899
23	26.823	.000	26.823
24	13.882	.000	13.882
25	10.896	.000	10.896
26	10.207	.000	10.207
27	10.048	.000	10.048

Sub-catchment No. 2

CLARK MODEL COMPUTATIONS

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
2.00	10.785	5.498
4.00	35.047	23.364
6.00	53.600	45.190
8.00	58.310	57.049
10.00	44.590	52.456
12.00	34.098	40.113
14.00	26.075	30.675
16.00	19.940	23.457
18.00	15.248	17.938
20.00	11.660	13.717
22.00	8.917	10.490
24.00	6.819	8.022
26.00	5.214	6.134
28.00	3.987	4.691
30.00	3.049	3.587
32.00	2.332	2.743
34.00	1.783	2.098

DESIGN FLOOD COMPUTATIONS USING UNIT HYDROGRAPH BASED APPROACH

T	CR	RI	UHO.	RA	DR	EXR	DSRO	DFLH.
0.	22.00	22.00	.00	.00	22.00	.00	.00	.00
2.	40.00	18.00	5.50	.00	22.00	7.00	.00	12.00
4.	62.00	22.00	23.36	.00	18.00	3.00	3.85	15.85
6.	.00	.00	45.19	18.00	.00	.00	18.00	30.00
8.	.00	.00	57.05	22.00	.00	.00	38.64	50.64

10.	.00	.00	52.46	22.00	.00	.00	53.49	65.49
12.	.00	.00	40.11	.00	.00	.00	53.83	65.83
14.	.00	.00	30.67	.00	.00	.00	43.82	55.82
16.	.00	.00	23.46	.00	.00	.00	33.51	45.51
18.	.00	.00	17.94	.00	.00	.00	25.62	37.62
20.	.00	.00	13.72	.00	.00	.00	19.59	31.59
22.	.00	.00	10.49	.00	.00	.00	14.98	26.98
24.	.00	.00	8.02	.00	.00	.00	11.46	23.46
26.	.00	.00	6.13	.00	.00	.00	8.76	20.76
28.	.00	.00	4.69	.00	.00	.00	6.70	18.70
30.	.00	.00	3.59	.00	.00	.00	5.12	17.12
32.	.00	.00	2.74	.00	.00	.00	3.92	15.92
34.	.00	.00	2.10	.00	.00	.00	3.00	15.00
36.	.00	.00	1.57	.00	.00	.00	2.29	14.29
38.	.00	.00	1.20	.00	.00	.00	1.73	13.73

NOTE:-

T IS TIME IN HOURS
CR IS CUMMULATIVE RAINFALL
RI IS RAINFALL INCREMENT
UHO. IS (DESIGN) UNIT HYDROGRAPH ORDINATES IN CUMEC
RA IS RAINFALL ARRANGED
DR IS (DESIGN) RAINFALL
EXR IS (DESIGN) EXCESS RAINFALL
DSRO IS (DESIGN) DIRECT SURFACE RUNOFF IN CUMEC
DFLH. IS (DESIGN) FLOOD HYDROGRAPH IN CUMEC
UNIT OF RAINFALL IS SAME AS UNIT OF UH UNIT VOLUME

In CUMEC

S. N	Flow prior to this catchment	Sub catchment Flow	Total Flow
1	130.000	.000	130.000
2	257.935	12.000	269.935
3	1242.144	15.849	1257.992
4	1908.763	30.004	1938.768
5	2836.505	50.642	2887.147
6	4124.544	65.491	4190.036
7	3908.566	65.834	3974.400
8	3736.510	55.816	3792.326
9	3670.343	45.506	3715.850
10	3495.710	37.623	3533.333
11	2823.842	31.594	2855.436
12	2174.284	26.983	2201.267
13	1807.773	23.458	1831.231
14	1316.348	20.762	1337.110
15	942.498	18.700	961.198
16	744.724	17.124	761.848
17	637.998	15.918	653.917
18	558.930	14.996	573.926
19	495.328	14.291	509.619
20	447.990	13.731	461.721
21	325.894	.000	325.894
22	82.899	.000	82.899

23	26.823	.000	26.823
24	13.882	.000	13.882
25	10.896	.000	10.896
26	10.207	.000	10.207
27	10.048	.000	10.048

COMPUTATION OF OUTFLOW HYDROGRAPH USING MUSKINGUM METHOD

****

Value of K= 2.0000 value of X = .2000 Baseflow = 10.00

Time in Hrs.	Inflow in Cumec	Outflow in Cumec
.000	130.000	140.000
2.000	269.935	172.293
4.000	1257.992	483.108
6.000	1938.768	1243.967
8.000	2887.147	2004.978
10.000	4190.036	2991.929
12.000	3974.400	3871.480
14.000	3792.326	3916.324
16.000	3715.850	3810.985
18.000	3533.333	3703.377
20.000	2855.436	3423.828
22.000	2201.267	2843.333
24.000	1831.231	2271.736
26.000	1337.110	1826.551
28.000	961.198	1371.001
30.000	761.848	1017.457
32.000	653.917	803.620
34.000	573.926	677.696
36.000	509.619	590.725
38.000	461.721	524.975
40.000	325.894	452.666.
42.000	82.899	306.766
44.000	26.823	129.312
46.000	13.882	55.180
48.000	10.896	30.416
50.000	10.207	22.934
52.000	10.048	20.799
54.000	.000	17.902
56.000	.000	11.824
58.000	.000	10.421
60.000	.000	10.097
62.000	.000	10.022

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	Channel Routing Parameters Estimation and Application		
1.1	Estimation of Muskingum Parameters using Graphical Method	DFMKG.DAT	MKG.OUT
1.2	Estimation of Muskingum Parameters using Method of Moments	DFMKM.DAT	MKM.OUT
1.3	Estimation of Muskingum Parameters using Optimization Technique	DFMKOP.DAT	MKOP.OUT
1.4	Routing of Inflow Hydrograph using Available Muskingum Parameters	DFMKR.DAT	MKR.OUT
1.5	Routing of Inflow Hydrograph using Muskingum-Cunge method	DFMKCR.DAT	MKCR.OUT
2	Reservoir Routing		
2.1	Reservoir Routing using Mass Curve Method	DFMASS.DAT	MASS.OUT
2.2	Reservoir Routing using Modified Puls Method	DFPULS.DAT	PULS.OUT
2.3	Reservoir Routing using Goodrich Method	DFGRICH.DAT	GRICH.OUT
2.4	Reservoir Routing using Coefficient Method	DFCOEFF.DAT	COEFF.OUT
3	Unit Hydrograph Development		
3.1	Processing and analysis of rainfall data		
3.1.1	Filling up of missing data	DFGAPF.DAT	GAPF.OUT
3.1.2	Consistency check of a record	DFDOUBLE.DAT	DOUBLE.OUT
3.1.3	Computation of areal average rainfall	DFTHIES.DAT	THIES.OUT
3.1.4	Computation of variation of depth with area	DFISO.DAT	ISO.OUT
3.1.5	Conversion of daily to hourly rainfall	DFDAILY.DAT	DAILY.OUT
3.2	Rating Curve Analysis and Computation of Discharge		
3.2.1	Discharge from velocity	DFVEL.DAT	VEL.OUT
3.2.2	Development of rating curve & discharge computation	DFRATING.DAT	RATING.OUT
3.2.3	Conversion of Stage Values to Corresponding Discharge Values	DFGAUGE.DAT	GAUGE.OUT
3.3	Excess Rainfall and Direct Surface Runoff Computations		
3.3.1	Computation of Excess Rainfall from Discharge Hydrograph	DFEFF.DAT	EFF.OUT
3.3.2	Estimation of Effective Rainfall and Direct Surface Runoff for a Storm Event	DFLOSS.DAT	LOSS.OUT
3.4	Unit Hydrograph Derivation		
3.4.1	Unit Hydrograph for Gauged Catchments		
3.4.1.1	Conventional Method	DFUNIT.DAT	UNIT.OUT
3.4.1.2	Unit Hydrograph Derivation using Collins Method	DFCOLUH.DAT	COLUH.OUT

OPTION NO.	DETAILS	INPUT FILE	OUTPUT FILE
	3.4.1.3 Unit Hydrograph using Conventional Nash Model		
	(a) Unit Hydrograph using Given Parameters of Nash Model	DFNASHG.DAT	NASHG.OUT
	(b) Unit Hydrograph using Conventional Nash Model (Method of Moments)	DFNASHF.DAT	NASHF.OUT
	(c) Unit Hydrograph using Conventional Nash Model (Optimisation)	DFNASHH.DAT	NASHH.OUT
	3.4.1.4 Unit Hydrograph Derivation using Integer Nash Model	DFINTNAS.DAT	INTNAS.OUT
	3.4.1.5 Unit Hydrograph Derivation using Clark Model		
	(a) Unit Hydrograph using Given Parameters of Clark Model	DFCLARKF.DAT	CLARKF.OUT
	(b) Unit Hydrograph using Clark Model (Optimization)	DFCLARKH.DAT	CLARKH.OUT
	3.4.2 Unit Hydrograph Derivation for Ungauged Catchments		
	3.4.2.1 Unit Hydrograph using Snyder's Approach	DFSNYD.DAT	SNYD.OUT
	3.4.2.2 Unit Hydrograph using the Regional Relationships Developed by CWC	DFCWC.DAT	CWC.OUT
	3.4.3 S- Hydrograph Computation	DFSCURVE.DAT	SCURVE.OUT
	3.4.4 Unit Hydrograph of Changed Duration using Superimposition Method	DFSUPERIM.DAT	SUPERIM.OUT
	3.4.5 Unit Hydrograph of Changed Duration using S-Curve Method	DFNEWD.DAT	NEWD.OUT
	3.4.6 Development of Dimensionless Hydrograph	DFDIMLESS.DAT	DIMLESS.OUT
	3.4.7 Development of Unit Hydrograph from a Dimensionless Hydrograph	DFUHDIM.DAT	DIM.OUT
4	UH Application on Small Catchment for Flood estimation		
	4.1 Computation of Direct Surface Runoff Hydrograph	DFSNYTH.DAT	SNYTH.OUT
	4.2 Computation of Direct Surface Runoff (DRH) and Error Functions	DFREPROD.DAT	REPROD.OUT
	4.3 Computation of Design Flood	DFDESIGN.DAT	DESIGN.OUT
5	Flood Estimation for Large Catchments	DFNET.DAT	NET.OUT
6	Plotting / editing / viewing of a file		
	6.1 Plotting of a file	PPLT1.PLT	
		PPLT2.PLT	

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